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Climate change affecting land use in the Mekong Delta: Adaptation of rice-based cropping systems (CLUES) SMCN/2009/021

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prepared by

Ngo Dang Phong, Postdoc Fellow, IRRI,
Reiner Wassmann, Senior Scientist, IRRI

co-authors/ contributors/ collaborators

Le Quang Tri, Director, Climate Change Institute, CTU

Nguyen Xuan Hien, Director, SIWRP

Nguyen Thi Lang, Head of Plant Breeding, CLRRI

Le Van Hoa, Dean of Faculty of Agronomy and Applied Biology, CTU

Dang Kieu Nhan, Vice Director, Institute of Mekong Delta Research, CTU

Nguyen Hieu Trung, Dean of Faculty of Environment and Natural Resources, CTU

Cao Van Phung, Head of Soil Science Department, CLRRI

International consultants:

Abdelbagi Ismail, Principal Scientist, IRRI

Russell Reinke, Scientist, IRRI

To Phuc Tuong, Principal Scientist, IRRI

Thelma Paris, Senior Scientist, IRRI

Bennet Macdonald, Senior Scientist, CSIRO

Peter Brown, Senior Scientist, CSIRO

Chu Thai Hoanh, Senior Scientist, IWMI

approved by	Robert Edis Research Program Manager| Soil Management and Crop Nutrition, ACIAR
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1 Acknowledgments

The project “Climate Change affecting land use in the Mekong Delta: Adaptation of rice-based cropping systems” (CLUES) was funded by the Australian Centre for International Agricultural Research (ACIAR) from March 2011 to September 2015.

We are grateful to the Department of Agricultural and Rural Development, Extension Center, and local authorities in An Giang, Bac Lieu, Can Tho, and Hau Giang provinces for their support and technical assistance for the project.

We acknowledge and appreciate the collaboration and support from GIZ Bac Lieu that raised the value of collaboration in the project and made it successful.

Last but not least, we appreciate the collaboration of farmers at the experimental sites and surrounding areas in four provinces (An Giang, Hau Giang, Can Tho, and Bac Lieu), which have been valuable to CLUES.

2 Executive summary

The CLUES project aimed at improving the adaptive capacity of rice-based farming systems for effectively managing impacts associated with climate change, with emphasis on capacity building, cooperation among CLUES members and local stakeholders, and internal and external information flows.

The report includes main results of the six themes derived from their final reports as well as additional information from the reports on the semi-final review and final review of CLUES. It focuses on technical and policy aspects during interactions among scientific advisors, team members of CLUES, local stakeholders, and policymakers during the implementation of project research activities.

In the theme on plant breeding, the project used marker-assisted backcrossing (MABC) to develop high-yielding rice cultivars that are tolerant of single or combined stresses of submergence, stagnant flood, and salinity. Through participatory varietal selection at multiple locations and in multiple seasons, some promising lines were identified and submitted for varietal release: OM3673 (short growth duration, tolerant of anaerobic seedling stage), OM10252 (submergence- and salinity-tolerant), and OM6328 and OM6677 (high yield and salinity-tolerant).

Through farmer participatory approaches, the project identified crop management technologies that help farmers to cope with climate variability and enhance their ability to adapt to climate change. The water-saving irrigation technique of alternate wetting and drying (AWD) is a win-win technology. It helped farmers to cope with water scarcity and reduced methane emissions from paddy fields up to 50% compared with continuous flooding conditions. Replacing the triple-rice system by double rice plus upland crops offered advantages such as increased farmers' income due to the high value of the upland crop and reduced irrigation water demand. Moreover, the short duration of the upland crop allowed site-specific adjustment of the crop calendar as a means to reducing risks stemming from salinity (in coastal zones) or floods (in flood-risk zones).

In terms of fertilization, farmers in the Mekong River Delta (MRD) have applied too much phosphorus fertiliser, resulting in substantial P accumulation in the soil. Farmers in An Giang, Can Tho, and Bac Lieu can reduce the P rate to a third of the current rate without compromising rice yield. Decreasing P applications increases farmers' net income and limits the environmental footprint of rice production. In the saline zone of Bac Lieu Province, traditional rice farming is based on long-duration local variety Mot Bui Do. Introducing short-duration high-yielding varieties not only avoids salinity risks, but is also a prerequisite for the shrimp-rice system, which increases income to farmers. Shorter rice duration also allowed more time for land preparation for the next shrimp phase.

The promising stress-tolerant rice varieties, rice-farming technologies, and their extension pathways have been assessed by CLUES with the participation of farmers and extension staff at four study sites. Participation of key local stakeholders and community-based organizations ensured the scaling of promising technologies by incorporating CLUES technologies into existing development programs.

A new conceptual model for land use analysis through a multiple-goal linear programming approach was developed for Bac Lieu Province as a coastal area of the MRD. It enhanced understanding of the current biophysical and socioeconomic conditions and adaptation opportunities for the study area under the impacts of current and future climate change (CC) and sea level rise (SLR). Simulation results showed that current brackish areas in Bac Lieu Province are the most sensitive to changes in future hydrological conditions and water management.

To increase greenhouse gas (GHG) awareness and climate change mitigation for local authorities and farmers, four training courses were held on GHG measurement for CLRRI staff, scientists, and students of Can Tho University (CTU). The first course was held at Hue University in June 2011 and the other three were conducted at CLRRI from the end of 2011 to mid-2012.

CLUES trained 3,960 farmers (3,260 men and 700 women) on participatory rice varietal selection (PVS). Farmers can use the attained knowledge in selecting varieties for their production. Four PhD theses and18 MSc theses of CTU were financed, supported, and supervised by CLUES. Two staff members at CTU were promoted to associate professor in 2015. Most CLUES staff working at CTU can use new knowledge in their teaching career. Some 64 publications with 31 peer-reviewed papers, 5 books and 15 leaflets were completed. CLUES have also increased the CC awareness of 2,979 local farmers and local government staff (including 862 females) through participatory discussions on CLUES activities.

The visibility of project activities and information has been maintained through the website of CTU or IRRI (http://irri.org/networks/climate-change-affecting-land-use-in-the-mekong-delta).

3 Background

The Mekong River Delta (MRD) is often referred to as Vietnam's "rice bowl," which accounted for 54% of Vietnamese rice production (and for ~90% of export rice volume) in 2005. Overall, Vietnam is the third-largest rice exporting country in 2015, with annual exports of 4.5 million tons, accounting for ~23% of rice annually traded globally (Nathan, 2016).

The agro-ecological zones of the MRD can be characterized by a combination of distinct soil types and hydrological features (Fig. 1). About 25% of the soils of the MRD can be classified as alluvial with relatively high soil fertility; the remaining soils are either acid sulfate (AS) soils or saline soils. Although AS soils can be found in different sections of the MRD, saline soils are confined to the coastal areas and result from reoccurring salinity intrusion in the dry season. The upper end of the Delta comprises flood-prone areas that could be either alluvial or AS soil.

Fig. 1. Map of soils in the Mekong Delta based on an atlas published by the Ministry of Education and Training in 2002 (source: www.delftcluster.nl/website/files/WAOP/Draft_final_report_Roads_and_Floods_-_Annexes.pdf). Target areas are indicated in blue (Omon), yellow (Hoa An), white (An Giang), and black (Bac Lieu)

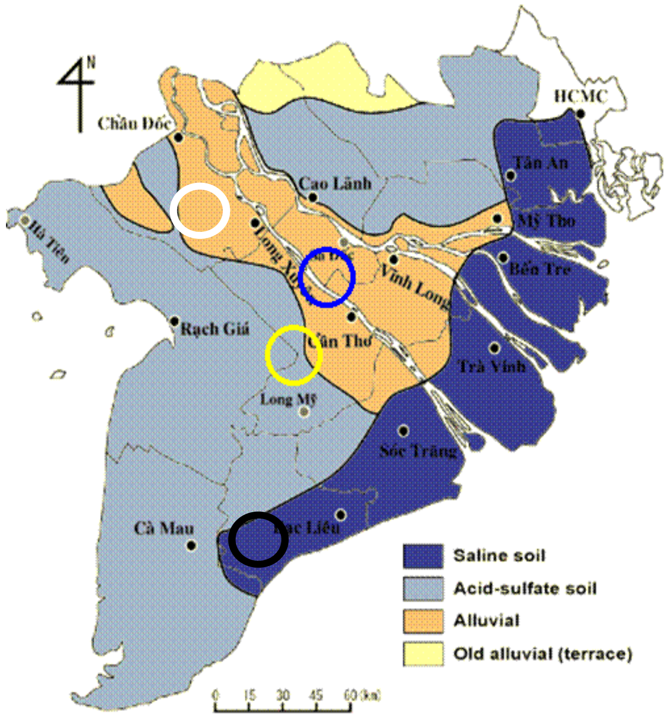

Fig. Distrubution of soil status in Mekong Delta

Climate change impacts in Vietnam's Mekong Delta region

Preliminary modelling has shown the changes to floodwater levels caused by sea-level rise that is discernible up to the Cambodian border (Wassmann et al 2004) and this will change Mekong Delta agro-hydrological zones. The changes to flooding and salinity at the scale predicted will directly threaten food security in the MRD.

Although seasonal flooding, droughts, and salinization directly affect agricultural production through exacerbating stresses to rice plants, a number of secondary impacts are also significant. A large part of the MRD is composed of AS soils in which elemental cycling is controlled by the seasonal fluctuation of the water table, so that a modification of the hydrological cycle due to climate change could cause significant changes, including dissolution and leaching of metals. Another secondary impact is changed nutrient (NPK) availability, with phosphorus being the key factor for productivity in the MRD.

Additionally, upstream dam development for hydro-electricity and irrigation supply will significantly alter the Vietnamese downstream flow and discharge characteristics of the

Mekong River. This will further affect the regional and national economy directly through the disruption of the agriculture, aquaculture, and forestry sectors and directly threaten the livelihoods of 10 million people who live within the MRD.

Over the last 30 years, Vietnamese farmers have been adapting to the changing environmental conditions by modifying and diversifying their production systems and water management. But, the recent and forecasted agro-hydrological changes threaten the viability of these farming and social systems and subsequently food security within Southeast Asia. Significant constraints that limit the ability of farmers to adapt to the new hydrological regime include the availability of suitable cultivars, soil nutrient management options, the lack of knowledge of the potential threats from acid sulfate soil inundation, and planning tools.

Research questions

The direct and indirect impacts of climate change will become a major challenge for maintaining food security in the near future, mainly through aggravating salinity and flood problems driven by hydrological dynamics of the Mekong River. Two meetings of the project proponents (November 2009 and July 2010) also identified a number of sub-issues and research questions:

1. What is the resilience of existing rice cultivars in terms of stagnant flood, salinity stress, and anaerobic conditions during germination? Could marker-assisted backcrossing be used for the introgression of these plant traits into popular varieties in the Mekong Delta varieties?
2. What will be the specific consequences of climate change in acid sulfate soils? Will intrusion by saline water reverse previous amelioration of this abundant soil of the MRD? What is the best management approach to prevent the mobilization of metals into the food chain?
3. What will be the best management strategy for optimizing soil nutrient cycling and maintaining high productivity under more extreme climatic events? To what extent can we learn from farmers' experiences in dealing with drought, flood, and salinity problems in recent years?
4. What are the main biophysical, social, and economic factors that determine the capacity of farmers to adapt to climate change? How do we improve the adaptive capacity of farmers and policymakers?

4 Objectives

The overall aim of the project was to improve the adaptive capacity of rice-based farming systems for effectively managing impacts associated with climate change.

To satisfy this aim, the project had the following objectives:

Objective 1: Location-specific impact and vulnerability assessment

The geo-spatial component will analyze flooding and salinity risks under different sea-level scenarios and implications for different land use options backed up by considering direct climate impacts.

Objective 2: Improvement of salinity and submergence resilience of locally adapted rice varieties and elite lines

The plant breeding component will improve the tolerance of rice germplasm of a variety of direct and indirect impacts of climate change, namely,

- complete submergence through transfer of the *SUB1* gene into locally developed lines;

- Partial stagnant flood through further identification and development of germplasm tolerant of these conditions, and investigation of the physiological mechanism conferring adaptation;

- flooding during germination through transfer of stage-specific tolerance to anaerobic conditions; and

- Salinity through transfer of the *Saltol* gene into varieties of suitable maturity and adaptation, separately and in combination with *SUB1* for coastal areas experiencing both stresses.

Objective 3: Managing resources for resilient rice-based systems coping with rapidly changing environments

The crop and NRM component aims at developing and refining management options for different agro-ecological zones and new decision support tools for CC-resilient rice-based systems through improved understanding of element cycling and soil-plant and cropping system responses to altered hydrology.

Objective 4: Analysis of farming systems and socioeconomic settings in rice farming households

The socioeconomic research component of the project will aim to identify the biophysical, social, and economic factors that determine the capacity of farmers to adapt to climate change, understand the role of key institutions in influencing farmers' decisions and capacity to adapt. It also aims to evaluate the benefits of the new rice varieties in terms of the extent of the adaptive capacity they are likely to confer under projected future climate and socioeconomic conditions.

Objective 5: Integrated adaptation assessment of Bac Lieu Province and development of adaptation master plan

The in-depth study on the coastal area will explore possible adaptation through land use planning through one case study (Bac Lieu Province). Based on detailed inventories of soils, hydrological features, and land use, yields and financial returns of different options will be compared using crop models coupled with GIS. Finally, this information will be used to optimize land use at the provincial scale derived from a multiple-goal linear programming approach.

Objective 6: Capacity building for assessing GHG emissions

The GHG component will provide training and scientific infrastructure facilitating initial GHG emission measurements in rice systems and recording baseline emissions from conventional management and adaptation technologies.

Coordination and integration

The coordination component will create a sound infrastructure for all project activities, ensure internal and external communication flow, supervise progress of activities, and organize workshops.

5 Methodology

5.1 Research and/or development strategy and relationship to other ACIAR investments and other donor activities

A matrix multidisciplinary × multi-location approach (Fig. 2) was developed to address research questions and objectives of the project. One axis of the matrix comprises the six themes, each referring to the scientific objectives 1–6 above. The scientific activities were carried out in four target areas, each of which represents a specific agro-ecological zone of the Mekong Delta. The target areas represent a cross-section through the most important agro-ecological zones (Fig. 1). Derived from the area-specific settings, the project deployed a flexible approach in terms of field experiments (Table 1 and Fig. 1 for study site locations). However, a set of uniform field experiments performed in all target areas ensures the compatibility of results obtained in the different zones. In the context of this proposal, a target area comprises an experimental farm plus the surrounding villages, which were used for socioeconomic studies as well as participatory research.

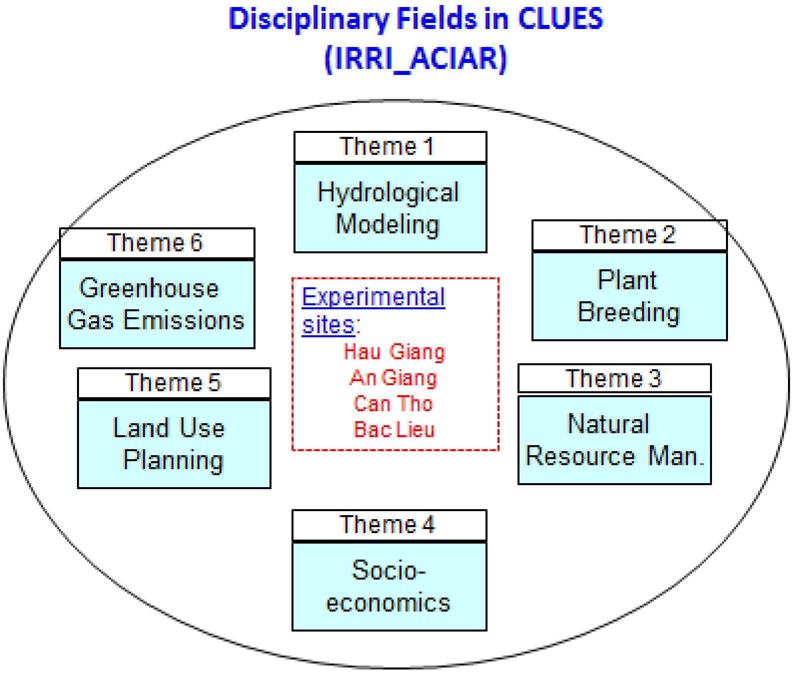

Fig. 2. Diagram of Themes and linked activities at four experimental study sites in CLUES.

In the first step, the project encompassed a comprehensive baseline survey as a joint activity of the project teams dealing with NRM, socioeconomics, and land use planning. The results of this survey were used for further definition of the activities within the respective objectives, for example, biophysical production constraints identified in the surveys were incorporated into the field design for improving NRM technologies. This project strategy for farm experiments was based on a "mother–baby trial" methodology (MBT) in which a researcher-driven trial was undertaken to generate statistically robust data and deliverable technologies.

In the next phase, the most promising options (varieties or management) were selected and further tested through "baby trials." These smaller baby trials were replicated and managed by farmers on their own farms. This generated more data while allowing farmers to experience and refines which genotypes or agronomic practices best suit their needs. This strategy has been employed previously by researchers in this current project and in ACIAR Project LWR/2002/032.

The socioeconomic work of this project had close links with other ACIAR projects on "Developing multi-scale climate change adaptation strategies for farming communities in Cambodia, Laos, Bangladesh, and India" (LWR/2008/019), in which some of the livelihood assessment and adaptive capacity work was developed during the scoping stage (LWR/2008/015; Roth et al 2009) and was based on the livelihoods framework of Ellis (2000).

The project did not develop and impose a rice adaptation model for the Mekong Delta. Instead, the project researched and developed new technologies and plants to improve overall resilience in rice-based production systems. The outcomes represented "a resilience toolbox," which local farmers and land managers can use to innovatively design production systems for the changing climatic and hydrological conditions. The development of the "resilience toolbox" enhanced capacity within and strengthened collaboration between the Vietnamese and Australian research communities.

Given the extensive amount of research needed to be undertaken, it is envisioned that an Advisory Committee (or Operational Board) will be formed to provide governance for many of the in-country activities (Table 1). The consortium will explore options for funding additional PhD and MSc student positions—either from Vietnam for studies in Australia or from Australia for field work in Vietnam—to further aid capacity building and address specific research questions.

Table 1. Matrix of links of work assignments between theme leaders and site managers in CLUES.

			Activities per site			
	Theme and objectives		An Giang	Hau Giang	Can Tho	Bac Lieu
Study sites involved in Theme activities (scientific)	1	Geo-Spatial component: Location-specific impact and vulnerability assessment	x	x	x	x
	2	Stress-tolerant rice varieties on improving salinity and submergence resilience of locally adapted rice varieties and elite lines	x	x	x	x
	3	(NRM component): Managing resources for resilient rice-based systems coping with rapidly changing environments	x	x	x	x
	4	(Socioeconomic component): Analysis of farming systems and socioeconomic settings in rice farming households	x	x	x	x
	5	Integrated adaptation assessment of Bac Lieu Province and development of adaptation master plan				x
	6	Capacity building for assessing GHG emissions	x	x	x	x

5.2 Theme 1: Objective 1 (Geo-Spatial component): Location-specific impact and vulnerability assessment

Activities of Theme 1:

- Activity 1.1 Literature review and meta-analysis of available data and documents on climate change projections for the MDR to identify potential production constraints to future production
- Activity 1.2: Assessing hydrological impacts of different sea-level rise scenarios in the MDR region (hydraulic and salinity modelling)
- Activity 1.3: GIS mapping of flooding depth and salinity levels within the MDR as a function of sea-level rise and envisaged upstream development projects for different land use options
- Activity 1.4: Comparative assessment of climate change impacts on rice production in the four target areas (An Giang, Can Tho, Hau Giang, and Bac Lieu)
- Activity 1.5: Mapping (delta-wide) of vulnerability and potential "hot-spots"

Theme 1 employed the following methods in this study:

- Data collection and synthesis.
- Modelling and simulation method (mathematical models, statistics, forecast) to study water balance and assessment of hydrological and hydraulic changes.
- Applying remote sensing, GIS, and software of database management to systematize and map computed results.

The "Vietnam River Systems and Plains" (VRSAP) model is a hydraulic model to simulate mainly one-dimensional hydrodynamic river flow or quasi two-dimensional flow on floodplains. Applying an implicit finite difference scheme for solving one-dimensional Saint-Venant equations, VRSAP is able to simulate water flow in complex branched and looped river networks. It is also designed to simulate dissolved or suspended particulates in water (e.g., salinity, acidity, etc.) using the scheme of implicit finite difference for the advection-dispersion equation. Updated data on hydrology, topography, and infrastructure system data for baseline year 2008 were used for model verification.

Detailed mathematical schemes have been constructed for the MRD with the updated data on rivers and sluice systems in 2008. The scheme of this model includes 3,486 nodes, 5,611 segments, and 2,666 plains. The total area simulated in this model is about 5.5 million ha (Fig. 3).

Upstream boundary: flow at Kratie; downstream boundary: water level and salinity; climate in the MRD and upstream.

Main outputs: hourly water level, flow, and salinity.

The impact and vulnerability assessment capitalized on a suite of models and GIS databases for a geo-spatial assessment of climate change and sea-level rise impacts in the MRD.

In this study, we used projected climate data from SEA-START (based on the PRECIS model developed by the UK Hadley Centre with A2/B2 scenarios) from 2010 to 2100. However, those data have no bias correction.

The MRC did bias correction for upstream (up to Kratie) and computed river discharge und CC scenarios; these data were used in the BDP2 project (MRC, 2011).

The representative years for time windows, namely, dry, normal, and wet years in the duration 2030 window (2020-35) and 2050 window (2036-50).

River discharge was computed for those selected years with a specific SLR for a given time window (17 cm for the 2030 window and 30 cm for the 2050 window based on the

MONRE's scenarios for SLR in the years of 2030 and 2050, respectively, with specific values for the East and West Sea (MONRE, 2012).

All computations were in three different representative years of the respective time windows of the 2030s and 2050s. A total of 27 scenarios were simulated for assessment, which combine many factors of SLR, CC, Upstream Development, and the Land Use Plan in the Mekong Delta.

Flood scenarios were computed from July to December, whereas salinity scenarios were computed from January to June for the entire MRD.

The scenario outputs used GIS software to present the flooding map and salinity maps in raster format.

The detailed methodology is referred to in Appendix 1 (the Theme 1 final report).

The following criteria for hot-spot delineation were used in the assessment for flooding and salinity risks:

Flood risk onset date is identified as the water level in a canal that is 0.4 m higher than the level of the field in a period from 7 to 15 consecutive days.

Flood risk recession date is defined as the water level in a canal that is +0.2 m lower than the field level.

Flood risk duration: Time when flooding appears – Time when flooding ends.

Salinity risk onset date: Date salinity commenced was identified as salinity of more than 3 dS/m in a canal lasting at least 7 days in a period of 15 days.

Salinity risk end date: date when salinity in a canal was less than 3 dS/m.

Salinity risk duration: Time when salinity appears – Time when salinity ends.

Potential for gravity irrigation: The area is capable of a gravity brackish-water supply if it satisfies the following condition: maximum daily water level in a canal is more than 0.25 m higher than the level of the field and, on the same day, maximum salinity in a canal is more than 9 dS/m. The area meets the above condition at least 7 days in February, which is the period that has the highest water demand and is considered as the area of potential brackish-water supply by gravity.

The area is capable of gravity freshwater supply if it satisfies the following condition: maximum daily water level in a canal is more than 0.25 m higher than the level of the field and, on the same day, maximum salinity in a canal is less than 3 dS/m. The area meets the above condition at least 7 days in February and is considered as the area of potential freshwater supply by gravity.

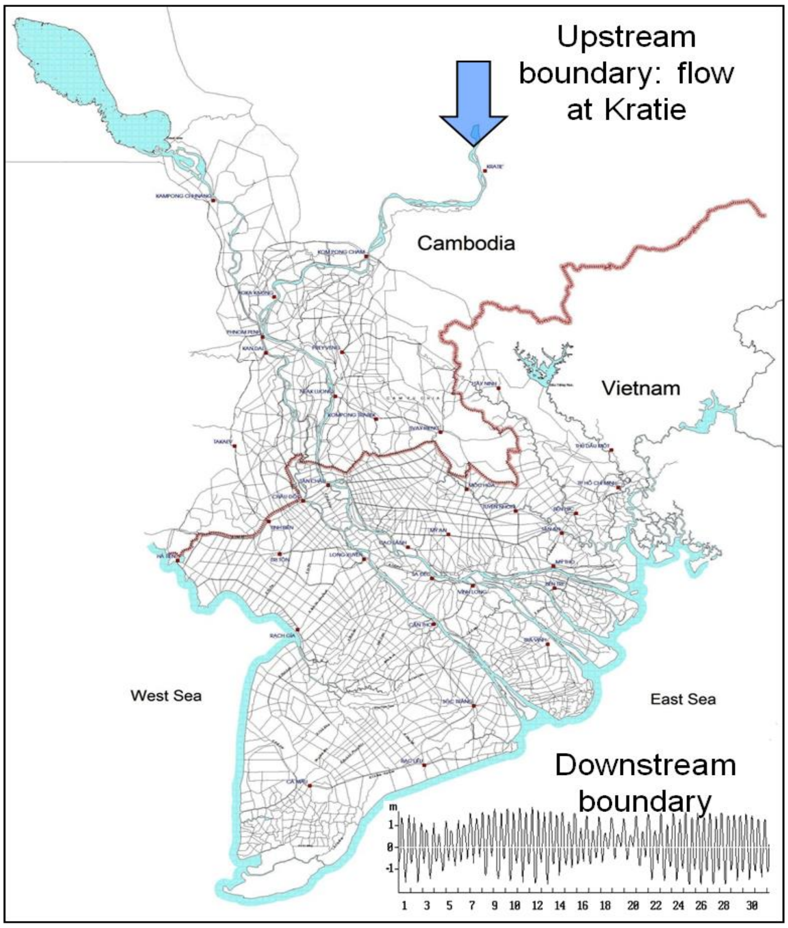

Fig. 3. Mathematical scheme of VRSAP.

5.3 Theme 2: Objective 2 (Stress-tolerant rice varieties) on improving salinity and submergence resilience of locally adapted rice varieties and elite lines

The strategy of germplasm development is to incorporate tolerances of specific abiotic constraints into locally adapted varieties and elite lines. This uses and transfers technology developed at IRRI, building capacity and setting in place the capability in Vietnam to rapidly introgress adaptive traits into future varieties and elite lines, in response to emerging threats. Objective 2 of Theme 2 employed the following approaches:

Marker-assisted backcrossing (MABC) for transfer of genes with tolerance of salinity (*Saltol*) and flooding (*SUB1*) and tolerance of anaerobic conditions during germination into locally adapted lines. The traits were transferred both separately and in combination.

Molecular approaches were implemented to select for the target loci (foreground), minimize linkage drag (flanking regions), and select for the background of the recurrent parents (background markers), which saves considerable time and results in the recovery of the genetic background adapted to the target environment.

Saltol was transferred into two Australian varieties (i.e., a temperate japonica background) and *SUB1* into a single Australian variety at IRRI. Broadly adapted Australian varieties were selected to receive the traits for direct variety improvement and to provide a repository of the traits in a temperate japonica background for future breeding.

Screening was conducted for the identification of donors for tolerance of partial stagnant flood to benchmark tolerance in existing traditional lines against current popular lines.

Local scientists received degree and non-degree training in MABC, both in-country and via exchange visits.

Activity 2.1 (Identify locally adapted varieties and elite breeding lines as recipients of *SUB1* and *Saltol).*

More than 200 landraces and current varieties were screened under anaerobic conditions, and promising lines identified. Then, F_2 populations between susceptible and tolerant lines were developed for QTL analysis.

Activity 2.2 (Generate and disseminate improved rice lines tolerant of temporary (complete) submergence through transfer of the *SUB1* gene into local popular varieties and newly developed elite breeding lines).

A total of 108 BC_3F_4 lines from the cross OM1490/IR64-Sub1 and 200 BC_3F_4 lines from the cross OMCS2000/IR64-Sub1 were genotyped for the presence of the *SUB1* QTL and tested under submergence stress to confirm the tolerance.

Activity 2.3 (Generating and disseminating improved rice lines tolerant of salinity through transfer of the *Saltol* gene into varieties of suitable maturity and adaptation, separately and in combination with *SUB1).*

Recipient lines identified: more than 100 BC_4F_3 lines have been selected from two backcross populations. *Saltol* was introgressed into two locally adapted materials from Vietnam and two to three varieties from Australia. These lines were genotyped for the *Saltol* QTL and screened under salinity at concentrations of EC = 8 and 15 dS/m.

Selected lines that matched the recipient parents were tested for release. Seed of BC_2F_4 populations was sent to Australia Plant Quarantine.

Activity 2.4 (Generating improved rice germplasm resilient to stagnant (partial) flood through further identification and development of germplasm tolerant of these conditions, and investigation of the physiological mechanism conferring adaptation).

Screening of germplasm: 100 landraces and 100 current varieties benchmarked.

Generating improved rice germplasm resilient to stagnant (partial) flood.

Testing of breeding lines under naturally occurring stagnant flood conditions: A total of 12 rice genotypes with a degree of tolerance of stagnant flood together with an additional farmer's variety were evaluated in selected farmers' fields in Hau Giang Province. Similarly, 12 stagnant-flood-tolerant rice genotypes and an additional entry of a farmer's variety were evaluated in selected farmers' fields in Can Tho.

Activity 2.5 (Exploring improvement of rice germplasm resilient to flooding during germination and early seedling establishment through investigation of tolerance of anaerobic conditions during germination).

A total of 14 rice varieties were tested with check variety IR64-Sub1. All experiments were evaluated in selected farmers' fields in An Giang Province.

About 20 submergence-tolerant and high-yielding genotypes along with two standard checks plus a farmer's variety were evaluated in this trial under naturally occurring stagnant and submergence conditions in farmers' fields in An Giang.

Each experiment was evaluated for agronomic traits, including days to heading, plant height, panicle length, and number of panicles per plant, percent sterility, grains per plant, 1,000-grain weight, and yield per plant.

Reaction to disease stress in the field was evaluated based on the standard evaluation system of IRRI, including brown plant-hopper, blast, stem borer, leaf blight, and rice tungro disease.

5.4 Theme 3: Objective 3 (NRM component): Managing resources for resilient rice-based systems coping with rapidly changing environments

Crop and natural resource management for CC adaptation were addressed by agronomic field trials in combination with process studies and modelling approaches. The promising technologies, including those involving non rice crops, were identified by participatory rural appraisal (PRA). When field trials produced acceptable results, these technologies were further tested by local farmers for wider dissemination. These steps are described in detail below.

Activity 3.1: Participatory rural appraisal

The PRA was carried out in the first year of the Project (2011) to investigate the prevailing cropping systems and resource profile of the target area of CLUES, how they were related, and to assess how cropping systems and management were affected by past extreme weather variability as well as farmers'/local authorities' strategies to cope with future climate change.

PRA surveys were carried out in the four target regions. In each region, two communes were selected; where one commune's biophysical conditions are unfavorable for agricultural production while the comparative site is a favorable one. In each commune, the PRA comprised two parts:

(i) Focus group discussions with local governments, extension workers, water users' associations, and irrigation water service providers.
(ii) General discussion with farmers, in groups or as individuals.

During these discussions, a series of questions were raised by project team members, with the aim of obtaining information and farmers' perceptions on (1) the baseline status of farming systems and yield gap analysis, (2) retrospective analysis of losses in rice production during years with climate-related extremes (drought, flooding, salinity), (3) assessment of agronomic vulnerability and adaptive capacity of rice-based farming systems, and (4) suggestions for strategies, what is needed to cope with increasingly unfavorable climatic events (i.e., possible climate change).

Activity 3.2: Field experiments

(i) Site selection and experimental design (derived from PRA)

Based on the PRA, constraints analysis and an experimental field program were conducted in each zone and this is generally described below (Tables 2 and 3). The cropping calendar at four study sites can be seen in Appendix 9.

Table 2. Climate change production threats identified by participatory rural appraisal for each ecological zone and season.

<table>
<tr><th>Ecological zone</th><th>Winter-spring (Dong Xuan) season</th><th>Summer-autumn (He Thu) season</th><th>Autumn-winter (Thu Dong) season</th></tr>
<tr><td>Deep flooded
(An Giang sites)</td><td rowspan="2">- Submergence
(early season)
- Water scarcity (late season)
- Acidity</td><td rowspan="2">- Water scarcity
(early season)
- Acidity
- Lodging</td><td rowspan="3">- Poor establishment
(rain)
- Poor pollination (due to rain)
- Lodging
- Stagnation flood
- Submergence</td></tr>
<tr><td>Acid sulfate soil,
intermediate flood
(Hau Giang sites)</td></tr>
<tr><td>Intermediate flood
with alluvial soil
(Can Tho sites)</td><td></td><td>- Water scarcity
(early season)
- Lodging</td></tr>
</table>

Saline zone (Bac Lieu, 3-rice system) (Bac Lieu, shrimp-rice system)	- Water scarcity - Salinity	- Salinity - Lodging	- Poor establishment (rain) - Stagnation flood
	(no rice)	*(no rice)*	- Poor establishment (rain) -Salinity at establishment - Salinity at end of season - Stagnation flood
All zones	- Low economic resilience (farms <1–2 ha) - Labor scarcity		

Table 3. Promising technologies to alleviate climate change production threats and related research questions in the Mekong River Delta (MRD).

CC-related production threats	Promising technologies	Related research questions in the MRD
Water scarcity	AWD, drought-tolerant variety	Is AWD safe in ASS and saline-risk soils? Can "safe AWD" maintain high yield and increase water productivity of winter-spring rice crop and farm productivity? How would P fertiliser be managed in AWD**?**
	Replace rice by upland crop	Technical and financial feasibility of introducing upland crop in rice system? How will these farm management changes affect acid sulfate soil properties?
Poor pollination; stagnation flooding and submergence (for Thu Dong crop, and He Thu for 2-rice crop)	Advance Autumn-Winter crop by replacing 3-rice systems with 2-rice + 1 upland crop	
	Advance Autumn-Winter crop by reducing fallow period after Winter-Spring and Summer-Autumn. Use stagnant flood- and submergence-tolerant varieties.	How to reduce drying period without rice burning (pollution) and not creating organic toxicity in rice plants?
Acidity	Reduce soil drying after Winter-Spring	
Lodging	AWD, Transplanting	How would AWD help reduce lodging? How can transplanting be done cost effectively vis-à-vis labor scarcity?

Salinity at establishment and near harvest (shrimp-rice system)	Enhance leaching, liming	Would land preparation and liming help leach salt from soil?
	Use short-duration rice. Use salinity-tolerant varieties.	What is the optimal (for rice and shrimp) date of rice seeding in combination with different maturity duration?
Low economic resilience	Diversification, intensification, lowering input costs, increasing yield	Do the CLUES farm management experiments reduce input costs and increase yield? How to increase annual productivity in 2-rice crops/year zones?

(ii) Site characterization

A soil survey was conducted at each site. Soil properties from each experimental field were monitored through routine biophysical analysis in the Soil Science Department at CTU. Weather and water conditions of the experiments were also monitored during the experiment. Methodologies for sample collection and analyses are reported in the final report of Theme 3.

(iii) Implementing field trials with promising rice varieties (from the MRD) and crop management strategies

Based on the PRA, an experimental field program was conducted in each zone and this is generally described below (Table 4).

Table 4. Experiments on integration of upland crops in rice-based cropping systems.

No.	Field experiment	An Giang	Can Tho	Hau Giang	Bac Lieu
Act. 2 a, b	Alternate wetting and drying and P reduction in triple- and double-rice production systems	x	x	x	x
Act. 2 c	Management of rice straw in acid sulfate soil			x	
Act. 2 d	Salinity management and use of short-duration varieties in shrimp-rice production systems				x
Act. 4	Insertion of upland crops into double-rice production systems	x	x	x	x

a. Is alternate wetting and drying suitable for acid sulfate and saline-risk soils?

Changed rainfall dynamics and SLR under CC will affect the salinity of the Mekong River in the dry season, thus further increasing water scarcity and the potential risk to production from drought.

Alternate wetting and drying (AWD) irrigation is a field water management technique developed by IRRI to improve water use efficiency in rice production. Most of the AWD field experiments that have been trialled successfully in non-saline soils have significantly decreased water use and increased farm profitability. Total water inputs (irrigation and rainfall) decreased by 15–30% without a significant impact on yield. In these studies, it was concluded that rice yield remained satisfactory if irrigation was re-supplied when the soil water tension was around –10 kPa or when the perched water table reached a threshold value of –15 cm below the soil surface.

Our experiments were implemented to investigate AWD-related questions listed in Table 2.

AWD experiments were conducted at all four sites (Table 3), in four cropping seasons during the first two years of the project. In these experiments, irrigation was applied in three treatments: (1) W1: Continuous flooding (CF): irrigate when the water level is at around 1 cm on the soil surface; (2) W2: AWD, irrigate when the water level percolates at about –15 cm; and (3) W3: AWD, when the water level is at –30 cm below the soil surface. In all water treatments, irrigation was applied to bring the field water level to 5 cm above the soil surface. Irrigation water was pumped from nearby canals.

Details of the field experimental design can be seen in Appendix 3, Theme 3 Final Report.

b. How would P fertiliser be managed in AWD and can P rates be reduced?

In the MRD, farmers have often applied very high P rates during rice production for three decades, mostly for a single crop of rice. Increasing to two or three rice crops per year recently might lead to a high substantial accumulation of P in the soil. Decreasing P fertiliser will directly improve farm profitability. However, the alternating REDOX conditions under AWD could affect soil P dynamics and subsequently yield. Understanding P dynamics under alternating REDOX conditions will also be beneficial to coping with CC, when drought stress may increase in frequency and intensity.

At each site, the effect of P rate was tested in combination with three levels of water management (W1, W2, and W3) as described above. Water management was the main plot factor. P rate was the subplot factor, ranging from 0 kg P_2O_5/ha to the farmers' practice, with one or two intermediate rates = half or a third of farmers' rates.

c. How to reduce drying period without rice burning (pollution) and not creating organic toxicity in rice plants?

The issue in Hau Giang Province is this long period of fallow, which causes soil drying and the burning of straw and stubble after REDOX increases acidity of the topsoil. Removal of the straw during fallow also results in increased soil evaporation, which brings acidity to the soil surface by capillary rise. If it is possible to reduce the fallow period between crops, it will be possible to move the crop forward by up to 3 weeks and potentially avoid flooding at the end of the He Thu season. The flooding risk has been predicted to increase with CC.

Residue management needs to be modified to enable shortening of the fallow period and maintenance of soil health.

Experiments on timing of seeding after plowing with the straw treatments (burning or incorporation or spraying rice straw and stubble with chemical *Trichoderma)* were carried out in Hau Giang Province before the summer-autumn crop in 2012 and 2013 at the CTU field station.

The two objectives addressed in the experiment were

- To identify the suitable fallow periods between the harvest of the previous crop and the establishment of the following crop.
- To identify improved straw treatments to facilitate rice growth and improve yield on acid sulfate soil.

The treatments were timing of seeding (1 day, 3 weeks, 6 weeks after plowing) and straw treatments (burning stubble, incorporation of rice straw, spraying the rice stubble with *Trichoderma)*. This experiment was carried out in Hau Giang Province during the SA crop in 2012 at a location near the CTU field station and again during the Summer-Autumn crop in 2013 at a new location.

d. How can productivity in shrimp-rice systems be improved with a high-yielding short-duration rice variety and enhanced salinity leaching?

Shrimp-rice cropping is an important production system in the coastal areas of the Mekong Delta. In this system, brackish-water shrimp are raised from January to August, when salinity in the field is >7 g/L. Rice is established in about mid-September.

More than 90% of the farmers grow traditional rice varieties that were harvested in mid-January. Late harvest exposes the rice crop to high salinity at the end of the rice season. Shortening rice growth duration could help minimize the risk of crop failure caused by salinity and shortage of irrigation water. Short-duration rice will also give farmers more time for them to grow shrimp, which brings the main income for farmers from the whole system.

Before rice crop establishment, farmers leach the residual salt on the field by rainwater and sometimes with irrigation. Reducing leaching duration could minimize the risk of drought and salinity when rice is established. The risk is aggravated with the anticipated sea-level rise and CC. There is a need to enhance the effects of leaching.

An experiment was carried out in Phuoc Long, Bac Lieu Province, with the overall objective of optimizing soil and crop management in a shrimp-rice cropping system to help farmers increase their income and their adaptability to possible sea-level rise and CC. We hypothesized that plowing and liming can enhance the effects of leaching before the start of the rice season.

Specific objectives include the following:

- To assess the possibility of introducing short-duration HYVs to replace the local traditional PS variety in the shrimp-rice system.

- To determine the effects of applying lime and plowing (solely and in combination) on soil salinity leaching and consequently on rice yield.

Activity 3.3: Process studies (pot experiments)

Stress responses in target regions through pot and column experiments (in Vietnam) and incubation studies (in Australia). A pot experiment was set up to assess the effect of different environmental stresses on element cycling and nutrient availability. Given the diversity of target areas, the pot experiment was designed as a site-specific trial under a range of environmental conditions (depth of flood and/or salt content) from the soil and plant(s). Measurements encompassed soil as well as plant parameters.

There were four process studies:

1. *Effect of salinity on carbon and nitrogen cycling*. Work was carried out in Australia. Soils from Australia were placed in incubation studies to assess the effect of salinity on carbon and nitrogen element cycling. Nitrous oxide, methane, and carbon dioxide measurements were made during the experiment.

2. *Effects of straw management on survival of IR64-Sub1 subjected to submergence at young seedling stage*. Alluvial soils with different residue treatments (no residue, Incorporation of burned residue, and Incorporation of fresh residue) from Omon were used to assess the survival of IR64-Sub1 seedlings (4 days) under submergence for a duration of 15 days.

3. *Enhancing salt leaching of shrimp-rice soil*. Soil columns were used to understand leaching processes and the effect of ameliorated techniques on salinized soils in shrimp-rice systems in Bac Lieu. The treatments were arranged in a randomized complete block, being seven combinations of (i) number of leaching, (ii) with and without lime, and (iii) with and without surface soil (0–5 cm) turnover (using a spatula). Further details are described in Phong N.H (2014).

4. *Soil P adsorption characteristics after seven crops at fixed P supply*. Soil samples at the end of each of the seven consecutive rice crops, from WS 2012 to WS 2014, in the P experiment in Bac Lieu (described in section iii b above) were taken to determine the maximum P adsorption. This determination aimed at elucidating how different P rate

application affects the amount of P adsorption, how much soils were buffered with P, and how long a reduced P application could be maintained without decreasing rice yield. Soil samples were equilibrated with phosphate solutions of known concentration for 24 hours at 20 ^{o}C. At the end of the process, the concentration of the phosphate remaining in the solution was determined. The quantity of P adsorbed per quantity of soil was calculated from the difference in phosphate concentration at the beginning and the end of the process.

Details of process studies can be seen in the Theme 3 Final Report.

Activity 3.4: Non rice crops in rice-based systems for climate change adaptation

Water shortage often occurs in the summer-autumn (SA) season in deep and medium flooded zones (An Giang, Can Tho, Hau Giang) and in the winter-spring (WS) season in saline-affected areas (Bac Lieu). The rice crop in the autumn-winter season is exposed to heavy rains during flowering, stagnant flooding at the latter stages of the crop in all zones, and submergence in deep-flooded zones. These climate risks will be aggravated in the foreseen CC.

We hypothesized that replacing one rice crop (WS rice in Bac Lieu or SA rice in other areas) with a short-duration upland crop would increase the economic resilience and CC adaptation via (i) increasing farmers' income, (ii) reducing the water requirement and hence the risk of water shortage in SA or WS seasons, and (iii) reducing the risks of partial flooding or submergence by advancing the establishment/harvest date of the SA cropping season.

A set of experiments (Table 5) was carried out to (i) explore the feasibility of an upland crop replacing SA rice in flooded zones and replacing the WS rice crop in saline-affected areas, (ii) quantify different upland crop management on crop performance and soil properties, and (iii) compare the economics of the triple-rice system vs the two-rice + upland crop system.

Table 5. Experiments on integration of upland crops in a rice-based cropping system.

	Bac Lieu (Lang Giai)	**Hau Giang (Vi Dong)**	**Can Tho (Thoi Tan)**	**Can Tho (CLRRI)**	**An Giang (Ta Danh)**
Cropping season with upland crop replacing rice	Winter-Spring 2011-12 and Winter-Spring 2012-13	Summer-Autumn 2012 and 2013	Summer-Autumn 2012 and Summer Autumn 2014	Summer-Autumn 2013	Summer-Autumn 2014
Upland crops tested	Soybean, mungbean, sesame, hybrid corn and pumpkin	Cucumbers and sticky corn	Sesame	Mungbean	Sesame, soybean, and sweet corn
Treatments of upland crops	N, P, K doses	Plastic cover, N fertiliser, and biological fertiliser (only in 2012)	Sesame varieties and fertiliser doses	P-fertiliser and residual effects of water management of the previous season	Crop varieties

Further details of the experiments are described in Chon et al (2015) and the Theme 3 Final Report (Appendix 3).

5.5 Theme 4: Objective 4 (Socioeconomic component): Analysis of farming systems and socioeconomic settings in rice farming households

The socioeconomic research theme in this project aimed to bring together a number of research components step by step as shown in Figure 4. Details of the methodology used in Theme 4 are referred to in Appendix 4 (the Theme 4 final report).

All aspects of the socioeconomic research will have a strong focus on stakeholder participation and look to include rice growers, researchers from both the wider project team and in-country institutions, and senior policymakers relevant to the research focus.

The socioeconomic baseline livelihood assessments (Act. 4.1) were conducted in the four study target areas (An Giang, Hau Giang, Can Tho, and Bac Lieu) in close consultation with Act. 3.1 (PRA) in 2011. Target communities (villages), social groups, and households, including representative farming systems, were identified through participatory community appraisals with agro-ecosystem analysis and wealth ranking.

The household survey was designed to assess the current status of (male-/female-headed) household livelihoods, problems/constraints, vulnerability factors, risks, and adaptation strategies of farmers (considering gender issues) to cope with problems/risks, giving more attention to weather variability/climate change (past, present, and future). Building on findings from the participatory community appraisals, household surveys were conducted by interviewing 480 households involved in major rice-based farming systems at eight study sites. In total, seven farming systems are considered: (1) double-rice cropping, (2) double-rice–fish integrated farming, (3) double-rice–upland crops rotational farming, (4) rice-shrimp rotational farming, (5) triple-rice cropping, (6) triple-rice–fish integrated farming, and (7) triple-rice cropping and upland crops. For each farming system at the respective study site, based on a list of households provided by commune officers or extension staff, farmers were randomly selected for interviews. Collected data include (1) the household's livelihood assets (human, natural, physical, financial, and social assets), (2) the communication pathway for accessing new farming technologies, (3) risk management strategies for natural hazards, (4) the household’s livelihood determinants and intents, and (5) farming inputs and outputs. In addition, gender issues in rice production and livelihoods were investigated with 205 male and female farmers involved. A pilot survey was carried out to finalize the questionnaire before full-scale surveys were conducted in all of the study communes

The sustainable livelihood and adaptation strategy assessment (Act. 4.2) used a self-assessment process for the impacts of extreme weather/hydrological changes on local farmers through focus group discussions (FGDs) (Roth et al 2009). It also explored the reactions to anticipated changes of local people and quantified the impacts of their strategies on representative farmers. Twenty-three local workshops at eight study sites were held to assess capacity and to identify the livelihood strategies of smallholders to adapt to climate change. Focus group discussions followed by individual in-depth interviews were conducted with a total of 233 participants involved. For each farming system per site, two groups—one with relatively larger farmers (>1 ha) and the other with relatively smaller farmers (<1 ha), with 7–15 participants per group—were interviewed. In addition, to investigate gender issues on adaptive capacity for climate change, three women’s groups, whose households practiced rice-based farming systems, at an unfavorable site in Hau Giang Province were invited to participate in the discussions. Local participants identified key indicators of their human, social, natural, physical, and financial assets that enabled or constrained their ability to manage their rice-based farming systems under climatic and non-climatic changes. They rated each indicator on a scale from 0 to 5 according to the degree to which the indicator was likely to be supporting adaptation in the future.

Policy and institutional arrangement analysis (Act. 4.3) employed stakeholder and institutional analysis for describing institutional structure (legal systems, policies, and organizational structure) and the external influencing factors at both national and local scales that enable the participants to improve their livelihoods and to adapt to past, present, and future weather variability/climate change.

To identify policy and institutional gaps in supporting the adaptive capacity of rice farmers, we collected information from eight local workshops (two workshops per province) with participants from the relevant sectors' officials (DARD, DONRE, DIT, and DOST), agricultural extension staff, community-based organization representatives at the district and provincial level, and service suppliers. In each workshop, we split the participants into two groups, one with governmental sector officials and another with extension staff, community-based organization members, and service suppliers. We applied PRA techniques to collect information from group discussions such as brainstorming, Venn diagram, and scoring.

We addressed the following four concerns:

(1) Important drivers and issues in developing the adaptive capacity of rice farmers in the present and future;

(2) Effectiveness, enablers, and constrainers of policy implementation in improving livelihood, particularly the capacity of farmers to adapt to climate change-induced effects;

(3) Policy and institutional gaps between the current stage and farmers' needs; and

(4) Relevant stakeholders and their roles in enhancing the adaptive capacity of rice farmers and in scaling out and scaling up promising technologies created from CLUES.

The fine-tuning of project-generated technologies (Act. 4.4) employed a participatory technology development approach (PTD) considering technological, socioeconomic, and environmental aspects, and suggestions for development and further improvement of selected technologies. This was accomplished during the course of the project (at the end of 2014 and the beginning of 2015) with close participation of local farmers, traders, extension workers, and government managers. For workshop assessments, the tested technologies were assessed through scoring the feasibility, in terms of technical, economic, social, and environmental aspects on a scale of 1 (low), 2 (medium), and 3 (high feasibility), and they were ranked in the order of importance or priority for out-scaling. Partial budgeting analysis was applied for assessing the economic viability of the tested technologies.

Possible extension pathways of research findings were explored (Act. 4.5) through regional workshops, printing materials/documents, public media, and training extension workers and potential farmers in four target areas in 2015. These workshops led to recommendations for scaling out research findings of the project to other areas. Given the feasible technologies of the project identified from the assessments, extension pathways of the technologies were determined through participatory impact pathway analysis (PIPA) (Douthwaite et al 2007). The PIPA was conducted with two local workshops in each province with participation of local stakeholders. The first workshop focused on problem analysis and stakeholder analysis and the second workshop addressed extension pathways and technology adoption by farmers, using an extension logic model and the ADOPT simulation model. Results of the extension logic model include technology extension methods and tools, target areas, target farmers, relevant stakeholders and their roles, and important assumptions.

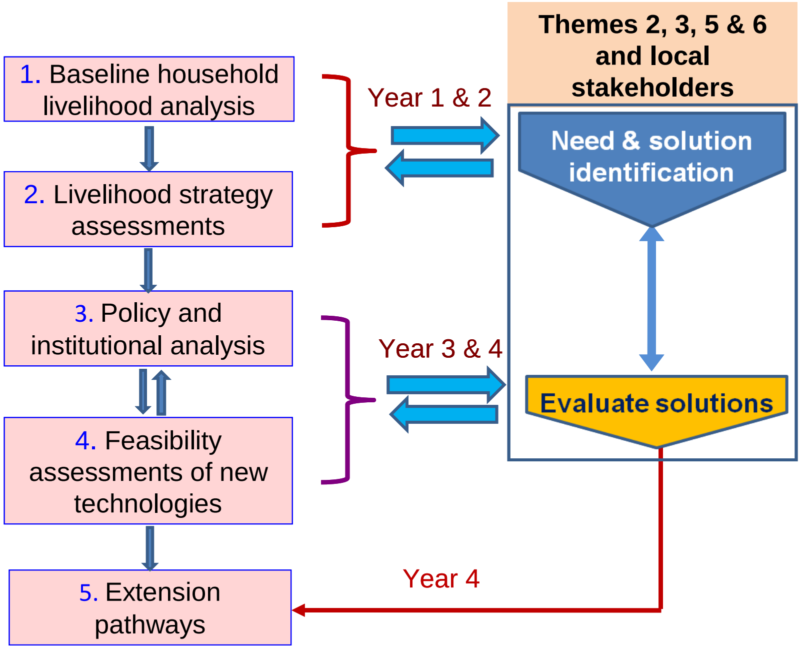

Fig. 4. Study framework of the socioeconomic team (Theme 4).

5.6 Theme 5: Objective 5 (Land use planning component): Integrated adaptation assessment of Bac Lieu Province and development of adaptation master plan

This study applied the Land Use Planning and Analysis System (LUPAS) methodology. (van Ittersum et al 2004) to examine the questions “what would be possible?” or “what would have to be changed?” in the analysis of different land use strategies under CC + SLR and socioeconomic conditions.

An interactive multiple-goal linear programming model (IMGLP) was developed in GAMS modelling language. The model allows interactively running a number of optimization scenarios. Figure 5 presents the model structure. The model has three main components: (i) biophysical land evaluation (BLE), (ii) socioeconomic analysis (SEA), and (iii) scenario analysis with IMGLP (SA).

The data were integrated and input into an IMGLP model (developed in GAMS software) for scenario analysis.

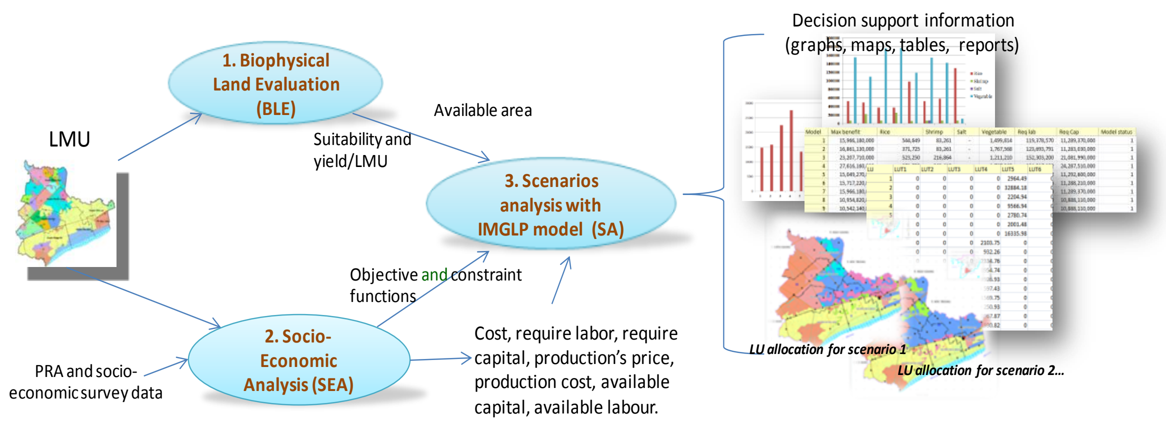

Fig. 5. The IMGLP model for land use adaptation strategy development.

Seven activities were defined for implementing the research:

In activity 5.1, the hydraulic model VRSAP (Vietnam River Systems and Plains, developed by the SIWRP) was calibrated and used to simulate the hydrology (water level, flow, salinity) under present conditions and different CC + SLR scenarios in three representative hydrological years based on flow from Kratie: (i) low water year (1998), (ii) average (normal) water year (2004), and high water year (2000). The model was also applied to analyze adaptation options (e.g., sluice operations and land use scenarios). Mapinfo software was used for the analysis of salinity intrusion and inundation boundaries under current and projected SLR + CC and sluice operations.

Activity 5.2 analyzed the impacts of potential improvements in hydraulic infrastructure using VRSAP. Information on water control infrastructure and its operations was collected at operation stations of the Water Resource Management Company in Bac Lieu and analyzed and reported.

Activity 5.3 (Fine-mapping of soils and current land use in Bac Lieu Province through remote sensing and ground-truth) used soil surveys and checking with recent satellite maps to update the current soils and land use map of Bac Lieu Province.

Activity 5.4 analyzed biophysical land suitability for rice-based land use systems under different SLR + CC and infrastructure development scenarios.

It determined resource availability (land area, water availability, soil and water qualities, labor, and capital), identifying promising land use types (LUT) and possible technical levels applied in each land mapping unit (LMU) at present and in the future.

Activity 5.5 interacted with stakeholder of all levels to identify socioeconomic constraints to the adoption of more resilient farming systems and to recommend institutional/policy changes.

This is linked with Act. 4.3 of Theme 4, which encompassed intensive stakeholder interactions through participatory workshops and policy recommendations in the case of Bac Lieu Province. (See detailed description of the method of Theme 4 in section 5.5 of this report.)

Activity 5.6 applied the IMGLP for land use planning and defining a master plan on climate change adaptation.

The objective functions in IMGLP were formed based on development targets such as rice production for food security and income per capita. In the study, the main development objectives proposed from the local stakeholders are to increase provincial benefits and to achieve the production targets (e.g., rice, shrimp). The constraints are land area that is suitable for each LUT (which varied with the biophysical conditions under CC and SLR scenarios), labor and capital availability, and market demand. Scenarios were built to explore future land use under changing biophysical and socioeconomic conditions or development goals.

During modelling work, meetings and workshops were organized to receive feedback from local stakeholders on the model results.

Activity 5.7 (Derive "lessons learned" from this case study for future development of adaptation master plans in other provinces). Through the scenario analysis (Activity 5.6), adaptive opportunities for Bac Lieu Province were established for different proposed land use maps corresponding to scenarios. The second-round modelling, including climate change impact analysis and adaptation strategies, was continued until August 2014.

See detailed method in Appendix 5 (the Theme 5 Final Report).

5.7 Theme 6: Objective 6: Capacity building for assessing GHG emissions

The emission theme was mainly conceived for capacity building, but still encompassed genuine research questions related to GHG emissions from rice fields under different technologies. Details of activities of the Theme follow:

Activity 6.1: Establishing a laboratory for gas analysis and training of researchers at CLRRI

An analytical lab for gas analysis was established at CLRRI. In the first year, the analytical operations of this new lab will be streamlined with the help of regular inter-calibration with the IRRI lab as a means of quality assurance.

Activity 6.2: Training in Theme 6 for researchers and students in flux sampling

Once the CLRRI staff were trained, they themselves trained others to set up and make flux measurements. To increase awareness of GHG emissions, CC, and emission mitigation, four workshops were held in the target zones.

Local staff were trained to do manual gas sampling of gas emissions (CH_4 and N_2O) deploying a “closed chamber” technique. Emissions measured in the project were sampled in field experiments implemented by Theme 3.

The project team conducted training courses and lectures on GHG emissions and mitigation strategies for students, researchers, and extension officers from CTU and other institutions in the MRD. These events used CLRRI facilities including dormitories. The project team also strived to incorporate students from CTU for thesis work. Students used lab facilities in their thesis work.

Activity 6.3: Conducting flux measurements

In the first 2 years, emission measurements were limited to the field sites of CLRRI and Hoa An station; emission rates were recorded at weekly intervals. Exploratory studies in Bac Lieu and An Giang followed in years 3 and 4 to allow comparative analysis. Gas samples were analyzed by gas chromatography, which was newly established in the gas chromatography lab. Gas samples from other target areas were shipped to CLRRI in air-tight vessels and were analyzed within a 24-hour period after sampling.

Activity 6.4: Assessing gaseous C and N emissions for a comprehensive analysis of element cycling and budgets

Greenhouse gas emissions were measured from samples in each of the four agro-ecological zones and were used to examine the mitigation potential of AWD, tillage, and residue management. Statistical analyses of data were performed by SAS 9.1 (SAS Institute 1988).

Activity 6.5: Deriving emission factors and spreadsheet tools from field data for quantifying GHG emissions in rice systems of the MRD

A spreadsheet tool was developed to allow the calculation of gas emissions from the concentrations of the collected gas samples using linear regression. The spreadsheet tool corrects the data for pressure and temperature effects, and instrument calibration, and performs and assesses the linear regression. Emission factors were developed for each agro-ecological zone.

See detailed method in the Theme 6 Final Report (Appendix 6).

5.8 Theme C: The Project Office: Coordination and integration

Theme C was established to create a sound infrastructure for all project activities, to ensure internal and external communication flows, to supervise progress of activities, to organize in-country training, seminars, forums, and workshops, and to establish linkages and partnerships with local governments, nongovernment organizations, private entities, and international institutions with similar programs on climate change (CC) within the Mekong River Delta (MRD).

Activity C.1: Creating sound logistics in the Project Office and target areas, establishing efficient administrative procedures, and organizing regular project meetings

To facilitate the activities of the project, the Project Office (PO) was established in Can Tho University (CTU). The PO facilitated the organization of the operational team composed of the national project director, national project coordinator, IRRI project facilitator, project assistant, theme leaders, and representatives from Provincial Departments of Agriculture and Rural Development of An Giang, Can Tho, Hau Giang, and Bac Lieu provinces. Project staffs were hired for the project assistant and routine operations were established for the whole of the CLUES project.

Themes were supported by international consultants from IRRI, CSIRO, IWMI, and ACIAR. Their activities had been coordinated through several operational team meetings, regular meetings of six theme leaders and members, training, field visits, and technical advice during its second year of operation. The operational meeting (OM) was organized in the PO bimonthly.

Activity C.2: Generating efficient pathways of information fluxes for internal purposes and public visibility

These activities were carried out by establishing a home page for CLUES, creating Dropbox and Google accounts for file sharing among team members, and writing frequent news articles in the IRRI Bulletin, ACIAR newsletter, and IRN Asia news.

The project coordination team applied up-to-date Internet technologies to establish a project home page separated into internal access for data exchange and communication as well as public access for high visibility of the project. The private area was used as the central information and communication platform, which provided ample space for exchange of data, ideas, and results. Access to the intranet for posting and updating information was granted to all groups involved in the project.

The public area contained all relevant information, including, among others, manuscripts and the latest publications of the project, information about upcoming meetings and educational programs, meeting reports, lists of methods and techniques available within the project, and links to relevant websites.

Activity C.3: The progress of individual tasks and the performance of project-derived adaptation packages to define eventual adjustment of activities were monitored by regular operational meetings, regular field monitoring and evaluation, and a semi-annual and annual project review.

Activity C.4: The relevance of project findings for other rice production environments, in particular, for other regions in Vietnam and for the Australian rice industry. This was comparatively assessed by stress-tolerant rice and best management practices developed and identified in the locality. Rice genotypes provided by international counterparts; this was carried out by Themes 2 and 3.

Activity C.5: Reporting and publications were carried out by a team through organizing semi-annual and annual technical and financial reports. The PO also wrote frequent news articles in the IRRI Bulletin, ACIAR VN, and IRN Asia news, plus publications in refereed journals.

6 Achievements against activities and outputs/milestones

Theme 1: Location-specific impact and vulnerability assessment

Act. 1.1. Literature review and meta-analysis of available data and documents on CC projections for MRD to identify potential production constraints to future production

No.	Activity	Outputs/ milestones	Scheduled completion date	Comments
1.1.1	Review existing and ongoing studies on CC projection for Mekong river, especially upstream boundary and SLR	Collecting and reviewing studies in MRD region (SIWRP)	2/2012	Done as planned
1.1.2	Review projected data (temperature and precipitation) of the Mekong Delta based on projected data of PRECIS	Projection data	2/2013	1 year later than as planned because of the study on simulated downscaling data on climate change in Vietnamese MRD. They are also input data of VRSAP
1.1.3	Adjust projected data from Regional Climate Model for hydraulic calculation	Adjusted data	2/2013	As above

Act. 1.2. Assessing hydrological impacts of different sea-level rise scenarios in MRD region (hydraulic modelling)

No.	Activities	Outputs/milestones	Scheduled completion date	Comments
1.2.1	Collecting and processing hydro-meteorological data, sluice operation schedule, and land use for baseline year 2008 and for three years of 1998 (dry year—low water), 2004 (normal year—average water), and 2000 (wet year—high water)	Data for 1998, 2004, 2000	2/2012	Completed as planned
1.2.2	Field surveys for checking existing data on land use, sluice operation, and other infrastructure		10/2011	Completed 4 months later than planned
1.2.3	Establishing projected scenarios, based on SLR scenarios (MONRE 2012).	Set of projected scenarios for SLR	8/2011	Finished as planned

1.2.4	Simulating salinity and flooding depth for recent year 2008 with current land use and sluice operation. Analysing results of simulation and writing report.	Result maps of salinity and flooding	12/2011	Finished 2 months later than planed
1.2.5	Simulating salinity and flooding depth for projected scenarios in normal, wet, and dry years with current land use and sluice operation. Analysing results of simulation and writing report.	Result maps of salinity and flooding	9/2011-6/2012	Finished in 4/2013, late due to waiting for simulated downscaling data on climate change in Vietnam MRD. They are also input data of VRSAP.

Act. 1.3. GIS mapping of flooding depth and salinity levels within the MRD as a function of sea-level rise and envisaged upstream development projects for different land use options

No.	**Activities**	**Outputs/milestones**	**Scheduled completion date**	**Comments**
1.3.1	Applying VRSAP model for different land use options for dry year (1998), normal year (2004), and wet year (2000) at different SLRs and upstream development. Analyzing results of simulation and writing report.	Result maps of salinity and flooding	12/2013	Finished as planned

Act. 1.4. Comparative assessment of CC impacts on rice production in the four target areas (An Giang, Can Tho, Hau Giang, and Bac Lieu)

No.	**Activity**	**Outputs/milestones**	**Scheduled completion date**	**Comments**
1.4.1	Finding out the trend of yield, productivity, and area changing from 2000 to 2010	Report	3/2014	Completed
1.4.2	Developing rice cropping pattern maps	Series of result maps	3/2014	Completed
1.4.3	Overlay rice cultivation map of each province with different sea-level rise, depth, and salinity scenarios to find out the effect of CC on rice production in four target areas	Time series of mapped hydrological conditions	4/2014	Completed for the entire Delta so that information for target areas can be derived from there
1.4.4	Field survey for checking the specific threats in the four target areas	Time series of mapped hydrological conditions	5/2014	Completed for the entire Delta so that information for target areas can be derived from there
1.4.5	Assessment of common and specific threats in each target area	Comprehensive report on common and specific threats in each target area	6/2014	Completed for the entire Delta so that information for target areas can be derived from there

Act. 1.5. Mapping (delta-wide) of vulnerability and potential "hot-spots" of flooding and salinity damage

No.	Activity	Outputs/milestones	Scheduled completion date	Comments
1.5.1	Collecting satellite images (MODIS images from 2000 to 2010)	Set of 1,082 MODIS images	2/2013	Incorporated into detailed land use map
1.5.2	Developing set of NDVI maps from 2000 to 2010 Initial rice sowing map in Mekong Delta	Set of 920 NDVI maps	4/2013	Incorporated into detailed land use map
1.5.3	Investigate current land use and time of rice sowing in Mekong Delta	List of data for validation	1/2014	Completed as planned
1.5.4	Overlay current land use map of MRD with maps of water depth and salinity under different CC and SLR scenarios	GIS map on risks completed	1/2014	Completed as planned
1.5.5	Mapping of vulnerability and potential "hot-spots" according to different scenarios	GIS map on risks completed	4/2014	Completed in 2015

Theme 2: Improvement of salinity and submergence resilience of locally adapted rice varieties and elite lines

Act. 2.1. To transfer the SUB1 *QTL into adapted germplasm*

No.	Activity	Outputs/ Milestones	Scheduled completion date	Comments
2.1.1	Identify locally adapted varieties and elite breeding lines as recipients of *SUB1*	Recipient lines identified	April to August 2011	Completed as planned
2.1.2	Generate and disseminate improved rice lines tolerant of temporary (complete) submergence through transfer of the *SUB1* gene into local popular varieties and newly developed elite breeding lines	*SUB1* introgressed into two locally adapted materials from Vietnam and one variety from Australia	March to December	Completed as planned
2.1.3	Backcross *SUB1* into Australian rice genetic background	Backcross populations produced and selected	April 2015	Seed of BC_2F_4 populations sent to Australia Plant Quarantine

Act. 2.2. To improve tolerance of partial stagnant flood

No.	**Activity**	**Outputs/ Milestones**	**Scheduled completion date**	**Comments**
2.2.1	Screening of germplasm	100 landraces and 100 current varieties benchmarked	December 2013	Three landraces demonstrated good survival and recovery-stage growth in Mot Bui Do, Tep Hanh, and Tai Nguyen Duc. Also, three improved varieties (OM10252, OM3673, and OM10276) had good survival and recovery.
2.2.2	Generating improved rice germplasm resilient to stagnant (partial) flood	Testing of breeding lines under naturally occurring stagnant flood conditions	March 2015	A total of 12 rice genotypes with some tolerance of stagnant flood together with an additional farmers' variety were evaluated in selected farmers' fields in Hau Giang Province. The farmers preferred five varieties (OM7347, Can Tho 2, Hau Giang 2, Can Tho 3, and OM6L) and three of these are already included in seed multiplication in 2014. Similarly, 12 stagnant-flood-tolerant rice genotypes and additional entries of farmers' varieties were evaluated in selected farmers' fields in Can Tho.

Act. 2.3. To investigate anaerobic germination

No.	**Activity**	**Outputs/ milestones**	**Scheduled completion date**	**Comments**
2.3.1	Screening of germplasm	Landraces and current varieties tested for tolerance of anaerobic germination	May 2012	More than 200 landraces and current varieties were screened under anaerobic conditions, and promising lines identified.
2. 3.2	Exploring the genetic basis of tolerance of anaerobic conditions during germination to facilitate improvement	F_2 populations between susceptible and tolerant lines were developed for QTL analysis	May 2014	Two significant QTLs associated with the AG trait were detected from cross Tai Nguyen/Andabyeo. They were located on chromosomes 1 and 11, respectively. In particular, the QTL on chromosome 1 had an LOD score of 7.45.

Act. 2.4. To transfer salinity tolerance into adapted germplasm

No.	Activity	Outputs/ Milestones	Scheduled completion date	Comments
2.4.1	Identify locally adapted varieties and elite breeding lines as recipients of *SUB1* and *Saltol*	Recipient lines identified	April to August 2011	Completed
2.4.2	Generating and disseminating improved rice lines tolerant of salinity through transfer of *Saltol* gene into varieties of suitable maturity and adaptation, separately and in combination with *SUB1*	*Saltol* introgressed into two locally adapted materials from Vietnam and two to three varieties from Australia	April 2015	More than 100 BC_4F_3 lines have been selected from two backcross populations: OM1490*4/Pokkali and OMCS2000*4/Pokkali. These lines have been genotyped for the *Saltol* QTL and screened under salinity at concentrations of EC = 8 and 15 dS/m. Selected lines that match the recipient parents can be tested for release.
2.4.3	Backcross *SUB1* into Australian rice genetic background	Backcross populations produced and selected	April 2015	Seed of BC_2F_4 populations sent to Australia Plant Quarantine

Theme 3: Managing resources for resilient rice-based systems coping with rapidly changing environments

Act. 3.1. To identify climate change-related stresses that will affect future production

No.	Activity	Outputs/ Milestones	Scheduled completion date	Comments
3.1.1	Participatory rural appraisal (PRA) for constraint analysis of cropping systems and identifying promising solutions for CC adaptation	CC-related stresses identified by constraint analysis	Mar. to Dec. 2011	Salinity and flooding are mostly identified stresses; besides that, AS is also the problem at the Hau Giang site.
		Promising solutions to CC-related stresses	Dec. 2011-Aug. 2013	Promising technologies proposed and being tested by experiments
3.1.2	Literature review of relevant research issues and testable hypotheses	Literature reviews completed and submitted	Mar. 2012-Aug. 2013	Two literature reviews on salinity and flooding affecting rice cultivation were reported
		Research proposal for each site completed and submitted	Aug 2011 - Dec 2013	Protocols were submitted before starting each experiment

Act. 3.2. To develop, test, and refine management options for different agro-ecological zones

No.	Activity	Outputs/ Milestones	Scheduled completion date	Comments
3.2.1	Field experiments (a) Site selection and characterization	Testing in villages and fields identified in different agro-ecological zones.	Mar. 2012	Completed as planned
		Experimental fields characterized	Mar. 2013	Completed as planned
	(b) Designing experiments	Experimental design completed for all four target zones	Aug. 2012	Completed as planned
	(c) Implementing experiments	Experiments in each of the target zones (BL, AG, HG, CT) started and completed	Sep. 2014	Completed as planned
3.2.2	Training on soil and water sampling and statistical design	Training workshop	Mar. 2012	Completed as planned
3.2.3	Soil and plant samplings and analyses	Data on soil and plant analyses for the trial crops in the first to fourth years	Dec. 2014	Completed as planned

Act. 3.3. To improve understanding of element cycling, soil-plant, and cropping system responses caused by the different management options

No.	Activity	Outputs/ milestones	Scheduled completion date	Comments
3.3.1	Processing studies on stress responses in target regions through pot experiments and column experiments	(a) Initial scoping document for process-based studies. Identification of key stressors and processes. (b) Review of experimental design. Inputs required from all participants. (c) Design column and pot experiments.	Mar. 2014	(a) Scoping document completed. (b-c) Mr. Minh has been awarded a John Alright Fellowship and will research nitrogen and carbon emissions using pot experiments. (c) Pot and column experiments on residue management and salt leaching, respectively, started and completed.

Act. 4. To assess the role of non-rice crops in rice-based systems for climate change adaptation

No.	Activity	Outputs/ milestones	Scheduled completio n date	Comments
3.4.1	Selection of stress-tolerant upland species and testing them in rice-based systems	- Experimental designs and land preparation for field experiments - Assessment of integrating upland crop in rice-based systems	Jan. 2012-May 2013	Experiments were carried out in all target zones.
3.4.2	Field trials for transferring identified techniques to the farmers		Jan.-May 2014	In Hau Giang and Can Tho, it was possible to insert two cucumber (or sesame) crops in Summer-Autumn for increasing economic resilience of farmers.

Theme 4: Analysis of farming systems and socioeconomic settings in rice farming households

Activities	Sub activities	Outputs/milestones	Scheduled completio n date (mm/yy)	Comments
4.1. Baseline livelihood assessments	- Participatory community appraisals on bio-physical and socio-economic constraints at community level - Household surveys on livelihoods - Household surveys on gender issues	- Well-trained team members with methods and skills of data collection - Identification of problems and constraints of physical and socio-economic setting at different levels and with different options - Roles and needs to enhance capacity of women to adapt to climate change	Mar. 2013	- Completed - Inputs to activities 4.2, 4.3, and 4.4, and themes 2, 3, and 5 - Manuscripts for publication in preparation
4.2. Sustainable livelihood and adaptation strategy assessments	- Self-assessment workshops with farmer groups in each study zone Through group discussions and in-depth interviews	- Well-trained team members with methods and skills of data collection - Identification of enablers of and constrainers to adaptability by households	Mar. 2013	- Completed - Inputs to activities 4.3 and 4.4 and themes 2, 3, and 5 - A manuscript for publication in preparation
4.3. Policy and institutional analysis	- Organize local workshops with participation of local extension staff, government officials, and	- Identification of policy and institutional gaps that influence capacity of farmers	Sep. 2014	- Completed - Inputs to activities 4.4 and 4.5

	service suppliers	and adoption of new technologies by farmers - Identification of opportunities for mainstreaming climate change adaptability measures into local and national development programs		
4.4. Participatory fine tuning of project-generated technologies and assessing benefits in terms of adaptive capacity	- Participatory evaluation of on-farm-tested rice varieties (PVS) - Feasibility assessments of on-farm-tested rice farming technologies with local stakeholders	- Agronomic criteria expected by farmers for future rice varieties by zone - Feasibility rank of tested technologies by zone - Improved management practices for new adaptation technologies in line with farmers' requirements	Sep. 2014	- Completed - Inputs to activity 4.5 and themes 2, 3, and 5; - Improved management practices for new technologies not achieved due to limited time
4.5. Explore possible extension pathways of research findings of the project	- Training and workshops with local stakeholders and project researchers on impact pathway and extension pathway analysis of CLUES' promising technologies - Simulation of adopting feasible technologies by farmers by zone	- Well-trained extension staff with impact pathway and extension pathway analysis methods - Identification of ways and options and recommendations for out-scaling and up-scaling of feasible technologies	Nov. 2014	- Completed - Feedback to activities 4.1, 4.2, 4.3, and 4.4 and themes 3 and 5.

Theme 5: Integrated adaptation assessment of Bac Lieu Province and development of adaptation master plan

No.	Activity	Outputs/ Milestones	Scheduled completion date	Comments
5.1	Fine mapping of salinity borders in high spatial and temporal resolution in different sections of Bac Lieu Province under current and projected sea level and sluice operations	GIS maps of salinity and flooding in scenarios: dry year (1998), normal year (2004), wet year (2000); dry, normal, and wet years + future CC + SLR + sluice gates operation schemas.	Mar. 2012	Completed as planned.

5.2	Determining the benefits from potential improvements in infrastructure (sluice and dike system) in terms of salinity and flooding risks	Report on the existing water management infrastructure and its operational schemas.	Mar. 2012	Completed as planned.
5.3	Mapping of soils and current land use in Bac Lieu	Updated GIS maps of soil, land use, and land mapping unit of Bac Lieu Province	June 2012	Completed as planned.
5.4	Analyze biophysical land suitability for rice-based land use systems under different CC, SLR, and infrastructure development scenarios	GIS maps on land suitability and descriptions (present and future scenarios of SLR + CC + sluice gates operation schemas)	Mar. 2013	Completed as planned.
5.5	Identify socioeconomic constraints to the adoption of more resilient farming	- Five workshops with policy and institutional stakeholders in Bac Lieu Province - A report on socioeconomic constraints of current agricultural land use patterns in Bac Lieu Province	Aug. 2013	Completed as planned.
5.6	Apply multiple-goal linear programming for land use planning and define a master plan on climate change adaptation	Optimized adaptation of land use options at provincial scale for different scenarios (biophysical and socio-economic constraints, development goals, and adaptation options)	Dec. 2014	Completed as planned.
5.7	Derive “lessons learned” from this case study for future development of adaptation master plans in other provinces	- Six scientific papers (5 in Vietnamese, 1 in English), one national work presentation, and one international workshop presentation. - Three training courses (40 participants, 15 females) with guidelines and tools available for developing adaptation master plans in other provinces of the MRD. - Three workshops with policy and institutional stakeholders.	April 2015	Completed as planned.

Theme 6: Capacity building for assessing greenhouse gas (GHG) emissions

Act. 6.1. Establishing a lab for gas analysis and training of researchers at CLDRRI

No.	Activity	Outputs/ Milestones	Scheduled completion date	Comments
6.1	Establishing a lab for gas analysis and training of researchers at CLRRI for GC operation, maintenance, and use of PeakSimple software for GHG analysis	Routine operations for efficient gas analysis (incl. calibration and accuracy cross-checks)	30 September, 2011	-GC lab upgraded and equipped with air conditioner to maintain room temperature at 25 °C. -Seven researchers at CLRRI are able to operate GC for GHG analysis. -20KVA UPS was also installed for GC operation continuously. -Dehumidifier was equipped to maintain RH at 60%.

Act. 6.2. Training of researchers and students in flux sampling at all benchmark sites

No.	Sub activities	Outputs/ Milestones	Scheduled completion date	Comments
6.2.1	Training of researchers and students in flux sampling at Hue University	First training course for two researchers of CLRRI and two lecturers of Can Tho University	4 June 2011	Three-day training course organized at Hue University.
6.2.2	Training on GC principle and GHG analysis	Second training course for CLRRI, Can Tho University and An Giang and Vinh Long extension staff	23-25 November 2011	Three scientists from CLRRI and 14 from Can Tho University will conduct Theme 3 experiments at four benchmark sites.
6.2.3	Training on flux sampling by closed chamber method	Third training course for students of An Giang, Cuu Long, and Can Tho Universities	4-5 May 2012	Two-day training on closed chamber fabrication and flux sampling for 16 students.
6.2.4	Flux sampling by closed chamber method	Fourth training course for six extension staff of Tra Vinh Province	16 November 2012	CLUES project supports GIZ Tra Vinh to evaluate GHG emissions from paddy rice under SRI model and farmers' routine practice method.
6.2.5	Flux sampling by closed chamber method	Fifth training course for seven extension staff of Long An Province	7 March 2013	CLUES project supports WINROCK Long An to evaluate GHG emissions from paddy rice under SRI model and farmers' routine practice method.

6.2.6	Workshops in Soc Trang, Vinh Long, and An Giang on GHG emissions from rice	79 extension workers participated	May-June 2014	Theme 6 in cooperation with the national project BĐKH.2014.57 on "Rational use of acid soils for CC adptation" and Provincial Extension Center.

Act. 6.3. Conducting flux measurements

No.	**Sub activities**	**Outputs/ Milestones**	**Scheduled completion date**	**Comments**
6.3.1	Conducting intensive flux measurements at CLRRI to study effects of cultivation methods on GHG emissions	Baseline emissions from Can Tho site. Cultivation methods and effects on GHG emissions.	Winter-Spring 2012-13	Can Tho site (shallow flooded alluvial soil)
6.3.2	Conducting intensive flux measurements at CLRRI to study effects of water management and fertiliser/manure on GHG emissions	Baseline emissions from Can Tho site. Water management and fertiliser/manure effects on GHG emissions.	Winter-Spring 2012-13	Water management on experimental plots could not be done properly in Mekong Delta soil because of high percolation and leaching.
6.3.3	Conducting intensive flux measurements in Hau Giang and An Giang	Baseline emissions at An Giang and Hau Giang sites	Summer-Autumn 2013	Hau Giang (acid sulfate soil) and An Giang (deep flooded alluvial soil)
6.3.4	Conducting intensive flux measurements in Bac Lieu	Baseline emissions in Bac Lieu	Summer-Autumn 2014	Lang Giai-Bac Lieu (salt-infected soil)

Act. 6.4. Assessing gaseous C and N emissions for a comprehensive analysis of element cycling and budgets

No.	**Activity component**	**Outputs/ milestones**	**Scheduled completion date**	**Comments**
6.4.1	Conducting intensive flux measurements on shrimp-rice cropping system in Bac Lieu	Baseline emissions from saline soil in Bac Lieu	Autumn-Winter 2013	Phuoc Long-Bac Lieu (saline soil)
6.4.2	Conducting intensive flux measurements on SRI model in Tra Vinh Province	Baseline emissions in Tra Vinh	Winter-Spring 2012-13	Tieu Can and Cau Ke districts-Tra Vinh (alluvial soil)
6.4.3	Conducting intensive flux measurements on SRI model in Long An Province	Baseline emissions in Long An	Summer-Autumn 2014	Tan Thanh and Chau Thanh districts-LA (acid soil)
6.4.4	Conducting intensive flux measurements on cropping systems at Can Tho site	Baseline emissions from R-R-R/R-mungbean-R or R-R-R/R-sesame-R	Summer-Autumn 2014	Thoi Lai District-Can Tho (shallow flooded alluvial soil)

Act. 6.5. Deriving emission factors and spreadsheet tools from field data for quantifying GHG emissions in rice systems of the MRD

No.	Sub activities	Outputs/ milestones	Scheduled completion date	Comments
6.5.1	Calculation of C and N cycling and budget for pilot study in Soc Trang	GHG emissions and C and N budget in Soc Trang	Dec. 2014	One MSc thesis from Can Tho University

Theme C: Coordination and integration

Activity	Outputs/ milestones	Scheduled completion date	Comments
1. Creating sound logistics in PO and target areas, establishing efficient administrative procedures, and organizing regular project meetings	Established Project Office and hired project staff. Organized operational team. Conducted routine operations in PO and in target areas.	July 2011-Sep. 2011	The database manager and the documentation and dissemination manager were hired from CTU.
2. Generating efficient pathways of information fluxes for internal purposes and public visibility	Home page established. Dropbox and Google account file sharing established. News articles in IRRI Bulletin, ACIAR newsletter, and IRN Asia news published.	Nov. 2011-June 2012	Technical references available from CLUES project: - As of this date, the PO has 210 technical reference materials of all kinds, including electronic files. Exchange data and information: • CLUES webpage at CTU: http://websrv.ctu.edu.vn/news_det.php?mn=4&id=619 • CLUES webpage at IRRI: http://irri.org/our-science/climate-change/climate-research/clues-project • Google file sharing: https://sites.google.com/a/irri.org/clues-file-sharing/home?pli=1 • Dropbox with e-mail: Cluesproject@yahoo.com • Data, reports, and other documents received from different themes
3. Monitoring progress of individual tasks and the performance of project-derived adaptation packages to define eventual adjustment of activities	Regular operational meetings. Regular field monitoring and evaluation. Semi-annual and annual project review. Capacity building.	Nov. 2011-June 2015	• 25 technical staff of CLUES project from Cuu Long Delta Rice Research Institute (CLRRI) and Can Tho University (CTU) participated in the training workshop on economic, social, and environmental assessments of new

			technologies. • Four operational meetings and 15 individual meetings of themes and international consultants to strengthen activities of CLUES. • 18 field visits with theme leaders, theme members, and ICs at four target study sites in four provinces.
4. Assessing the relevance of project findings for other rice production environments, in particular, for other regions in Vietnam and for the Australian rice industry	Stress-tolerant rice and best management practices developed and identified in the locality	Jan. 2012-June 2015	Rice genotypes provided by international counterparts. This is being carried out by Themes 2 and 3.
5. Reporting and publications	Semi-annual and annual technical and financial reports. News articles in IRRI Bulletin, ACIAR VN, and IRN Asia news. Publications in refereed journals.	Oct. 2011-June 2015	Scientific reports of themes in August 2012 and March 2013. Semi-annual and annual reports of themes, including financial reports. Ten news articles published.
6. Completion activities in no-cost extension duration	Publication, Internal Review and local workshops and reports	July-Sept 2015	- 10 leaflets, 3 books, 6 final theme reports and 1 synthesis final project report finished. - 2 CTU staffs was promoted as Assoc. Professors - 8 local workshops of internal review and evaluation organized at four provinces - The report on internal evaluation of performances of CLUES themes
7. Policy, planning and investment implications workshops	Workshops for stakeholders at National and District levels in Hanoi and Can Tho	Sept. 2015	Workshops successfully conducted

7 Key results and discussion

The details of the final reports of the six themes appear in Appendix 1 to 6. Below is a compilation of short narratives of accomplishments of the different themes.

Theme 1: Geo-spatial component

Some key results and discussion

In Theme 1, we conducted a wide range of scenario analyses that produce a highly differentiated and complex setting for our results:

1. SLR baseline plus 2 different SLR scenarios (15 and 30 cm) with and without Climate Change
2. River discharge baseline plus discharge reduction scenario
3. all SLR scenarios have been simulated for years with high, medium and low water levels; the river discharge scenario has only been simulated for the year with low water level

Thus, we are unable to show ALL maps/ scenarios of this study, but limit this report to the highlights. In a nutshell, the hydrological scenario analysis revealed the following:

- CC and SLR impacts on flood-related stress are more pronounced than on salinity stress.
- CC and SLR impact on flood-related stress:
  - Partial stagnant flood will become more prevalent.
  - It will be more pronounced in Ca Mau Peninsula than in the current flood-risk zone.
  - It will negatively affect rainy-season crops (Summer-Autumn and Autumn-Winter crops).
- CC and SLR impact on salinity-related stress:
  - Higher salinity and longer duration will occur in 9% of the currently salinity-intruded area.
  - It will be more pronounced in the main Mekong estuaries along the East Sea.
- Not all CC and SLR impacts are negative. SLR will facilitate freshwater accessibility and support gravitational irrigation.
- Adaptation to CC and SLR requires both “hard” and “soft” strategies. Climate-smart agriculture plays a central role.

1. Hydrological characteristics of the Mekong Delta in present situation (baseline)

Figure 6 indicates the differences of maximum salinity of channel salinity that existed among the simulated salinity intrusion in areas in the MRD for 3 years of low, average, and high water. In areas that have a salinity control system such as Quan Lo–Phung Hiep (QLPH), Lower U Minh, South Mang Thit, and Go Cong, the difference in salinity is generally insignificant.

Figure 7 shows the flood-risk depth (maximum channel water level above the average ground) increased in the year of high water and decreased in the year with low water. The flood-risk depth was most significant in upstream areas of the MRD (near the border with Cambodia). Coastal areas such as Ca Mau Peninsula were minimally affected by the flow of the Mekong River. They were mainly affected by tidal regimes of both the East and West Seas, local rain, and the current drainage system.

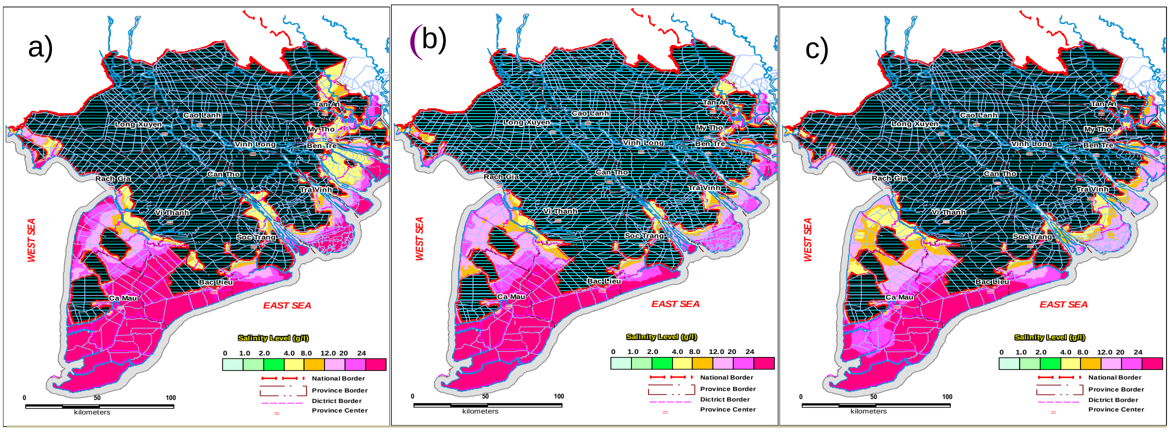

Fig. 6. Maximum salinity of channel water in the dry season without SLR in years of a) low water (1998), b) average water (2004), and c) high water (2000).

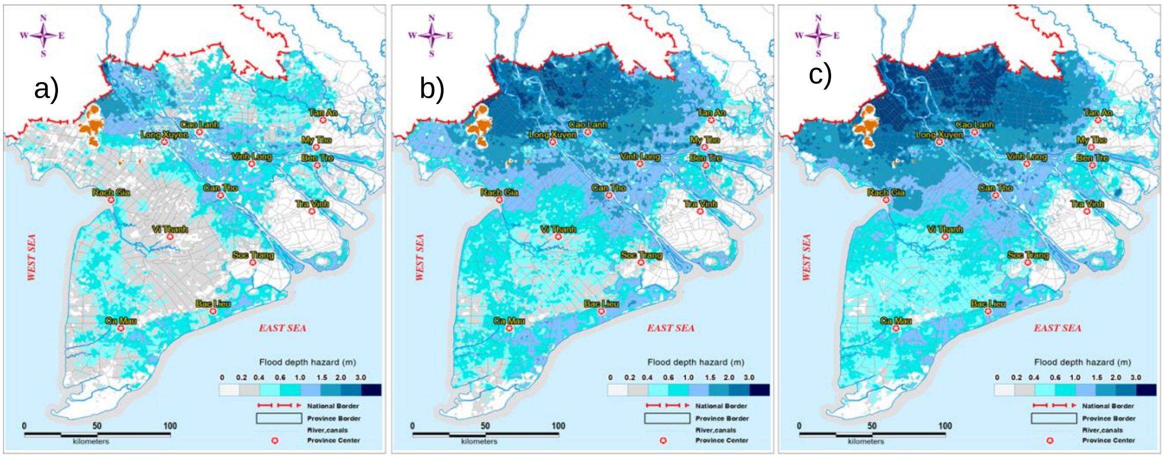

Fig. 7. Flood-risk depth (maximum water level above average ground) in rainy season without SLR in years of (a) low water (1998), (b) average water (2004), and (c) high water (2000).

Figure 6 indicates the differences of maximum salinity of channel salinity that existed among the simulated salinity intrusion in areas in the MRD for 3 years of low, average, and high water. In areas that have a salinity control system such as Quan Lo–Phung Hiep (QLPH), Lower U Minh, South Mang Thit, and Go Cong, the difference in salinity is generally insignificant.

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In the normal year, the saline-affected area is about 33% of the MRD, corresponding to 1.3 million ha of the MRD, and the affected area by flooding is about 50% of the MRD, corresponding to 2.0 million ha of the MRD.

2. Effect of SLR and CC on salinity and flooding risks in the Mekong Delta

2.a Flood risk

Generally, flood-risk depth in the 2030s and 2050s increased compared with that in current conditions.

The incorporated effect of CC with SLR has increased the risks of flooding or submergence in the MRD, especially in years with low water. The flood-risk depth increased significantly, especially in the 2050s, with flood-risk area approximately 190,000 ha at flood depth greater than 1 m.

Figure 8 presents the effects of CC and SLR on the advance of the flood-risk onset date (when flood-risk depth is >0.4 m continuously for more than 7 days). The flood-risk onset date in a high water year and climate change in 2050s were sooner from 1 to 30 days in deep-flooded risk areas (in the center of the Plain of Reeds and Long Xuyen quadrangle). In Ca Mau Peninsula, the flood-risk onset date was at least 30 days sooner than that in the baseline stage.

Figure 9 shows the effect of CC and SLR on the time of flood-risk recession. In the 2050s, the time of flood-risk recession was later than at least 30 days for areas in the center of Ca Mau Peninsula and quicker than from 1 to 30 days for shallow-flooded areas (in the center of the Plain of Reeds and Long Xuyen quadrangle).

Figure 10 indicates the flood-risk duration in the 2050s under SLR and CC compared with baseline conditions. It could be from 15 to 60 days.

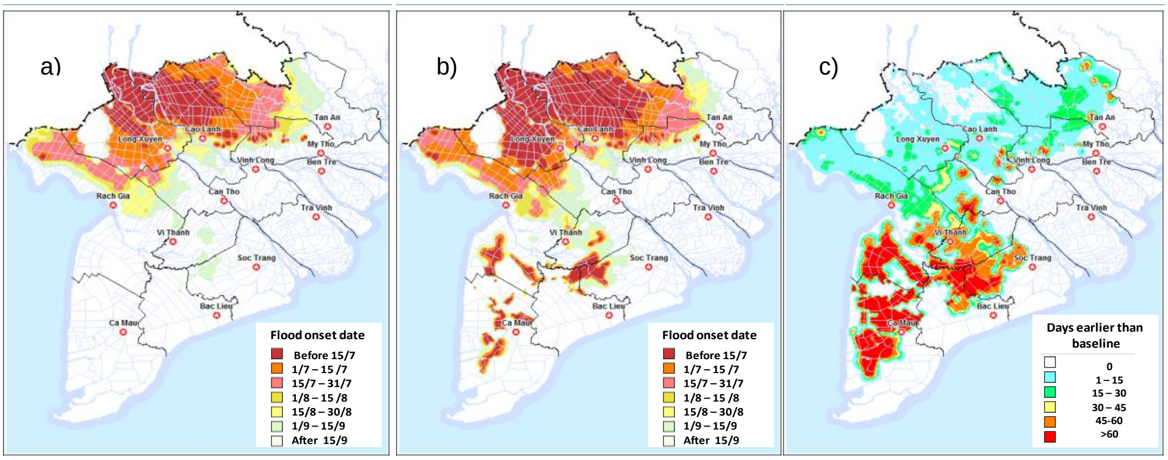


Fig. 8. Flood-risk onset date in (a) baseline year (no SLR and CC in high-water year), (b) 2050s with SLR 30 cm and CC, and (c) change in number of days earlier in 2050s from the flood-risk onset date in baseline year.

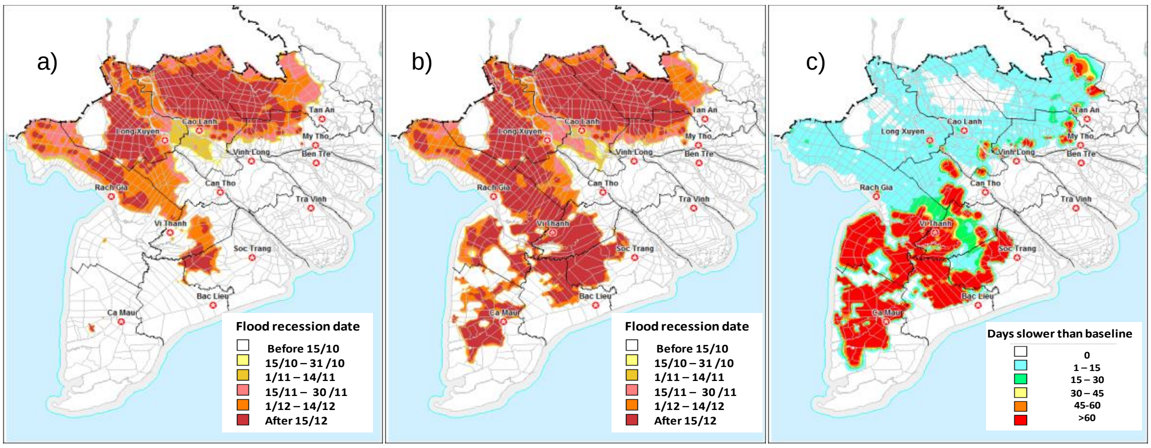


Fig. 9. Flood-risk recession date in (a) baseline year (high-water year without SLR and CC), (b) 2050s with SLR 30 cm and CC, and (c) change in number of days delayed in 2050s from the flood-risk recession date in baseline year.

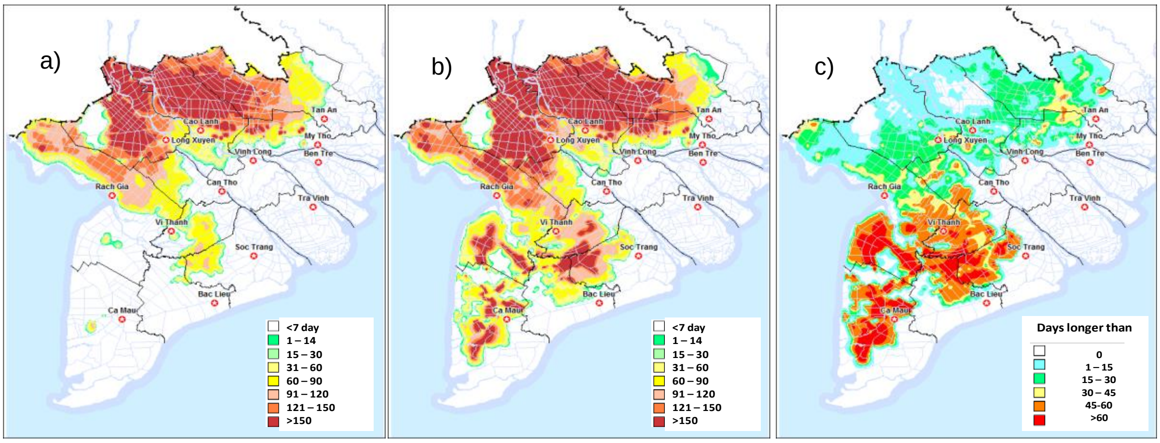
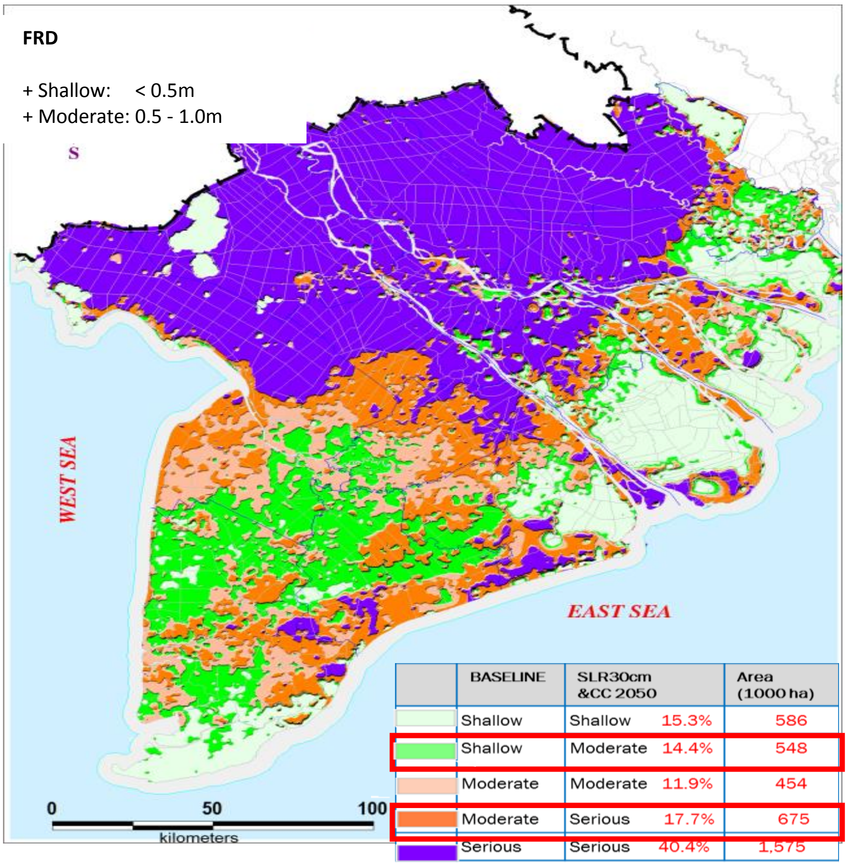


Fig. 10. Flood-risk duration in (a) baseline year (in high-water year without SLR and CC), (b) in 2050s with SLR 30 cm and CC, and (c) change in flood-risk duration between scenarios (a) and (b).



	BASELINE	SLR30cm &CC 2050		Area (1000 ha)
	Shallow	Shallow	15.3%	586
	Shallow	Moderate	14.4%	548
	Moderate	Moderate	11.9%	454
	Moderate	Serious	17.7%	675
	Serious	Serious	40.4%	1,575

Fig. 11. Variations and hotspots in flood-risk depth (FRD) in 2050s with CC and SLR 30 cm from baseline year (without CC and SLR).

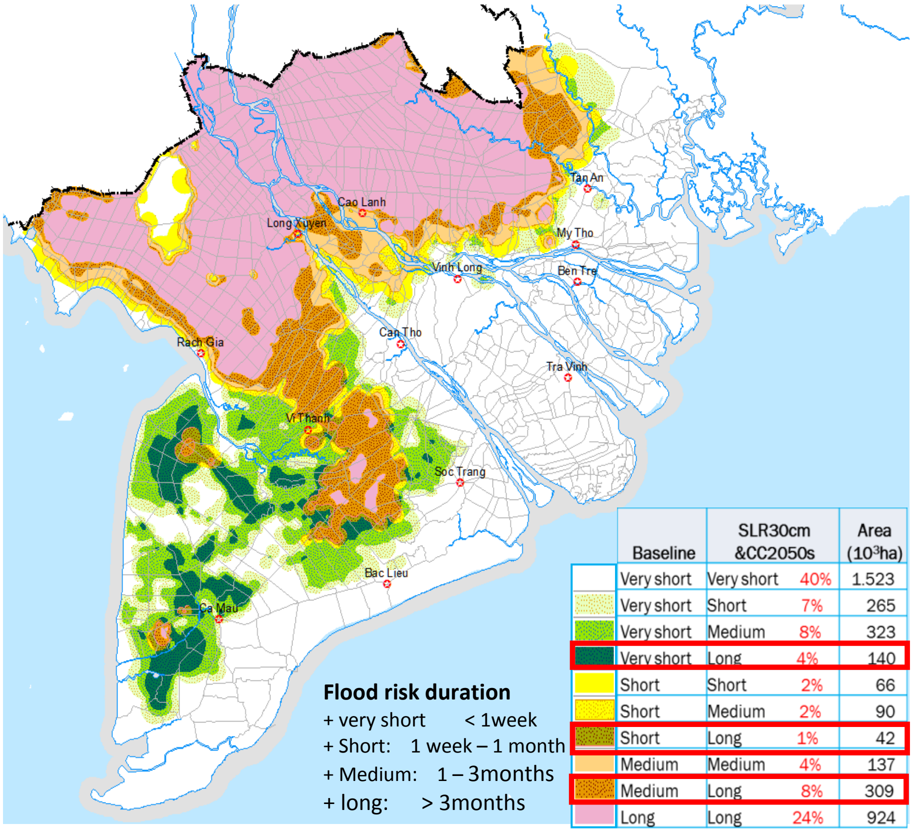


Fig. 12. Variations and hotspots in flood vulnerability duration from baseline year (without CC and SLR) to 2050s with CC and SLR SLR 30 cm.

Figure 11 shows the changes in flood-risk depth from present conditions (baseline year) to the 2050s under the effect of SRL 30 cm and CC, where areas highlighted by red boxes in the legend indicate that the flood-risk area in the 2050s changed from shallow (<0.5 m) to moderate (0.5 to 1 m) and from moderate to serious (>1 m).

Furthermore, figure 12 presents the changes in flood-risk duration from present conditions (baseline year) to the 2050s under the effect of SRL 30 cm and CC, where areas highlighted by red boxes in the legend indicate that the areas of flood-risk duration changed from short (<1 week) to medium (1 to 3 months) and from medium to long (>3 months).

2.b Salinity risk

SLR increased average water levels in the dry season. The increase decreased gradually toward the upstream.

When CC is considered with SLR, the affected areas with salinity of more than 4 g/L clearly increased compared with the baseline. The increase in salinity area was lower in the high-water year than in low- and average-water years.

Figure 13 shows maximum salinity under present conditions and in 2050s with CC and SLR SLR 30 cm in the low-water year. The hotspots of salinity variation are shown in Figure 13 with attention to the salinity increase from fresh (<2 g/L) to brackish (2–4 g/L) and brackish to saline (>4 g/L) (highlighted by the red boxes in the legend). These hotspots, covering about 9% of the saline area, are mainly located at the interface between fresh and saline water along the coastal provinces, in particular on the East Sea side where tidal variation is higher than on the West Sea side.

By 2050, salinity in Northern Mang Thit and Ben Tre provinces might be much higher. In the normal and low-water years, the most areas with salinity of >4 g/L were in Ben Tre, Vinh Long, and Tra Vinh provinces. Salinity in central Ca Mau Peninsula decreased to less than in current conditions.

Figure 14 shows areas in the MRD with medium and long duration of salinity of >4 g/L in current conditions of the baseline scenario, which occupied 35% (or >1,300,000 ha). A few areas had short duration of salinity (4% or 142,000 ha). Most of the freshwater area in the protected infrastructure (dikes, dams, or sluices) along the East Sea are scarcely affected by salinity in 1 week and occupy 44% (or >1,690,000 ha).

Under the impacts of CC and SLR 30 cm in the 2050s, the areas with longer duration of salinity of >4 g/L from 1 to 3 months increased 7% (or 231,000 ha) and small risky areas with salinity longer than 3 months increased 2% (or 88,000 ha). These areas were found in the coastal provinces of Ben Tre Tra Vinh and Tien Giang.

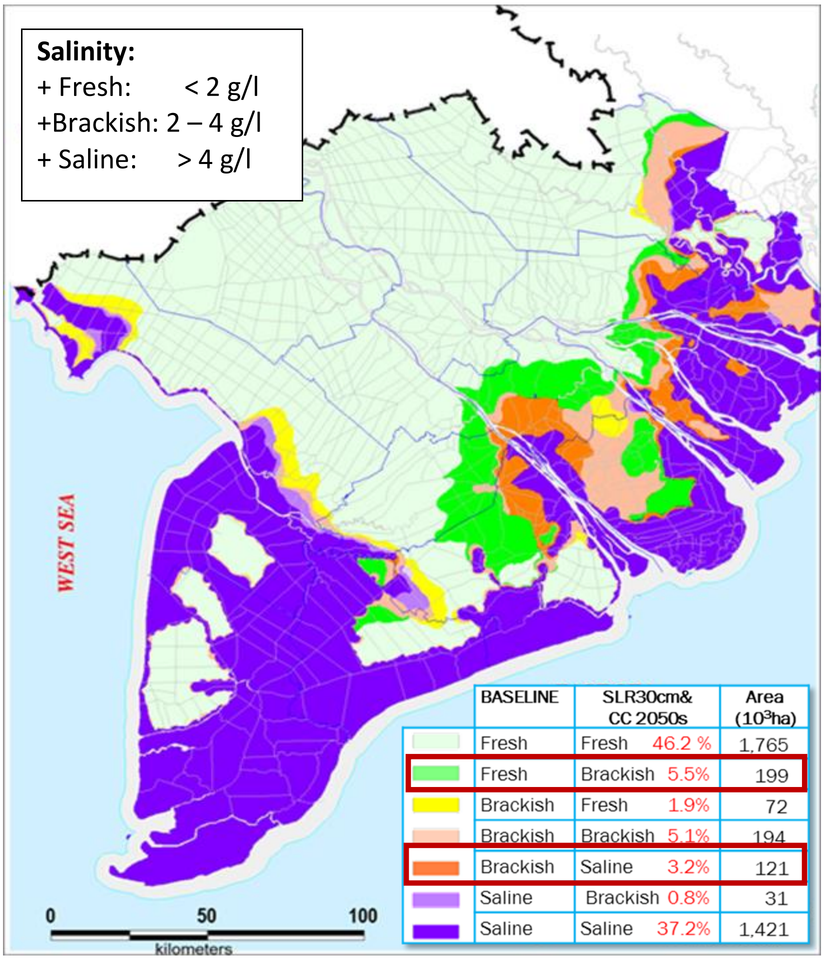


Fig. 13. Variations and hotspots in salinity under baseline year and in 2050s (with CC and SLR 30 cm).

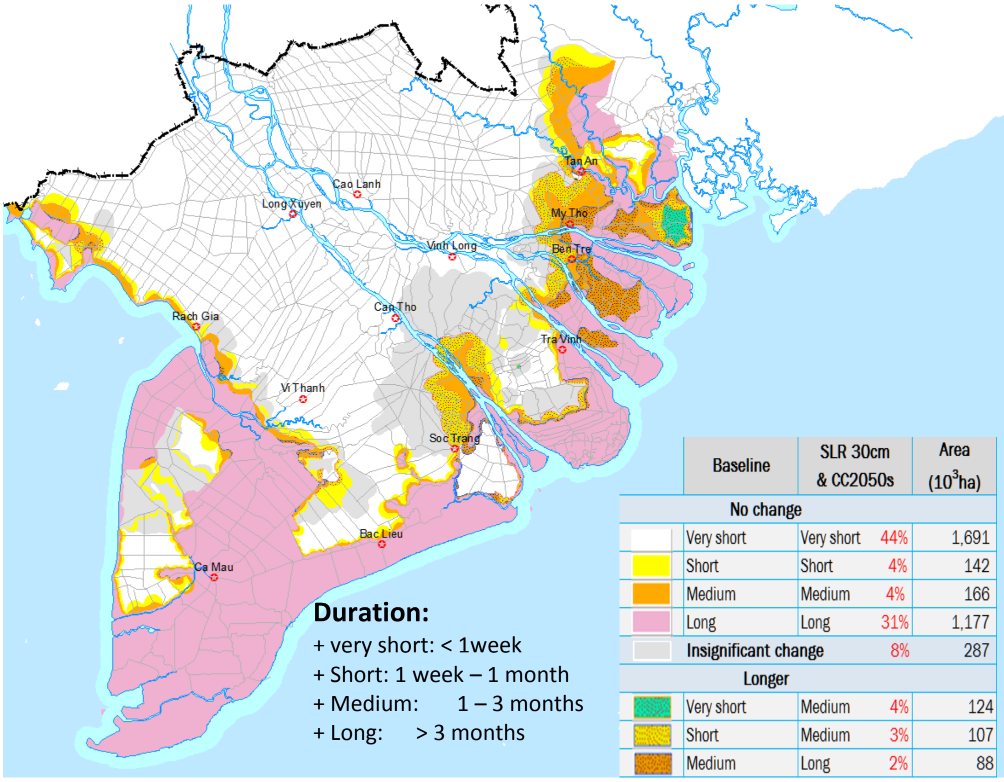


Fig. 14. Salinity vulnerability duration under present conditions and CC 2050s and 30 cm SLR in the high-water year.

The length of salinity intrusion in the main rivers increased considerably in the low-water year with SLR and CC 2050s. The length of salinity intrusion (with salinity of 4 g/L) in the Bassac River varied from 69 km in 2030 to 72 km in 2050 (Fig. 15). In the topography conditions of the baseline scenario, the change in length of salinity intrusion in the main streams is influenced by main factors such as topography of the stream, upstream flow, SLR, and CC.

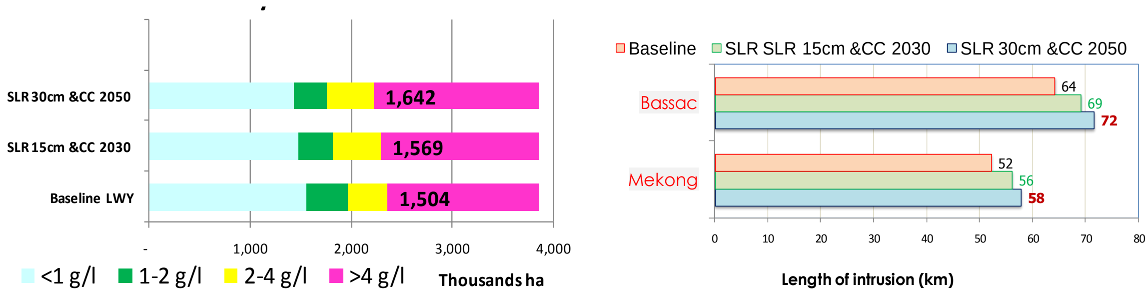


Fig. 15. Change in length of saline intrusion (>4 g/L) in main rivers in scenarios of SLR and CC 2050s in the year of low water.

3. Changes in potential area of gravity irrigation

Figure 16 shows the area irrigated by gravity increased significantly under the impact of SLR and CC. The freshwater area irrigated by gravity could increase from 369,000 ha in current conditions to 780,000 ha (more than a 411,000 ha increase) in 2050s.

The expansion of gravity irrigation areas in MRD in 2050s was mainly a result of SLR. The additional effect of CC on gravity irrigation is only marginal and affected only around 1,000 ha.

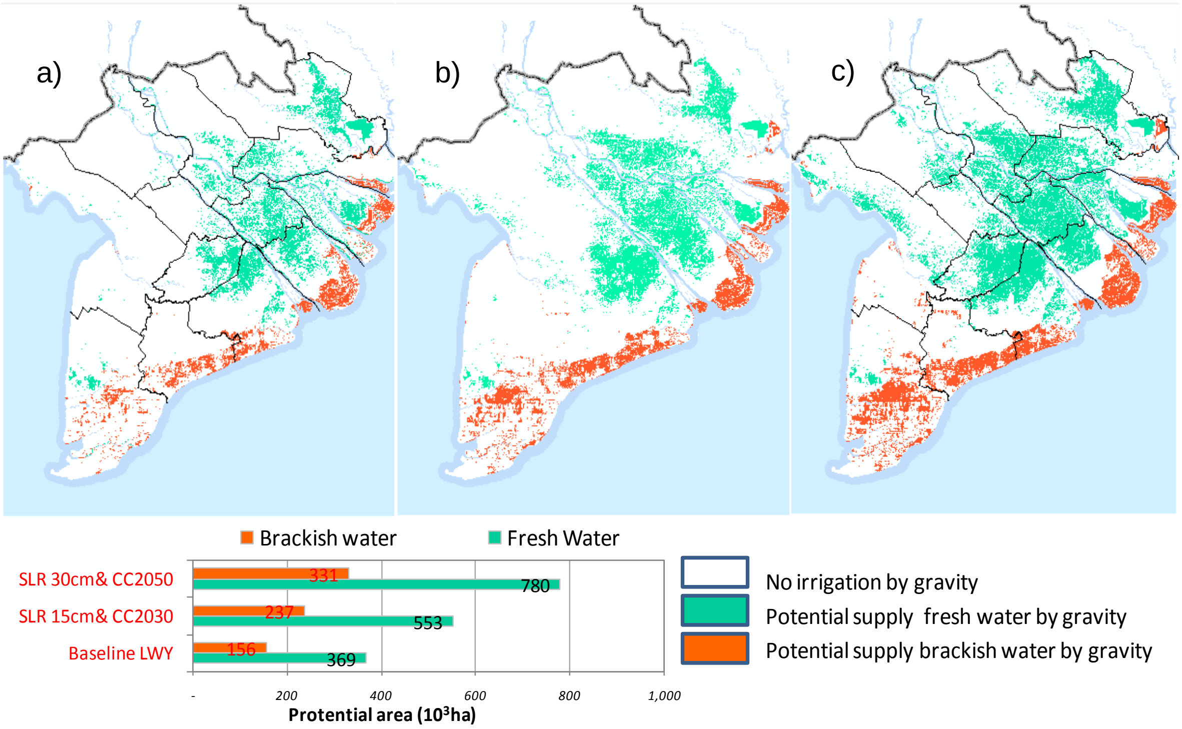


Fig. 16. Potential area of gravity irrigation in low-water year in (a) baseline year and with SLR and CC in (b) 2030s and (c) 2050s.

4. **Comparing impacts of SLR vs upstream flow reduction**

The upstream development of Mekong river basin including building dams and expansion of upstream irrigation in China, Laos and Cambodia will undoubtedly alter the flow regime in the delta (MRC, 2011). However, there is large uncertainty on the precise impacts of these changes – and if those will affect rice production in a positive or negative way. The initial source of uncertainty derives from the questions (i) how many dams will be build and (ii) how big the reservoirs will be in the future. But even if these figures are taken as given (based on incumbent development plans), the crucial question will be (iii) how they will be operated in terms of discharge in the dry vs. wet season.

Obviously, these uncertainties pose serious methodological problems in any assessment of future hydrological conditions in the MRD. After assessing different options, we decided to conduct a sensitivity analysis of changes in river discharge vis-à-vis the changes in SLR+CC. For this purpose, we assumed a 20%-reduction of river discharge at the Kratie gauge which is located 100 km upstream from the Vietnam/ Cambodia border. We conducted this simulation for Low Water Year, namely using the baseline condition of 1998.

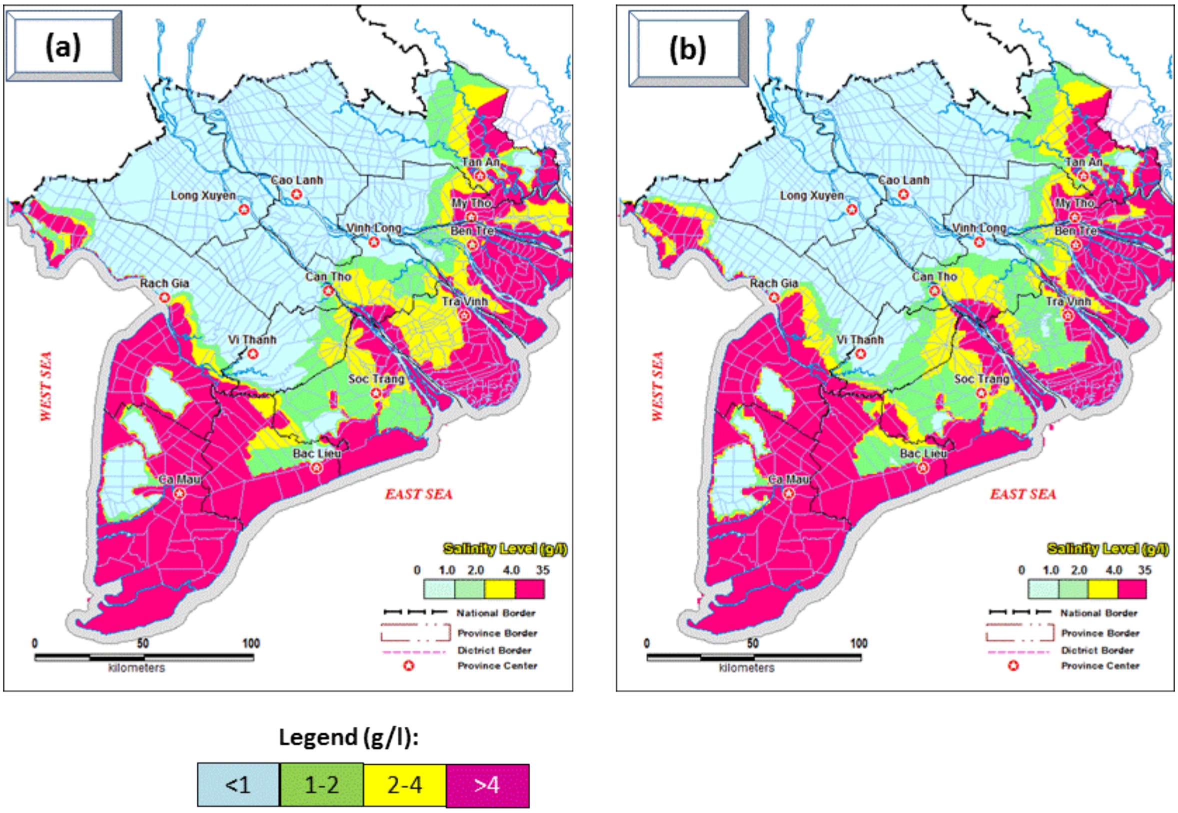


Figure 17: (a) Salinity levels in low water year under SLR scenario; (b) under reduced discharge scenario (-20% discharge at Kratie)

The juxtaposition of the maps in Fig. 17a/b clearly shows that the impact of a 20% reduction is comparable to the projected conditions under SLR – without any changes in river discharge. In turn, it seems simplistic to limit the assessment of future hydrology to SLR while these changes may drastically be aggravated by upstream development.

As we are unable to show all these scenarios/ maps within the scope of this report, it should highlight that we can expect an expansion of saline area in MRD is 1.6 mil ha over the next decades (under SLR of 15cm and reduced river discharge of 9%). This corresponds to about 5% increase in saline area compared with 1.5 mil ha in 1998 of low water year. This increase in area corresponded with an inland shift of the salinity contours in the big river branches. The salinity affected stretches of the Bassac and Mekong branches expanded from 52 to 57 km and 64 to 69 km, respectively.

Under the CC and SLR effects on salinity intrusion and flooding in MRD, intensity and duration of salinity and flooding risks will be changed and they are the main concerns for production and livelihood of habitants in MRD. To cope with these constraints, some adaptation options have been suggested in Table 6.

Table 6. Some adaptation strategies to cope with flooding and salinity impacts under effect of CC and SLR

CC and SLR effects	Strategies
Increased Flood-Risk Depth and Duration	Improve flood control structures
	Deploy submergence-tolerant varieties
Increased salinity	Improve salinity control structures
	Deploy salinity-tolerant varieties

Reduced gravity drainage capacity	Rely more on pump drainage
Shortened cultivation windows	Shorten the turnaround time between crops, for example, with better residue management
	Use short-duration varieties Use (mechanized?) transplanting to reduce the time of the crop in the main fields
	Replace dry-season rice with a short-duration upland crop
Prolonged and high field water level	Deploy partially flood-tolerant varieties and salinity-tolerant + partially flood-tolerant varieties

Note: Detailed results of Theme 1 can be found in the Theme 1 Final Report (Appendix 1).

Theme 2: Stress-tolerant rice varieties

The development of improved rice varieties in Theme 2 was undertaken by using the backcross method as well as through conventional bi-parental and complex (3- and 4-way) crosses, coupled with subsequent marker-assisted selection and screening under controlled and natural stress conditions to develop improved breeding lines and varieties.

In total, 36 single and multiple crosses have been made to combine submergence tolerance, salinity tolerance, stagnant flood tolerance, and high grain quality into high-yielding genetic backgrounds. Two of these crosses were made to combine genes for tolerance of both submergence and salinity stresses. Pedigree generations were grown under controlled submergence conditions at CLRRI, and under natural stagnant water conditions.

A second component of the project was to test breeding lines and varieties under a range of seasons and environments to validate the performance of the new lines and to offer farmers the opportunity to participate in the observation and selection of new varieties. To date, more than 27 participatory varietal selection (PVS) trials have been conducted using 78 varieties throughout An Giang, Hau Giang, Bac Lieu, and Can Tho provinces.

- Two crosses were made specifically to combine genes for tolerance of both salinity and submergence and progenies from these crosses were advanced to BC_3F_4 using the combined effects of marker-aided selection and screening under stress conditions. Pedigree generations were grown under controlled submergence conditions at Cuu Long Rice Research Institute (CLRRI); under natural stagnant flood conditions at sites in Can Tho, Hau Giang, and An Giang provinces; and under salinity stress in Bac Lieu Province. In total, 108 progenies were selected from BC_3F_4 populations, and 239 plants from the F_4 generation were tested for two stress tolerance genes (*SUB1* and *Saltol*) in combination. A further 12 backcross populations were developed to transfer *SUB1* and *Saltol* into adapted genetic backgrounds of rice varieties from Australia, and lines selected from these populations were transferred back to Australia under the necessary quarantine protocols.

Some main results

- Existing genetic material (landraces, modern varieties, and breeding lines) with greater stress tolerance was also evaluated throughout the term of the project, using PVS procedures, and many beneficial lines were identified. Under rainfed lowland conditions in Can Tho Province, five advanced lines/varieties as OM10041, Can Tho 1, OM3673, OM4488, and OM8108 demonstrated improved productivity following exposure to submerge under 0.8–1.0-m water depths for

15–20 days, and producing 4–5 t/ha yield. As the same time, the common check variety IR64-Sub1 demonstrated yield of 4 t/ha. Similarly, under submergence stress conditions in An Giang Province, the lines/varieties OM8928, OM10179, and IR64-Sub1 demonstrated yields in excess of 4 t/ha.

- In Bac Lieu Province, where the predominant stress is salinity, OM6328, OM3673, and OM10252 were shown to be best-bet varieties for famers. In Hau Giang Province under a combination of submergence stress and acid sulfate soils, OM8928, OM8108, and OM3673 showed improved yield stability from 2011 to 2014 that were ranged from 6 to 7.6 ton/ha in Summer Autumn compared to the yield of 5 to 7.2 ton/ha of other popular varieties and of common checked varieties AS966 and IR64-Sub1.
- In areas currently suffering from the individual or combined effects of salinity and submergence, the provision of nucleus seed of improved breeding lines/varieties can speed adoption. A total of 5 tons of seed of beneficial lines/varieties was distributed during the term of the project within each of the targeted provinces, including Bac Lieu (990 kg of eight lines), Hau Giang (990 kg of eight lines), Can Tho (1,276 kg of four lines), and An Giang (a total of 1,725 kg comprising four lines).
- The breeding component of the CLUES project sought to increase the impact of such varieties with enhanced stress tolerance, which can be amplified by distributing seed to target areas and multiplying quantities of seed of available varieties on-farm for immediate distribution. Although beyond the scope of this component, impacts could be further amplified by establishing seed multiplication facilities in target areas for further multiplication.
- Four varieties were submitted to DARDs for release during 2014, and was confirmed by trails in the four target provinces in 2015 as the final year of the project, including OM3673 with short growth duration and improved anaerobic germination, OM10252 with tolerance of submergence and salinity, and OM6328 and OM6677 with improved salinity tolerance and high yield potential.

Theme 3: Natural Resource Management (NRM)

The PRA undertaken in March 2011 identified potential CC-related threats (Table 2). At each site during the winter-spring (WS) and summer-autumn (SA) season, water scarcity and lodging were identified as key future threats (Table 2). This water scarcity could cause increased acidification through the further oxidation of acid sulfate soils and salinization through capillary rise. During the wet-season crops, stagnant flood and submergence were identified as key threats (Table 2). Across all sites and seasons, labor scarcity and low economic resilience due to small farm size were identified as current and future problems that challenge current production methods.

The CLUES research team identified promising technologies and research questions. Prior to implementation and testing, meetings were held, which included the research group leaders, farmers and extension officers, and local government officials at each site. At these meetings, the merits of each technology and research question were discussed and areas were selected for field testing (Table 3). Major findings of the experiments are described below.

The direct and indirect impacts of climate change (CC) and sea-level rise (SLR) will become a major challenge for maintaining food security in the near future, mainly through aggravating salinity and flood problems driven by hydrological dynamics of the Mekong River. After nearly four years conducting experiments and field trials to improve profitability and resilience to environmental stress, the results show the following.

Alternate wetting and drying (AWD) irrigation is a win-win water management technology. It reduces water application by 30% to 50% and pumping costs and GHG emissions.

A key advantage of the technology is that it has an immediate impact on farm profitability. Economic analysis shows that the reduction in pump hours increases farm income by reducing fuel and labor costs (Table 7) relative to traditional continuously flooded rice.

Table 7. Average income (in VND 1,000 per hectare) from three water management regimes in Ta Danh, An Giang (Nhan et al 2015).

Water management regimes	DX 2011-12	HT 2012
W1	15,191	24,678
W2	19,926	26,254
W3	17,723	25,957

Our experimental trials indicated that AWD with threshold –15 cm (free water at 15 cm below the field surface) could be a good solution for overcoming water scarcity under current and future conditions in all soil tested. The use of this technology by farmers will potentially increase MRD rice production by making systems more resilient to water scarcity. AWD will also directly increase farm profitability by reducing fuel and labor costs associated with irrigation.

Water delivery and management were a constraining factor at all sites throughout the field campaign; for example, in Lang Giai during successive seasons, upland crop trials were flooded and saline water was pumped into the field. A principal consideration for future climate change management is improving the delivery and management of irrigation water and drainage.

Farmers are over-fertilizing and it is possible to reduce fertilization. It is recommended that farmers can reduced the fertiliser P application to 40 kg P_2O_5/ha to maintain the balance of P input and P removed from soil and to sustain soil P supplying capacity and rice yield.

In combination with AWD, this increased farmers' income in each rice crop by about VND 4 million (~ US$200) per ha. The increased profitability allows farmers to become more resilient to CC. Reducing P also alleviates the environmental footprint of rice production.

Farmers can improve yield by using the existing cultivars suited to farm environmental characteristics. For example, replacement of the traditional varieties in Phuoc Long, Bac Lieu, with a high-yielding variety (HYV) directly increased profits from the rice phase but, more importantly, it shortened the rice season and lengthened the shrimp season.

In Phung Hiep District, Hau Giang Province, residue management, AWD, and P field trials failed because of commune-level water management and acid sulfate soils. In the future, changed climatic conditions could exacerbate acid sulfate soils and generate further acidity.

The trials on replacing one rice crop (winter-spring (WS) rice in Bac Lieu or summer-autumn (SA) rice in other areas) with a short-duration upland crop increased the economic resilience and CC adaptation via (i) increasing farmers' income, (ii) reducing the water requirement and hence the risk of water shortage in SA or WS seasons, and (iii) reducing the risks of partial flooding or submergence in the AW season by advancing the establishment/harvest date of the AW season.

Note: Detailed results of Theme 3 can be found in Appendix 3.

Theme 4: Socio-economic component

The theme focused on scientific impacts, policy and institutional analysis, feasibility assessments, and impact pathway analysis of new technologies implemented by Themes 2 and 3. Linkages with field activities of Themes 2 and 3 and Theme 4 enhanced the fine-tuning and scaling out of tested technologies at the project sites. The following are the theme's outputs:

- Rice farmers in the study zones have faced multiple threats and problems, not only climatic threats but also harmful pests and other socioeconomic factors.
- Poorer farmers are considered more vulnerable because of relatively lower livelihood capacity than better-off farmers. Diversification by rotating upland crops (in freshwater areas) or shrimp (in saline-water areas) with rice helped farmers earn higher income but this option was constrained by the unavailability of off-farm labor, poor accessibility to and instability of output market systems, and poor irrigation or drainage systems.
- To enhance the adaptive capacity of rice farmers to changes in the study zones, not a single solution but a package of solutions is needed, including rice farming technologies, structural measures, and socioeconomic measures with respect to specific contexts.
- Informal farmers' groups, informal in-kind credit, and availability of telephone and television in households are enablers of the livelihood capacity of farmers. Women play an important role in rice farming and household livelihood. However, their knowledge on climate change and their participation in extension activities were relatively poorer than that of their husbands.
- Feasible rice farming technologies need to satisfy important criteria such as the ease of practice, economic viability, and the availability and stability of markets for outputs. Target areas of feasible farming technologies created by the project require relatively favorable conditions of soil and water (i.e., alluvial or slightly acidic soils with available irrigation and drainage systems), except for an appropriate P application technique in the acid sulfate zone.
- Single-component technologies such as appropriate P application or AWD practice were ranked as a high priority.
- Future rice varieties should be not only tolerant of water-related threats and major pests but also have high yield potential and good grain quality for eating and marketing.
- The rice-upland crop rotation and rice transplanting technique, which are considered promising under water-related threats, were ranked a lower priority for the current stage from intensive-labor input and/or limited markets for outputs.
- Farmer cooperation is an important enabler of the out-scaling of the feasible technologies, for instance, AWD practice, while rice transplanting and rotation of upland crops with rice require farmers to have availability of on-farm labor or accessibility to local off-farm labor, or availability of output markets.
- The ease of practice and economic viability are important determinants of the adoption of technologies by farmers.
- Effective out-scaling and up-scaling of promising technologies created by CLUES need effective coordination and participation among key governmental actors together with community-based organizations, and incorporation into local existing development programs. New technologies from CLUES will need constant adjustments and improvement in order to adapt to the changing needs of farmers. DARD and its agencies are important actors in the out-scaling and up-scaling of the technologies. In addition, other actors related to services for inputs and outputs and farming cooperation play an important role.
- The Vietnamese government has promulgated several policies relevant to rice production, rice trade, and rice farmers' livelihoods. However, the implementation of the policies at the local level was not as effective as expected. Weak integration, inflexibility, and unsuitability of the policies in local contexts caused difficulties in institutional coordination in policy implementation.

Note: Detailed results of Theme 4 can be found in the Theme 4 Final Report (Appendix 4).

***Theme 5:* Integrated land use planning**

This study was conducted through an integrated land use planning approach to explore possible adaptations to climate change and sea-level rise of the coastal area of the MRD. Some main results follow:

- *Soil and land use*

Soil and land use maps of the province have been updated to 2012. In general, the main soil problem of the province is that more than two-thirds of its area is acid sulfate soil and saline soil (see Theme 5 final report (Appendix 5)).

Sixteen land use types were delineated, including triple, double, and mono rice crops, rice-shrimp, aquaculture (shrimp), forest, salt field, and urban (see Theme 5 final report).

- *Land mapping unit maps*

The agro-ecological zone (AEZ) maps of Bac Lieu Province, in different CC and SLR and water management scenarios, were mapped as a result of overlaying terrain, soil, and water maps of the corresponding scenarios. Each zone in the map is described by its saline intrusion period, saline value range, soil type, irrigation capacity, cultivation period, and cropping pattern. This is very important information for biophysical land use suitability analysis. The current AEZ map of Bac Lieu is presented in Figure A4 of Appendix 2 Theme 5 Final Report.

In order to integrate socioeconomic information with biophysical information, land mapping units (LMUs) of the province were built by overlaying the AEZ maps on the administrative boundary maps (village). Since AEZs depend on hydrology, AEZs will change under the impacts of CC and SLR.

- *Land suitability*

Land suitability maps of Bac Lieu Province under CC and SLR in a dry year, normal year, and wet year were developed.

The biophysical suitability of the promising LUTs in different SLR and hard measure (infrastructure) intervention scenarios was evaluated. Nine promising LUTs were selected for land suitability evaluation. The selection was done based on stakeholders' perceptions as a result of SWOT analysis.

The selected promising LUTs are triple rice, double rice, shrimp-rice, shrimp, rice-vegetable, vegetable, forest-shrimp, shrimp-fish, and salt-fish.

- *Socioeconomic constraint analysis*

Farmers in the study area consider increasing income as the most important objective. Farmers also consider water (both quantity and quality) and bio-diversification as the most important environmental factors that affect crop yield.

Farmers are highly concerned about markets for agricultural and aqua cultural products. Production price fluctuation strongly affects their income.

Through key informant interviews in each LMU, farming inputs and outputs were estimated. These are important input data for the land use optimization analysis.

The study identified constraints and room for further improvement of existing farming systems and for adaptive planning of agricultural land uses under anticipated changes.

Constraining factors of the farming systems differed among the zones and included not only technical and hydraulic structural factors but also service for inputs and outputs and production organization.

Agriculture, particularly shrimp and rice production, played an important role in the economy of Bac Lieu Province. Rice and shrimp production developed into intensive resource uses. Rice yield and income did not differ significantly among cropping systems in the freshwater zone while a large variation in yield and income occurred among shrimp farming patterns in the brackish and saline zones.

In the freshwater zone, rotational upland crops with rice gave high income but were labor-intensive.

The income of extensive shrimp farming patterns could be improved with appropriately increased feed input levels and refuge pond areas for shrimp.

Semi-intensive shrimp culture had high economic returns with high external inputs and high economic risks. Shrimp yield and income were highly influenced by several factors because they are not sensitive to both technological and environmental factors.

Technical efficiency in terms of yield and income was higher in rice cropping systems in the freshwater zone than in shrimp production patterns in the brackish and saline zones. Attainable yields and income of extensive shrimp culture are lower, because of low input levels, than in semi-intensive shrimp culture.

These results reflect the higher stability of income of farming systems in the freshwater area than in the brackish and saline water areas.

Rice and shrimp income variation by yield change was larger than that by output price, reflecting significant impacts of farming technologies on sustaining the farming systems in Bac Lieu.

- *Optimized adaptation of land use options at the provincial scale in different scenarios*

The data were integrated and input into an MGLP model (developed in GAMS software) for scenario analysis.

The data for component BLE are the LMU map and land use requirements. The results of this component are land suitability, yield estimation for each LUT/LMU, and available area. These results will be the input data for component SA.

The component SEA evaluates the PRA and socioeconomic survey data to provide required labor, required capital, production cost, and production price of each LUT per LMU. SEA also calculates the available capital and labor, and defines the constraint and objective functions for component SA.

Based on detailed inventories of the present and anticipated CC and SLR, affected soils, hydrological features and land use, yields and financial returns, a CC adaptation land use strategy for Bac Lieu Province has been proposed through an MGLP approach.

Applying the model for Bac Lieu Province, the results from scenarios imply the following:

- Capital and farming technique limitations are main constraints to provincial rural income;
- The current imposed production targets reduce provincial land use effectiveness and would be infeasible in the future under the impacts of CC and SLR;
- Optimizing the use of available resources would reduce the negative impacts of CC and SLR; and
- Operation of the new proposed Ninh Quoi sluice gate would improve the biophysical condition of the province. However, the hard measure is less economically effective than improvement of farming technical level and increasing capital investment combined with an optimal operation of the existing sluice and dike system.

Therefore, in the medium term, the adaptation strategy of Bac Lieu Province (up to the 2030s under CC and SLR) follows:

- Improve farming technology.
- Provide farmers with higher financial support.
- Base land use decisions on optimal use of available resources and market orientation rather than on production targets.
- Optimize the use of available resources (both biophysical and socioeconomic) based on the land use options proposed by the model.
- Improve the operational scheme of the existing sluice system.

The model also provides detailed information on the levels of the achievement of objectives, the total input requirements, and total production (see Appendix 2, Theme 5 final report).

- *Guidelines and tools available for developing adaptation master plans in other provinces of the MRD*

Based on the developed IMGLP model or provincial adaptation plan, Theme 5 has prepared and carried out three training courses with guidelines and tools. The training courses have been conducted for both technical staff and district/provincial managers. More than 40 people have been trained, with 15 female participants. The participants are not only from Bac Lieu Province but also from Hau Giang and An Giang provinces. Technical staff of the Integrated Coastal Management Program in Bac Lieu Province also attended the training courses. These courses are ready for further activities in the Mekong Delta.

Note: Detailed results of Theme 5 can be found in Appendix 5.

Theme 6: GHG component

- Capacity building was accumulated through training and collaboration with other projects. Training was held for eight staff from the Centre of Agricultural Extension of Long An Province and six students of Cuu Long University in carrying out pot experiments on the effect of N rates and nitrification inhibitors on N_2O emissions from rice growing on alluvial, acid sulfate, and saline soils.
- AWD is a promising option for reducing methane emissions in paddy rice. On average, methane emission rates under continuous flooding (CF) were about two times higher than in AWD conditions under all P treatments. CH_4 emissions were significantly lower (46%, 40%, and 70%) in AWD treatment compared with CF treatment at three study sites in An Giang, Hau Giang, and Bac Lieu, respectively.
- Cumulative N_2O emissions varied from 0.1 to 4.5 kg N_2O/ha/season. There were no significant differences in N_2O emissions among different phosphate fertiliser doses as well as between AWD and CF treatments in An Giang (alluvial soil), Hau Giang (acid sulfate soil), and Bac Lieu (saline soil). As reference, the global Emission Factor given by IPCC (IPCC 2006) is 1% of the fertiliser N applied, so that this would correspond to approximately 1 kg N_2O/ha/season.
- Different soil types induced methane emissions differently. Methane emissions increased in the order deep-flooded alluvial soil (An Giang) > shallow-flooded alluvial soil (Can Tho) > acid sulfate soil (Hau Giang) > saline soil (Bac Lieu, Ca Mau, Kien Giang). In alluvial soils at CLRRI (Can Tho), AWD treatment significantly decreased CH_4 emissions (54%) compared with CF treatment.
- The most striking result in the SA 2013 cropping season was that the triple-rice system emitted significantly higher CH_4 than the rice-maize-rice system at CLRRI. The reverse was true for N_2O.

- Seasonal variations in methane emissions were observed in the MRD. Methane emissions from rice paddies were highest in autumn-winter and lowest in the summer-autumn crop.
- The introduction of upland crops into the triple-rice system reduced methane emissions significantly. Mungbean or soybean reduced methane flux by 75% but sesame or maize could decrease it by up to 95%. The beneficial effect of methane mitigation was also observed for sucessive rice crops on upland by about 30%.
- Overall N_2O emissions increased in mungbean-rice system by 88% in comparison with the rice-rice system at the CLRRI (Can Tho) study site but there was no significant difference in N_2O emissions between the rice-rice system and the sesame-rice system at the Thoi Lai (Can Tho) study site.

Note: Detailed results of Theme 6 can be seen in the Theme 6 Final Report (Appendix 6).

***Theme C** (or Coordination and integration theme)*

This theme has been established to create a sound infrastructure for all project activities; ensure internal and external communication flow; supervise progress of activities; organize in-country training, seminars, forums, and workshops; and establish linkages and partnerships with local governments, nongovernment organizations, private entities, and international institutions with similar programs on climate change within the Mekong River Delta.

The CLUES project management encompassed closely overseeing the implementation of work plans and activities of six themes and four experimental sites. Activities of these components have been implemented and coordinated at the same time. For each activity, protocols and reports were completed and submitted to the theme leader and the PO.

At each site, site managers had an important role in overseeing the linkage activities between themes and with local people (local authorities and farmers in the provinces). Their frequent reports to the PO and operational meetings were important to carry out all activities of CLUES at four target sites smoothly.

Frequent meetings and visits between the PO and field sites or themes helped facilitate the activities of CLUES. Local workshops were organized yearly for the exchange of results and activities of CLUES with local stakeholders.

Until the end of the project, the PO organized and coordinated 20 official operational team meetings, 10 other individual meetings with team members or collaborative partners, 3 project training events, 16 project workshops including mid-term and final review workshops (see Fig. 18 for the third CLUES annual review workshop), and nearly 50 field visits at four study sites of CLUES. The PO also organized more than 25 visit trips for international consultants of CLUES and five visits of other overseas and national projects, and journalists.

The collaboration with the GIZ project in Bac Lieu was also important for CLUES in out-scaling technology of AWD and P reduction. There were 41 demonstrations and training on AWD for 1,418 farmers who were trained on AWD. The assessment report and workshop on AWD were also accomplished successfully by CLUES, GIZ Bac Lieu, and local staff of Bac Lieu DARD.

Until this time, the spontaneous network of CLUES team with local stakeholders and institutes have been remained fruitfully for other coming projects that were after CLUES.

More than 330 references and documentation of CLUES were available for use by the project team. A CLUES database has been established for use among the CLUES team.

Of 64 papers, 31 were peer reviewed. Three books in Vietnamese and English were published. Eleven leaflets were produced and distributed to team members and other partners. Two CLUES videos were made by CIAT and IRRI. Bi-annual news was published in ACIAR newsletters.

Fig. 18. The Third Annual Review and Planning Workshop of CLUES on 1-3 April 2014.

8 Impacts

8.1 Scientific impacts—now and in 5 years

Actors in CLUES that were influenced by scientific engagement include researchers of CTU, SIWRP, IRRI, ANU, and CSIRO; MSc and PhD students of CTU and other universities; ongoing projects in Bac Lieu Province such as the Integrated Coastal Management Program; and provincial and local staff of DARD and DONRE.

During the project, some current impacts were found in the target areas and nationally:

1. The methodology of assessing CC and SLR impact on hydrology has been improved and presented in different scientific venues. The method has been applied in an ongoing DANIDA-funded project to assess the impact of SLR on flooding and salinity in the Red River Delta (2014). In the future, the methodology can be more widely used in other areas.

2. The project used marker-assisted backcrossing (MABC) to develop high-yielding rice cultivars, which are tolerant of single or combined stresses of submergence, stagnant flood, and salinity. Enhanced understanding of the extent to which major QTLs such as *Saltol* and *SUB1* could contribute to abiotic stress tolerance has been used for breeding programs by CLRRI beyond CLUES. In the next five years, the presence of these genes/QTLs in more varieties more broadly adapted to the Mekong Delta region will facilitate their further movement into lines adapted to all provinces. In the next five years, further fine mapping of these genes will allow them to be transferred readily into new varieties, thereby being added to the suite of stress tolerances built into new lines.

3. Then, the PVS methodology has been used at multiple locations and in multiple seasons in four target provinces of the project. The study on stress-tolerant rice varieties had a great impact on local staff and farmers in four provinces who were invited to attend farmers' field days (or PVS) to select the rice genotypes they most preferred. By applying PVS, seeds of the most preferred rice genotypes and varieties were distributed to farmers. In 2011-15, a total of 5 tons of seed of beneficial lines/varieties was distributed during the term of the project within each of the targeted provinces, including Bac Lieu (990 kg of eight lines), Hau Giang (990 kg of eight lines), Can Tho (1,276 kg of four lines), and An Giang (a total of 1,725 kg comprising four lines). During the project, some promising lines were identified and prioritized by farmers. Some rice varieties have been submitted for varietal release, such as OM3673 (short growth duration, tolerant of anaerobic seedling stage), OM10252 (submergence- and salinity-tolerant), and OM6328 and OM6677 (high yield and salinity-tolerant).

4. One of techniques studied by IRRI and introduced by CLUES, the water-saving irrigation technique of alternate wetting and drying (AWD), is a win-win technology. It helped farmers to cope with water scarcity and reduced methane emissions from paddy fields by up to 50% compared with continuous flooding. GIZ, in collaboration with CLUES, organized 41 training classes: 1,418 farmers with areas of 30 demo sites of 30 ha. The activities of GIZ were also integrated with large-scale fields in Vinh Loi (439 ha).

5. A new model tool for land-use analysis through a multiple-goal linear programming approach was developed in Bac Lieu Province as a coastal area of the MRD. It enhanced understanding of the current biophysical and socioeconomic conditions and adaptation opportunities for the study area under the impacts of current and future CC and SLR.

6. The study on salt leaching in the rice-shrimp system (applying lime, plowing, and leaching frequencies solely or in combination) enhances salt leaching in the rice-shrimp farming system. It has been applied to another rice-shrimp system of similar

conditions in the Mekong Delta within the project “Improving the sustainability of rice-shrimp farming systems in the Mekong Delta, Vietnam” funded by ACIAR (SMCN/2010/083).

7. CTU has developed and submitted a new scientific proposal investigating soil microbial community functioning in greenhouse gases emissions under AWD application. The new scientific collaboration was established with the Division of Soil Microbiology in the Swedish University of Agricultural Sciences to study the soil microbial community under different soil amendments in the rice-shrimp system.

8. CLUES proposed a new modelling tool for land-use planning that supports better use of natural resources in Bac Lieu Province. At present, the tool can be applied for other provinces in the MRD.

9. The study on GHG measurements in Vietnam using a closed chamber for flux samplings in CLUES has been out-scaled to other projects such as GIZ–Tra Vinh and WINROCK–Long An. They have applied the same method in CLUES to measure GHG emissions from paddy rice. CLUES also participated in three MRV workshops organized by the Institute of Agricultural Environment initially supported by WINROCK-Vietnam to formulate protocols/guidelines for studying GHG emissions from the rice crop in Vietnam.

10. Scientific publications (see section 10.2 for details).

As of this date, the PO has more than 250 technical reference materials of all kind, including electronic files of data, reports, and other documents received from different themes.

Sixty-four publications that include nine peer-reviewed international papers, 22 papers in Vietnamese, and 10 presentations at international conferences.

Seven posters were presented at international conferences and 20 posters in CLUES workshops.

It is expected in the next 5 years that at least six papers will be published in national and international journals, and four to five new research proposals that will build on scientific knowledge from CTU partners of CLUES will be prepared.

8.2 Capacity impacts – now and in 5 years

Stronger linkages and exchange of knowledge have been found through project networks (such as CTU, SIWRP, Sub-NIAPP) on a broad range of approaches in climate change-related research. Furthermore, the active involvement and proper training of partners through this project eventually guarantee the relevance of the project to their needs and continued impact beyond the project timeframe. Most of the beneficiaries were CLUES team members, local staff in four provinces, and university students.

The main capacity impacts through the project network are summarized as the following:

1. Expanding understanding of the impact of climate change on hydrology, salinity, and rice production in the Mekong Delta and target provinces in CLUES. It also enhances the understanding and skill of staff about GIS and remote sensing in delineating and manipulating spatial data.

2. Enhanced capacity of local partners, such as CLRRI, in applying MABC to simultaneously select for well-characterized genes conferring tolerance of abiotic stresses, while recovering the genetic background of the recurrent parents (popular varieties or elite breeding lines). MABC could then be incorporated as part of national breeding programs to introduce genes of agronomic importance as they become available.

3. Established laboratory facilities (gas chromatography) for GHG emission studies in the MRD and supplied necessary field equipment (closed chambers) and training for emission records in agricultural systems.

4. A cadre of experts formed on climate change adaptation and mitigation that could initiate and steer future climate change projects in the Mekong Delta and liaise with Vietnamese groups in charge of National Communication to the UNFCCC.

5. Enhanced capacity of young scientists by taking on roles in different aspects of the project and through participation in various training workshops and scientific visits.

6. Men and women farmers, NGOs, and extension personnel at selected sites trained on-site in aspects of participatory research and evaluation, and in providing feedback during different stages of the project, for eventual impact and relevance.

7. Within the socioeconomic component of the project, this includes training to conduct household surveys, running and facilitating workshops, incorporation of biophysical modelling into livelihood assessments, analysis and write-up of data for publications, and presentations at scientific meetings.

8. Findings from the project have been shared with local extension workers and farmers, which provide them with new insights and adopting capacity toward new techniques feasibly applied in the management of rice-based natural resources.

9. Impacts in the next five years would extend to the technical staff of the Mekong Delta provinces, new projects in Bac Lieu such as the Climate-Smart Agriculture/Village (CCAFS, CGIAR), and other researchers and students in the Mekong Delta.

10. Trainees and activities from CLUES training activities from March 2011 to June 2015 are summarized in Tables 8 and 9, where gender is also recognized. Some 3,960 farmers attended PVS training on rice varieties (see Appendix 10) and another 111 individuals were trained on other themes or related activities of CLUES. Some 733 women participated in training activities, representing 19% of the total of trainees from CLUES.

Table 8. List of non-degree training from March 2011 to June 2015 and expected outcomes in the next 5 years.

Theme	Name of activity	Date	Length of activity	No. of people involved	Males	Females	Expected outcome and what will change in the next 5 years
1	Guidance on using the inundation and salinity risk maps in the Mekong Delta at CTU	28 Feb. 2014	1 day	21	15	6	
3	Soil and plant sampling methods at CLUES, CTU	Dec. 2011	1 day	20	15	5	(Lecturers: Đông, Tường, Phong)
3	Sampling methodologies for soil solution, sediment and field experimental design and statistical analyses atCLUES, CTU (funded by the Crawford fund)	Mar. 2012	5 days	30	20	10	(Lecturer: Ben Macdonald)
3	Agricultural research management in IRRI, Philippines	2014	5 days	3	3	0	(Bac Lieu site)
3	Research data management & scientific communication in IRRI, Philippines	2015	5 days	1	1	0	(Hau Giang site)

3	Research data management & scientific communication in Australia	Feb-Mar 2015	40 days	1	1	0	(Bac Lieu site)
4	Technology assessment	1 Dec. 2013	1 day	24	16	8	Perceptions and attitude on promising rice-shrimp farming systems
4	Participatory Adaptation Research Refresher Course at CTU	Nov. 2011	4 days	5	4	1	Applying the approach and methods in farming technology evaluation at CTU and CLRRI
4	Assessments on technical, socioeconomic, and environmental impacts of new technologies at CTU	Sep. 2012	1 day	4	3	1	Applying (and developing) the approach and method to relevant research projects at CTU
4	Agricultural research management program (the John Dillon Fellowship) in Australia	Feb.-Mar. 2013	40 days	1	1	0	Improved individual and team's scientific writing and presentation skills, leadership, and research management; Improved achievements and sustainability of later research projects
4	English training (the John Allwright Scholarship by ACIAR for PhD candidate) in HCMC	Oct. 2012-Mar. 2013	6 months	1	1	0	English communication in research
4	Research data management at IRRI, Philippines	Nov. 2014	4 days	1	1	0	Sharing with colleagues to apply methods and tools in research data management
5	Training on "Tool for support of decision making on land use under conditions of climate change" at CTU	11-14 Mar. 2014	4 days	17	13	4	Identify and analyze the problem before decision making
6	Training on flux sampling at CLRRI	7 Mar. 2014	1 day	7	6	1	Set up closed chambers and do sampling for quantifying GHG emissions
6	Workshop on SRI model demonstration at Cau Ke , DARD Tra Vinh	23 April 2013	1 days	30	24	6	GHG mitigation under SRI model
Total				**111**	**84**	**27**	

Table 9. List of staff that participated in degree training from March 2011 to June 2015 and expected outcomes in the next 5 years.

Theme	**Name of activity**	**Date**	**Length of activity (years)**	**No. of people involved**	**Males**	**Females**	**Expected outcome/what will change In the next 5 years**
5	Mr. Pham Thanh Vu. Title of study: Strategic planning for sustainable use of land resources by the Mekong Delta coastal areas: a case study in Bac Lieu Province	2011	4	1	1		PhD in land management
4	MSc theses in rural development at CTU	Dec. 2013 -Oct. 2014	10 months	3	3		Improved career of graduate students and increased performance of their employers. Develop new research project building on results from the theses by MDI.
4	Mr. Hua Hong Hieu, awarded the John Allwright Fellowship by ACIAR for PhD studies at the Australian National University (2013-17)	Sep. 2013 -Sep. 2017	4 years	1	1		Improved career of Mr. Hieu and performance of MDI/CTU. Further improved network between CTU and ANU/CSIRO.
3	Mr. Dang Duy Minh, awarded the John Allwright Fellowship in 2012 for his research on nitrogen and carbon emissions using pot experiments. He is currently enrolled in the Australian National University and is based at CSIRO Black Mountain.	2012	4	1	1		PhD in soil science Improved career of Mr. Minh and performance of CTU. Further improved network between CTU and ANU/CSIRO.
2	Mr. Bui Phuoc Tam enrolled in the University of the Philippines Los Baños for his MSc program in plant genetics (from October 2013 to	2013	2	1	1		MSc in plant breeding

	October 2015)						
2	Ms. Tran Thi Nhien enrolled in the University of the Philippines Los Baños for her MSc program in plant genetics (school year October 2014 to October 2016)	2014	2	1		1	MSc program in plant genetics
2	Mr. Chau Thanh Nha enrolled in the University of the Philippines Los Baños for his MSc program in plant genetics (school year June 2012 to April 2014)	2012	2	1	1		MSc program in plant genetics
2	Ms. Vo Thi Tra My enrolled in the University of the Philippines Los Baños for her MSc program in plant genetics (school year June 2012 to April 2014)	2012	2	1		1	MSc program in plant genetics
2	Mr. Bui Thanh Liem enrolled in Scuola University, Italy, for his PhD program in plant breeding (school year April 2012 to March 2015)	2012	3	1	1		PhD in plant breeding
1, 5	Students enrolled in Can Tho University with research theses related to the study of Themes 1 and 5.	2011 -15	1	12	8	4	MSc
3	Students enrolled in Can Tho University with research theses related to the study of Theme 3		2	14	10	4	MSc
3	Students enrolled in Can Tho University with research theses related to the study of Theme 3		4	1	1		PhD
3	Students of Australian universities, Ms. Temma Carruthers-Taylor and Ms. Leah Garnett, were awarded a Crawford Fund training fellowship to undertake their honors thesis work in Bac Lieu, Hau Giang, and An	2013	0.25	2		2	MSc

	Giang.						
	Total			**40**	**28**	**12**	

The list of CLUES publication can be found in section 10.2 of this report.

8.3 Community impacts – now and in 5 years

The connections among staff of the project themes, the PO, and local DARD counterparts were closer at the end of CLUES. Partnership and exchange of expertise between organizations have been enhanced through local workshops or training.

8.3.1 Economic impacts

The results of CLUES have increased the capacity of farmers and communities to mitigate the negative impacts of climate change by making use of different adaptation options that are economically feasible for their characteristics. Some economic impacts expected from CLUES follow:

1. Significant economic benefits to breeding programs and to farmers from the use of MABC. Both *Saltol* and *SUB1* could be incorporated into popular varieties within two to three years, thus considerably reducing the duration required using conventional methods. In addition, the incremental economic benefits of using MABC for both traits over the long run could be enormous (estimated at US$50 to $900 million over 25 years; Alpuerto et al 2009).

2. The use of short-maturing varieties, together with effective NRM practices and efficient cropping systems, has increased annual productivity, enhanced farmers' income, and provided more opportunities for sustainable livelihood options. The economic impacts of these activities will be realized in future years as farmers adopt stress-tolerant and improved varieties.

3. The results from field experiments on AWD and reduced fertiliser P application showed that a lower fertiliser P application in combination with AWD (irrigating when the water level is at –15 cm from the soil surface) is feasible to reduce the investment cost for fertilization and irrigation and consequently bring more income to farmers. Soil resources in the MRD under intensive rice cropping supply sufficient available P to meet the demand for P nutrient for 2 years, equivalent to six sequential crops. For long-term P nutrient management, it is necessary to take into consideration the balance of soil P in fertiliser P application. AWD application in the winter-spring crop could save 50% of the irrigation cost and reduce methane emissions by 85% compared with CF (Tinh et al 2015). Net profit in AWD was US$350 higher than in CF.

4. In addition, in rice-shrimp farming systems, feasible techniques applied to efficiently remove salt from soil after the shrimp season would lead to a better following rice crop that in turn sustains the whole cropping system, consisting of both rice and shrimp. Replacing local varieties with short-duration and high-yielding rice varieties would help to shorten the rice standing period, thus extending the following period of shrimp cultivation, which brings more income for farmers.

5. Upland cropping could significantly increase farm income and profitability, thus improving farm economic resilience to climatic stresses. The cost-benefit ratio for upland cropping is double the ratio for triple-rice cropping. However, without carefully planning and connecting to the market, there is a potential risk for market oversupply. Under the

direction of MARD on restructuring agriculture to increase profit for farmers, upland crops (maize, soybean, sesame, etc.) are promoting high-profit crops. Recent information from Thoi Lai District-Can Tho City indicated that area under sesame has expanded nearly two times from 800 to 1,500 ha simply because the profit from sesame was much higher than that from rice (4–10 times).

6. Assessments of farmers' perceptions in socioeconomic surveys:

No.	Actors	Current impacts	Indicator(s)	Expected in next 5 years
1	Farmers use improved rice varieties	350 farmers participated in rice variety evaluation and have changed their knowledge, perception, and attitude (KPA)	Survey data from the Plant Seed Centre and Agricultural Extension Centre	3,500 farmers will use improved rice varieties (3,500 ha × VND 0.5 million = VND 1.75 billion per year)
2	Farmers apply new farming technologies (AWD, P application, soil salinity management, and rice-UC cropping system)	157 farmers participated in technological assessment and have changed their KPA	Survey data from Agricultural Extension Centre, farmers	1,570 farmers will apply new technologies (1,570 ha × VND 1 million = VND 1.57 billion per year)

8.3.2 Social impacts

Social impacts are the outstanding achievement of CLUES. A lot of local farmers and staff participated in the project activities. Awareness and participation of local stakeholders have increased through participatory discussions and assessments, and the verification of research results.

1. The reduced vulnerability to climate change impacts of rice-based production systems within the Mekong Delta has prevented the collapse of this important food-growing area.

2. Empowerment of the community through better access to knowledge through posting distilled recommendations and policies on IRRI's and Vietnamese web-based knowledge banks, and the provision of printed materials as policy briefs, posters and handbooks, and CDs to ensure efficient technology transfer and adoption, and speeding up the extension of the project outputs within and beyond the target sites.

3. Securing food supply and providing diversity of livelihood through CLUES technical options have reduced drudgery for women by reducing male migration and encouraging investments in children's education and health care, thus improving the well-being of the community. The project helped strengthen community-based local seed systems to ensure effective and efficient production and the timely distribution of sufficient high-quality seeds to farmers, which will in turn, contribute to higher yields and income.

4. Reduced vulnerability and social inequity by enhancing farmers' portfolio of options to better manage risk in a climate change context and providing adaptation options to the most disadvantaged groups.

The socioeconomic theme of CLUES addressed gender issues by involving women farmers in the early stages of the project phase, thus helping more women to be more confident and recognized as "farmers" rather than farm helpers. Details of the impacts are presented in Table 10.

Table 10. Farmers' participation in CLUES and expected change in the next 5 years.

Site	Actors/workshops/ training	Date	Length of activity	No. of people involved	Males	Females	Expected change in next 5 years
Study sites	Farmers participated in livelihood capacity assessments and gender analysis	2011-12	0.5 day	1,312	1,010	302	Enhanced capacity of farmers and participation in livelihood assessments and improved KAP on gender equality
Study sites	Farmers participated in participatory rice varietal assessments	2012-14	0.5 day	1,407	897	510	Empowering farmers and their participation, particularly women, in rice varietal evaluation, local extension activities, and local community development plan using participatory approaches
Study sites	Farmers participated in rice farming technology assessments	2013-14	0.5 day	157	125	32	Empowering farmers and their participation, particularly women, in agricultural technology feasibility assessments, local extension activities, and local community development plan using participatory approaches
Study sites	Local extension staff participated in assessing technological feasibility and exploring impact and extension pathways	2014	1 day	45	33	12	Improved effectiveness and efficiency of extending new technologies from CLUES and other projects
Study sites and CTU	Governmental officials/officers participated in workshops on institutional analysis, farmers' livelihood capacity, and out-scaling/up-scaling of new technologies	2012-14	1 day	58	52	6	Improved effectiveness and efficiency of policy implementation on better uses of natural resources, enhanced capacity of farmers' livelihood, further scaling up of new technologies from CLUES and other projects
	Total			**2,979**	**2,117**	**862**	

8.3.3 Environmental impacts

The project was not expected to have any negative impacts on the environment, yet, considerable gains are expected, including the following:

1. The use of salt- and submergence-tolerant varieties will help bring back land and water resources that are currently underused or not being used, and this could free precious water resources in other areas for alternative uses, including environmental services.
2. Providing alternative income sources and livelihood options will help prevent overexploitation of natural resources and ease environmental degradation in these highly vulnerable coastal areas.
3. Careful assessment of the consequences of climate change in these areas will help formulate policies and practices to reduce undesirable impacts of climate change and facilitate designing proper coping strategies to mitigate likely harmful consequences.
4. Judicious NRM and improved technologies will reduce pollution load (acidity, agrochemicals) in the surrounding water and greenhouse gas losses to the atmosphere.

The environmental impacts of adaptation options will be examined through an assessment of the overall livelihood responses likely with climate change. Consideration will be given to important trade-offs.

8.4 Communication and dissemination activities

Users of information essentially included stakeholders (farmers, scientists, extension personnel, and policymakers) and the scientific community. The existing and new means being made available at IRRI, in Vietnam, and in Australia were used to disseminate project information to target audiences. The outcomes follow:

1. Communication took place with engaged activities at four study sites of CLUES, and liaison units for target zones/provinces were established composed of representatives from the Department of Agriculture and Rural Development (DARD), provincial and district offices, and CLUES site managers. Liaison units have facilitated regular communication among CLUES members, selected farmers, and local agricultural staff during the experiment.

The findings of CLUES have been evaluated and disseminated by CLUES team members with local growers, seed production companies, local governments, and farmers through demonstration farmer fields, workshops, and training courses.

2. Community participation in activities of CLUES: Communication activities have been frequently done within the socioeconomic component with other themes and local counterparts during the implementation of project activities. Field or PVS days of technology feasibility assessments would facilitate the gradual dissemination of feasible rice varieties and farming technologies with the communities where on-farm trials were established.

3. Communication outputs:

CLUES webpage at IRRI: http://irri.org/networks/climate-change-affecting-land-use-in-the-mekong-delta.

Google file sharing: https://sites.google.com/a/irri.org/clues-file-sharing/home?pli=1.

Dropbox of CLUES for internal exchange of data and documents.

A total of 10 news articles were published locally or internationally (*IRRI Bulletin, ACIAR VN*).

Thirteen leaflets (in English and Vietnamese) and five technical books (in Vietnamese) were produced by the themes and disseminated.

Media: There were three visits to CLUES project sites by journalists and communication staff of CCAFS (May 2013), to CIAT (in March 2014), and to IRRI (in November 2014) for photos, documentation, and farmer interviews. Two videos about CLUES and climate change were made by IRRI (2015) and CIAT (2014).

4. Project facilitation: For consistency of documentation in CLUES, uniform templates for all theme progress reports, semi-annual and annual reports, posters and oral presentations, and scientific reports were applied. Uniform templates for data collection from field experiments as well as experimental protocols were also developed and shared with the researchers involved in CLUES.

5. Collaboration with GIZ-Bac Lieu and others: Collaboration has been good between CLUES and GIZ-Bac Lieu on rice production improvement (2012-14). Some activities follow:

2011: A study tour on AWD in An Giang Province was organized by the CLUES office for GIZ and local people in Bac Lieu.

2011: Through facilitation provided by the CLUES Project Office, the socioeconomic component collaborated with the GIZ Project and PPS Bac Lieu to conduct a survey on assessment of AWD techniques in rice production in Bac Lieu.

2012: A training course on stress-tolerant rice cultivation by experts from IRRI and CLUES.

2013-14: In response to this, GIZ supported 30 ha of AWD demonstrations and training.

AWD was applied by farmers on 701.53 ha during winter-spring 2013-14.

6. The CLUES database on GHG emissions will be used in the national MRV network. At least three journal articles will be published in 2015 on effects of soil type, cultivation method, and cropping system on methane and nitrous oxide emissions from paddy in the Mekong Delta. Interacting will be done with national agencies (Institute of Agricultural Environment) for GHG mitigation and inventories (e.g., Task Force for National Communication to UNFCCC).

7. Interaction with the ACIAR research project on rice-shrimp systems (SMCN/2010/083). The staff of CLUES have also participated in the rice shrimp project. So their experiences and results from CLUES can be useful for that project.

8. Workshops in Hanoi (15/9/2016) and Can Tho (11/9/2016) at the end of the project to communicate with stakeholders, particularly national and district level policy makers about what the implications of the project are for policy, planning and investment.

9 Conclusions and recommendations

Different conclusions and recommendations have been made by themes.

9.1 Conclusions

Impact of CC and SLR in the MRD

Hydro-climate-related problems in the MRD show a complex matrix in time and space encompassing a variety of distinct constraints to rice production:

- SLR + CC aggravate both flood-related and salinity stresses in the MRD.
- Impacts on flood-related stress are more widespread than on salinity stress.
- Adaptation to CC and SLR cannot be seen in isolation from upstream development.
- Adaptation to CC and SLR requires both hard and soft strategies. Climate-smart agriculture plays a central role.
- Not all SLR + CC impacts are negative. SLR raises the water level higher inland in the dry season, which facilitates freshwater accessibility and supports gravitational irrigation.

Developing stress-tolerant rice varieties

- Through the use of innovative breeding methods such as marker-assisted backcrossing (MABC), good progress was made in developing submergence- and salt-tolerant varieties. The key varieties chosen to receive the *SUB1* QTL were OM1490 and OMCS2000. QTL analysis was also performed to identify QTLs associated with tolerance derived from Vietnamese variety Tai Nguyen (TN) under anaerobic conditions during germination.
- Four varieties were submitted for release in 2014: OM3673 with short growth duration and tolerance of anaerobic seedling stage, OM10252 with tolerance of submergence and salinity, and OM6328 and OM6677 with salinity tolerance and high yield.

Natural resource management

- The findings from AWD experiments in three years (2012-14) proved that sole application of AWD or reduced P fertilization did not have an adverse effect on soil capacity in supplying available P as well as the growth and production of rice. AWD irrigation can be applied well at An Giang and Bac Lieu sites.
- Upland crop diversification in the rice-based farming system improved profitability and increased flexibility in the cropping calendar, which mitigates the risks of CC. The connection between the market and farmers should be supported to ensure the integration of upland cropping into double- and triple-rice production systems.
- Short-duration and high-yielding rice varieties that were tested in the rice-shrimp farming system could replace local rice varieties and give more time for the shrimp season.

Socioeconomics

- Most of the feasible farming technologies created by the project (AWD, P reduction) suit alluvial or slightly acidic soils with available irrigation and drainage systems, except for appropriate P application technique in the acid sulfate zone (Hau Giang Province).

- The out-scaling of the AWD practice is more preferable to cooperative irrigation management or a "large-scale" field model.

- Rotation of upland crops into rice-based systems, which needs an intensive labor input and/or limited markets for outputs, was not considered as a high priority.

- DARD and its agencies are important actors in the out-scaling and up-scaling of the technologies. In addition, farmers' groups, business enterprises, and agricultural and rural development banks play an important role. Successful extension of the promising technologies needs necessary enablers such as availability and accessibility of formally favorable loans, improved irrigation and drainage systems, farmers' cooperation, zoning and services for inputs and outputs, mechanization, and an effective extension program.

GHG emissions

- CH_4 emissions were significantly lower (46%, 40%, and 70%) in AWD treatment compared with CF treatment at three study sites in An Giang, Hau Giang, and Bac Lieu, respectively.

- There were no significant differences in N_2O emissions among different phosphate fertiliser doses as well as between AWD and CF treatments in An Giang (alluvial soil), Hau Giang (acid sulfate soil), and Bac Lieu (saline soil).

- Different soil types induced methane emissions differently. Methane emissions increased in the order deep-flooded alluvial soil (An Giang) > shallow-flooded alluvial soil (Can Tho) > acid sulfate soil (Hau Giang) > saline soil (Bac Lieu, Ca Mau, Kien Giang). In alluvial soils at CLRRI (Can Tho), AWD treatment significantly decreased CH_4 emissions (54%) compared with CF treatment.

- Seasonal variations in methane emissions were observed in the Mekong Delta. Methane emissions from rice paddies were highest in autumn-winter and lowest in the summer-autumn crop.

- The introduction of upland crops into the triple-rice system reduced methane emissions significantly.

9.2 Recommendations

- The study delineates the extent of vulnerable area under different levels of depth of flooding and of salinity on different land-use types, which should be considered in the levels of damage and crop yield losses or levels of vulnerability under different climate change scenarios.

- Future efforts should focus on further collection and evaluation of local germplasm to identify landraces with greater tolerance of submergence and salt stress and drought stress as sources of new genes or alleles for breeding.

- Additional breeding efforts such as exciting developments in the field of genomics and additional resources and efforts should be directed toward the identification of QTLs and genes underlying tolerance of the multiple stresses experienced in the problem soils of the Mekong Delta, for their subsequent integration into modern varieties and elite breeding lines through marker-aided breeding. Fine mapping of these genes will allow them to be transferred readily into new varieties, thereby adding to the suite of stress tolerances built into the new lines.

- Acidity and salinity management plans for upland cropping must be considered. These plans should be regularly evaluated and modified.

- A methodology for appropriate land-use strategy for climate change adaptation of the coastal area of the Mekong Delta was applied in a case study in Bac Lieu Province, one of the most CC-vulnerable provinces of the Mekong Delta. To assure successful development of the CCA strategies, the following studies are essential:
    - Risk management on crop failure (by disease, water pollution, extreme weather) and on market fluctuation.
    - Land- and water-efficient use (e.g., the large-farm model).
    - Changes in rural labor (both quantity and quality) due to migration and mechanization.
    - Longer term impacts of CC and SLR and additional impacts of land subsidence on salinity and flooding in the Mekong Delta.
    - An appropriate platform to support innovation practices in Mekong Delta rural development (financial, manufacturing, enterprise, distributor, and farmer innovation, etc.).

9.3 Intellectual property

Four varieties developed by CLUES were submitted by CLRRI to DARDs at four target provinces of CLUES for release in 2014. Then CLRRI (Nguyen thi Lang) submitted document for release to Ministry of Agricultural and Rural Development – Vietnam in 2015:

- OM3673: short growth duration, salinization time, and tolerance of anaerobic seedling stage.
- OM10252: tolerance of submergence and salinity.
- OM6328 and OM 6677: salt tolerance and high yield.

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Phong N. H. 2014. Effects of liming, plough and salinity washing increasing on soil salinity removal and rice yield in shrimp-rice cropping system in Phuoc Long District, Bac Lieu Province”. Master thesis in Soil Science. College of Agriculture and Applied Biology, Can Tho University.

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10.2 List of publications produced by CLUES project

Eight peer-reviewed papers of CLUES were published in international and national journals in 2013-15:

10.2.1 Refereed publications

Refereed papers in English

1. Nguyen Thi Lang, Pham Thi Thu Ha, Chau Thanh Nha, Nguyen Van Hieu, Doan Van Hon, A. Ismail, R. Reinke, and Bui Chi Buu. 2013. Introgression of Sub1 gene into local popular varieties and newly developed elite breeding lines in the Mekong Delta adapted to climate change. Omon Rice 19 (2013):27-39.

2. Nguyen Thi Lang, Nguyen Van Hieu, Tran Thi Nhien, Bui Phuoc Tam, Vo Thi Tra My, Bui Chi Buu, R. Labios, A. Ismail, R.Reinke, and R. Wassmann. 2013. Enriching gene pool to enhance rice productivity under submergence and medium stagnant water stress in Mekong Delta. Omon Rice 19 (2013):89-96.

3. Ngo Dang Phong, To Phuc Tuong, Nguyen Dinh Phu, Nguyen Duy Nang, and Chu Thai Hoanh. 2013. Quantifying source and dynamics of acidic pollution in a coastal acid sulphate soil area. Water, Air and Soil Pollution *224:1765*.

4. Ngo Dang Phong, Chu Thai Hoanh, Tran Quang Tho, Nguyen Van Ngoc, Tran Duc Dong, To Phuc Tuong, Nguyen Huy Khoi, and Nguyen Xuan Hien. 2014. Impact of sea level rise on submergence, salinity and agricultural production in a coastal province of the Mekong River Delta, Vietnam. In: C.T. Hoanh, V. Smakhtin, and R. Johnston (Editors). Climate change and agricultural water management in developing countries. CABI Climate Change Series. CABI Publishing, UK.

5. Ngo Dang Phong, Chu Thai Hoanh, To Phuc Tuong, and Hector Malano. 2014. Effective management for acidic pollution in the canal network of the Mekong Delta of Vietnam: a modeling approach. Journal of Environmental Management 140 (2014):14-25. DOI: 10.1016/j.jenvman.2013.11.049.

6. Ngo Dang Phong, Chu Thai Hoanh, To Phuc Tuong, and Reiner Wassmann. 2014. Sea level rise effects on acidic pollution in a coastal acid sulphate soil area. In: Ames, D.P., Quinn, N.W.T., Rizzoli, A.E. (Eds.), Proceedings of the 7th International Congress on Environmental Modelling and Software, June 15-19, San Diego, California, USA. ISBN: 978-88-9035-744-2.

7. Nguyen Thi Lang, Bui Phuoc Tam, Nguyen Van Hieu, Chau Thanh Nha, Abdelbagi Ismail, Russell Reinke, and Bui Chi Buu. 2014. Evaluation of rice landraces in Vietnam using SSR markers and morphological characters. SABRAO Journal of Breeding and Genetics 46 (1):1-20.

8. Nhan P. P., Hoa L.V., Qui C.N., Huy N.X., Huu T.P., McDonald B.C.T. and Tuong T.P.. 2015. Increasing profitability and water use efficiency of triple rice crop production in the Mekong Delta, Vietnam. Journal of Agricultural Science. doi:10.1017/S0021859615000957.

Refereed publications in Vietnamese

1. Nguyen Thi Lang, Bui Thanh Liem, Vo Thi Tra My, Chau Thanh Nha, Bui Chi Buu, Russell Reinke, Abdelbagi Ismail, Reiner Wassmann. 2012. Selection of varieties to adapt to salt – marsh in Mekong Delta. Science and Technology Journal of

Agriculture and Rural Development. Topic on plant and animal breeding. Book 1. February/2012, 5–10. (In Vietnamese.)

2. Nguyễn Thị Lang, Bùi Thanh Liêm, Võ Thị Trà My, Châu Thanh Nhã, Bùi Chí Bửu, Rusell Reinke, Abdelbagi Ismail và Reiner Wassmann. 2012. Chọn lọc các giống lúa thích ứng với vùng biến đổi khí hậu ngập mặn tại Đồng Bằng Sông Cửu Long. *Tạp chí Nông Nghiệp và Phát Triển Nông Thôn,* chuyên đề giống cây trồng vật nuôi. Tập 1. Tháng 2/2012, trang 5–10.
3. Pham Phuoc Nhan, Cu Ngoc Qui, Tran Phu Huu, Le Van Hoa, B. McDonald, and T. P. Tuong. 2013. Effects of alternate wetting and drying irrigation, crop establishment methods, and reduced phosphorus application on OM5451 growth and yield in 2012 Winter Spring Crop Season. Journal of Science Can Tho University. Part B: Agriculture, Aquaculture and Biotechnology 28 (2013):103-111. (In Vietnamese.)
4. Pham Thanh Vu, Nguyen Trang Hoang Nhu, Vuong Tuan Huy, and Le Quang Tri. 2013. Determination of socio-economic and environment factors that affect the selection of farming models in Bac Lieu province. Journal of Science Can Tho University. Part D: Science, Politics, Economics and Law 27 (2013):68-75. (In Vietnamese.)
5. Phạm Thanh Vu, Le Quang Tri, Vương Tuan Huy. 2013. Adaptation of farmers on change farm model in Bac Lieu province. Science and Technology Journal of Agriculture and Rural Development 15 (2013):24-31. (In Vietnamese.)
6. Truong Thi Ngoc Chi, Thelma R. Paris, Tran Thi Thuy Anh, Chau Chieu Y, Huynh Nhu Dien, Tran Quang Tuyen, Romeo Labios, and Nguyen Thi Lang. 2013. Male and female farmers' participation in varietal selection. The First National Conference on Crop Sciences on 5-6 Sept. 2013. Agriculture Publisher, Ha noi, 2013:1336-1342. (In Vietnamese.)
7. Vuong Tuan Huy, Van Pham Dang Tri, Pham Thanh Vu, Le Quang Tri và Nguyen Hieu Trung. 2013. Application of Aquacrop model to simulate rice yield in the context of climate change in the northern area of the national road 1A. Bac Lieu Province. Science and Technology Journal of Agriculture and Rural Development 13 (2013):48-53. (In Vietnamese.)
8. Nguyen Thi Lang, Bui Phuoc Tam, Pham Thi Chuc Loan, Nguyen Trong Phuoc, Tran Bao Toan, Bui Chi Buu, Abdelbagi M.Ismail, Glenn Gregorio, Russell Reinke, and Reiner Wassmann. 2014. Screening gene tolerant to salinity on short-term rice in the seedling stage. Journal of Vietnam Agricultural Science and Technology. No. 4 (50) 2014:23-28 (ISSN-1859-1558). Published by Vietnam Academy of Agricultural Sciences. (In Vietnamese.)
9. Nguyen Thi Lang, Nguyen Van Hieu, Pham Thi Thu Ha, Bui Chi Buu, and Abdelbagi M. Ismail. 2013. Quantitative trait loci (QTLs) mapping with submergence tolerance in rice (*Oryza sativa* L.) at Mekong Delta. In: Proceedings of Biotechnology Conference 2013 at National Conference Center in Hanoi, Vietnam, 27 September 2013. Volume 2. Molecular Biotechnology and Plant Biotechnology. Science and Technology Publisher. p 893-895.
10. Pham Thanh Vu, Le Quang Tri, Nguyen Hieu Trung, and Nguyen Huu Kiet. 2014. Optimization for land use planning option in Bac Lieu province. Science and Technology Journal of Agriculture and Rural Development 8 (2014):13-20. ISSN 1859-4581. (In Vietnamese.)
11. Pham Thanh Vu, Le Quang Tri, Nguyen Hieu Trung, Vuong Tuan Huy, Nguyen Tan Đat, and Le Thi Nuong. 2014. Using multi-criteria decision analysis in agricultural land uses in Bac Lieu province. Journal of Science Can Tho University 31 (2014):106-115. (In Vietnamese.)

12. Pham Thanh Vu, Nguyen Hieu Trung, and Le Quang Tri. 2014. Exploitation of scenarios for strategic land use option for agricultural development. Scientific Conference. Journal of Science and Technology. ISBN: 978-604-6703655. (In Vietnamese.)
13. Truong Thi Ngoc Chi, Tran Thi Thuy Anh, and Thelma Paris. 2014. Gender roles in household, constraints, risk-coping mechanisms in response to climate change. Journal of Vietnam Agricultural Science and Technology. No. 4 (50) 2014:73-79. ISSN-1859-1558. Published by Vietnam Academy of Agricultural Sciences. (In Vietnamese.)
14. Truong Thi Ngoc Chi, Tran Thi Thuy Anh, Thelma Paris, Le Duy. 2014. The gender dimensions of the relationship between climate change and rice-based farming systems: an exploratory assessment in the Mekong Delta. Omon Rice (in press). (In Vietnamese).
15. Truong Thi Ngoc Chi, Tran Thi Thuy Anh, Thelma Paris, Le Duy, Dang Tuyet Loan, and Nguyen Thi Lang. 2014. Farmers' feedback on rice varieties tested under farmer-managed trials. Omon Rice (in press). (In Vietnamese.)
16. Vo Van Tuan, Le Canh Dung, Vo Van Ha, and Dang Kieu Nhan. 2014. Adaptive capacity of farmers to climate change in the Mekong Delta. Journal of Science Can Tho University 31 (2014):63-72.
17. Nguyen Thi Hong Diep, Vo Quang Minh, Phan Kieu Diem, Pham Quang Quyet. 2014. Observing changes of aquacultural land in An Giang province from 2008 to 2012 using remote sensing and GIS. Journal of Science Can Tho University. Volume 30a (2014):78-83. ISSN: 1859-2333. (In Vietnamese.)
18. Nguyen Thi Ha Mi, Vo Quang Minh. 2014. Assessing the impact of climate change on rice farming in An Giang province. Journal of Science Can Tho University. Special issue: Agriculture. Volume 3 (2014):42-52. ISSN: 1859-2333. (In Vietnamese.)
19. Nguyen Quang Trung, Vo Quang Minh, Phan Kieu Diem. 2014. Assessing the changes of rice cropping in An Giang province in the period 2000-2013 on the basis of using MODIS image. Proceedings of Application of Nationwide GIS Conference 2014, Can Tho City, Vietnam, 28-29 November 2014. Cantho University Publisher: p 41-49. ISBN: 978-604-919-249-4. (In Vietnamese.)
20. Nguyen Thi Hong Diep, Vo Quang Minh, Phan Kieu Diem, Nguyen Van Tao. 2014. Climate change impact on land use in the coastal area of the Mekong Delta. Proceedings of Application of Nationwide GIS Conference 2014, Can Tho City, Vietnam, 28-29 November 2014. Cantho University Publisher: p 88-94. ISBN: 978-604-919-249-4. (In Vietnamese.)
21. Le Minh Hop, Tran Thi Hien, Vo Quang Minh, Nguyen Thi Hong Diep, Phan Kieu Diem. 2014. Application of MODIS image for monitoring the rice cropping pattern changes for services in agricultural management in Mekong Delta. Proceedings of Application of Nationwide GIS Conference 2014, Can Tho City, Vietnam, 28-29 November 2014. Cantho University Publisher: p 169-180. ISBN: 978-604-919-249-4. (In Vietnamese.)
22. Nguyen Van Phuc, Nguyen Thi Ha Mi, Phan Kieu Diem, Vo Quang Minh, Le Quang Tri, Nguyen Xuan Hien. 2014. Assessing the impact of climate change scenarios to current land use and land use planning in Hau Giang province. Proceedings of Application of Nationwide GIS Conference 2014, Can Tho City, Vietnam, 28-29 November, 2014. Cantho University Publisher: p 845-854. ISBN: 978-604-919-249-4. (In Vietnamese.)

10.2.2 Presentations

Presentations at international conferences

1. Nguyen Hieu Trung, Pham Thanh Vu, and Van Pham Dang Tri. 2014. An interactive approach to support natural resources use policy: a case study in the Vietnamese Mekong Delta coastal areas. *Proceedings of the International Symposium on GeoInformatics for Spatial-Infrastructure Development in Earth & Allied Sciences (GIS-IDEAS)*. Da Nang City, Vietnam, 6-9 December 2014. Available at http://gisws.media.osaka-cu.ac.jp/gisideas14/viewabstract.php?id=479.

2. Nguyen Thi Lang, Phạm Thị thu Hà, Nguyễn Văn Hiếu, Nguyễn Ngọc Hương, Bùi Chí Bửu, Russell Reinke, Abdelbagi M. Ismail, and Reiner Wassmann. 2014. Generating and disseminating improved rice lines tolerant of temporary (complete) submergence -- through transfer of the Sub1 gene into local popular varieties and newly developed elite breeding lines in rice *Oryza sativa* L. *8th Asian Crop Science Association Conference (ACSAC8): "Sustainable Crop Production in Response to Global Climate Change and Food Security."* Vietnam National University of Agriculture, Ha Noi, 23-25 September 2014. Book of abstracts. p 38.

3. Nguyen Thi Lang, Pham Thi Thu Ha, Nguyen Van Hieu, Tran Thi Nhien, Bui Chi Buu, Russell Reinke, and Abdelbagi M. Ismail. 2014. Gene pyramiding of salt and submergence gene and relevant genes in rice *Oryza sativa* L. *8th Asian Crop Science Association Conference (ACSAC8): "Sustainable Crop Production in Response to Global Climate Change and Food Security."* Vietnam National University of Agriculture, Ha Noi, 23-25 September 2014. Book of abstracts. p 36.

4. Nguyen Thi Lang, TranThi Nhien, Nguyen Van Hieu, Bui Phuoc Tam, Chau Thanh Nha, Tran Minh Tai , Bui Chi Buu, Russell Reinke, Abdelbagi M. Ismail, and Reiner Wassmann. 2014. Identify locally adapted varieties and elite breeding lines as recipients of *Sub1* and *Saltol* in rice. *8th Asian Crop Science Association Conference (ACSAC8): "Sustainable Crop Production in Response to Global Climate Change and Food Security."* Vietnam National University of Agriculture, Ha Noi, 23-25 September 2014. Book of abstracts. p 59.

5. Pham Phuoc Nhan, Le Van Hoa, Nguyen Truong Giang, To Phuc Tuong, and Ben Macdonald. 2014. Effects of alternate wetting and drying irrigation and phosphorous fertiliser rates on the growth and yield of rice in double rice cropping system at An Giang province. *Oral presentation in the 8th Asian Crop Science Association Conference (ACSAC8): "Sustainable Crop Production in Response to Global Climate Change and Food Security."* Vietnam National University of Agriculture, Ha Noi, 23-25 September 2014.

6. Pham Phuoc Nhan, Phan Thi Be Sau, Le Van Hoa, and Ben McDonald. 2014. Residue management effects on survival rate, growth and yield of rice cultivar IR64-Sub1 subjected to submergence at young seedling stage in pots. *Oral presentation in the 8th Asian Crop Science Association Conference (ACSAC8): "Sustainable Crop Production in Response to Global Climate Change and Food Security."* Vietnam National University of Agriculture, Ha Noi, 23-25 September 2014.

7. Reiner Wassmann and Ngo Dang Phong. 2014. Climate change affecting rice production in the Vietnamese Mekong Delta: potential and constraints of adaptation options. Invited presentation at the Mega Delta Symposium, 4th International Rice Congress, Bangkok, Thailand, 27 October–1 November 2014. International Rice Research Institute, Los Baños, Philippines. IRC14-1137.

8. To Phuc Tuong, Chu Thai Hoanh, Tran Quang Tho, Ngo Dang Phong, Nguyen Van Ngoc, Tran Duc Dong, Nguyen Huy Khoi, Nguyen Xuan Hien, and Reiner Wassmann. 2014. Climate change and sea level rise effects on rice-based production systems in the Mekong River Delta. Invited presentation at the Mega Delta Symposium, 4th International Rice Congress, Bangkok, Thailand, 27 October–1 November 2014. International Rice Research Institute, Los Baños, Philippines. IRC14-0497.

9. Vo Quoc Thanh, Chu Thai Hoanh, Nguyen Hieu Trung, and Van Pham Dang Tri. 2014. A bias-correction method of precipitation data generated by regional climate model. *Proceedings of the International Symposium on GeoInformatics for Spatial-Infrastructure Development in Earth & Allied Sciences (GIS-IDEAS)*. Da Nang City, Vietnam, 6-9 December 2014. Available at http://gisws.media.osaka-cu.ac.jp/gisideas14/viewabstract.php?id=505 or http://gisws.media.osaka-cu.ac.jp/gisideas14/viewabstract.php?id=505.

10. Vo Quang Minh, Huynh thi thu Huong, Nguyen Thi Hong Diep. 2012. Monitoring and delineating rice cropping calendar in the Mekong delta using Modis images. Proceedings of International Conference on Geo-Informatics for Spatial Infrastructure Development in Earth and Allied Sciences (GIS-IDEAS 2012). Ho Chi Minh City, 16-20 October 2012. JVGC (Japan-Vietnam GeoInformatics Consortium) Technical Document No. 8. p 150-156.

Presentations at national conferences

1. Nguyen Quang Trung, Phan Kieu Diem, Vo Quang Minh. 2014. Assessing the changes of rice cropping in An Giang province in the period 2000-2013 on the basis of using MODIS image. *Proceedings of Information Technology for Climate Change in developing exportable agricultural products in Vietnam.* Kien Giang Province, Vietnam, 29 September 2014. Science and Technology Publisher. ISBN: 978-604-6703655. (In Vietnamese.)

2. Vo Quang Minh, Phan Kieu Diem, Nguyen Xuan Hien, Le Quang Tri. 2014. Application of Geographic Information Technology (GIS) to identify vulnerable areas under the impact of climate change in the Mekong Delta. *Proceedings of Information Technology for Climate Change in developing exportable agricultural products in Vietnam.* Kien Giang Province, Vietnam, 29 September 2014. Science and Technology Publisher. ISBN: 978-604-6703655. (In Vietnamese.)

3. Temma Carruthers-Taylor, Gary Owens, Seija Tuomi, Ben Macdonald and Nasreen I. Khan. 2014. Application of the Molybdenum Blue method for Arsenic Determination: In Vietnamese Acid Sulphate Agricultural Soils. Proceedings Australian National Soil Science Conference

4. Leah Garnett, Jason Condon, Chau Minh Khoi, Ben Macdonald. 2015. Phosphorus fertiliser requirements of rice under alternate wetting and drying irrigation in the Vietnamese Mekong Delta. Proceedings of the 17th ASA Conference, 20 – 24 September 2015, Hobart, Australia. Web site www.agronomy2015.com.au.

10.2.3 Posters

Posters at international conferences

1. Chau Minh Khoi, Nguyen Van Qui, Nguyen Minh Dong, Bennett Macdonald, and To Phuc Tuong. 2014. Possibility of introducing high-yielding, short-duration rice varieties to replace local traditional photoperiod sensitive variety in the shrimp-rice cropping system in the Mekong Delta, Vietnam. Poster presented in 4th International Rice

Congress, Bangkok, Thailand, 27 October–1 November 2014. International Rice Research Institute, Los Baños, Philippines. IRC14-0841.

2. Chau Minh Khoi, Nguyen Van Qui, To Phuc Tuong, and Bennett Macdonald. 2014. Effects of alternate wetting-drying irrigation management on soil phosphorus availability and rice growth in the Mekong Delta, Vietnam. Poster presented in 4th International Rice Congress, Bangkok, Thailand, 27 October–1 November 2014. International Rice Research Institute, Los Baños, Philippines. IRC14-0855.

3. Nguyen Thi Lang, Pham Thi Thu Ha, Bui Phuoc Tam, Trinh Thi Luy, Tran thi Nhien, Nguyen Van Hieu , Nguyen Hoang Thai Binh, Bui Chi Buu, Romeo V. Labios, Russell Reinke, and Abdelbagi M. Ismail. 2014. Participatory varietal selection (PVS) for salt tolerance in rice in Mekong Delta. Poster presented in 4th International Rice Congress, Bangkok, Thailand, 27 October–1 November 2014. International Rice Research Institute, Los Baños, Philippines. IRC14-0692.

4. Nguyen Thi Lang, Nguyen Van Hieu, Pham Thi Thu Ha, Bui Chi Buu, and Abdelbagi M. Ismail. 2014. Backcrossing analysis to detect quantitative trait loci (QTLs) related to submergence tolerance in rice (*Oryza sativa.* L) in Mekong Delta. Poster presented in 4th International Rice Congress, Bangkok, Thailand, 27 October–1 November 2014. International Rice Research Institute, Los Baños, Philippines. IRC14-0273.

5. Nguyen Thi Lang, Pham Thi Thu Ha, Bui Phuoc Tam, Tran Thi Thanh Xa, Trinh Thi Luy, Tran Thi Nhien, Nguyen Van Hieu , Nguyen Hoang Thai Binh, Bui Chi Buu, Glenn Gregorio, Russell Reinke, and Abdelbagi M. Ismail. 2014. Breeding the rice varieties tolerant to salt by molecular markers. Poster presented in 4th International Rice Congress, Bangkok, Thailand, and 27 October – 1 November 2014. International Rice Research Institute, Los Baños, Philippines. IRC14-0265.

6. Pham Phuoc Nhan, Le Van Hoa, Tran Phu Huu, Nguyen Giang Truong, Danh Phuc Viet, Benett Macdonald, and To Phuc Tuong. 2014. Profit improvement in rice production by alternate wetting and drying irrigation and phosphorous reduction. *Poster presented in 4th International Rice Congress*, Bangkok, Thailand, 27 October–1 November 2014. International Rice Research Institute, Los Baños, Philippines. IRC14-0356.

7. Vo Quang Minh, Tran Thi Hien, Phan Kieu Diem, Nguyen Thi Ha Mi, Nguyen Xuan Hien, Le Quang Tri, Ho Van Chien. 2014. Rice crop monitoring for early warning pest occurrence using remote sensing and geographic information systems. Poster presented in 4th International Rice Congress, Bangkok, Thailand, and 27 October-1 November 2014. International Rice Research Institute, Los Baños, Philippines. IRC14-xxxx.

10.2.4 Leaflets of CLUES

- Thirteen leaflets about the products and technologies developed by the themes in the Final Review Workshop 2015 are available for dissemination (in both Vietnamese and English).

10.2.5 Publications In preparation

Refereed paper

1. Le Canh Dung, Vo Van Ha, Vo Van Tuan, Dang Kieu Nhan, John Ward, and Peter Brown. 2016. Financial capacity of rice-based farming households in the context of climate change in the Mekong Delta, Vietnam. The Asian Journal of Agriculture and Development. Submitted. Under review.

2. Ngo Dang Phong, Tran Quang Tho, To Phuc Tuong, Chu Thai Hoanh, Reiner Wassmann, Nguyen Huy Khoi, and Nguyen Xuan Hien. 2016. Flood and salinity

dynamics in canal network of the Mekong River Delta under climate change and sea level rise. (In preparation)

3. Khoi C.M., Qui N.V., Macdonald B.C.T., Tuong T.P. 2015. Improving phosphorus fertiliser use efficiency in salt affected intensified rice lands of the Mekong Delta. Agronomy Journal. Submitted. Under Review.

Conferences

1. Vo Quang Minh, Nguyen Thi Ha Mi, Tran Thi Hien. 2016. Monitoring changes of cultivated area of rice cropping in Mekong Delta by remote sensing. Proceedings of Application of Nationwide GIS Conference 2015, Ha Noi, Vietnam, 2015. (Under review.)

2. Nguyen Thi Ha Mi, Vo Quang Minh, Thai Thanh Du. 2016. Application of GIS technology in assessing the impact of climate change on rice farming in Mekong Delta. Proceedings of Application of Nationwide GIS Conference 2015, Ha Noi, Vietnam, 2015. (Under review.)

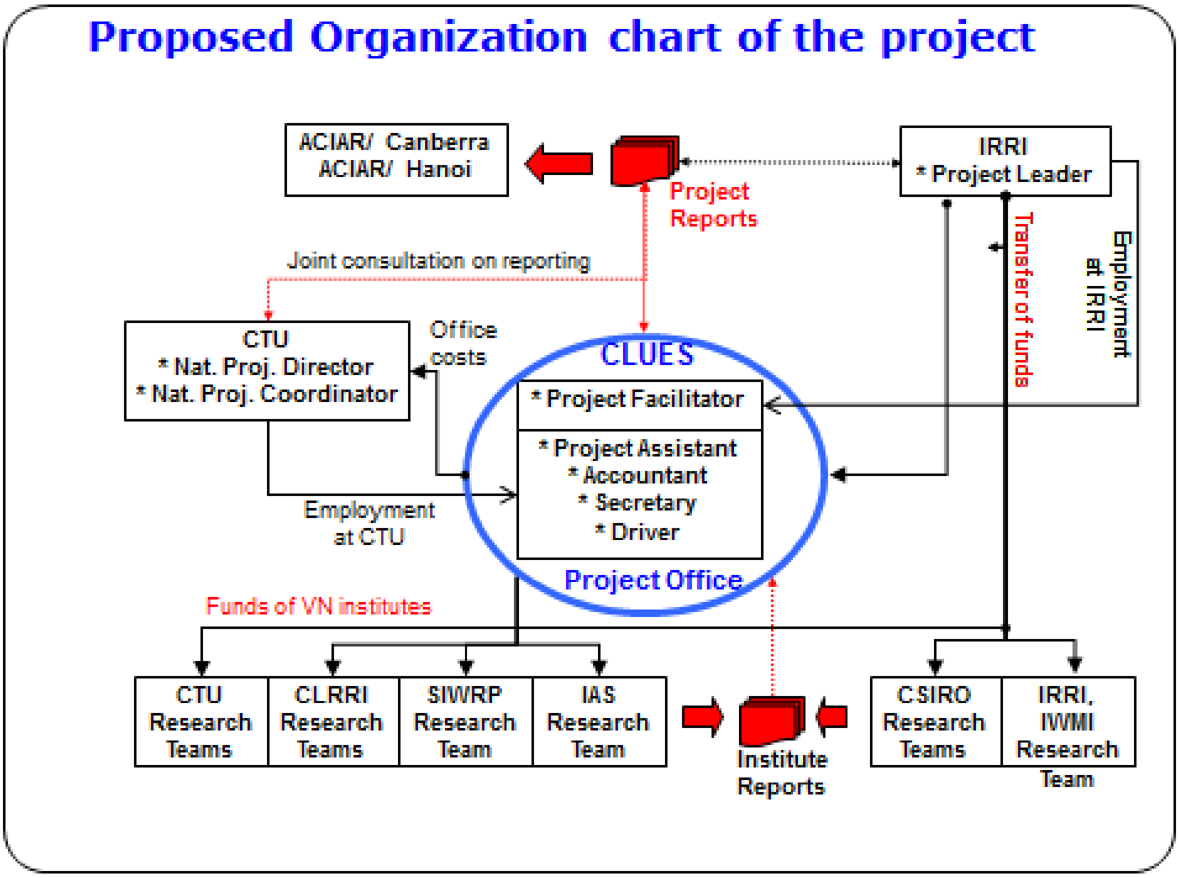
3. Thai Thanh Du, Nguyen Thi Ha Mi, Vo Quang Minh. 2016. GIS in the assessment of variation of rice crops under impacts of climate change in Bac Lieu province. Proceedings of Application of Nationwide GIS Conference 2015, Ha Noi, Vietnam, 2015. (Under review.)

11 Appendixes

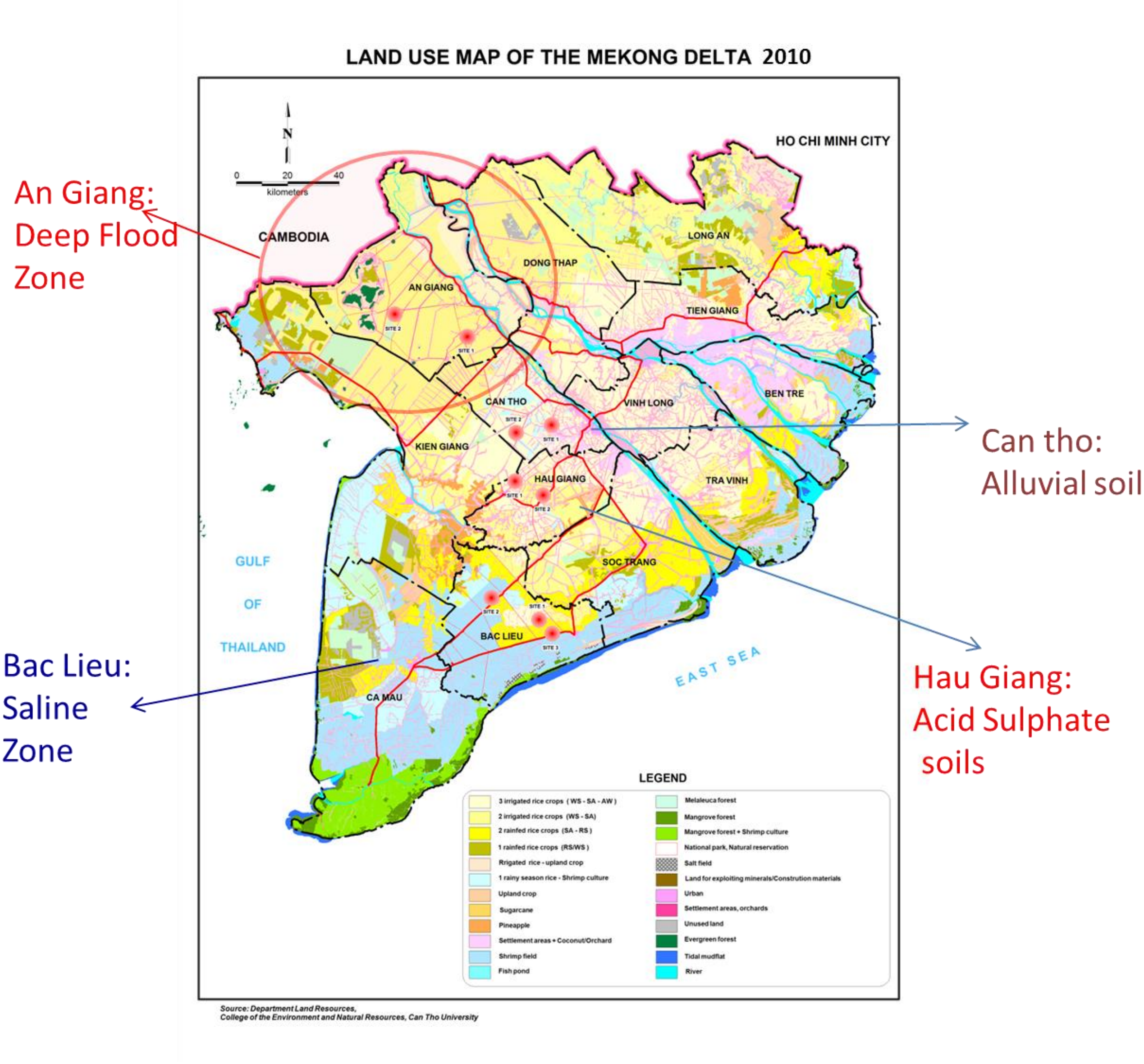
Appendixes 1–6. Six Theme Final Reports

(Included in other files)

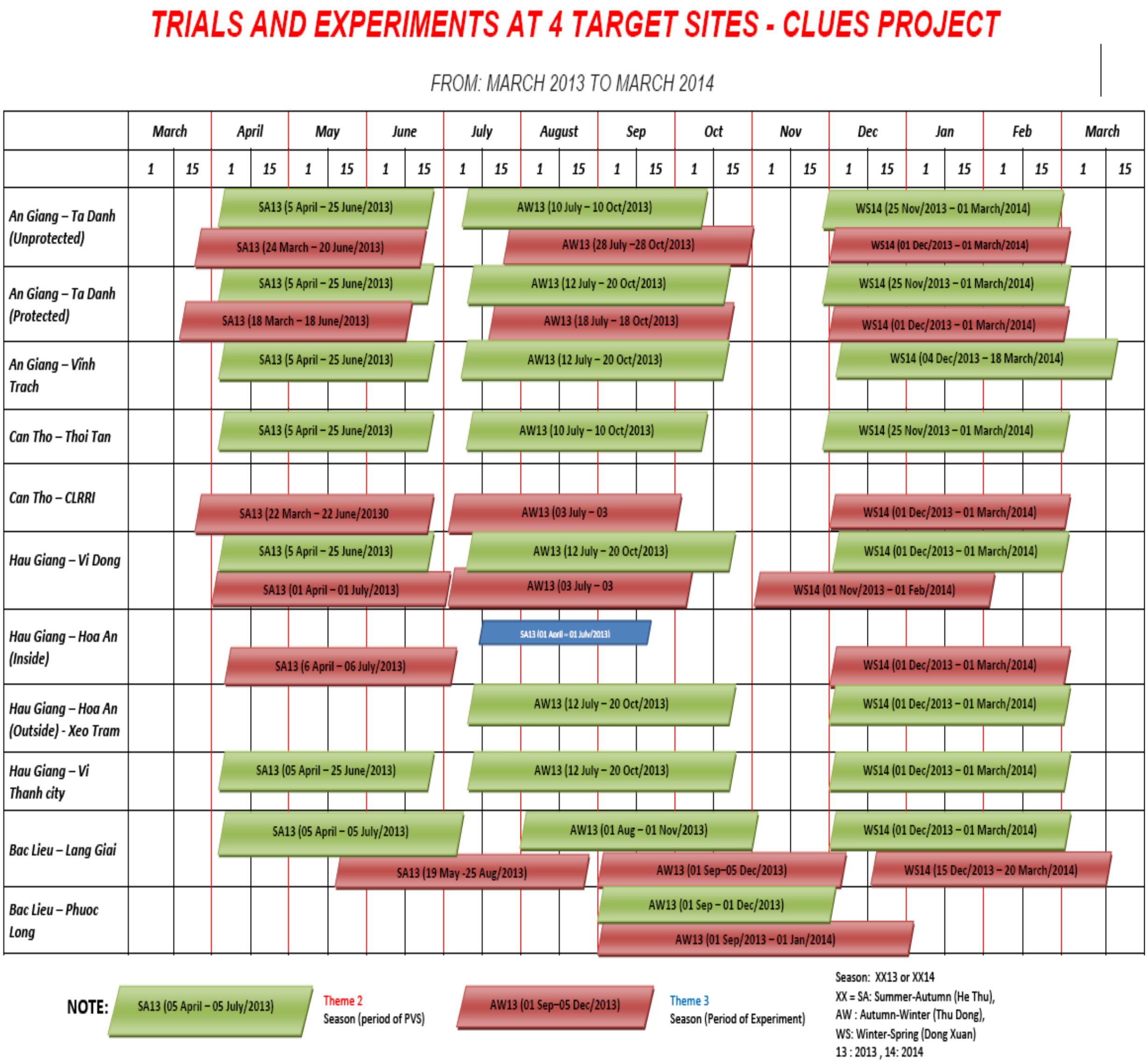
Appendix 7. Structure of organization of CLUES



Appendix 8. Location of study sites of CLUES



Appendix 9. Cropping calendars of experiments at study sites of CLUES



Appendix 10. Capacity building by Theme 2 (Plant breeding component)

10.1 Bac Lieu Province

No.	Name of activity	Date	Length of activity	No. of people involved	Males	Females	Expected outcome
	2012						
1	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Hòa Bình, Bạc Liêu	5 April 2012	1	55	43	12	A hands-on training in phenotype for selected new varieties Good land preparation and land levelling Fertiliser application and soil improvement Pest control (IPM) Selected some new OM 6677 OM 4900 OM 8104 OM 10252 OM 6328
		18 August 2012	1				OM 8105 OM 90L OM 10041 OM 8108 OM 10252
2	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Minh Diệu, Hòa Bình, Bạc Liêu	10 December 2012	1	49	33	16	A hands-on training in phenotype for selected new varieties Good land preparation and land levelling Fertiliser application and soil improvement Pest control

							(IPM) Selected some new OM 90L OM 4488 MNR1 OM 10252 OM 6677
3	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Phước Thạnh, Diệu, Phước Long, Bạc Liêu	18 December 2012	1	59	38	21	OM 6677 TLH 1 OM 8105 OM 10252 OM 5629
Year 2013							
4	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Minh Diệu, Hòa Bình, Bạc Liêu	22 March 2013	1	28	22	6	A hands-on training in phenotype for selected new varieties Good land preparation and land levelling Fertiliser application and soil improvement Pest control (IPM) Selected some new OM 90L OM 4488 MNR1 OM 4900 OM 6677
5	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Bạc Liêu	12 August 2013	1	35	26	9	OM 3673 OM 5629 OM 6162 OM 6677 TLH1
		20 December 2013		27	27	0	A hands-on training in phenotype for selected new

							varieties Good land preparation and land levelling Fertiliser application and soil improvement Pest control (IPM) Selected some new OM 5629 TLH1 OM 6677 OM 8105
6	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Phước Long, Bạc Liêu	24 December 2013		31	20	11	OM 5629 TLH2 OM 10252
	Year 2014						
7	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Láng Giài A, Hòa Bình, Bạc Liêu	22 April 2014	1	26	21	5	A hands-on training in phenotype for selected new varieties Good land preparation and land levelling Fertiliser application and soil improvement Pest control (IPM) Selected some new OM 4900 OM 3673 OM 6070 OM 6677 OM 5629
8	Training Workshop in Participatory Varietal Selection (PVS)	12 January 2015		30	20	10	OM10252, OM8108 OM3673

	for Enhanced Varietal Development Láng Giài A, Hòa Bình, Bạc Liêu						
				340	250	90	

10.2 Can Tho City

	Name of activity	Date	Length of activity	No. of people involved	Males	Females	Expected outcome
1	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development	5 March 2012	1	126	89	37	A hands-on training in phenotype for selected new varieties Good land preparation and land leveling Fertiliser application and soil improvement Pest control (IPM) Selected some new varieties in Thoi Tan Village: 1. OM4488 2. OM 10041 3. Can Tho 2 4. OM 6L 5. OM 8928 Truong Xuan A Village: 1. OM 4488 2. OM 10041 3. Can Tho 2 4. OM 8928 5. OM 7L
2	Training Workshop at CLRRI	22 Feb. 2012	1	283	260	23	Information on new varieties for next season Need to change varieties or multiply new varieties
3	Training Workshop	26 June	1	30	20	10	A hands-on training in

	in Participatory Varietal Selection (PVS) for Enhanced Varietal Development	2012					phenotype for selected new varieties Good land preparation and land leveling Fertiliser application and soil improvement Pest control (IPM) Selected some new varieties in Thoi Tan village: 1. OM 8108 2. OM 4488 3. Can Tho 2 4. OM 8928 5. OM 10041
4	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development	11 October 2012	1	30	25	5	A hands-on training in phenotype for selected new varieties Good land preparation and land leveling Fertiliser application and soil improvement Pest control (IPM) Selected some new varieties in Thoi Tan village: 1. OM 8108 2. OM 96L 3. OM 4488 4. IR64-Sub1 5. OM 10418
5	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development	22 February 2013	1	30	26	4	A hands-on training in phenotype for selected new varieties Good land preparation and land leveling Fertiliser application and soil improvement Pest control (IPM) Selected some new varieties in Thoi Tan Village: 1. OM 8108 2. OM 10040 3. OM 10041

							4. OM 4488 5. OM 4900
6	Training Workshop at CLRRI	3 March 2015	1	200	180	20	Information on new varieties for next season. Need to change varieties or multiply new varieties.
7	Training Workshop at CLRRI	22 August 2013	1	312	289	23	Information on new varieties for next season. Need to change varieties or multiply new varieties.
8	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development	4 October 2013	1	30	27	3	A hands-on training in phenotype for selected new varieties Good land preparation and land leveling Fertiliser application and soil improvement Pest control (IPM) Selected some new varieties in Thoi Tan Village: 1. OM 7L 2. TLR375 3. OM 4488, OM 8928 4. OM 8108 5. OM 70L
9	Training Workshop at CLRRI	10 March 2013		210	179	31	Information on new varieties for next season. Need to change varieties or multiply new varieties.
10	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development	15 March 2014	1	30	26	4	A hands-on training in phenotype for selected new varieties Good land preparation and land leveling Fertiliser application and soil improvement Pest control (IPM) Selected some new varieties in Thoi Tan Village: 1. OM 6161 2. OM 8108 3. Can Tho 1

							4. OM 10041 5. TLR 392
11	Training Workshop at CLRRI	22 July 2014	1	109	69	40	Information on new varieties for next season. Need to change varieties or multiply new varieties.
12	Training Workshop at CLRRI	2 November 2014	2	120	99	21	OM 10373, OM 8108, OM 3673
	Total			1,510	1,289	221	

10.3 An Giang Province

No.	Name of activity	Date	Length of activity	No. of people involved	Males	Females	Expected outcome
	Year 2012						
1	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Tân Thuận, Xã Tà Đảnh, Huyện Tri Tôn, An Giang	7 March 2012	1	50	30	20	A hands-on training in phenotype for selected new varieties Good land preparation and land leveling Fertiliser application and soil improvement Pest control (IPM) Selected some new varieties: 1. OM 10040 2. OM 4900 3. OM 10041 4. OM 10000 5. OM 7347
2	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Trung Bình Tiến, Xã Vĩnh Trạch, Huyện Thoại Sơn, An Giang	7 March 2012	1	45	23	22	A hands-on training in phenotype for selected new varieties Good land preparation and land leveling Fertiliser application and soil improvement Pest control (IPM) Selected some new varieties: 1. OM 10000 2. OM 7347 3. OM 10041 4. OM 10040 5. OM 8108
3	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Tân Thuận, Tà Đảnh, huyện Tri Tôn, An Giang (inside dyke system)	23 July 2012	1	54	31	23	1. OM 7347 2. OM 4900 3. OM 8108 4. OM 10000 5. OM 8928 6. OMCS 2012
4	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development (Workshop at Tân Thuận, xã Tà Đảnh, Tri Tôn, An	23 July 2012	1	54	31	23	1. OM 4900 2. OM 8108 3. OM 8104 4. OM 7347 5. OM 10041 6. OM 10000

	Giang (outside the protection dyke system)						
5	Workshop at Trung Bình Tiến, xã Vĩnh Trạch, huyện Thoại Sơn, An Giang	23 July 2012	1	55	35	20	1. OM 7347 2. OM 10000 3. OM 8928 4. OMCS 2012 5. OM 8104
6	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Tân Thuận, xã Tà Đảnh, huyện Tri Tôn, An Giang (inside the flood protected dyke system	7 November 2012	1	55	35	20	1. OM 8928 2. OM 90L 3. OM 7347 4. TLR 402 5. OM 8108
7	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Trung Bình Tiến, xã Vĩnh Trạch, huyện Thoại Sơn, An Giang	7 November 2012	1	43	32	11	1. OM 8928 2. OM 90L 3. OM 10040 4. OM 7347 5. OM 10000
Year 2013							
8	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Tân Thuận, xã Tà Đảnh, huyện Tri Tôn, An Giang inside the flood protected dyke system	15 Feb. 2013	1	52	35	17	A hands-on training in phenotype for selected new varieties Good land preparation and land leveling Fertiliser application and soil improvement Pest control (IPM) Selected some new varieties: 1. OM 4900 2. OM 7347 3. OMCS 2012 4. OM 8108 5. IR64-Sub1 5. OM 8928
9	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Tân Thuận, xã Tà Đảnh, huyện Tri Tôn, An Giang outside the flood protected dyke system	15 Feb. 2013	1	52	35	17	1. OM 4900 2. OM 7347 3. OMCS 2012 4. OM 8108 5. IR64-Sub1

10	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Tân Thuận, xã Tà Đảnh, huyện Tri Tôn, An Giang outside the flood protected dyke system	20 Sept. 2013	1	50	25	25	A hands-on training in phenotype for selected new varieties Good land preparation and land leveling Fertiliser application and soil improvement Pest control (IPM) Selected some new varieties: 1. OM 3673 2. OMCS 2012 3. OM 10179 4. OM 10418 5. OM 7347
Year 2014							
11	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Vĩnh Trạch, Huyện Thoại Sơn, An Giang	1 April 2014	1	52	32	20	A hands-on training in phenotype for selected new varieties Good land preparation and land leveling Fertiliser application and soil improvement Pest control (IPM) Selected some new varieties: 1. OM 10179 2. TLR 596 3. OMCS 2012 4. OM 10252 5. MNR 5
	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Vĩnh Trạch, Huyện Thoại Sơn, An Giang	12 December 2014		50	38	12	TLR 10373 TLR 596
	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Tri Ton			70	45	25	OM 10252 OM 4488 TLR 596

	Total			682	427	255	

10.4 Hau Giang Province

No.	Name of activity	Date	Length of activity	No. of people involved	Males	Females	Expected outcome
	Year 2012						
1	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Hòa Đức, Hòa An, Phụng Hiệp, Hậu Giang	18 March 2012	1	39	15	24	A hands-on training in phenotype for selected new varieties Good land preparation and land leveling Fertiliser application and soil improvement Pest control (IPM) Selected some new varieties: 1.OM 6162 2.OM 6161 3.OM 6677 4.MNR2 5.AS 996
2	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Ấp 3, Vị Đông, Vị Thủy, Hậu Giang	1 March 2012	1	48	41	7	Selected some new varieties: 1.OM 7347 2.OM 6L 3.Can Tho 2 4.OM 6161 5.OM 6162
3		14 June 2012	1	50	36	14	1.OM 8108 2.OM 6L 3.OM 8928 4.OM 7347 5.OM 6162
4		24 Sept. 2012	1	51	39	12	Selected some new varieties: 1.OM 6161 2.OM 8108 3.OM 6L 4.OM 10041 5.OM 7347
	Year 2013						

5	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Hòa Đức & Xẻo Trăm, Hòa An, Phụng Hiệp, Hậu Giang	7 March 2013	1	40	31	9	A hands-on training in phenotype for selected new varieties Good land preparation and land leveling Fertiliser application and soil improvement Pest control (IPM) Selected some new varieties: Xẻo Trăm: 1.OM 3673 2.TLR 397 3.OM 6677 4.OM 6063 5.OM 6161 Hòa Đức: 1.OM 7L 2.MNR4 3.OM 6677 4.OM 6161 5.OM 10252
6	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Xẻo Trăm, Hòa An, Phụng Hiệp, Hậu Giang	28 June 2013	1	31	25	6	Selected some new varieties: 1.OM 3673 2.OM10418 3.OM 6063 4.TLR 397 5.OM 6677 & OM 10252
7	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Ấp 3, Vị Đông, Vị Thủy, Hậu Giang & TP. Vị Thanh, Hậu Giang	16 Feb. 2013	1	41	31	10	Selected some new varieties: Ấp 3, Vị Đông, Vị Thủy: 1.OM 6L 2.OM 6161 3.OM 7L 4.OM 6162 5.OM 4900 6.OM 8928 TP. Vị Thanh:

							1.OM 3673 2.OM10174 3.OM10179 4.OMCS 2012 5.TLR 375
8	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Ấp 3, Vị Đông, Vị Thủy, Hậu Giang	25 May 2013	1	25	22	3	A hands-on training in phenotype for selected new varieties Good land preparation and land leveling Fertiliser application and soil improvement Pest control (IPM) Selected some new varieties: 1.OM 8108 2.OM 8928 3.OM 7L 4. OM 3673 5.OM 6161
9		9 Sept. 2013	1	33	20	13	1.OM 8108 2.OM 3673 3.OM 8928 4.OM 7L 5. OM 10097-2
	Year 2014						
10	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Xẻo Trăm, Hòa An, Phụng Hiệp, Hậu Giang	27 March 2014	1	25	21	4	Selected some new varieties: 1.OM 3673 2.TLR 397 4.OM 4488 5.OM 6161 & OM 6677
11	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Ấp 3, Vị Đông, Vị Thủy, Hậu Giang & TP. Vị Thanh, Hậu Giang	5 March 2014	1	39	31	8	A hands-on training in phenotype for selected new varieties Good land preparation and land leveling Fertiliser application and soil improvement Pest control (IPM) Selected some new varieties:

							Vị Thủy: 1.OM 8108 2.OM4488 3.OM 10041 4.OM 7347 5.OM 8928 & OM 3673 Vị Thanh: 1.OM 4488 2.TLR 437 3.OM 10418 4.OM 6691 5.OM 10174 & TLR 378
12	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Ấp 3, Vị Đông, Vị Thủy, Hậu Giang	3 June 2014	1	27	21	6	Selected some new varieties: 1.OM 3673 2.OM 10097-2 3.OM 8928 & OM 8108 4. OM 10179 & OM 4488
	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Ấp 3, Vị Đông, Vị Thủy, Hậu Giang	12 September 2014		40	29	11	OM 6L OM 8108
	Training Workshop in Participatory Varietal Selection (PVS) for Enhanced Varietal Development Ấp 3, Vị Đông, Vị Thủy, Hậu Giang	1 January 2015		39	32	7	OM 4900 OM 6L OM 3673
	Total			528	394	134	

Australian Government

Australian Centre for International Agricultural Research

Final report

project	**Climate Change Affecting Land Use in the Mekong Delta: Adaptation of Rice-based Cropping Systems (CLUES)** Theme 1: Location-specific impact and vulnerability assessment
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date published	
prepared by	Mr. Nguyen Xuan Hien and Theme 1 team: SIWRP: T.Q.Tho, N.H. Khoi, N.V.Ngoc, T.D. Dong IRRI: Dr.N.D. Phong CTU: CTU: Dr. V.Q. Minh, N.T.H. Mi, P.K. Diem
co-authors/ contributors/ collaborators	Dr. Reiner Wassmann (IRRI) Dr. Chu Thai Hoanh (IMMI) Dr. To Phuc Tuong (IRRI)
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1 Contents

Abbreviations

BDP	Basin Development Plan Programme
CC	Climate change
CTU	Can Tho University
GIS	Geographic information system
MRD	The Mekong River Delta
MR	The Mekong River
MRC	The Mekong River Commission
MONRE	Ministry of Natural Resources and Environment
QLPH	Quan Lo –PhungHiep
SLR	Sea level rise
Sub-NIAPP	Sub-National Institute of Agricultural Planning and Projection
SIWRP	Southern Institute for Water Resources Planning
UD	Upstream development
VRSAP	Vietnam River Systems and Plains

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2 Acknowledgment

The study is carried out under the CLUES project entitled “Climate change affecting land use in the Mekong delta: Adaptation of rice base cropping systems” has been funded by ACIAR (Australian Center for International Agricultural Research) from March 2011 to June 2015.

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We appreciate SIWRP, the collaboration of CTU and the support of the CLUES Project Office for our work during the project.

3 Executive summary

The Mekong River Delta (MRD) is the most important area of farming rice in the whole country. In recent years, MRD annual production of 20 million tones of paddy to provide for Vietnam over 50% of the total rice production, 90% of rice exports, about 65% of fish, 60% of fruit, along with many other agricultural products. It is easy to see that the agriculture of the Vietnamese Mekong Delta (VMD) is production-oriented for markets and export; with three main products are rice, followed by fish and fruit. The MRD is a fertile vast flat plain with favorable natural conditions for agricultural development. This area had been soon exploited and cultivated from the 18th century and only produced the rice monoculture during a very long period. Land is cultivated with large scale since the late 19th century.

Currently, the rice production in MRD still depends too much on natural conditions. Especially, water resource is an important factor in the stability and development of rice production. MRD has major advantages in water resources. On the other hand, MRD is dominated by saline intrusion, flooding, and water resources management of the upstream countries. In recent years, hydropower development and climate change struggle are one of the priority issues in the study of MRD.

The deltaic formation is a low flat landscape with elevation in range of 0–3 meters. The Mekong River (MR) and its tributaries are important to rice production in Vietnam. The MRD, popularly known as the "Rice Bowl" of Vietnam, which contains about 17 million people and 80% of them are engaged in rice cultivation. The delta produced about 20 million tons of rice production in 2008, about a half of the country's total production. The MRD has assured food security to its population whose 75% of daily meals are rice. The low terrain compared sea level, located in downstream of MekongRiver and be contiguous with sea; therefore Mekong River ought to face many challenges, especially it is affect of Climate Change (Duong Ngoc Chinh, 2009). According to forecasts by international organizations and scientists, the Mekong Delta will be negative affect of climate change and rising seawater level. In recent years, the coastal provinces of the Mekong Delta face to face continuous with saltwater that instruded to mainland in the dry season and flooding in rainy season. The main reason could be the impact of climate change.

Based on the review of the done and on-going researches, the measurement data, and the use of mathematical models, remote sensing, and geographic information system (GIS), major tasks set for Theme 1 are as follows:

This study helps to identify some ideas for a strategy of water resources exploitation and management in MRD, including:

The overall picture of flow variation in the main river and in MRD under conditions of climate change and sea level rise as well as the impact of upstream development in both the future and present offers the planning and managers sharper “insights” into building economic development strategy for MRD.

Assessment the hot spots and rice affected areas under the impact of climate change in Mekong Delta .The study was realized to assess the effect due to salinity and flooding in the Mekong Delta and four provinces: An Giang, HauGiang, Can Tho, and Bac Lieu.

Key words: Mekong River Delta, climate change, flooding, rice production, saline intrusion

4 Background

In MRD, areas affected by flooding and saline intrusion varied in years depending on the regime of Sea Water Level Rise (SLR), upstream flow of Mekong River and rainfall which has been affected by Climate Change (CC). To understand these environmental effects on submerged and saline affected areas, this study has been conducted to assess flooding and saline intrusion in MRD of Vietnam during both dry and wet seasons in different hydrological years of low, average and high water years. As a result, possible threats for future rice production within the region will be identified. The assessment of the impact of climate change on the land use under difference saline intrusion, flooding scenario to rice cropping to assist the managers having a comprehensive view and more specifically of land use planning under the impact of climate change in the future thereby giving responses to protect agricultural sustainability and for food security and livelihoods. The study was realized to assess the effect due to salinity and flooding in the Mekong Delta and four provinces: An Giang, HauGiang, Can Tho, and Bac Lieu.

Rationale for building scenarios:

In this study we used projected climate data from SEA-START (based on PRECIS with A2/B2), from 2010 -2100. However, those data have no bias correction.

The MRC did bias correction for upstream (up to Kratie) and computed river discharge und CC scenarios; this data was used on the BDP2 project (MRC, 2010).

For the Mekong Delta, Theme 1 (CLUES) built bias correction for rainfall data for every year until 2050.

In the next step, we identified ‘representative’ years for time windows, namely dry, normal and wet year in the duration 2030-window (2020-2035) and 2050-window (2036-2050).

River discharge were computed for those selected years with a specific SLR for a given time window (17cm for 2030-window and 30 cm for 2050-window based on the MONRE's scenarios SLR in the years of 2030 and 2050, respectively, with specific values for East and West Sea (MONRE, 2011).

All computations were at 3 different representative years of respective time window. Total 27 scenarios were simulated and assessment.

Flood scenarios were computed from July to December, while salinity scenarios were computed from January to June for the entire MRD.

5 Objectives

This Theme provides maps of salinity isohalines and submergence or flood depth as fundamental information to other Themes for their study in regions with different hydrological condition.

The general objectives of this geo-spatial component is to analyse flooding and salinity risks under different sea-level scenarios and their implications for different land use options backed up by considering direct climate impacts. All study in this theme is included 5 objectives as follow:

Objective 1.1. Literature review and meta-analysis of available data and documents on CC projections for MRD to identify potential production constraints for future production;

Objective 1.2. Assessing hydrological impacts of different sea level rise scenarios in MRD Region (hydraulic modelling);

Objective 1.3. GIS mapping of flooding depth and salinity levels within the MRD as a function of sea-level rise and envisaged upstream development projects for different land use options;

Objective 1.4. Comparative assessment of climate change impacts on rice production in the 4 target areas (An Giang, Can Tho, HoaAn, and Bac Lieu);

Objective 1.5. Mapping (delta-wide) of vulnerability and potential “hot-spot” of flooding and salinity damage.

6 Methodology

The methods applied in this study include:

- Data collection and synthesis;
- Modeling and simulation method (mathematical models, statistics, forecast) to study water balance and assessment of hydrological and hydraulic changes.
- Applying remote sensing, GIS, and software of database management to systematize and map computed results.

Implementation methods are described inthe following diagram:

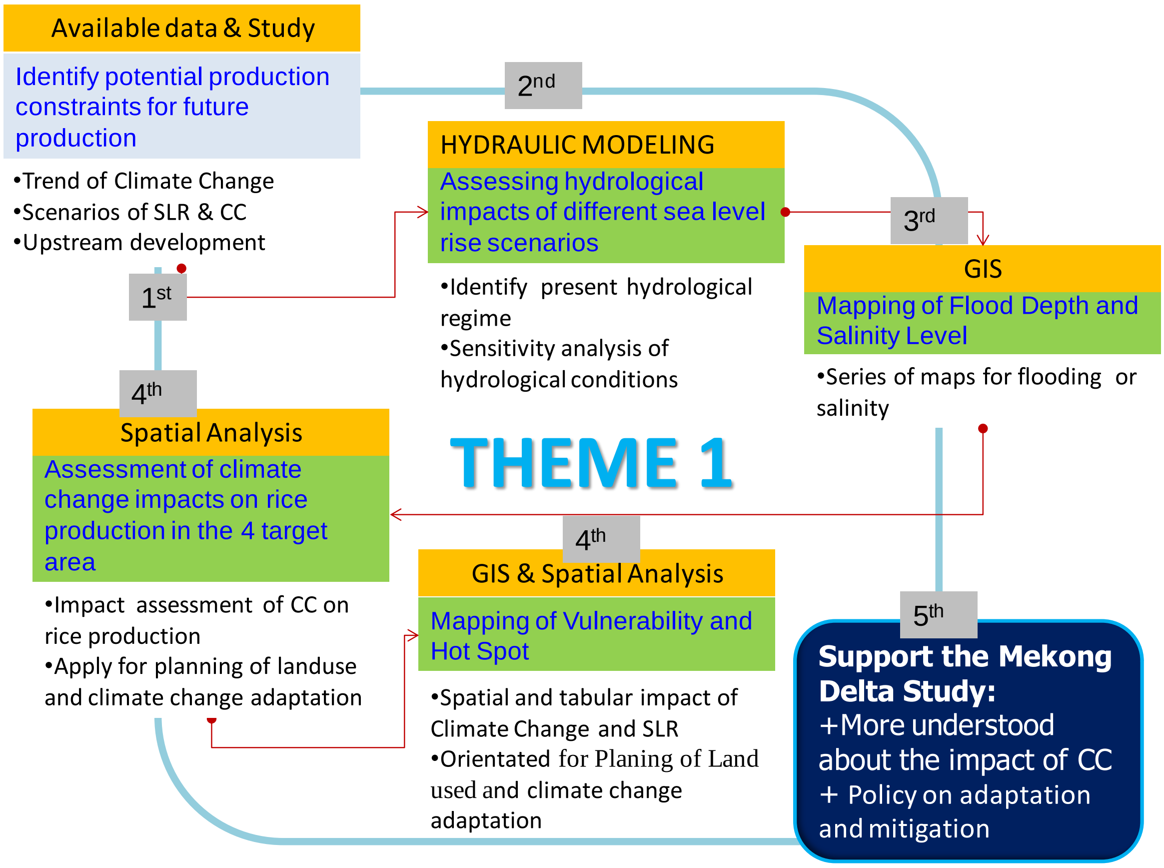


Figure 1. Diagram of implementation methods

6.1 Literature review and proposing scenarios

The Objective identifies constraints for future production under effect of climate change (CC) & sea level rise (SLR), and Upstream Development for Selected scenario of Study.

The review covers the studies on effects of upstream development, sea level rise (SLR) and climate change (CC) on the hydrology of the lower Mekong River. During the review, agricultural and water resource plans for MRD under climate change was also summarized by SIWRP team.

Study by SEA START on downscaling weather data (temperature and rainfall) in the MRD was also reviewed by CTU group of Theme 1. A Review on the climate change projections in the MRD was based on data 1980 - 1990 and projected 2010s – 2050s.

However, the report has not taken into account the bias in simulation of observed climate and in projection of future climate. For example, compared with observed and simulated rainfall at Can Tho station in 1980-2004. The simulated rainfall of SEA START downscaled by using PRECIS model is rather low but number of rainy days is larger.

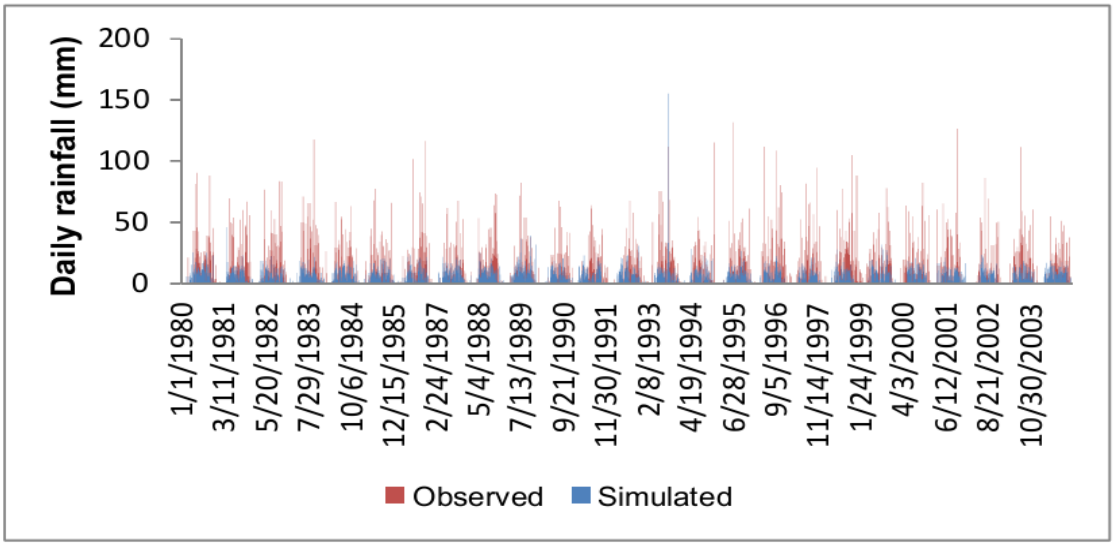
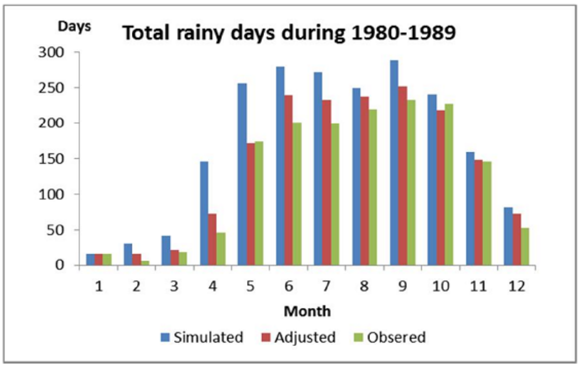
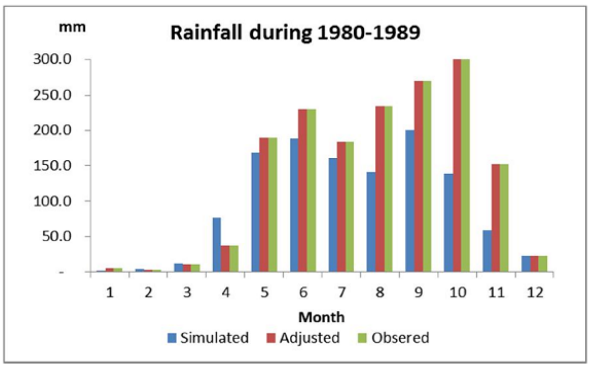


Figure 2. Observed and simulated rainfall at Can Tho station in 1980-2004

Therefore bias correction has to be done before using the PRECIS for downscaling climate change data provided by SEA-START for hydraulic and salinity modelling.

The team reviewed many bias correction methods from the literature to develop the suitable methods for bias correction. The applied method includes the incorporation of artificial neural network (ANN) concept with the cumulative distribution function (CDF) to analyse and adjust the rainfall frequency (rainy days) and intensity (rainfall) to match seasonal variations of simulated data with observed data. Figure 3 and Figure 4 present the bias correction for 3 periods of 10 year each: training period 1980-1989, testing period 1990-1999 and applying period 2030-2039 for Can Tho station. The same method is applied for other stations in the Mekong Delta of Cambodia and Vietnam where rainfall data are used for hydrological modelling.





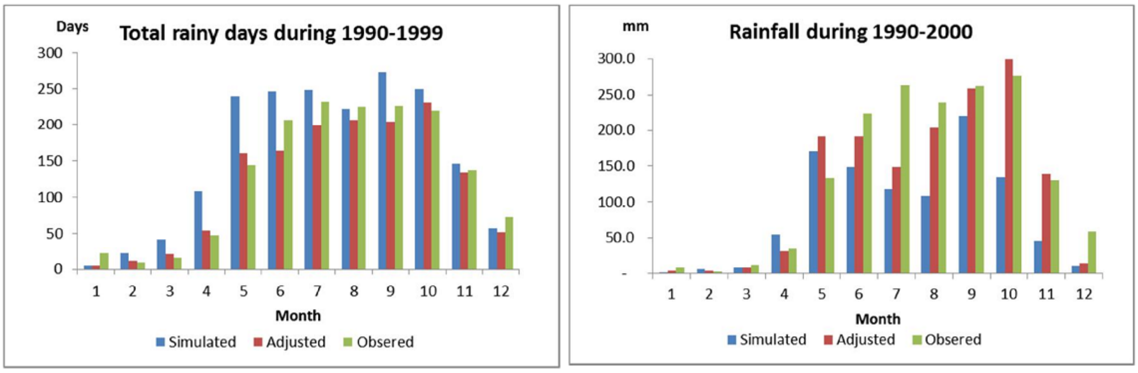


Figure 3. Observed and preliminary adjusted rainfall at Can Tho station in 1980-2004

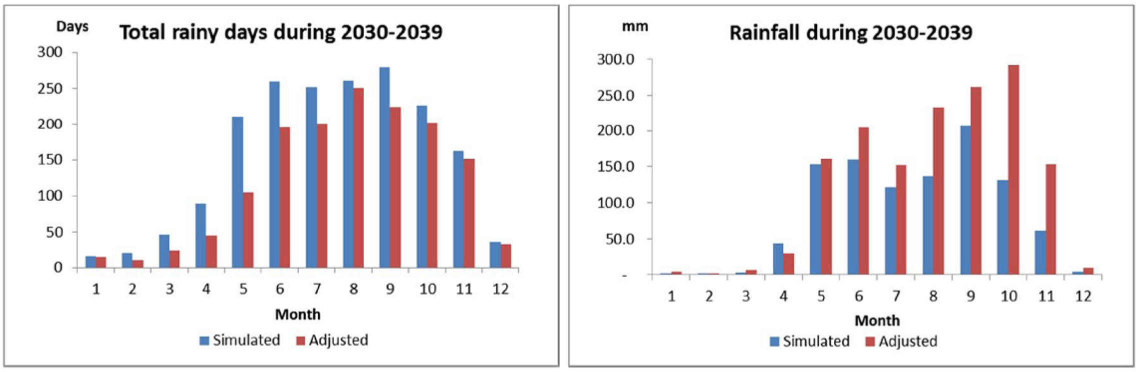


Figure 4.Preliminary adjusted rainfall at Can Tho station in 2030-2039

6.2 Hydraulic modeling

The “Vietnam River Systems and Plains” (VRSAP) model is a hydraulic model to simulate mainly one-dimensional hydrodynamic river flow or quasi two-dimensional flow on floodplains. Applying an implicit finite difference scheme for solving one-dimensional Saint-Venant equations, VRSAP is able to simulate water flow in complex branched and looped river networks. It is also designed to simulate dissolved or suspended particulates in water (e.g. salinity, acidity etc) using the scheme of implicit finite difference for the advection-dispersion equation.

Updated data on hydrology, topography and infrastructure system data for baseline year 2008 have been collected. A field survey for checking existing data of the land use, sluice operation and other infrastructure was organized and data were incorporated into the model schemes. Data in 2008 will be used for model verification.

Detail mathematical schemes have been constructed for MRD with the updated data on rivers and sluices systems in 2008. The scheme of this model is included 3,486 nodes; 5,611 segments and 2,666 plains. The total area simulated on this model is about 5,5 million ha.

The model has simulated 27 scenarios which combine many factors of SLR, CC, Upstream Development and Landuse Plan in Mekong Delta.

The scenarios outputs was used the GIS software to presented the flooding map and salinity maps in raster format.

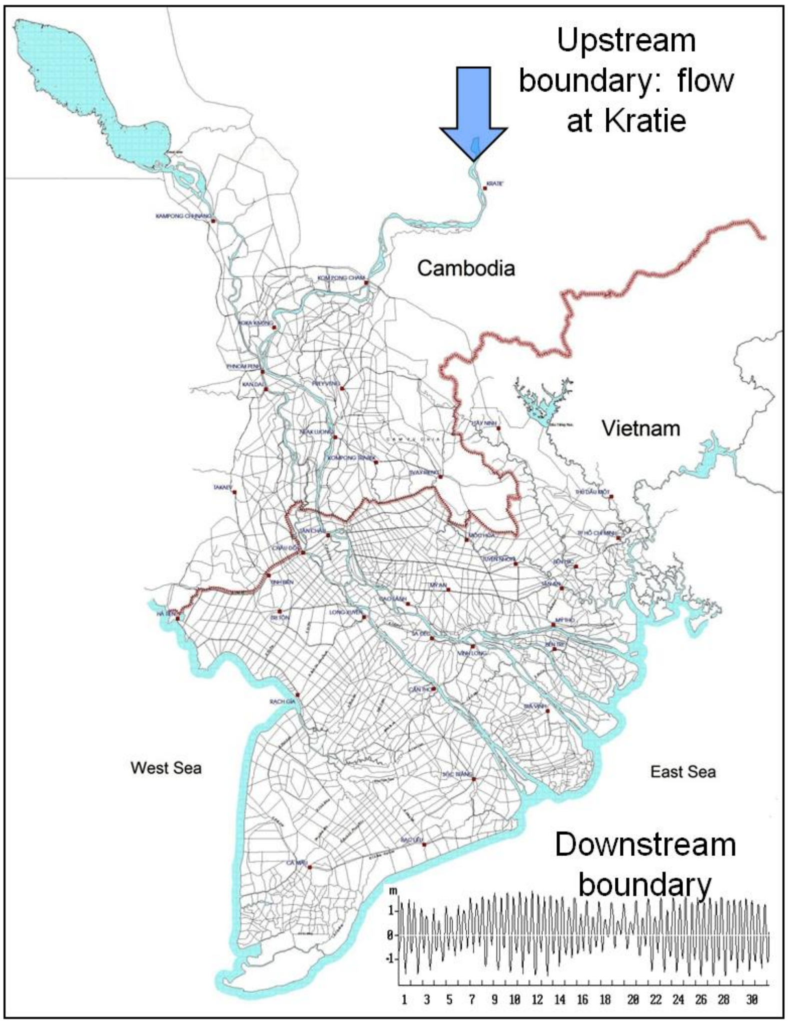


Figure 5. Mathematical scheme of VRSAP

6.3 GIS and Spatial analysis

6.3.1 Processing satellite image

MODIS image from January 2000 to May 2013 and relevant LANDSAT image were collected.

Initial maps of rice crop pattern at 4 target areas (An Giang, Can Tho, HoaAn, and Bac Lieu) were built.

6.3.2 Field survey for validation

Field survey for validation the results of images classification was done in Febuary 2014. Finalizing the rice cropping pattern map from 2000 to 2013 in the 4 target areas (An Giang, Can Tho, Hoa An, and Bac Lieu) was finished.

6.3.3 Spatial Analysis

The flooding and salinity maps included: Risk map and Variation Maps in raster format was converted to vector to overlay with land use map and administrative boundaries of MRD.

The salinity and flooding data in vector format divided into three levels: high, medium and low, which were used to delineate the hot spot of on difference land uses according to scenarios.

The ArcGIS software was used to manipulate maps of salinity, flooding, the current land use, administrative, etc to assess the effects of salinity and flooding on the status of land use, compared climate change scenarios for the current year 1998, 2000 and 2004.

6.4 Criteria for hot spot delineation

6.4.1 Flood level

Rice can grow in flooded conditions but if flooding excess 2/3 the plant height for long duration, the rice growing can be affected. In the Mekong Delta, flooding season coincides at the end of the rainy season. It can combines with heavy rainy and high tidal effect to cause damage to rice cultivation of farmers. According to Nguyen Ngoc De (2009) for the short duration high-yielding rice in Vietnam, depending on the rice growing stage and dates of flooding entirely, the impact may vary. The percentage of rice survived in the fields affected by flooding belongs to the number of flooding days. These affected thresholds for flood are used on this study in below:

Time when flooding appears: is identified as water level in canal is at 0.4 m higher than the level of the field in the period from 7 to 15 consecutive days.

Time when flooding ends: is defined as water level in canal is +0.2 m lower than the field level.

Flooding duration: Time when flooding appears – Time when flooding ends.

6.4.2 Salinity level

In coastal fields, the average yield in the saline effected area can get approximately 2 tonnes/ha if apply salt-tolerant varieties. With experience in many fields, salt-tolerant limit of rice depends on the variety, level ad duration of salinity. The risk period for rice due to salinity is from flowering to grain filling stages, the loss of rice productivity can be up to 70-80%. When the salt concentration in the saline water up to 4 ‰ and prolonged continuously for a week, it can damage to most of the varieties are susceptible to salinity. On other hand, some salt-tolerant rice varieties can recover but the yield may decrease to 20 -50%, depending on the growing stage. When the concentration of salt in the water is more 6 ‰ and extends in a week, most of the rice fields would be a total loss. In this study the canal salinity level of 2g/l is set as the threshold of salinity that can affect to rice cultivation.

Time when salinity appears: Date commenced salinity is identified as salinity of more than 2 g/L in canal is lasting at least 7 days in the period of 15 days.

Time when salinity ends: Date on when salinity in canal is less than 2 g/l.

Salinity duration: Time when salinity appears – Time when salinity ends.

6.4.3 Potential to gravity Irrigation

The area is capable of brackish water supply by gravity: Condition: maximum daily water level in canal is over 0.25 m higher than the level of the field and on the same day, maximum salinity in canal is more than 6 g/L. The area meets the above condition at least 7 days in February which is the period which have the water demand highest is considered as the area of potential brackish water supply by gravity.

The area is capable of gravity freshwater supply: Condition: maximum daily water level in canal is over 0.25 m higher than the level of the field and on the same day, maximum salinity in canal is less than 2 g/l. The area meets the above condition at least 7 days in February is considered as the area of potential freshwater supply by gravity.

7 Achievements against activities and outputs/milestones

Summary achievements against activities

2011-2012	2012-2013	2013-2014	2014-2015
1.Identify CC& SLR, UD for Selected scenario of Study	1. Understood the Baseline hydraulic regime of MRD in difference hydrological 2. The effects of CC,SLR, UD to MRD's hydraulic	1. Mapping the stress of Salinity and Inundation depth to MRD. 2. Spatial Analysis for assessment the effects of CC,SLR and UD to rice production 3. Find out "Hot spot" and Vulnerability to Agriculture cultivation in Mekong Delta	1. Implementation Workshop constructive contribution to climate change adaptation strategies 2. Publication, Reports

Objective 1.1. Literature review and meta-analysis of available data and documents on climate change projections for MRD to identify potential production constraints for future production

NO	Activity	Outputs /Milestones	Completion date
1.1.1	Review existing and ongoing studies on climate change projection for MKR, especially upstream boundary and SLR	Collecting and reviewing studies in MRD region (SIWRP)	02/2012
1.1.2	Review projected data (temperature and precipitation) of the Mekong Delta based on projected data of PRECIS	Projection Data	02/2013
1.1.3	Adjust projected data from Regional Climate Model for hydraulic calculation	Adjusted data	02/2013

Objective 1.2: Assessing hydrological impacts of different sea level rise scenarios in MRD Region (hydraulic modelling)

NO	Activities	Outputs	Milestones
1.2.1	Collecting and processing hydro-meteorological data, sluice operation schedule and land use (for water demand computation) for baseline year 2008 and for three years of 1998 (dry year), 2004 (normal year), 2000 (wet year))	Data collection in 1998, 2004, 2000	Completed 02/2012
1.2.2	Field surveys for checking existing data of the land use, sluice operation and other infrastructure		Completed 01/2012
1.2.3	Establishing projected scenarios, based on SLR scenarios of MONRE of Vietnam.	Set of projected scenarios for SLR	Finished 08 /2011
1.2.4	Simulating salinity and flooding depth for projected scenarios for recent year 2008 with current land use and sluice operation. Analyzing results of simulation, and writing report	Result maps of salinity and flooding	Finished 02/2012
1.2.5	Simulating salinity and flooding depth for projected scenarios for normal, wet and dry years with current land use and sluice operation. Analyzing results of simulation, and writing report	Result maps of salinity and flooding	Finished 4/2013

For simulating salinity and flooding depth for projected scenarios in normal, wet and dry years with current landuse and sluice operation in objectives 1.2.4 and 1.2.5, we had proposed the projected scenarios based on sea level rise scenarios (Ministry of Natural Resources and Environment (MONRE) of Vietnam, 2011), climate change and upstream development. These factors are selected and combined into 15 scenarios for impact analysis presented in

Table 1.

Group A are scenarios that only include present conditions of the above factors (upstream development, SLR and current CC), group B includes the change of SLRs in 2030 and 2050, and group C includes the impact of SLRs and CC in 2030 and 2050.

Table 1.The scenarios for impact the SLR and CC

	Upstream Development		Hydrological Year			SLR			Landuse options		Climate	
						Pre	2030	2050				
Scenarios	U0	U1	LF	HF	AF	0	15	30	2008	2020	Pre	B2
GROUPA	*Baseline conditions*											
Low	x		x			x			x		x	
Average	x			x		x			x		x	
High	x				x	x			x		x	
GROUPB	*Access the Impact of SLR*											
Period 2030s												
Low	x		x				x		x		x	
Average	x			x			x		x		x	
High	x				x		x		x		x	
Period 2050s												
Low	x		x					x	x		x	
Average	x			x				x	x		x	
High	x				x			x	x		x	
GROUP C	*Access the Impact of SLR+CC*											
Period 2030s												
Low	x		x				x		x			x
Average	x			x			x		x			x
High	x				x		x		x			x
Period 2050s												
Low	x		x					x	x			x
Average	x			x				x	x			x
High	x				x			x	x			x

Notes:

U0: the upstream water resource developmentis at present period

U1: the operation of upstream water resource system affects positive affects to downstream of the Mekong River

Pre: At Present situation

B2: Climate change scenarios with assumption of normal emission of landuse

Objective 1.3. GIS mapping of flooding depth and salinity levels within the MRD as a function of sea-level rise and envisaged upstream development projects for different land use options

Activities	Outputs	Completed
Applying VRSAP model for different land use options for dry year (1998), normal year (2004) and wet year (2000) at different SLRs and upstream development. Analysing results of simulation, and writing report	Result maps of salinity and flooding	12/2013

To clarify the effect of saline intrusion and flooding regime in the term of Planning of Landuse in 2020 and Upstream Development, we simulated the 12 scenarios of SLR and CC effects in 2020 landuse and upstream development up to period 2050s (The upstream development scenarios was based on BDP2 results(MRC, 2010)).

The 12 scenarios for evaluation of the effect of upstream development and change of landuse under the impact of both CC and SLR are included in **Table 2**. Scenario of landuse change in the MRD has been based on the land use planning for 2020 (Sub NIAPP, 2014).

Table 2. Scenarios for evaluation of the effect of upstream development and change of landuse under the impact of both CC and SLR

Scenarios	Upstream Development		Hydrological Year			SLR			Landuse options		Climate	
						Pre	2030	2050				
	U0	U1	LF	HF	AF	0	15	30	2008	2020	Pre	B2
GROUP D	*Access the Impact of SLR+CC + Landuse 2020*											
Period 2030s												
Low	x		x				x			x	x	
Average	x			x			x			x	x	
High	x				x		x			x	x	
Period 2050s												
Low	x		x					x		x	x	
Average	x			x				x		x	x	
High	x				x			x		x	x	
GROUP E	*Access the Impact of SLR+CC + Landuse 2020+ Upstream Development*											
Period 2030s												
Low		x	x				x			x		x
Average		x		x			x			x		x
High		x			x		x			x		x
Period 2050s												
Low		x	x					x		x		x
Average		x		x				x		x		x
High		x			x			x		x		x

Objective 1.4. Comparative assessment of climate change impacts on rice production in the 4 target areas (An Giang, Can Tho, Hoa An, and Bac Lieu)

- Literature review and meta-analysis of available data and documents on rice production were collected in the 4 target areas (An Giang, Can Tho, HoaAn, and Bac Lieu).
- Processing satellite images:
  - MODISimage from January 2000 to May 2013 and relevant LANDSAT image were collected.
  - Initial rice cropping pattern maps in the 4 target areas (An Giang, Can Tho, HoaAn, and Bac Lieu) were built.
- Field survey for validation
  - Field survey for validation the results of images classification was done in Febuary 2014. We are doing accuracy assessment and finalizing the rice cropping pattern map from 2000 to 2013 in the 4 target areas (An Giang, Can Tho, Hoa An, and Bac Lieu)

No.	Activity	Outputs/ milestones	Completion date
1.4.1	Finding out the trend of yield, productivity and areas changing from 2000 to 2010	Report	March 2014
1.4.2	Developing rice cropping pattern maps	Series of result map	March 2014
1.4.3	Overlay rice cultivation map of each province with different sea level rise, depth and salinity scenarios to find out the effect of climate change on rice production in 4 target areas	Completed	4/2014

1.4.4	Field survey for checking the specific threats in the 4 target areas	Completed	5/2014
1.4.5	Assessment common and specific threats at each target areas	Completed	6/2014

PC = partner country, A = Australia

Objective 1.5. Mapping (delta-wide) of vulnerability and potential "hot-spot" of flooding and salinity damage

No.	Activity	Outputs/ milestones	Completion date
1.5.1	Collecting satellite image (MODIS image from 2000 to 2010)	Set of 1082 MODIS image	2/2013
1.5.2	Developing set of NDVI map from 2000 to 2010 Initial rice sowing map in Mekong Delta	Set of 920 NDVI map	4/2013
1.5.3	Investigate the current land use and rice cropping pattern in Mekong Delta.	List of data for validation	1/2014
1.5.4	Map of present land use and rice cropping pattern in Mekong Delta	Completed	1/2014
1.5.5	Overlay current land use map of MRD with different sea level rise, depth and salinity scenarios	Completed	4/2013
1.5.6	Mapping of vulnerability and potential "hot-spot" according to different scenarios.	Completed	5-6/2014

8 Key results and discussion

8.1 Hydrology and cropping systems of MRD

8.1.1 Characterises of hydrological in Mekong Delta on present situation

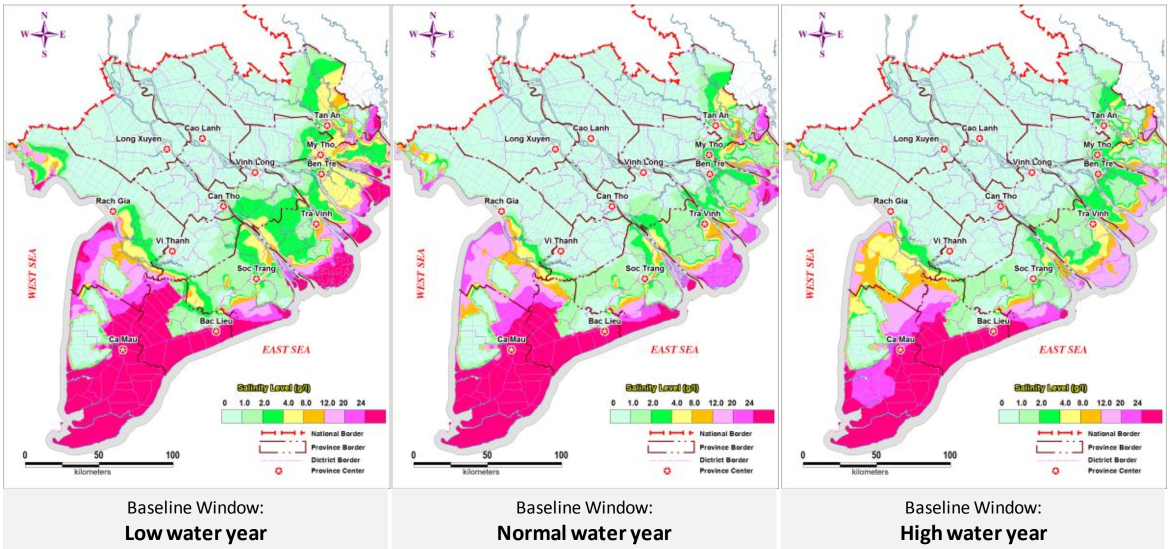


Figure 6. Maximum salinity in the dry season without SLR in the years of low water (1998), average water (2004) and high water (2000)

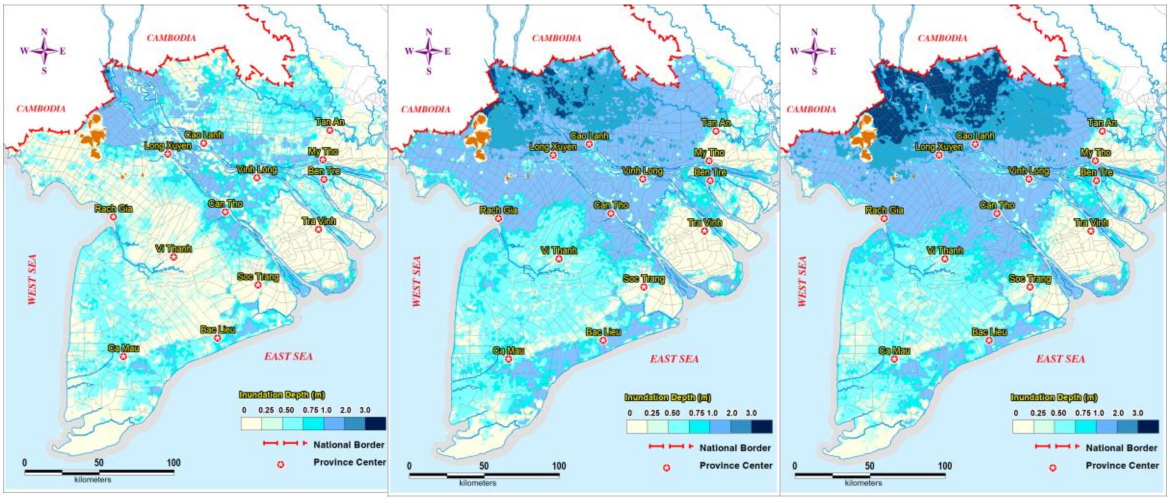


Figure 7. Maximum inundation depth (maximum water level – average level of ground surface) in rainy season without SLR in the years of low water (1998), average water (2004) and high water (2000)

In summary, there are the differences between simulated salinity intrusion in the mainstream and the areas with/without salinity control systems for both 3 years of low, average and high water (Figure 6). In areas that have salinity control system such as Quan Lo – PhungHiep (QLPH), Lower U Minh, South MangThit, and Go Cong, the change of salinity intrusion is generally insignificant. In the normal year, the saline affected area is about 33% corresponding with 1.3 million ha. In dry water year the saline affected area reach by 1.5 milion ha and in high water year is about 1,2 milion ha.

The maximum depth of inundation increases in year of high water and lowers in low water year due to the change of upstream discharge of Mekong River (Figure 7). Overflow along frontier of Vietnam- Campuchia is a source to cause flooding for MRD. In flooding season, most of areas near the National border of Vietnam and Campuchia that belong to Plain of Reeds, Long Xuyen quadrangle, Western side of Bassac River and Nothern part of Mang Thit River in CIS Bassac are inundated with average flooding depth from 0.5-2.5 m. In years with high flood, the flooded area could expand larger downstream from the National border to the East Sea and maximum flooded depth could be to 3.5 m in year 2000.

The flood is the most significant with severe inundation depth in the flood area of the MD (near the border of Campuchia). The coastal area such as Camau peninsular was trivially affected by flow of Mekong River, but it was mainly affected by tidal regime, local rain and existing drainage system. The variation beetween hydraulic year is more signical than affected by saline water: In the normal year, the affected area is about 50% corresponding with 2.0 million ha, In high water year the affected area can up to 2,8mil ha (66%) but in 1998 the area affected only 1,4 milion ha (34%).

However, there are some areas that have not been affected by any flood from the East Sea side to: CIS Bassac to Mang Thit River, Tan An, My Tho, Ben Tre, Soc Trang and upper part of QLPH in the North of National Road 1A

8.1.2 Characterizes of rice cultivate in Mekong Delta

VMD has 13 provinces with about 4 million hectares where the economy is characterized by the production of agriculture, in which rice production is dominat and its area is growing very fast (See Table 3 and Figure 8).

The production and yield of paddy continuously increased in the MRD in recent decades is due to several factors, such as the application of short-term high-yield rice varieties, improvement of cultivation techniques and the most important factor of the water resources development that has solved the problems of irrigation, drainage, saltwater intrusion, flood control and reclamation of acidity land.

Table 3.Change of rice production from 1937-2012

Year	1937	1975	1985	1990	1995	2000	2005	2010	2012
Production of Paddy (10^3ton)	2,700	4,600	7,600	9,500	12,832	16,703	19,299	21,596	24,293
Rice crop area (10^3ha)	2,200	2,300	2,714	2,969	3,191	3,946	3,826	3,946	4,181

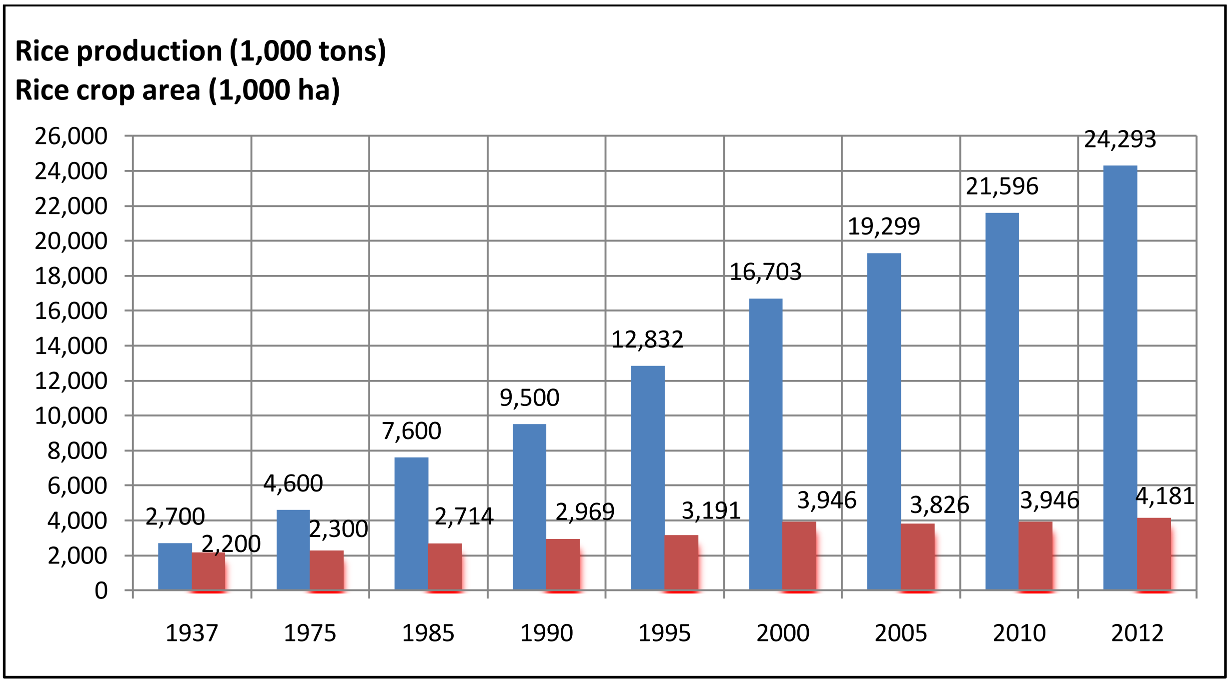


Figure 8. The change of rice production from 1975-2012 (Source: GSO, 2013)

In the MRD, the natural conditions in each ecosystem are differences, depending on the favourable of soil, hydrological conditions, and rice varieties, the rice cropping systems and cropping seasons in each area are difference and very complex. According to the results of interpretation and field surveying from 2000 to 2013, the rice cropping calendar in the MRD can divided into some main groups as follow (Figure 9):

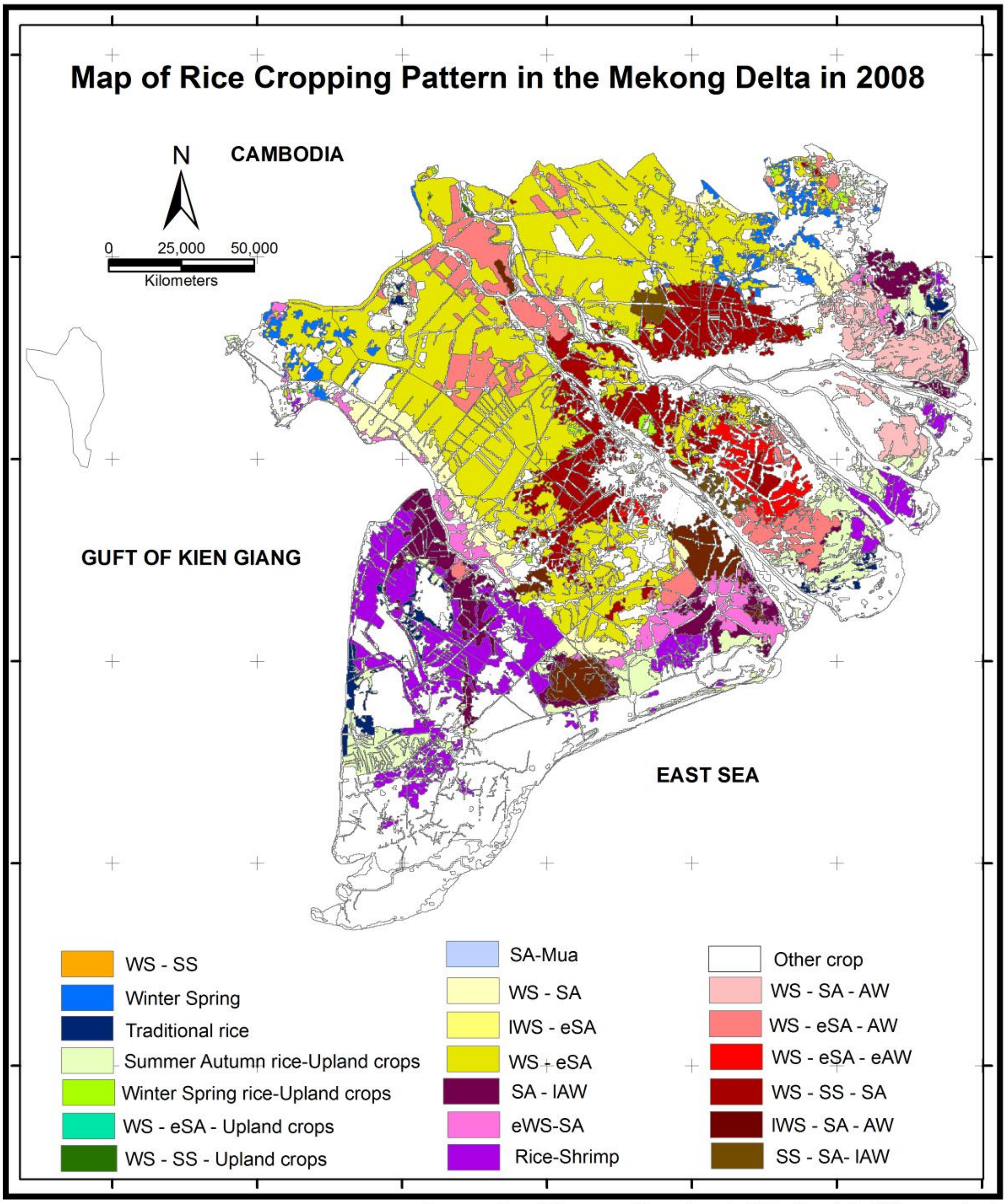
- Mono rice crop: traditional or Winter-Spring rice crop
- Double rice crops: Winter Spring-Summer Autumn, Winter Spring-Early Summer Autumn, Late Winter Spring-Early Summer Autumn, Early Winter Spring- Summer Autumn, Summer Autumn-Winter, Summer Autumn-Autumn Winter.
- Tripple rice crops: Winter Spring-Early Summer Autumn- Autumn Winter, Winter Spring-Early Summer Autumn- Early Autumn Winter, Winter Spring-Summer Autumn- Autumn Winter, Late Winter Spring- Summer Autumn-Autumn Winter, Winter Spring- Summer Autumn- Late Autumn Winter, Winter Spring-Spring Summer-Summer Autumn
- Rice-Upland crops: Winter Spring-Upland crop, Summer Autumn-Upland crop.
- Shrimp-Rice: Shrimp-Winter Rice season, Shrimp- Rice Autumn Winter
- Others: Mixed of Uplands crops, sugarcane, Pineapple, Build up areas, shrimp.

The trend of cropping structure in the area of rice cultivation: The analysis of MODIS remote sensing image from 2000 to 2013 shows that the area of mono rice crop and double rice crops tend to decrease while that of triple rice crops and shrimp-rice tend to increase.

Table 4. Cropping systems analysed by MODIS remote sensing image

Cropping systems	2000	2005	2010	2000	2005	2010
	Area('000Ha)			Percentage (%)		
Single rice	337	97	68	16%	5%	3%
Double rice	1378	1133	1120	64%	56%	52%
Triple rice	433	650	731	20%	32%	34%
Shrimp-Rice	14	145	225	1%	7%	10%
Total	2162	2025	2144	100%	100%	100%

Due to depending on natural factors, the rice cropping calendar in the areas dominated by salinity and flooding is markedly different [see Figure 10]. Generally, the difference between cultivation periods of a crop of the areas is from 2 to 4 weeks.



Source: Land Resource Department, Objective 1.5 of Clues project

Figure 9. Map of Rice cropping pattern in the Mekong Delta in 2008

*Note: **WS-SS:** Winter Spring- Spring Summer;**WS-SA:** Winter Spring-Summer Autumn ;**WS-eSA:** Winter Spring-Early Summer Autumn;**IWS-eSA:** Late Winter Spring -Early Summer Autumn; **eWS-SA:** Early Winter Spring-Summer Autumn ;**SA-Mua:** Summer Autumn–Mua ;**SA-IAW:** Summer Autumn-Late Autumn Winter ;**WS-eSA-AW:** Winter Spring-Early Summer Autumn-Autumn Winter; **WS-eSA-eAW:** Winter Spring-Early Summer Autumn–Early Autumn Winter ;**WS-SA-AW:** Winter Spring-Summer Autumn-Autumn Winter; **IWS-SA-AW:** Late Winter Spring-Summer Autumn-Autumn Winter; **WS-SS-SA:** Winter Spring-Spring Summer–Summer Autumn; **SS-SA-IAW:** Spring Summer-Summer Autumn–late Autumn Winter ; **WS-eSA-Upland crop:** Winter Spring-Early Summer Autumn- Upland crop;**WS-SS- Upland crop:** Winter Spring-Spring Summer - Upland crop*

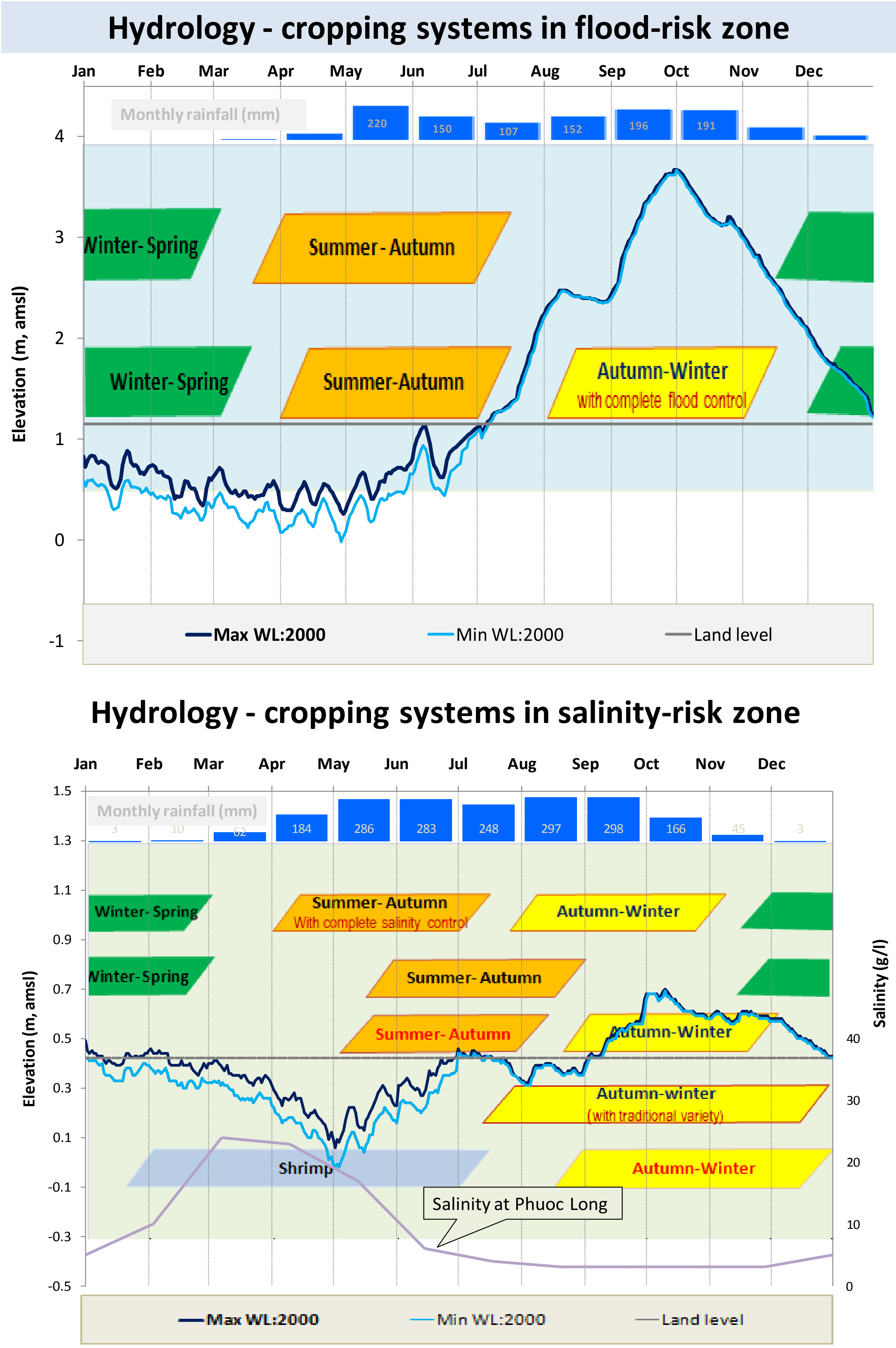


Figure 10. Hydrology - cropping system in Flood risk and Salinity risk

8.2 The impact of SLRs on salinity and submergence in the MRD

8.2.1 In rainy season

In general, the increase of maximum inundation in the MRD is consistent with SLR (Figure 11). The effect of SLR is most significant in coastal areas but decreases significantly in areas upstream Mekong River.

In the areas along East Sea which have good irrigation system such as Go Cong, Ben Tre, South MangThit and TiepNhat, the effect of SLR on maximum inundation is insignificant. This is because the sluice system is functional well and minimum tidal water level is fairly lower than the elevation level of ground surface. Therefore, drainage ability is still good.

In the areas along the West Sea, the usual high tidal water level foots incorporated with SLR affect heavily on drainage ability in these areas.Drainage is more difficult since tidal water level is usually higher than ground surface and the SLR is higher than that of the East Sea.

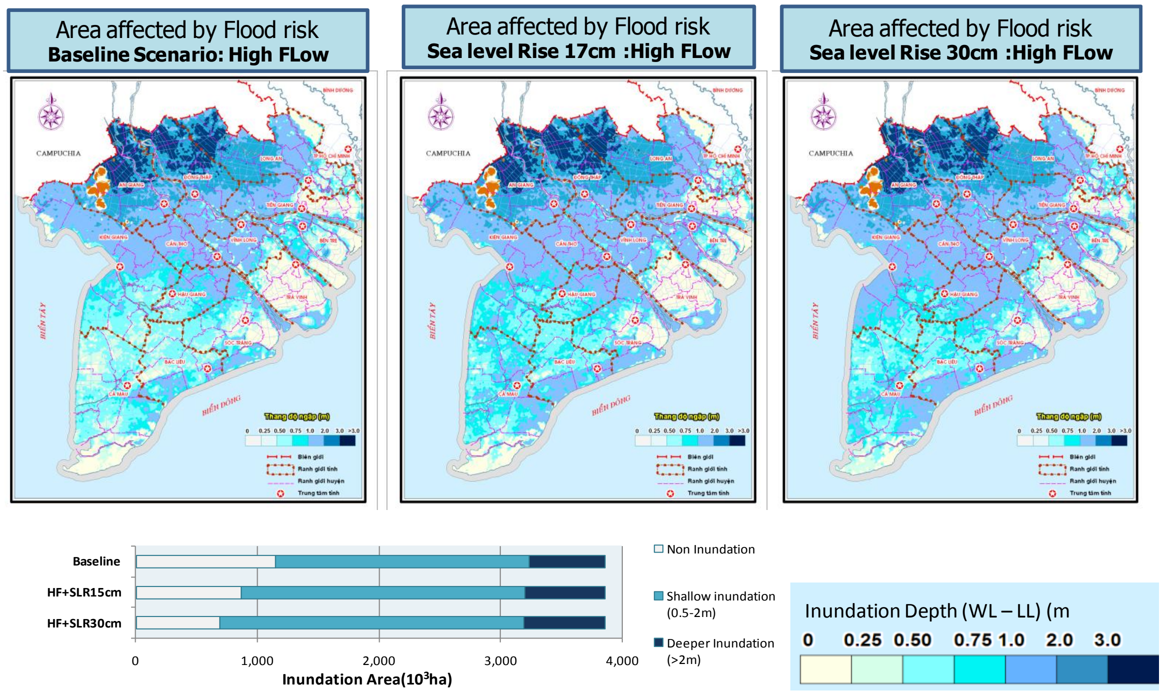


Figure 11. Maximum inundation depth in rainy season in years of high flow water (2000) and without and with SLR effect

The effect SLR results in the sooner flood onset date. Considering flood with water depth greater than 0.4 m continuously for 7 days, flood onset date in high flow year and SLR 15cm is sooner from 1 to 30 day in deep-flooded areas (in the centre of Plain of Reeds and Long Xuyen quadrangle). In Ca Mau peninsula, flood onset date in that case is at least 30 days sooner than that in baseline stage (Figure 13).

CC and SLR affect on the time of flood recession. In climate change 2050 window, time of flood recession is later than at least 30 day in the centre of Ca Mau peninsula and later than from 1 to 30 days in shallow-flooded areas (in the centre of Plain of Reeds and Long Xuyenquadrange) [see Figure 14].

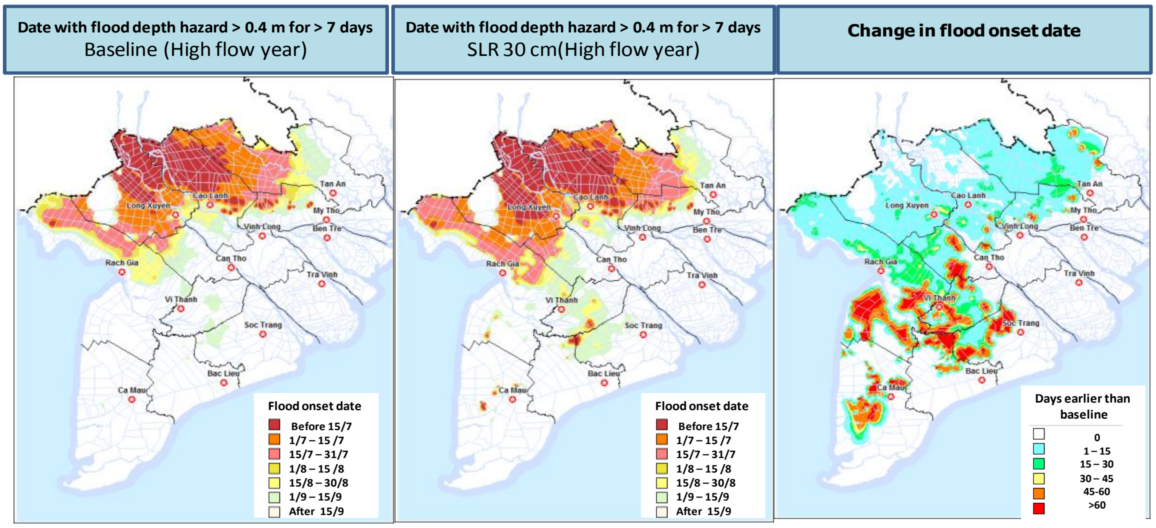


Figure 12. Effect of Sea Level Rise 30 cm on changed in flood onset date

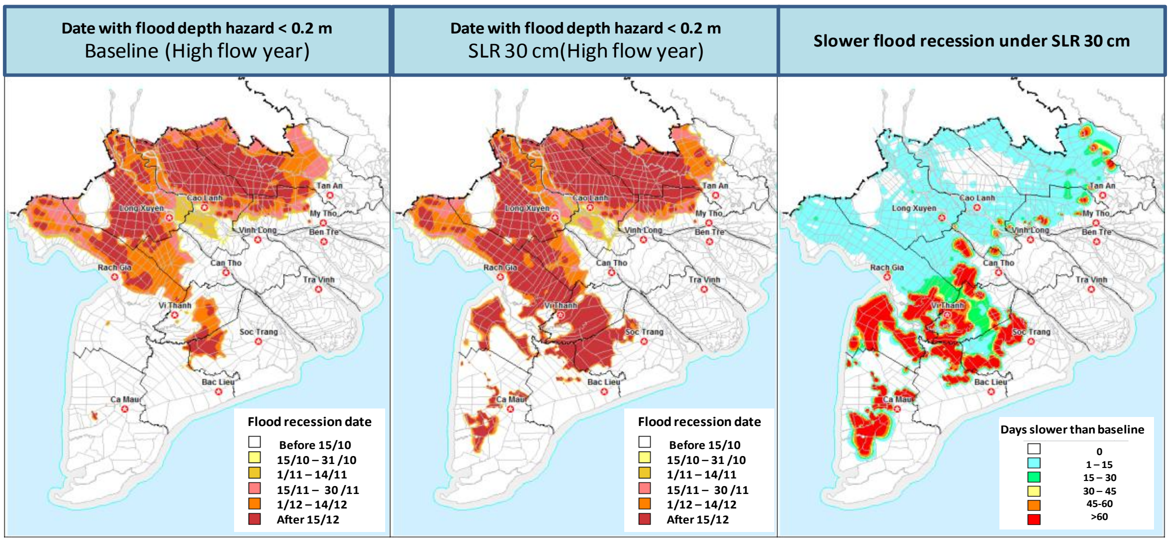


Figure 13. Affect of Sea Level Rise 30 cm on changed in flood recession date

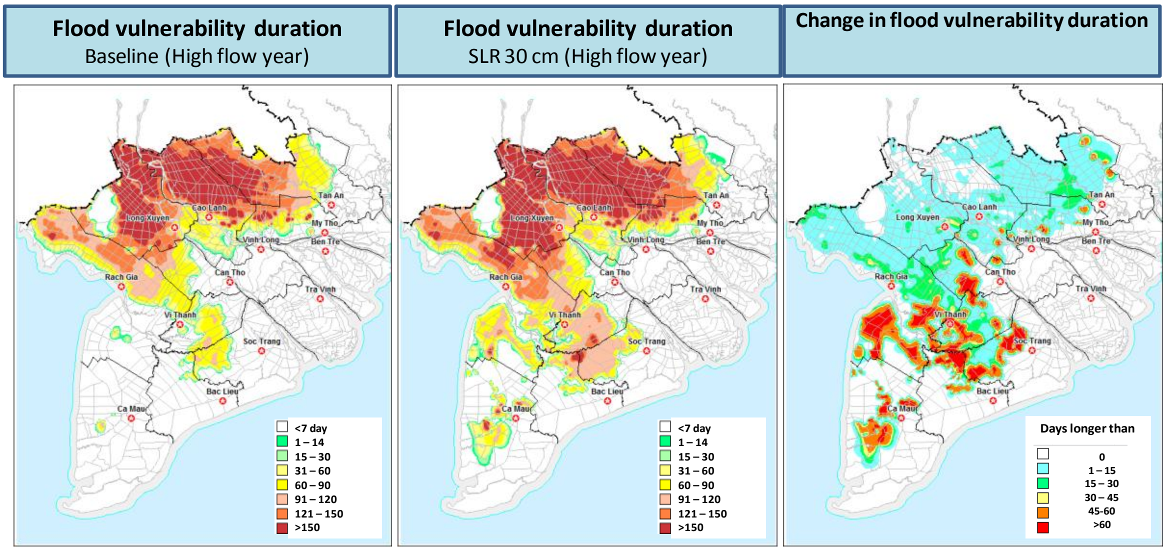


Figure 14. Affect of Sea Level Rise 30 cm on changed in flood vulnerability

8.2.2 In dry season

Variation in Water level

In the dry season, maximum, minimum and average water level in rivers and canals of the MRD increased in a similar value of the SLR, especially in areas in the coastal zone and areas along the main streams.

Variation in Salinity Intrusion

In SLR condition, the isohaline of 4g/l is likely to shift deeper into all river mouths by 1-4 km (in low water year). The increased salinity is especially deeper in Hau (Bassac) River Mouths (Co Chien, Tran De) (64, 66 and 67 km for baseline condtion, SLR17 and SLR30, respectively) compared to Mekong river mouths (52, 53 and 54 km for baseline condtion, SLR17 and SLR30, respectively)(Figure 15).

Besides the threats of SLR in causing saline intrusion toward upstream of Mekong River, however, SLR also increased water level in main rivers as upstream of canals going to the Camau peninsula and Long Xuyen Quadrangle, thus fresh water has a tendency to flow from main rivers into these areas. This helped to decrease salinity level in Ca Mau Peninsula Centre by 4-6 g/l with scenario of SLR of 15 cm and 4-10 g/l with scenario of SLR30 cm

Changes in gravity irrigation potential

Furthermore, SLR also increased more water level downstream areas in Vinh Long, Hau Giang, TienGiang provinces with gravity irrigation (Fig. 16). In the case of SLR, the area applied gravity irrigation increases significantly. The potential fresh water area in 2030 rises 400,000 ha compared to that in present, and the brakish water areas are also increasing nearly 172,000ha.

In areas which have fully salinity control system, such as Go Cong (TienGiang Province), South MangThit (TraVinh Province) and QLPH, the effect of SLR on salinity or submergence risks can be mitigated by these systems.

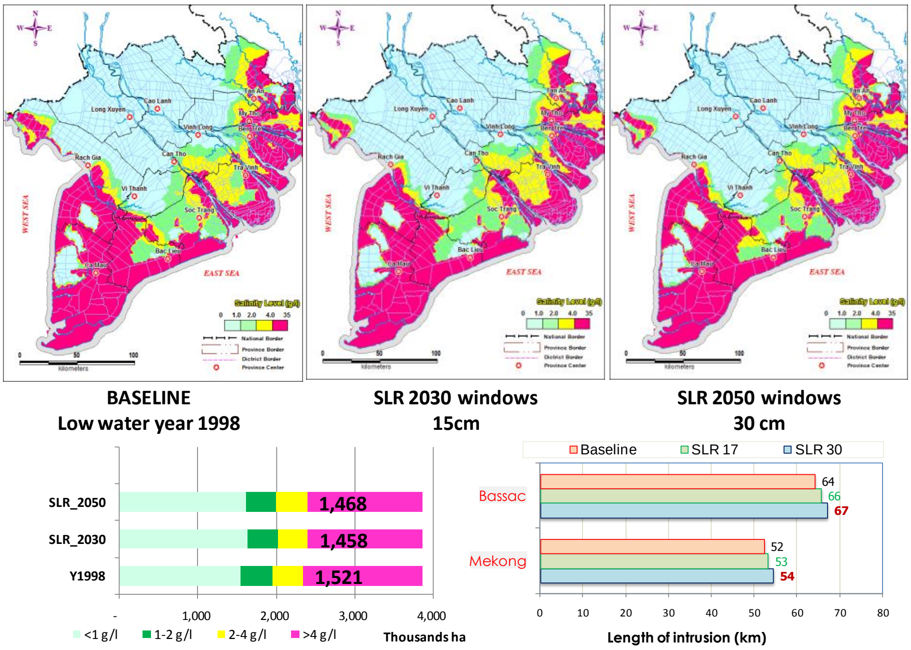


Figure 15.Maximum area affected by salinity intrusion and Length of intrusion in Main River in dry season in years of low flow on Baseline discharge (1998)

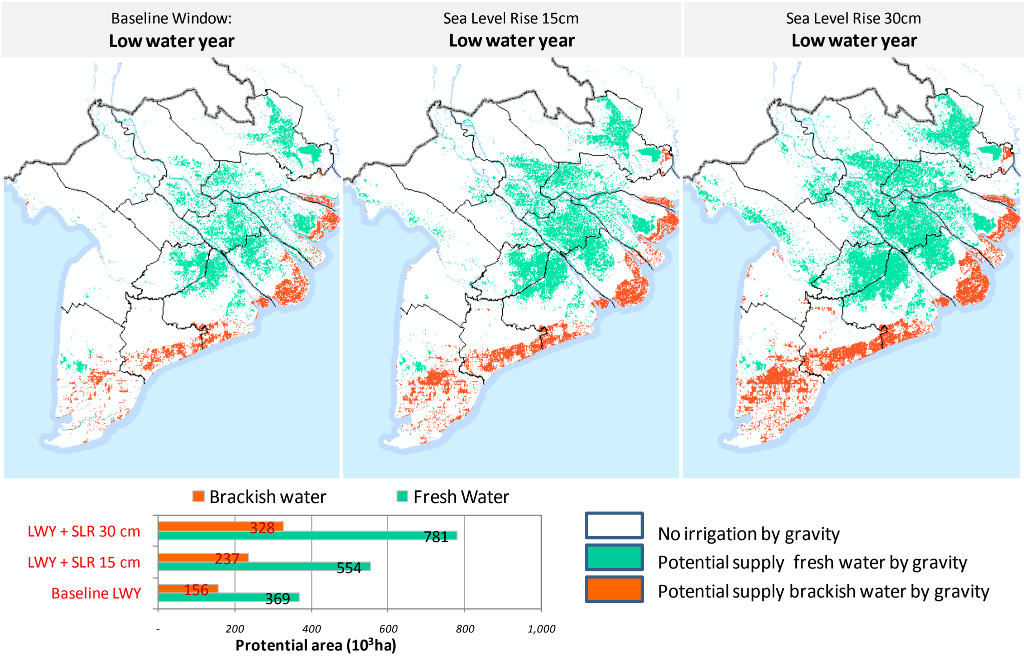


Figure 16. Maximum area affected by salinity intrusion and Length of intrusion in Main River in dry season in years of low flow on Baseline discharge (1998) without and with SLR effect.

8.3 Effect of both SLR and CC on salinity and flooding risks in the Mekong Delta

8.3.1 In rainy season

Generally, in both years of 2030 and 2050 the inundation depth will increase gradually which is compared with those in baseline condition (Figure 17).

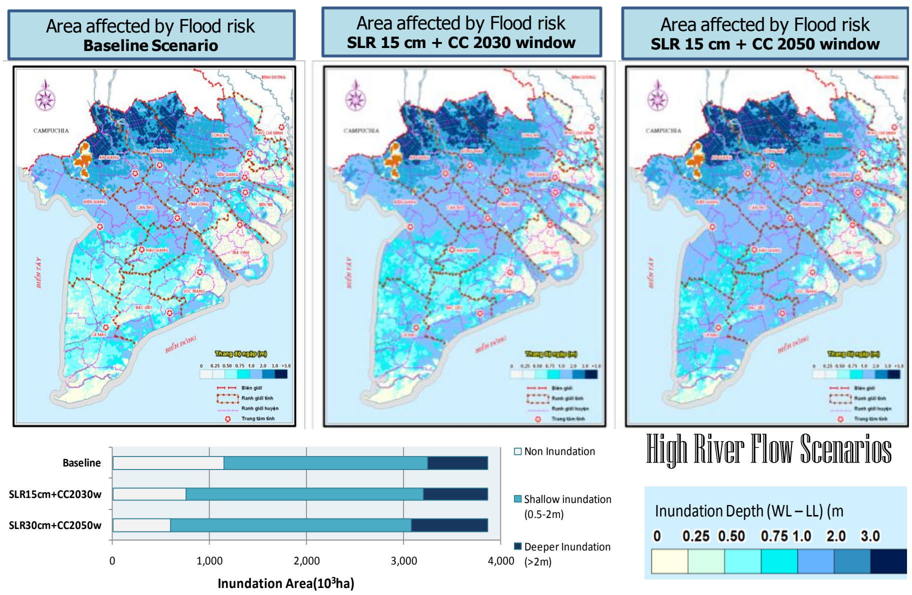


Figure 17. Maximum inundation depth in rainy season in years of high flow water Baseline and With Climate Change combine with SLR on 2030 window and 2050 window

The incorporated effect of CC with SLR has increased the risks of flooding or submergence in the MRD, especially in years of normal and low water. The maximum inundation depth increases significantly, especially by 2050, with inundation depth area increasing approximately 190,000 ha at water depth greater than 2 m.

The effect of CC and SLR results make the time of flood is longer. Compared with scenarios affected by SLR, the area has sooner flood and later flood recession is expanded more significantly, especial in Ca Mau Peninsula Centre (see Figure 18- Figure 20)

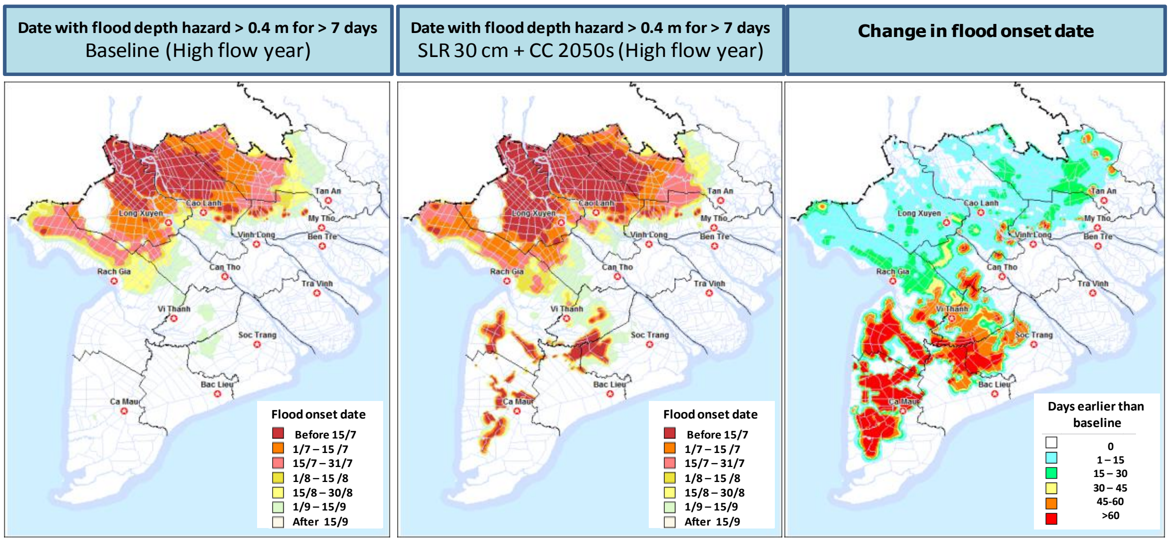


Figure 18.Affect of Sea Level Rise 30 cm and Climate change 2050 window on changed in flood onset date

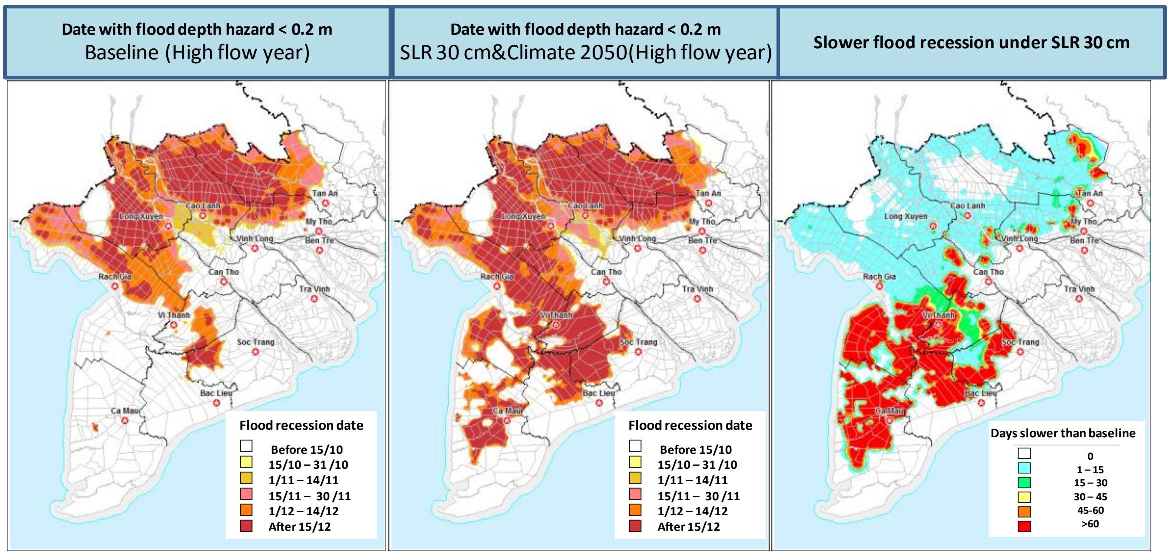


Figure 19. Affect of Sea Level Rise 30 cm and Climate change 2050 window on changed in flood recession date

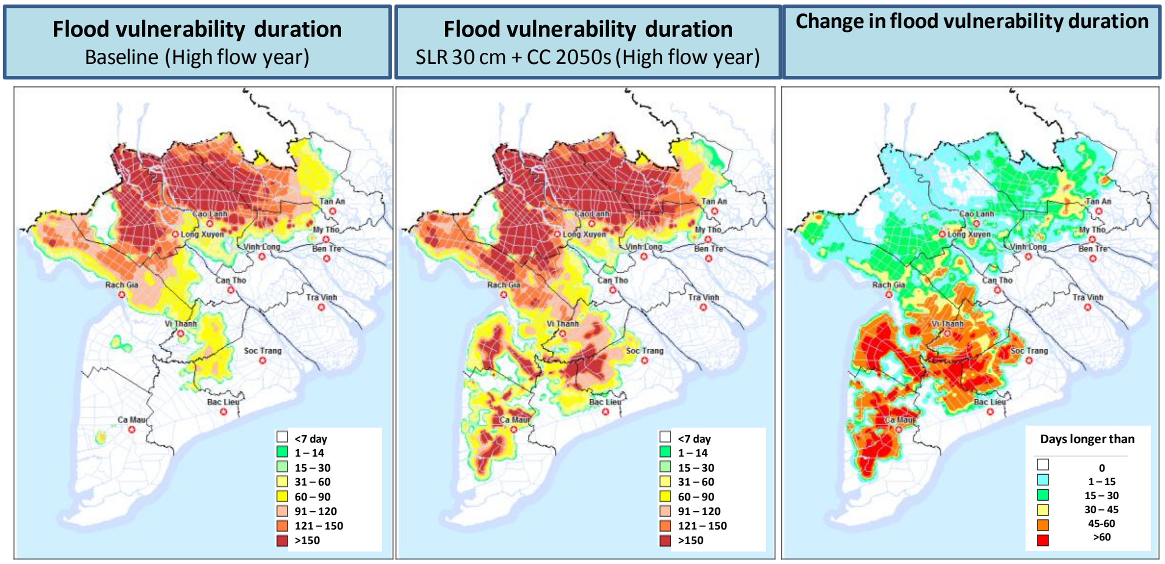


Figure 20. Affect of Sea Level Rise 30 cm and Climate change 2050 on changed in flood vulnerability duration

8.3.2 In the dry season

Average water levels in dry season increased corresponding to SLR. The increase reduced gradually towards the upstream. The increase water level in mainstream of Mekong River also created a gradient of water head towards areas along Mekong River.

When CC is considered with SLR, the affected areas with salinity of over 4 g/l clearly increase. The increase of salinity area was lower in the high water year than those in low and average water years. The maximum affected area was in low water year with about 180,000 ha. Besides the impact of upstream flow of Mekong River, the change of rainfall in the inner regions in the MRD also affected strongly to salinity intrusion.

By 2030:

In the high water year, the percentage of salinity area increased insignificantly, but in the years of low and average water, the increased area was quite high, about 2-3% even 8% for the average water year. The salinity area might share up to 40% area of the MRD in case of low water year. The length of salinity intrusion in the main rivers is likely to increase considerably in case of SLR. Because of the effects of decreased minimum discharge and monthly water volume, the length of salinity intrusion in the Bassac River sometimes reaches 69 km (Fig. 21). Salinity concentration of 4 g/l directly affected the water intakes along Bassac and MangThit Rivers.

Maximum salinity level increased from 2 to 4 g/l compared to that one in baseline situation. The most change area is the central of QLPH, along West Sea, and along main rivers. Especially, in cases of low and average water years, salinity intruded upwards to South MangThit, PhungHiep (Bassac River), and Ben Tre (Fig.21).

By 2050:

Salinity intrusion is very serious in the low water and normal water years. In low water year, area of salinity might go up 41% area of MRD and the length of salinity intrusion might be up to 72km in main streams, which affects the intakes of fresh water along main streams (Figure 21. Change in Length of Saline Intrusion (>4g/l) in main rivers in scenarios of SLR and CC in year of low water).

Maximum salinity affected higher in 2050 than in year 2030. Salinity in Northern MangThit and Ben Tre provinces might be much higher. In the normal and low water years, the most areas with salinity > 4g/l were in Ben Tre, Vinh Long and TraVinh provinces.

Salinity in central of Camau Peninsula decreased lower than that in baseline condition. However, salinity in QLPH and Nang Ren canals had an increase (salinity in Nang Ren canal might be approximately 12g/l). Which can lead to out of function of the operation of sluice system in QLPH.

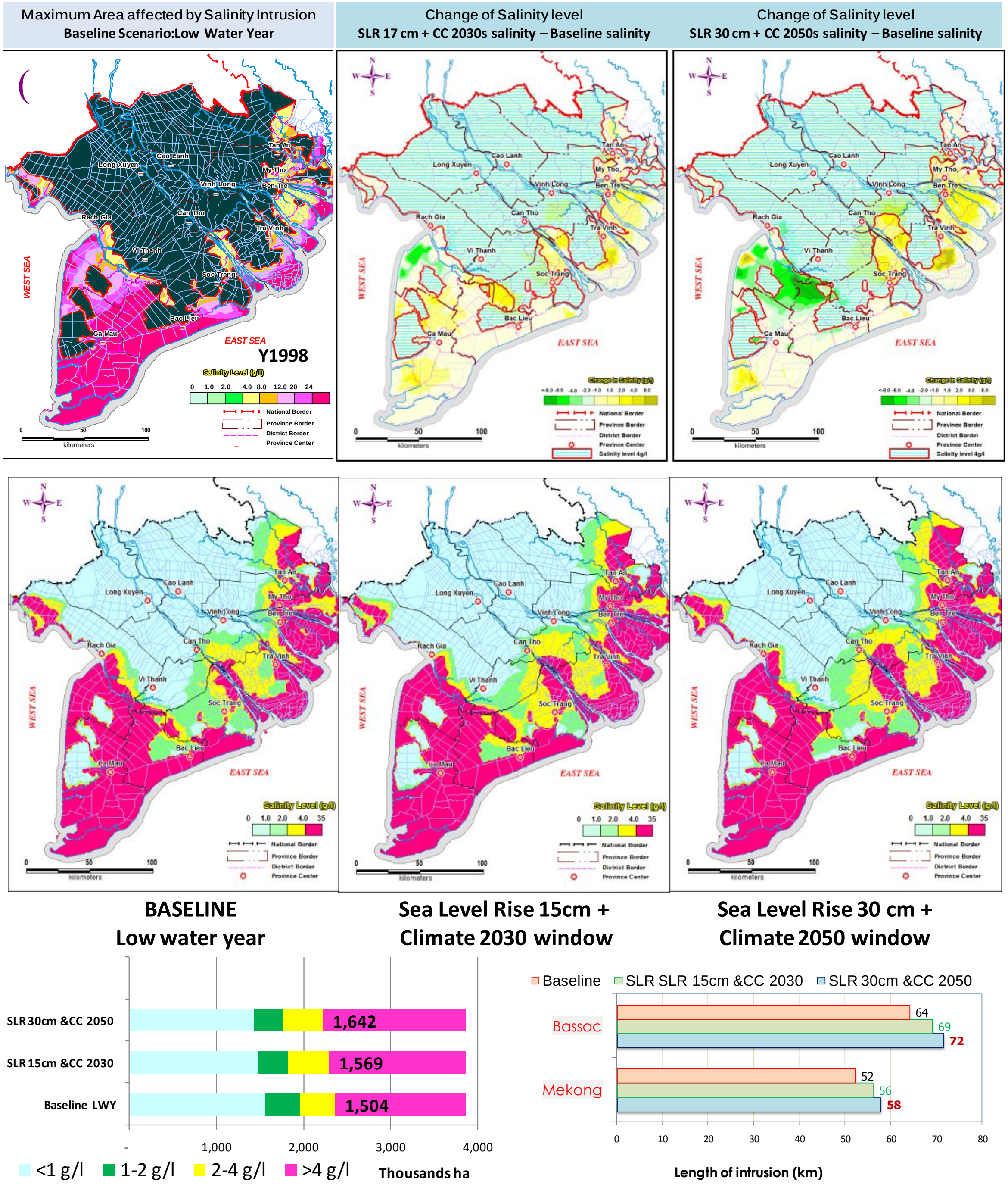


Figure 21. Change in Length of Saline Intrusion (>4g/l) in main rivers in scenarios of SLR and CC in year of low water

8.3.3 Changes in gravity irrigation potential

The area irrigated by gravity increases significantly, the same as the case of sea level rise. However, in the case of climate change consideration, there is the decrease in flow in dry season so that gravity irrigation potential for the areas cultivated by freshwater is less while brackish water supply potential by gravity decreases when compared with those in the case of SLR – baseline discharge. However, the different area from 2 cases is approximately 1,000 ha.

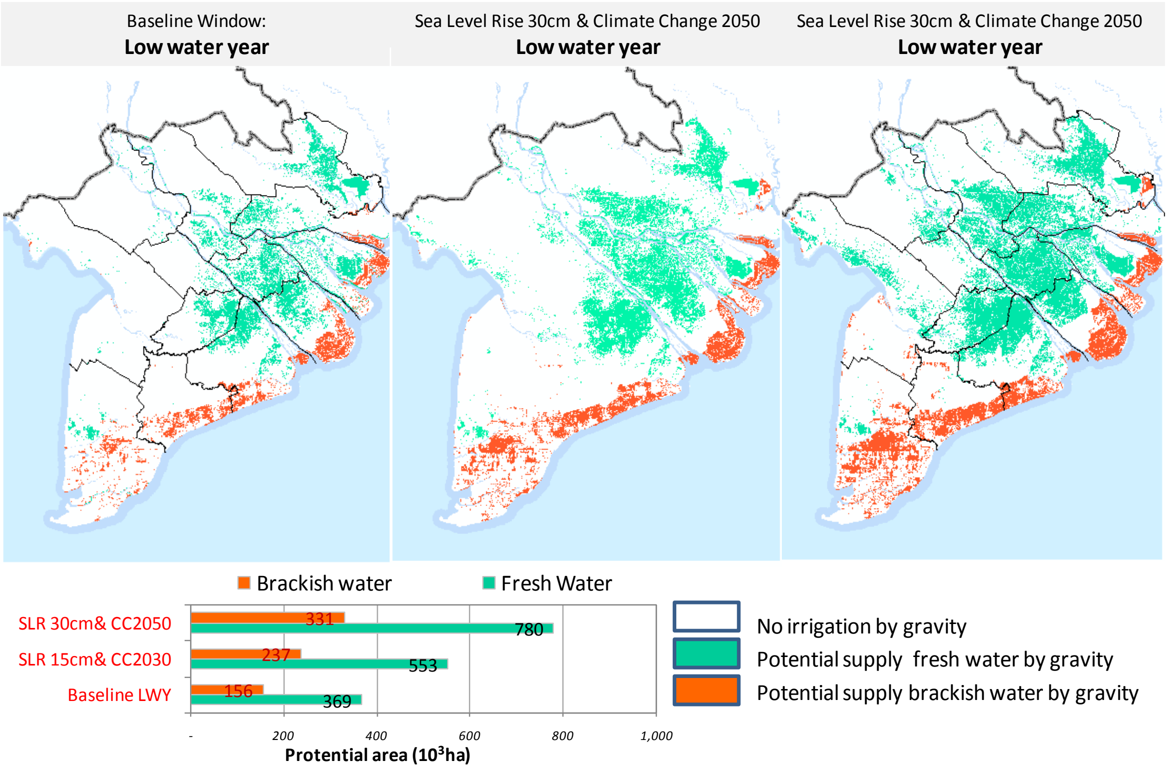


Figure 22. Potential area of gravity irrigation in low water year with Climate change in 2030 and 2050

8.4 Sensitive Analysis for Landused option and Upstream Development

8.4.1 Effect of landuse change in MRD

Analysis of Plan 2020 landuse change in MRD (Source: Sub NIAAP, 2013) under impact of CC and SLR and it will be compared to the results of Current Landuse and CC+SLR.

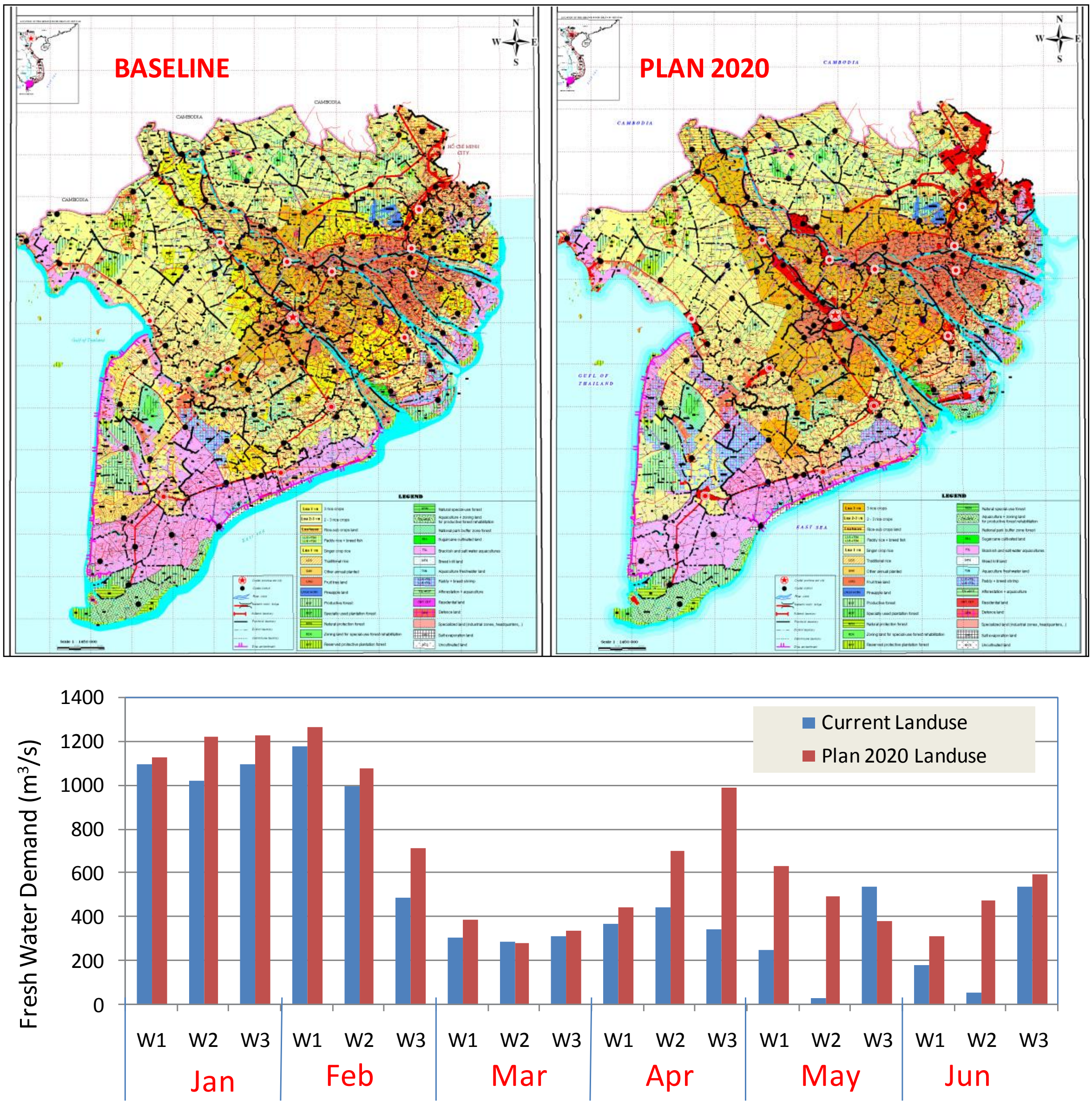


Figure 23. Map and Chart of the fresh water demand in case Baseline and Plan Landuse 2020

Water demand of agricultural production in MRD in 2020 increases more than 20% in 2020 compared to baseline condition.

Effect on salinity intrusion

Generally, the land use planning for MRD indicates water use is more in the regions on the West Sea from Ha tien to RachGia and Vai Co River. These regions will be affected strongly by saline intrusion than those in scenario group C (i.e. CC+SLR +LU2008)..

There are more areas of saline intrusion when land use change under CC and SLR impact. In low and average water years, the areas of saline intrusion are higher than those in high water year.

In low water year, the areas of saline intrusion at salinity level > 4g/l are around 1,653 million ha that is 43% total area of MRD with 90,000 ha increase compared to areas in Baseline Landuse 2008.

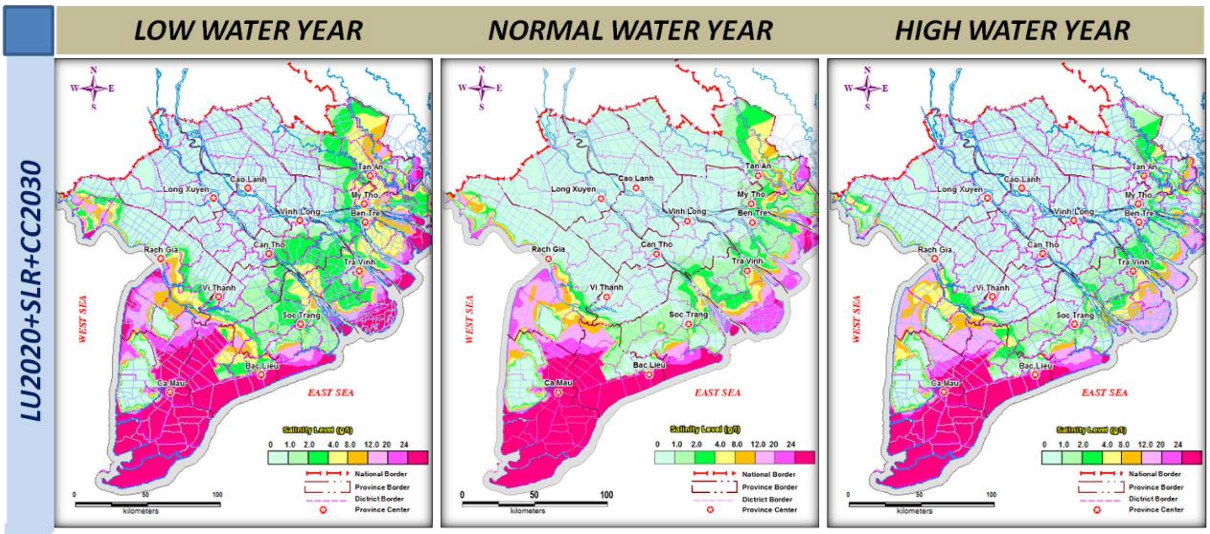
In inland canals, salinity increase slightly from từ 1-2g/l compared with of GROUP C scenarios (that means CC+SLR +LU2008).

Length of salinity intrusion

Maximum length of salinity intrusion in main streams from river mouths varies not much in baseline condition that compared to those in scenarios under the impacts of CC and SLR (CC+SLR +LU2008). CC and SLR cause wider salinity expansion.

Variation of water level in inland canals

Simulated water levels are not much different with those in scenarios of group C. In mainstream, the computed water level decreases 1-2 cm compared to that of scenarios of group C.



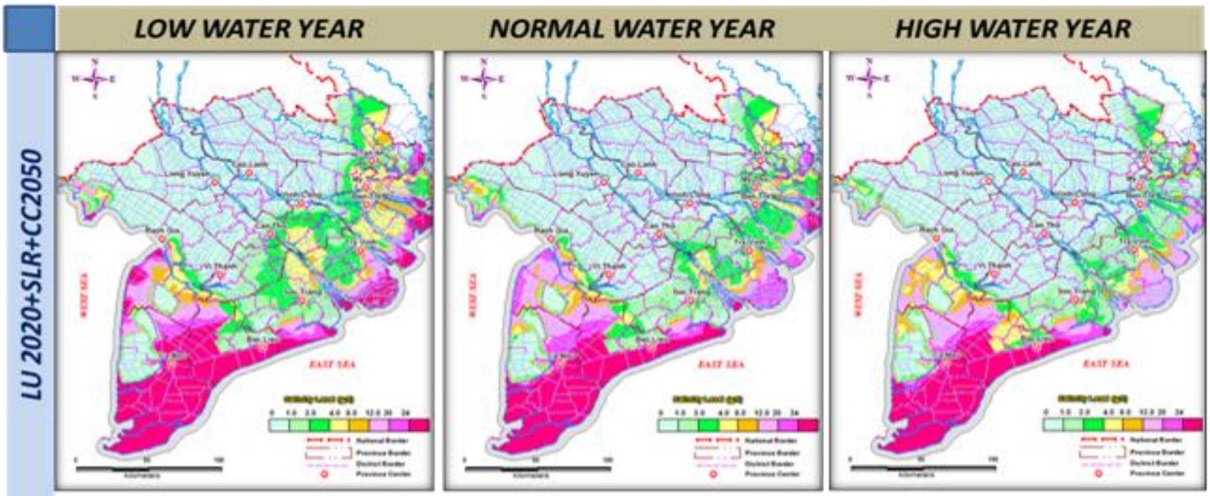


Figure 24. Maximum area affected by salinity in dry season in 3 hydrological years under the effect of landuse change under CC and SLR in two stages of 2030 and 2050.

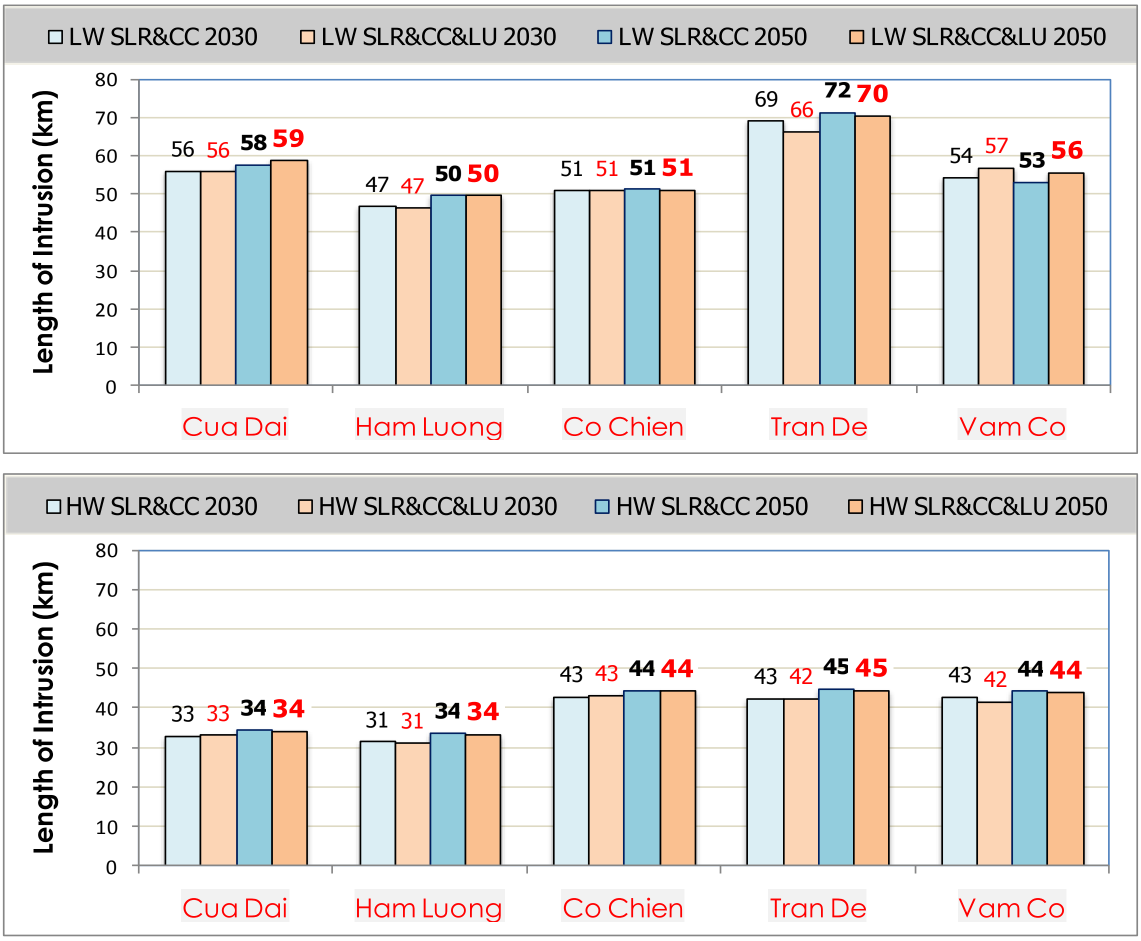


Figure 25. Maximum length of salinity intrusion in main streams from river mouths in 3 hydrological years with consideration of land use change under the impacts of CC and SLR compared with GROUP C (without landuse change)

8.4.2 Effect of upstream flow to salinity Intrusion:

For assessment the effect of upstream flow reduction to salinity we chose in the projected flow at Kratie in term of Climate Change from 2010 -2050, the specific years has flow reduction compared with Low Water Year in baseline condition (1998).

Water flow and salinity have been simulated in 3 cases:

- ✓ Total flow after reduction in dry season of: 2030 (reduction 9%) and 2046 (reduction 11%) (Figure 26a)
- ✓ Total lowest monthly flow: 2024 (-20%); 2026(-28%) and 2028 (-9%) (Figure 26b)
- ✓ Reduction of 10% and 20% in every day in Jan-Apr of Low Water Year in Baseline(1998)

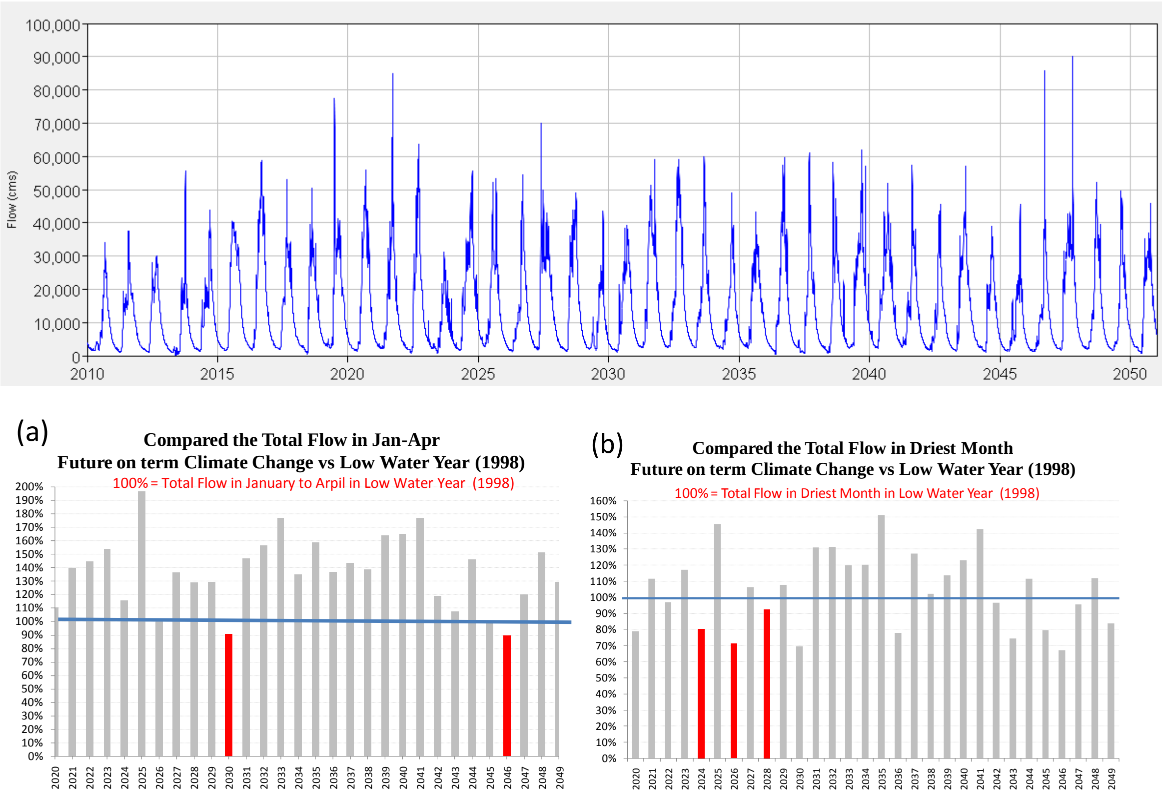


Figure 26: Projected flow at Kratie station in term of Climate Change (Source BPD 2- MRC 2009) compared wirh Baseline Low Water Year (1998)

Figure 27 shows the results of maximum salinity affected on Baseline 1998 vs reduction of 9% and 11% in Jan-Apr in Flow of year 2030 and 2046. Saline area is slightly expanded when upstream flow in the dry season at Kratie decreases, about 80,000 ha with 11% reduction. Effect of changes in upstream flow is not as strong as expected because of the natural regulation of Great Lake (store water in flood season and release to the delta during dry season), and also dike and sluices for salinity control in the delta.

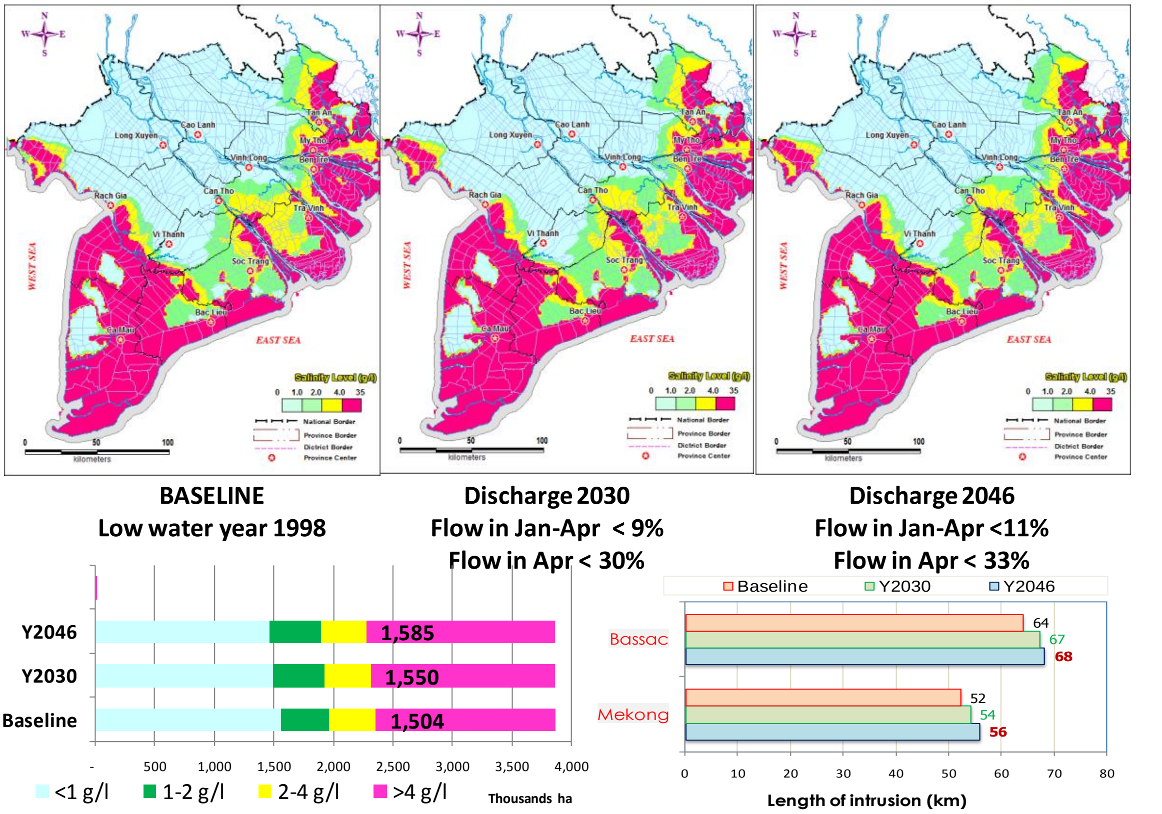


Figure 27. Baseline LWY vs reduction of 9% (2030), 11%(2046)total Flow in Jan - April

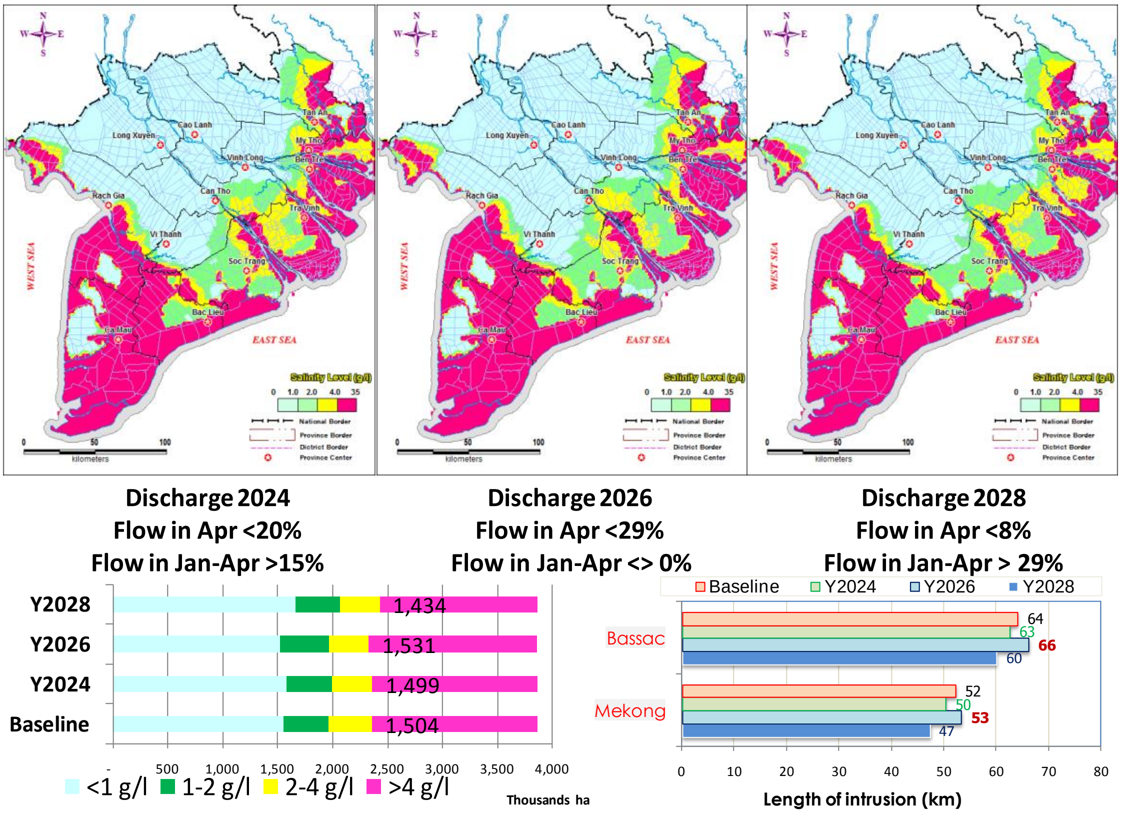


Figure 28. Baseline vs reduction of 8%, 20% and 29% in Apr (minimum flow) in 2028, 2024 and 2026.

Figure 28 shows the Baseline compared with Cases reduction of 8%, 20% and 29% in Apr (minimum flow) in 2028, 2024 and 2026. Decrease in upstream flow in short period as one month (April) only does not influence salinity area as total flow in the dry season (areas in 2024 and 2028 is smaller when flow in April decreases but total flow Jan-Apr increases)

Figure 29 shows the Reduction of 10% and 20% in every day in Jan-Apr. Saline area is slightly expanded. Regular reduction of flow in every day during Jan-Apr does not cause large expansion of saline area as in the case of smaller reduction during the period but higher reduction in certain month. This could be due to flow regulation by Great Lake. So not only the flow change in certain month or in the whole period Jan-Apr would determine the saline area, but the combination of both.

In all these flow change scenarios, expansion of saline area is maximum 1.6 mil ha, about 5% increase compared with 1.5 mil ha in 1998 of low water year. These changes do not cause much longer salinity intrusion into the mainstream (only about 4 km, from max 64 km to 68 km).

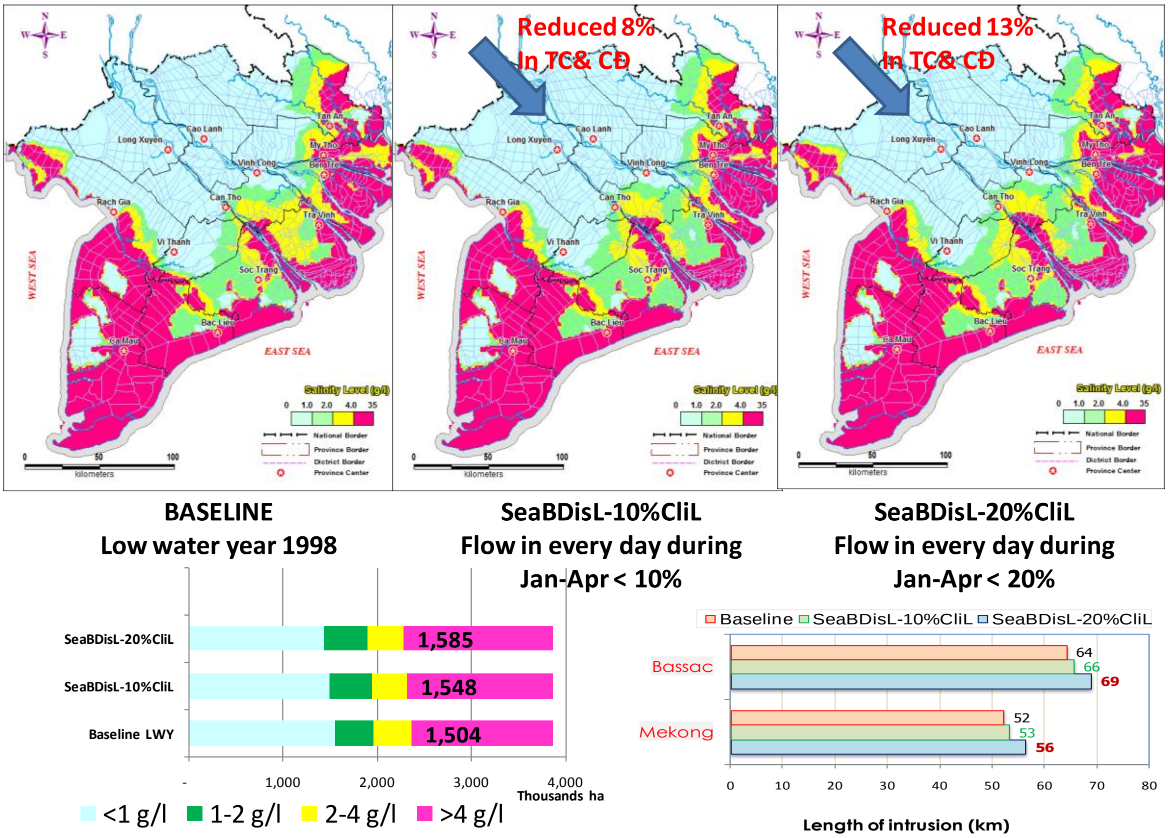


Figure 29. Baseline(LWY) vs Reduction of 10% and 20% in every day in Jan-Apr.

8.4.3 Effect of upstream development (BDP projection)

Figure 30 and Figure 31 show the difference between flows at Kratie under Climate Change and effect of Hydro Power Dam development upstream.

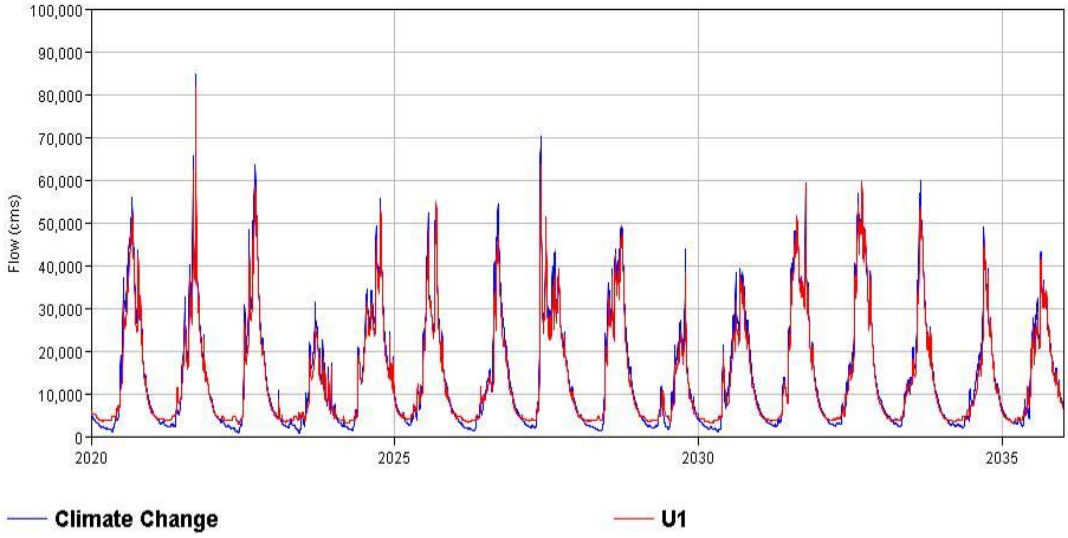


Figure 30. Flow variation at Kratie under the effect of upstream developmentin 2030 without climate change

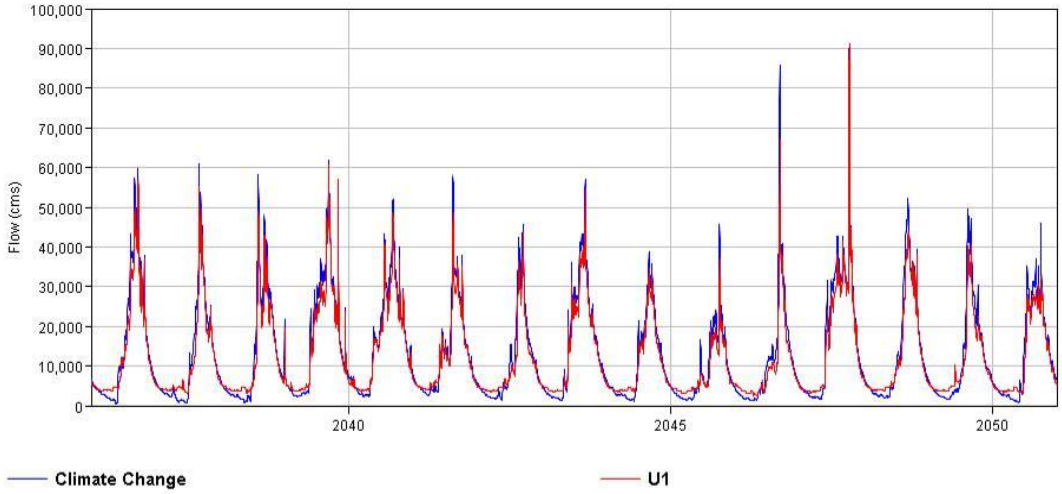


Figure 31. Flow differences at Kratie under the effect of upstream development in 2050 and at baselinecondition

Generally, when upstream dam system operates in normal condition, it will help to increase discharge of mainstream in dry season, and salinity intrusion boundary on mainstream will be reduced that compared to other scenarios without upstream dam operation. In 2030, the area affected by salinity of 4 g/l ranges from 1,214 million ha to 1,417 million ha. That area will be declined from 51,000 ha to 176,000 ha that compared to other scenarios without upstream system.

In 2050, the discharge in main flows is further improved. The area affected by salinity intrusion in the driest year only accounts for 36 % (about 1.4 million ha). Maximum length of salinity intrusion in the Hau River is about 57 km.

Salinity affected area in low water year will be reduced that is compared to baseline condition. In average and high water years, the salinity affected areas increase slightly, compared to considering to scenarios only affected by SLR (Group B) . However, if the area will be reduced much if it is compared with the results of scenarios affected by Climate change and SLR with landuse 2008(Group C) and landuse plan (Group D)

Although salinity boundary of 4g/l on the mainstream decreases more than those at baseline condition but the variation of salinity in region inland of MRD is very complex, especially in CMP. In low and average water years, its results in CMP indicate the salinity decreases and it increases in high water year.

The water level increases in all primary canals in this scenario. The average value increases about 4-9 cm compared to scenario group C and D.

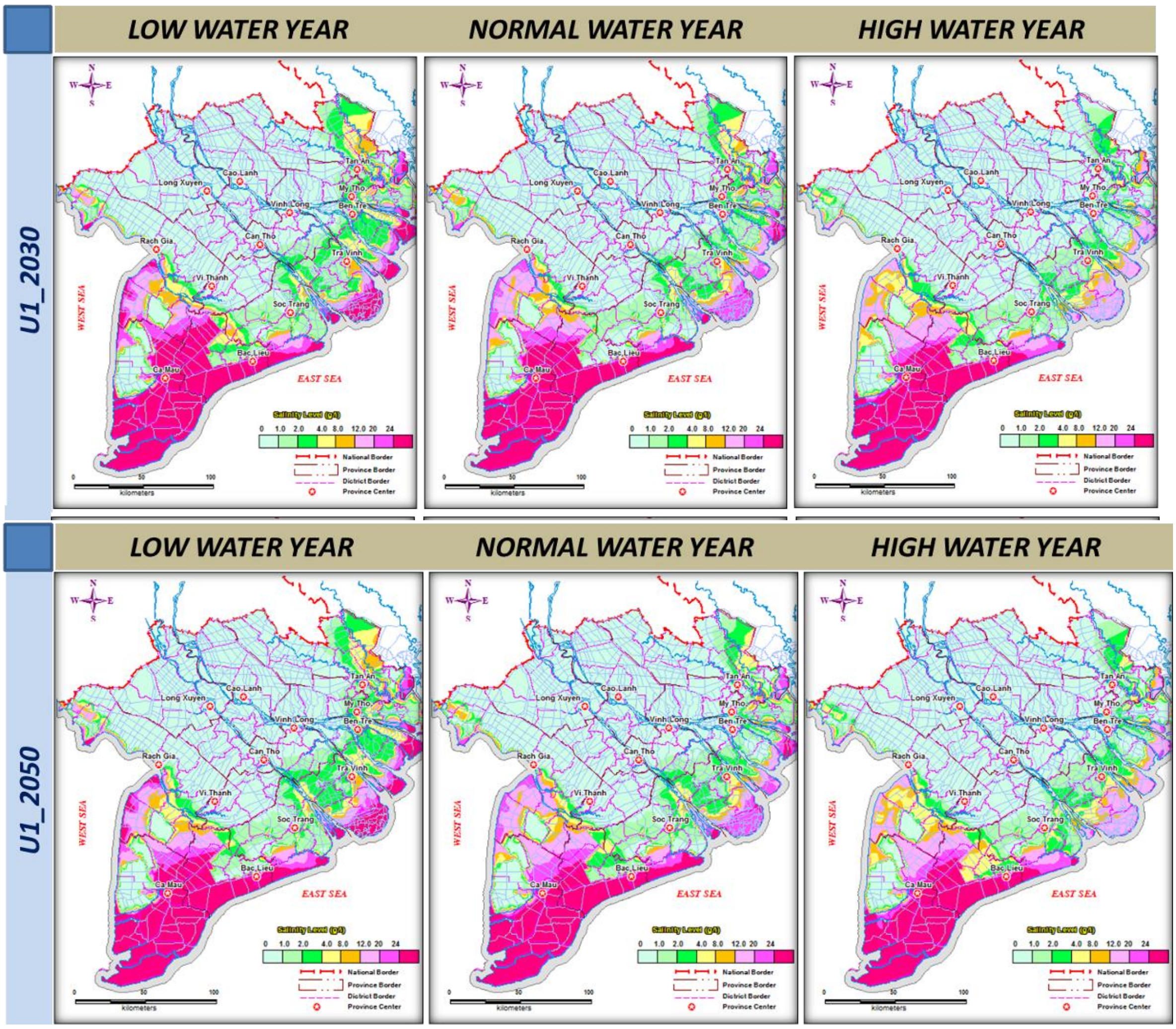


Figure 32. Maximum area affrected by salinity in dry season in 3 hydrological years under the effect of upstream development in two stages of 2030 and 2050

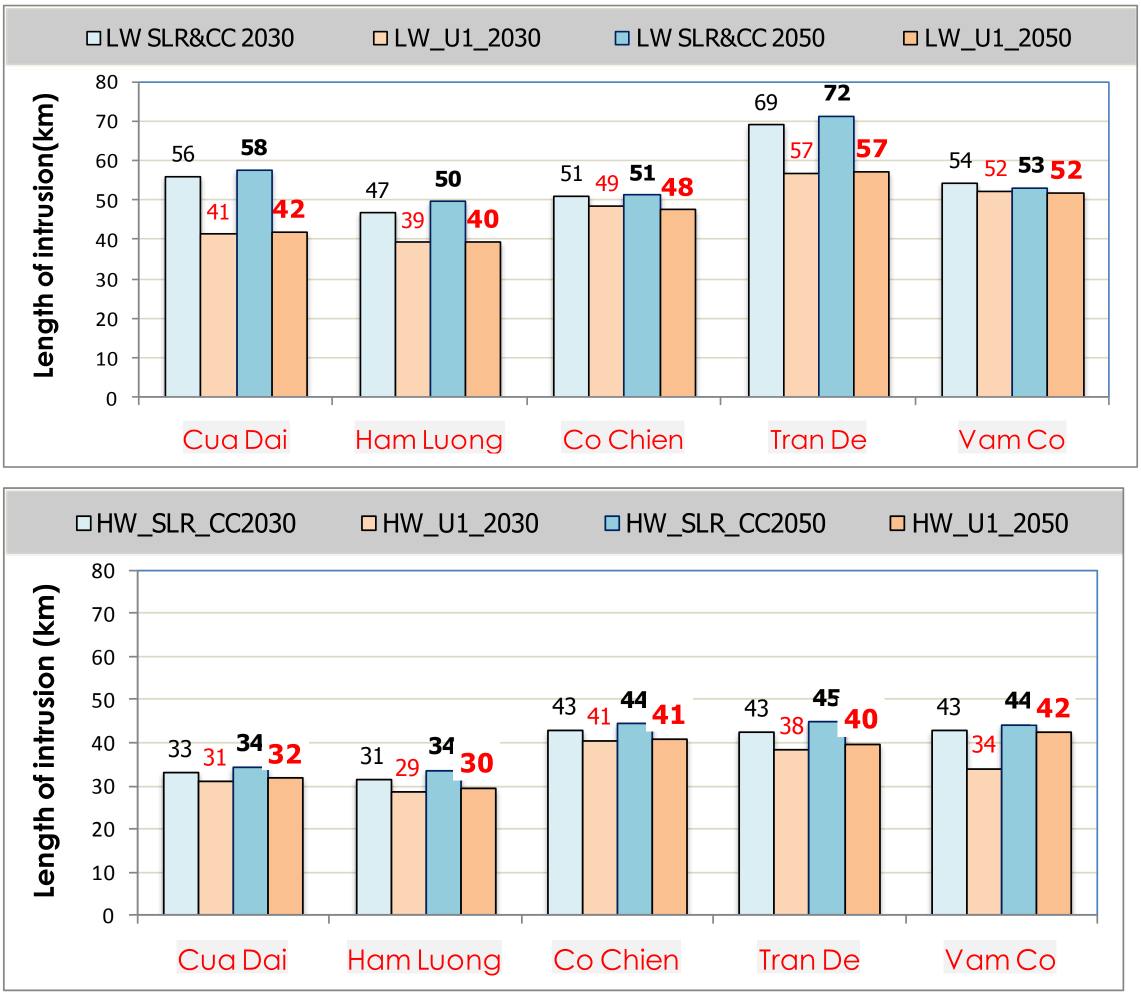


Figure 33. Maximum length of salinity intrusion in main streams from river mouths in 3 hydrological years with consideration of upstream development and land use in 2020 under the impacts of CC and SLR

8.5 Assessment the hot spots and rice affected areas under the impact of climate change in Mekong Delta

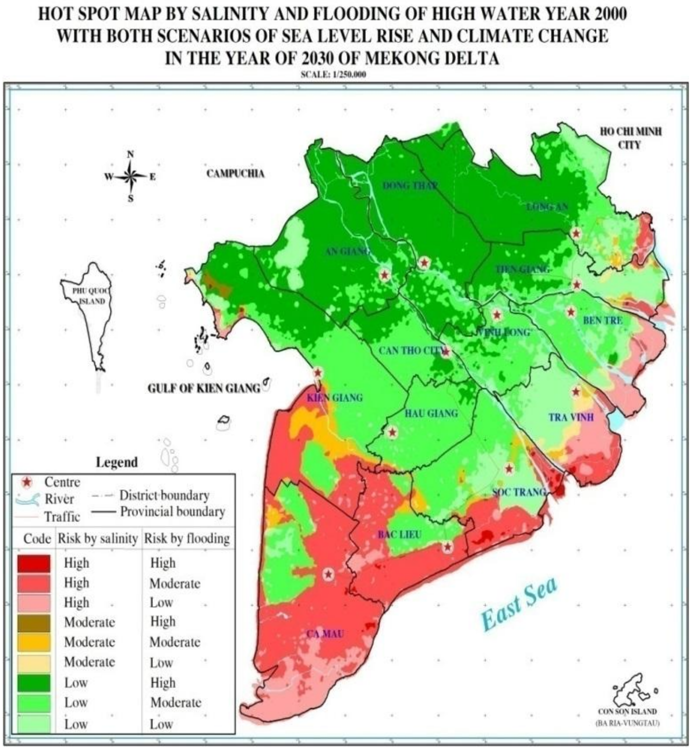


Figure 34.Map of vulnerability area of Mekong Delta under effect of CC and SLR in HWY 2000

8.5.1 Compare the affected and hot spot area of Mekong Delta according to 1998, 2000 and 2004 water year scenerio

The high risk areas affected by salinity and flooding scenarios were determined on the basis of overlaying the climate change scenarios maps (salinity and flooding) corresponding to the year 1998, 2000, 2004, and SLR30, SLR30CC, SLR30US, SLR50, SLR50CC, SLR50US scenario. The hot spot areas in Mekong Delta found with highest flooding depth (≥1.5m) and strongly salinity (salt ≥8‰) which founded among those high risk areas created. There are 21 maps of hot spot areas for MRD according to salinity and flooding scenarios in 1998, 2000 and 2004 water years. They are showed in Appendix 20.

Table 5.The area of high risk by Flooding and Salinity in MRD (unit: ha)

Scenario	1998	2000	2004
HT	0.0	658.6	238.2
SLR30	627.5	2,931.6	2,254.4
SLR50	1,327.1	11,120.2	11,782.1
SLR30CC	1,304.2	12,319.4	12,080.7
SLR50CC	1,284.3	12,888.7	11,928.7
SLR30US	439.4	3,115.6	3,436.9
SLR50US	1,630.6	12,768.5	11,423.9

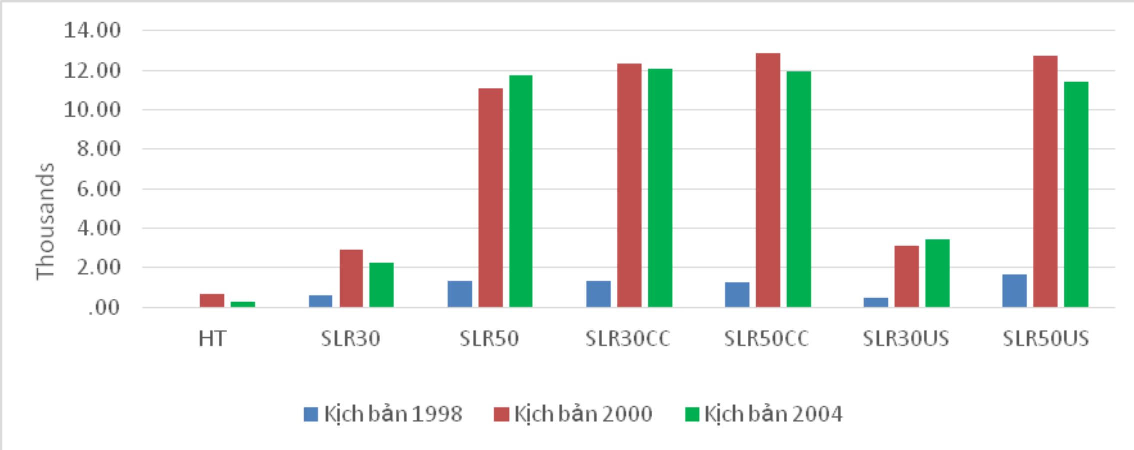


Figure 35. Diagram of vulnerability area in Mekong Delta according to climate change scenarios in 1998, 2000 and 2004

The salinity and flooding maps were overlaiedd with administrative and land use maps to assess the impact of climate change on the land use status in the Mekong Delta. The results are as follows:

We also computed scenarios in 1998 water year having hot spot areas are lesser than 2000 and 2004 water years. The average of hot spot areas of scenarios in 1998 were 1,300 ha, in 2000 were 12,300 and in 2004 were 12,100 ha.

The scenario in 1998, area of hot spot zones of the sea level rise scenario are increasing with time, in 2030 is 627 ha and in 2050 is 1,327 ha; According to the sea level rise scenario having climate change (SLR30CC and SLR50CC), the area of hot spot are similar, about 1,300 ha; the sea level rise scenario having climate change and upstream development (SLR30US and SLR50US), the area of hot spot zones corresponding are 439 and 1,630 ha.

With the scenario in 2000 water year, area of hot spot zones in the sea level rise scenario are increasing with time, in 2030 (SLR30) is 2,930 ha and in 2050 (SLR50) is 11,120 ha; In the sea level rise scenario having climate change (SLR30CC and SLR50CC), the area of hot spot are similar, about 12,800 ha; Against the sea level rise scenario having climate change and upstream development (SLR30US and SLR50US), the area of hot spot zones matching are 3,115 and 12,768 ha.

Similarly scenario in 2004, that areas are increasing too, about 238 ha in baseline year 2004, the SLR30 scenario is 2,254 ha and the SLR50 scenario is 11,782 ha. According to the sea level rise scenario having climate change (SLR30CC and SLR50CC), the area of hot spot are similar, approximately 12,000 ha; Along with the sea level rise scenario having climate change and upstream development (SLR30US and SLR50US), the area of vulnerability zones corresponding are 3,436 and 11,423 ha.

Universal, the scenario in 2000 is base water year, having the vulnerability area is largest in climate change scenarios. In which, the SLR50CC scenario in 2004 has highest hot spot, about 12,888 ha.

8.5.2 Evaluation of vulnerability rice area due to the effects of climate change under climate change scenarios in 1998, 2000 and 2004 at Mekong Delta

The vulnerability rice areas of MRD by the impact of climate change were delineated based on the results of overlaying of land use map in 2008 with administrative map with climate change scenarios (SLR30, SLR30CC, SLR30US, SLR50, SLR50CC, SLR50US) about salinity and flooding corressponding the baseline year 1998, 2000 and 2004.

Table 6.The rice area affected by climate change scenario in MRD (unit: ha)

Total of rice area	1998	2000	2004
HT	0.0	50.6	0.0
SLR30	327.8	173.2	20.6
SLR50	118.9	434.0	337.4
SLR30CC	2.7	416.6	631.2
SLR50CC	2.7	388.4	155.6
SLR30US	190.2	125.1	169.5
SLR50US	186.9	460.8	167.1

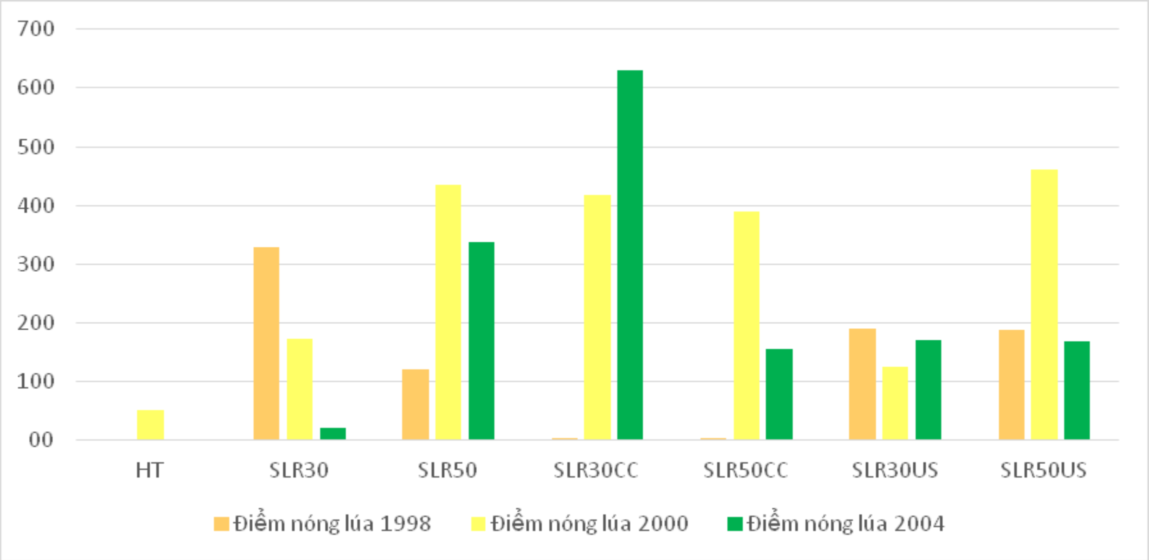


Figure 366. The total of vulnerability rice area due to the impact of climate change in Mekong Delta under the scenario in 1998, 2000 and 2004

Thus in Figure 366, the results of the base (1998) and 2004 water years have not shown the vulnerability rice area while in 2000 water year is 50.6 ha by salinity and flooding elements.

The scenario in 1998 water year, the most vulnerability rice areas were found in sea level rise scenarios to 2030 (SLR30), approximately.

According to 2000, the vulnerability rice areas showed in all scenarios and the most concentration was sea level rise scenarios to 2050 with climate change and upstream development (SLR50US), approximately 460.8 ha

With scenario in 2004, the vulnerability rice areas appeared in all scenarios and most dominated in sea level rise scenario having climate change to 2030 (SLR30CC), about 631 ha.

9 Impacts

9.1 Scientific impacts – now and in 5 years

– Evaluation of all effect of climate change, Upstream Development and Sea level rise on hydrology and salinity in the Mekong Delta

– Proposed 27 Scenarios of CC, SLR, Upstream Development for Hydraulic assessment

– Bias correction before the using the PRECIS climate change data (SEA-START).

– Evaluation the trend of Climate change and impact of CC & Development to future upstream flow.

– Proposed the evaluation method of CC & SLR impact on rice cultivation mode of 4 study areas in particular and Mekong Delta in general

9.2 Capacity impacts – now and in 5 years

Understanding of the impact of climate change on hydrology, salinity and rice production in the Mekong Delta and target provinces in CLUES

Enhancing understanding and skill of staff about GIS and remote sensing in delineating and manipulating the spatial data

9.3 Community impacts – now and in 5 years

Enter text

9.3.1 Economic impacts

Training local farmers and staffs on using risk maps at 4 provinces of CLUES could help:

- Increased capacity of farmers and communities to mitigate the negative impacts of climate change by making use of different adaptation options that are economically feasible for their characteristics.

- Increased efficiency in the use of government resources by enhancing the capacity of policy makers to understand the agricultural systems in the context of climate change

9.3.2 Social impacts

1. Social benefits are likely to be considerable. Understanding risky maps of salinity intrusion or flooding could reduce vulnerability to climate change impacts of rice-based production systems within the Mekong Delta that will prevent the collapse of this important food growing area.

9.3.3 Environmental impacts

Model simulation of water levels and salinity in theMekong River canal network under effect of climate change and sea water rise indicates submergence and salinity conditions in MRD will change that result inagro-ecological changes in MRD in 2030 or 2050. Stagnant flood will expand broader in MRD and become seriously in future compare to saline intrusion.

9.4 Communication and dissemination activities

Progress of the project will be carefully monitored through local workshops for showing risk maps and feedback from stakeholders regularly solicited through interviews conducted by social scientists, to ensure target delivery and to make further adjustments where and when needed. The final maps of salnity and flooding depth under impact of CC and SLR have been disseminated to local offciers for use in their work.

The scientific outputs of risk maps have been published nationally and internationally and shared through scientific conferences and symposia.

10 Conclusions and recommendations

10.1 Conclusions

- Hydraulic regime and salinity intrusion in the MRD are very complicated, because they depend on many factors: freshwater discharge from upstream, water use in the MRD, operation of sluices, SLR and CC.
- Flooding and salinity conditions in sub-region will be changed under SLR and CC, and will result ecological changes subsequently.
- The impact of CC on Rice production is increasing more severe not only by the increasing of Salinity intrusion, Flood inundation but also the shift of Climate (Rainfall regime)
- The impact of SLR + CC on flood-related stress is more pronounced than on salinity stress
    - SLR + CC increases flood depth hazard, and prolongs flood vulnerability duration.
    - Partial stagnant flood will become more prevailing
    - The impact is more pronounced in some coastal zones than in the presently flood-risk zone.
    - Will negatively affect rainy season crops (Summer Autumn and Autumn Winter)
- Not all SLR+CC impacts are negative. SLR will cause higher water level in dry season that facilitate fresh water accessibility and support gravitational irrigation.
- The study only delineate the extend of vulnerability area under difference levels of depth of flooding and levels of salinity on difference land use types, which should be considered on the levels of damages and crop yields losses or levels of vulnerability under difference climate change scenarios.

10.2 Recommendations

- Simulation of SLR and CC is a difficult task and contain many unsurely factors so that continue additional research on uncertainty effect of CC and SLR
- It is necessary to project the land use planning appropriately to cope with the impact of salinity intrusion and flooding at difference hot spot or vulnerability areas.
- It is necessary to have the more detailed studies to assess comprehensively the impact of climate change on the vulnerability of the current farming and planning for whole region of MR.

11 References

11.1 References cited in report

1. Ministry of Natural Resources and Environment, 2011. Scenarios of climate change and sea level rise for Vietnam.Publisher: : 12 cm: 2020, 30 cm: 2050, 75 cm: 2100.

2. World Bank,2007. The impact of sea level rise on developing countries: Comparative Analysis Continued growth of greenhouse gas emissions and associated global warming could well promote SLR of lm-3m in this century, and unexpectedly rapid breakup of the Greenland and West Antarctic ice sheets might produce a 5m SLR.

3. Intergovernmental Panel on Climate Change (IPCC), 2006. Mekong basin in 2030: Temp entire region will increase by 0.79°C, rainfall will increase 200 mm, and the annual volume increase 21 %.

4. ADB, 2009. Quoted results of IPPC (2007): to period 2070-2099, monthly flow of the Mekong will increase in downstream (41 %) and is 19 %(in the Delta), minimum discharge will decrease 24% (downstream) and 29 % (in the Delta).

5. MRC, 2010. Scenario BDP2 focused on the impacts of CC on the Mekong basin and included the impact of upstream development: increasing water use by production, population growth and construction of hydropower. BDP2 has built time series data such as: flow at Kratie, changing precipitation, evaporation due to climate change (MRD has been divided into many part by stations evaporation, 120 irrigation zones for rain) from 2010 to 2050.

6. IWMI, 2011.Studies on transformation of rain that were incorporated into BDP2.

7. Nguyen Sinh Huy, 2011. Research scientific facilities and proposal of measures to respond to the MRD to ensure the development in term CC - NBD". In that study, the tidal deformation was studied under SLR 30 cm, 50 cm, 70 cm, 100 cm, 150 cm and 200 cm. However, the upstream developments are not mentioned in this study.

8. IRRI &SIWRP, 2007. The effect of sea level rise on the Mekong delta To assess the impact of the SLR at 10, 20, 30, 40, 50, 60, 70,100 cm. This study mentioned the construction of 08 dams by China.

9. Integrated Water Resources Planning for the Mekong Delta in the Context of CC - SLR (SIWRP, 2010): To focus to the scenarios SLR 12 cm, 17 cm, 30 cm and 75 cm, respectively the flow on the upstream dry season decreased *2 %,* 5 %, 10 *%* and 15 *%,* in flood season increase 5 *%,* 10 %, 15 %. The study has also included the change of temperature and rainfall under CC in the Mekong Delta.

10. Other studies such as: Assessment of climate change scenarios for Ca Mau Province (WWF & SIWRP, 2008), Assessing the impact of climate change and propose plans to respond to climate change in Kien Giang province (SIWRP, 2011), the regional water resources planning, provincial investment projects, etc... These studies only mention the main effect of SLR.

Additional references

1. Trần Thị Hiền, Võ Quang Minh, 2010. Ảnh viễn thảm MODIS trong theo dõi tiến độ xuống giống trên vùng đât trồng lúa ở ĐBSCL Kỷ yếu hộỉ thảo ứng dụng GIS toàn quốc 2010. Nhà xuất bản Nông nghiệp. Trang 85-93

2. Trần Thị Hiền, Võ Quang Minh, 2010. Ảnh viễn thám MODIS trong xây dựng cơ cấu mùa vụ lúa ở ĐBSCL Kỷ Yểu hội thảo ứng dụng GIS toàn quổc 2010. Nhà xuất bản Nông nghiệp. Trang 94-101.

3. Trần Văn Hùng, Lê Quang Trí, Võ Quang Minh, 2010. Đánh giá khả năng thích nghỉ đất đaỉ vùng ven biển Bạc Liêu dưởi sự hỗ trợ của hệ thống thông tin địa ỉý GIS. Kỷ Yếu hội thảo ứng dụng GIS toàn quốc 2010. Nhà xuất bản Nông nghiệp. Trang 126-132.

4. Võ Quang Minh, Nguyễn Thị Hồng Điệp, Nguyễn Thị Bích Vân, 2010. Mô phỏng sự ngập lụt ở ĐBSCL dưới ảnh hưởng của cao trình mặt đất do sự dâng cao mực nước - bằng kỹ thuật thống kê và nội suy không gian. Kỷ Yếu hội thảo ứng dụng GIS toàn quốc 2010. Nhà xuất bản Nông nghiệp Trang 184-189.

5. Trần Thị ngọc Trinh, Huỳnh Ngọc Vân, Võ Quang Minh, Quách Phương Thảo, 2010. Nghiên cứu ứng dụng GIS trong đánh giá phạm vi thích nghi một số nhóm giống lúa chịu mặn có triển vọng của Sóc Trăng. Kỷ Yếu hội thảo ứng dụng GIS toàn quốc 2010. Nhà xuất bản Nông nghiệp. Trang 264-270.

Collection data

<u>Maps</u>

Land use and cropping pattern map of the Mekong delta 1/250,000. 2008. Department of Land resources. College of Environment and Natural resources. Cantho University

Land use and projected to 2020 maps of Bac lieu province 1/100,000- 2009. Sub-NIAAP

Soilmap (WHB) of the Mekong delta 1/250,000. 2009. Department of Land resources. College of Environment and Natural resources. Can Tho University

Soil map (FAO) of Bac lieu province 1/100,000.1999. Sub-NIAAP.

<u>Satellite images</u>

M0DIS satellite images (Original resolution) 2000 to upto dated (Mekong Basin)

MODIS Land Surface Reflectance - 8 days MODIS Land surface Temperature -16 days

SPOT Quicklook (60x60m) 2000 to up to dated (Mekong delta)

LANDSAT 7 (Original resolution) 2005 to up to dated (Mekong delta)

ALOS satellite image (Original resolution) 2010 – Bac Lieu province

<u>Hydro-meteorological data</u>

Collecting and processing hydro-meteorological data, for baseline year 2008 and for three years of 1998 (dry year), 2000 (wet year), and 2004 (normal year)

List of Stations and data type as following:

Data of Upstream Discharge stations (01): Kratie;

Data of Hourly Water Level &salinty stations (09 stations): Vung Tau, VamKenh, Ben Trai, An Thuan, My Thanh, GanhHao, Ong Doc, Xeo Ro, and RachGia;

Data of Rainfall stations (41 stations): Kratie, KomPongCham , KomPongChnang, DamDek, PhnomPenh, PreyVeng , SaDan, SnoulVayRieng, TaKeo, ChauDoc,Tinh Bien, Tan Chau, VamNao, Cao Lanh, Tan An, Ha Tien, Long Xuyen, KienBinh, My Tho , Tri Ton, Nui Sap, Cai Lay, MocHoa , RachGia, Tan Hiep, VinhHung,TuyenNhon, Hung Thanh, My Thuan, Can Tho, PhungHiep, Bac Lieu, NganDua, Ca Mau, BinhThanh, Go Dau Ha, SocTrang, Vi Thanh, Ben Tre, andTraVinh;

Inside Water level stations (22 stations): Tan Chau, Cao Lanh, Chau doc, VamNao, My Thuan, My Tho, TraVinh, Cao Lanh, Cau 13, Tan hiep, TraVinh, Cho Lach, Hung Thanh, KienBinh, Cai Lay, Long Dinh, Mochoa, TuyenNhon, Tan An, Ben Luc, Phuoc Long, and Ca Mau;

Inside Salinity stations (12): CauNoi, CauQuan, Phuoc Long, ThanhPhuHuong My, Long Phu, Dai Ngai, Travinh , Ca Mau, My Tho, Tan An, and Ben Luc;

Inside Discharge stations (02 stations): Tan Chau andChau Doc.

11.2 List of publications produced by project

List of peer-reviewed papers in English:

1. Ngo Dang Phong, Chu Thai Hoanh, Tran Quang Tho, Nguyen Van Ngoc, Tran Duc Dong, To Phuc Tuong, Nguyen Huy Khoi and Nguyen Xuan Hien (2014). Impact of Sea Level Rise on submergence, salinity and agricultural production in a coastal province of the Mekong River Delta, Vietnam. In: C.T. Hoanh, V. Smakhtin and R. Johnston (Editors). Climate change and agricultural water management in developing countries. CABI Climate Change Series. CABI Publishing, UK (in press).

2. Ngo Dang Phong, Chu Thai Hoanh, To Phuc Tuong and Hector Malano (2014). Effective management for acidic pollution in the canal network of the Mekong Delta of Vietnam: a modeling approach. *Journal. of Environmental Manag*ement 140 (2014):14-25. DOI 10.1016/j.jenvman.2013.11.049.

3. Ngo Dang Phong, Chu Thai Hoanh, To Phuc Tuong and Reiner Wassmann (2014). Sea level rise effects on acidic pollution in a coastal acid sulphate soil area. In: Ames, D.P., Quinn, N.W.T., Rizzoli, A.E. (Eds.), *Proceedings of the 7th International Congress on Environmental Modelling and Software*, June 15-19, San Diego, California, USA. ISBN: 978-88-9035-744-2.

List of peer-reviewed papers in Vietnamese:

1. Nguyen Thi Hong Diep, Vo Quang Minh, Phan Kieu Diem, Pham Quang Quyet (2014). Observing changes of aquacultural land in An Giang province from 2008 to 2012 using remote sensing and GIS. *Journal of Science Can Tho University.* Volume 30a (2014): 78-83 IISSN: 1859-2333). (in Vietnamese).

2. Nguyen Thi Ha Mi, Vo Quang Minh (2014). Assessing the impact of climate change on rice farming in An Giang province. *Journal of Science Can Tho University*. Special issue: Agriculture. Volume 3 (2014): 42-52 (ISSN: 1859-2333). (in Vietnamese).

3. Nguyen Quang Trung, Vo Quang Minh, Phan Kieu Diem (2014). Assessing the changes of rice cropping in An Giang province the period 2000 - 2013 on the basis of using MODIS image. Proceedings of Application of nationwide GIS Conference 2014, Can Tho city, Vietnam, 28-29 November, 2014. Cantho University Publisher: 41-49 (ISBN: 978-604-919-249-4). (in Vietnamese).

4. Nguyen Thi Hong Diep, Vo Quang Minh, Phan Kieu Diem, Nguyen Van Tao (2014). Climate change impact on landuse in the coastal area of the Mekong Delta. Proceedings of Application of nationwide GIS Conference 2014, Can Tho city, Vietnam, 28-29 November, 2014. Cantho University Publisher: 88-94 (ISBN: 978-604-919-249-4). (in Vietnamese).

5. Le Minh Hop, Tran Thi Hien, Vo Quang Minh, Nguyen Thi Hong Diep, Phan Kieu Diem (2014). Application of MODIS image for monitoring the rice cropping pattern changes for services agricultural management in Mekong Delta. Proceedings of Application of nationwide GIS Conference 2014, Can Tho city, Vietnam, 28-29 November, 2014. Can tho University Publisher: 169-180 (ISBN: 978-604-919-249-4). (in Vietnamese).

6. Nguyen Van Phuc, Nguyen Thi Ha Mi, Phan Kieu Diem, Vo Quang Minh, Le Quang Tri, Nguyen Xuan Hien (2014). Assessing the impact of climate change scenarios to current of land use and land use planning in Hau Giang province. Proceedings of Application of nationwide GIS Conference 2014, Can Tho city, Vietnam, 28-29 November, 2014. Cantho University Publisher: 845-854 (ISBN: 978-604-919-249-4). (in Vietnamese).

Presentation at international conference

1. Reiner Wassman and Ngo Dang Phong (2014). Climate change affecting rice production in the Vietnamese Mekong Delta: potential and constraints of adaptation options. Invited presentation at the Mega Delta Symposium*, 4th International Rice Congress, Bangkok, Thailand 27 October – 1 November 2014*. International Rice Research Institute, Los Banos, Philippines. (IRC14-1137).

2. To Phuc Tuong, Chu Thai Hoanh, Tran Quang Tho, Ngo Dang Phong, Nguyen Van Ngoc, Tran Duc Dong, Nguyen Huy Khoi, Nguyen Xuan Hien and Reiner Wassmann (2014). Climate change and sea level rise effects on rice-based production systems in the Mekong River Delta. Invited presentation at the Mega Delta Symposium, *4th International Rice Congress, Bangkok, Thailand 27 October – 1 November 2014*. International Rice Research Institute, Los Banos, Philippines. (IRC14-0497).

3. Vo Quang Minh, Tran Thi Hien, Phan Kieu Diem, Nguyen Thi Ha Mi, Nguyen Xuan Hien, Le Quang Tri, Ho Van Chien (2014). Rice crop monitoring for early warning pest occurence using remote sensing and geographic information systems. Science at the 4th International Rice Congress (IRC2014), 27 October - 1 November, 2014, Bangkok, Thailand.

4. Vo Quoc Thanh, Chu Thai Hoanh, Nguyen Hieu Trung and Van Pham Dang Tri (2014). A bias-correction method of precipitation data generated by regional climate model. *Proceedings of the International Symposium on GeoInformatics for Spatial-Infrastructure Development in Earth & Allied Sciences (GIS-IDEAS)*. Da Nang City, Vietnam, 6 – 9 December, 2014. Available in http://gisws.media.osaka-cu.ac.jp/gisideas14/viewabstract.php?id=505 or http://gisws.media.osaka-cu.ac.jp/gisideas14/viewabstract.php?id=505

5. Vo Quang Minh, Huynh thi thu Huong, Nguyen thi hong Diep (2012). Monitoring and delineating rice cropping calendar in the Mekong delta using Modis images. Proceeding of International Conference on Geomatics for spatial Infrastructure development in Earth and Allied Sciences-GIS-IDEAS 2012. HoChiMinh City16-

20/October/2012. JVGC (Japan-Vietnam GeoInformatics Consortium) Technical Document No 8. Pp: 150-156.

Presentation at national conference

1. Nguyen Quang Trung, Phan Kieu Diem, Vo Quang Minh (2014). Assessing the changes of rice cropping in An Giang province the period 2000 - 2013 on the basis of using MODIS image. *Proceedings of Information Technology for Climate Change in developing exportable agricultural product in Vietnam.* Kien Giang province, Vietnam, 29 September, 2014. Science and Technology Publisher (ISBN: 978-604-6703655). (in Vietnamese).

2. Vo Quang Minh, Phan Kieu Diem, Nguyen Xuan Hien, Le Quang Tri (2014). Application of Geographic Information Technology (GIS) to identify vulnerable areas under the impact of climate change in the Mekong Delta. *Proceedings of Information Technology for Climate Change in developing exportable agricultural product in Vietnam.* Kien Giang province, Vietnam, 29 September, 2014. Science and Technology Publisher (ISBN: 978-604-6703655). (in Vietnamese).

Publication in preparation

Refereed Papers

1. Ngo Dang Phong, Tran Quang Tho, To Phuc Tuong, Chu Thai Hoanh, Reiner Wassmann, Nguyen Huy Khoi, and Nguyen Xuan Hien (2015). Flood and salinity dynamics in canal network of the Mekong River Delta under climate change and sea level rise. (Under writing)

Conference

1. Vo Quang Minh, Nguyen Thi Ha Mi, Tran Thi Hien (2015). Monitoring changes of cultivated area of rice cropping in Mekong Delta by remote sensing. Proceedings of Application of nationwide GIS Conference 2015, Ha Noi, Vietnam, 2015. (Under review

2. Nguyen Thi Ha Mi, Vo Quang Minh, Thai Thanh Du (2015). Application of GIS technology in assessing the impact of climate change on rice farming in Mekong Delta. Proceedings of Application of nationwide GIS Conference 2015, Ha Noi, Vietnam, 2015. (Under review)

3. Thai Thanh Du, Nguyen Thi Ha Mi, Vo Quang Minh (2015). GIS in the assessment of variation of rice crops under impacts of climate change in Bac Lieu province. Proceedings of Application of nationwide GIS Conference 2015, Ha Noi, Vietnam, 2015. (Under review)

12 Appendixes

12.1 Verification model in year 2008

No	Station	EF	R2	Rank	Maximum Water level (Flood Season)		Average Water level (Dry Season))	
					Observed	Simulated	Observed	Simulated
1	Tan Chau	0.98	0.93	Perfect	3.94	3.89	1.01	0.97
2	Chau Doc	0.97	0.98	Perfect	3.54	3.46	0.92	0.84
3	Cao Lanh	0.82	0.96	Good	2.33	2.31	0.72	0.62
4	My Thuan	0.98	0.98	Perfect	2.01	2.09	0.43	0.42
5	My Tho	0.95	0.96	Perfect	1.83	1.89	0.31	0.27
6	Long Xuyen	0.90	0.96	Good	2.5	2.6	0.76	0.69
7	Can Tho	0.94	0.95	Good	2.17	2.24	0.46	0.44
8	Dai Ngai	0.97	0.97	Perfect	2.13	2.16	0.29	0.29
9	MocHoa	0.87	0.92	Good	2.03	2.15	0.62	0.59
10	Tan An	0.90	0.92	Good	1.58	1.66	0.33	0.29
11	Ben Luc	0.95	0.95	Perfect	1.61	1.72	0.32	0.30
12	Hung Thanh	0.92	0.97	Good	2.33	2.36	0.78	0.65
13	KienBinh	0.85	0.90	Good	1.62	1.73	0.61	0.57
14	Xuan To	0.95	0.90	Perfect	3.32	3.35		
15	Tri Ton	0.97	0.93	Perfect	2.38	2.38	0.51	0.60
16	Tan Hiep	0.97	0.89	Perfect	1.53	1.47	0.43	0.45
17	ViThanh	0.87	0.67	Accepted	0.81	1.06	0.37	0.31
18	PhungHiep	0.86	0.94	Good	1.53	1.54	0.50	0.44
19	Phuoc Long	0.72	0.54	Accepted	0.79	0.93	0.46	0.40
20	Ca Mau	0.70	0.74	Accepted	0.92	1.41	0.45	0.48

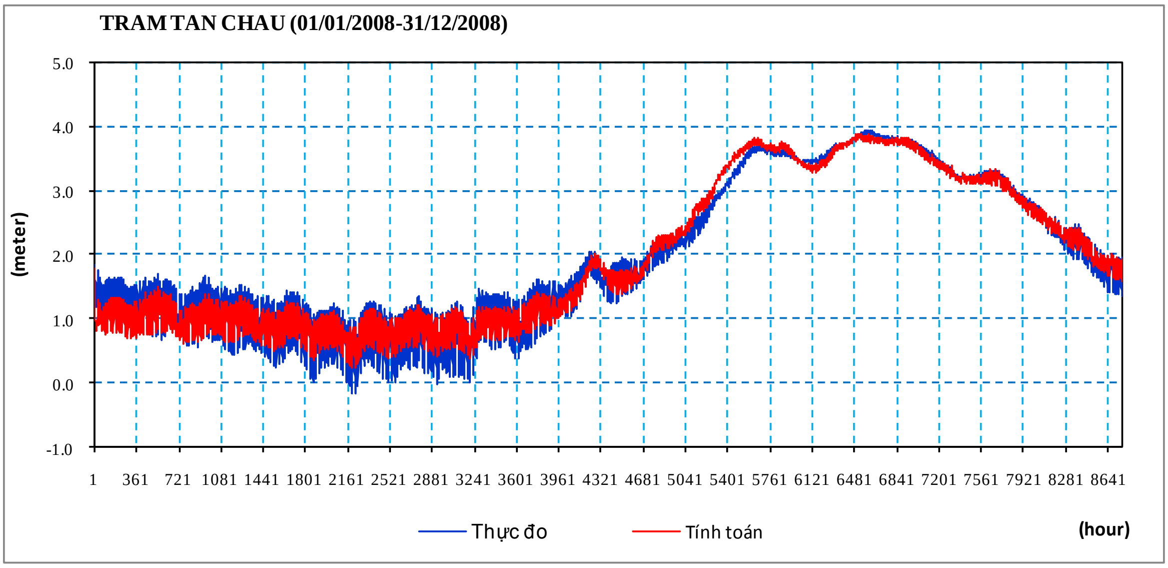


Figure 37.Observed and simulated water level at Tan Chau station in 2008

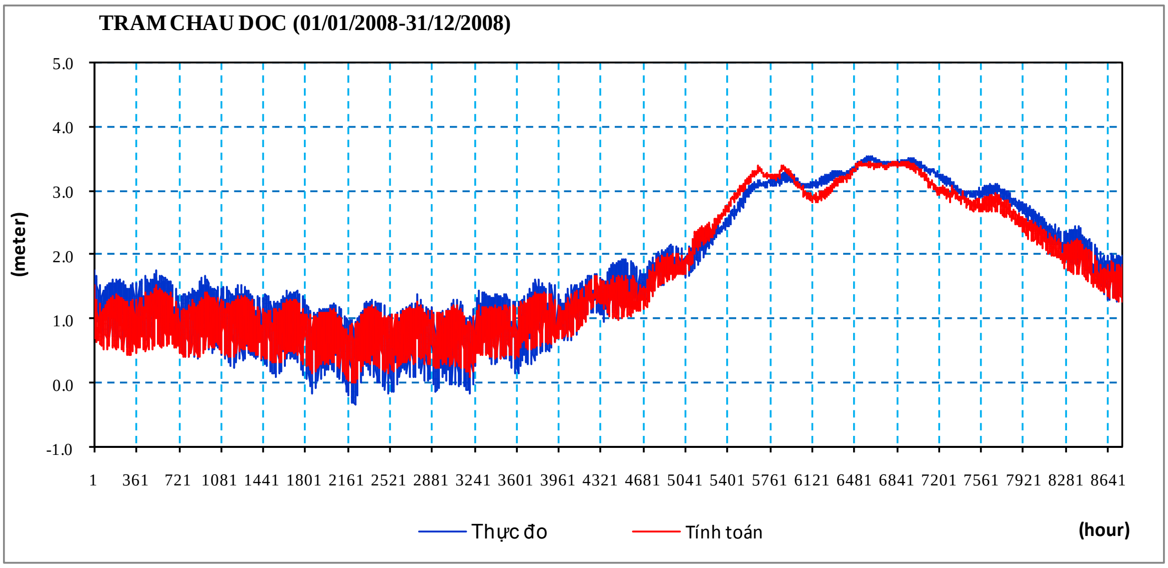


Figure 38.Observed and simulated water level at Chau Doc station in 2008

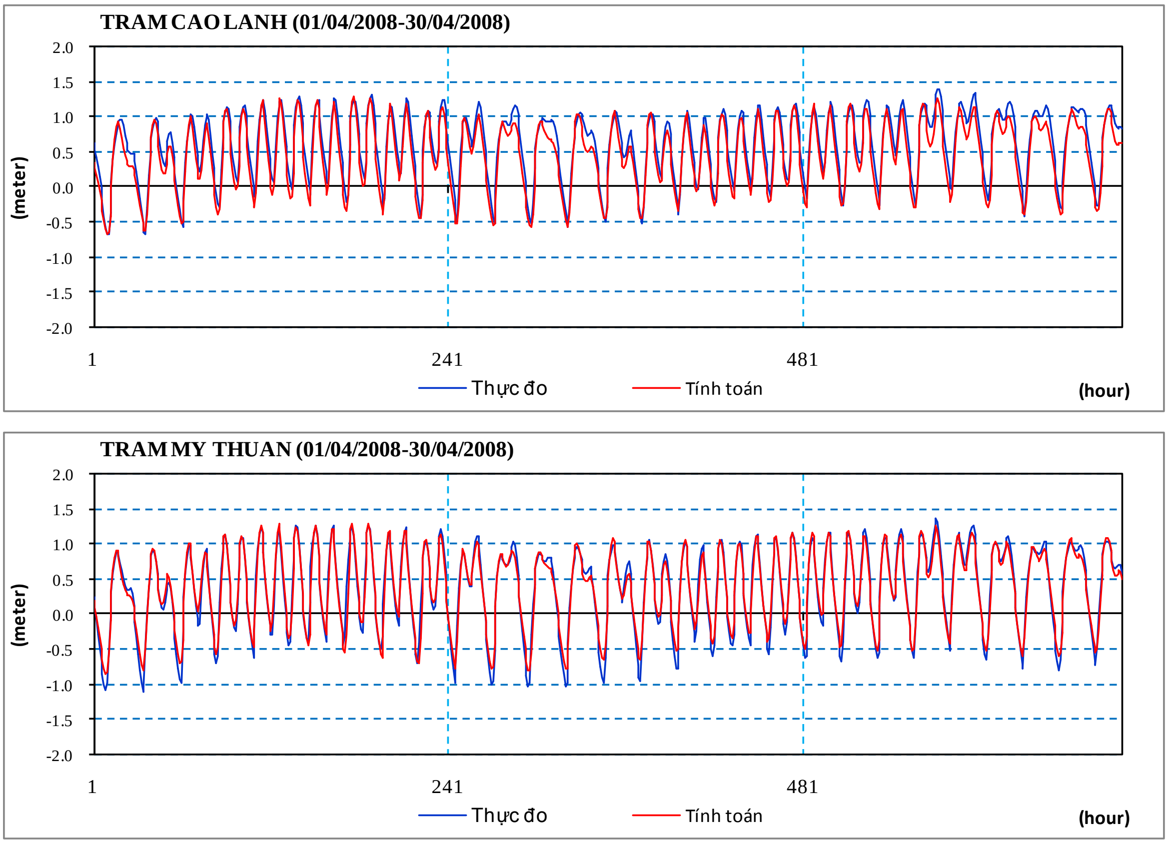
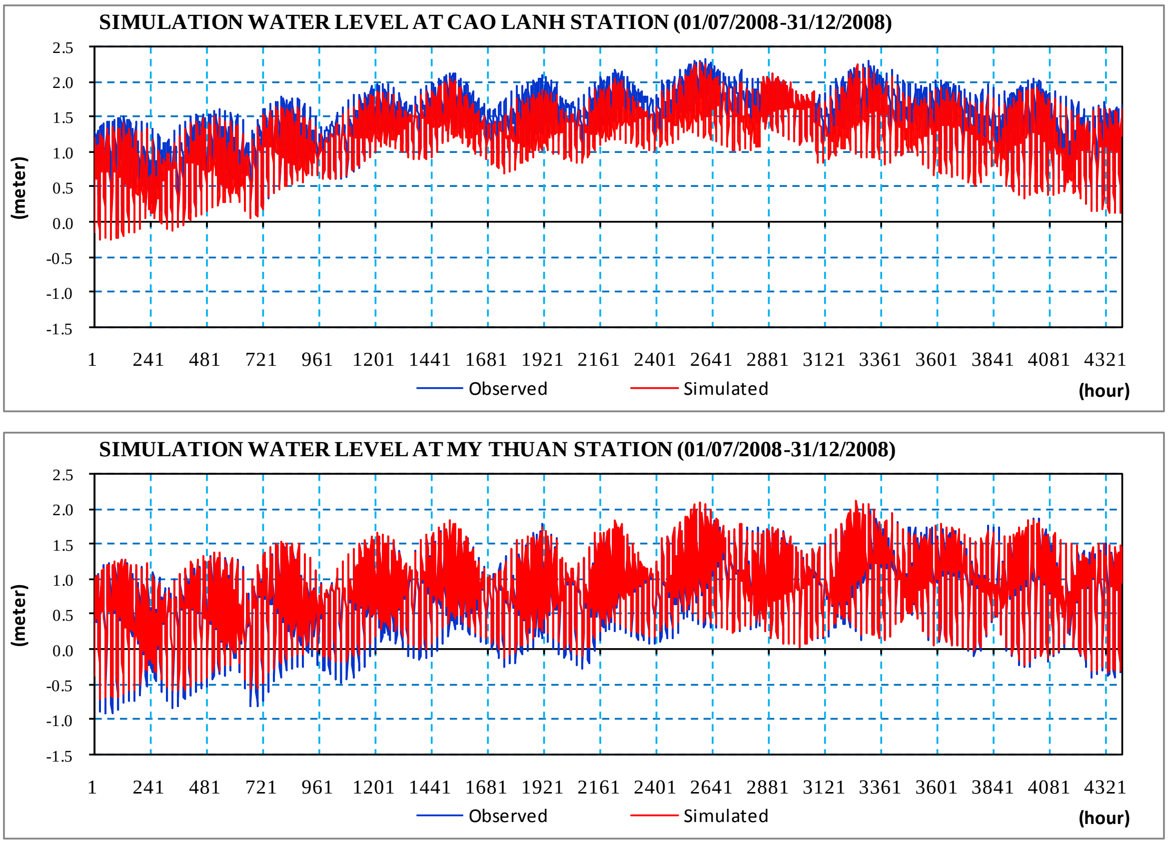


Figure 39.Observed and simulated water level at Cao Lanh, My Thuan, and My Tho stations in April 2008



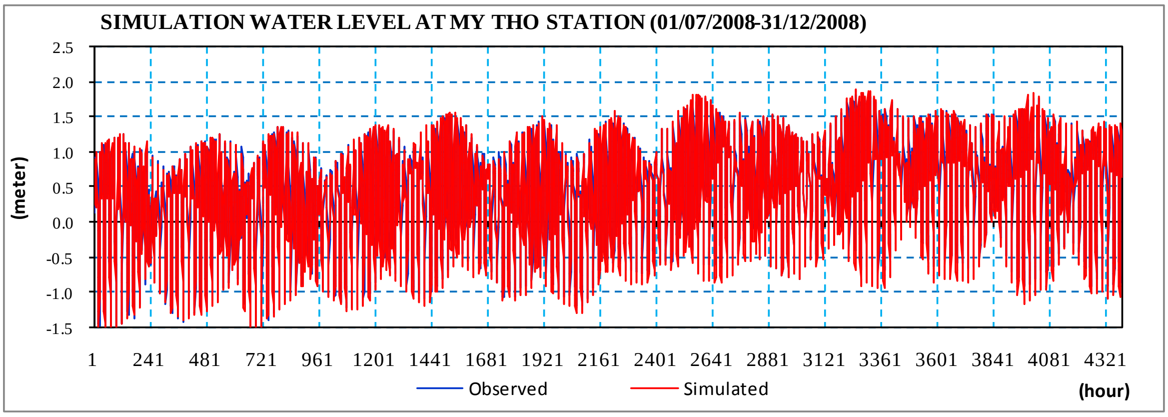
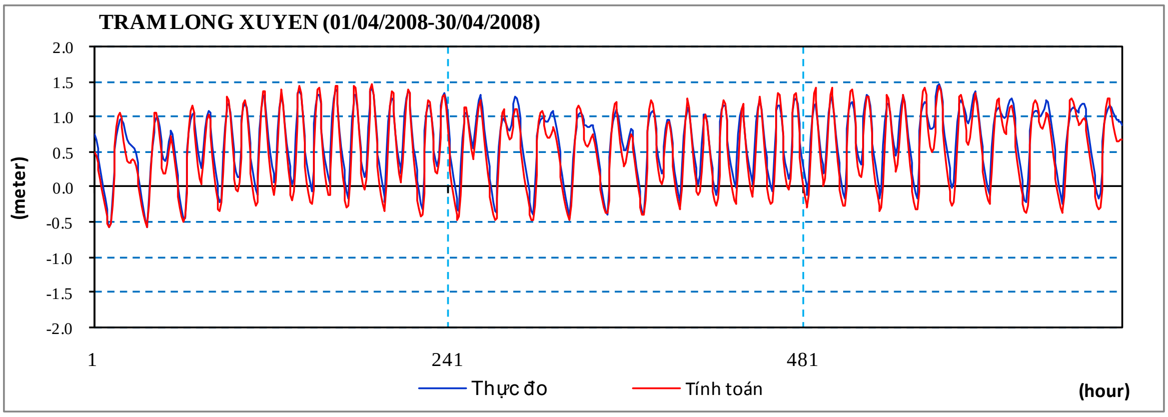
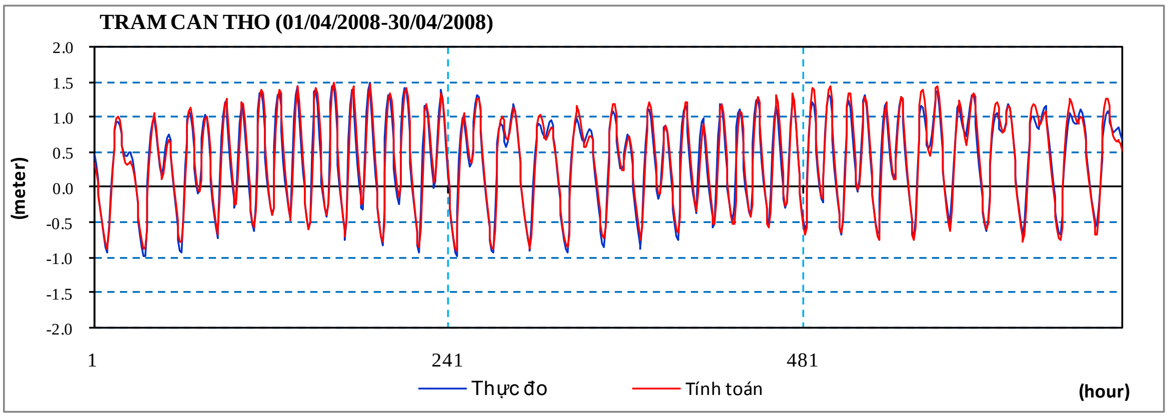


Figure 39.Observed and simulated water level in Cao Lanh, My Thuan and My Tho station in flood season of the year 2008 (July – December)





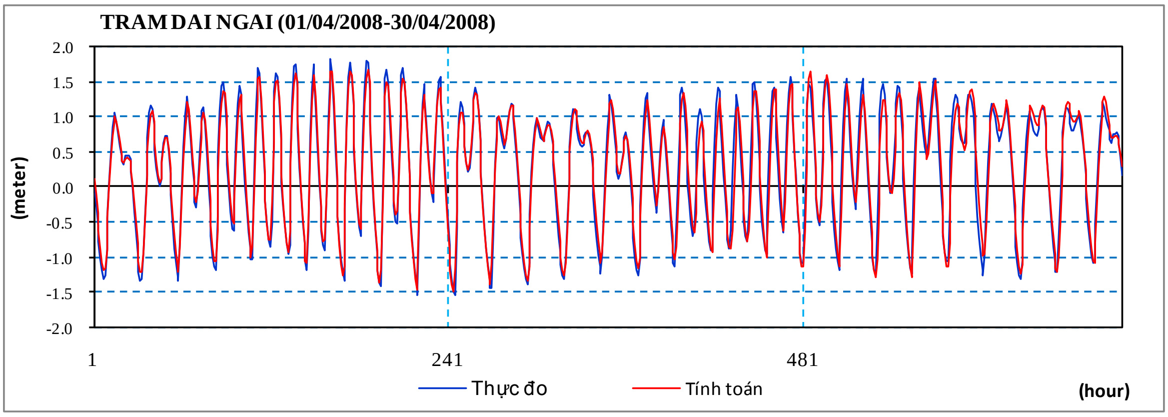


Figure 40.Observed and simulated water level at Long Xuyen, Can Tho, and Dai Ngai stations in April 2008

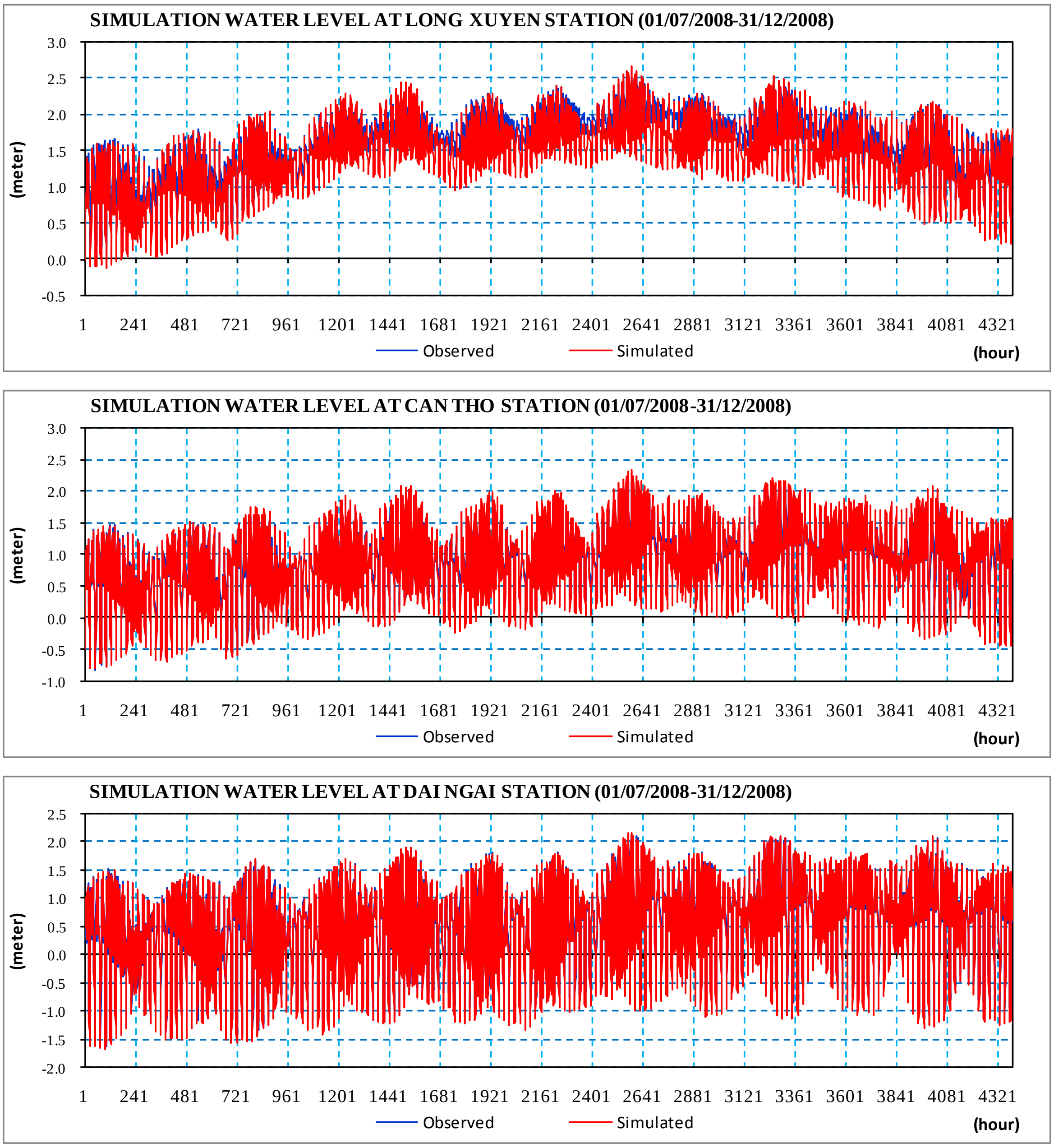


Figure 41.Observed and simulated water level at Long Xuyen, Can Tho, and Dai Ngai stations in flood season of the year 2008 (July – December)

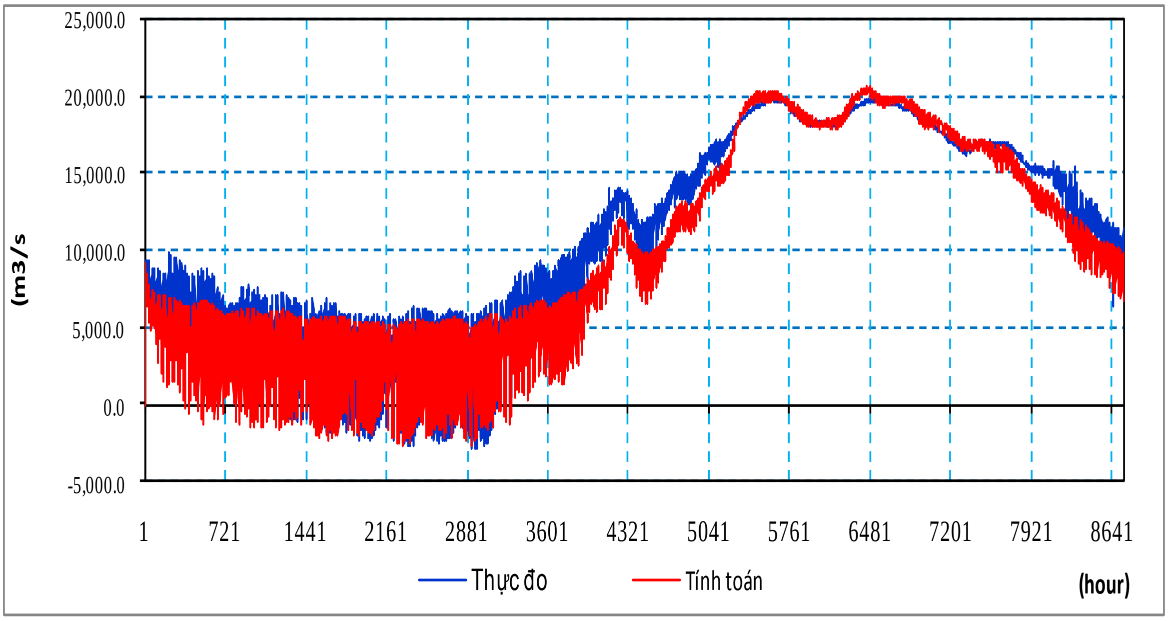


Figure 42.Observed and simulated discharge at Tan Chau station in 2008

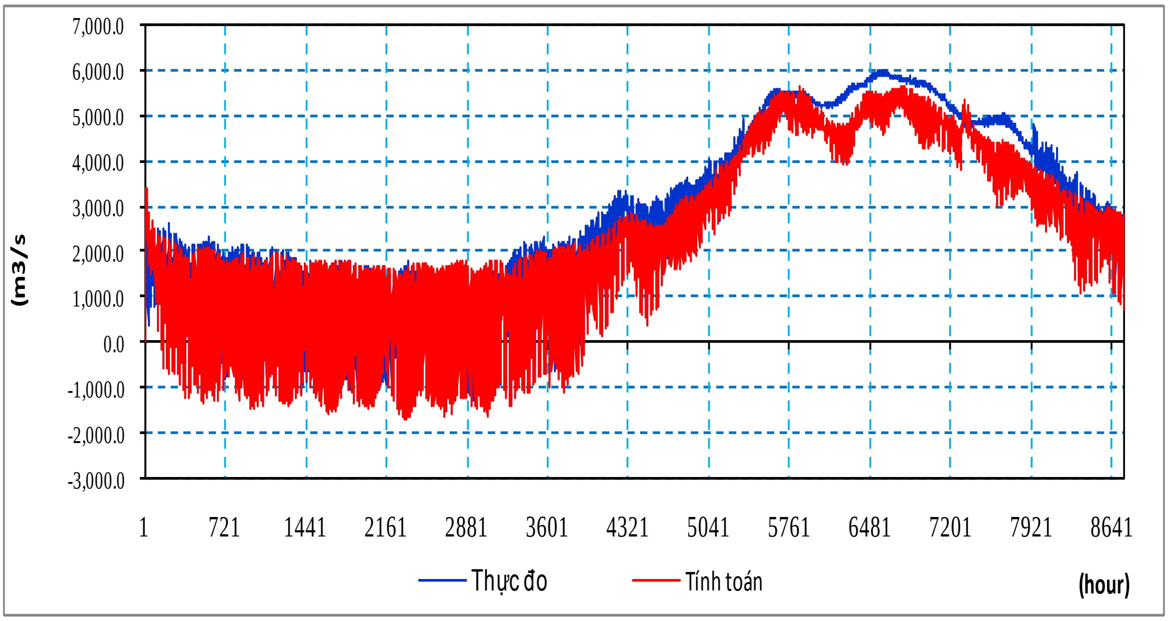


Figure 43.Observed and simulated discharge at Chau Doc station in 2008

12.2 Selection conditions of low, rainfall, and sea level for future scenarios

a. Selection of sea level data

Water level at coastal boundaries for low, average and high water years are observeddata in 1998, 2004 and 2000, respectively.

Sea level rise is based on the new revised MoNRErepport in 2011, 15 cm and 27 cm inthe East Sea, and 15 cm and 30 cm in the West Sea for 2030 and 2050, respectively.

b. Selection of low, average and high rainfall years.

The following procedure was applied to select the low, average and high rainfall years.

An example of the selection is presented in Table 7.

- Calculate annual rainfall for at each station in the model scheme for 2 periods: near future 2020-2035 and far future 2035-2050 from adjusted PRECIS rainfall data.
- Calculate average annual rainfall for the whole MRD for the 2 periods.
- Calculate 3-year moving average rainfall of MRD annual rainfall for the 2 periods.
- Select values of low, average and high rainfall from 3-year moving average rainfall for each period.
- Select years with annual rainfall closest to these low, average and high 3-year moving averages in each period. The 3-year moving average is used to avoid from selecting on extremely irregular rainfall in certain year.
- Revise the monthly variations in selected years to check if irregular monthly rainfall (e.g. too high rainfall in dry season or beginning of rainy season) appears in these years. If there is irregular monthly rainfall in certain year, select another year with annual rainfall close to the target value (not necessary to be closest)

The selected years for MRD rainfall are presented in Table 7 by applying that selectionprocess.

Table 7. Selected years for MRD rainfall under B2 climate change scenario

Specific year	Baseline (1995-2010)	2030 window (2020-2035)	2050 window (2035-2050)
Low rainfall	1998	2033	2041
Average rainfall	2004	2028	2045
High rainfall	2000	2030	2044

Note: * For the past, these selected years are based on upstream flow at Kratie, therefore corresponding rainfall in these year are used.

c. Analysis of upstream flow changes

The cyclic analysis method was implemented to show the changes of the Mekong flow from the past 1985-2000 to the future in two periods 2020-2035 and 2035-2050 projected by the study of Mekong River Commission (MRC). The analysis included the percentile, max, min, average flows and frequencies of flows. The following results are from the analysis as examples.

Flow distribution at P = 50%

Figure 445 shows the results of flow at P=50% in the past 1985-2000, near future 2020-2035 and far future 2035-2050. In June to August, the flow in the near future is higher than that in the past, but in the far future flow will be lower. From September to February the flows in both near and far futures will be higher than in the past around 10,000 m3/s.

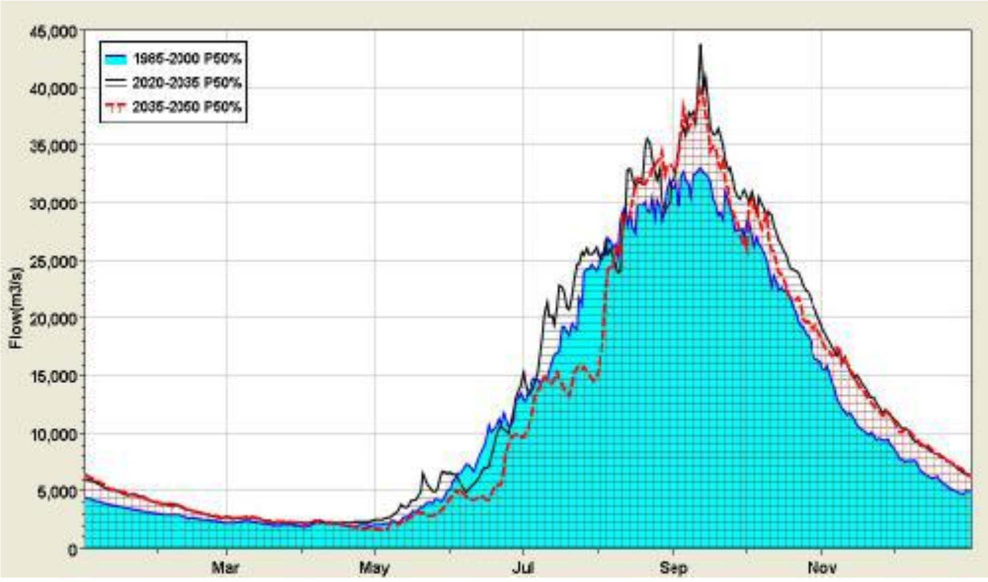


Figure 44. Variations of P=50% flow in the past (1985-2000), near future (2020-2035) and far future (2035-2050)

Maximum flow

As showed in Figure 45, maximum flow gradually decreases from January to April, then increases from May to reach a peak in August to October. However, in the near future, peak flow may also exist early in May. Peak flows in both near and far future periods are higher than the past. The highest of over 90,000 m^3/s will appear in the far future, but higher peak flows will occur during the near future.

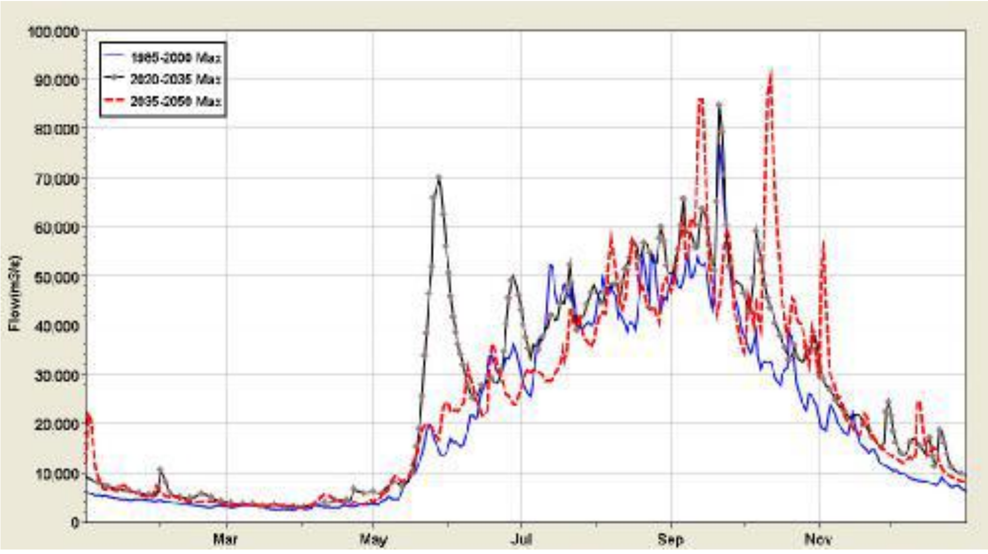


Figure 45. Maximum flow in the past (1985-2000), near future (2020-2035) and far future (2035-2050)

The monthly peak flows in each period are presented in ***Table 8***. In the past the peak flow used to appear in August (8 times in 16 years). However, it will appear frequently in September (10 and 9 times in 16 years in the near future and far future, respectively).

Table 8. Frequency of peak flow in each month during the flood season

Unit: times in 16 years

Month	1985-2000	Near future 2020-2035	Chuyểntiếp future 2035-2050
May	0	1	0
June	0	0	0
July	2	0	0
August	8	2	4
September	4	10	9
October	2	3	3

Average flow

As showed in Figure 46, the average flow from May to September in the near and far future periods does not change much from the past that compared to the variation of maximum flow. However, from September to the end of rainy season, the average flows in these periods are higher than in the past, the maximum flows in these months are also higher.

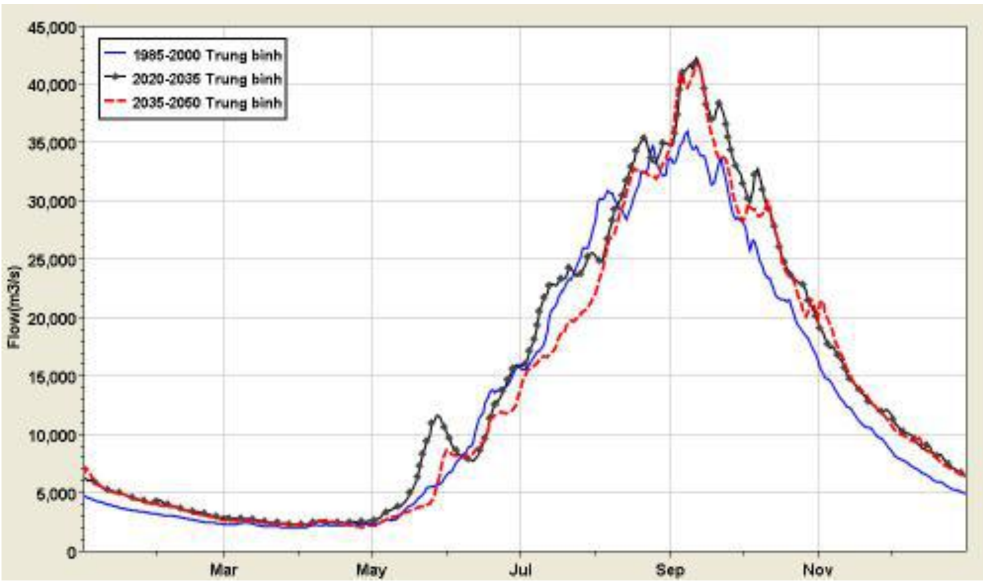


Figure 46. Average flow in the past (1985-2000), near future (2020-2035) and far future (2035-2050)

Minimum flow

As showed in Figure 47, the minimum flow from June to September in future periods is lower than in the past. From September to the year end, minimum flow in the near future is close to that in the past, but in the far future minimum flow is higher.

Figure 47. Minimum flow in the past (1985-2000), near future (2020-2035) and far future (2035-2050)

In the past, minimum flow and volume used to appear in March and April (***Table 9***) and rarely exist in May, but in future these extremes will be found in May and June.

Table 9. Frequency of minimum flow Q and month volume V in each month

Unit: times in 16 years

Month	1985-2000		Near future 2020-2035		Far future 2035-2050	
	Qmin	Vol. min	Qmin	Vol. min	Qmin	Vol. min
March	4	8	0	4	2	3
April	11	8	9	9	3	8
May	1	0	4	3	9	4
June	0	0	2	0	2	1
July	0	0	1	0	0	0

Taking into account the maximum flow in the rainy season and the minimum flow in the dry season, years with low, average and high water in the future are presented in

Table 10 .

We cannot select certain year that satisfies for all low, average or high water in both flood season (for considering inundation) and dry season (for considering salinity intrusion). Therefore different years were selected for flood and dry seasons.

Table 10. Selected years represented for low, average and high water in the future

Specific year	Near future 2020-2035		Far future 2035-2050	
	Dry season	Flood season	Dry season	Flood season
Low water	2030	2023	2045	2045
Average water	2031	2033	2036	2050
High water	2025	2032	2041	2047

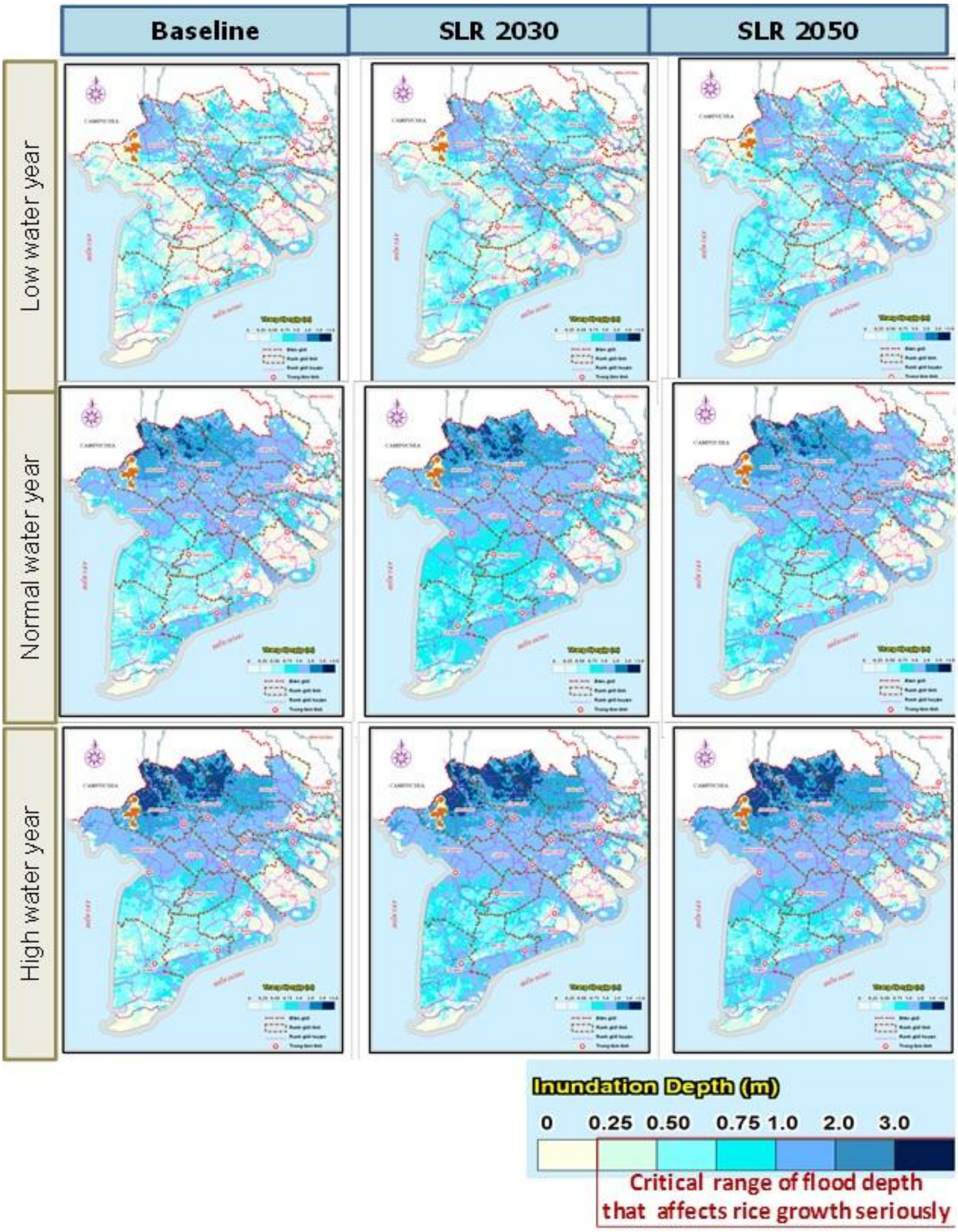


Figure 49.Maximum inundation depth in rainy season in years of low water (1998), high water (2000) and average water (2004) without and with SLR of 15 and 30 cm

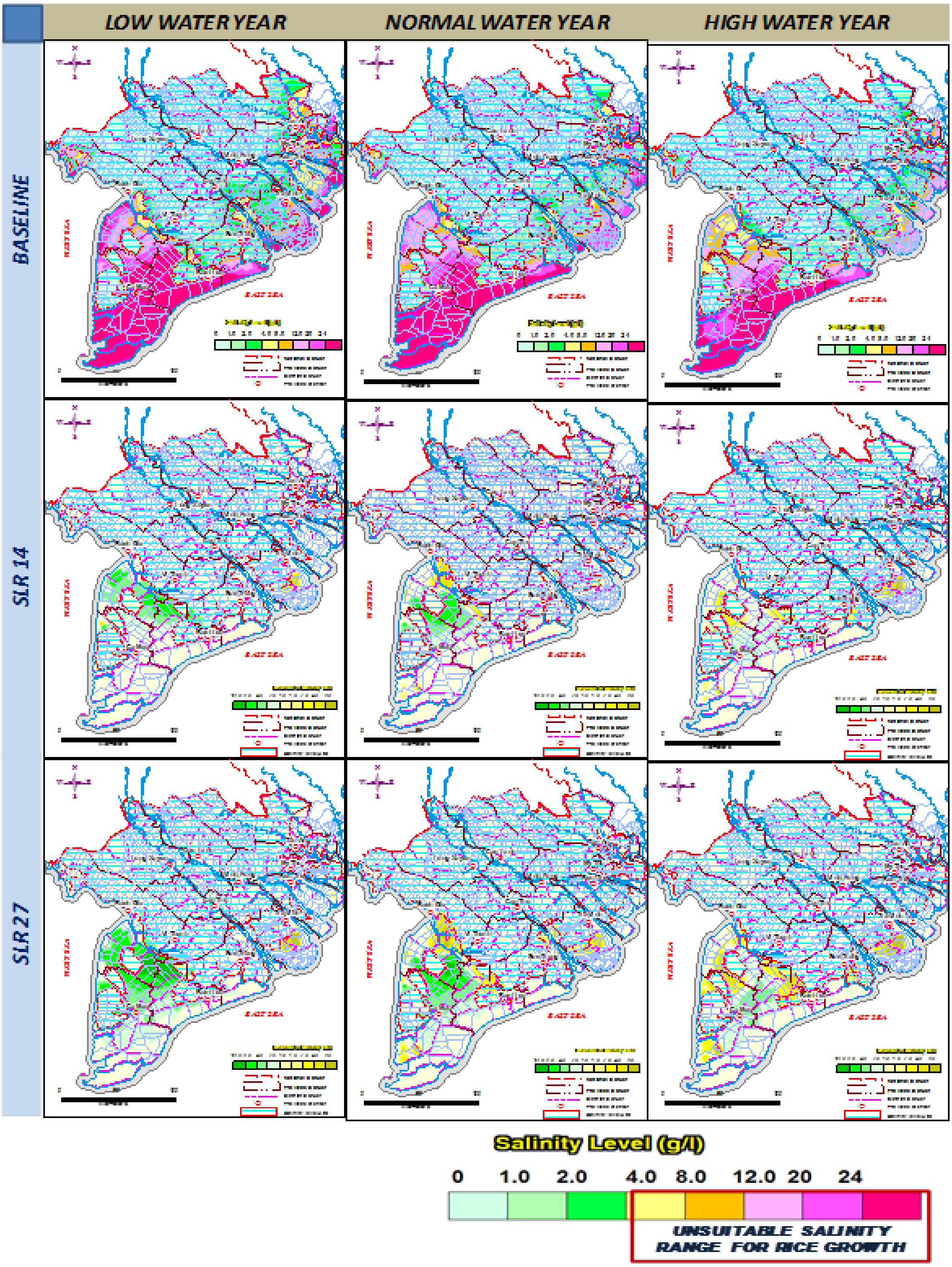


Figure 48.Saline intrusion in dry season ofyears of low water (1998), high water (2000) and average (2004) without and with SLR of 14 and 27 cm

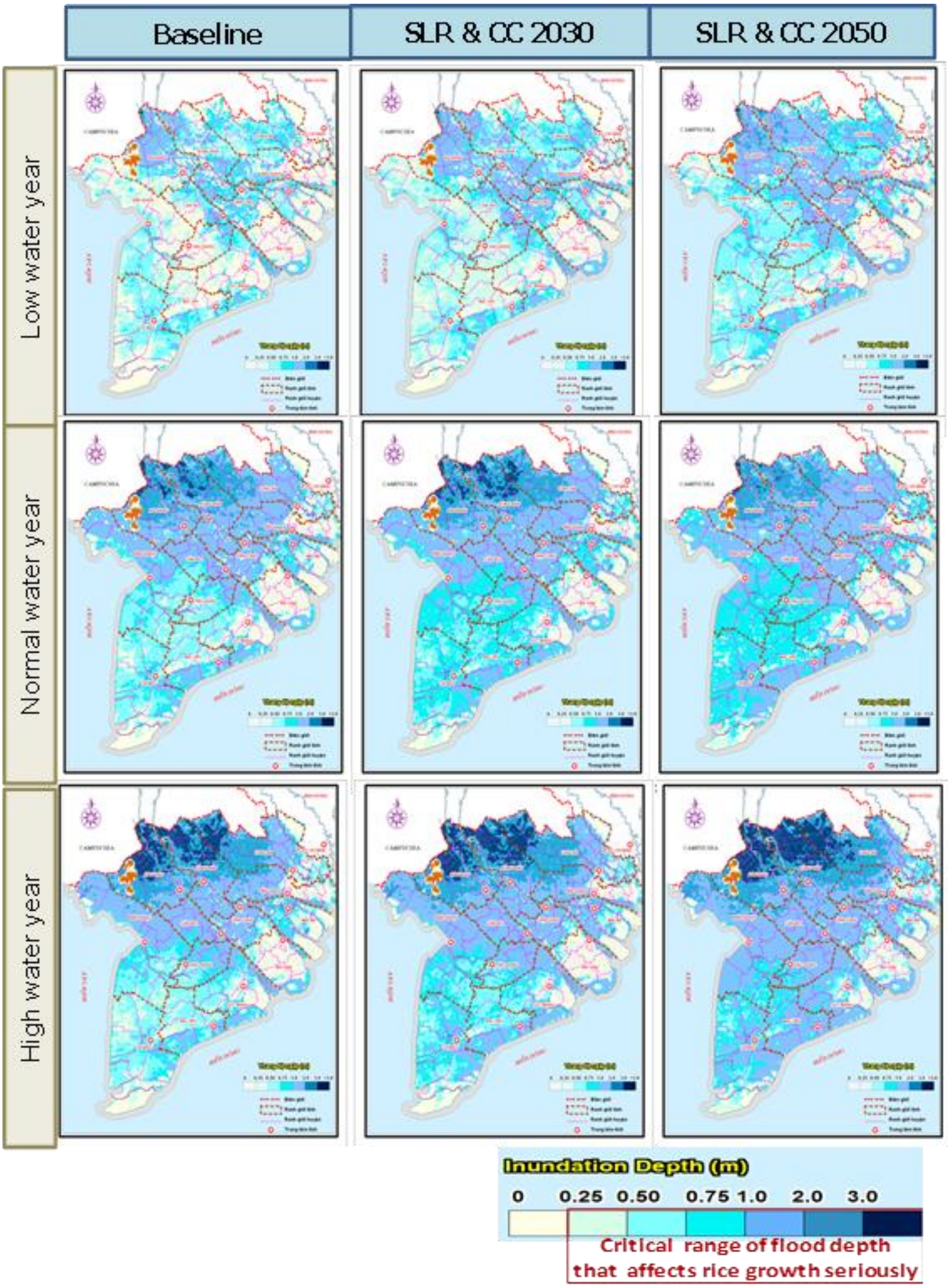


Figure 49.Maximum inundation depth in rainy season in years of low water (1998), high water (2000) and average water (2004) without and with SLR + CC

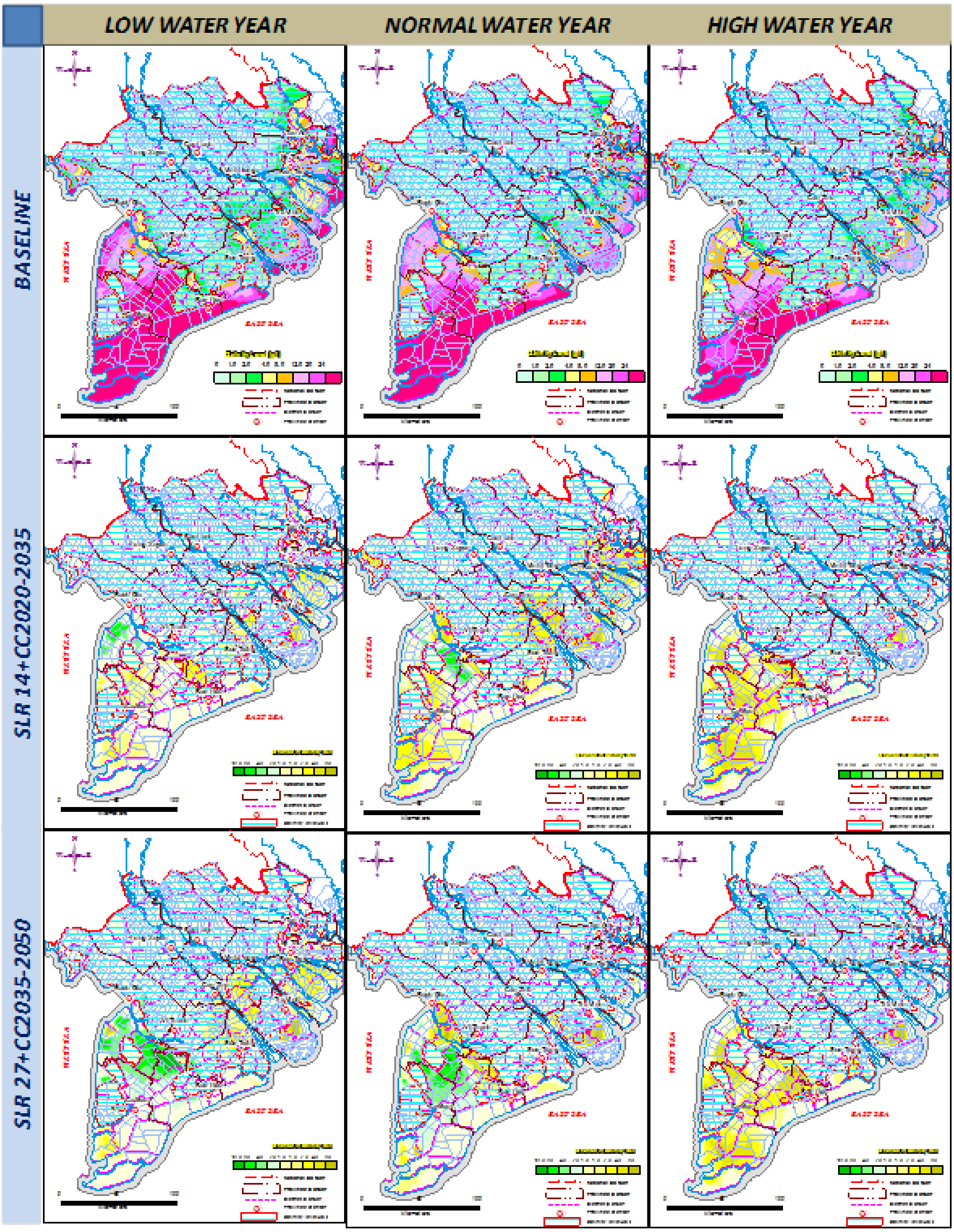


Figure 50.Saline intrusion in dry season ofyears of low water (1998), high water (2000) and average (2004) without and with SLR + CC

Australian Government

Australian Centre for
International Agricultural Research

Final report

project	**Climate Change Affecting Land Use in the Mekong Delta: Adaptation of Rice-based Cropping Systems (CLUES)** Theme 2: Improvement of salinity tolerance and submergence resilience of locally-adapted rice varieties and elite lines
project number	SMCN/2009/021
date published	May 2015
prepared by	Nguyen Thi Lang, Russell Reinke & Abdel Ismail
co-authors/ contributors/ collaborators	Pham Thi Thu Ha, Bui Phuoc Tam, Tran Thi Nhien, Nguyen Trong Phuoc,Tran Bao Toan, Nguyen van Hieu, Nguyen Hoang Thai Binh, Pham Cong Tru, Bui Chi Buu, Romeo V. Labios, Reiner Wassmann.
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Contents

1 Acknowledgments

The work of the entire team of students, researchers and technicians at Cuu Long Rice Research Institute is gratefully acknowledged, for their efforts in planning and conducting research trials at CLRRI, but also in farmer's fields in each of the four Vietnamese provinces on which the project work was focused. Successful conduct of the trials involved multiple visits requiring significant travel, but these trials were the key to evaluation of breeding material and engagement with farmers and each are of similar importance in creating impact.

Thanks is due also to the farmers, who were willing co-operators, allowing research staff to visit their fields to establish and monitor trials, and who participated extensively in evaluating the trial plots at maturity.

2 Executive summary

The breeding component of the CLUES project was aimed at developing high-yielding rice varieties with enhanced stress tolerance to provide farmers with additional options to respond to the impacts of climate change.

We aimed to develop varieties tolerant to periods of complete submergence, tolerant to periods of stagnant flood (in which plants are not submerged but must withstand 25-50cm depths for extended periods), and tolerant to saline conditions. A further aim was to combine tolerance to multiple stresses, and multiple crosses were done for combining salinity tolerance, submergence tolerance, medium stagnant water tolerance, earliness, and premium quality rice into high-yielding genetic backgrounds.

Two crosses were made specifically to combine genes for tolerance to both salinity and submergence and progeny from these crosses were advanced to BC_3F_4 using the combined effects of marker-aided selection and screening under stress conditions. Pedigree generations were grown under controlled submergence conditions at Cuu Long Rice Research Institute (CLRRI), under natural stagnant flood conditions at sites in Can Tho, Hau Giang, and An Giang provinces, and under salinity stress in Bac Lieu province. In total, 108 progenies were selected from BC_3F_4 populations, and 239 plants from the F_4 generation were tested for two stress tolerance genes (*Sub1* and *Saltol*) in combination. A further 12 backcross populations were developed to transfer *Sub1* and *Saltol* into adapted genetic backgrounds of rice varieties from Australia, and lines selected from these populations transferred back to Australia under the necessary quarantine protocols.

Existing genetic material (landraces, modern varieties and breeding lines) with greater stress tolerance were also evaluated throughout the term of the project, using participatory varietal selection procedures, and many beneficial lines were identified. Under rainfed lowland conditions in Can Tho province, five advanced lines/varieties demonstrated improved productivity following exposure to 0.8-1.0 m water depths for 15-20 days, and producing 4-5 t/ha yield. As a result of this testing, advanced lines/varieties such as OM10041, Can Tho 1, OM3673, OM4488 and OM8108 are being out-scaled. Similarly under submergence stress conditions in An Giang province, the lines/varieties OM8928, OM10179, and IR64-Sub1 demonstrated yields in excess of 4 tonnes/ha. In Bac Lieu province where the predominant stress is salinity, OM6328, OM3673, and OM10252 were shown to be best-bet varieties for famers, while in Hau Giang province under a combination of submergence stress and acid sulfate soils, OM8928, OM8108, and OM3673 showed improved yield stability.

In areas currently suffering from the individual or combined effects of salinity and submergence, provision of nucleus seed of improved breeding lines/varieties can speed adoption. A total of 5 tonnes of seed of beneficial lines/varieties was distributed during the term of the project within each of the targeted provinces, including Bac Lieu (990kg of eight lines), Hau Giang (990kg of eight lines), Can Tho (1,276kg of four lines) and to An Giang (a total of 1,725kg comprising four lines).

The breeding component of the CLUES project sought to increase the impact of such varieties with enhanced stress tolerance can be amplified by distributing seed to target areas, multiplying quantities of seed of available varieties on-farm for immediate distribution. Although beyond the scope of this component, impacts may be further amplified by establishing seed multiplication facilities in target areas for further multiplication.

The breeding component of the CLUES project has facilitated scientific research and training of scientific staff. Participatory variety selection involved a total of 3,960 (3,260 male and 700 female) farmers across four provinces – An Giang, Can Tho, Hau Giang, and Bac Lieu). Two workshops were held to discuss progress with farmers and deliver useful information from the project, with extensive involvement of local staff. One hand book for training was also delivered to the farmers and will be valuable reference for subsequent research. Four varieties were submitted for release during 2014, the final year of the project, including: OM3673 with short growth duration and improved anaerobic germination; OM10252 with tolerance to submergence and salinity; and OM6328 and OM6677 with improved salinity tolerance and high yield potential.

3 Background

The Mekong Delta is Vietnam's main rice area and accounts for half of the annual rice production. The Delta's rice land use is divided into agro-hydrological zones which are controlled by the hydrology, especially the flood duration and depth, water availability and the salinity regimes. Over the last 30 years Vietnamese farmers have been adapting to the changing environmental conditions by modifying and diversifying their production systems and water management.

The overall aim of the project was to increase the adaptive capacity of rice production systems in the Mekong Delta Region (MDR). The immediate objective is to provide to farmers and management agencies the technologies and knowledge that will improve food security in the Mekong Delta. Of the five main project objectives, Theme 2 focused on the improvement of salinity and submergence resilience of locally-adapted rice varieties and elite lines.

Lines with greater tolerance to these abiotic stresses will add to the resilience of rice farmers in the face of increasing stresses from flooding and salinity, and the breeding component of the CLUES project aimed at improving cultivars in terms of tolerance to stagnant flood, salinity stress, and anaerobic conditions during germination. Marker assisted backcrossing in combination with screening under naturally occurring stress conditions was carried out to enable introgression of these plant traits into popular varieties and high-yielding genetic backgrounds adapted to the Mekong Delta.

4 Objectives

Theme 2: Improvement of salinity and submergence resilience of locally-adapted rice varieties and elite lines

The plant breeding component aimed to improve tolerance of rice germplasm to a variety of direct and indirect impacts of climate change, namely:

1. complete submergence through transfer of the *Sub1* gene into locally developed lines
2. partial stagnant flood through further identification and development of germplasm tolerant of these conditions, and investigation of the physiological mechanism conferring adaptation
3. flooding during germination through transfer of stage-specific tolerance to anaerobic conditions
4. salinity through transfer of *Saltol* gene into varieties of suitable maturity and adaptation, separately and in combination with *Sub1* for coastal areas experiencing both stresses

5 Methodology

The strategy germplasm development is to incorporate tolerances to specific abiotic constraints into locally-adapted varieties and elite lines. This uses and transfers technology developed at IRRI, building capacity and setting in place the capability in Vietnam to rapidly introgress adaptive traits into future varieties and elite lines, in response to emerging threats.

Theme 2 employed the following approaches:

- Marker-assisted backcrossing (MABC) for transfer of tolerance genes to salinity (*Saltol*) and flooding (*Sub1* and tolerance to anaerobic conditions during germination, AG) into locally-adapted lines. The traits will be transferred both separately and in combination
- Molecular approaches were implemented to select for the target loci (foreground), minimize linkage drag (flanking regions) and select for the background of the recurrent parents (background markers) which saves considerable time and results in the recovery of the genetic background adapted to the target environment.
- *Saltol* was transferred into two Australian varieties (i.e. a temperate japonica background) and *Sub1* into a single Australian variety at IRRI. Broadly-adapted Australian varieties were selected to receive the traits, for direct variety improvement and to provide a repository of the traits in a temperate japonica background for future breeding.
- Screening was conducted for the identification of donors for tolerance to partial stagnant flood to benchmark tolerance in existing traditional lines against current popular lines
- Local scientists received degree and non-degree training for in MABC, both in-countries as well as via exchange visits.

Activities:

Activity 2.1: Identify locally adapted varieties and elite breeding lines as recipients of *Sub1* and *Saltol*

Activity 2.2: Generate and disseminate improved rice lines tolerant of temporary (complete) submergence -- through transfer of the *Sub1* gene into local popular varieties and newly developed elite breeding lines

Activity 2.3: Generating and disseminating improved rice lines tolerant to salinity through transfer of *Saltol* gene into varieties of suitable maturity and adaptation, separately and in combination with *Sub1*

Activity 2.4: Generating improved rice germplasm resilient to stagnant (partial) flood – through further identification and development of germplasm tolerant to these conditions, and investigation of the physiological mechanism conferring adaptation

Activity 2.5: Exploring improvement of rice germplasm resilient to flooding during germination and early seedling establishment – through investigation tolerance to anaerobic conditions during germination

6 Achievements against activities and outputs/milestones

Objective 1: To transfer the Sub1 QTL into adapted germplasm

No.	Activity	Outputs/ Milestones	Completion Date	Comments
1.1	Identify locally adapted varieties and elite breeding lines as recipients of Sub1	Recipient lines identified	April to - August 2011	Completed
1.2	Generate and disseminate improved rice lines tolerant of temporary (complete) submergence -- through transfer of the Sub1 gene into local popular varieties and newly developed elite breeding lines	Sub1 introgressed into 2 locally adapted materials from Vietnam and one variety from Australia	March to December	A total of 108 BC_3F_4 lines from the cross OM1490/IR64-Sub1 and 200 BC_3F_4 lines from the cross OMCS2000/IR64-Sub1 have been genotyped for the presence of the SUB1 QTL and tested under submergence stress to confirm the tolerance. These lines match the performance of the OM1490 and OMCS2000 parents and selected lines can be multiplied and tested for release
1.3	Backcross SUB1 into Australian rice genetic background	Backcross populations produced and selected	April 2015	Seed of BC_2F_4 populations sent to Australia Plant Quarantine

PC = partner country, A = Australia

Objective 2: To improve tolerance to partial stagnant flood

No.	Activity	Outputs/ Milestones	Completion Date	Comments
2.1	Screening of germplasm	100 landraces and 100 current varieties benchmarked	December 2013	Three landraces demonstrated good survival and recovery stage growth, Mot Bui Do, Tep Hanh and Tai Nguyen Duc Also three improved varieties, namely OM10252, OM3673 and OM10276 had good survival and recovery
2.2	Generating improved rice germplasm resilient to stagnant (partial) flood	Testing of breeding lines under naturally-occurring stagnant flood conditions	March 2015	A total of 12 rice genotypes with a degree of tolerance to stagnant flood together with an additional farmer's variety were evaluated in selected farmer's fields at Hau Giang province The farmers preferred five varieties - OM 7347, Can Tho 2, Hau Giang 2, Can Tho 3 and OM 6L, and three of these varieties are already included in seed multiplication in 2014. Similarly, 12 stagnant-flood tolerant rice genotypes and additional entry of farmer's variety were evaluated in selected farmer's fields at Can Tho

PC = partner country, A = Australia

Objective 3: To investigate anaerobic germination

No.	Activity	Outputs/ Milestones	Completion Date	Comments
3.1	Screening of germplasm	Landraces and current varieties tested for tolerance to anaerobic germination	May 2012	More than 200 landraces and current varieties were screened under anaerobic conditions, and promising lines identified.
3.2	Exploring the genetic basis of tolerance to anaerobic conditions during germination to facilitate improvement	F_2 populations between susceptible and tolerant lines were developed for QTL analysis	May 2014	Two significant QTLs associated with the AG trait were detected from a cross Tai Nguyen/Andabyeo. They were located on chromosomes 1 and 11, respectively In particular, the QTL on chromosome 1 had an LOD score of 7.45

PC = partner country, A = Australia

Objective 4: To transfer salinity tolerance into adapted germplasm

No.	Activity	Outputs/ Milestones	Completion Date	Comments
4.1	Identify locally adapted varieties and elite breeding lines as recipients of *Sub1* and *Saltol*	Recipient lines identified	April to - August 2011	Completed
4.2	Generating and disseminating improved rice lines tolerant to salinity through transfer of *Saltol* gene into varieties of suitable maturity and adaptation, separately and in combination with *Sub1*	Saltol introgressed into 2 locally adapted materials from Vietnam and 2-3 varieties from Australia	April 2015	More than 100 BC_4F_3 lines have been selecting from two backcross populations: OM1490*4/Pokkali and OMCS2000*4/Pokkali These lines have been genotyped for the *Saltol* QTL and screened under salinity at concentrations of EC= 8 and 15 dS/m Selected lines which match the recipient parents can be tested for release
4.3	Backcross SUB1 into Australian rice genetic background	Backcross populations produced and selected	April 2015	Seed of BC_2F_4 populations sent to Australia Plant Quarantine

PC = partner country, A = Australia

7 Key results and discussion

The development of improved rice varieties in Theme 2 was undertaken by using the backcross method as well as through conventional bi-parental and complex (3 and 4-way) crosses, coupled with subsequent marker-assisted selection and screening under controlled and natural stress conditions to develop improved breeding lines and varieties.

In total, 36 single and multiple crosses have been made to combine submergence, salinity tolerance, stagnant flood tolerance, and high grain quality into high yielding genetic backgrounds. Two of these crosses were made to combine genes for tolerance to both submergence and salinity stresses. Pedigree generations were grown under controlled submergence conditions at Cuu Long Rice Research Institute (CLRRI), and under natural stagnant water conditions.

A second component of the project was to test breeding lines and varieties under a range of seasons and environments, to validate the performance of the new lines and to offer farmers the opportunity to participate in the observation and selection of new varieties. To date more than 27 participatory varietal selection (PVS) trials have been conducted using 78 (see Table 3, on page 16) varieties throughout An Giang, Hau Giang, Bac Lieu and Can Tho provinces.

7.1 The transfer of submergence tolerance

The transfer of submergence tolerance has been carried out through extensive crossing using IR64-Sub1 as the donor parent. The backcross process involves recurring cycles of hybridisation and marker-assisted selection to ensure that the region of interest (gene or QTL) is transferred to the progeny, while with each successive backcross an increasing amount of the genome of the recipient parent is captured. The aim is to have the recipient parent with exactly the same performance and characteristics, but with the key difference that it contains the additional gene/s for stress tolerance, in this case *SUB1* for submergence tolerance.

The key varieties chosen to receive the SUB1 QTL were OM1490 and OMCS2000 and the general scheme for the transfer of the trait is shown in Figure 1. The difference between parents largely determines the number of backcrosses required, and each additional backcross adds a complete generation to the time taken to develop the variety. The backcrossing scheme indicates that lines may be produced after two backcrosses, but in most cases a minimum of three backcrosses is required to capture a high proportion of the recipient parent's genetic background, to minimise the negative influence of linkage drag from unrelated regions of the donor parent genome.

At the completion of the project there are 108 lines under evaluation from the OM1490*3/IR64-Sub1 population and 200 lines from the OMCS2000*3/ IR64-Sub1 population. These lines are now at BC_3F_4 stage and following evaluation under stress conditions to validate that the stress tolerance has indeed been transferred successfully, seed can be increased and lines tested in multi-environment trials. Preliminary results from submergence testing after 14 days show survival in excess of 80% while the recipient parents without the *SUB1* QTL showed complete mortality.

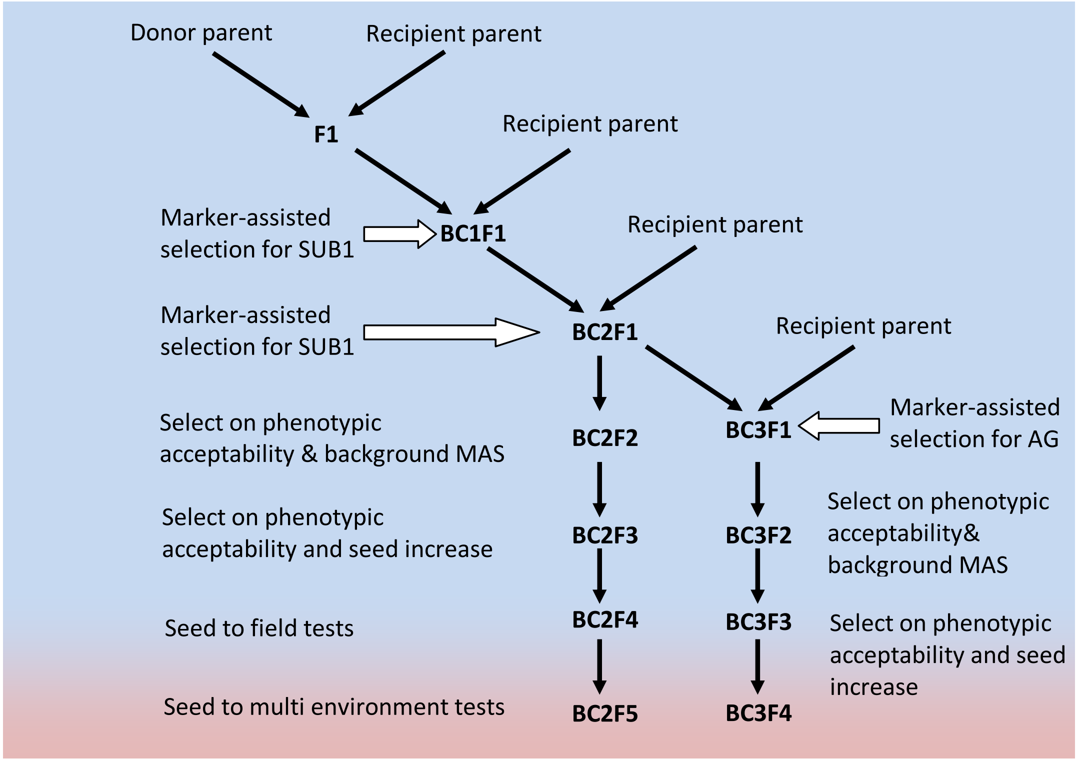

Figure 1. Backcrossing and selection schema for transferring SUB1 to recipient variety. The number of backcrosses depends on the degree of genetic difference between donor and recipient, and for widely different parents more backcrosses are required.

A series of crosses were also made to transfer the *SUB1* QTL to two or more representative Australian rice varieties. A number of populations were developed, and genotyped for the presence of the *SUB1* QTL and seed readied for transfer to Australia (Table 1). The aim was to ensure the transfer of the QTL with further backcrosses to be made once the material is successfully transferred through the necessary quarantine procedures.

Table 1. Single cross and backcross lines transferred to Australia to transfer the *SUB1* QTL

Genus & species	Entry No.	Combination	Seed amount (g)
Oryza sativa	12	Langi/IR64-Sub1	26
Oryza sativa	13	Langi/IR64-Sub1	52
Oryza sativa	14	Langi/IR64-Sub1	63
Oryza sativa	15	Kyeema/IR64-Sub1	56
Oryza sativa	16	Amaroo/IR64-Sub1//Amaroo	38
Oryza sativa	17	Doongara/IR64-Sub1//Doongara	64
Oryza sativa	18	Doongara/IR64-Sub1//Doongara	24
Oryza sativa	19	Doongara/IR64-Sub1//Doongara	63
Oryza sativa	20	OMCS2000/Langi	53
Oryza sativa	21	OMCS2000/Langi	55
Oryza sativa	22	Doongara/IR64-Sub1	51
Oryza sativa	23	Doongara/IR64-Sub1	71
Oryza sativa	24	Doongara/IR64-Sub1	47

7.2 The transfer of salinity tolerance

The key varieties chosen to receive the *Saltol* QTL were OM1490 and OMCS 2000, as for the transfer of the *SUB1* QTL. The same parents were chosen to facilitate the later combination of the two traits together in the one new variety. The donor variety for the *Saltol* QTL was the original source, the landrace Pokkali. Given that Pokkali is a landrace with many traits requiring improvement, a minimum of 4 backcrosses was required for the development of adapted breeding lines.

More than 100 BC_4F_3 lines from each population were screened under two salinity levels, with concentrations of EC=8 and 15 dS/m. While flanking markers are available to define the genomic region of the *Saltol* locus, salinity tolerance is conditioned by many other genes of smaller effect, acting together with the *Saltol* QTL. Consequently efforts were jointly directed at phenotypic screening using saline conditions, as well as genotypic analysis for the flanking and peak markers.

Results were generated by testing the BC_3F_4 lines of each of the populations under varying concentrations of salinity (see Figure 2 and Figure 3 below).

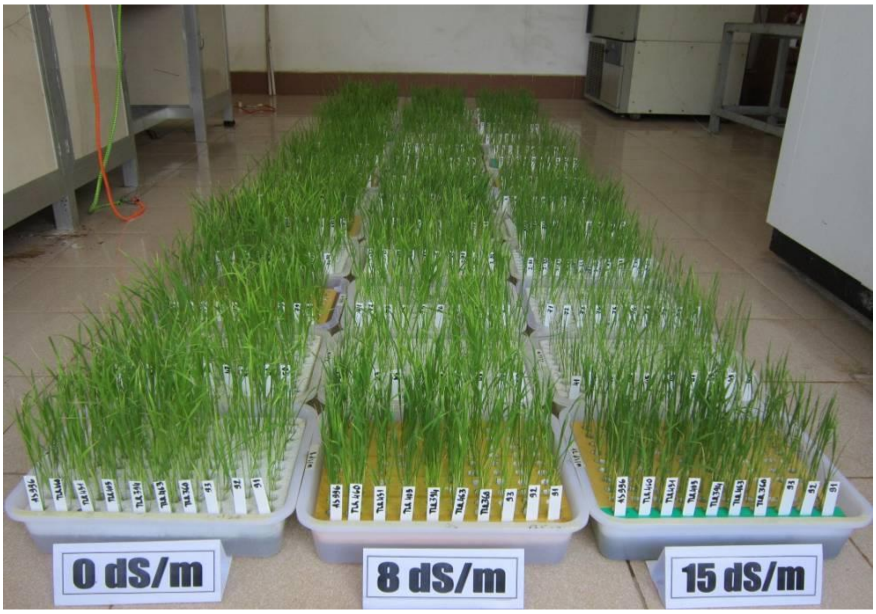

Figure 2. Salinity tolerance screening at Cuu Long Rice Research Institute, BC_3F_4 seedlings prior to imposition of salinity treatments.

On each hybrid population we selected 100-200 plants to screen for salinity and submergence. Experimental design was completely randomised lines within salinity treatments with 3 replications. Populations included:

- OM1490//IR64-Sub1//2*OM1490
- OMCS2000//IR64-Sub1//2*OMCS2000
- OM1490/Pokkali //2*OM1490
- OMCS2000/Pokkali //2*OMCS2000

From the two backcross populations, 84 lines were selected from OM1490/Pokkali//OM1490 and 93 lines from OMCS2000/Pokkali //OMCS2000 having improved tolerance to salinity.

Figure 3. Salinity screening 30 days after the imposition of salinity treatments. Few lines survived the higher concentration.

A series of crosses were also made to transfer the *Saltol* QTL to two or more representative Australian rice varieties. A number of populations were developed, and genotyped for the presence of the *Saltol* QTL and seed readied for transfer to Australia (Table 2). The aim was to ensure the transfer of the QTL into lines with a degree of adaptation, with further backcrosses to be made in Australia once the material is successfully transferred through the necessary quarantine procedures.

Table 2. Single cross and backcross lines transferred to Australia for transfer of Saltol QTL

Genus & species	Entry No.	Combination	Seed amount (g)
Oryza sativa	1	Langi/Pokkali	21
Oryza sativa	2	Langi/Pokkali	55
Oryza sativa	3	Langi/Pokkali	59
Oryza sativa	4	Langi/Pokkali	42
Oryza sativa	5	Langi/Pokkali//Langi	45
Oryza sativa	6	Langi/Pokkali//Langi	35
Oryza sativa	7	Kyeema/Pokkali	18
Oryza sativa	8	Kyeema/Pokkali	30
Oryza sativa	9	Amaroo/FL478//Amaroo	49
Oryza sativa	10	Amaroo/FL479	57

Two crosses were made specifically to combine genes for tolerance to both salinity and submergence and progeny from these crosses were advanced to BC_3F_4 using the combined effects of marker-aided selection and screening under stress conditions. Pedigree generations were grown under controlled submergence conditions at Cuu Long Rice Research Institute (CLRRI), under natural stagnant flood conditions at sites in Can Tho, Hau Giang, and An Giang provinces, and under salinity stress in Bac Lieu province. In total, 108 progenies were selected from BC_3F_4 populations, and 239 plants from the F_4 generation were tested for two stress tolerance genes (*Sub1* and *Saltol*) in combination.

7.3 Participatory Varietal Selection for stress tolerant lines

This project has completed an extensive series of PVS trials. These trials have provided extensive data with respect to the location, season, and abiotic stress likely to be experienced, giving farmers access to the best information and varieties for the future.

Throughout the project the total number of trial plots for each growing season, province, and location within the province exceeds 1000. This is to show the extent of testing and the combination of provinces and seasons. A key outcome from this series of trials has been the provision of significant quantities of seed of new varieties to all four provinces.

Participatory Varietal Selection (PVS) protocols were used for evaluating stress tolerant rice (STR) genotypes on-farm. In each season of the project high yielding genotypes with submergence tolerance along with standard checks and additional entry of farmer's variety were evaluated in selected farmers' fields at Bac Lieu, An Giang, Hau Giang provinces and Can Tho city. IR 64-Sub1, OM 4900, and IR 42 were used as common checks in all PVS submergence trials.

In Bac Lieu province salinity and submergence-tolerant high yielding genotypes along with standard checks and additional entry of farmer's variety were evaluated in selected farmers' fields. The variety OM 4900 was used as a common check in all PVS trials focused on salinity. In Bac Lieu the varieties OM 6328, OM 10252 and OM 6677 were selected, demonstrating high yield under saline conditions (Hoa Binh). Their yield was 4 t/ha, equivalent to the yield of OM 4900 at 4.01 t/ha.

Further, 12 acid-sulphate tolerant rice genotypes and additional entry of farmer’s variety were evaluated in selected farmer’s fields in Hau Giang province using AS996 as the local check variety. At An Giang, The farmers preferred 5 varieties - OM 7347, OM8018, OM4900, OM8928 and OM10000, and three of these varieties are already included in seed multiplication in 2012 such as OM 10041, OM7347, OM8928.

The extent of the PVS trials conducted throughout the project is demonstrated in Table 3 below, which shows the complete list of varieties/breeding lines which have been tested in the target provinces, and the specific stresses most commonly encountered in each. That a particular stress is likely to be experienced however doesn't mean that each trial was subject to the listed stress. Particularly with flooding stress, there are no guarantees that a particular stress will occur, of if it does, that the timing of the stress will be suitable for creating selection pressure. Flooding which occurs during the reproductive or grain filling phases for example cannot be withstood by any varieties.

Nonetheless, the trials demonstrate that there are significant new types with enhanced tolerance to a range of abiotic stresses (Table 4), and in the absence of stress the yield potential of these lines/varieties has been shown to be equal to or better than existing varieties. Thus the incorporation of greater stress tolerance, through using known genes/QTLs and modern techniques (marker-assisted backcrossing) to ensure they are present in new lines, or through selection under stress conditions allowing the accumulation of many genes of small effect, is shown to have no yield penalty under non-stress conditions, but can have significant benefits when stresses are imposed.

The extensive array of PVS trials also provided opportunities to improve the skills and technical knowledge of many farmers through frequent training and field visits. Theme 2 staff met with farmers groups for training in growing salt and submergence tolerant rice varieties following the PVS RM approach. Further, more information on rice varieties and management packages should be made available to farmers cooperatives in supporting the intensive farming systems on a sustainable basis. Although seeds of best-bet varieties were provided to farmers (4,946 kg of seed) there is an ongoing need for training of research and extension staff and increased extension activities.

Table 3. List of 78 breeding lines/varieties tested at multiple sites and seasons within each province throughout the CLUES project.

Line no.	Name	Bac Lieu (Saline)	An Giang (Stagnant deep flood)	Hau Giang (Acid Sulfate Soil)	Can Tho (Submergence)	Line no.	Name	Bac Lieu (Saline)	An Giang (Stagnant deep flood)	Hau Giang (Acid Sulfate Soil)	Can Tho (Submergence)
1	Can Tho 1	x	x	x	x	40	OM 10373		x		
2	Can Tho 2	x	x	x	x	41	MNR1	x		x	
3	Can Tho 3	x		x	x	42	MNR2			x	
4	OM 10040	x		x	x	43	MNR4	x		x	
5	OM 10041	x		x	x	44	OM6677	x		x	
6	OM 8928	x	x	x	x	45	AS996	x		x	
7	OM 4900	x	x	x	x	46	OM5981	x		x	
8	OM 6L		x	x	x	47	TLR390			x	
9	OM 7L	x		x	x	48	TLR391			x	
10	OM 70L	x		x	x	49	TLR393			x	
11	OM 6161	x		x	x	50	TLR394			x	
12	OM 4488	x		x	x	51	TLR395			x	
13	OM 8108	x	x	x	x	52	TLR397	x		x	x
14	IR 64 SUB1	x	x	x	x	53	TLR378	x	x	x	
15	OMCS 2012		x	x	x	54	TLR421			x	
16	TLR 375		x	x	x	55	TLR437			x	
17	OM 10000			x		56	TLR456	x		x	
18	TLR 598	x			x	57	TLR461	x		x	
19	OM 10252		x	x		58	TLR467			x	
20	OM 8927		x			59	OM6691			x	
21	OM 90L	x	x			60	OM6063			x	
22	OM 10418			x	x	61	OM10258	x	x	x	x
23	TLR402		x			62	OM5954			x	
24	OM 27 L			x		63	OM10097			x	
25	OM 62 L			x		64	OM10097-2			x	
26	OM 6707		x	x		65	TLH1	x	x		x
27	Swarna			x		66	TLH2	x			
28	PCR5			x		67	TLH7	x			
29	MNR5		x	x		68	OM6070	x			
30	OM 10174		x	x		69	TLR363			x	
31	OM 10179		x	x		70	OM10033			x	
32	OM 3673	x	x	x	x	71	OM2395			x	
33	TLR10/OM10041			x		72	OM 96L				x
34	OM28L		x			73	TLR 392				x
35	TLR595		x			74	TLR368		x		
36	TLR596		x			75	OM 10375		x		
37	TLR597				x	76	OM90L	x			
38	TLR598				x	77	OM5629	x			
39	TLR392	x		x	x	78	TLR402		x		

Table 4. The suite of varieties with tolerance to various stresses which are available to rice farmers in the Mekong Delta. This is not an exhaustive list, but is to indicate the range of options available, many of which were validated in PVS trials conducted as part of the CLUES project.

Variety	Origin	Duration	Plant height	Amylose content	BPH tol.	Blast tol.	Yield	Tolerance	Salinity (dS/m)
AS996	IR64/Oryza rufipogon	85-90	95-100	24-25	3	3	5-7	acid sulfate soil, salinity and stagnant flood	EC=6
Can Tho 2	Basmati/Jasmine 85	95-100	100-105	16-18	3	3	6-8	drought , stagnant flood	
Can Tho 3	OM4900/OMCS2000	95-100	100-105	18-20	3	3	6-8	drought , stagnant flood	
OM10000	Zhao89/OM4900	90	100	22-23	3	3	6-8	drought , stagnant flood	
OM10252	OM6162/OM6161	100-105	110-120	24-25	3	3	6-8	salinity and stagnant flood	EC=12
OM11267 (MNR1)	OM1490/OM3536	100-105	100-110	22-23	3-5	5	5-7	acid sulfate soil tolerance with stagnant flood and salinity	EC=6
OM11268 (MNR2)	OM6073/OMCS2004	90-95	100-110	24.50	3	3	6.5-7.0	acid sulfate soil tolerance with stagnant flood and salinity	EC=8
OM11269 (MNR3)	OM6073/DS20//DS20	95	100-110	23-24	3	3	5-6	acid sulfate soil tolerance with stagnant flood and salinity	EC=8
OM11270 (MNR4)	AS996/Jasmine 85	95-100	100-110	23-24	3	3	6-7	acid sulfate soil tolerance with stagnant flood and salinity	EC=8
OM11271 (MNR5)	OM1490/AS996//AS996	95-100	100-110	23-24	3	3	6.5-8.0	acid sulfate soil tolerance with stagnant flood and salinity	EC=6
OM4498	IR64/CS2000	100	100-105	24-25	3-5	1-3	5-7	drought and salinity	EC=6
OM4900	C53/Jasmine 85//Jasmine 85	95-100	100	16.20	3-5	3	6-8	stagnant and salinity	EC=8
OM5629	C27/IR64//C27	95-100	105	24.50	3	3-5	5-7	stagnant and salinity	EC=10
OM5930	Mutation CS21-12-7-N-1	100	105-110	22.0-22.5	1-3	3	5-7	drought and salinity	EC=8
OM5953	C53/OM269//OM269	98-105	95-105	17-18	1-3	3	6-7	acid sulfate soil tolerance with stagnant flood and salinity	EC=8
OM5954	OM1644/OM1490//OM1644	95-100	102	21-22	3	3	5-7	Stagnant flood and salinity	EC=8
OM5981	IR28/AS996	90-95	90-100	22.8	1-3	1-3	6-8	acid sulfate soil tolerance and salinity	EC=8
OM6073	C3/D3	105	102-110	26.50	1-3	5	5-7	salinity	EC=6
OM6162	C50/Jasmine 85/C50	95-100	100	18-20	3	3	5-7	salinity and drought tolerance	EC=6
OM6328	30K/Nho Thom	90	95-100	24-25	3	3	6-8	acid sufate soil, stagnant flood and salinity	EC=12
OM6377	IR64/TYPE3-123	90-95	100-105	23-24	3	3-5	6-8	stagnant flood and salinity	EC=8
OM6600	C43/Jasmine 85//C43	100	105-115	19.50	3	3-5	6-8	stagnant flood and salinity	EC=8
OM6610	AS996/ OM 4900	90-100	100-110	23.0	1-3	1-3	5-7	drought tolerance	
OM6677	M22/AS996//AS996	95-105	105	22-23	1-3	1-3	5.0-7.5	acid sulfate soil tolerance with drought and salinity	EC=6
OM6707	OMCS2009/OM2514	95-100	100	18-20	3	3	5-7	Drought	
OM6L	OM1490/Hoa Lài//Hoa Lài	90	95-100	20.50	3	3	6-8	stagnant flood	
OM70L	D3/Jasmine 85//Jasmine 85	95-100	100-105	18.50	3	3	6-8	tolerance with stagnant flood	
OM7347	Khao Dawk Mali/BL//BL	95-100	110-112	16-17	1-3	1-3	6-9	salinity and drought tolerance	
OM7364	C50/D21	90-95	95-105	21-22	3	3	6-7	drought tolerance	
OM7398	AS996/IR72043B-R-8-2-3-1	98-105	95-105	22-23	1-3	3	5-7	drought tolerance	
OM7L	IKO116/OM1490	90-95	100	21.50	3	3	6-8	stagnant flood	
OM8104	OM2718/OM2717	90-95	100	24.50	3	3	6-8	stagnant flood and salinity	EC=8
OM8105	M21/AS996	90-95	95-100	24	3	3	6-8	acid sulfate soil with stagnant flood and salinity	EC=12
OM8108	M362/AS996	90-105	110-115	24.20	1-3	1-3	7-8	stagnant flood and salinity	EC=8
OM8901	OM1490/OM4495//OM4495	90-95	100-105	23.3	1-3	1-3	6-8	drought tolerance	
OM8927	PANA/OMSub1	95-100	100-105	23-24	3	3	6-8	submergence	
OM8928	OM3536/AS996	90-95	95-100	24-25	3	3	6-8	acid sulfate soil tolerance with stagnant flood and salinity	
OMCS2009	OM1314/OM2514//OM2514	93-100	95-105	22-23	3-7	4	5-7	stagnant and salinity	EC=8

7.4 Improving tolerance to stagnant flood

Flooding of rice fields is a common problem in many rice production areas, and not all floods involve complete inundation of the crop. Variations in the depth and duration of flooding have led to the classification of flood-prone rice environments (Ismail et al. 2010) based on the type of stress imposed on the crop. These include complete submergence, partial or stagnant flood, and flooding during the germination stage of direct seeded crops causing anaerobic conditions and consequent seedling mortality.

Complete submergence can occur for a short time (<14 d) following heavy rain or overflowing rivers, causing complete inundation. This is referred to as flash flooding. The extent of damage to rice caused by complete submergence is dependent on floodwater characteristics such as temperature, turbidity, and depth. These affect various plant processes such as chlorophyll retention, underwater photosynthesis, carbohydrate accumulation, elongation, and survival. Rice genotypes tolerant of complete submergence retain their chlorophyll and adopt a slow-growth strategy depicted by limited elongation when submerged. This enables plants to maintain sufficient carbohydrate reserves to sustain metabolism during submergence and also recovery once the floodwater recedes.

However, the mechanism conferring tolerance to stagnant flooding requires plants to have sufficient elongation ability remain clear of the water surface, in direct contrast to the adaptive mechanism of the Sub1 lines, making them susceptible to stagnant flooding stress. Thus Sub1 lines that are short such as Swarna-Sub1 are adversely affected because a significant portion of the crop canopy is submerged, resulting in poor elongation ability because of the influence of the SUB1A gene. This is particularly severe when stagnant flooding persists immediately after complete submergence. The challenge therefore, is to combine the two different adaptive mechanisms in the one variety. One way may be to develop Sub1 lines with taller plant stature which can more effectively tolerate stagnant flooding following submergence.

Screening of local varieties for tolerance to stagnant flood

A total of 200 Vietnamese rice lines (100 landraces and 100 current varieties) and 2 checks, Swarna-Sub1 and IR64-Sub1 were evaluated in this experiment. Sprouted seeds were sown in the plant physiology anaerobic tank. At 21 d after sowing, 10 seedlings were collected for measuring initial seedling height and weight and thinning was also done, keeping eight seedlings in each row. After thinning, plants were submerged at 75 cm water depth for 14 d. During submergence, the water of the tank was made turbid twice daily and the light intensity in upper level (surface), midlevel (30 cm below the water surface) and lower level (70 cm below the water surface) of the tank were measured using the LI-250 light meter. The water pH and water temperature were also measured. At 14 d after submergence, the water was drained. Survival and recovery data were taken at 5 and 25 days after de-submergence, respectively. Survival scoring was done according to SES.

During the stagnant flooding stress treatment, a number of the local varieties elongated fast and the tip of the longest leaf of these germplasm came out from the water surface. So, these germplasm were discarded initially and were not selected as tolerant but their survival, elongation and recovery were assessed. Among the fast elongating types, three genotypes had 100% survival with excellent recovery. Three improved varieties, namely OM10252, OM3673 and OM10276 scored 1, i.e. good growth at recovery stage. Some lines were able to survive the screening treatment but their recovery growth was poor, while other lines had a variable response.

From the 100 landrace accessions, a number had seedling height of less than 55 cm and these were selected as slow elongating types. Among these, only 3 landraces demonstrated good survival and recovery stage growth. They were Mot Bui Do, Tep Hanh and Tai Nguyen Duc, and all scored 3, i.e. good growth at recovery stage. Some lines were selected as medium elongating type with good to excellent recovery ability.

A total of 12 rice genotypes with a degree of tolerance to stagnant flood together with an additional farmer's variety were evaluated in selected farmer's fields at Hau Giang province (Vi Thuy). The farmers preferred five varieties - OM 7347, Can Tho 2, Hau Giang 2, Can Tho 3 and OM 6L, and three of these varieties are already included in seed multiplication in 2014. Similarly, 12 stagnant-flood tolerant rice genotypes and additional entry of farmer's variety were evaluated in selected farmer's fields at Can Tho.

7.5 Anaerobic germination

Rice production systems are constantly changing, not only in response to changes in the physical environment but also to socio-economic factors including the cost of labour. Direct seeding is one way of reducing these costs, but seedling growth of existing varieties is not well adapted to low oxygen conditions. The capacity to germinate under anoxic or hypoxic conditions is an adaptive trait for varieties suited to direct seeding, and earlier screening studies have identified a small number of genotypes with greater ability to germinate and establish under flooding. Additional sources of tolerance may allow 'pyramiding' of tolerance genes to further improve adaptation under oxygen-depleted conditions.

This study was conducted to compare new sources of anaerobic germination identified through screening of traditional Vietnamese varieties, with the known AG tolerant line Khao Hlan On (KHO) and with two Korean weedy rices (WD3 and PBR) previously identified as having AG tolerance.

AT CLRRI screening was carried out by direct dry seeding in seeding trays as shown in Figure 4. Seeds of individual lines were sown in rows and covered by a thin layer of soil and then immediately submerged to a water depth of 10 cm. This depth was maintained for 21 days after which root and shoot length, biomass and survival was determined.

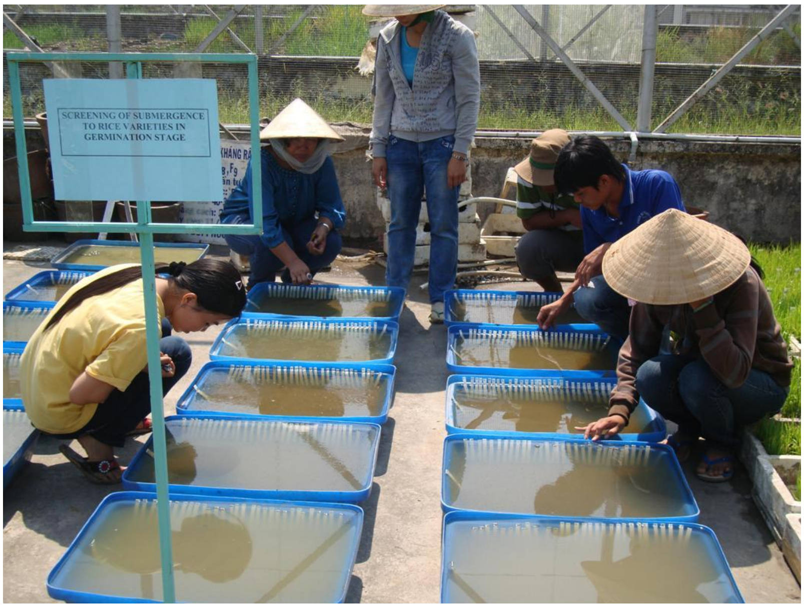

Figure 4. Screening traditional Vietnamese varieties for germination under 10cm water depth

Similarly in Korea germination and early growth seven lines was tested under varying temperatures (mean temperatures 21°C and 27°C) by sowing imbibed seeds into soil followed by inundation with 10cm water depth for 21 days.

The Vietnamese lines Tai Nguyen (TN) and Mot Bui Do (MBD) were identified as tolerant to flooding at germination (Table 5) with greater than 60% seedling survival and high biomass relative to other traditional varieties.

To find screening conditions which best discriminate between tolerant and susceptible types, germination and early growth was tested in the phytotron under varying temperatures (21°C ± 4°C and 27°C ± 4°C). Testing included the known AG tolerant line Khao Hlan On (KHO), two Korean weedy rices (WD3 and PBR), the Vietnamese varieties (TN and MBD), the Korean variety Juanbyeo (japonica) and IR42 as the susceptible check.

The shoot lengths of Vietnamese lines MBD and TN, and the Korean weedy rice PBR, were similar to that of KHO under both temperature treatments (Figure 5). The Korean weedy rice WD3 was slow to germinate and grow resulting in similar root and shoot lengths to the susceptible check.

Table 5. Results of screening for anaerobic germination among selected Vietnamese land races sorted in order of selection index based on all measured traits. Positive values are colour-coded green, lower values in red.

Varieties	*Shoot (mm)*	*Root (mm)*	*Biomass (mg)*	*Survival (%)*
Cà Đun Đỏ	128.9	44.8	157.3	16.7
Chín Tèo	193.0	53.1	203.0	21.7
Lùn Minh Hải	115.4	46.4	281.0	30.0
Mốc Salinh	239.4	66.8	201.7	21.7
Nếp Khmau	134.3	57.3	328.3	35.0
Krohoma Thungông	153.0	61.9	300.0	31.7
Rẽ Hành Trắng	197.2	53.5	305.0	31.7
Nếp mường	160.3	53.4	364.3	38.3
Vàng Lựa	221.5	73.9	327.7	33.3
Lúa Ponh Tia Méal	162.5	54.2	633.0	66.7
Néang OM	176.1	58.7	584.7	61.7
Lúa Ponga Lok	189.5	52.1	612.0	65.0
Một bụi đỏ	168.7	62.6	605.3	63.3
Trắng Tép	188.0	67.1	571.7	60.0
Nàng Quốc	199.5	66.2	587.7	61.7
Tài nguyên	206.0	61.5	640.0	68.3
CV (%)	10.66	10.49	0.17	18.53
F-test	7.47**	7.83**	11.27**	10.45**

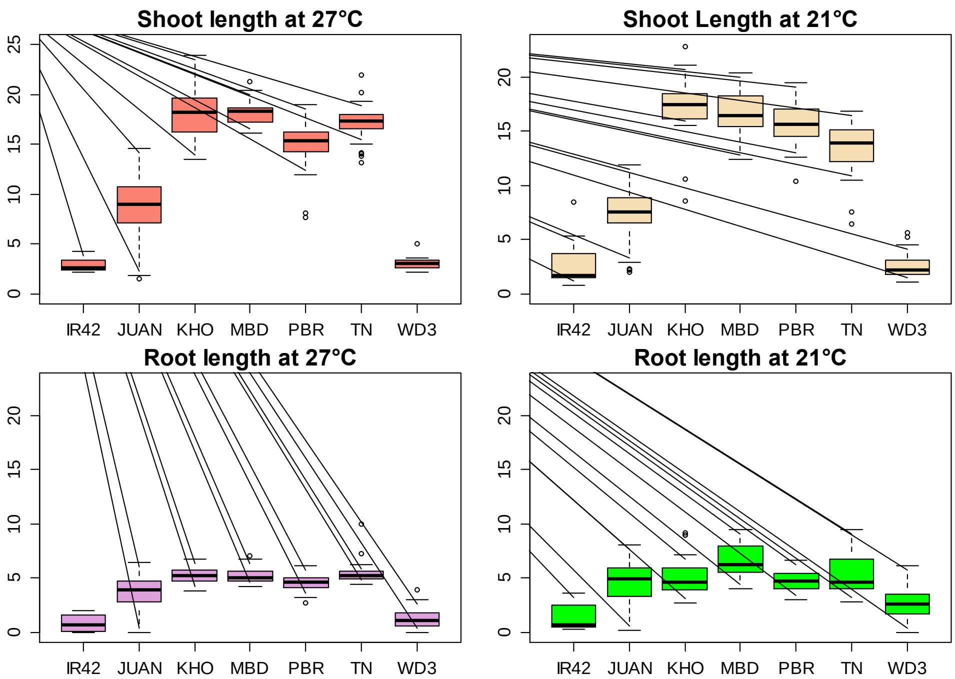

Figure 5. **Shoot length and root length following 21 days submergence under 10cm water depth at two temperature regimes**

Levels of dissolved oxygen approached saturation (6-8 mg/L) throughout the trial. Subsequent trials were conducted using water with low levels of dissolved oxygen after bubbling with N_2 gas, and in these trials the average root and shoot lengths of MBD, TN and PBR declined relative to KHO, but remained greater than the IR42 check variety. Low oxygen also resulted in greater variability within lines and lower rates of seedling survival (data not shown).

QTL analysis was performed to identify QTLs associated with tolerance derived from Vietnamese variety Tai Nguyen (TN) under anaerobic conditions during germination. The population, derived from a cross between TN (an AG tolerant indica line) and Anda (susceptible japonica), was used for collection of phenotypic data based on the survival rates of the seedlings at 21 days after sowing under 10cm of water. A total of 286 $F_{2:3}$ families of the population were used for QTL mapping and the genotyping was carried out with the infinium 6K SNP-chip based on the Illumina Infinium platform. The genotyping and QTL analysis was completed using the Infinium 6K SNP-chip with a total of 5274 potential SNP markers. This Illumina infinium platform detects SNP alleles by adding fluorescence-labeled allele-specific nucleotide via single-base extension and subsequent detection of the fluorescence color. Linkage mapping was carried out using IciMapping Ver. 3.2. A total of 945 polymorphic markers were used for the analysis (Table 6).

Table 6. **Summary of the linkage map for QTL-analysis**

Chromosome	Used markers	Polymorphic Markers	Polymorphism	Length*(cM)	AMI** (cM)
1	603	90	14.9%	198.36	2.2
2	508	82	16.1%	169.89	2.1
3	541	104	19.2%	158.29	1.5
4	493	80	16.2%	174.34	2.2
5	428	92	21.5%	142.78	1.6
6	430	96	22.3%	128.58	1.3
7	420	68	16.2%	89.62	1.3
8	389	99	25.4%	125.88	1.3
9	340	37	10.9%	100.37	2.7

10	316	49	15.5%	85.62	1.7
11	410	65	15.9%	129.77	2.0
12	396	83	21.0%	142.63	1.7
Whole genome	5274	945	17.9%	1645.74	1.7

* Length: chromosomal length ** AMI: average marker interval

The varieties included Khao Hlan On (KHO) & Ma-Zhan Red as AG tolerant checks, with IR42 and Anda as susceptible checks. The mapping population was 286 $F_{2:3}$ families from a cross between TN and Andabyeo. Lines were phenotyped by sowing 10 dry seeds per line (3 replications) after dormancy breaking treatment, followed by soil cover to a depth of 0.8 - 1.0cm using commercial soil. Seeds were submerged with 10cm of tap water (average water temperature of 25-30°C) and evaluated at 14 and 21 days after treatment. Lines with shoots less than 3cm were classed as susceptible, with 3-5cm shoots classed as moderately resistant, and lines with shoots greater than 5cm classed as tolerant.

Two significant QTLs associated with the AG trait were detected on chromosomes 1 and 11, respectively (Table 7). In particular, the QTL on chromosome 1 had an LOD score of 7.45 and R^2 of 14.21% (Figure 6).

We plan to confirm the identified QTLs in further studies and develop varieties with improved anaerobic germination ability using advanced backcross lines.

Table 7. Putative QTLs associated with seed germination under anaerobic conditions detected by composite interval mapping

QTLs	Chromo some	Position	Left Marker	Right Marker	LOD*	PVE**(%)	Add***	Dom+
qAG1	1	66.00	id1006604	275011	7.4549	14.2139	0.0333	-0.0058
qAG11	11	106.00	id11008888	11756589	2.9849	5.4623	-0.0038	0.0261

* LOD experiment-wise P=0.05 was equivalent to critical LOD score threshold of 2.5
** Percent phenotypic variation explained by the QTL
*** Positive values indicate additive effects from TN. + Estimated dominance effect of the QTL

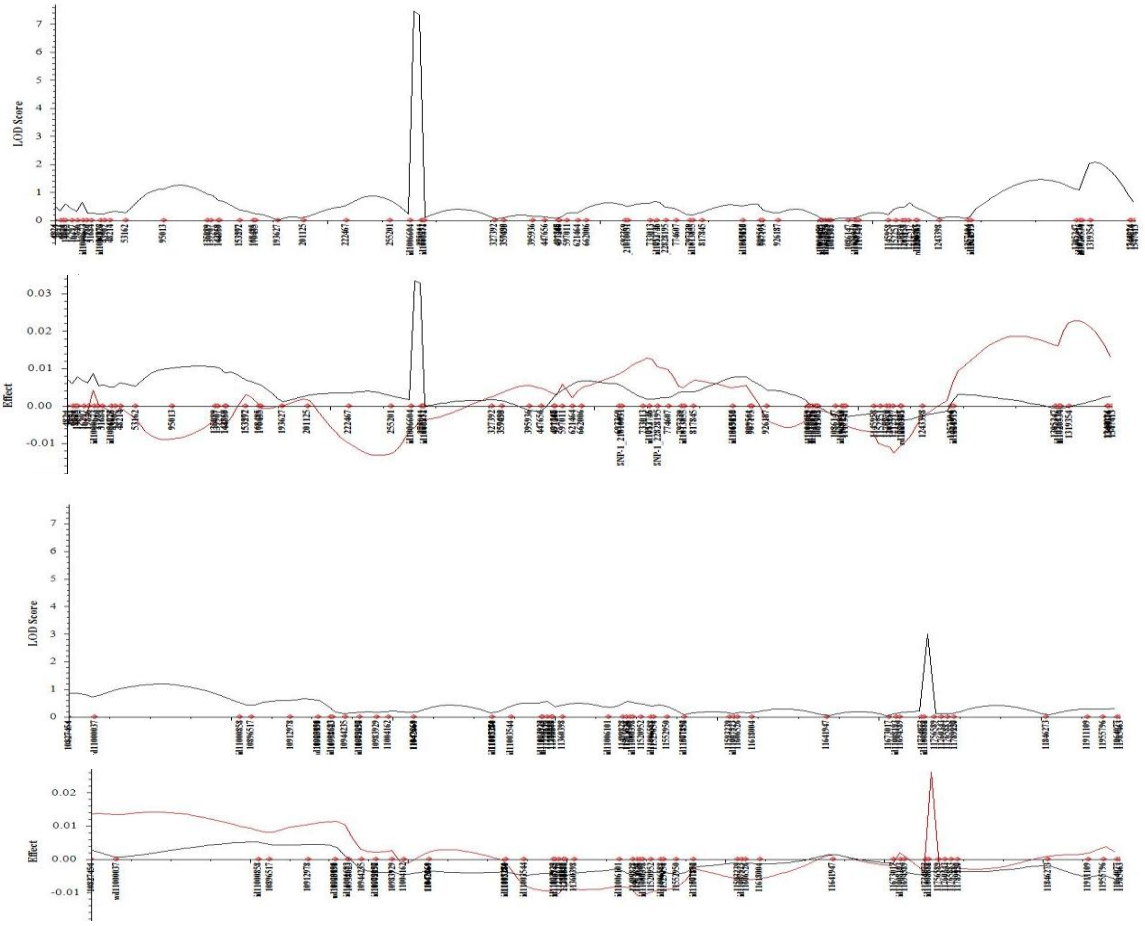

Figure 6. **Map location of detected QTLs related to the tolerance of AG and the LOD score. Peaks on the upper images indicate the QTL's LOD scores on Chromosome 1 within flanking region by SNP markers, while the lower images shows QTLs detected on Chromosome 11. Curves in black on bottom each figure represent the regression coefficients (additive effects) and curves in red represent the dominant effects for the traits**

8 Impacts

8.1 Scientific impacts – now and in 5 years

The focus of the breeding component (Theme 2) of this project was on applied research to achieve impact. The molecular markers for *SUB1* and *Saltol* QTLs were deployed to track the passage of these genomic regions through the progeny of the backcrossing programs aimed at improving existing varieties.

In the next five years, the presence of these genes/QTLs in more varieties more broadly adapted to the Mekong Delta region will facilitate their further movement into lines adapted to all provinces.

Similarly, new donor lines for anaerobic germination (AG) were identified through extensive screening, and research into the genetic basis of AG has identified two new QTLs in the Vietnamese landrace Tai Nguyen, which may be exploited in future, crosses. A number of candidate genes were identified in the region of the strongest QTL.

In the next five years, further fine mapping of these genes will allow them to be transferred readily into new varieties, thereby adding to the suite of stress tolerances built-in to new lines.

8.2 Capacity impacts – now and in 5 years

Capacity strengthening and staff development through degree and non-degree training: six young scientists were sent to IRRI for hands-on training in genotyping using SSR markers and in the use of different software for analysis of genetic data.

Stronger linkages and exchange of knowledge through project networks and meetings have also given considerable impacts on capacity strengthening through:

- meetings with scientists, extension workers, civil society organizations in affected areas to plan on the distribution of seed and other adaptation activities to assure farmer acceptance of seed;
- determining the quantity of seed required for distribution;
- development of seed multiplication plans for different varieties needed for different areas identifying the most likely partners to participate in the finalization of seed development and distribution; and identifying training needs of these in terms of technology adaptation, evaluation, and dissemination

8.2.1 Degree Training:

Mr. Bui Thanh Liem is now enrolled at Scuola University, Italy for his PhD program in Plant Breeding (school year April 2012 to March 2015)

Mr. Chau Thanh Nha and Ms. Vo Thi Tra My are now enrolled at the University of the Philippines Los Baños for their MSc program in Plant Genetics (school year June 2012 to April 2014).

Mr Bui Phuoc Tam is now enrolled at the University of the Philippines Los Baños for his MSc program in Plant Genetics (school year October 2013 to October 2015).

Ms Tran Thi Nhien is now enrolled at the University of the Philippines Los Baños for her MSc program in Plant Genetics (school year October 2014 to October 2016).

8.2.2 Non-Degree Training:

Six scientists, Bui Phuoc Tam, Nguyen Van Hieu attended a hands-on training in genotyping techniques on marker-assisted selection for BC_1F_1 at the Physiology Laboratory, IRRI of Dr. Abdelbagi Ismail from 12 Nov to 23 Nov 2011.

Tran Binh Tan, Vo Thanh Toan attended a hands-on training in marker-assisted selection at IRRI in the laboratory of Dr. Abdelbagi Ismail from 12 Nov to 23 Nov 2012

Nguyen Ngoc Huong and Nguyen Hoang Thai Binh attended a hands-on training in genotyping techniques and marker-assisted selection for BC_2F_1 samples at the Physiology Laboratory, IRRI of Dr. Abdelbagi Ismail from 12 Nov to 23 Nov 2012.

In partnership with GIZ Bac Lieu, a 5-day training workshop titled Technology updates on stress tolerant rice testing in coastal areas of the Mekong Delta, was held on 25-29 June 2012 at the Department of Agriculture and Rural Development (DARD) in Bac Lieu, South Vietnam. A total of 44 participants from DARD-Bac Lieu, Can Tho University (CTU), and the Cuu Long Delta Rice Research Institute (CLRRI) joined the activity.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

The economic impacts of these activities will be realized in future years as farmers adopt stress tolerant and improved varieties.

8.3.2 Social impacts

Having available new varieties to grow in stress-prone environments will help bridge the gap in food supply as well as release the pressure in the demand of limited water and farm resources of growing rice in favourable environments

8.3.3 Environmental impacts

By the nature of plant breeding, there is no immediate impact on the environment.

8.4 Communication and dissemination activities

In 2011: 980 kg seeds

- 150 kg BacLieu (OM 6677, OM4900)
- 180 kg seeds to Vi Thuy, and Hoa An, Hau Giang (OM4488, OM 6161)
- 250kg seeds to Can Tho (OM4488, CanTho 1,Can tho 2, Can Tho 3, OM 8928)
- 400kg seeds to An Giang (OM 7347, OM4900, IR64-Sub1)

In 2012: 880kg seeds

- 30kg Bac Lieu (OM 6677, AS 996, OM 10252, OM 4900, OM 5629)
- 50 kg seeds to Vi Thuy, Hau Giang (Can Tho 1, Can Tho 2, Can Tho 3, and Hau Giang 2)
- 400 kg seeds to CanTho (Can Tho 1, Can Tho 2, Can Tho 3, OM 4488, OM 10041)
- 400 kg for An Giang (OM 7347, OM 10041, OM 4900)

In 2013: 908 kg seeds

- 193 kg Can Tho (OM10041-20kg; OM4488-50kg; OM8104-10kg, CT 2-50kg, OM 3673-10kg, OM6677-5kg . OM CS2012-5kg , OM8108-43kg)
- 270 kg Hau Giang (OM 8108-150kg, OM 3673-50kg, OM 6L-50kg, OM7L-20kg)
- 125 kg Bac Lieu (OM 3673-40kg, TLH 1-20kg, OM8108-30kg, OM4488-35kg)

- 320 kg An Giang (OM8108-200kg, OM 3673-20kg, OMCS 2012-100kg)

IN 2014:1678 Kg seeds

- 405kg Bac Lieu (OM 6677, OM5629 OM 10252, OM 4900,)
- 410 kg seeds to Vi Thuy, Hau Giang (OM8108, OM 6L, OM 7347)
- 263 kg seeds to CanTho (OM3673, OM10252, OM6677 and OM 8108)
- 600 kg for An Giang (OM 7347, OMCS2012 , OM10000, OM 4900)

In 2015: 500 kg seeds

- 50 kg Bac Lieu :OM3536
- 80 kg Hau Giang OM10252
- 170 kg Can Tho : OM8108
- 200 kg :An Giang : TLR 397

The following lines were submitted for release in 2014:

OM3673 - short growth duration, tolerant to anaerobic conditions at the seedling stage

OM10252 - tolerant to submergence and salinity

OM6328 and OM6677 - tolerant to salinity, with high yield potential

9 Conclusions and recommendations

9.1 Conclusions

Salt- affected soils of the Mekong delta are highly degraded, with a complex of abiotic stresses including salinity, acid sulfate, complete submergence and stagnant flood. To enhance and sustain productivity of these soils, we adopted an integrated approach involving the development of adapted high yielding and salt tolerant varieties developed via novel breeding methods by marker-assisted backcrossing (MAB) methods. Through the use of innovative breeding strategies involving conventional and modern tools, together with effective phenotyping techniques, good progress was made in developing submergence salt tolerant varieties with broad adaptation to the conditions of the Mekong Delta. The key varieties chosen to receive the SUB1 QTL were OM1490 and OMCS2000. QTL analysis was performed to identify QTLs associated with tolerance derived from Vietnamese variety Tai Nguyen (TN) under anaerobic conditions during germination, .

To reach poor farmers currently suffering from salinity and submergence, and likely to suffer increased losses in the future, supplies of seed and conversion of additional varieties to submergence and salinity tolerance are urgently needed by (a) multiplying large quantities of seed of available varieties on the farm for immediate distribution; (b) distributing seed to target areas; and (c) establishing seed multiplication facilities in target areas for further multiplication. This project has commenced this process with seed distribution of best-bet varieties of 4,946kg. This project has also contributed in improving the quality of scientific research and training scientific staff with parallel integration of other research plans going on. Training courses for farmers and technicians were conducted during the period (total 3,960 farmers in 4 provinces – An Giang, Can Tho, Hau Giang, and Bac Lieu) comprising 3,260 male and 700 female during the training workshops from 2011-2015

Four varieties were submitted for release in 2014.

The varieties were OM3673: short growth duration, tolerant to anaerobic seedling stage. OM10252: tolerant to submergence and salinity, OM6328 and OM6677: salinity tolerance and high yield potential.

9.2 Recommendations

Future efforts should focus on further collection and evaluation of local germplasm to identify landraces with greater tolerance of submergence and salt stress and drought stress, as sources of new genes or alleles for breeding. Additional breeding efforts such as exciting developments in the field of genomics, additional resources and efforts should be directed towards identification of QTLs and genes underlying tolerance to the multiple stresses experienced in the problem soils of the Mekong Delta, for their subsequent integration into modern varieties and elite breeding lines through marker aided breeding. Fine mapping of these genes will allow them to be transferred readily into new varieties, thereby adding to the suite of stress tolerances built-in to new lines.

Special efforts should also be placed on training of young scientists to prepare a new generation that can effectively tackle these problems in a team approach.

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Final report

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co-authors/ contributors/ collaborators	CM Khoi (CTU), PP Nhan (CTU), NN De (CTU), Cao Van Phung (CLRRI), NQ Chon (IAS)
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Contents

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2 Executive summary

The direct and indirect impacts of climate change (CC) and sea level rise (SLR) will become a major challenge for maintaining food security in the near future, mainly through aggravating salinity and flood problems driven by hydrological dynamics of the Mekong River. After nearly four years conducting experiments and field trials to improve profitably and resilience to environmental stress, the results show that:

1. Alternate wetting and drying (AWD) irrigation is a win-win water management technology. It reduced the application of water by 30 to 50% and pumping costs and GHG emission.
2. Water delivery and management was a constraining factor at all sites throughout the field campaign, for example at Lang Giai during successive seasons upland crop trials were flooded and saline water was pumped into the field. A principal consideration for future climate change management is improving the delivery and management of irrigation water and drainage.
3. Farmers are over fertilizing and it is possible to reduce the application of P to between 40-60 kg ha^{-1}. In combination with AWD increased the farmer income in each rice crop about 4 millions VND (~ $200 USD) per ha. The increased profitability allows farmers to become more resilient to CC. Reducing P also alleviate environmental foot-print of rice production.
4. Farmers can improve yields by utilizing the existing cultivars suited to the farm environmental characteristics. For example replacement of the traditional varieties at Phuoc Long, Bac Lieu with high-yielding variety (HYV) directly increased profits from the rice phase but more importantly it shortened the rice season and lengthened of the shrimp season
5. In Phung Hiep district, Hau Giang province, residue management, AWD and P field trials failed due to commune level water management and acid sulphate soils. In the future changed climatic conditions could exacerbate acid sulphate soils and generate further acidity.
6. The trials on replacing one rice crop (Winter-Spring (WS) rice in Bac Lieu or Summer-Autumn (SA) rice in other areas) with a short duration upland crop increased the economic resilience and CC adaptation via (i) increasing farmers income; (ii) reducing water requirement, hence the risk of water shortage in SA or WS seasons; and (iii) reduced the risks of partial flooding or submergence AW season, by advancing the establishment/harvest date of AW season.

3 Background

Delta regions are especially vulnerable to climate change impacts due to the imminent impacts of sea level rise (IPCC, 2007). Additionally upstream dam development for hydro-electricity and irrigation supply will significantly alter the flow and discharge characteristics of the Mekong River. Lack of knowledge and education in coping with the external changes, including climate impacts also increases the level of vulnerability of the disadvantaged and vulnerable regional population (Nguyen, 2007).

MRD is highly intensive cropped; farmers grow 2 to 3 rice crops per year. CC and SLR, together with upstream development will affect different cropping seasons in different ways. Water shortage may be aggravated during the dry season crops (WS, part of SA). Increased salinity during the dry season will be detrimental to dry season crops in areas near to the coast. On the other hand, increase sea level may aggravate flooding (Wassmann et al., 2004), increasing stagnant flooding and submergence risk of wet season crops (SA and AW).

While seasonal flooding, droughts and Stalinisation directly affect agricultural production through exacerbating stresses to rice plants there are a number of secondary impacts that will also be significant. A large part of the MRD is composed of acid sulfate soils in which elemental cycling is controlled by the seasonal fluctuation of the water table, so that the modification of the hydrological cycle due to climate change could cause significant changes including leaching of arsenic and other metals (Berg et al., 2007; Buschmann et al., 2007, 2008). Other secondary impacts include changed nutrient (NPK) availability, with phosphorus being the key factor for productivity in the MDR (Tan *et al.*, 1995) and cycling caused by adaptive farming systems and the altered hydrological cycle.

It is important to quantify how the CC- and SLR-induced hydro-climatic stresses affect/constraint the cropping systems in the MRD, to find technologies that can alleviate these stresses, improve farmers profitability and hence, improving farm resilience to CC.

4 Objectives

Main objective: The Crop and NRM component aims at developing and refining management options for different agro-ecological zones and new decision support tools for a climate change resilient rice-based systems through improved understanding of element cycling, soil-plant and cropping systems responses to altered hydrology.

Specific objectives (Activities):

Act. 1: Participatory rural appraisal (PRA) survey for constraint analysis of cropping systems and identifying promising solution for CC adaptation.

Act. 2: Field experiments for identification of CC adaptation technologies, comprising (i) site selection and experiment design (derived from PRA), (ii) site characterization, (iii) implementing field trials with promising rice varieties (from the MDR) and crop management strategies, and (iv) data analysis and reporting.

Act. 3: Process studies on stress responses in target regions through pot experiments (In Vietnam) and solid column studies (in Australia).

Act. 4: Assess the role of non-rice crops in rice based for climate change adaptation.

5 Methodology

Four provinces, An Giang, Bac Lieu, Can Tho and Hau Giang have been selected to develop solutions for future environmental challenges in each of the agro-hydrological zones within the Mekong Delta. Key members of the research group at different target zones have been identified. Through discussion with project consultants, research group leaders, farmers and extension officers and local government within each province target districts and testing sites for different zones were identified and selected for experimental sites.

Act. 1: Participatory rural appraisal (PRA)

Participatory rural appraisal (PRA) was carried out to investigate the prevailing cropping systems and resource profile of target area of CLUES, how they were related and to assess cropping systems and management were affected by past extreme weather variability as well as farmers/local authorities strategies to cope with future climate changes.

The biophysical production constraints were defined through a PRA approach within the first year (2011) of the project. The PRA survey in the 4 target regions was designed to consider: (1) baseline status of farming systems and yield gap analysis, (2) retrospective analysis of losses in rice production during years with climate-related extremes (flooding, salinity, acidity), (3) assessment of agronomic vulnerability and adaptive capacity of rice-based farming systems. The PRA comprised of two parts

1. Focus group discussions with local governments, extension workers, water user association, and irrigation water service providers.
2. General discussion with farmers, in group or individuals

During the focus group and general discussions are number of questions and discussion points were raised to initiate debate. These are summarized below:

- General description on soil types, hydrology
- Cropping systems in relation to resource profile, especially hydrology and weather; evolution of cropping systems.
- Varieties used in each crop, soil and water management, inputs, fallow period management.
- Stresses and main constraints for each crops in the cropping systems, how to overcome.
- Unfavourable weather/climate events in the last 15 years, how they affected cropping systems, yield and socio economic conditions. Strategies and options farmers and local government utilised to adapted to and become resilience to with the unfavourable event(s).
- Perception about “climate change”.
- Suggestions for strategies, what are needed to cope with increasingly unfavourable climatic events (i.e. possible climate change).

Act. 2: Field experiments

(i) Site selection and experiment design (derived from PRA)

The Mekong Delta is characterised by 4 broad agro-ecological zones (see Bui Chi Buu *et al* 1995) based on soil type hydrology (Table 1). Two communes from a single province within each zone were selected, where one commune’s biophysical condition is unfavourable for agricultural production while the comparative site is a favourable one. It was anticipated by the research scientists involved with this project that different agrological zones would face different natural and human-induced hazards Based on the

PRA an experimental field program was conducted in each zone and this is generally described below (Table 1 and Table 2).

Table 1. Climate change production threats identified by participatory resource analysis for each ecological zone and season.

<table>
<tr><th>Ecological Zone</th><th>Winter-Spring (WS) Season</th><th>Summer-Autumn (SA) Season</th><th>Autumn-Winter (AW) Season</th></tr>
<tr><td>Deep flooded
(An Giang sites)</td><td rowspan="2">Submergence
(early season)
Water scarcity
(late season)
Acidity</td><td rowspan="2">Water scarcity
(early season)
Acidity
Lodging</td><td rowspan="3">Poor establishment
(Rain)
Poor pollination (due to rain)
Lodging
Stagnation flood
Submergence</td></tr>
<tr><td>Acid Sulphate Soil,
Intermediate flood
(Hau Giang sites)</td></tr>
<tr><td>Intermediate flood
with alluvial soil
(Can Tho sites)</td><td></td><td>Water scarcity
(early season)
Lodging</td></tr>
<tr><td rowspan="2">Saline Zone
(Bac Lieu, 3 rice system)
(Bac Lieu, Shrimp Rice system)</td><td>Water scarcity
Salinity</td><td>Salinity
Lodging</td><td>Poor establishment
(Rain)
Stagnation flood</td></tr>
<tr><td>(no Rice)</td><td>(no Rice)</td><td>Poor establishment
(Rain)
Salinity at establishment
Salinity at end of season
Stagnation flood</td></tr>
<tr><td>All zones</td><td colspan="3">Low economic resilience (Farms < 1-2 ha)
Labor scarcity</td></tr>
</table>

Table 2. Technologies to adapt and alleviate climate change production threats and related research questions in the Mekong River Delta (MRD).

CC related Production Threats	Promising technologies	Related research questions in the MRD
Water scarcity	AWD, drought tolerant variety	Is AWD safe in ASS and saline-risk soils? How would P fertilizer be managed in AWD?
	Replace rice by upland crop	Technical and financial feasibility of introducing upland crop in rice system? How will these farm management changes affect the acid sulphate soil properties?
Poor pollination; stagnation flooding and submergence (for Autumn-Winter crop, and Summer-Autumn for 2 crop)	Advance AW crop by replacing 3 rice systems with 2 rice + 1 upland crop	
	Advance AW crop by reduce fallow period after WS and SA Use stagnant flood-and submergence-tolerant varieties	How to reduce drying period without rice burning (pollution) and not creating organic toxicity to rice plants?
Acidity	Reduce soil drying after WS	
Lodging	AWD transplanting	How would AWD help reduce lodging? How can transplanting be done cost effectively vis labor scarcity?
Salinity at establishment and near harvest (Shrimp-Rice System)	Enhance leaching, liming	Would land preparation and liming help leach salt from soil?
	Use short duration rice Use salinity-tolerant varieties	What is the optimal (for rice and shrimp) date of rice seeding in combination with different maturity duration?
Low economic resilience	Diversification, intensification, lowering input costs, increasing yield	Do the CLUES farm management experiments reduce input costs & increase yield? How to increase annual productivity in 2 crops/year zones?

(ii) Site characterization

Prior to the PRA field researchers developed a resource profile (soils, land use hydrology climate) of the target zones using secondary data (area, rice production, cropping systems, general socio-economic condition) of the district/village. The profile was discussed with district agronomists, local government and consultant with the farmers and villagers during PRA.

A soil survey was conduct at each site. Soil properties from each experiment field were monitored through routine bio-physical analysis at the soil science department at CTU. Weather and water condition of the experiments were also monitored during the experiment. Methodologies for sample collection and analyses are reported in project outputs and publications

(iii) Implementing field trials with promising rice varieties (from the MDR) and crop management strategies

a. Is alternate wetting and drying suitable for acid sulphate and saline-risk soils?

It is predicted that CC will increase rainfall variability and potentially increase the occurrence of drought in the Mekong Delta. During the dry season farmers rely on Mekong River to irrigated rice and vegetable crops. At the distal end of the delta the river becomes increasingly saline as river flow decreases during the dry season. Changed rainfall dynamics and sea level raise will also affect the salinity of the Mekong River in the dry season further increasing water scarcity. Farmers, researchers, extension officers and government officials all recognise the potential risk to production from drought.

Alternate wetting and drying irrigation (AWD) is a tool to improve water use efficiency in rice production. Most of AWD field experiments that have been trialled successfully in non-saline soils and have significantly reduced water use and increase farm profitability (Cabangon et al., 2004; Belder et al., 2004; Lampayan et al., 2005; and Tabbal et al., 2002) In these studies it was concluded that rice yield remains safely if irrigation (hence the terminology “safe” AWD) was re-supplied when soil water tension was around -10 kPa, or when the perched water table reaches a threshold values of -15 cm below the soil surface.

The MRD is characterised by 3 broad soil types, alluvial, saline and acid sulphate soils (ASS) (Figure 1) and AWD has only been trialled in alluvial soils. In acid sulphate soils the draining of the soil profile could lead to oxidation within the profile and cause further acidification and elemental toxicities and subsequent yield decline. In saline soils there is the potential for the capillary raise of saline water from the deeper profile which in turn will cause yield decline.

Experimental trial was conducted to

(i) validate that “safe” AWD can maintain high yield and increase water productivity of WS and SA rice crops.

(ii) Investigate whether AWD increase the risk of Stalinisation of the root-zone.

(iii) Investigate whether AWD increases the risk of soil acidification.

(iv) Investigate if AWD increases farm productivity.

(v) To expose farmers, researchers, government extension officers and officials to AWD.

AWD experiments were conducted at all 4 sites during the first two years of the project (Table 3). The experiment at Can Tho was not successful due to difficulties controlling water at the original sites. Thus the experiment has been moved on to the CLRRI farm for the 2012-2013 season.

In these experiments, irrigation was applied in three treatments: (1) W1: Continuous flooding (CF): irrigate when water level is at around 1 cm on the soil surface, (2) W2: AWD, irrigate when water level percolated about -15 cm and (3) W3: AWD, when water level was at -30 cm below the soil surface. In all water treatments, irrigation was applied to bring the field water level to 5 cm above the soil surface. Irrigation water was pumped from near-by canals.

Table 3. AWD activities conducted at each site.

Time period	Bac Lieu (Salinity affected)	An Giang (ASS and flood affected)	Hau Giang (ASS)	Can Tho
Summer – Autumn 2012	3 rice/year	2 rice/year 3 rice/year	2 rice/year 3 rice/year	2 rice/year 3 rice/year
Autumn – Winter 2012 Continuous flood	3 rice/year	3 rice/year	3 rice/year	
Winter – Spring 2012-2013	3 rice/year	2 rice/year 3 rice/year	2 rice/year 3 rice/year	3 rice/year (Upland crop-Rice)

b. *How would P fertilizer be managed in AWD and can P rates be reduced?*

Fertilizer recommendation for the MD was developed about 3 decades ago, mostly for single crop of rice. Since then, farmers have increased the cropping intensity to 2 or 3 crops/year with most of residue either burned (end of WS and SA or ploughed into the soil (end of SA or AW crops). In either case, apart from the amount of phosphorus (P) in the grains, which are removed from the fields, the major part of phosphorous fertilizer is returned to the soil. Through the years, there might be substantial accumulation of P in the soil. Improving P fertiliser use efficiency in rice cropping systems in the MRD will directly affect farm profitability and resilience.

AWD has been identified as a technology to be used to increase water use efficiency in MDR rice production systems, enhancing farmer adaptive capacity to CC. However no AWD experiments have been carried out on acid sulphate soils and potentially the alternating REDOX conditions under AWD could affect the soil P dynamics and subsequently yield. Understanding P dynamics under alternating REDOX conditions will also beneficial to cope with CC, when drought stress may increase in frequency and intensity.

At each site, the effect of P rate was tested in combination with three levels of water management, W1, W2, W3 as described above. Water management was the main plot factor. P rates was the sub plot factor, ranging from 0 kg P_2O_5 / ha, to Farmers' practice, with 1 or 2 intermediate rates = half or a third of farmers rates (Khoi et al., 2015; Nhan et al. 2015).

During field trials soil nutrient status was periodically assessed using standard agronomic measurements of soil P. Soil ground water accessed via piezometers was monitored rather than pore waters due to technical difficulties with the pore water samplers. Irrigation water samples were monitored for electrical conductivity, pH and temperature. Plant physiological measurements (e.g. leaf area index, height, biomass) was made at the same time as the soil and gas sampling. Sampled biomass was also analyzed for N-P-K and C. Sampling across the whole annual cropping season allowed for the calculation of a representative nutrient budget with each farming system.

c. *How to reduce drying period without rice burning (pollution) and not creating organic toxicity to rice plants?*

The issue at Hoa An (Hau Giang province) is this long period of fallow that causes soil drying and the burning of straw and stubble after DX that increases acidity of the top soil. Removal of the straw during fallow also results in increase soil evaporation which brings acidity to the soil surface by capillary rise. If it is possible to reduce the fallow period between the crops it will be possible to move the crop forward by up to 3 weeks and potentially avoiding flooding at the end of the He Thu season. The flooding risk has been predicted to increase with CC.

Residue management is needed to be modified to enable shortening of the fallow period and maintenance of soil health. Previous research has shown that rice plants can be stressed when previous crop straws are buried in the soil and decomposed in anaerobic conditions. As a result, rice yield in the following crops were decreased (Nguyen Thanh Hoi et al., 2007). Rice straw and stubble can increase rice yields when composted (Tran Quang Tuyen and Pham Sy Tan, 2001) or incubated with fungi (*Trichoderma sp*.; Luu Hong Man et al., 2005). Thus anaerobic decomposition of the residue (straw and stubble) prior to land preparation and seeding may be a solution.

The two objectives addressed in the experiment are:

- To identify the suitable fallow periods between the harvest of the previous crop and the establishment of the following crop.
- To identify an improved straw treatments to facilitate the rice growth and improve yield on acid sulphate soil.

The treatments that were tested were seeding directly right after ploughing, seeding 3 weeks after ploughing seeding 6 weeks after ploughing and the straw treatments were burning stubble and ploughing, incorporation of rice straw and ploughing and spraying the rice stubble with *Trichoderma* spraying and ploughing. This experiment has been carried out at Hoa An, within Hau Giang province, during the SA crop in 2012 at a location near the CTU field station and again during the SA crop in 2013 at a new location (within CTU field station).

d. How the productivity in Shrimp - Rice Systems can be improved with high yielding short-duration rice variety and enhanced salinity leaching

The shrimp-rice cropping is an important production system in the coastal areas of the MRD. In this system, brackish-water shrimp is raised from January to August, when salinity in the field > 7 g L^{-1}. Rice is established at about mid of September. More than 90% of farmers grow photoperiod sensitive (PS), local varieties, which were harvested, in mid January. Late harvest exposes the rice crop to high salinity at the end of the rice season. Shortening rice growing duration could help minimize the risk of crop failure caused by salinity and shortage of irrigation water. These will become more serious in the future when the global CC is anticipated. Short duration of rice will also give farmers more time for farmers to grow shrimp, which brings the main income for farmers from the whole system.

With non-photoperiod, high yielding varieties (HYV), early establishment can bring the rice harvest forward. However, one of the constraints for rice production in this cropping system is the accumulation of salt during previous shrimp growing season. Before rice establishment, farmers leach the residual salt by rainwater and some time with irrigation. Advancing rice establishment may reduce the leaching duration and increasing the risk of drought and salinity during rice establishment. The risk is aggravated with the anticipated sea level rise and CC. There is a need to enhance the effects of leaching. We hypothesized that ploughing and liming can enhance the effects of leaching before the start of the rice season.

An experiment was carried out in Phuoc Long, Bac Lieu during September 2012 - January 2013, and September 2013 - January 2014 (NM Dong et al., 2015) with the overall objective of optimize management of soil and crop in a shrimp-rice cropping system to help farmers increase their income and their adaptability to possible sea level rise and CC.

Specific objectives include:

- To assess the possibility of introducing short-duration HYV to replace the local traditional PS variety in shrimp rice system.

- To determine the effects of applying lime and plough (solely and in combination) on soil salinity leaching and consequently on rice yield.

The experiment was a split-split-plot design with three replications. The main plots consisted of 4 levels of leaching and land preparation. The sub plots 2 levels of liming (no and 2 T ha^{-1} of CaO). The sub plots were 2 varieties (Local PS variety, Mot Bui Do and short duration HYV, OM4900).

Act. 3: Process studies

Stress responses in target regions through pot and column experiments (In Vietnam) and incubation studies (in Australia). Pot experiment was set up to assess the effect of different environment stresses on element cycling and nutrient availability. Given the diversity of target areas, the pot experiments was designed as site-specific trials under a range of environmental conditions (depth of flood and/or salt content) from the soil and plant(s). Measurements encompassed soil as well as plant parameters.

1. *Effect of salinity on carbon and nitrogen cycling*

Soils from Australia were in incubation studies to assess the effect of salinity on carbon and nitrogen element cycling. Nitrous oxide, methane and carbon dioxide measurements were made during experiment. In-situ sensors (N_2O and NOx micro-sensors) were not appropriate for the design of the experiment and were not used. Measurement of greenhouse gas emission was conducted from acid sulphate soil and alluvial soil under different salinity concentration. Twenty grams of field soil samples (0 – 15 cm) in 125 ml jar were submerged with 15 ml of various saline solution including salinity concentration 0.03 dS m^{-1} (fresh water), 10 dS m^{-1} (low salinity), 16 dS m^{-1} (medium salinity) and 21 dS m^{-1} (high salinity). According certain treatments, 5 mL of a solution providing 300 µg glucose-C g^{-1} soil and 50 µg NO_3-N g^{-1} soil which was recommended by Luo et al. (1996) to avoid limitation of denitrification activity from high concentration of nitrogen and carbon solution or 5 ml of distilled water was added into jar to ensure all jars having the same water content.

2. *Survival of IR64-Sub1 subjected to submergence at young seedling stage*.

Alluvial soils with different residue treatments from O-mon were used to assess the survival of IR64-Sub1 seedlings (4 days) under submergence. While submergence tolerance at vegetative stage of Sub1-cultivars has been well established (Xu et al., 2006), but there is little information on performance of IR64-Sub1 when it is subjected to submergence during young seedling stage (<20 days), especially when the bio-chemistry of the soil water is governed by anaerobic decomposition of the residue. The experiment was carried out in pots, arranged in split plot design with 4 replications (Nhan et al., 2014, 2015).

(i) Submergence was main factor (S): Seedlings were subjected to submergence for duration of 15 days (S1); or without submergence (S0, control).

(ii) Residue management was sub-factor (R): With three levels, namely R0: without residue incorporation; R1: Incorporation of burnt residue; and R2: Incorporation of fresh residue. The amount of residue in each pot of treatments R1 and R2 were equivalent to 5 tons/ha.

3. Enhancing salt leaching of shrimp rice soil

Soil columns were used to understand leaching processes and the effect of ameliorated techniques on Stalinized soils in shrimp rice systems in Bac Lieu. An intact soil cores were sampled in the beginning of September 2013 when finishing the shrimp season. Soil samples were taken at a depth of 0-10 cm from soil surface by using a PVC core (30 cm length x 4.9 cm diameter). The cores were closed at their bottom and punched 0.5 cm in diameter at its bottom in order to drain the leaching solution. The treatments were arranged in randomized complete block, being 7 combination of (i) number of leaching; (ii) with and without lime and (iii) with and without surface soil (0- 5 cm) turn over (using a spatula). Further details are described in Khoi et al., 2015).

4. *Soil P adsorption characteristics after 7 crops at fixed P supply*

Soil samples at the end of each of the 7 consecutive rice crops, from the WS 2012 to WS 2014, in the P experiment in Bac Lieu (described in section iii – b above) were taken to determine the maximum P adsorption. This determination aimed at elucidating how different P rate application affect the amount of P adsorption, how much soils were buffered with P and how long a reduced P application could maintained without declining rice yield. The P maximum adsorption analyses were based on the method proposed by Houba et al. (1988). Basically, soil samples were equilibrated with phosphate solutions of known concentration for 24 hrs at 20 ^{o}C. At the end of the process, the concentration of the phosphate remained in the solution was determined. The quantity of P adsorbed per quantity of soil was calculated from the difference in phosphate concentration at the beginning and the end of the process. A Langmuir two surface equation was fitted to the data (Holford et al., 1974) using SPSSx v 16.0. For most soils which are under saturated with P this equation takes the form of

$$x = \frac{k'x'_m CE}{1 + k'CE} + \frac{k''x''_m CE}{1 + k''CE},$$

Where x = adsorption, k = adsorption/desorption equilibrium constant, x_m = monolayer adsorption capacity and CE = equilibrium solution concentration.

Act. 4: Non-rice crops in rice based for climate change adaptation

Thanks to warm weather year round and the availability of short duration rice varieties, with proper water management, about 30% (Nguyen Ngoc De, personal communication, Aug 2013) of the rice area in the MRD are cropped with three rice crops per year. Though the productivity of the triple-rice system can be high (~ 13 T ha^{-1}), farmers benefit from rice cultivation is low due to high labor, input costs and low rice price. The system is subjected to many climate risks. Water shortage often occurs in AW season in deep and medium flooded zones (An Giang, Can Tho, Hau Giang) and in WS season in saline affected area (Bac Lieu). The rice crop in AW season is exposed to heavy rains during flowering, stagnant flooding at the latter stages of the crop in all zones and to submergence in deep flooded zone. These climate risks will aggravate in the foreseen CC.

We hypothesized that replacing one rice crop (WS rice in Bac Lieu or SA rice in other areas) with a short duration upland crop would increase the economic resilience and CC adaptation via (i) increasing farmers income; (ii) reduce water requirement, hence the risk of water shortage in SA or WS seasons; and (iii) reduce the risks of partial flooding or submergence by advancing the establishment/harvest date of SA cropping season.

A set of experiments (Table 4) was carried out to (i) explore the feasibility of an upland crop replacing SA rice in flooded zones and replacing WS rice crop in saline affected area; (ii) quantify different upland crop managements on crop performance and soil properties; (iii) to quantify effects of upland crops on soil properties and on the subsequent rice; and (iv) comparing the economics of the triple-rice system vs the two-rice + upland crop system.

Table 4. Experiments on integration of upland crops in rice-based cropping system

	Bac Lieu (Lang Giai)	**Hau Giang (Vi Dong)**	**Can Tho (Thoi Tan)**	**Can Tho (CLRRI)**	**An Giang (Ta Danh)**
Cropping season that upland crop replacing rice	DX 2011-2012 and DX 2012-2013	HT 2012 and 2013	HT 2012 and HT 2014	HT 2013	HT 2014
Upland crops tested	Soybean, mungbean, sesame, hybrid corn and pumpkin	Cucumbers and sticky corn	Sesame	Mungbean	Sesame, soybean and sweet corn
Treatments of upland crops	N, P, K doses	Plastic cover, N fertilizer and biological fertilizer (only in 2012)	Sesame varieties and fertilizer doses	P-fertilizer and residual effects of water managemen t of the previous season	Crop varieties
Overall upland crop performance	Grew well at earlier stages but died at later stages due to water logging (2012) and salinity (2013)	Grew well in both years	Poor performance due to water logging (2012) Grew well (2014)	Grew well	Grew well

The experiments are briefly described below, further details are described in Chon et al., (2015)

1. Lang Giai village, Bac Lieu province

Upland crops (soybean, mungbean and pumpkin) were compared with rice in WS 2011 – 2012; 2012 – 2013. In WS 2013 – 2014 season, pumpkin was replaced by maize. For each of the upland crops, management options were also tested. In each season, crops were arranged in randomized complete block design with four treatments, with rice as a control treatment. Management treatments (fertilizer rates and types, mulching ….) were sub-treatments within each crop. Plot sizes ranged from 25 to 40 m^2. They were separated by bunds 30 x 30 cm. Bunds separating upland crops and rice plots were lined with plastic to 20 cm depth. In WS 2013-2014 plastic sheet (0.15 mm thickness and 1.2 m width) was lined at the rice plots' side of the bund at depth of 0.4 m below the soil surface and then covered on top and to the upland crop plots' side.Apart from management treatments, "best management" practices were applied to each of the cropsBund construction: The only one main bund (0.3 m height and 0.4 m width) with plastic lining was constructed in order to separate all upland crop plots in one side and rice plots in the other side.

2. Vi Dong village, Hau Giang province

a. Spring-Summer (SS) and Summer-Autumn (SA) 2012 and SS and SA 2013.

Four cucumber (variety F1 – 311) crop field trials were grown during SS and SA 2012 and 2013. Management treatments, as urea, DAP and NPK (20-20-15) for treatment 1; urea, DAP, fused magnesium phosphate (FMP), KCl and Biogro for treatments 2, 3 and 4 were sub-treatments within each crop. The plots were 4 m x 8 m = 32 m^2 (all plots were separated by water ditches of 40 cm depth and 40 cm width).

b. Two demonstrations were conducted at two separated farmer's fields (Mr Nguyen Ngoc Chanh and Mr Nguyen Huu Tri) during Summer-Autumn 2014.

Cucumber (variety F1 – TN456) and sticky maize (variety F1 – MX10) were grown and fertilized with 120 N + 120 P_2O_5 + 60 K_2O. The plot size was 500 m^2 (for each crop in both sites)

3. Thoi Tan village and CLRRI, Can Tho city

In 2012 the experiment was conducted in Thoi Tan village, Can Tho city

A sesame crop was grown during summer-autumn 2012 in a randomized split plot design with three replications. A second experiment was conducted in 2013 to replace the SA crop with mungbean. Overall the cropping sequence was WS 2012-2013 rice crop, SA 2013 upland crop (mungbean) compared to rice crop and AW 2013 rice crop. The design was a randomized complete block – split, split plot with three replications. The three factors were water management (AWD vs CF), cropping system, and P fertilizer rate (0, 40 and 60 kg P_2O_5 ha^{-1}) during the rice season.The plot size was 6 m x 5 m = 30 m^2 (double bunds with plastic lining were constructed to separate the plots in the experiment; plastic sheets with 0.15 mm thickness and 1.2 m width were lined at the inner side of bunds at depth of 0.4 m below the soil surface and then covered on top to the outer side of the bunds)

In SA 2014 three demonstration sesame crops were conducted in Thoi Phong A village, Thoi Lai district, Can Tho city, at three separated farmer's fields (Mr Huynh Thanh Son, Mr Nguyen Trong Danh and Mr Nguyen Huu Thanh). The plot sizes were 500 m^2 (for each treatment in three sites) a with different land preparation (tillage and residue management) and seed sowing occurred at the three sites.

In all field trials, crop yield and yield component were examined, and soil samples (0 – 15 cm) at both before and after experiment conducted were collected for some soil chemical properties analysis. Data collected from the trials were analyzed using Gen Stat and ANOVA was used to compare differences between means.

6 Achievements against activities and outputs/milestones

Objective 1: To identify climate change related stresses which will affect future production

No.	Activity	Outputs/ milestones	Completion date	Comments
1.1	Participatory rural appraisal (PRA) for constraint analysis of cropping systems and identifying promising solution for CC adaptation	CC related stresses identified by constraint analysis	Mar to Dec 2011	Salinity and flooding are the identified stresses; ASS is also the problem in Hau Giang site
		Promising solutions to CC-related stresses	Dec 2011 - Aug 2013	Promising technologies proposed and being tested by experiments
1.2	Literature review of relevant research issues and testable hypotheses	Literature reviews completed and submitted	Mar 2012 - Aug 2013	Literature reviews on salinity and flooding affected to rice cultivation completed
		Research proposal for each site completed and submitted	Aug 2011 - Dec 2013	Protocols were submitted before starting each experiment

PC = partner country, A = Australia

Objective 2: To develop, test and refine management options for different agro-ecological zones

No.	Activity	Outputs/ milestones	Completion date	Comments
2.1	Field experiments (a) Site selection and characterization	Testing villages and fields identified in different agro-ecological zones.	Mar 2012	Done
		Experimental fields characterized	Mar 2013	Done
	(b) Designing experiments	Experimental design completed for all 4 target zones	Aug 2012	Done
	(c) Implementing experiments	Experiments in each of the target zones (BL, AG, HG, CT) started and completed	Sep 2014	Completed.

2.2	Training on soil and water sampling and statistical design	Training workshop	Mar 2012	Done
2.3	Soil and plant samplings and analyses	Data on soil and plant analyses for the trial crops in the 1st to 4th years	Dec 2014	Completed

PC = partner country, A = Australia

Objective 3: To improve understanding of element cycling, soil-plant and cropping systems responses cause by the different management options

No.	Activity	Outputs/ milestones	Completion date	Comments
3.1	Processing studies on stress responses in target regions through pot experiments and column experiments	(a) Initial scoping document for process based studies. Identification of key stressors and processes. (b) Review of Experiment Design. Inputs required from all participants. (c) Design column and pot experiment	Mar 2014	(a) Scoping document completed. (b-c) Mr Minh has been awarded a John Alright Fellowship and will research nitrogen and carbon emissions using pot experiments. (c) Pot and column experiments on residue management and salt leaching, respectively, started and completed.

PC = partner country, A = Australia

Objective 4: To assess the role of non-rice crops in rice based for climate change adaptation

No.	Activity	Outputs/ milestones	Completion date	Comments
4.1	Selection of stress tolerant upland species and test them in rice-based systems	- Experimental designs and land preparation for field experiments - Assessment of integrating upland crop in rice based systems	Jan 2012 - May 2013	Experiments were carried out at all target zones.
4.2	Field trials for transferring identified techniques to the farmers		Jan - May 2014	At Hau Giang and Can Tho it was possible to insert 2 cucumber (or sesame) crops in SA for increasing economic resilience of farmers.

PC = partner country, A = Australia

7 Key results and discussion

Activity 1: Participatory Resource Analysis

The PRA undertaken in March 2011 identified potential CC-related threats (Table 1). At each site during the Winter-Spring (WS) and Summer-Autumn (SA) season water scarcity and lodging was identified as a key future threat (Table 1). This water scarcity could cause increased acidification through the further oxidation of acid sulphate soils and Stalinisation through capillary raise. During the wet season crops stagnant flood and submergence were identified as key threats (Table 1). Across all sites and seasons labour scarcity and low economic resilience due to small farm size were identified a current and future problem which challenge current production methods.

The CLUES research team identified promising technologies and research questions. Prior to implementation and testing meetings were held, which included the research group leaders, farmers and extension officers and local government at each site. At these meeting the merits of each technology and research question was discussed and the selected for field testing (Table 2). Major findings of the experiments are described below.

Activity 2: Field Trials

a. *Is alternate wetting and drying suitable for acid sulfate and saline-risk soils?*

In most cases, AWD did not affect rice yield. But, there was a yield penalty in applying AWD at the Bac Lieu (salinity affected soil) site during WS 2011-2012 season when abundant P was applied. In this condition, there was a statistical difference (0.1 level) in the yield between the continuous flooded plots (4.16 t/ha ± 0.40) and the -15 cm threshold (3.52 t/ha ± 0.36) and -30 cm threshold (3.82 t/ha ± 0.18). There was no yield penalty at An Giang (ASS) triple rice crop site in all cropping seasons. Overall AWD reduced irrigation water use significantly (from 20% to 50%) (Khoi et al., 2015; Nhan et al., 2015).

At both sites the EC of the ground increased in AWD-30 cm threshold and this indicates that the may be capillary rise and concentration of salt at Bac Lieu. At An Giang during the cropping season the pH of the ground water increases during the cropping season from pH 4 to neutral. This suggests that the EC increase during the cropping season is due to concentration of salts rather than direct pyrite oxidation in the surface horizon with the application of -30 cm threshold AWD. These salts however could be derived in-situ weathering due to existing soil acidification and oxidation of the profile during land preparation and/or prior fallow period. In relation to yield the application of AWD using a threshold value of -15 or -30 cm for “safe” AWD appears to be site specific, but -15 cm would be a safe threshold to use in the tested saline and acid sulphate soils.

A key advantage of the technology is that it has an immediate impact on farm profitability. Economic analysis shows that the reduction in pump hours increases the farm income by reducing fuel and labour costs (Table 5) relative to traditional continuous flooded rice.

Table 5. Average income (in 1,000 VND per hectare) from 3 water management regimes Ta Danh, An Giang (Nhan et al., 2015).

Water management regimes	DX 2011-2012	HT 2012
W1	15,191	24,678
W2	19,926	26,254
W3	17,723	25,957

Our experimental trials indicated that AWD with threshold – 15 cm, could be a good solution to overcome water scarcity under current and future conditions in all soil tested. The use of this technology by farmers will potentially increase MRD rice production systems resilient to water scarcity. AWD will also directly increase farm profitable by reducing fuel and labour costs associated with irrigation.

b. *How would P fertilizer be managed in AWD and can P rates be reduced?*

At An Giang there was no significant difference between the measured yields from each fertiliser treatment in the each season. There were no significant fertiliser and water interactive effects on yields in each treatment at each site (Khoi et al., 2015, Nhan et al., 2015). At all sites the implications for farmers is that AWD does not appear to reduce the availability of P or significantly reduce the yield in acid, alluvial or saline soils during the 2 years of the trial.

There is currently an excessive P application in the intensive rice cropping, which is leading to residual P accumulation. Soil P availability remained unchanged through 7 consecutive crops at reduced application rates, but applying P below 40 kg P_2O_5 significantly reduced soil total P level in the final season (Khoi et al., 2015). The application fertilizer P higher than 60 kg P_2O_5 was excessive to the crop demand building up the soil P pool and increased soil P availability. It is recommended that farmers can reduced the fertilizer P application from 60 – 90 kg P_2O_5/ha to 40 kg P_2O_5/ha but still is necessary to balance of P input and P removed from soil to sustain soil P supplying capacity and rice yield Farmers can improve farm productivity and profitability through reducing P fertiliser application and hence improve overall household resilience to climatic stresses.

c. *How to reduce drying period without rice burning (pollution) and not creating organic toxicity to rice plants?*

The 2012 experiment suffered from submergence and poor bund construction which may have allowed the movement of *Trichoderma* between the experimental plots. However there were positive indications that there were no significant differences in yields between each treatment. The residue management experiment in 2013 was strongly affected by soil acidity. About 70% rice plants died after seeding and more than 60% of plots strongly affected: roots of young seedlings could not set. The acidity affects to rice performance severely and causes irregular and scattered rice developments in these plots.

The failure of the residue manage 2013 crop shows the significance of the acid sulphate soil risk in the Mekong Delta. In the future changed climatic conditions could exacerbate acid sulphate soils and generate further acidity.

d. *How the productivity in Shrimp-Rice Systems can be improved with high yielding short-duration rice variety and enhanced salinity leaching*

Intensive leaching (3 to 6 repetitions) (solely and/or in combination with lime amendment) prior to rice cropping season tended to improve the adverse effects of saline soil subjected to shrimp- rice system in Bac Lieu. Ploughing the top soil of rice fields did not affect the properties of soil and soil solution, neither rice yield and yield contributing characters. The application of 2.0 tons of CaO per ha greatly influenced the chemical properties of the soil solution reducing sodium content, increasing pH, reducing soil SAR, ESP and significantly increasing rice yields. It is there possible to reduce the amount of water required to leach the sodium from the profile if CaO applications are included in land preparation. We can also conclude that short duration HYV could give higher yield and should replace Mot Bui Do in the shrimp rice system in Bac Lieu. Its early harvest helped it escaping salinity stress at the end of the season and left more time for farmers to prepare the land for the next shrimp crop.

Activity 3: Process Based Studies

a. Soil C and N dynamics

The cumulative N_2O-N flux in the acid sulphate soil was not influenced by the salinity treatments (Figure 1). The cumulative N_2O-N flux in alluvial soil was significantly influenced by salinity and was greater than those of the fresh water treatment. Climate change induced sea level raise could significantly affect carbon and nitrogen dynamics in increase nitrous oxide production non-saline alluvial soils and potentially reducing emissions in acid sulphate soils.

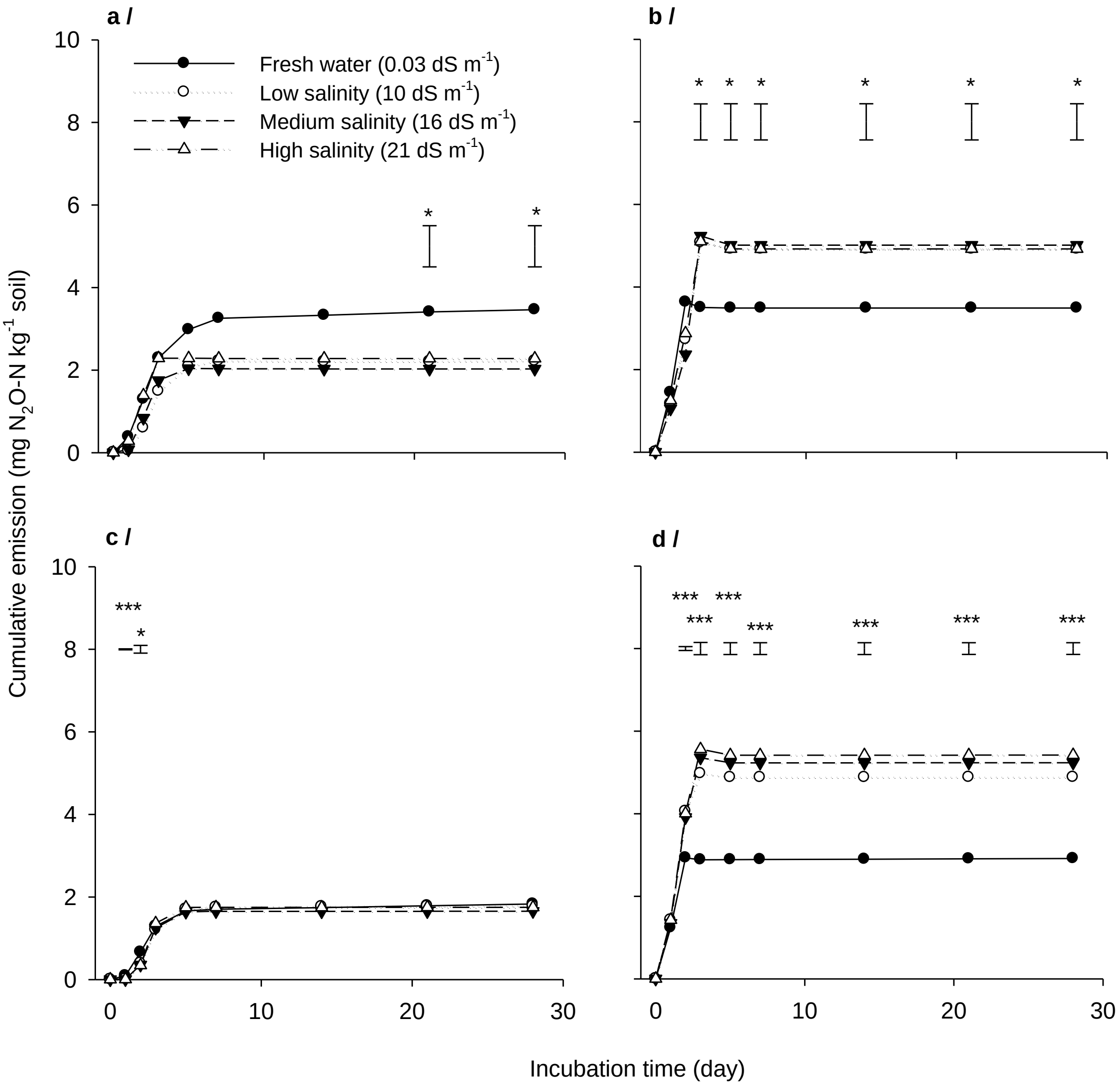

Figure 1. Cumulative amount of N_2O emission from soils during four week incubation. Figure 1a and 1b present the results from acid sulphate soil without and with glucose and nitrate addition, respectively, while figure 1c and 1d show the results from alluvial soil without and with both nutrient addition. Error bars present LSD values with significant level of 5 % (*) and of 0.1 % (***).

b. IR64-Sub1 Pot Study

Survival under completely submerged conditions of IR64-Sub1 3-day rice seedlings might be not longer than 3 weeks. In the dark conditions, imposed to mimic the natural condition of water turbidity, there was a low probability of survival after 15 days. The results indicate that a 15 day flood on starting 3 DAE on IR64-sub 1would still significantly reduce yield due to seedling mortalities of 70-80%. Further testing of the survival of high yielding rice cultivars under field condition is required.

Submerged rice plants elongated more in contrast to those of non-submergence, this is surprising because IR64-Sub1, like other high yielding rice cultivars, uses the quiescence strategy for survival under completely flooded conditions (Voesenek and Bailey-Serres, 2009; Nishiuchi et al., 2012). The presence of Sub-1 should limit the elongation response (Bailey-Serres et al., 2010). It is also possible that early flooded rice seedlings might result in more frequency of lodging at harvest.

The incorporation of the rice straw stubble and rice straw ash improved the level of rice seedlings survival. This was unexpected because fresh rice straw incorporation typically causes seedling mortality. It is not clear why rice straw stubble or ash improved survival rates. The residue treatments did not affect the EC or pH of the water, rather the depth of water was more important probably through dilution.

In conclusion, IR64-Sub1 can survive a 3 week-duration of complete submergence in darkness beginning 3 days after emergence, but there is significant mortality. This indicates that early season flooding could still have a significant effect on yield if growers are unable to replant. The incorporation of rice straw or ash increased the survival rate relative to the control. At harvest the ash had the greatest affect on yield when the rice under both flooding treats. The management of rice straw is an important factor for intensive rice production systems whilst incorporation of fresh residue boosted survival it also had a negative impact on yield.

c. Salt Leaching and Liming

The soil column studies show clearly that applying 3 leaching treatments in combination with soil ploughing could significantly removed soil soluble Na+ and reduced soil EC Using of CaO in equivalent of 2 tons/ha before leaching was effective in removing adsorbed Na^+ and reducing soil ESP. A further benefit of using CaO is the potential amelioration of acidity and Fe and Al toxicity in acid sulphate soils.

d. Soil P adsorption characteristics after 7 crops at fixed P supply

There was no statistical difference between the P-adsorption capacity or Langmuir parameters of the different fertilizer treatments (Figure 2). The field soil in all treatments could adsorb a maximum of 700 mg P/kg and assuming that soil bulk density was 1.2 g/cm^3 and a soil depth of 0-15 cm, the soil could adsorb an equivalent of 2,885 kg P_2O_5/ha. Interestingly, applying fertilizer P at 60 kg P_2O_5/ha did not significantly reduce the saturation sites of P on soil colloids compared to no fertilizer P was applied

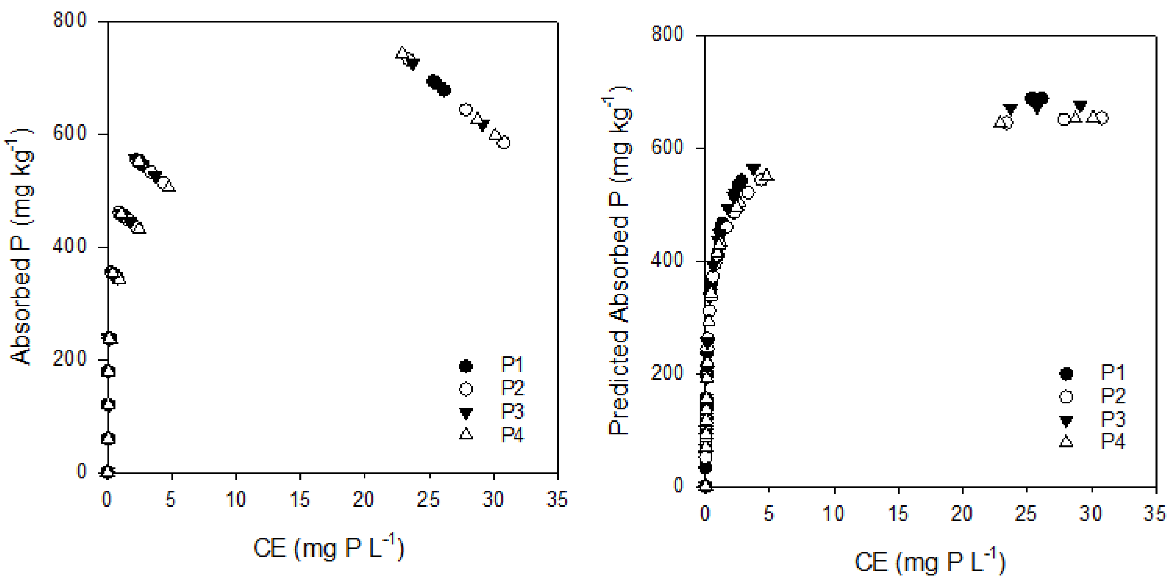

Figure 2. P adsorption relationship (left) of soil samples at the end of the 7 consecutive cropping seasons with different P rate treatments. Absorbed P (mg P/kg) is the amount of

P absorbed onto the colloid in the suspension and CE (mg P/L) is the remaining P concentration in the equilbrating solution. Predicted adsorption relationship (right) of soil samples at the end of the 7 consecutive cropping seasons with different P application rates.

In this study, soil received 0, 140, 280, 420 kg P_2O_5/ha and the irrigation water supplied approximately 35 kg P_2O_5 /ha during the 7 cropping seasons. During harvest approximately 302-325 kg P_2O_5/ha removed from the soil after 7 crops. These calculations implied that applying fertilizer P at a rate of higher than 40 kg P_2O_5/ha could offset the amounts of P removed from soil through harvesting. The lowest farmer fertilizer practice (60 kg P_2O_5/ha) resulted 19 kg P_2O_5/ha accumulated in the soil after each crop. This accumulated P did not significantly narrow the P-binding sites on soil colloids. The cost to the farmer based on the 2015 average price US$475 per ton DAP of the excessive fertilization is $30 per ha. If the excessive fertilization continues within 50 years soil P-binding sites will be completely saturated, equating to 2,885 kg P_2O_5/ha and a total net capital drain of $US643/ha. This equates to 0.5 to 1.5% of the average Mekong Delta farm income.

Activity 4: Upland Land Cropping

Would the integration of an upland crop in rice-based systems increase farmers' income and reduce climate risks?

Integration of an upland crop in rice-based systems did increase farmers' income and would potentially reduce climate risks by improving farm profitability. Upland crops were successfully established at all sites and were grown through to maturity at sites were water management was tightly controlled. Successful cucumber, sticky maize and mungbean cultivation at Vi Dong and CLRRI, respectively; and good performance of soybean, mungbean, pumpkin for the first month after establishment indicated that it may be possible to grow upland crops in the rice-based cropping system. However, water logging control and land preparation were essential factors for upland crop production integrated in lowland rice-based cropping systems. At Vi Dong the cost-benefit of double-rice upland, 2.12, was significantly greater than triple rice production 0.98. At double-rice sites an An Giang upland crops were successfully grown within the double rice systems and have been shown that to provide additional income (De et al., 2015).

There are some land and water management issues that must be addressed with the upland cropping in the Mekong Delta.

1. Both soil physical and chemical properties of the acid sulphate soils quickly changed during the soil drying for upland crops cultivation. Key changes included soil surface cracking, more than 20-fold EC increase, soil acidification and higher exchangeable Al than that of the native soil.
2. Water management issues, supply, drainage and quality, caused the failure of the upland crops within the rice cropping system. This indicates that a barrier for the adoption of upland cropping is the management of water within farming groups.
3. Optimisation of fertiliser management.
4. Up land crop production required both high financial investment and intensive use of labor both man-days and skills. This was one of the big challenges for upland crop development in the Mekong Delta.
5. There were market barriers preventing successful and widespread upland cropping. Future market research will be essential before deciding on what crops and what scale should be grown beside the adaptability of crops to certain agro-ecosystems.

8 Impacts

8.1 Scientific impacts – now and in 5 years

- The results from the reduced P experiments show that growers can reduce P fertiliser and optimal P fertilization recommendation for rice in the region needs to be evaluated. Saving fertilizer P usage means reducing high-energy consumption, so mitigating global warming footprint. It is clear from the study that growers can reduce P fertilizer inputs in all zones.

- The AWD experiments have shown that this water management strategy can be applied in acid sulphate soils and previously saline-affected area. This is new knowledge. But further evaluation and monitoring is required to quantify long term changes to the acidification and Stalinisation rates and any future limits to soil nutrient availability.

- The project identified the lime, ploughing and leaching frequencies that enhance salt leaching in the rice-shrimp farming system. The findings from salt leaching trials in rice-shrimp system have been applied to another rice-shrimp system of similar conditions in the Mekong Delta within the project “Improving the sustainability of rice-shrimp farming systems in the Mekong Delta, Vietnam” funded by ACIAR (SMCN/2010/083).

- 14 MSc degrees (10 M + 4 F) in the disciplines of Soil, Crop and Ecology Sciences were completed, and another 01 PhD degree (M) in the disciplines of Soil Science is under progress and plan to complete on the year 2016.

- CTU has developed and submitted a new scientific proposal investigating soil microbial community functioning on greenhouse gases emission under AWD application is under preparation.

- A new scientific collaboration was established with the Division of Soil Micrology in Swedish University of Agricultural Sciences to study on soil microbial community under different soil amendments in rice-shrimp system.

- Currently 3 scientific papers are under review and further publications will be published in national and international journals.

8.2 Capacity impacts – now and in 5 years

- Extension workers at four sites (nine villages) were involved into PRA, farm selection, data analysis, issues determination and experimental design development.

- Through the workshop and scientific meetings, staffs and participants have been trained in differently scientific issues, i.e. sampling and analysing techniques for soil, plant, evolved gasses; data analyses and writing skill; project management.

- The project has been providing financial support for the project members to be trained in abroad and to attend international conferences to share their scientific findings. There were 03 (from BL site) and 01 (HG site) staffs attending the training in IRRI for data analyses and scientific writing skills; 01 staff (BL site) participating in the course in Modelling and Simulation held in Australia; 01 (BL site) and 02 (AG site) staffs attending the International Rice Congress (IRC2014) held in Thailand.

- 01 project member from Vietnamese partner was successful in his PhD fellowship application to John Albright Grant and is pursuing the researches in CSIRO and ANU. Another staff has been awarded a John Dillon Memorial Fellowship to undertake the trainings in leadership and management skills in Australia. On their return, their gained knowledge and skills will be shared to colleagues or given to students through lectures and trainings. It also gives an opportunity to make connection and collaboration with

Australian scientists or other scientists from IRRI or from relevant institutes/ organizations for further researches.

- The project provides opportunities for knowledge, professional and cultural exchange between Australian and Vietnamese scientists/ staffs/ students through the meetings, workshops and field trips. Theme 3 hosted 02 honour Australian students conducted their theses in both field and lab studies.

- There were 5 (in Bac Lieu site), 7 (in An Giang site) and 2 (in Hau Giang site) MSc theses conducted on the issues within Theme 3, also 01 PhD study (BL site) is in progress and expected to be defended in 2016.

- Findings from the projects have been shared with local extension workers and farmers which provide them with new insights and adopting capacity toward new techniques feasibly applied on the management of rice-based natural resources.

8.3 Community impacts – now and in 5 years

At each site we have been briefing about the ACIAR project local leaders, farmer unions and farmers living at the selected farms. We have provided detail information about the aims of the field trials and have engaged farmers to evaluate the performance of the experiments, rice varieties and future experimental design for next season crop.

8.3.1 Economic impacts

The results from field experiments on reduced fertilizer P application showed that soil under intensive rice cropping in the studied site has a supplying capacity of available P enough to meet the demand of P nutrient for 2 years, equivalent to 6 sequential crops. As for long term P nutrient management, it is necessary to take into consideration of the balance of P input and P removed from soil. A saving strategy of fertilizer P application would save this finite resource. Besides, a reduced fertilizer P application in combination with AWD (irrigating when water level is at -15 cm from soil surface) is feasible to reduce investment cost for fertilization and irrigation so consequently bring greater income and hence profits to the farmers.

In the rice-shrimp farming systems, feasible techniques applied to efficiently remove salt from soil after the shrimp season would lead to a better followed rice crop that in turns sustain the whole cropping system, consisting of both rice and shrimp. Replacing short duration and high yielding rice varieties for local varieties would help to shorten the rice standing period, so extending the following period of shrimp cultivation which brings more income for farmers.

Upland cropping could significantly increase farm income and profitability, thus improving farm economic resilience to climatic stresses. The cost benefit ratio for upland cropping is double the ratio for triple rice cropping. However without carefully planning and connection to the market there is a potential risk for market over supply.

8.3.2 Social impacts

Results from on-farm evaluation and interviewing farmers/ local extension workers and agricultural managers showed that the techniques on AWD in combination with reduced fertilizer P application in triple rice cropping area as well as applying short duration rice varieties combined with removing salt by liming and leaching in rice-shrimp cropping area have a high capacity for adoption. Upland cropping can improve the profitability of many farmers and can be applied for the similar areas in the Mekong Delta. Improved farm profitability will lead to social impacts.

8.3.3 Environmental impacts

- The use of fertilizer P has been increasing in line with increasing rice cropping intensity and high pressure on productivity, and this increased soil P accumulation. A conservative estimate, based on industry data, indicated that a depletion of high quality, highly accessible reserves of rock phosphate could occur by 2033 (Cordell et al., 2009; Jasinski, 2011). After that, the lower quality and difficulty in accessing the remaining phosphate reserves make them uneconomical to mine and process. Thus, an efficient use of fertilizer P while stabilizing rice yield would save this finite resource, reduce excessive P accumulation, P fertilization cost and avoid environmental problems. In addition, fertilizer P production is also high-energy consumption so an effective P usage means mitigating global warming footprint.

- Saving water for irrigation in rice cultivation is included in the campaign “1 must, 5 reduction” promoted by Vietnamese Ministry of Agriculture and Rural Development in order to reduce input cost while increasing rice production. An appropriate “safe” alternate wetting and drying irrigation (AWD) strategy will improve water use efficiency whilst maintaining yield. Under future predictions the rainfall variability and sea level are set to increase, which could lead to more water scarcity in the dry season, saving water in irrigation would help the rice farmers to adapt better to the extreme conditions of drought and water scarcity in the future.

In a shrimp-rice cropping system in the coastal areas, salt accumulation along a shrimp growing duration may hamper the growth and production of the following rice crop. In the scenario of climate change with the increases of salinity intrusion and drought, the effects of salt accumulation on rice production may be more severe. The findings on the techniques to remove salt effectively from soil after a shrimp season would help to make the followed rice crop perform better and consequently sustain the whole cropping system of rice and shrimp.

- Acid sulphate soils and Stalinisation pose a significant risk to production and management plans should be developed to manage existing and to mitigate future soil acidification and Stalinisation.

8.4 Communication and dissemination activities

Communication has been conducted regularly between members, selected farmer and locally agricultural staffs during the experiment.

Liaison units for each target zone/province established, composed of representatives from provincial Department of Agriculture and Rural Development (DARD), district level DARD, and CLUES target zone manager.

There has been good collaboration with GIZ - Bac Lieu in disseminating AWD, varieties and fertiliser management to farmers across the province (please see details in Synthesis report of Theme 0).

The findings will be communicated and disseminated to local growers, seed production companies, local governments and finally to farmers through demonstration fields, workshops, training courses and means of communication.

9 Conclusions and recommendations

9.1 Conclusions

The findings from AWD experiment in three years (2012-2014) proved that solely application of AWD or reduced P fertilization did not result in an adverse effect on soil capacity in supplying available P as well as the growth and production of rice. AWD irrigation can be applied in An Giang and Bac Lieu sites. It is possible to increase income, profitabilty by utelising AWD and reducing P.

In rice-shrimp farming system, a short-duration rice variety (HYV) could give higher yield and could be used to replace the local rice variety (Mot Bui Do in the shrimp rice system in Bac Lieu. HYV is harvested earlier help it avoiding salinity stress at the end of season and give more time to farmer in land preparation for the coming shrimp crop.

Diversification with upland crops improves profitability and flexibility in the cropping calendar. Successful cucumber, sticky maize and mungbean cultivation and good performance of soybean, mungbean, and pumpkin indicated that it may be possible to grow upland crops in the rice-based cropping system. The cost benefit of growing upland crop with double rice was also double that of the triple rice production system. However, water logging control, land preparation and labour were essential factors for upland crop production integrated in lowland rice-based cropping systems. The farmers also feel disconnected from the upland crop market and there is potential risk of oversupply.

Cropping failures at acid sulphate soil sites indicates that the acidification risk is still great and Acid sulphate soil management should by developed and implemented by farmers. In other parts of the world successful acid management resulted in increased yields and profits. The acid sulphate soil zones will also be very susceptible to climate change induced acidification.

At all sites water delivery, management and drainage critical and caused a number of failures and needs to be improved. There is an opportunity to address water management during the next phase of agriculture aggregation and mechanism in the Mekong Delta.

9.2 Recommendations

Dissemination of feasible findings is needed in collaboration with local extension workers and agricultural managers.

Alternate wetting and drying irrigation technique appears as an adaptive strategy for rice production under climate change but the sustainability of phosphorous reduction on acid sulfate soil in Mekong Delta requires further investigation.

Strategies for upland crop development and market need to be recognized.

Suitable land preparation and water management are two key factors for upland crop production integrated in lowland rice-based cropping system for climate change adaptation.

Potential upland crops (sesame, cucumber and maize) integrated in lowland rice-based cropping system should be up-scale and out-scale for not only climate change adaptation but also for crop diversification and lower risk of mono rice cropping system. Partnerships should be established between the market and the farmer to ensure the development and integration of upland cropping into the double and triple rice production systems.

Where salt intrusion, it should be paid much attention to the reclamation of salt contaminated soil prior to crop cultivation.

Acidity and salinity management plans for upland cropping must be developed for upland cropping with the Mekong Delta. These plans should regularly been evaluated and modified.

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International

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National

Pham Phuoc Nhan, Cu Ngoc Qui, Tran Phu Huu, Le Van Hoa, B. McDonald and T. P. Tuong (2013). Effects of alternate wetting and drying irrigation, crop establishment methods, and reduced phosphorus application on OM5451 growth and yield in 2012 Winter Spring Crop Season. *Journal of Science Can Tho University.* Part B: Agriculture, Aquaculture and Biotechnology, 28 (2013):103-111. (in Vietnamese).

Refereed Proceedings/book chapters

International

Pham Phuoc Nhan[1], Le Van Hoa[1], Nguyen Truong Giang[1], To Phuc Tuong[2], Ben Macdonald[3]. 2015. Effects of alternate wetting and drying irrigation and phosphorous fertilizer rates on the growth and yield of rice in double rice cropping system at An Giang province. ?? (Eds.) Proceedings of the the 8th ASIAN CROP SCIENCE ASSOCIATIONCONFERENCE (ACSAC8) "Sustainable Crop Production in response to Global Climate Change and Food Security". Submitted.

Pham Phuoc Nhan[1], Phan Thi Be Sau[1], Le Van Hoa[1], Ben Macdonald[2]. 2015. Residue management effects on survival rate, growth and yield of rice cultivar IR64-Sub1 subjected to submergence at young seedling stage in pots. ?? (Eds.) Proceedings of the the 8th ASIAN CROP SCIENCE ASSOCIATIONCONFERENCE (ACSAC8) "Sustainable Crop Production in response to Global Climate Change and Food Security". Submitted.

Presentations

International

Le Van Hoa, Pham Phuoc Nhan, Tran Phu Huu, Nguyen Truong Giang, Danh Phuc Viet, Ben McDonald and To Phuc Tuong (2014). Effects of AWD irrigation and reduced phosphorous fertilization on the growth and yield of rice cultured in double rice cropping system at An Giang province. *Oral presented in the 8th ASIAN CROP SCIENCE ASSOCIATIONCONFERENCE (ACSAC8) "Sustainable Crop Production in response to Global Climate Change and Food Security".* Vietnam National University of Agriculture, Ha Noi, September 23 – 25, 2014.

Pham Phuoc Nhan, Phan Thi Be Sau, Le Van Hoa and Ben McDonald. 2014. Effects of incorporation of rice straws and flooding on seedling growth and yield of IR64-Sub1. *Oral presented in the 8th ASIAN CROP SCIENCE ASSOCIATION CONFERENCE (ACSAC8) "Sustainable Crop Production in response to Global Climate Change and Food Security".* Vietnam National University of Agriculture, Ha Noi, September 23 – 25, 2014.

Posters

Chau Minh Khoi, Nguyen Van Qui, Nguyen Minh Dong, Bennett Macdonald and To Phuc Tuong. 2014. Possibility of introducing high yielding, short-duration rice varieties to replace local traditional photoperiod sensitive variety in the shrimp-rice cropping system in the Mekong Delta, Vietnam. *Poster presented in 4th International Rice Congress*, Bangkok, Thailand 27 October – 1 November 2014.

Chau Minh Khoi, Nguyen Van Qui, To Phuc Tuong and Bennett Macdonald (2014). Effects of alternate wetting-drying irrigation management on soil phosphorus availability and rice growth in the Mekong delta, Vietnam. *Poster presented in 4th International Rice Congress*, Bangkok, Thailand 27 October – 1 November 2014.

Pham Phuoc Nhan, Le Van Hoa, Tran Phu Huu, Nguyen Truong Giang, Danh Phuc Viet, Ben MacDonald and To Phuc Tuong. 2014. Profit improvement on rice production by alternate wetting and drying irrigation and phosphorus reduction. *Poster presented in 4th International Rice Congress*, Bangkok, Thailand 27 October – 1 November 2014.

Non-refereed publication

Chau Minh Khoi, Nguyen Van Qui, and Bennett Macdonald 2015. Enhancing salinity leaching efficiency by topsoil turnover and amendment: a soil column study. Theme 3 CLUES Project Report (to be upgraded to journal paper in May-June).

Chau Minh Khoi, Nguyen Van Qui, To Phuc Tuong and Bennett Macdonald 2015. Effects of alternate wetting-drying irrigation management on soil phosphorus availability and rice growth on salinity affected soils in the Mekong river delta, Vietnam. Theme 3 CLUES Project Report (to be upgraded to journal paper in May-June).

Nguyen Ngoc De, Do van Hoang, Nguyen quang Chon 2015. Comparing triple rice cropping and double rice cropping with integrated rice - upland crops in Vi Thuy district, Hau Giang province. Theme 3 CLUES Project Report (to be upgraded to journal paper in May-June).

Nguyen quang Chon, Tran Dang Dzung, Tran Duy Viet Cuong and Mai Thanh Truc and others. 2015. Integration of upland crop production in lowland rice-based cropping systems for climate change adaptation. Theme 3 CLUES Project Report.

11 Appendixes

11.1 Appendix 1:

Table 1. Site selection for on-farm and on-station experiments at four agro-ecological zones.

Ecological Zone	Target district and Province	Target village for benchmark survey	Testing site-farmers' field in a hamlet within the target village	Testing site - on-station	Comparative village for benchmark surveys
Deep flooded	Tri Ton, An Giang	Ta Danh village for 2 rice cropping	Tan Thanh hamlet	Ta Danh station of Seed company	Dinh Thanh village (Thoai Son District)
	Thoai Son, An Giang	Vinh Trach for 3 rice cropping	Trung Binh hamlet	Dinh Thanh station of Seed company	
Intermediate flood with alluvial soil	Thoi Lai, Can Tho	Truong Xuan A village	Trung Hoa hamlet	CLRRI	Thoi Tan village (Thoi Lai District)
Acid Sulfate Soil	Phung Hiep, Hau Giang	Hoa An village	Hoai Duc hamlet	Hoa An Station	Vi Dong village (Vi Thuy District)
Saline Zone	Phuoc Long, Bac Lieu	Phuoc Long village for shrimp Rice system	Phuoc Thanh hamlet	Seed production station of Seed Company	Lang Giai village (Hoa Binh District)
	Hoa Binh, Bac Lieu	Minh Dieu for 3 rice crop/year	Long Thanh hamlet		
Rice-Based system with non-rice crop	In collaboration with 3 sites selected as above: Lang Giai (Hoa Binh), Thoi Tan (Thoi Lai) and Vi Dong (Vi Thuy).				

Australian Government

Australian Centre for International Agricultural Research

Final report

Project	**Climate Change Affecting Land Use in the Mekong Delta: Adaptation of Rice-based Cropping Systems (CLUES)** Theme 4: Analysis of farming systems and socio-economic settings in rice farming households
project number	SMCN/2009/021
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prepared by	Dang Kieu Nhan
co-authors/ contributors/ collaborators	Le Canh Dung, Truong Thi Ngoc Chi, Vo Van Tuan, Vo Van Ha, Vo Thanh Danh, Nguyen Duy Can, Peter Brown, Thelma Paris, John Wards
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Contents

1 Acknowledgments

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2 Executive summary

Improving capacity of rice production means improving capacity of rice farming households to adapt to climate change. Hence, barriers and enablers of rice production and farmer's livelihoods need to be determined. The study theme addresses three specific objectives: (1) identify bio-physical and socio-economic factors determining the capacity of farmers to adapt to climate change; (2) understand needs for improving the effectiveness of policies and for enhancing the role of key institutions in enabling farmers' decisions and adaptive capacity; and (3) evaluate feasibility of tested farming technologies in terms of the extent of adaptive capacity under projected future climate and socio-economic conditions. Sustainable livelihood framework and participatory approaches were applied to identify enablers and constrainers of livelihoods capacity of rice farmers to climate change at different scales, from household, community to provincial scale.

We implemented study activities at eight communes (hereafter referred to study sites), where Themes 2 and 3 conducted experiments, in four study provinces (hereafter referred to study zones; flood, alluvial, acidic and saline zones). Two study sites per zone were selected, one with favourable and another with unfavourable conditions, considering soil quality, accessibility of irrigation water, availability of flood or saline management structure, and connectivity as key proxies.

We implemented five activities: (1) baseline livelihood analysis, (2) sustainable livelihood strategy assessments, (3) policy and institutional analysis, (4) feasibility assessments of tested farming technologies, and (5) extension pathways. Baseline household's livelihood surveys and household's livelihood strategy assessments were conducted, with local workshops and household surveys, to identify needs and possible solutions in improving capacity of rice farming and farmer's livelihoods to adapt to climate change. In this aspect, we also understood gender issues in rice production and livelihoods by in-depth interviewing 205 male and female couples. To identify policy and institutional gaps in supporting adaptive capacity of rice farmer, we collected information from eight local workshops, two workshops per zone, with participants from relevant governmental and community-based actors at district and provincial level, and service suppliers. Given on-farm trials of promising rice varieties and rice farming technologies created from Themes 2 and 3, we assessed feasibility of tested rice varieties and five rice farming technologies though field-days and local workshops with local stakeholders and project researchers. Finally, extension pathways of feasible farming technologies identified from the previous step were determined through the participatory impact pathways analysis and technological adoption simulation with participation of local stakeholders.

Results show that rice farmers in the study zones have faced multiple threats and problems, not only climatic but also harmful pests and other socio-economic factors. The climatic threats and socio-economic problems differ with zones and sites within the same zone. The saline zone is most vulnerable to climatic threats and the unfavorable sites are more vulnerable than the favorable sites. Poorer farmers are considered more vulnerable because of relatively lower livelihood capacity than better-off farmers. Farming diversification by rotating upland crops (in freshwater areas) or shrimp (in saline water areas) with rice helped farmers earn higher income but this option was constrained by unavailability of off-farm labor, poor accessibility to and instability of output market systems, and poor irrigation or drainage systems. Informal farmer's groups, informal in-kind credit and availability of telephone and television of households are enablers of livelihood capacity of farmers. Women play an important role to rice farming and household's livelihoods. However, their knowledge on climate change and their participation in extension activities were relatively poorer than their husbands. Enhancing adaptive capacity of rice farmers to changes in the study zones, not a single solution but a package of solutions is needed, including rice farming technologies, structural measures, and socio-economic measures with respect to specific contexts.

The Vietnamese government has promulgated several policies relevant to rice production, rice trade and rice farmer's livelihoods. However, the implementation of the policies at local level was not effective as expected. The problems are weak integration, inflexibility and suitability of the policies in local contexts, which in turn caused difficulties in institutional coordination in policy implementation. Effective out-scale and up-scale of promising technologies created by CLUES needs effective coordination and participation among key governmental actors together with community-based organizations, and incorporation into local existing development programmes. New technologies from CLUES will need constantly adjustments and improvement in order to adapt to changing needs of farmers.

Farmers and local stakeholders expected that feasible rice varieties or rice farming technologies have multiple adaptive characteristics with simultaneously. Future rice varieties should be not only tolerant to water-related threats and to major pests, but also having high-yielding potential and good grain quality for eating and marketing. Feasible rice farming technologies need satisfy important criteria like the ease of practice, economic viability, and the availability and the stability of markets for outputs. Single component technologies like appropriate P application or AWD practice were ranked at high priority. Rice-upland crop rotation and rice transplanting technique, which are considered promising under water-related threats, were ranked lower priority for the current stage from intensive-labour input and/or limited markets for outputs.

Target areas of feasible farming technologies created by the project require relatively favourable conditions of soil and water (i.e. alluvial or slightly acidic soils with available irrigation and drainage systems), except for appropriate P application technique in acid sulphate zone. Farmer cooperation is an important enablers of the out-scale of the feasible technologies, for instance the AWD practice, while rice transplanting and rotation of upland crops with rice require farmers with availability of on-farm labour or accessibility to local off-farm labour, or with availability of output markets. DARD and its agencies are important actors in out-scale and up-scale of the technologies. In addition, other actors related to services for inputs and outputs, farming cooperation plays an important role. The ease of practice and economic viability are important determinants of the adoption of technologies by farmers.

In conclusion, enhancing capacity of rice production and livelihoods of rice farmers needs a package of optional solutions in respect with site-specific contexts. Local stakeholders need not only technical solutions but enablers to foster innovative capacity, which need multi-dimensioned flows of knowledge and innovation processes. Up-follow pilot models, where proposed packages of solutions will be tested, should be established, monitored and evaluated, incorporating in local existing development programmes at the study sites,

3 Background

In the Vietnamese Mekong Delta, agricultural production and farmer's livelihoods are highly susceptible to soil acidity and abnormities in the Mekong river's flow and in the weather and/or climate (Hoanh et al., 2003; Nhan et al., 2011; Smajgl et al. 2015). The delta is prone to monsoon flooding in the upper zone in the wet season, to salinity intrusion in downstreams in the dry season and to acidity in swampy floodplains. The problems would be more severe in the future under anticipated climate and water-related changes (CarewReid 2008; Schmidt-Thomé et al. 2015), which in turn would have strongly negative impacts on agricultural production and households in the delta (Smajgl et al. 2015).

Rice production is an important economic sector for both national and farming household's economies. Annually, rice produced in the Mekong delta accounted for about 90-95% of total rice export volume of the country and rice farming contribute to 60-70% of farming household income (GSO, 2010-2014). Realizing the importance of rice industry in the Mekong delta to national food security and exports, in 2009 the Vietnamese government issued a national strategic plan for agricultural land use and food security to 2020. Accordingly, for the Mekong Delta, about 1.75 million ha of rice land has been set aside for rice production and about 3.5 million ha of rice grown area should be maintained. Since 2010, the Vietnamese government has released several policies addressing maintained rice land for food security, improvement of rice production technologies, enhancement of rice farmer's livelihood, and rice trade.

Strategic solutions are necessary to not only enhance capacity of rice farming sector and rice farmers to adapt to changing bio-physical and socio-economic circumstances but also contribute to the effectiveness of the aforementioned government policies. Rice farming is a livelihood activity of farmers. Improving adaptive capacity of rice production, therefore, means improving adaptive capacity of rice farming households to anticipated changes. However, together with endogenous factors of farming households, external institutional factors strongly influence their capacity in agricultural production as well as livelihoods (Garschagen et al., 2012). Agricultural scientists have attempted to create adaptive farming technologies in order to promote resilience of agricultural production and hence livelihoods of farmers. However, the up-take of new technologies by farmers highly depends upon enabling and constraining factors of farmer's livelihoods and their communities (Nhan et al., 2007; Bosma et al., 2012). The overarching questions are (1) what are needs of rice farmers and possible solutions that would help rice farmers adapt to anticipated changes in the future, and (2) what are priority rice farming technologies and how the technologies can be adopted and extended at study areas.

Applying participatory and livelihood approaches, Theme 4 members have worked closely with local stakeholders to identify constraining and enabling factors, and needs of rice farmer's livelihoods. These results were used as baseline information to design research activities of other themes of the project. Subsequently, by collaboration with other themes and local stakeholders, the theme members assessed feasibility of tested farming technologies created by the project and determine extension pathways of feasible technologies.

4 Objectives

Theme 4 contributes to the goal of the project, improving the adaptive capacity of rice-based farming systems to anticipated impacts associated with climate change, through informing decisions on enhancing adaptive capacity of farmers and policy implementers. To archive this aim, the theme addresses three following objectives:

- Identify bio-physical and socio-economic factors determining the capacity of farmers to adapt to climate change
- Understand needs for improving the effectiveness of policies and for enhancing the role of key institutions in enabling farmers' decisions and adaptive capacity
- Evaluate feasibility of tested farming technologies in terms of the extent of adaptive capacity under projected future climate and socio-economic conditions.

Research findings from the Theme have been provided to the project's researchers, scientific communities, and local farmers and policy implementers for effectively making decisions to enhance capacity of rice farming systems to adapt to anticipated climate change at the study zones.

5 Methodology

5.1 Approaches and study framework

We assume that adaptive capacity of rice-based farming systems can be improved through enhanced livelihood capacity of rice farming households to adapt to changes. An understanding on the livelihood elements of households and their contexts, structures and processes is necessary. We therefore followed the sustainable livelihood framework (DFID, 1999) to identify enablers and constrainers of adaptive capacity of rice farmers to climate change. The Theme focuses on issues on different levels, from household, community to provincial scale.

In addition, we applied participatory approaches with local workshops, focus groups discussions and individual interviews (Figure 2). We have worked closely with local farmers, service suppliers and governmental staff to understand baseline livelihood contexts and livelihood strategies of farmers, and to identify gaps of transforming structures and processes, that would influence the capacity of farmers to adapt to anticipated changes. Moreover, local stakeholders and CLUES Themes' members have participated in feasibility evaluation of on-farm tested technologies and validation of obtained results.

Theme 4 consists of five major activities: (1) baseline livelihood analysis, (2) sustainable livelihood strategy assessments, (3) policy and institutional analysis, (4) feasibility assessments of tested farming technologies, and (5) extension pathways (Figure 1). In the 1st and the 2nd years of the project, baseline household's livelihood surveys and household's livelihood strategy assessments were conducted to identify needs and possible solutions in improving rice cropping adaptation. Results were used as inputs of other research Themes of CLUES to set up, tune fine trials and/or develop adaptation plans. In the 3rd and 4th years, we conducted policy and institutional analysis, and feasibility assessments of promising farming technologies created by CLUES. These two activities aim to identify policy and institutional gaps, and the feasibility of tested technologies under farmer's environment. Obtained results were matched with local needs and possible solutions suggested in the 1st and 2nd years, and the allowed identifying possible pathways of scaling out and scaling up the feasible technologies through local workshops with participation of local farmers and other stakeholders in the last year.

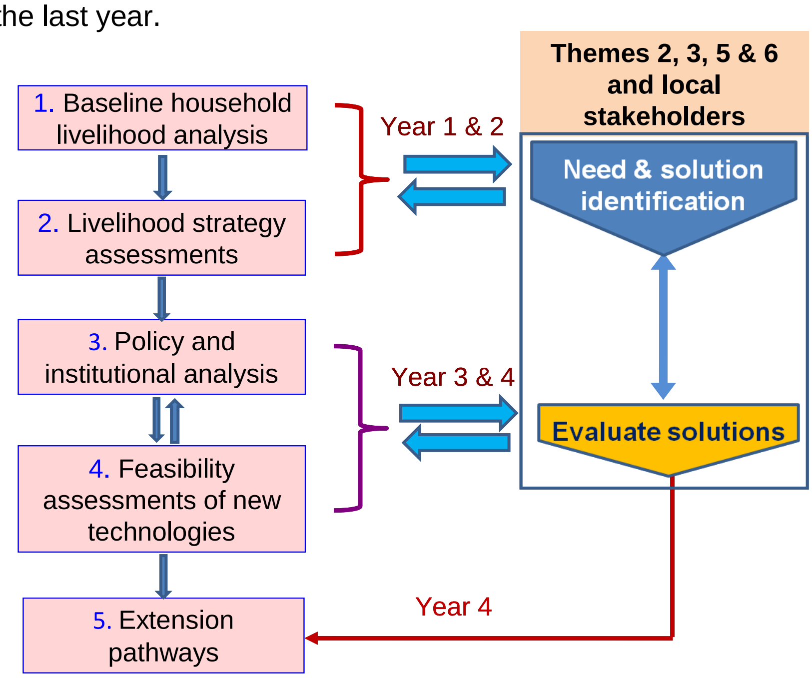

Figure 1: Study framework of Theme 4

Figure 2: Focus group discussions with local farmers (left), local government and agricultural extension staff (right) at a study site (photographed by L.C. Dung and V.V.Tuan)

5.2 Study sites

The project addressed four study provinces, which are considered to be representative to major agro-ecological zones in the delta: An Giang (flood zone), Can Tho (alluvial zone), Hau Giang (acid-sulfate-soil zone) and Bac Lieu (saline zone). We implemented the activities at the same communes (hereafter referred to study sites) as Themes 2 and 3 (see more details in reports of Themes 2 and 3). Two study sites for each province were selected, one with favourable and another with unfavourable conditions, in terms of bio-physical factors. Soil quality (i.e. alluvial *vs*. acidity or salinity), accessibility of irrigation water (irrigated *vs.* rainfed), availability of flood or saline management structure (with/good structure *vs.* without/poor structure), and connectivity (close to *vs.* far from main roads or markets) are considered main proxies of the favourableness. Eight study sites are as follows:

- An Giang province - the flood zone: (1) Ta Danh commune of Tri Ton district (unfavourable site) and (2) Vinh Trach commune of Thoai Son district (favourable site);
- Can Tho city - the alluvial zone: (1) Truong Xuan A commune (unfavourable site) and Thoi Tan commune (favourable site) of Thoi Lai district;
- Hau Giang province - the acid-sulfate-soil zone: (1) Hoa An commune of Phung Hiep district (unfavourable site) and Vi Dong commune of Vi Thuy district (favourable site);
- Bac Lieu province - the saline zone: Phuoc Long commune of Phuoc Long district (unfavourable site) and Minh Dieu commune of Hoa Binh district (favourable site).

5.3 Data collection

5.3.1 Baseline livelihood analysis

The baseline livelihood analysis aims to identify livelihood elements that could enable or constrain adaptive capacity of farmers and hence to determine needs and possible solutions to improve adaptive capacity of farmers to climate change. We conducted participatory community appraisals with focus group discussions to get an understanding the context at community level before focused down on household surveys with structured interviews.

For participatory community appraisals, three target groups, 8-12 participants per group, were selected each study site: (1) commune staff, community-based organisations' members and rice farming service suppliers, (2) better-off farmers and (3) worse-off farmers. The better-off or worse-off farmers were determined by wealth ranking done by local staff using their local indicators such as farm size, house type, farm implement, educational attainment of household's members and social networking (Appendix 1). Main concerned issues for the discussions are land and water resource uses, roles of formal and informal institutions, SWOT (strengths, weaknesses, opportunities and challenges) of rice farming and adaptive measures to climate change.

Building on findings from the participatory community appraisals, household surveys were conducted with interviewing 480 households involved in major rice-based farming systems at eight study sites. Totally, seven farming systems considered are: (1) double rice cropping, (2) double rice - fish integrated farming, (3) double rice - upland crops rotational farming, (4) rice – shrimp rotational farming, (5) triple rice cropping, (6) triple rice – fish integrated farming, and (7) triple rice cropping and upland crops. For each farming system in respective study site, based on a list of households given by commune officers or extension staff, farmers were randomly selected for interviews. Collected data include (1) household's livelihood assets - human, natural, physical, financial and social assets; (2) communication pathway of accessing new farming technologies, (3) risk management strategies to natural hazards, (4) household's livelihood determinants and intents, and (5) farming inputs and outputs. In addition, gender issues in rice production and livelihoods were investigated with 205 male and female farmers involved. A pilot survey was carried out to finalise the questionnaire before full-scale surveys conducted at all of the study communes.

5.3.2 Sustainable livelihood strategy assessment

Twenty-three local workshops in eight study sites were held to assess capacity and to identify livelihood strategies of small-holders to adapt to climate change. Focus group discussions followed by individual in-depth interviews were conducted. For each farming system per site, two groups – one with relatively larger farmers (> 1 ha) and another with relatively smaller farmers (< 1 ha), 7-15 participants per group, were interviewed. A total of 233 participants were involved in focus group discussions. In addition, to investigate gender issues on adaptive capacity to climate change, three women groups, whose households practiced rice-based farming systems, in unfavourable site in Hau Giang province were invited to participating in discussions (Appendix 3).

Local participants identified key indicators of their human, social, natural, physical and financial assets that enabled or constrained their ability to manage their rice-based farming systems under climatic and non-climatic changes. They rated each indicator on a scale from 0 to 5 according to the degree to which the indicator was likely to be supporting adaptation in the future (Figure 3).

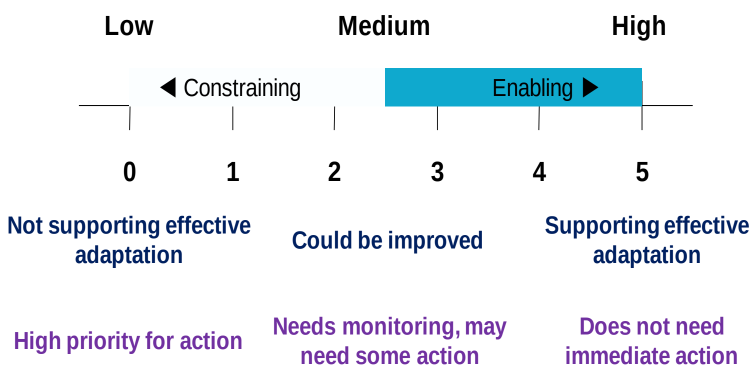

Figure 3. Scoring process used to assess capacity of rice-based farmers to manage for climate change

5.3.3 Policy and institutional analysis

To identify policy and institutional gaps in supporting adaptive capacity of rice farmer, we collected information from eight local workshops, two workshops per province, with participants from relevant sectors' officials (DARD, DONRE, DIT and DOST), agricultural extension staff, community-based organisation representatives at district and provincial level, and service suppliers. Each workshop, we split participants into two groups, one with governmental sector's officials and another one with extension staff, community-based organisations' members and service suppliers. We applied PRA techniques to collect information from group discussions such as brain-storming, Venn diagram and scoring

We addressed four following issues:

(1) Important drivers and issues in developing adaptive capacity of rice farmers at the present and future;

(2) Effectiveness, enablers and constrainers of policy implementation in improving livelihood livelihoods, particularly capacity of farmers to adapt to climate change-induced effects;

(3) Policy and institutional gaps between the current stage and farmer's needs;

(4) Relevant stakeholders and their roles in enhancing adaptive capacity of rice farmers and in scaling out and scaling up promising technologies created from CLUES.

5.3.4 Feasibility assessment of rice farming technologies

Participatory rice varietal assessments

Under the CLUES, new lines or varieties or rice were tested for tolerance to submergence, acidity or salinity through through researcher-managed and farmer-managed trials and sensory evaluation at the study sites. We, in collaboration with Theme 2, organised 53 field days to assess suitability of rice varieties. For each field day, the assessment was conducted separately by local male and female farmers, 10 to 15 participants per groups. A total of 1409 farmers, of which women accounted for 34%, participated in the assessment. Agronomic characteristics and yields of the test lines or varieties were assessed in comparison with currently-grown varieties by farmers. In addition, with farmer-managed trials, farmers had the opportunity to assess the postharvest, cooking and eating quality of the test varieties.

Participatory assessments of tested technologies

In the 3rd and 4th year of the project, five promising farming technologies, which had been tested with researcher-managed experiments in the 1st and 2nd year, were tested with farmer-managed trials. Each tested technology was triplicated one three farmer fields, measuring from 1000 to 3000 m^2 each. By close collaboration with Theme 3, site managers and local partners to assess feasibility of tested technologies, we organised nine field-days with participation of local farmers, extension staff and CLUES researchers (197 participants totally), which was followed by four workshops with participation of local farmers, extension staff, farmer and women unions' preventatives, governmental officials and CLUES researchers (72 participants totally) to assess feasibility and rank priority of the tested technologies.

Five promising technologies are: (1) alternate wetting-drying (AWD) irrigation in rice production, (2) reduced phosphorus (P) application rate in rice production, (3) rice production applying transplanting technique to shorten cropping duration in order to avoid flood risks, (4) rice-upland crop rotation, and (5) adaptive rice farming techniques to salinity in rice-shrimp farming system (i.e. short growth-duration rice varieties, soil salinity flushing by irrigation, and calcium application). The tested technologies by sites are as the following Table 1.

For on-farm assessments with local farmers, extension staff and CLUES researchers, the feasibility of tested technologies was assessed through direct observation and discussions advantages and disadvantages of the technologies as well as preconditions of technological option by farmers. For workshop assessments, the tested technologies were assessed through scoring the feasibility, in terms of technical, economic, social and environmental aspects with an scale 1 (low), 2 (medium) and 3 (high feasibility), and they were ranked in the order of important or priority for out-scale. Partial budgeting analysis was applied for assessing economic viability of the tested technologies.

Table 1: On-farm tested technologies by site

Provinces	Communes	Tested technologies	Reference technologies
An Giang (flood zone)	Ta Danh (unfavourable site)	1. Reduced P application plus AWD 2. Reduced P application plus rice transplantation 3. Rice – upland crops - rice	Double rice cropping system with farmer's common practices
Can Tho (alluvial zone)	Thoi Tan (favourable site)	1. AWD irrigation technique 2. Rice – sesame - rice	Triple rice cropping system with farmer's common practices
Hau Giang (acid sulphate soil zone)	Vi Dong (favourable site)	1. Rice – cucumber/maize– rice	Triple rice cropping system with farmer's common practices
	Hoa An (unfavourable site)	1. Appropriate P application	Double rice cropping system with farmer's common practices
Bac Lieu (saline zone)	Minh Dieu (favourable site)	1. Reduced P application 2. AWD technique 3. Rice – upland crops - rice	Triple rice cropping system with farmer's common practices
	Phuoc Long (unfavourable site)	1. Adaptive rice farming to salinity (short growth-duration varieties, soil salinity flushing, and calcium application)	Single traditional rice cropping rotated with shrimp culture with farmer's common practices

5.3.5 Extension pathways

Given feasible technologies of the project identified from the assessments, extension pathways of the technologies were determined through the participatory impact pathways analysis (PIPA) (Douthwaite *et al*., 2007). The PIPA was conducted with two local workshops each province with participation of local stakeholders (Table 2). The 1st workshop focused on problems analysis and stakeholder analysis and the 2nd workshop addressed extension pathways and technology adoption by farmers, using an extension logic model and the ADOPT simulation model. Results of the extension logic model include technology extension methods and tools, target areas, target farmers, relevant stakeholders and their roles, and important assumptions.

Table 2. Participants involved in PIPA workshops

Provinces	PIPA workshops	Participants*						Total
		Farmers	FR	EW	FA	WU	PA	
An Giang (flood zone)	1	3	1	6	3	3	2	18
	2	4	2	6	3	3	4	22
Can Tho (alluvial zone)	1	2	1	1	1	1	2	8
	2	3	2	6	2	2	3	18
Hau Giang (acidic zone	1	5	3	4	2	2	3	19
	2	5	3	4	3	3	4	23

Bac Lieu	1	2	2	2	1	1	2	10
(saline zone)	2	3	3	4	2	2	4	18

SR: site researchers; ES: extension staff; FA: Farmer Association; WU: Women Union; GO: governmental officials (Department of Agricultural and Rural Development, Department of Plant Protection, Department of Sciences and Technology)

5.4 Statistical analysis

Both qualitative and quantitative data analyses were applied. For qualitative analysis, preference, scoring and ranking methods were applied. For quantitative analysis, a one-way or two-way factorial ANOVA (Analysis of Variance) were applied to test for the effect farming system or zone and site as well as zone and site interaction. Turkey tests at 5% significance level were used to compare means among farming systems, zones and sites. In addition, principal components analysis was applied to evaluate cross-relationships among variables related to natural hazards, production and livelihood determinants that likely occur and have impacts on household's livelihoods, and to identify major underlying factors of those relationships. The use of this technique is to reduce the dimensionality of potential explanatory variables without substantially compromising the degree of observed variability (Latin et al., 2003).

6 Achievements against activities and outputs/milestones

To achieve three specific objectives as aforementioned, Theme 4 has focussed on five main activities. Achievements against the activities are presented as below.

Activities	Sub-activities	Outputs/milestones	From (mm/yy)	Completion date (mm/yy)	Comments
4.1. Baseline livelihood assessments	- Participatory community appraisals on bio-physical and socio-economic at community level - Household surveys on livelihoods - Household surveys on gender issues	- Well-trained team members with methods and skills of data collection - Identification of problems and constraints of physical and socio-economic setting at different level and options - Role and needs to enhance capacity of women to adapt to climate change	Oct 2011	Mar 2013	- Completed - Inputs to activities 4.2, 4.3 and 4.4, and themes 2, 3 and 5 - Manuscripts for publication in preparation
4.2. Sustainable livelihood and adaptation strategy assessments	- Self-assessment workshops with farmer groups in each study zone Through group discussions and in-depth interviews	- Well-trained team members with methods and skills of data collection - Identification of enablers and constrainers of adaptability by households	April 2012	Mar 2013	- Completed - Inputs to activities 4.3 and 4.4 and themes 2, 3 and 5 - A manuscript for publication in preparation
4.3. Policy and institutional analysis	- Organise local workshops with participation of local extension staff, government officials and service suppliers	- Identification of policy and institutional gaps that influence capacity of farmers and adoption of new technologies by farmers - Identification of opportunities for mainstreaming climate change adaptability measures to local and national development programmes	Mar 2012	Sep 2014	- Completed - Inputs to activities 4.4 and 4.5

Activities	Sub-activities	Outputs/milestones	From (mm/yy)	Completion date (mm/yy)	Comments
4.4. Participatory fine tuning of project-generated technologies and assessing benefits in terms of adaptive capacity	- Participatory evaluation of on-farm tested rice varieties (PVS) - Feasibility assessments of on-farm tested rice farming technologies with local stakeholders	- Agronomic criteria expected by farmers for future rice varieties by zone - Feasibility rank of tested technologies by zone - Improved management practices for new adaptation technologies in line with farmers' requirements	Mar 2012	Sep 2014	- Completed - Inputs to activity 4.5 and themes 2, 3 and 5; - Improved management practices for new technologies not be achieved due to limited time
4.5. Explore possible extension pathways of research findings of the project	- Training and workshops with local stakeholders project researchers on impact pathway and extension pathway analysis of CLUES's promising technologies - Simulation of adopting feasible technologies by farmers by zone	- Well-trained extension staff with impact pathway and extension pathway analysis methods - Identification of ways and options and recommendations for out-scale and up-scale of feasible technologies	Mar 2014	Nov 2014	- Completed - Feedbacks to activities 4.1, 4.2, 4.3, 4.4 and themes 3 and 5.

7 Key results and discussion

7.1 Livelihoods and adaptability of rice farmers

7.1.1 Threats and key determinants of livelihoods

Rice land shares 70-80% of surface area, except for favorable sites of alluvial and acidic zones and for salinity-affected site of the saline zone, the figures being slightly lower (60%). About 70-90% of households depend on rice farming as the main livelihood activity. Major natural threats that farmers faced differ with zones and even sites within the same zone (Table 3). The saline zone is more vulnerable to the threats than the others and the unfavorable site is more vulnerable to the favorable site within the same zone. Pest occurrence is the common problem all the sites and zones.

Table 3: Major natural threats to rice-based farming systems perceived by farmers with zones[1]

Threats	Zones			
	Flood	Alluvial	Acid sulphate	Saline
Abnormally high temperatures[2]				FS & UFS
Big flood or inundation[3]	UFS	UFS	UFS	UFS
Abnormally heavy rains[4]		UFS	UFS	UFS
Droughts in the wet season				FS & UFS
Salinity intrusion				FS & UFS
Acidity			UFS	
Pests[5]	FS & UFS	FS & UFS	FS & UFS	FS & UFS

[1] FS (favourable site), UFS (unfavourable site)
[2] Abnormally high temperature occurring in the dry season that would cause heat and water stresses
[3] Big floods or early floods in September would severely damage the 2nd wet season rice crop while inundation from upstream floods or locally heavy rains would cause submergence or stagnancy for the rice crop.
[4] Abnormally heavy rains occurring in the wet season that would cause prolong inundation in depressive and poorly drained areas.
[4] Pests including pest insects, fungi, weeds, golden snail and rat

There are similarities and disparities in constrainers and enablers of livelihoods, which would determine capacity of farmers to adapt to climate change by zone. From livelihood asset points of view, rice farmers have faced not only natural threats but also socio-economic constrains for their rice farming and livelihoods (Table 4). For natural asset, together with climatic, water and soil threats as aforementioned, water pollution, in terms of agricultural production and domestic uses was perceived the common problem of all the zones. The decline of soil fertility (flood and alluvial zones), organic toxicity (acid sulphate zone) and salinity (saline zone) are important constrainers of sustainable rice production. For human asset, lacking off-farm labor is the common problem for farmers to diversify farming activities while on-farm labor is not enough and agricultural mechanisation is poorly developed, which is definitely seen for rice harvest and post-harvest and upland crop production rotated with rice. For physical asset, poor accessibility to output market systems makes instability of output market prices and lowers the potential added values of rice, upland crop and shrimp commodities, which in turn limit farming income of rice farmers (see further in the report of Theme 5's activity 5.5). For finance, farmers poorly saved from low farming income, particularly in acid sulphate zone, and from high interest rates of informal in-kind credits supplies from local agro-chemical shops. About 70-90% farmers got informal in-kind credit sources, due to inflexibility and complicated formalities micro-credit programme by the government for farmers. Finally, poor accessibility to rice seed supply of adaptive varieties was considered as a constrainer of farmers in acid sulphate and saline zones, while the contrary occurred in flood zone, where farmer's groups and rice seed service cooperatives played a great importance. Therefore, there should not be a single solution but strategy packages are needed to enhance adaptive capacity of rice farmers in the study zones.

Table 4: Key constraining and enabling factors of livelihood capacity of rice farmers to climate change by zone

Livelihoods assets		Zones			
		Flood	Alluvial	Acid sulphate	Saline
Natural	Constrainers	- water pollution - declined soil fertility	- water pollution - declined soil fertility	- water pollution - organic toxicity[1]	- salinity - water pollution
	Enablers	- freshwater availability	- freshwater availability		
Human	Constrainers	- lacking off-farm labour	- lacking off-farm labour	- lacking off-farm labour	- lacking off-farm labour
	Enablers	- rice farming technologies and experience	- rice farming technologies and experience	- rice farming technologies and experience	- rice farming technologies and experience
Physical	Constrainers	- poor harvest, post-harvest and output market systems	- poor harvest, post-harvest and output market systems - poor dike systems[1]	- poor harvest, post-harvest and output market systems	- poor harvest, post-harvest and output market systems
	Enablers	- irrigation and dike systems[2]	- irrigation and dike systems[2]	- irrigation and dike systems[2]	
Financial	Constrainers	- poor saving - poor accessibility to formal loans	- poor saving - poor accessibility to formal loans	- poor saving - poor accessibility to formal loans - low income	- poor saving - poor accessibility to formal loans
	Enablers	- informal in-kind credits	- informal in-kind credits	- informal in-kind credits	- informal in-kind credits
Social	Constrainers			- poor accessibility to rice seed supply	- poor accessibility to rice seed supply
	Enablers	- Farmer's groups and cooperative activities			

[1] *with unfavourable site only*
[2] *with favourable site only*

At household level, livelihood capacity depends upon site and farm site. Farmers in favourable sites have higher capacity than those in unfavourable site (Figure 4a). Larger farmers have higher capacity than smaller farmers (Figure 4b). This confirms finding above and could reflects that smaller farmers and those in unfavourable conditions would be more vulnerable to climate change. Thus, solutions for enhancing adaptive capacity of farmers should be paid more attention to the poorer and those in unfavourable areas.

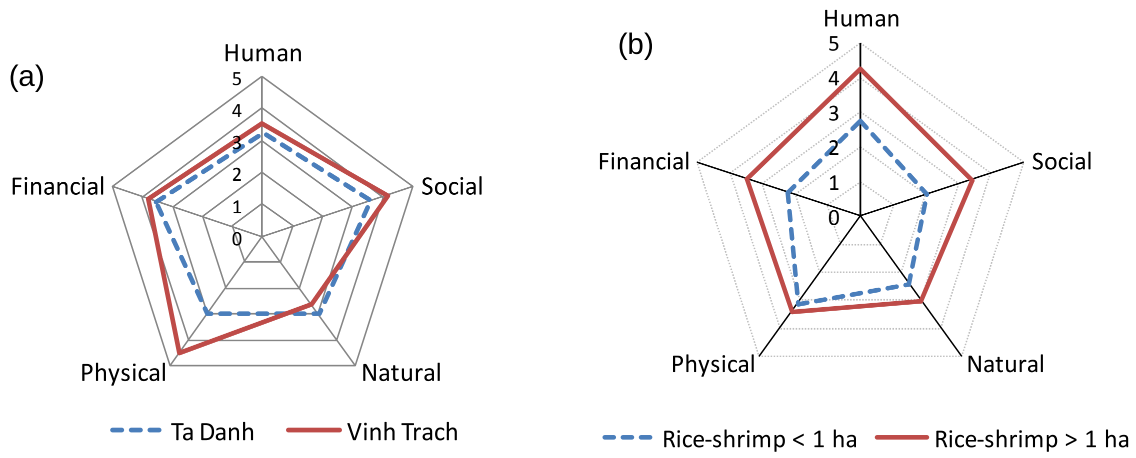

Figure 4: Livelihood capacity of farmer's by site in flood zone (a) and by farm size in saline zone (b). Vinh Trach is favourable and Ta Danh is unfavourable.

Farming and household income depends on several factors related to livelihood assets (Figure 5). Farmers with larger land, more available labour and farm implements earned higher income. In the same zone, farmers living in more favourable site and having more diverse sources of income had higher farming and household income. This implies that rice intensification with high inputs and more crops per year could not be a strategy in the long-run, and that

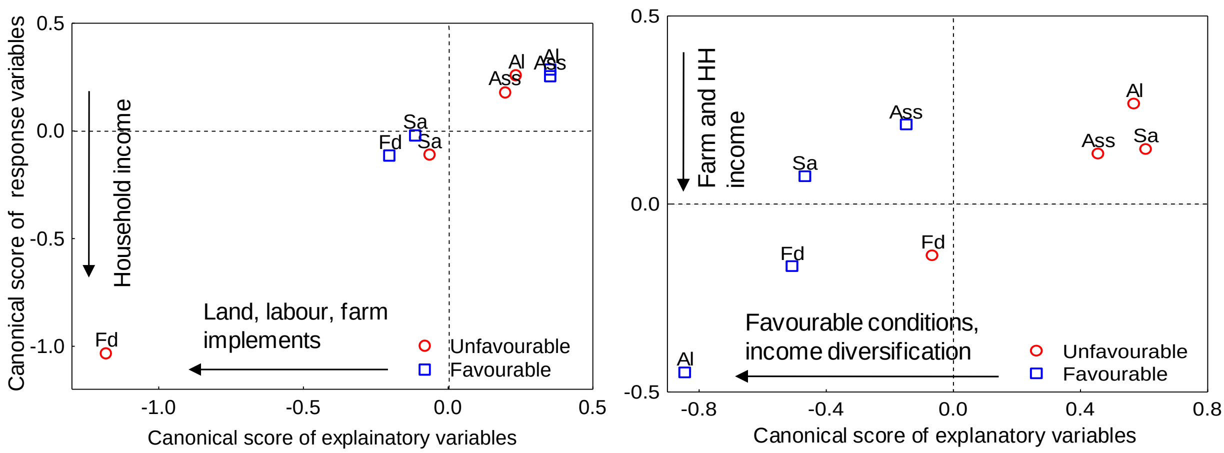

Figure 5: Determinants of farming and household income of farmers by study sites. Fd = flood zone; Al = Alluvial zone; Ass = Acid sulphate soil zone ; Sa = Saline zone.

There is a need of integrated solutions to enhance adaptive capacity of rice farmers in the study zones. Adaptive solutions can be categorized into: (1) rice farming technical measures, (2) structural measures and (3) socio-economic measures.

Rice farming technological measures include: (1) growing adaptive rice varieties (i.e. tolerance to submergence, acidity or salinity; tolerance to major pests, short-growth duration, grain quality satisfying market needs, etc.); (2) adaptive rice farming practices (i.e. 1 must-five reductions, flushing acidity or salinity, etc.); (3) adaptive rice-based farming systems (i.e. rice-upland crop rotation in freshwater or rice-shrimp rotation in saline areas); (4) labour-extensive farming practices.

Structural measures include: (1) farming mechanisation (for rice and upland crops, particularly for harvest and post-harvest), (2) water structure (i.e. flood or salinity management, irrigation and drainage systems).

Socio-economic measures include: (1) development of farmer's groups or collective activities for irrigation or drainage management, flood or salinity management, rice-upland crop rotational system development; and (2) development of service systems for inputs and outputs (i.e. crop seeds, farm labour and/or implements, safe agro-chemicals, technologies, harvest and post-harvest technologies, and output markets).

7.1.2 Role of women to adaptive capacity of rice farming households

Women plays an important role in improve livelihood capacity and adaptive capacity to climate change of rice farming households. In rice farming, women contributed 40-46% of total labour inputs in rice production. More women than men provided labour in pulling of seedlings, gap filling, hand-weeding, removing off-types in the field, manual harvesting and drying rice. Women had worked harder, especially in the unfavourable areas to ensure household food security and to manage farming and household expenditures. Women are also custodians of household cash and thus they bear the burden of allocating the limited cash among farm, household and children's needs.

Aside from these making these decisions, they also supervise them as well as prepare their food. Women also dominate in decisions on whether to sell or consume the harvested crop, to quantity of output to sell and consume, when and where to sell the harvested crop, sell the animals and what types of food to consume in times of crisis. In times of disasters such as floods or salinity intrusion, they bear the burden of looking for food for their families. They are also forced to consume or sell their small animals including poultry at lower prices. Moreover, when the husband migrate, it is important that the wife is equipped with technical knowledge (received from training or agricultural extension services) so that she can make informed and timely decisions particularly in times of floods and salinity intrusion in the fields caused by extreme climate variability. Thus, it is important that both husband and wife should be involved in enhancing capacity of households to adapt to climate change.

Wives were considered as consultants of husbands to decide what crops or varieties to be grown and what farming practices to be applied. Usually, rice breeders and extension staff pay less attention to participation of women in technical training, field days for farming technology evaluation or rice variety evaluation. Our findings showed women having their own opinions with regards to their preference for rice traits (see more details in the following section).

Women have less knowledge on or pay less attention to "climate change" than men. Seventy per cent of interviewed men and 53% of women heard the term "climate change". More men than women knew causes of climate change. Therefore, participatory approaches and associated training activities to enable both men and women farmers to better adapt to climate change, ensure food security and reduce poverty are of great important.

7.2 Policy and institutions

In the last 5 years, several strategies and policies were released addressing sustainable natural resources uses, rice production and rice farmer's livelihoods. In 2009, the government released a national food security strategy. Accordingly, rice land was set aside for food security with 3,8 million ha for the whole country, of which 1,75 million ha or about 3,5 million ha of rice grown area for the Mekong Delta. In 2012, the government approved the National Sustainable Development Strategy for the period 2011-2020[1]. Accordingly, for sustainable development, the strategy defines eight prioritized areas closely related to efficient use of natural resources, sustainable agricultural systems, rural poverty reduction, bio-diversity conservation, and environmental protection. At lower level, the Ministry of

[1] *http://www.chinhphu.vn/portal/page/portal/English/strategies/strategiesdetails?categoryId=30&articleId=10050825*

Agriculture and Rural Development (MARD promulgated about six Action Plan Frameworks or Directives on adaptation to climate change for the Agriculture and Rural Development Sector till 2020. In 2013, MARD advocated restructuring agriculture, aiming at increased value of agricultural outputs and sustainable rural development, through shifting to agricultural systems with high income and improving their value chains. For rice production in the Mekong Delta, MARD has promoted to shift rice-mono systems with low income to rice-based farming systems with higher income.

Since 2010, several policies were released to address food security, rice farmer's livelihoods, competitive rice production and rice value chains. Relevant policies could be classified into two groups: (1) rice production policies and (2) rice trade policies.

The rice production policy group includes six major policies: (1) supports in maintaining and developing paddy land and paddy production, (2) supports in reducing rice input costs, (3) supports in developing infrastructure and irrigation for agricultural production, (4) credit supports for rice producers, (5) science and technology development, and (6) agricultural insurance.

The rice trade policy group includes five major policies: (1) supports in market accessibility and development, (2) rice export management, (3) tariff-rate quotas for preferential import of rice, (4) price support measures, (5) developing linkage in rice production and consumption, and (5) improving capacity of exporting enterprises, linking with the sustainable development of rice sector.

There are plentiful of single policies and the implementation of the policies at local level was not effective. An integrated policy package to be flexible and fitting in local specific context is still lacking. The decision making mostly applied a "top-down" and a "supply-driven" approach rather than a "bottom-up" and a "market-driven" approach. According to local stakeholders, to effectively implement policies for capacity development of farmers to adapt to climate change, important issues are: policy appropriateness and policy implementation effectiveness, farming organization and service accessibility, staff's and farmer's capacity, government's budget and availability of new farming technologies (Table 5). Policy appropriateness and policy implantation effectiveness, and farmer's technical knowledge are the common issues concerned by all the zones. Budget limitation is not an important issue, except for the alluvial zone.

Table 5: Most important issues of adaptive capacity development of farmers by zone

Issues	Zones			
	Flood	Alluvial	Acid sulphate	saline
Appropriate policies and policy implementation	+	+	+	+
Farming organization and service accessibility	+		+	
Staff capacity	+	+		+
Governmental budget		+		
Farmers' technical knowledge	+	+	+	+
New farming technologies			+	+

Coordination and participation of relevant governmental agencies is essential in promulgating and implementing policies. The provincial Department of Agriculture and Rural Development (DARD) has acted as the leading agency to implement the policies at local level. However, not DARD but the Department of Industries and Trades (DIT) is responsible for managing post-harvest, processing and marketing of commodities. Effective out-scale and up-scale of promising technologies created by CLUES needs effective coordination and participation among DARD, DIT, DOST (Department of Science and Technology) and other community-based organizations like Women Union (WU) and Youth Union (YU) (Table 6). The DIT plays an important role in developing services of rice variety and upland crops rotated with rice. Agricultural Extension Centre (AEC) and Plant Protection Department (PPD) will play an important role in supporting the development of the technologies. New technologies from CLUES will need constantly adjustment and improvement in order to adapt to changing needs of farmers. Doing so, a participatory technology development approach needs to be applied, continuously optimizing technologies in specific contexts.

Table 6: Key leading and implementing agencies involved in extension of CLUES's promising technologies by zone[1]

Promising technologies	Zones			
	Flood	Alluvial	Acid sulphate	Saline
Adaptive rice varieties	DARD, ASC, RSSC, DOST	DARD, PPD, AEC, DIT	DARD, AEC, DIT	DARD, AEC, DOST
Rice farming techniques	DARD, PPD, AEC	DARD, AEC, DIT	DARD, PPD, AEC	DARD, PPD, AEC, WU, YU
Field salinity management				AEC, PPD, WU
Upland crop rotation with rice	DARD, PPD, AEC, DIT	DARD, AEC, RI, DIT	DARD, AEC, DIT	

[1] The first agency is the leading and the others are supporting agencies. AEC (Agricultural Extension Centre), ASC (Agricultural Seed Centre), DARD (Department of Agriculture and Rural Development), DIT (Department of Industries and Trades), DOST (Department of Sciences and Technologies), PPD (Plant Protection Department, RSSC (Rice Seed Service Cooperation), RI (Research Institutes), WU (Women Union), YU (Youth Union)

Farmer's adaptive capacity development and farming technology extension need to be mainstreamed into existing agricultural and rural development programmes. Relevant existing programmes include: (1) agricultural extension, (2) high-tech agricultural development, (3) "large-scale" rice field, (4) agricultural restructure, and (5) rural development (Table 7). Enhancing adaptive capacity of farmers to changes need considering both farmer's decision making for their farming and livelihoods and public decision making in resource allocation and institutional arrangements. Achieving this, fostering innovative capacity of all relevant stakeholders, not only providing technical solutions, is of great importance.

Table 7: Important development programmes to adaptive capacity development of farmers and extension of CLUES's promising technologies by zone

Programmes	Zones			
	Flood	Alluvial	Acid sulphate	saline
Agricultural extension	+	+	+	+
High-tech agricultural development	+			+
Large-field rice production	+		+	+
Agricultural restructure		+	+	
Rural development	+		+	+

7.3 Feasibility of CLUES's tested technologies

7.3.1 Rice varieties

Both male and female farmers participated in feasibility assessments of rice varieties tested on-farm at the study zones. Farmers preferred rice varieties that have multiple expected characteristics simultaneously (Table 8). The common agronomic characteristics expected are: (1) tolerance to water-related threats, (2) strong tillering and stiff stem or erect leaves, (3) short-growth duration, (4) tolerance to major insects and diseases, and (5) good grain-quality for both eating and marketing. In acid sulphate and saline zones, farmers preferred high yield potential as an important characteristic, which was not mentioned in flood and alluvial zone with more favourable natural conditions. In addition to similarities, there are differences in preference for expected characteristics of assessed rice varieties. Women paid much attention to tillering capacity, stiff stem and cooked-rice quality for eating for lower labour inputs and household food security objectives. To meet all those expectations of farmers is challenging for rice breeders and agronomists. Commonly-grown varieties only have a few characteristics as expected by farmers.

Table 8: Major agronomic characteristics of varieties expected by farmers at the study zones

Flood	Alluvial	Acid sulphate	Saline
- Submergence tolerance - Strong tillering - Quick flowering - Tolerance to major insects and diseases - Grain quality for eating and marketing	- Submergence tolerance - Strong tillering - Stiff stem - Short-growth duration - Quick flowering - Tolerance to major insects and diseases	- Acidity tolerance - Strong tillering - Stiff stem and erect leaves - Short-growth duration - Tolerance to major insects and diseases - High yield potential - Grain quality for eating and marketing	- Salinity, drought and/or submergence tolerance - Erect leaves - Short-growth duration - Tolerance to major insects and diseases - High yield potential - Grain quality for eating and marketing

7.3.2 Rice farming and rice-based cropping system technologies

Ranking feasibility of tested technologies was done independently by famers, technicians and managers, considering technical, economical, social and environmental feasibility. From two to three tested technologies per site or zone were assessed and ranked for their feasibility. Table 9 shows overall rank of feasibility of the technologies per zone. Participants paid more attention to criteria such as the ease of practice (i.e. soil and water suitability, low labour input or mechanization ability, technological simplicity - technical feasibility), high economic return, availability and stability of markets for outputs (economical feasibility), technology up-take and investment ability by small farmers (social feasibility), and externally environmental impacts (environmental feasibility). There are a few differences in ranking feasibility among the groups from their points of views. Farmers and technicians considered more about the feasibility at their household and community contexts while mangers paying more attention to development plans and socio-economic objectives of local government, besides farmers' contexts. In general, simple farming practices were ranked at high priority.

Rotation of upland crops with rice culture was considered a promising practice under anticipated climate change, due to higher income; shorter cropping duration and lower water need that rice crop. Intensive-labour input, unavailability of mechanisation and limited markets for outputs at large-scale production, however, are major constraints of this practice. In saline zone, growing high-yielding rice with short-growth duration was ranked high priority by farmers and technicians, because of being easy to practise. This point of view was contrary with governmental officials from agricultural land planning and long-term environmental sustainability. The results imply that the adoption and out-scale of CLUES's feasible technologies at the study zone need time and efforts to fine tune the technologies under local contexts before extension in large-scale. Achieving this, a participatory technology development approach and other enabling factors, not only technologically, are essential.

Table 9: Overall rank of feasibility of tested technologies by zone

Provinces/Zones	Tested technologies	Overall ranking		
		Farmers	Technicians	Officials
An Giang (flood zone)	1.P reduction plus AWD	-	1	1
	2.P reduction plus rice transplantation	-	2	2
	3.Rice – upland crops – rice	-	3	3
Can Tho (alluvial zone)	1.AWD irrigation technique	1	-	2
	2.Rice – sesame – rice	2	-	1
		4.		
Hau Giang (acid sulphate	1.Appropriate P application	1	1	1
	2.Rice – cucumber/maize – rice	2	2	2

soil zone)				
Bac Lieu (saline zone)	*Freshwater site:*			
	1.P reduction	1	1	1
	2.AWD technique	2	2	2
	3.Rice – upland crops - rice	3	3	3
	Brackish water site:			
	1.Short-growth varieties	1	1	3
	2.Soil salinity flushing	2	2	1
	3.Calcium application	3	3	2

7.3.3 Extension pathways of promising technologies

Extension pathways of promising technologies, which were tested and assessed for feasibility as aforementioned, were identified through consultations with local stakeholders (Table 10). Results show that most of the technologies suit alluvial or slightly acidic soils with available irrigation and drainage systems, except for appropriate P application technique in the unfavourable site of acid sulphate zone (Hau Giang province). The AWD practice is more preferable to farmer cooperative model like participatory irrigation management or "large-scale" field model. Rotation of upland crops with rice would be taken up by farmers with availability of on-farm labour or accessibility to local off-farm labour. The extension pathway analysis confirms findings from institutional analysis that DARD will play leading in out-scale and up-scale of the technologies with vital implementation supports given from local extension agency, plant protection department and community-based organisations. For extending the rotation of upland crops with rice, farmer's groups, business enterprises and Agricultural and Rural Development Banks are important actors. Existing extension channels together with participatory extension approach will be appropriate. Successful extension of the promising technologies need necessary enablers such as availability and accessibility of formally favourable loans, improved irrigation and drainage systems, farmer's cooperation, zoning and services for inputs and outputs, mechanisation and effective extension programme.

Table 10: Extension pathways of CLUES's promising technologies

Feasible technologies	Target areas	Target farmers	Key stakeholders	Important enablers
An Giang (flood zone)				
P reducion plus AWD	Alluvial and slightly acidic areas	All rice farmers	DARD, AEC, DPP, CBOs	Formal loan accessibility, farmer's cooperation and extension programme
P reducion plus rice transplanting	Double rice plus upland crops or triple rice areas	Better-off farmers and/ or seeds producers	DARD, AEC, DPP, CBOs, Enterprises	Formal loan accessibility, farmer's cooperation, extension programme, labour and/or mechanization availability
Rice – upland crops – rice	Double and triple rice areas with alluvial soils and drainage system	Better-off farmers or farmers with labour availability	DARD, AEC, DPP, CBOs, Enterprises, Banks	Formal loan accessibility, zoning and farmer's cooperation, output service development
Can Tho (alluvial zone)				
AWD irrigation technique	Irrigated rice areas with alluvial and slightly acidic soils	All rice farmers, farmers involved in "large-scale field" model	DARD, AEC, DPP; CBOs, Farmer's Group	Formal loan accessibility, irrigation improvement, farmer's cooperation and extension programme
Rice – sesame – rice	Triple rice area with alluvial soils	Small farmers with labour availability	DARD, AEC, DPP, CBOs, Farmer's	Zoning, output and input service development, farmer's

	and drainage system		Group, Enterprises	cooperation, mechanisation
Hau Giang (Acid sulphate zone)				
Appropriate P application	Heavily acid sulphate soil areas	All rice farmers	DARD, AEC, DPP, CBOs, Mass media	Extension programme
Rice – upland crops – rice	Triple rice area with slightly acidic soils and good drainage systems	Small farmers with labour availability and upland crop farming experience	DARD, AEC, DPP, CBOs, Mass media	Formal loan accessibility, output and input service development, irrigation and drainage improvement, integration with agricultural restructure programme
Bac Lieu (saline zone)				
AWD irrigation technique	Irrigated and freshwater rice areas	All rice farmers, preferably with "large-scale field" model or cooperatives	DARD, AEC, DPP, CTU, CLRRI	Irrigation system improvement, farmer's cooperation
P reducion	Freshwater rice areas with slightly or intermediate acidic soils	All rice farmers	DARD, AEC, DPP, CTU, CLRRI	Extension programme, incorporation in "1 must – 5 reductions" programmes
Salinity management practices for rice culture in rice-shrimp farming system	Brackish water rice – shrimp areas	Rice - shrimp farmers	DARD, AEC, DPP, CTU, CLRRI, CBOs	Extension programme, irrigation and drainage improvement, farmer's cooperation

[1] DARD = Department of Agricultural & Rural Development, AEC = Agricultural Extension Center; DPP = Department of Plant Protection, CBOs = Community-Based Organizations, CTU = Can Tho University, CLRRI = Cuu Long Rice Research Institute, P = phosphorus fertiliser.

Adoption level of the promising technologies was simulated using ADOPT software. Assuming all relevant factors in the future as those expected currently, the adoption level of AWD practice by farmers in five years from the start of extension program is 43% for Ta Danh (An Giang – flood zone), 26% for Minh Dieu (Bac Lieu – saline zone) and 17% for Thoi Tan (Can Tho – alluvial zone). Higher adoption level of AWD practice in An Giang than in Bac Lieu and Can Tho could be relatively better cooperation among local farmers, availability of irrigation groups and larger farm size. Whereas, AWD technique is relatively new for farmers in Can Tho and Bac Lieu zones, and water scarcity is not an important issue with farmers in Can Tho. Results show that two important determinants of the adoption of technologies by farmers are the ease of practices (technological feasibility) and economic viability (economic feasibility).

8 Impacts

8.1 Scientific impacts – now and in 5 years

By implementing project activities, data and analysis and reporting by Theme members, there are scientific impacts as below.

No.	Actors	Current impacts	Indicator(s)	Expected in next 5 years
1	Theme members: - More understanding on research methods on livelihood assessments, policy and institutional analysis, technology feasibility assessment, and extension pathway analysis - More knowledge on livelihood capacity of farmers, needs of local stakeholders to adapt to predicted changes - Improved scientific writing skill - Perceiving policy and institutional analysis as an important area for MDI/CTU Other themes' members: - More understanding linkages between technical and socio-economic aspects in enhancing adaptive agricultural production and technological adoption by farmers	- 05 publications in Vietnamese journals - 01 manuscript submitted to a Regional Journal - 01 manuscript in preparation - Applying the methods for developing 02 proposals	No. of peer-reviewed publications, research proposals and research projects related to this aspect	- 04 publications in Vietnamese journals - 04 publications in International journals - 3-4 news research projects building scientific knowledge from CLUES from CTU partners

8.2 Capacity impacts – now and in 5 years

Knowledge, skills and management of theme members have been enhanced through discussions with local people during workshops, literature reviews, data analysis, reporting and training activities. Capacity impacts are as below.

Site	Name of trainings	Date	Length of Activity	No. of people involved	Male	Female	Expected change in next 5 years
Non-degree training							
CTU	Participatory Adaptation Research Refresher Course	Nov 2011	04 days	05	04	01	Applying the approach and methods in farming technology evaluation at CTU and CLRRI
CTU	Assessments on technical, socio-economic and environmental impacts of new technologies	Sep 2012	01 day	04	03	01	Applying (and developing) the approach and method to relevant research projects at CTU

Site	Name of trainings	Date	Length of Activity	No. of people involved	Male	Female	Expected change in next 5 years
Australia	Agricultural research management program (the John Dillon Fellowship	Feb – Mar 2013	40 days	01	01	0	Improved individual and team's scientific writing and presentation skills, leaderships and research management; Improve achievements and sustainability of later research projects
HCMC, Vietnam	English training (the John Allwright Scholarship by ACIAR for PhD candidate)	Oct 2012 – Mar 2013	6 months	01	01	0	English communication in research
CTU	Multi-criteria decision making on land uses using mDSS (by Theme 5 of CLUES)	Mar 2014	3 days	01	01	0	Sharing with colleagues to apply the approach and the tool to other research projects
IRRI	Research data management	Nov 2014	4 days	01	01	0	Sharing with colleagues to apply methods and tools in research data management
	Total			**13**	**11**	**02**	
Degree training							
CTU	Msc. theses in Rural Development	Dec 2013 - Oct 2014	10 months	03	03	0	Improved career of graduated students and increased performance of their employers; Develop new research project building on results from the theses by MDI
ANU/Australia	Mr. Hua Hong Hieu awarded the John Allwright Fellowship by ACIAR for PhD studies at the Australian National University (2013-2017).	Sep 2013 – Sep 2017	4 years	01	01	0	01 Ph.D for CTU; Improved career of Mr. Hieu and performance of MDI/CTU; Further improved network between CTU and ANU/CSIRO
	Total			**04**	**04**	**0**	

8.3 Community impacts – now and in 5 years

Theme members have worked closely with local stakeholders during implementing the project activities. Community impacts have been realised so far as below.

8.3.1 Economic impacts

There are no economic impacts yet during the project phase. Economic impacts are expected in the next 5 years as below.

No.	Actors	Current impacts	Indicator(s)	Expected in next 5 years
1	Farmers use improved rice varieties	350 farmers participated in rice variety evaluation and have changed their knowledge, perception and attitude (KPA)	Survey data from Plant Seed Centre and Agricultural Extension Centre	3500 farmers will use improved rice varieties (# 3500 ha x 0.5 million $VN =1.75 billion $VN per year)
2	Farmers apply new farming technologies (AWD, P application, soil salinity management and rice-UC cropping system)	157 farmers participated in technological assessment and have changed their KPA	Survey data from Agricultural Extension Centre, farmers	1570 farmers will apply new technologies ((# 1570 ha x 1 million $VN = 1.57 billion $VN per year)
3	Local extension staff have gained knowledge/ skills	45 extension staff participated in assessing technological feasibility and exploring impact and extension pathways, and have changed their KPA	Surveys from Agricultural Extension Centres/Stations	Improved effectiveness and efficiency of extending new technologies from CLUES and other projects. It is impossible to quantify economic impacts
4	Local government officials have enhanced knowledge on policy and institutional analysis, farmer's livelihood capacity and out-scale/up-scale of new technologies from CLUES	58 governmental officials/officers participated in workshops and have changed their KPA	Surveys from Agricultural and Rural Development Department	Improved effectiveness and efficiency of policy implementation and scaling up new technologies from CLUES and other projects. It is impossible to quantify economic impacts

8.3.2 Social impacts

Social impacts would be the outstanding achievement of Theme 4. A lot of local farmers and staff participated in the project activities. Awareness and participation of local stakeholders have increased through participatory discussions and assessments, and verification of research results. The theme addressed gender issues by involving women farmers in the early stages of the project phase, helping more women are more confident and recognized as "farmers" rather than farm helpers. Details of the impacts are presented in the flowing table.

Site	Actors/workshops/ trainings	Date	Length of Activity	No. of people involved	Male	Female	Expected change in next 5 years
Study sites	Farmers participated in livelihood capacity assessments and gender analysis	2011-2012	0.5 day	1312	1010	302	Enhanced capacity of farmers and participation in livelihood assessments and improved KAP on gender equality

Site	Actors/workshops/ trainings	Date	Length of Activity	No. of people involved	Male	Female	Expected change in next 5 years
Study sites	Farmers participated in participatory rice variety assessments	2012-2014	0.5 day	1407	897	510	Empowering farmers and their participation, particularly women, in rice variety evaluation, local extension activities and local community development plan using participatory approaches
Study sites	Farmers participated in rice farming technology assessments	2013-2014	0.5 day	157	125	32	Empowering farmers and their participation, particularly women, in agricultural technology feasibility assessments, local extension activities and local community development plan using participatory approaches
Study sites	Local extension staff participated in assessing technological feasibility and exploring impact and extension pathways	2014	1 day	45	33	12	Improved effectiveness and efficiency of extending new technologies from CLUES and other projects
Study sites and CTU	Governmental officials/officers participated in workshops on institutional analysis,, farmer's livelihood capacity and out-scale/up-scale of new technologies	2012-2014	1 day	58	52	6	Improved effectiveness and efficiency of policy implementation on better uses of natural resources, enhanced capacity of farmer's livelihood, further scaling up new technologies from CLUES and other projects.
	Total			**2979**	**2117**	**862**	

8.3.3 Environmental impacts

There is no direct environmental impact yet. The theme, however, has indirect impacts on environment through assessing environmental feasibility of tested technologies of CLUES. By participating in the assessments, local farmers, extension staff and officials have perceived and had attitudes on environmental issues of new technologies. Hence, this would contribute to development of environment-friendly rice farming practices in the study areas in the future.

8.4 Communication and dissemination activities

Communication activities have been frequently done within theme 4 and with other themes and local counterparts during implementing the project activities. In addition, through facilitation given CLUES project office, theme collaborated with GIZ Project for sharing information and conducting assessments on AWD techniques in rice production in Bac Lieu. Field days of technology feasibility assessments would facilitate gradual dissemination of feasible rice varieties and farming technologies with the communities where on-farm trials were established.

The theme published two short communications in ACIAR Newsletter in Vietnam (2012 & 2014). This allows sharing information among researchers participating in ACIAR-funded projects.

9 Conclusions and recommendations

9.1 Conclusions

Rice farmers in the study zones have faced not only climatic but also socio-economic constrains for their rice farming and livelihoods. The constraints differ with zones and sites within the same zone. The saline zone is most vulnerable to climatic threats and the unfavorable sites are more vulnerable than the favorable sites. Poorer farmers are more vulnerable that better-off farmers. Farming diversification by rotating upland crop with rice helps farmers earn higher income but it is constrained by lack of off-farm labor, poor accessibility to and instability of output market systems. Informal in-kind credit, farmer's groups and availability of telephone and mass media are enablers of adaptive capacity of farmers. In addition, women play important role to rice farming and household's livelihoods. Not a single solution but a package of solutions is needed to enhance adaptive capacity of rice farmers in the study zones. An adaptive solution package include: (1) rice farming technological measures, (2) structural measures, and (3) socio-economic measures.

There are several single policies relevant to rice production, rice trade and rice farmer's livelihoods. The effective implementation of a package of relevant policies is an important issue. Effective out-scale and up-scale of promising technologies created by CLUES needs effective coordination and participation among key governmental actors together with community-based organizations. New technologies from CLUES will need constantly adjustments and improvement in order to adapt to changing needs of farmers.

Farmers and local stakeholders expected feasible rice varieties or rice farming technologies with simultaneously multiple adaptive characteristics preferred rice varieties that have multiple expected characteristics. For adaptive rice varieties, tolerance to water-related threats and to major pests, high yield potential and good grain quality were expected. For rice farming technologies, the ease of practice, economic viability, and the availability and the stability of markets for outputs were considered as important criteria. Single component technologies like appropriate P application or AWD practice were ranked at high priority. While rotation of upland crops with rice culture or rice transplanting, which need intensive-labour input and/or limited markets for outputs, was not considered as high priority.

Most of the feasible farming technologies created by the project suit alluvial or slightly acidic soils with available irrigation and drainage systems, except for appropriate P application technique in acid sulphate zone (Hau Giang province). The out-scale of AWD practice is more preferable to cooperative irrigation management or "large-scale" field model. Rotation of upland crops with rice and rice transplanting would be suit farmers with availability of on-farm labour or accessibility to local off-farm labour. DARD and its agencies are important actors in out-scale and up-scale of the technologies. In addition, farmer's groups, business enterprises and Agricultural and Rural Development Banks also play an important role. Successful extension of the promising technologies need necessary enablers such as availability and accessibility of formally favourable loans, improved irrigation and drainage systems, farmer's cooperation, zoning and services for inputs and outputs, mechanisation and effective extension programme. The ease of practice and economic viability are important determinants of the adoption of technologies by farmers.

The Theme has achieved significant capacity and community's social impacts. Thousands of farmers, particularly women, and a lot of local staff participated in all the activities of the Theme during project implementation. This is of great importance for promoting the efficiency and sustainability of CLUES as well as other project in the future.

9.2 Recommendations

Together with other Themes, Theme 4 has established a large network with local stakeholders at the study areas. To take use of this advantage, up-follow outreach programmes need to be implemented. Pilot models, where a package of solutions will be tested, should be established and incorporated in local existing development programmes at the respective study sites, building on a participatory technology development approach, continuously optimizing technologies in specific contexts. By doing so, new technologies will be scaled out and scaled up and project impacts will be identified.

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10.2 List of publications produced by project

1. Truong Thi Ngoc Chi, Tran Thi Thuy Anh, Thelma Paris (2014). Gender roles in household, constraints, risk- coping mechanisms in response to climate change. Journal of Vietnam Agricultural Science and Technology. No. 4 (50) 2014. page 73-79 (ISSN-1859-1558). Published by Vietnam Academy of Agricultural Science (in Vietnamese with English abstract)
2. Truong Thi Ngoc Chi, Thelma Paris, Tran Thi Thuy Anh, Huynh Nhu Dien, Tran Chieu Y, Tran Quang Tuyen, Romeo Labios, Nguyen Thi Lang (2014) Male and female farmers' participation in rice varietal selection. In Conference Proceedings of The 1st National Conference on Crop Sciences, September 5-6th 2013 in Ha Noi, Vietnam. Agricultural Publishing House, pp 1336-1343.
3. Truong Thi Ngoc Chi, Tran Thi Thuy Anh, Thelma Paris, Le Duy. The gender dimensions of the relationship between climate change and rice-based farming systems: an exporatory assessment in the Mekong Delta. Omon Rice (in press; in Vietnamese with English abstract)
4. Truong Thi Ngoc Chi, Tran Thi Thuy Anh, Thelma Paris, Le Duy, Dang Tuyet Loan and Nguyen Thi Lang (2014). Farmers' feedback on rice varieties tested under farmer-managed trials. Omon Rice (in press; in Vietnamese with English abstract)
5. Vo Van Tuan, Le Canh Dung, Vo Van Ha and Dang Kieu Nhan (2014). Adaptive capacity of farmers to climate change in the Mekong Delta. *Journal of Science Can Tho* University.31 (2014): 63-72 (in Vietnamese with English abstract).

In addition, one submitted manuscript is under review:

6. Le Canh Dung, Vo Van Ha, Vo Van Tuan, Dang Kieu Nhan, John Ward and Peter Brown. Financial capacity of Rice-based farming households in the context of climate change in the Mekong Delta, Vietnam (Submitted to The Asian Journal of Agriculture and Development)

11 Appendixes

11.1 Appendix 1:

Table 1: Number of households interviewed by RBFSs and commune

Provinces (zones)	Communes	Farming systems[1]							Total
		2 R	2 R-F	2 R-U	R-S	3 R	3 R-F	3 R-U	
An Giang (flood)	Ta Danh	31	2	7	0	18	1	0	59
	Vinh Trach	1	0	0	0	43	0	1	45
Can Tho (alluvial)	Truong Xuan A	6	9	0	0	40	10	0	65
	Thoi Tan	9	0	12	0	26	27	7	81
Hau Giang (acid sulphate)	Hoa An	27	11	11	4	40	5	1	99
	Vi Dong	6	2	3	0	32	0	2	49
Bac Lieu (saline)	Phuoc Long	0	1	0	48	2	1	0	52
	Minh Dieu	5	1	0	0	24	0	0	30
Total		85	26	37	52	225	44	11	480

[1] 2 R (2 rice crops), 2 R-F (2 rice crops - fish); 2 R-U (2 rice crops - upland crops); R-S (traditional rice - shrimp); 3 R (3 rice crops); 3 R-F (3 rice crops - fish); 3 R-U (3 rice crops - upland crops)

Australian Government

Australian Centre for International Agricultural Research

Final report

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prepared by	Dr. Nguyen Hieu Trung (CTU)
co-authors/ contributors/ collaborators	Dr. Chu Thai Hoanh (IWMI), Dr. To Phuc Tuong (IRRI), Dr. Nguyen Xuan Hien (SIWRP), Dr. Le Quang Tri (CTU), Dr. Vo Quang Minh (CTU), Dr. Dang Kieu Nhan (CTU), Dr. Pham Thanh Vu (CTU), Dr. Van Pham Dang Tri (CTU).
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Contents

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2 Executive summary

This in-depth study was conducted, through an integrated land use planning approach, to explore possible adaptations to climate change (CC) and Sea Level Rise (SLR) of the coastal area of the Vietnamese Mekong Delta (VMD).

Based on detailed inventories of the present and anticipated CC and SLR affecting soils, hydrological features and land use, yields and financial returns, a CC adaptation land use strategy for Bac Lieu province has been proposed by applying a Multiple Goal Linear Programming (MGLP) approach.

Important impacts of this study are:

- Enhanced understanding of the dynamic of inundation (in the rainy season) and salinity intrusion (in the dry season) of the study area in specific and the coastal of the Mekong Delta in general;
- Enhanced understanding of the integration between biophysical conditions of the study area (agro-ecological zone) and socio-economic constraints under current condition and future CC and SLR impacts;
- Improved knowledge of the current land use issues and opportunity for climate change adaptation;
- Developed strategy for CC and SLR adaptation at provincial level (Bac Lieu case study) by applying an integrated land use analysis with guidelines and tools suitable to the Mekong Delta, Vietnam;
- Enhanced capacity of local partners and provincial officers on integrated land use planning under the impacts of CC and SLR.
- Increased efficiency in using government resources by enhancing knowledge of policy makers on agricultural systems under climate change.

To assure the successful of the climate change adaptation strategies, further studies are essential:

- Risk management on crop failures (by disease, water pollution, extreme weather) and on market fluctuation.
- Soil and water efficiency used (e.g. large-farm model).
- Changes of rural labour resources (both quantity and quality) due to migration and mechanization.
- Long-term impacts of CC&SLR and additional impacts of land subsidence on salinity and flooding in the Mekong Delta.
- Appropriate platform to support innovation practices in the Mekong Delta rural development (financial, manufactory, enterprise, distributor, and farmer innovation…).

3 Background

In order to sustain the development of the VMD's coastal area, an appropriate decision support approach should be developed, in which the natural resources and socio-economic dynamics are interactively considered. Such approach should be able to:

- support the participation of different relevant stakeholders in the region and strengthen their capacity in planning and management;
- support multi-scales and multi-disciplinary analysis;
- consider both spatial and temporal dimensions.

Even though there are salinity control systems to protect the salinity intrusion at the coastal area of the VMD, it is still facing with risks of unsustainable development. The area have been dealing with the conflicts between fresh water and brackish water production systems (e.g. rice versus shrimp) and between economic development and environment protection and conservation (shrimp versus forest) at both inside and outside the salinity control area (Ha et al., 2013; Sakamoto et al., 2009; Trung, 2006). The situation would become worse under the impacts of CC and sea level rise (SLR) (Nhan et al., 2011; Smajgl et al., 2015). With changing in natural resources, the life of people in the coastal area would be more vulnerable.

This study explores possible adaptation to SLR through land use planning in one case study (Bac Lieu province) in the coastal area of the VMD. Based on detailed inventories of soils, hydrological features and land use, yields and financial returns of different options will be compared. Promising land use systems with new technologies (e.g. new varieties, improved farming techniques), social economic (e.g. labour, revenues) and environmental impacts were taken into account. This case study demonstrates how to involve stakeholders in developing a plan for climate change (CC) adaptation.

Theme 5 has completed the following research activities:

- Fine mapping of salinity boundary in high spatial and temporal resolution different sections of Bac Lieu province under current and projected sea level and sluice operations.
- Fine mapping of soils and current land use in Bac Lieu Province through remote sensing and ground-truth surveys.
- Determining the benefits from potential improvement in infrastructure (sluice and dyke system) in terms of salinity and flooding risks of Bac Lieu province.
- Analysing biophysical land suitability for rice based land use systems under different sea level rise and infrastructure development scenarios.
- Interacting with stakeholder of all levels to identify socio-economic constraints for the adoption of more resilient farming systems and recommend institutional/policy changes.
- Applying multiple-goal linear programming for land use planning and define a master plan on climate change adaptation.
- Deriving ‘lessons learnt’ from this case study for future development of adaptation plans in other provinces.

4 Objectives

As mentioned in the CLUES project proposal, objective of Theme 5 are integrated adaptation assessment and development of adaptation master plan for Bac Lieu Province.

The in-depth study on the coastal area will explore possible adaptation through land use planning through one case study (Bac Lieu province). Based on detailed inventories of soils, hydrological features and land use, yields and financial returns of different options will be compared using crop models coupled to GIS. Finally, this information will be used to optimize land use at province scale derived from a Multiple Goal Linear Programming approach.

5 Methodology

The study is carried out in Bac Lieu province, a coastal province of the Vietnamese Mekong Delta (VMD). The province's rice production is facing to (i) the annual drought in the dry season combine with saline intrusion into the rivers and canals lead to lack of fresh water for irrigation; and (ii) the annual inundation in the wet season due to heavy local rainfall and upstream Mekong River flow. This problem is projected to be more serious in the future under impacts of upstream water use, climate change and sea level rise.

This study applies the Land Use Planning and Analysis System (LUPAS) methodology. (van Ittersum et al., 2004) to address the questions “what would be possible?” or “what would have to be changed?” in the analysis of different land use strategies under CC + SLR and socio-economic conditions. LUPAS is applied for land use optimization in some part of the Mekong Delta in tangible contexts and showed its capacity to overcoming the limitation of a traditional top-down land use planning approach, in which achievements and impacts are not quantified and socio-economic conditions and technology development are not considered in detail (Hoanh et al., 2012). With its capacity of quantitative scenario analysis, LUPAS is suitable for analysing land use systems under different socio-economic and CC scenarios.

LUPAS consists of three main modules: (i) Biophysical land evaluation, (ii) Socio-economic analysis, and (iii) Interactive multiple goal linear programming. This study adapted a model developed by Trung (2006), basing on LUPAS framework. GAMS modelling language (Rosenthal, 2014) was used to perform Interactive Multiple Goal Linear Programming (IMGLP). Seven activities were defined for implementing the research:

- Activity 5.1: Mapping of the salinity Intrusion and inundation boundaries under current and projected sea level + CC and sluice operations.
- Activity 5.2: Determining the impacts of operation and potential improvements in hydraulic infrastructure in terms of salinity and flooding characteristics.
- Activity 5.3: Fine-mapping of soils and current land use in Bac Lieu Province through remote sensing and ground-truth surveys.
- Activity 5.4: Analyse biophysical land suitability for rice based land use systems under different SLR + CC and infrastructure development scenarios
- Activity 5.5: Interact with stakeholder of all levels to identify socio-economic constraints for the adoption of more resilient farming systems and recommend institutional/policy changes.
- Activity 5.6: Apply interactive multiple-goal linear programming for land use planning and define a master plan on climate change adaptation.
- Activity 5.7: Derive ‘lessons learnt’ from this case study for future development of adaptation master plans in other provinces.

Activities 5.1 – 5.6 grouped themselves in the three LUPAS modules as described in the following sections.

Theme 5's research team includes Vietnamese experts from CTU, SIWRP (see detailed roles of team members in Appendix 1). Theme 5 also received repeatedly involvements of the local stakeholders in Bac Lieu province. Theme 5 also earned advices and technical supports from the theme ICs, Dr. Chu Thai Hoanh from IWMI and Dr. To Phuc Tuong from IRRI.

5.1 Biophysical land evaluation

Soil and water characteristics, land uses, infrastructure data of the study area are obtained through remote sensing, soil survey and hydraulic modelling. The water, water infrastructure management and soil data are obtained through research activities 5.1, 5.2 and 5.3. The biophysical land evaluation was performed in activity 5.4.

In activity 5.1 the hydraulic model VRSAP (Vietnam River Systems and Plains, developed by the SIWRP) is calibrated and used to simulate the hydrology (water level, flow, salinity) under present conditions and different CC + SLR scenarios. It is also applied to analyze adaptation options (e.g. sluice operations and land use scenarios). The hydrology of Bac Lieu province depends strongly on the tide in the West and East seas and the upstream flow from Kratie (Cambodia). Local rainfall also contributes greatly to the fresh water availability and inundation in the province during the rainy season. This study analyzes the water resources of the province in 3 representative hydrological years based on flow from Kratie: (i) low water year (1998), (ii) average (normal) water year (2004), and high water year (2000).

Activity 5.2 analyses the impacts of potential improvements in hydraulic infrastructure, using VRSAP. Water control infrastructure and its operations are surveyed and analyzed. Activity 5.3 used soil surveys and remote sensing technique to update soils and land use map of Bac Lieu province.

Activity 5.4 *"Biophysical land evaluation*" is essential to determine resource availability (land area, water availability, soil and water qualities, labour, and capital), identifying promising land use types (LUT), and possible technical levels applied in each land mapping unit (LMU) at present and in the future. LMU is defined as an area of land that is a unique combination of agro-ecological, administrative, and socio-economic conditions. Promising LUTs and possible production technologies are those either representing major production activities or having great potential on each LMU determined by qualitative land evaluation, statistical analysis of experimental and survey data, literature review or expert consultation.

Yield of the LUTs in each LMU is estimated based on the suitability of the particular LUTs for each LMU at the corresponding technology. The yield estimation is based on surveys and expert judgment.

The assessment of resource availability/constraint such as labour, capital, land or water are done by applying land evaluation methodology (FAO, 1993), expert knowledge and literature review.

5.2 Identify socio-economic constraints and recommend institutional/policy changes

In Activity 5.5 interactions with stakeholder of all levels, from provincial to representative district and commune, are organized to identify socio-economic constraints for the adoption of more resilient farming systems and recommend institutional/policy changes. Data used for this activity are obtained by participation rural appraisal techniques (PRA) and key informant interviews (KIP). The results of this activity helps to formulate objectives or targets of the province in short-term (toward 2020s) and long-term (toward 2030s) future.

Development objectives/targets are distinguished based on policy views that represent stakeholders' perceptions on which goals should be focused. Production targets also referred to provincial socio-economic development plans. For each technical level in production at each LMU, corresponding production costs and returns are estimated. Production costs consist of total input cost and labour cost per unit of area.

In order to implement the socio-economic analysis in this study, a total of 31 hamlets of 15 communes are selected for household surveys. The selected hamlets are located in 6 districts, i.e. Bac Lieu town, Hoa Binh, Phuoc Long, Hong Dan, Gia Rai and Dong Hai. The site selection is based on land mapping units developed by Activity 5.4. Favourable conditions and unfavourable conditions, which are related to soil acidity, availability and quality of water and irrigation/drainage systems, are considered for sampling stratification.

A total of 460 farming households are selected for interviews. For each farming system, the households are randomly selected using a household list given from hamlet leaders. The study also organizes five workshops (one at the district, one at provincial level and three at sub agro-ecological zones) to receive feedback from famers, experts, and decision makers on the results from biophysical land evaluation and obtain their development targets and opinions on future climate change adaptation strategies. Figure A1 in Annex 11.2 shows some pictures of stakeholder involvement during the study.

5.3 Interactive multiple goal linear programming (IMGLP)

IMGLP is applied to define the climate change adaptation strategy of Bac Lieu province (Activity 5.6). In this step, based on development objectives resulted from Activity 5.5, the objective functions are defined. The constraints are based on the resources available such as labour and capital limitations. The objective functions are formed based on the development targets such as rice production for food security, income per capita.

In this study, the main development objectives proposed from the local stakeholders are to increase provincial benefits and to achieve the production targets (e.g. rice, shrimp). The constraints are land area that suitable for each LUT (which varied with the biophysical conditions under CC and SLR scenarios), labour and capital availability, and market demand.

Scenarios are built to explore the future land use under changing biophysical, socio-economic conditions or development goals. The results of different land use scenarios are analyzed to show trade-offs between costs and benefits of attaining different goals. In this study the scenarios are based on biophysical conditions under CC scenarios, new technical levels including new farming technologies, cropping systems and plant varieties developed or promoted by the CLUES project.

The results are presented in graphical or tabular forms, and mapped by geographic information system (GIS).

During modelling implementation, meetings and workshops are organized to receive feedback of local stakeholders on the model results.

6 Achievements against activities and outputs/milestones

No.	Activity	Outputs/ Milestones	Completion date	Comments
5.1	Fine mapping of salinity borders in high spatial and temporal resolution different sections of Bac Lieu province under current and projected sea level and sluice operations	GIS maps of salinity and flooding in scenarios: dry year (1998), normal year (2004), wet year (2000); dry, normal, and wet years + future CC + SLR + sluice gate operations.	Mar 2012	Completed as planned.
5.2	Determining the benefits from potential improvements in infrastructure (sluice and dyke system) in terms of salinity and flooding risks	Report on the existing water management infrastructure and its operations.	Mar 2012	Completed as planned.
5.3	Mapping of soils and current land use in Bac Lieu	Updated GIS maps of soil, land use, and land mapping units of Bac Lieu province	June 2012	Completed as planned.
5.4	Analyse biophysical land suitability for rice based land use systems under different CC, SLR and infrastructure development scenarios	GIS maps on land suitability maps and descriptions (present and future scenarios of SLR + CC + sluice gates operation schemas)	Mar 2013	Completed as planned.
5.5	Identify socio-economic constraints for the adoption of more resilient farming	- Five workshops with stakeholders in Bac Lieu Province. - A report on socio-economic constraints of current agricultural land use systems in Bac Lieu province.	Aug 2013	Completed as planned.
5.6	Apply multiple-goal linear programming for land use planning and define a master plan on climate change adaptation	Optimized adaptation land use options for at province scale at different scenarios (biophysical and socio-economic constraints, development goals, and adaptation options)	Dec 2014	Completed as planned.
5.7	Derive 'lessons learnt' from this case study for future development of adaptation master plans in other provinces	- Six scientific papers (6 in Vietnamese, 1 in English), one national workshop presentation, and one international workshop presentation. - Three training courses (51 participants, 36 females) on guidelines and tools for developing adaptation master plans in other provinces of the VMD. - Three workshops with stakeholders on policy and institutional issues.	April 2015	Completed as planned.

7 Key results and discussion

7.1 Maps of salinity and flooding in current and future scenarios

The current water issues

The VRSAP model analysis suggests that: (i) the effect of sluices operations in Quan Lo Phung Hiep (QLPH) canal system along the National road 1A (NR1A) is very significant to the control inundation and saline intrusion; (ii) the risk of inundation in wet season is not only serious in high water year but also in low and average water years; and (iii) the saline intrusion in the low and average water years is more severe than in high water year.

Maximum inundation depth in the south of NR1A is higher than in the north-west (area with bold boundary in Figure 1), mainly due to higher tide amplitude (2.5-3 m) from the East Sea, but drainage is better, therefore the impacts by inundation is less than the north-west part with lower tide amplitude (0.4-1.2 m) from the West Sea.

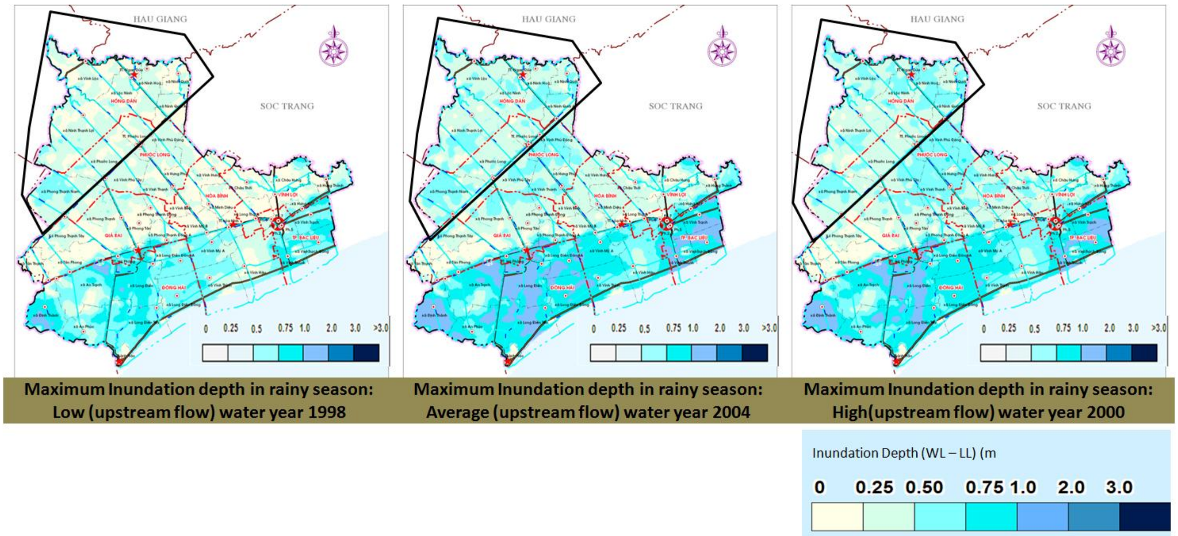


Figure 1. Maximum inundation depth in October of low, average and high water years.

The maps in Figure 2 present maximum salinity in low, average and high water years. These maps show that Bac Lieu has two vulnerable areas in terms of salinity intrusion: (i) rice area next to Soc Trang province inside the QLPH salinity control project where salinity increases significantly in low water year (0 to 1 g/l in average and high water years but 2 to 4g/l in low water year), and (ii) area with shrimp-rice or shrimp monoculture in the south of QLPH canal where salinity fluctuates from 8 g/l to 24 g/l in high, average and low water years. The high salinity variations in these areas would affect not only rice but also shrimp cultivation.

A survey on water management infrastructure and its operations is conducted. Main finding from this survey is that there are possibilities for proper operations to optimize the surface water use in Bac Lieu province for both agriculture and aquaculture. Figure 3 presents the difference of salinity between the low water year and the two salinity control scenarios: (a) operate the QLPH system as year 2008 with a newly proposed sluice at Ninh Quoi and (b) increase fresh water to the main salinity intake sluices (Lang Tram, Ho Phong and Gia Rai). The results suggest that the proposed Ninh Quoi sluice could significantly reduce salinity in rice area but if it is operated to provide more fresh water to the main salinity intake sluices, salinity in shrimp-rice area will also decrease.

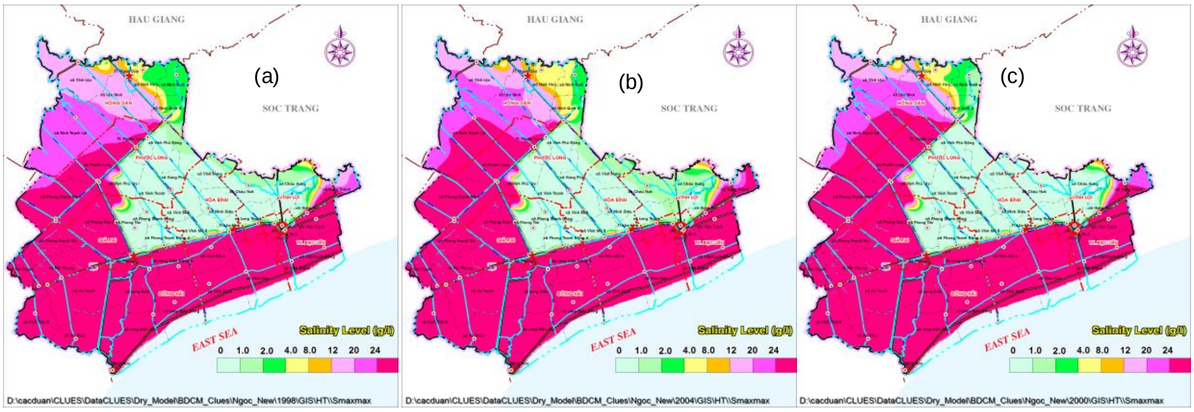


Figure 2. Maximum salinity in low (a), average (b) and high (c) water years.

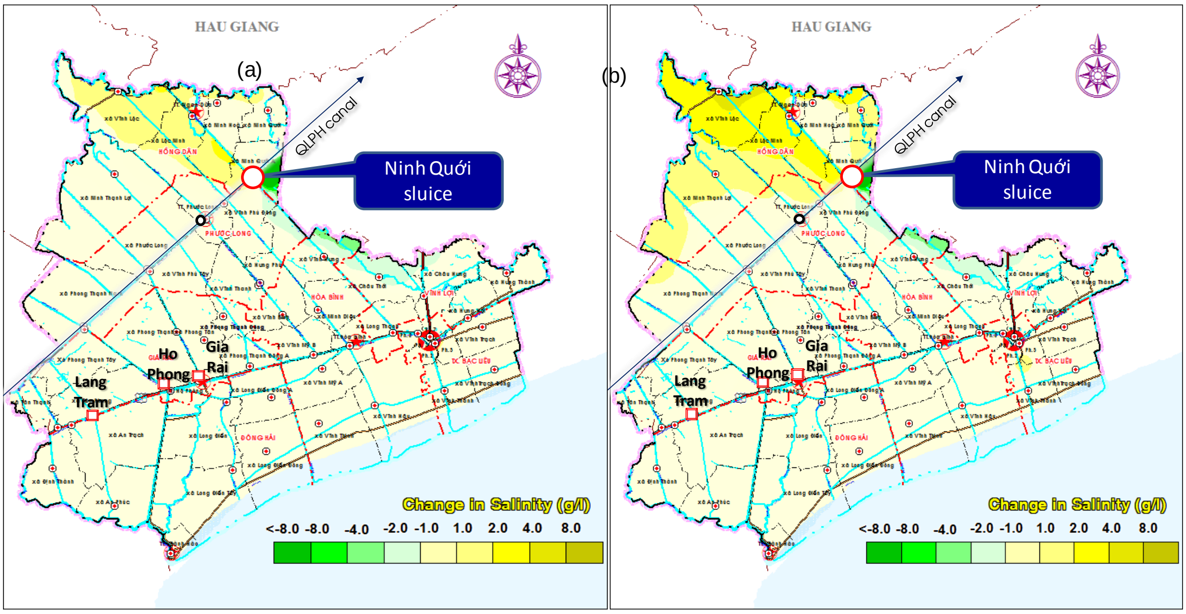


Figure 3. Effects of the proposed Ninh Quoi sluice on salinity of the study area in a low water year (2008) (a) operate the QLPH system as year 2008 with newly proposed sluice at Ninh Quoi and (b) increase fresh water to main salinity intake sluices (Lang Tram, Ho Phong and Gia Rai).

The future salinity issues

Figure 4 presents salinity maps of Bac Lieu in three future scenarios: (a) SLR in low water year, (b) SLR in high water year, and (c) SLR in average water year. If SLR of 17cm in average water year, the current rice area (northern NR1A of Phuoc Long and Vinh Loi districts) is still in fresh water condition. However, area between NR1A and QLPH Canal of Gia Rai district is under saline water from 12 to 25 g/l during 6 to 10 months. The northern part of QLPH Canal (in Phuoc Long and Hong Dan districts) is the most vulnerable area. In the average water year, its salinity is from 4-12 g/l during 2 to 6 months, but in the low water year, its salinity increases to 12 to 20 g/l during 6 to 8 months. Salinity in the south of NR1A continues to be high for shrimp culture.

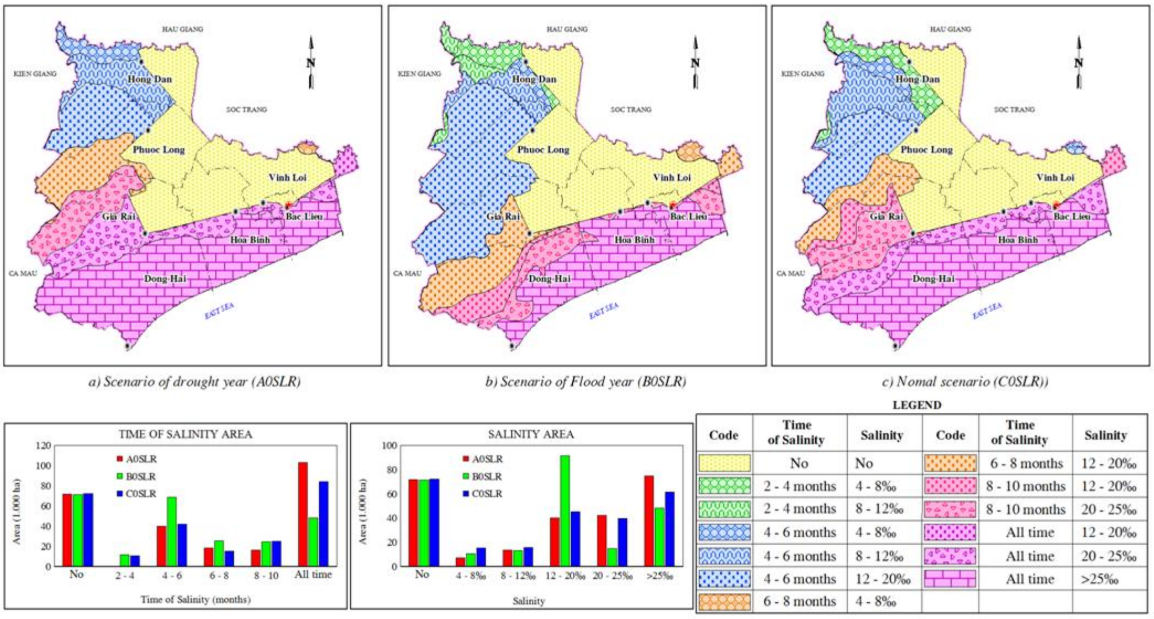


Figure 4 Future salinity intrusion when SLR of 17cm in (a) low water year, (b) high water year, and (c) average water year.

7.2 Maps of soil, land use, and land mapping unit of Bac Lieu province under current and future CC&SLR condition.

7.2.1 Soil and land use

Soil and land use maps of the province are updated to 2012. In general, the main soil problem of the province is that more than 2/3 of its area is acid sulphate soils and saline soils (see Figure A2 in Annex 11.2).

Six teen land use types are delineated including triple, double, mono rice crops, rice-shrimp, aquaculture (Shrimp), forest, salt field, and urban (see Figure A3 in Annex 11.2).

7.2.2 Land Mapping Unit maps

Agro-ecological zones (AEZ) of Bac Lieu province under different CC&SLR and water management scenarios are mapped by overlaying terrain, soil and water maps. Each zone in the map is described by its saline intrusion period, saline value range, soil type, irrigation capacity, cultivation period, and cropping pattern. These are important characteristics for land suitability analysis. The current AEZ map of Bac Lieu is presented in Figure A4 of Annex 11.2.

In order to integrate socio-economic conditions with biophysical characteristics, Land Mapping Unit maps (LMU) of the province are built by overlaying the AEZ maps on the administrative boundary map (village). Since AEZs depend on hydrological conditions, AEZs are changed under impacts of CC and SLR (Figure 5).

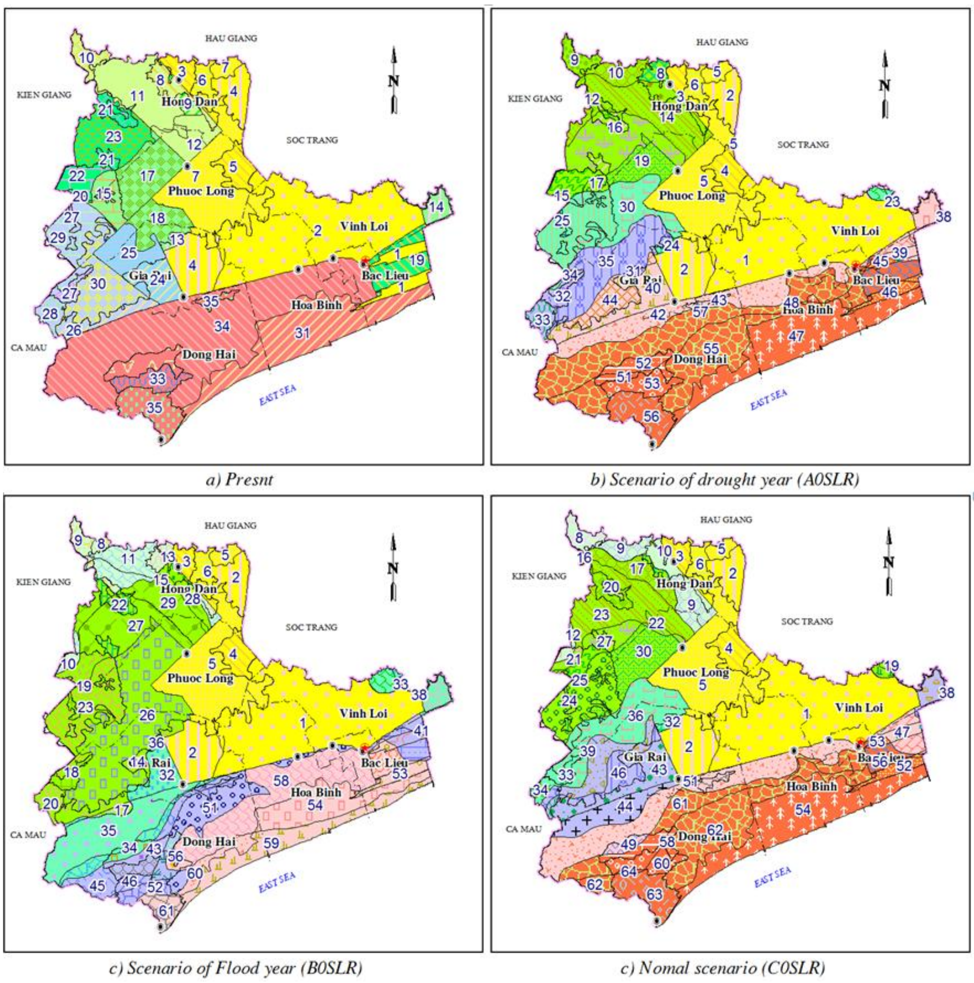


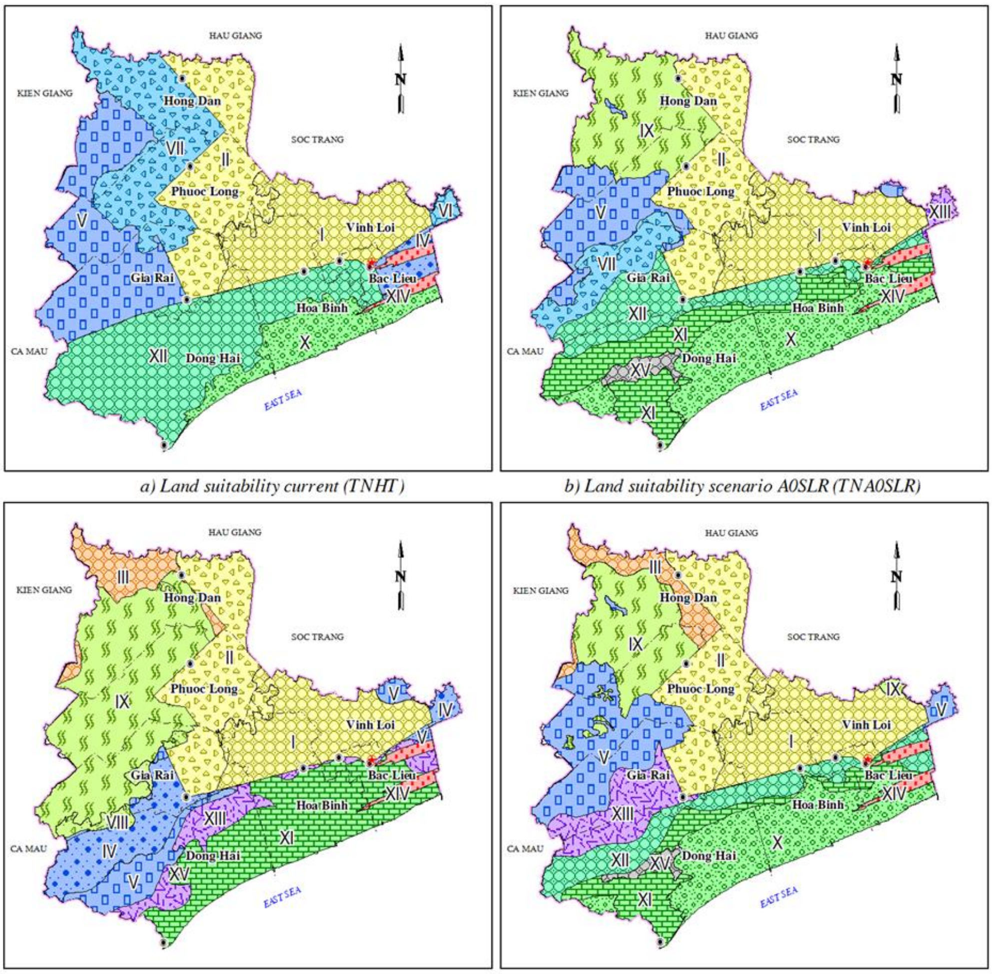
Figure 5. Land Mapping Unit in Bac Lieu province. a) Present, b) Scenario of drought year + sea level rise (A0SLR), c) Scenario of flood year + sea level rise (B0SLR), d) Scenario of normal year + sea level rise (C0SLR).

7.3 Land suitability

Biophysical suitability of promising LUTs under different SLR and infrastructure intervention scenarios are evaluated. Nine promising LUTs are selected for land suitability evaluation based on stakeholder perceptions as results of a SWOT analysis. The selected promising LUTs are triple rice, double rice, shrimp-rice, shrimp, rice-vegetable, vegetable, forest-shrimp, shrimp-fish and salt-fish.

Figure 6 presents land suitability maps under (a) current conditions, (b) SLR 17 cm (projected for the 2030s) in low water year, (c) SLR 17 cm in high water year, and (d) SLR 17 cm in average water year (no new infrastructure in b, c and d). The results show that there are small changes in current LMUs I and II (map a) protected by existing sluices and dykes. These two LMUs are suitable for all rice and vegetable LUTs. Current LMU VII (map a) suitable for double rice will be suitable for shrimp-rice in the future due to the expansion of brackish water. Shrimp-fish will be an option in the future for LMUs III, IV, VIII, IX, X, XI, XII, XIII (maps c and d).

Land suitability maps under CC&SLR in low, average and high water years with new salinity control infrastructure are also developed. Figure 7 presents land suitability maps of Bac Lieu province in low water year when the proposed Ninh Quoi sluice is in operation for different purposes. The results show that current brackish areas are the most sensitive to changes in hydrological conditions and water management.



a) Land suitability current (TNHT)

b) Land suitability scenario A0SLR (TNA0SLR)

c) Land suitability scenario B0SLR (TNB0SLR)

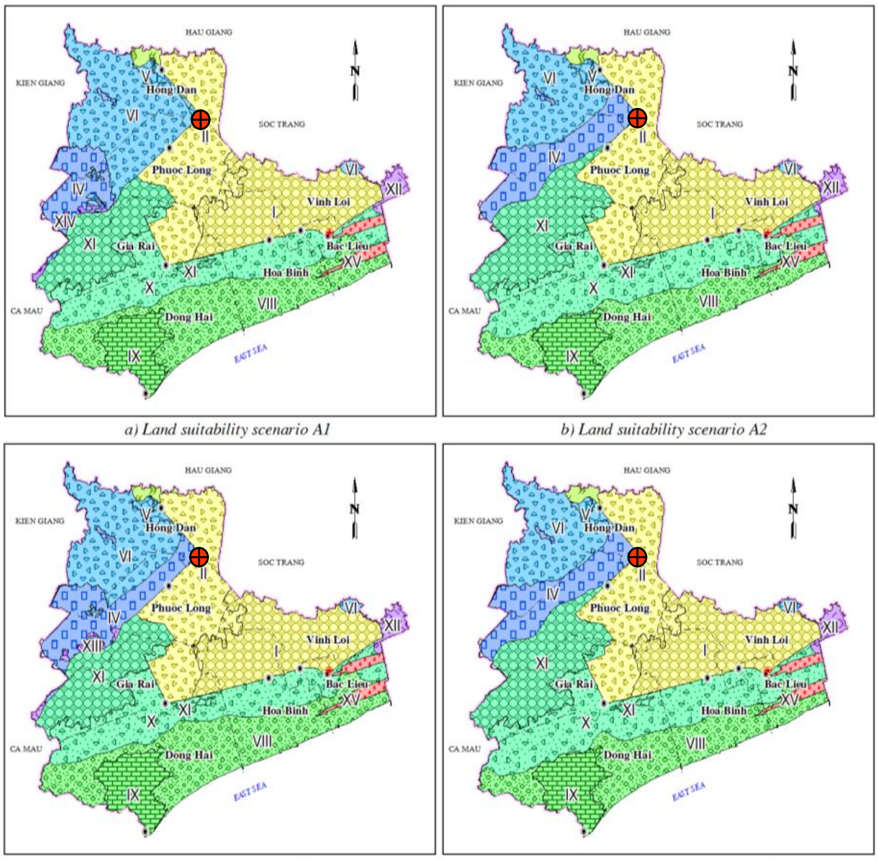
c) Land suitability scenario C0SLR (TNC0SLR)

LEGEND

Code	LUT1	LUT2	LUT3	LUT4	LUT5	LUT6	LUT7	LUT8	LUT9	Land Use Suitability
I	S1	S1			S2	S2				LUT1, LUT2, LUT5, LUT6
II	S2	S2			S2	S2				LUT1, LUT2, LUT5, LUT6
III		S2								LUT2
IV			S1	S2				S2		LUT3, LUT4, LUT8
V			S2	S2				S2		LUT3, LUT4, LUT8
VI			S1	S2						LUT3, LUT4
VII			S2	S2						LUT3, LUT4
VIII			S1							LUT3
IX			S2							LUT3
X				S2			S1	S2	S1	LUT4, LUT7, LUT8, LUT9
XI				S2			S2	S2	S1	LUT4, LUT7, LUT8, LUT9
				S2			S2	S2		LUT4, LUT7, LUT8
XIII				S2				S2		LUT4, LUT8
XIV					S1	S1				LUT5, LUT6
XV									S1	LUT9

LUT1: 3 rice crop; LUT2: 2 rice crop; LUT3: shrimp - rice; LUT4: intensive cultivation shrimp; LUT5: rice - vegetable/upland crops; LUT6: vegetable/upland crops; LUT7: mangrove forest - shrimp; LUT8: shrimp - other aquaculture; LUT9: salt pan - aquaculture

Figure 6. Biophysical land evaluation of Bac Lieu province under (a) current conditions; (b) SLR 17 cm (projected for the 2030s) in low water year; (c) SLR 17 cm in high water year; and (d) SLR 17 cm in average water year.



a) Land suitability scenario A1 *b) Land suitability scenario A2*

c) Land suitability scenario A1SLR *c) Land suitability scenario A2SLR*

LEGEND

Code	LUT1	LUT2	LUT3	LUT4	LUT5	LUT6	LUT7	LUT8	LUT9	Land Use Suitability
I	S1	S1			S2	S2				LUT1, LUT2, LUT5, LUT6
II	S2	S2			S2	S2				LUT1, LUT2, LUT5, LUT6
IV			S2	S2				S2		LUT3, LUT4, LUT8
V			S1	S2						LUT3, LUT4
VI			S2	S2						LUT3, LUT4
VII			S2							LUT3
VIII				S2			S1	S2	S1	LUT4, LUT7, LUT8, LUT9
IX				S2			S2	S2	S1	LUT4, LUT7, LUT8, LUT9
X				S2			S1	S2		LUT4, LUT7, LUT8
XI				S2			S2	S2		LUT4, LUT7, LUT8
XII				S1				S1		LUT4, LUT8
XIII				S2				S2		LUT4, LUT8
XIV				S2						LUT4
XV					S1	S1				LUT5, LUT6

LUT1: 3 rice crop; LUT2: 2 rice crop; LUT3: shrimp - rice; LUT4: intensive cultivation shrimp; LUT5: rice - vegetable/upland crops; LUT6: vegetable/upland crops; LUT7: mangrove forest - shrimp; LUT8: shrimp - other aquaculture; LUT9: salt pan - aquaculture

⊕ Nin Quoi sluice gate

Figure 7. Land suitability maps of Bac Lieu province in low water year: (a) new Ninh Quoi sluice (operated for salinity protection); (b) new Ninh Quoi sluice + increase fresh water to other exiting sluices; (c) SLR + new Ninh Quoi sluice as in (a); (d) SLR + new Ninh Quoi sluice and increase fresh water to other exiting sluices as in (b).

7.4 Socio-economic constraints and institutional arrangements

7.4.1 Socio-economic constraints

PRAs are implemented in 3 AEZs: fresh water, brackish water, and saline water to identify farmers' perceptions on factors affecting their land uses. Farmers in the study area consider increasing income is the most important objective. Farmers also consider water (both quantity and quality) and biodiversity are the most important environmental factors that affect crop yield. Farmers highly concern about market for agriculture and aquaculture products because production price fluctuation is strongly affecting their income. Through

KIPs at each LMU, inputs and outputs for production systems are estimated to provide input data for land use optimization.

The study identifies constraints and opportunities for further improvement of existing farming systems and for adaptive planning of agricultural land uses under anticipated changes. Agriculture, particularly shrimp and rice production with intensive resource uses, played important roles in the economy of Bac Lieu province. Rice yield and income are not different significantly among cropping system in the fresh water zone while a large variation in yield and income exists among shrimp farming systems in brackish and saline zones. In the freshwater zone, rotational upland crops with rice provide high income but are labour-intensive. Income from extensive shrimp farming systems could be improved with appropriately increasing feed inputs and refuge locations for shrimp. Semi-intensive and intensive shrimp culture with high inputs may bring back high economic returns but at high risks because shrimp yield and income are highly influenced by cultivation technologies and also environmental factors that may cause severe losses due to shrimp diseases.

Technical efficiency in terms of yield and income is higher for rice cropping systems in the freshwater zone than for shrimp production systems in the brackish and saline zones. Attainable yield and income of extensive shrimp culture are relatively low due to low inputs compared to semi-intensive and intensive shrimp culture. These results reflect higher stability of income of farming systems in the freshwater zone, compared to that in the brackish and saline water zones. Variation in rice and shrimp income by yield change is larger than that by output prices, reflecting significant impacts of farming technologies on sustaining farming systems in Bac Lieu. Constraining factors of farming systems differ among AEZs and include not only technical factors and hydraulic infrastructure but also services by input providers and output market, and production organization.

7.4.2 Institutional arrangements

The Ministry of Agriculture and Rural Development and Ministry of Natural Resources and Environment formulated several policies and legal documents on agricultural development, coastal mangrove resources management, rural development and climate change response strategies. However, effective implementation of policies at local level is an important issue. There is lack of relevant policies to address a particular problems, policy inflexibility and unclear responsibility of local government in implementing policies.

Effective implementation of policies at local level has been highly driven by many factors. Important factors are: context relevance of policies, farmer's cooperation, availability and accessibility of input and output services, capacity of staff and farmers, availability and accessibility of new technologies and availability of off-farm labour. The Department of Agriculture and Rural Development (DARD) is considered as leading in implementing policies related to agricultural and rural development and coastal resources management. However, services for agricultural inputs and outputs, agricultural environmental management and climate change actions are out of the scope of DARD. The effective coordination and participation, therefore, among DARD and other agencies (i.e. Department of Industry and Trades, Department of Environment and Natural Resources, Department of Labour, Invalid and social Affairs) are of great importance. In addition, informal institution plays an important role in enhancing farmer capacity in their agricultural production and livelihoods (see Theme 4's report). Enhancing and developing farmer's groups, agricultural cooperatives, linkages between farmers and enterprises are necessary. Future agricultural land use plans need mainstreaming to relevant policies and development strategies to add synergies for effectiveness and efficiency.

7.5 Optimized adaptation land use options for at province scale at different scenarios

To adapt to the recent and near future biophysical and socio-economic changes in the Mekong Delta, a decision support system is developed. The system allows defining promising land use options with detailed quantitative information. The system is interactively implemented with high level of stakeholder involvement. An IMGLP model is developed in GAMS modelling environment. The model allows interactively running number of optimization scenarios (see Nguyen Hieu Trung and Pham Thanh Vu, 2014). The model structure with three main components: (i) Biophysical Land Evaluation (BLE), (ii) Socio-Economic Analysis (SEA), and (iii) Scenario Analysis with IMGLP (SA) is presented in Figure 8.

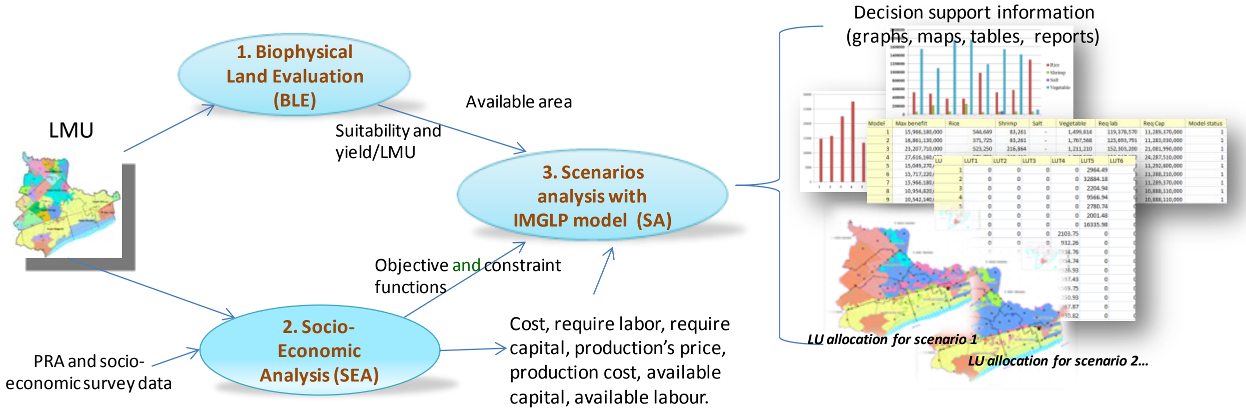


Figure 8. The IMGLP model for developing land use adaptation strategy.

Input data for BLE component are LMU maps and land use requirements. The results of this component are land suitability, yield estimation for each LUT in each LMU and available area. These results will be input data for SA component. The SEA component analyzes PRA and socio-economic survey data to provide required labour, capital, production costs and production prices of each LUT in each LMU. SEA also calculates the available capital and labour, and defines constraints and objective functions for SA component.

Results from SA component are decision support information such as whether development goals or targets are feasible under the analysed scenarios, and how much investment requirements (capital and labour) to achieve these goals or targets. Quantitative inputs/outputs of each scenario are estimated. By using GIS tools, the results can be visualised in forms of maps, graphs, tables, or reports.

Figure 9 shows the comparison of regional income in 4 scenarios:

a) Average water year without and with improved cultivation technologies;
b) Low, high and average water year with present cultivation technologies;
c) Low water year under SLR with new Ninh Quoi sluice and present cultivation technologies;
d) High water year under SLR with new Ninh Quoi sluice and present cultivation technologies.

In this Figure A1 is the case of new Ninh Quoi sluice operated alone and A2 is the case of combining new Ninh Quoi sluice operation and increase fresh water to existing sluices for saline water intake. The results show that:

- Limitations in capital availability and cultivation technologies are main constraints in improving income for rural people;
- The current imposed production targets reduce the provincial land use effectiveness and will be infeasible under CC and SLR;

- Optimizing the use of available resources will reduce negative impacts of CC and SLR; and
- Operation of new (proposed) Ninh Quoi sluice will improve biophysical suitability of the province. However such hard measure of infrastructure is less economic than improvement of cultivation technologies, increasing capital availability combined with optimal operation of exiting sluices.

Therefore, in the medium term (up to 2030s under CC and SLR) adaptation strategy of Bac Lieu province are:

- Improving cultivation technologies;
- Providing higher financial support to farmers;
- Planning land use based on optimal use of available resources and projection of market demand rather than based on production targets;
- Improving operations of exiting sluice system.

The model also provides detailed achievements in development goals, total input requirements and total productions (see Figure A5 in Annex 11.2).

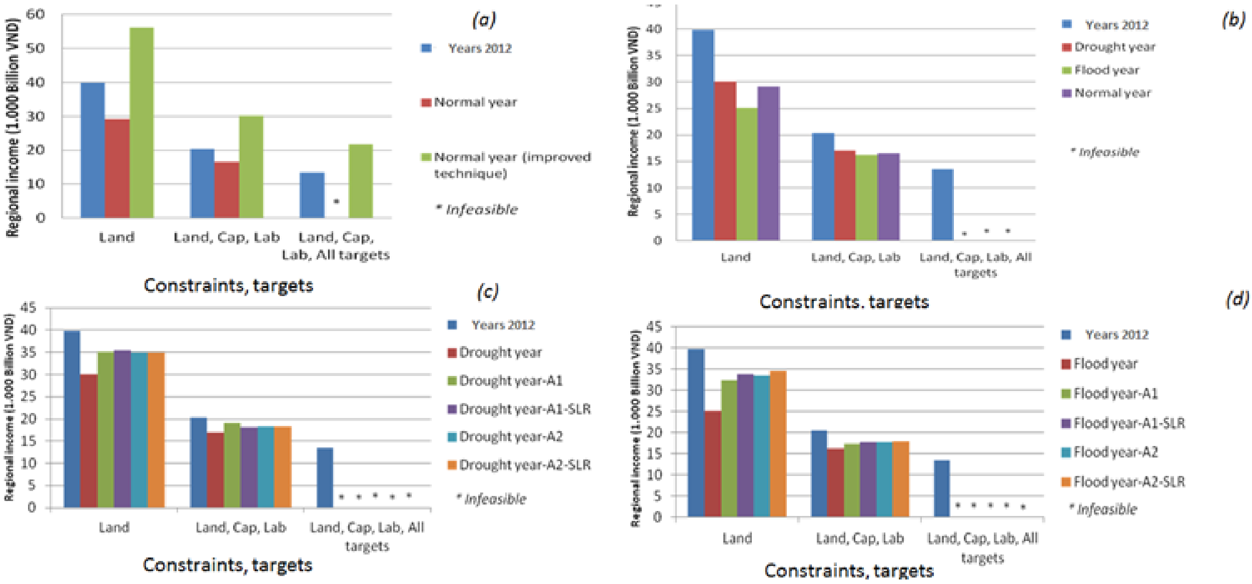


Figure 9. Comparison of 2012 regional income in (a) average water year without and with improved cultivation technologies under current climate and sea level; (b) low water (drought), high water (flood) and average (normal) water year with present cultivation technologies under current climate and sea level; (c) low water (drought) year with SLR scenario of 17 cm and new Ninh Quoi sluice (A1 or A2, see text); (d) high water year with SLR of 17 cm and new Ninh Quoi sluice (A1 or A2, see text).

7.6 Guidelines and tools available for developing adaptation master plans in other provinces of the MDR

Based on the developed IMGLP model and provincial adaptation plan, Theme 5 team has prepared and carried out 3 training courses with guidelines and tools. The training courses were conducted for more than 51 participants (36 female) of both technical staff (such as staff from the Integrated Coastal Management Programme in Bac Lieu province funded by GIZ, BMZ and DFAT) and district/provincial management. These participants are not only from Bac Lieu province but also from Hau Giang and An Giang provinces. Training materials are ready for further training courses in the Vietnamese Mekong Delta.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Activities of theme 5 have improved knowledge of research team, local stakeholders, and scientific communities on: (i) current and future impacts of CC&SLR in 2030s in terms of inundation and salinity intrusion; (ii) existing water management infrastructure and its possible operations for better use of water resources; (ii) the dynamics of soil and land use; (iv) integration between bio-physical and socio-economic conditions under current stage and future impacts of CC&SLR; and (v) current land use management and opportunities in adaptation to climate change.

Development of land use strategy to adapt to CC&SLR for the VMD is very challenging because of the complexity and uncertainty in both bio-physical and socio-economic variations. Land use in the VMD are influenced by both external driving factors (such as increasing water use in upstream countries) and internal factors (such as changes of water conditions due to water management in different provinces within the delta). Moreover, defining a future strategic development for the delta under CC&SLR is even more difficult due to high uncertainty in spatial and temporal variations of these changes. Therefore the contribution of this study is not only an adaptation land use plan for Bac Lieu province now and future (2030s), but more important a methodology for development of strategic land use plan under uncertain bio-physical and socio-economic variations. One important key for the success in applying this methodology is the participation of provincial and local stakeholders.

The present beneficiaries from scientific outputs of theme 5 are: (i) researchers of CTU, SIWRP, IRRI, ANU, CSIRO; (ii) MSc and PhD students of CTU; (iii) on-going projects in Bac Lieu province such as the Integrated Coastal Management Programme and (iv) provincial and local staff of DARD and DONRE.

In five years, besides the present beneficiaries, potential beneficiaries will be the future projects in Bac Lieu such as the Climate Smart Village project under CCAFS of CGIAR, and other projects in other Mekong Delta provinces.

No.	Actor	Current impacts	Indicator(s)	Expect in next 5 years
1	- Researchers of CTU, SIWRP, IRRI, ANU, CSIRO; - MSc and PhD students of CTU; - On-going projects in Bac Lieu province such as the Integrated Coastal Management Programme and - Provincial and local staff of DARD and DONRE. searchers of CTU, SIWRP, IRRI, ANU, CSIRO;	- Improved knowledge of research team, local stakeholders, and scientific communities on: (i) current and future impacts of CC&SLR in 2030s in terms of inundation and salinity intrusion; (ii) existing water management infrastructure and its possible operations for better use of water resources; (iii) the dynamics of soil and land use; (iv) integration between bio-physical and socio-economic conditions under current stage and future impacts of CC&SLR; and (v) current land use management and opportunities in adaptation to climate change - More understanding on research methods on natural resources assessments, policy and institutional analysis, technology feasibility assessment. - Improved scientific writing skill	- 07 publications in Vietnamese journals - 01 publications in International journals - 03 manuscripts for training courses - Applying the developed methods for developing 01 proposal to the South Western Committee of the Mekong Delta.	- 02 publications in Vietnamese journals - 02 publications in International journals - At least 2 new research projects building scientific knowledge from CLUES from CTU partners

8.2 Capacity impacts – now and in 5 years

As mentioned in Section 8.1 several activities have been carried out to build capacity for stakeholders (technical staffs of from DARD and DONRE of Bac Lieu, Hau Giang, and An Giang provinces), project team in Bac Lieu province of the Integrated Coastal Management Programme, researchers/teaching staffs of CTU, SIWRP, IRRI, ANU, CSIRO, and CTU MSc and PhD students.

Capacity building is implemented through participatory workshops and technical training courses. In the total of five workshops in Bac Lieu province three were organised for three agro-ecological units. During these workshops, theme 5 team have chance to improve their capacity on facilitating participatory methods such as group discussions.

During the project period, one theme member of CTU completed his PhD study and six CTU MSc students (2 female) completed their theses by combining their studies with the theme topics. Besides, four members of theme 5 were trained by theme 4 on socio-economic surveys and analysis. One theme member participated a short training course in IRRI.

The capacity impacts of theme 5 are:

- Capacity in implementing the interactive and integrated climate change adaptation (CCA) strategy by applying land use analysis approach.
- Capacity in facilitating stakeholder participatory.
- Capacity in using scientific information to make decision on land use management and CCA strategy planning
- Improving CTU curriculums on Land Resources (BSc, MSc, PhD), Natural Resources Environment Management (BSc, MSc), Water Resources (BSc).

The current impacts are mainly to (i) technical staffs and decision makers in Bac Lieu, Hau Giang, and An Giang provinces; (ii) staffs of other on-going projects in Bac Lieu province; and (iii) researchers and students of CTU, SIWRP, IRRI, ANU, SCIRO.

In the next five years impacts would extend to technical staffs of other provinces in the Mekong Delta, new projects in Bac Lieu and other researchers and students in the Mekong Delta.

Site	Name of trainings	Date	Length of Activity	No. of people involved	Male	Female	Expected in next 5 years
Non-degree training							
CTU	Decision support tools for Climate change adaptation land use planning	Mar 11-14, 2014	04 day	17	13	4	Applying (and/or developing) the approach and method to the similar research projects.
CTU	Basic course on application of Decision support tools for Climate change adaptation land use planning.	Nov 10-12, 2014	03 day	20	14	6	Local experts will apply the approach in adaptation land use planning
CTU	Advance course on application of Decision support tools for Climate change adaptation land use planning	Nov 12-15, 2014	03 day	14	9	5	Local experts will apply the approach in adaptation land use planning
IRRI	Data Management	Aug 2014	03 day	01	01		To apply methods and tools in research data management
CTU	Participatory Adaptation	Nov - 2011	04 day	01	01		Applying the methods in farming technology evaluation for CCA
	Total			**53**	**38**	**15**	
Degree training							
CTU	Msc. theses	2011-2014	03 years	06	04	02	Improving CTU's curriculums
CTU	PhD. theses	2010-2014	04 years	01	01	0	
	Total			**07**	**05**	**02**	

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

Theme 5 proposes economical suitable land use types for current and future context of Bac Lieu. Moreover, the study suggests for a change from top-down production targets to optimized land use plans. This leads to the more efficient use of resources, therefore reduces costs and increase income of people in Bac Lieu province.

Current impacts are on farmers, agriculture and aquaculture extension staffs and decision/policy makers of Bac Lieu province. The next five years impacts would extend to other Mekong Delta provinces if the study outputs are used in the National Target program on New Rural Development (NRD) and Agricultural Restructuring (AR) policy.

No.	Actor	Current impacts	Indicator(s)	Expect in next 5 years
1	Farmers and Planers	The study proposed: - Economical suitable land use types for current and future context of Bac Lieu. - A policy change from top-down production targets to optimized land use plans.	The scenarios' economic returns and feasible adaptation (see Figure 9)	Impacts would extend to other Mekong Delta provinces if this integrated land use planning approach is applied wider in the Mekong Delta.

8.3.2 Social impacts

The CCA strategy approach applied in this study supports better stakeholder engagement at all levels through communication, consultation, participation and partnership.

The current impacts are on farmers of Bac Lieu province. In the next five years, if the study outputs are used in policy, the impacts would extend to many other Mekong Delta farmers.

Theme	Site	Name of Activity	Date	Length of Activity	No. of people involved	Male	Female	Expected outcome
5	Bac Lieu	Workshops on Adaptation Assessment and Developing of Adaptation Land Use for Bac Lieu province	Aug 07, 2013	01	86	82	4	- Improving knowledge of local stakeholders on the current conditions and CC impacts in Bac Lieu province. - Raising awareness of local stakeholders on optimizing use of water resources under context of CC
	Phuoc Long – Bac Lieu	Workshops on Adaptation Assessment and Developing Adaptation Land Use for the brackish water sub-agro-ecological zone	Nov 11, 2013	01	65	59	6	- Increasing the efficiency use of land in the sub-agro-ecological zones of Bac Lieu province. - Identifying the potential adaptation measures. - Introducing stakeholders the implemented methodology. - Improving policies for better uses of natural resources and enhance farmer's livelihood
	Hoa Binh – Bac Lieu	Workshops on Adaptation Assessment and Developing Adaptation Land Use for the freshwater sub-agro-ecological zone	Nov 12, 2013	01	62	59	3	
	Bac Lieu	Workshops on Adaptation Assessment and Developing Adaptation Land Use for the salt water sub-agro-ecological zone	Nov 13, 2013	01	48	46	2	
		Total			**261**	**246**	**15**	

8.3.3 Environmental impacts

The study proposes a strategy for better use of natural resources. This will help to reduce environment impacts. The impacts will not be only in the Bac Lieu province but also in the whole Mekong Delta.

8.4 Communication and dissemination activities

Theme 5 has implemented several activities to communicate and disseminate its outputs to provincial and local stakeholders.

Five workshops were organised to obtain local people and government feedbacks on research methodology and results, and local stakeholders' perception on development goals and constraints. Participants at these workshops are representative farmers from Bac Lieu districts (more than 100 farmers), agriculture and aquaculture extension officers, leaders and staff of Bac Lieu districts, Bac Lieu DARD, DOSTE, and DONRE (50 staff), and staff from local radio, television and news paper (Figure A6 in Annex 11.2).

To disseminate theme outputs, as presented in the Capacity impact session (see 8.2), three training courses on CCA strategy methodology (Figure A7 in Annex 11.2) have been carried out and seven scientific papers were published. Six of these papers are in Vietnamese in order to achieve immediate awareness to the Vietnamese scientific community and published in popular Vietnamese journals such as Vietnamese Science and Technology Journal of Agriculture and Rural Development, Can Tho University Journal of Science, Vietnamese Journal of Science and Technology. Theme members also presented their results at the International Conference on Geo-Informatics for Spatial-Infrastructure Development in Earth & Allied Sciences (GIS-IDEAS) in Da Nang City, 06 - 09, December, 2014

Theme 5 also greatly contribute to training programs of Can Tho University for improvement of lecturers' capacity, related curriculum and students research activities (see 8.2) .

9 Conclusions and recommendations

9.1 Conclusions

Theme 5 has successfully achieved its research objectives to develop an appropriate climate change adaptation strategy approach for the coastal area of the Mekong Delta and applied it in a case study in Bac Lieu province, one of the most CC vulnerable provinces of the Mekong Delta. The approach is able to:

- Facilitating participation of different levels of stakeholders (farmer, community, agro-ecological units) during design, implementation and making decision/policy in the CCA strategy development.
- During applying this approach, improving knowledge, perception and attitude of local famers, extension officers and especially the decision/policy makers of the province.
- Quantifying inputs (requirements of land, water, labour, investment) and outputs (production, benefit) of adaptation options (alternative LUTs, infrastructure development).
- Providing better information on climate change and adaptation possibilities to farmers and decision/policy makers.

9.2 Recommendations

- To Bac Lieu province in specific and to the coastal Mekong Delta in general, a proposed CCA strategy pathway of 30 years is:
    - to improve cultivation technologies for more efficient use of resources (reduce input costs, labour) and higher production quality/value.
    - to promote innovation practices (e.g. encouragement by tax policy or financial accessibility)
    - to look for more domestic and international markets of major products.
    - to optimize use of water resources through better operation of existing water management infrastructure. Water should be used for higher production values and mitigate environment impacts rather than only to fulfill production targets.
- To assure the successful of the CCA strategies, The following studies are essential:
    - Risk management on crop failures (by disease, water pollution, extreme weather) and on market fluctuation.
    - Land and water efficient use (e.g. the large-farm model).
    - Changes of rural labor (both quantity and quality) due to migration and mechanization.
    - Longer term impacts of CC&SLR and additional impacts of land subsidence on salinity and flooding in the Mekong Delta.
    - Appropriate platform to support innovation practices in the Mekong Delta rural development (financial, manufactory, enterprise, distributor, and farmer innovation…).

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Workshops carried out by Theme 5

- Workshops on Adaptation Assessment and Developing Adaptation Land Use for Bac Lieu province. Bac Lieu city, Aug 07, 2013.
- Workshops on Adaptation Assessment and Developing Adaptation Land Use for the brackish water sub-agro-ecological zone. Phuoc Long district, Nov 11, 2013.
- Workshops on Adaptation Assessment and Developing Adaptation Land Use for the freshwater sub-agro-ecological zone. Hoa Binh district, Nov 12, 2013.
- Workshops on Adaptation Assessment and Developing Adaptation Land Use for the salt water sub-agro-ecological zone. Bac Lieu city, Nov 13, 2013.

Training courses' handouts

- Decision Support Tools for Climate Change Adaptation Land Use Planning. Can Tho University, Mar 11-14, 2014.
- Basic course on Application of Decision Support Tools for Climate Change Adaptation Land Use Planning. Nov 10-12, 2014.
- Advance course on Application of Decision Support Tools for Climate change adaptation land use planning. Nov 12-15, 2014.

11 Appendixes:

11.1 The research team:

- Theme leader: Asso. Prof. Nguyen Hieu Trung (CTU)
- Water: Dr. Nguyen Xuan Hien (SIWRP, theme 1 leader) and SIWRP staff, Dr. Van Pham Dang Tri (CTU, also theme 1 member) and CENRes staff.
- Soil: Assoc. Prof. Vo Quang Minh (CTU, also theme 1 member) and CENRes staff.
- Land evaluation: Prof. Le Quang Tri, Mr. Pham Thanh Vu (CTU) and CENRes staff.
- Socio-economic: Dr. Dang Kieu Nhan (CTU, also theme 4 leader) and MDI staff.
- Land use planning analysis: Assoc. Prof. Nguyen Hieu Trung, Dr. Pham Thanh Vu and CENRes staff.

International consultants:

- Dr. To Phuc Tuong (IRRI),
- Dr. Chu Thai Hoanh (IWMI)

11.2 Pictures

Figure A1. Stakeholder involvement during the study

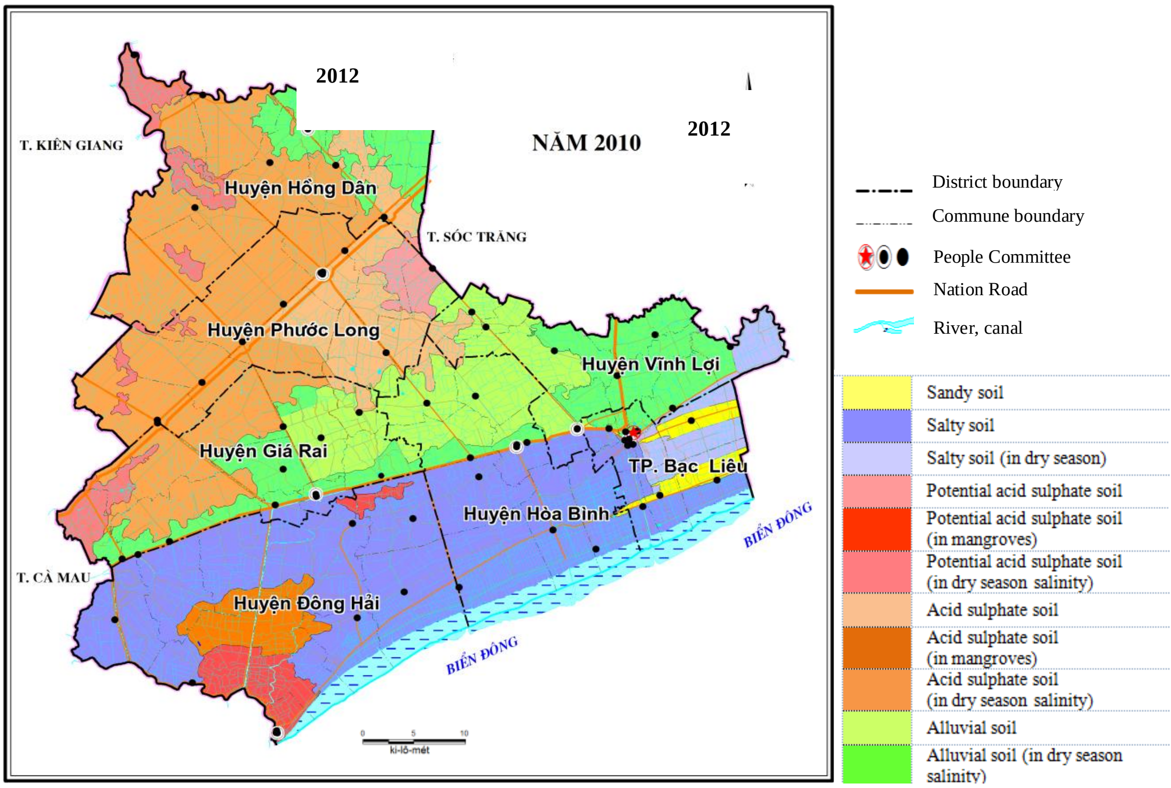


Figure A2. Soil map of Bac Lieu province (updated based on survey data in 2012)

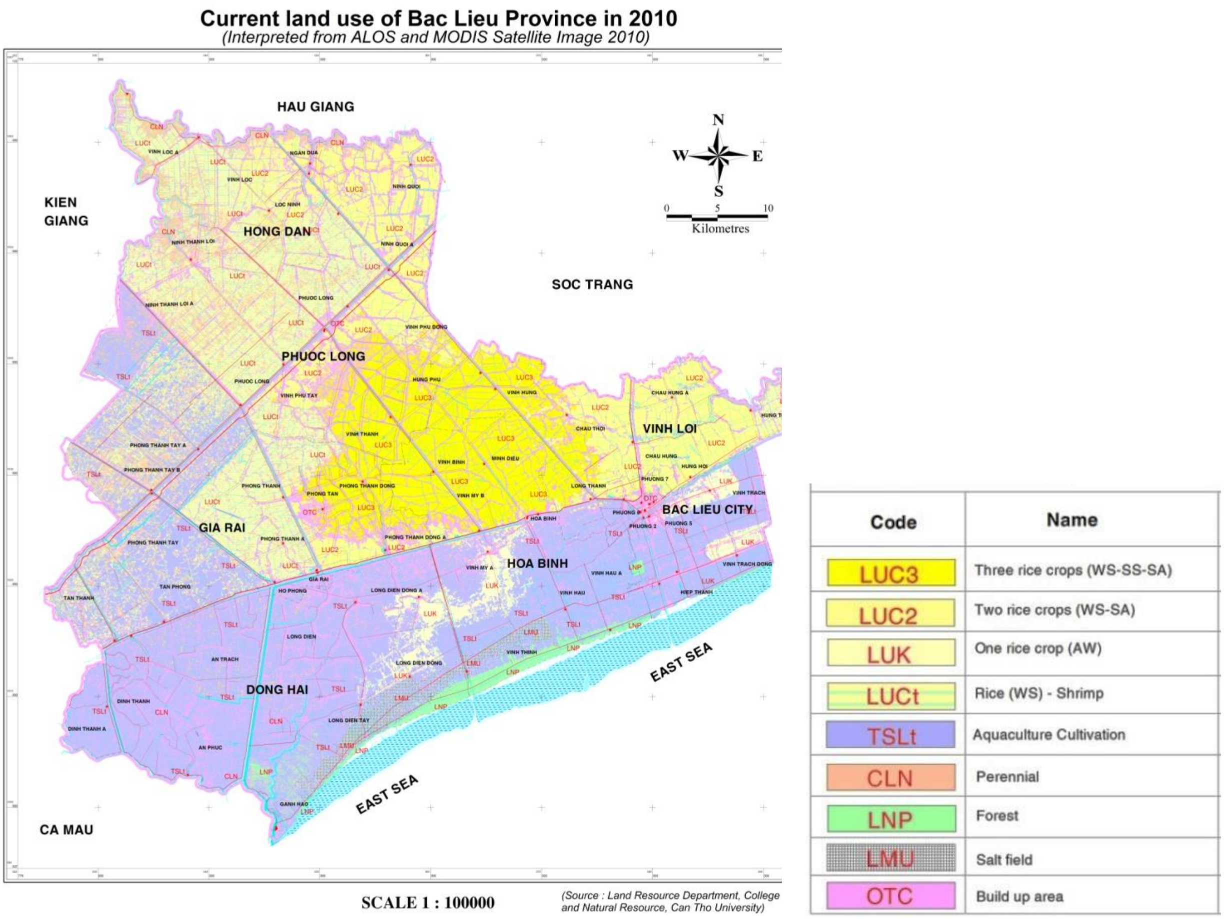
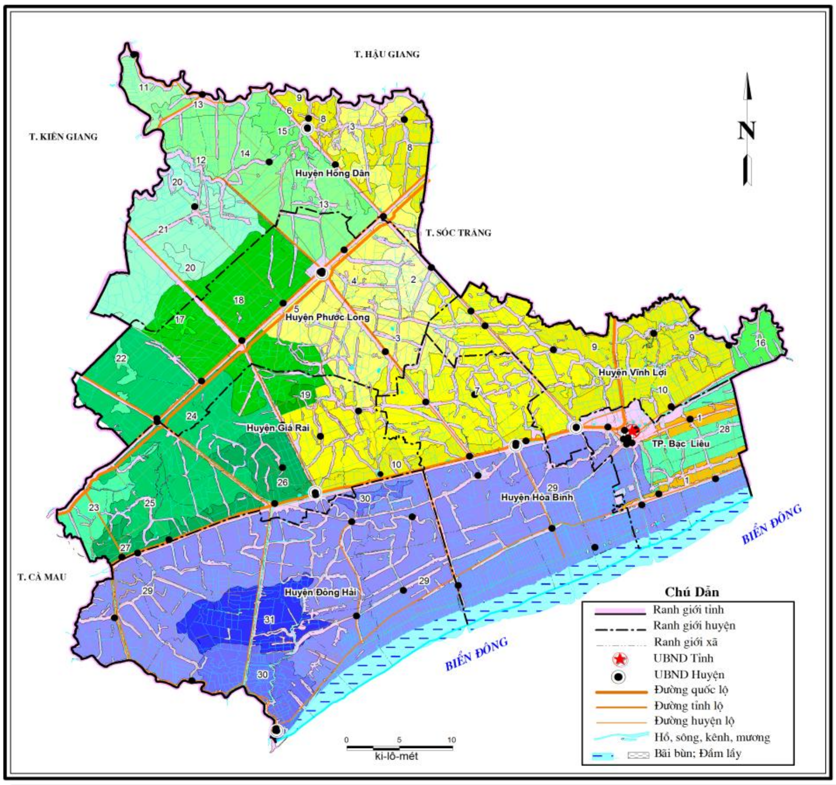


Figure A3. Land use map of Bac Lieu province in 2010

Figure A4. Local stakeholders discuss on the land sustainable map resulted from theme 5 (local workshop at Bac Lieu city, August 2013). 65 local participants were separated into four discussion groups (3 groups of farmers and agriculture officers of 3 zones, saline water zones, and 1 group of local government



ECOLOGICAL ZONE	TIME OF SALINITY	SALINITY	SOIL	SUPPLYING FRESH WATER CAPABILITY	PERIOD OF CULTIVATION	ECOLOGICAL ZONE UNIT	LAND USE TYPE (Agricultural calendar I II III IV V VI VII VIII IX X XI XII)
	Non	Less than 4‰	Sandy soil	C3	T3	1	Upland crop Rice-Upland crop
FRESH WATER	Non	Less than 4‰	Potential acid sulphate soil	C2	T1	2	
			Actual acid sulphate soil	C1	T1	3	
				C2	T1	4	3 rice crops (SuA-AW-WSp)
				C2	T2	5	
			Actual acid sulphate soil, salinity in dry season	C2	T1	6	2 rice crops (WSp-SuA)
			Alluvial soil without compensation	C1	T1	7	
			Alluvial soil without compensation, salinity in dry season	C1	T1	8	2 rice crops (SuA-by rain)
				C2	T1	9	
				C2	T2	10	
BRACKISH WATER	From 3 to 6 months	From 4 to 10‰	Potential acid sulphate soil, salinity in dry season	C2	T1	11	
				C2	T2	12	
			Actual acid sulphate soil, salinity in dry season	C2	T1	13	
				C2	T2	14	Extensive shrimp
			Alluvial soil without compensation, salinity in dry season	C2	T1	15	
		More than 10‰	Salinity soil in dry season	C2	T2	16	Rice-Shrimp
			Potential acid sulphate soil, salinity in dry season	C2	T2	17	
			Actual acid sulphate soil, salinity in dry season	C2	T2	18	
			Alluvial soil without compensation, salinity in dry season	C2	T2	19	
	More than 6 months	From 4 to 10‰	Potential acid sulphate soil, salinity in dry season	C2	T3	20	
			Actual acid sulphate soil, salinity in dry season	C2	T3	21	
		More than 10‰	Potential acid sulphate soil, salinity in dry season	C2	T3	22	
				C3	T3	23	Extensive shrimp
			Actual acid sulphate soil, salinity in dry season	C2	T3	24	
				C3	T3	25	
			Alluvial soil without compensation, salinity in dry season	C2	T3	26	
				C3	T3	27	
	More than 6 months	More than 10‰	Salinity soil in dry season	C3	T3	28	Intensive shrimp
SALT WATER	Around year	More than 10‰	Salinity soil in around year	C3	T4	29	Extensive shrimp
			Potential acid sulphate soil, salinity in around year	C3	T4	30	Forest-Aquaculture
			Actual acid sulphate soil, salinity in around year	C3	T4	31	Salt marsh

Non-agriculture
C1: Capable of supplying fresh water in around year
C2: Capable of supplying fresh water in some months of the first of dry season
C3: Non-capable of supplying fresh water (by rain)
T1: by rain from 6 to 7 months
T2: by rain from 5 to 6 months
T3: by rain from 3 to 5 months
T4: by rain less than 3 months

Figure A5. The current agro-ecological map of Bac Lieu province

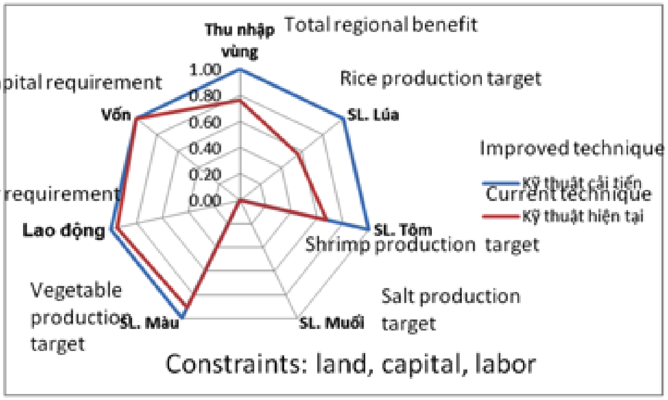


Figure A6. An example of the detailed information resulted from the optimization model. Two scenarios (current cropping techniques and improved cropping techniques) were compared in term of the levels of the objectives achievement (total regional income), the total input requirements (capital, labour) and the production targets (rice, shrimp, vegetable, salt). The achievable level is from 0 (no) to 1 (fully).

Figure A7. Activities in the training course "Decision support system for land-use in the context of climate change".

Australian Government

Australian Centre for International Agricultural Research

Final report

project	**Climate Change Affecting Land Use in the Mekong Delta: Adaptation of Rice-based Cropping Systems (CLUES)** Theme 6: Capacity building for assessing greenhouse gas (GHG) emissions
project number	SMCN/2009/021
date published	
prepared by	Dr.Cao Van Phung (CLRRI)
co-authors/ contributors/ collaborators	Dr.Ben Macdonald (CSIRO), Dr. Reiner Wassmann (IRRI)
approved by	
final report number	
ISBN	
published by	ACIAR GPO Box 1571 Canberra ACT 2601 Australia

Contents

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All works of Theme 6 on capacity building for assessing GHG emission were part of CLUES project which was funded by ACIAR entitled ”Climate change affecting land use in the Mekong delta: Adaptation of rice base cropping systems”.

Sample collection and analysis were done by author and all staffs in the department of Soil and Microbiology of Cuu Long Rice Research Institute (CLRRI). Dr. Ole Sander generously helped in training researcher for flux sampling by closed chamber method and data calculation and processing.

Dr. Reiner Wassman, the project leader, was directly planned all activities of Theme 6 and encouraged researchers to fulfill their duties. Dr. Ben MacDonald greatly contributed in preparation of manuscript and scientific papers. The contribution of all IC’s are highly appreciated.

The warm atmosphere in working at the CLUES project office at CanTho University and materials allowance by CLRRI Directors are very valuable in completion experiments of Theme 6.

Thanks were also given to local authorities of An Giang, CanTho, Hau Giang and Bac Lieu who had given meaningful supports for carrying-out studies and surveys at their sites.

Last but not least all discussions and exchange views on experiments with scientist from Cantho University, CSIRO, IRRI, IAS and SIWRP were very meaningful and appreciated.

2 Executive summary

Right at the beginning of the CLUES project, theme 6 had proceeded to procure GC for GHG analysis as well as renewable laboratory for instrument installment at CLRRI by the end of October 2011.

Total four training courses for CLRRI staffs, scientists and students of Cantho University were done first at Hue University in June 2011 and the other three were conducted at CLRRI at the end of 2011 to mid 2012. Theme 6 cooperated with projects GIZ-Tra Vinh and WINROCK –Long An for training 12 extension workers on flux sampling by closed chamber method. 12 students from Cuu Long University were benefitted from CLUES project for completion BSc dissertation on GHG measurent at CLRRI.

To increase GHG awareness and climate change adaptation for local authorities and farmers, theme 6 participated in 8 workshops organised either by CLUES project or GIZ, WINROCK and national project during 2012-2014 at 4 target sites (An Giang, CanTho, Hau Giang and Bac Lieu) and 4 other provinces (Long An, Tra Vinh, Vinh Long and Soc Trang).

In order to have baseline emission from the Mekong delta, Theme 6 had itself conducted several experiments at CLRRI to investigate effects of cultivation methods (crop estblishment either by direct seeding or transplanting, land preparation tillering or rotivating vs. plowing then puddling), fertilization (inorganic fertilizes and organic manure alone or incombination). The joined research between Theme 6 and Theme 3 in this project had been clearly demonstrated at 4 target sites for deep flooded alluvial soil in An Giang, shallow flooded alluvial soil at Cantho, acid sulphate soil at Hau Giang and salt infected soil at Bac Lieu for evaluation effects of water management (CF vs. AWD), P reduction and cropping sequence as well as soil types on GHG emission.

IRRI provided excel templates and trained CLRRI staffs for calculation of emission and calibration GC instrument at CLRRI during time of project in operation. International consultants either from CSIRO (Dr. Ben MacDonald) or IRRI (Dr. Reiner Wassmann, Dr. Ole Sander and Dr. To Phuc Tuong) regularly recommended and help in planning experiments or finalised results before submission to ACIAR.

3 Background

Global warming directly influenced by GHG is now being worldwide concerned not only because of climate change affecting to agricultural production but also to calamities happening more frequently which threaten to all human activities. Current GHG emissions generated by anthropogenic activities include land use and land use change in agricultural and forest systems, industrial development, and urban expansion, among other sources. All of them have contributed to disrupt the C and N cycles in terrestrial ecosystems (IPCC, 2007). The contribution of agricultural soils to CO2, N2O and CH4 emissions depends on the biophysical processes, and the incorporation/decomposition of organic residues in the soil. Soil aerobic conditions produce CO2, while anaerobic conditions produce CH4, and nitrification and denitrification processes of mineral-N result in N2O emission. Methane (CH4) and nitrous oxide (N2O) emissions from paddy rice caused increasing atmospheric green house gas (GHG) concentrations. It is estimated that approximately 6 % of anthropogenic N2O (FAO, 1981) meanwhile CH4 emission from paddy rice occupied about 5-20 % (IPCC, 1996). Recently FAO (2014) that informed that agriculture greenhouse emissions have nearly doubled over the past 50 years and may increase by another 30 per cent by 2050. Emissions from crop and livestock production grew in 2001 from 4.7 billion tonnes of carbon dioxide equivalents (CO2 eq) to more than 5.3 billion tonnes in 2011 – a 14 per cent increase.

Implementing the Kyoto Protocol, Viet Nam has issued a number of legal documents.These include Directive 35/2005/CT-TTg dated 17th October 2005 on organizing the implementation of the Kyoto Protocol to the United Nations Framework Convention on Climate Change, Decision 47/2007/QÑ-TTg dated 6th April 2007 on approving the plan.

for the organization of the implementation of the Kyoto Protocol under the United Nations Framework Convention on Climate Change in the 2007 - 2010 period, Decision 130/2007/QÑ-TTg dated 2nd August 2007 on several financial mechanisms and policies applied to Clean Development Mechanism investment projects. To proactively respond to climate change, Viet Nam approved the National Target Program to Respond to Climate Change through Decision 158/2008/QÑ-TTg dated 2nd December 2008. The Program's strategic objectives are to assess climate change impacts on sectors and regions in specific periods and to develop feasible action plans to effectively respond to climate change in the short-term and long-term to ensure sustainable development of Vietnam, to take opportunities to develop towards a low-carbon economy, and to join the international community's efforts in mitigating climate change and protecting the climatic system.

The majority of emission factors used are default values taken from the Revised 1996 IPCC Guidelines. In addition, certain country-specific emission factors were also developed and used for the inventory, such as CH4 emission factor for rice paddies. It was estimated that the total amount of GHG emissions from agriculture was 65,090.7 thousand tonnes of CO2e. Rice cultivation emitted 37,430 thousand tonnes of CO2e, equal to 57.5%, agricultural soils mitted 14,220 thousand tonnes of CO2e, or 21.8%, enteric fermentation produced 7,731 thousand tonnes of CO2e, or 11.9%, and fertilizer management emitted 3,447 thousand tonnes of CO2e, or 5.3% of the total amount. However, reliable and synchronous data and information are sparse, and the data collection process is slow.

- The data collection system for greenhouse gas inventory is incomplete and there is a shortage of Ministry and sector-level GHG inventory technical experts.
- Research, assessment and verification for certain country-specific emission factors remains incomplete.

CLUES project is pioneered in carrying out baseline study on GHG emission from paddy rice in the Mekong river delta in order to have data for comparison with the GHG mitigation methods which will be developed later by scientists involved in this project while maintaining rice production at security level for country.

The Mekong river delta is the most important rice production of Vietnam having around 1.9 millions hectare of intensive rice farming with the intensity of 2-3 crops per annum. Up to now, information gaps have made it extremely difficult for scientists and policymakers to make strategic decisions regarding how to respond to climate change and has hampered efforts to mitigate agriculture's emissions, Data on emissions for agriculture, forests and other land use activities support member countries in better identifying their mitigation options and enable their farmers to take faster and more targeted climate-smart.

4 Objectives

Objective 6: Capacity Building for assessing GHG emissions

Act. 6.1: Establishing a laboratory for gas analysis and training of researchers at CLRRI
Act. 6.2: Training of researchers and students in flux sampling
Act. 6.3: Conducting flux measurements
Act. 6.4: Assessing gaseous C and N emissions for a comprehensive analysis of element cycling and budgets
Act. 6.5: Deriving emission factors and spreadsheet tools from field data for quantifying GHG emissions in rice systems of MDR

5 Methodology

Act. 6.1: Establishing a laboratory for gas analysis and training of researchers at CLRRI

A disused laboratory at CLRRI was selected for the established of a GHG laboratory. An SRI Greenhouse Gas GC chromatograph (Model SRI-GC 9650) and Air Conditioning was installed at the lab and was operation by October 2011. During installation technicians for SRI trained CLRRI in the operation of the instrument, gas handling and calibration. This was followed up by training for IRRI staff members again on the operation of the instrument, gas handling and calibration. Further training and trouble shooting of the instrument was done on a regular basis.

Act. 6.2: Training of researchers and students in flux sampling

4 formal classroom and field training workshops were held to train researchers and students in flux sampling. During the project informal training sessions were held by the project team. Once the CLRRI staff were trained they themselves trained others to set up and make flux measurements. To increase awareness of GHG emissions, climate change and emission mitigation 4 workshops were held in the target zones.

Act. 6.3: Conducting flux measurements

Greenhouse gas sampling and analysis procedures followed the static closed chamber method that is widely used to assess agricultural emissions. The chamber was made from plastic tank (1 mm thick)) and consisted of two parts:

1/ an anchor or base in tube shape (60 cm tall by 50 cm diameter) having ridge at top end for sealing chamber by water at time of sampling. This ridge was also served for levelling at time of anchor instalment into soil.

2/ a cone shape chamber with dimension of 65 cm tall by 50 cm base diameter and 37 cm top diameter. The anchor was inserted to a depth of 5 cm into the soil, leaving 55 cm above the surface. Two sleeve type -butyl rubber septum were fixed at one side of chamber for drawing gas from chamber and another was fixed at top for insertion of thermometer at sampling. 9V battery operated fan was installed inside top end of closed chamber to homogenise gas in chamber.

Anchors were installed at least 24 hours before sampling to avoid error due to soil disturbance at the minimum distance 2m from bund or levee. Gas samples were collected between 8 A.M. to 10 A.M. at 7 d intervals but only 1d interval at 3 consecutive days at fertilization time. Samples were collected during the same period in each day to reduce diurnal effect of temperature on GHG fluxes. Samples were collected at 0, 10, 20, and 30 min using a syringe and injected in evacuated 6 ml vials. Concentrations of N_2O, and CH_4 in gas samples inside the vials were determined with a gas chromatograph (Model SRI-GC 9650) in a laboratory.

Act. 6.4: Assessing gaseous C and N emissions for a comprehensive analysis of element cycling and budgets

Greenhouse gas emissions were measured from each of the 4 agro-ecological zones and examine the mitigation potential of AWD, tillage and residue management. Statistical analyses of data were performed by SAS 9.1 (SAS Institute, 1988). The effect of different plant density, rice varieties, soil tillage methods, water schemes, phosphate fertilizer season and crop rotations on CH_4 emission were examined by two-way ANOVA (proc glm). When the treatment effect was significant, difference in means were compared using the Duncan (alpha= 0·05) post-hoc test for multiple comparisons.

Act. 6.5: Deriving emission factors and spreadsheet tools from field data for quantifying GHG emissions in rice systems of MDR

A spreadsheet tool was developed to allow the calculation of gas emissions from the concentrations of the collected gas samples using linear regression. The spreadsheet tool corrects the data for pressure and temperature effects, instrument calibration and performs and assesses the linear regression. Emission factors were developed for each agro-ecological zone.

6 Achievements against activities and outputs/milestones

Activity 6.1: Establishing a lab for gas analysis and training of researchers at CLDRRI

No.	Activity	Outputs/ Milestones	Completion Date	Comments
1.1	Establishing a lab for gas analysis and training of researchers at CLRRI for GC operation, maintenance and use of PeakSimple software for GHG analysis	Routine operations for efficient gas analysis (incl. calibration and accuracy cross-checks)	30th September, 2011	-GC lab upgraded and equipped with air conditioner to maintain room temperature at 25^{0}C -7 researchers at CLRRI are able to operate GC for GHG analysis. -20KVA UPS was also installed for GC operation continuously. -Dehumidifier was equipped to maintain RH at 60%

PC = partner country, A = Australia

Activity 6.2: Training of researchers and students in flux sampling at all benchmark sites

2.1	Training of researchers and students in flux sampling at Hue University	1st training course for 2 researchers of CLRRI and 2 lecturers of CanTho University	4th June, 2011	3-day training course organised at Hue University
2.2	Training on GC principle and GHG analysis	2nd Training course for CLRRI, Can Tho University and An Giang, Vinh Long extension staffs	23rd -25th November, 2011	3 scientists from CLRRI and 14 from Cantho University will conducted experiments of Theme 3 at 4 benchmark sites
2.3	Training on Flux samplings by closed chamber method	3rd training course for students of An Giang , Cuu Long and Can Tho Universities	4-5th May, 2012	2-day training on closed chamber fabrication and flux sampling for 16 students
2.4	Flux samplings by closed chamber method	4th training course for 6 extension staffs of Tra Vinh province	16th November, 2012	CLUES project support GIZ Tra Vinh to evaluate GHG emission from paddy rice under SRI model and farmer routine practice method.
2.5	Flux samplings by closed chamber method	5th training course for 7 extension staffs of Long An province	7th March, 2013	CLUES project support WINROCK Long An to evaluate GHG emission from paddy rice under SRI model and farmer routine practice method
2.6	Workshops at Soc Trang, Vinh Long and An Giang on GHG emission from rice	79 extension workers participated	May-June 2014	Theme 6 in cooperation with the National project BĐKH.2014.57 on 'Rational use of acid soils for CC adptation' and Provincial Extension Center

Act. 6.3: Conducting flux measurements

No.	Activity	Outputs/ Milestones	Completion Date	Comments
3.1	Conducting intensive flux measurements at CLRRI to study effects of crop establishment on GHG emission	Baseline emission from Cantho site. Cultivation methods effects on GHG emission	WS 2012-2013	Cantho site (shallow flooded alluvial soil)
3.2	Conducting intensive flux measurements at CLRRI to study effects of water management, fertilizer/manure on GHG emission	Baseline emission from Cantho site. Water management, fertilizer/manure effects on GHG emission	WS 2012-2013	Water management on experimental plots could not be done properly in Mekong delta soil because of high percolation and leaching
3.3	Conducting intensive flux measurements at Hau Giang and An Giang	Baseline emission at An Giang and Hau Giang sites	SA 2013	Hau Giang (acid sulphate soil) and An Giang (deep flooded alluvial soil)
3.4	Conducting intensive flux measurements at Bac Lieu	Baseline emission at Bac Lieu	SA 2014	Lang Giai-Bac Lieu (salt infected soil)

Act. 6.4: Assessing gaseous C and N emissions for a comprehensive analysis of element cycling and budgets

No.	Activity	Outputs/ Milestones	Completion Date	Comments
4.1	Conducting intensive flux measurement on shrimp-rice cropping system at Bac Lieu	Baseline emission from saline soil at Bac Lieu	AW 2013	Phuoc Long-Bac Lieu (saline soil)
4.2	Conducting intensive flux measurements on SRI model at Tra Vinh province	Baseline emission at Tra Vinh	WS 2012-2013	Tieu Can and Cau Ke districts-Tra Vinh (alluvial soil)
4.3	Conducting intensive flux measurements on SRI model at Long An province	Baseline emission at Long An	SA 2014	Tan Thanh and Chau Thanh districts-LA (acid soil)
4.4	Conducting intensive flux measurement on cropping system at Cantho site	Baseline emission from R-R-R/R-Mungbean-R or R-R-R/R-Sesame-R	SA 2014	Thoi Lai district-Cantho (shallow flooded alluvial soil.
4.5	Conducting intensive flux measurement on maize at An Giang site	GHG emission from maize	SA 2014	

4.6	Conducting intensive flux measurements on SRI model at Long An province	Baseline emission at Long An	SA 2014	
4.7	Conducting intensive flux measurement on cropping system at Cantho site	Baseline emission from R-R-R/R-Mungbean-R or R-R-R/R-Sesame-R	SA 2014	
4.8	Conducting intensive flux measurement on maize at An Giang site	GHG emission from maize	SA 2014	

PC = partner country, A = Australia

Act. 6.5: Deriving emission factors and spreadsheet tools from field data for quantifying GHG emissions in rice systems of MDR

No.	Activity	Outputs/ Milestones	Completion Date	Comments
5.1	Calculation C&N cycling and budget for pilot study at Soc Trang	GHG emission and C&N budget at Soc Trang	Dec. 2014	MSc thesis from Can Tho University

7 Key results and discussion

7.1. Effects of Agronomic practices on CH_4 emission

7.1.1 Effects of rice variety and plant density from alluvial soils (CLRRI)

Studies on effects of cultivation methods on CH4 and N2O emission from paddy rice were carried out at CLRRI during 2012-2013. The first experiment was conducted in Winter-Spring (WS) 2012-2013 in which two varieties namely OM576 (V1) and Jasmine85 (V2) were transplanted at spacing of 15x15 cm (T1) and 20x20 cm (T2) or row seeding at rate of 100 kg/ha (S1) and 140 kg/ha (S2) . Fertilizers formula of 80-40-30 kg/ha for N-P_2O_5-K_2O respectively was applied for all treatments. Data presented in Figure 1 indicated that the higher rice density establishment either by transplanting (T1) or direct seeding (S2) had significantly higher CH_4 emission than wide spacing (T2&S1). Varietal difference in CH_4 emission was observed in this experiment in which Jasmine 85 emitted CH_4 higher than OM576 (Fig.1a&b) because methane emission varies with rice varieties (Adhya et al.,1994) probably because of morphological differences in the aerenchyma (Butterbachbahl et al., 1997) and root porosity (Singh S, et al., 1998).

Studies on effects of cultivation methods on CH_4 and N_2O emission from paddy rice were carried out in alluvial soil at CLRRI during Winter-Spring rice season (WS) 2012-2013. The first field experiment included 2 factors, in which first factor is rice varieties namely OM576 (V1) and Jasmine85 (V2) and second factor was transplanting density 15x15 cm (T1) and 20x20 cm (T2). The second field experiment also had 2 factors, in which first factor is rice varieties namely OM576 (V1) and Jasmine85 (V2) and second factor was seeding rate with 100 kg/ha (S1) and 140 kg/ha (S2). Both field experiment layout were split plot design with 4 treatments and 3 replications for each of treatment.

The fertilizer formula of 80-40-30 kg ha^{-1} for N-P_2O_5-K_2O was the same for all treatments and the rice was grown under a continuous flooded water management regime. There was no significant difference were found on cumulative CH_4 emission between two rice varieties V1 and V2, and two transplanting density T1 and T2, respectively (Fig. 1A). While V1 rice variety showed significant higher cumulative CH_4 emission than V2 rice variety (Fig. 1B) because methane emission varies with rice varieties (Adhya et al.,1994). This is due to morphological differences in the aerenchyma (Butterbachbahl et al., 1997) and root porosity (Singh S, et al., 1998).

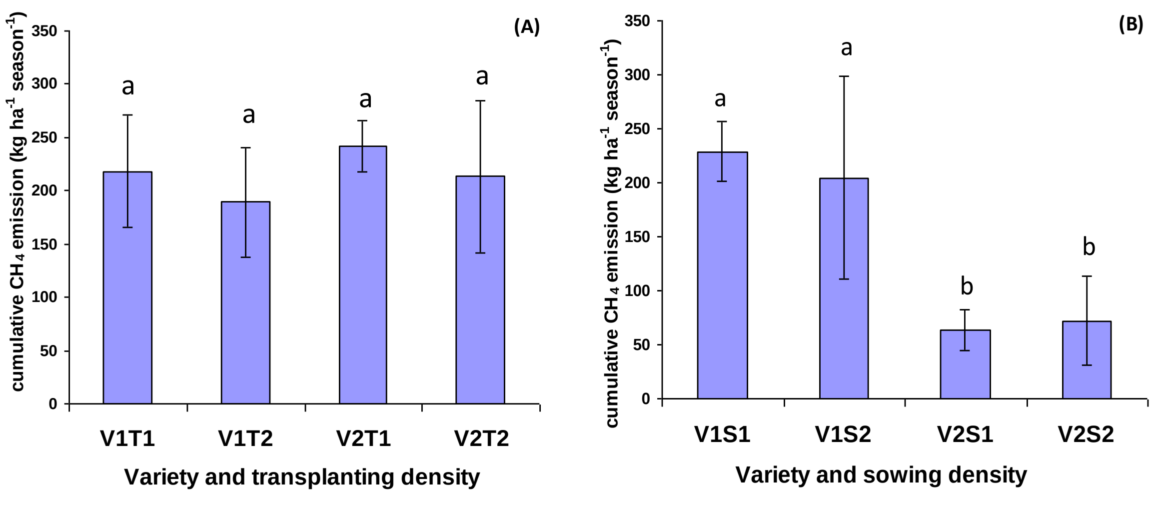


Fig.1(A) and 1(B): Effect of rice varieties and densities on CH_4 emission at CLRRI

7.1.2. Effects of soil tillage and water management from alluvial soils (CLRRI)

This study examined the effect of soil tillage methods (plowing and rotary tillage) and water management schemes (continuous flooding; CF, and alternative wetting and drying; AWD) on CH_4 emission from paddy rice. The field experiment layout were split plot design with 4 treatments and 3 replications for each of treatment.

In this study, soil ploughing treatment showed significant higher CH_4 emission compared to rotary tillage treatment, 329.0 and 170.4 kg ha^{-1} $season^{-1}$, respectively (table 1). At the CLRRI site AWD treatment (drainage at maximum tillering stage and after grain filling stage) induced significantly less CH_4 emission (54%) compared to CF treatment (Table 1). This is less than other studies which find that found that that methane emissions could be reduced around 85 % in AWD treatment as compare to CF (Tinh et al., 2014)

Table 1: Effect of soil tillage and water management on CH_4 emission (kg ha^{-1} $season^{-1}$) from paddy rice field in summer autumn rice season 2012

Water schemes	Soil tillage methods		Average of water schemes
	Ploughing	Rotary Tillage	
AWD	194.9 b	119.9 b	157.4 B
CF	463.2 a	220.9 b	342.1 A
Average of soil tillage methods	329.0 A	170.4 B	

Note: Different small letters indicate significance of treatments on interaction of water schemes and soil tillage methods ($p < 0.05$), different capital letters indicate significance of treatments on average of water schemes or average of soil tillage method ($p < 0.05$).

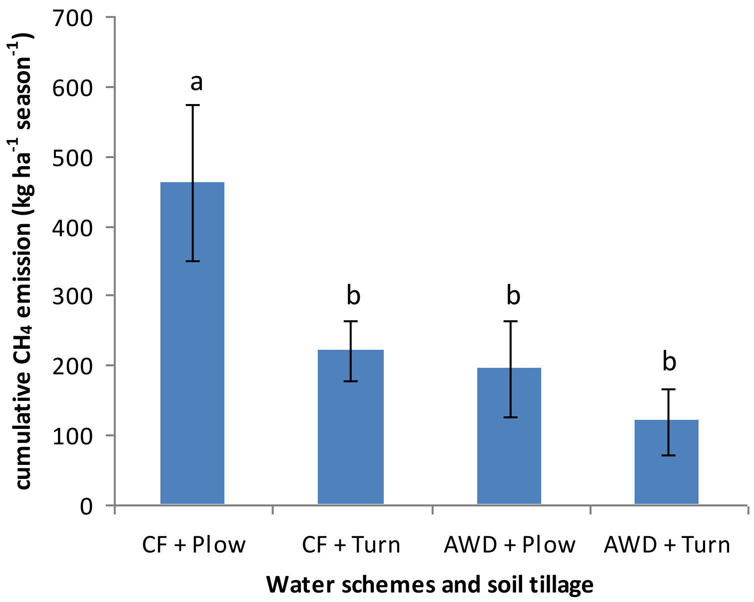


Figure 2: Effect of soil tillage and water management on CH_4 emission. Error bars indicate standard deviation (n=3). Different letters indicate significance ($p < 0.05$) of treatments in spring autumn rice season (2012).

7.1.3. Effects of straw and manure compost management from alluvial soils (CLRRI)

To maintain long term fertility of paddy soil it is recommended by CLRRI that 5-10 T/ha organic manure be added seasonally as an amendment. But organic fertilisers have been found to increase CH_4 emission from cropping soils. In WS 2012-2013 a field trial was monitored to quantify the effect of fertilisers and organic manure on the CH4 emission. The field layout was a random completed block design with 6 treatments which was replications 3 times. This resulted in 18 plots with size 30 m^2 (5 x 6 m) separated by soil embankments.

Treatments:

1 (F80): 80N : 40 P_2O_5 : 30 K_2O kg/ha
2 (F100): 100N : 40 P_2O_5 : 30 K_2O kg/ha
3. (Vermi-compot): Vermicompost 5 T/ha;
4. (Vermi-compost + F40): Vermicompost 2.5 T/ha+ 40N : 40 P_2O_5 : 30 K_2O kg/ha
5. (Straw-compost): straw compost 5T/ha
6. (Straw-compost + F40): Straw compost 2.5 T/ha+ 40N : 40 P_2O_5 : 30 K_2O kg/ha

The CH_4 emission were lowest in treatment amended inorganic fertilizer (F80) and highest in treatment amended vermin-compost with inorganic fertilizer (Vermi-compost + F40; Figure 3).

The combined amendment of vermicompost and inorganic fertilizer showed significant higher CH_4 emission compared to amendment of inorganic fertilisers (F80; F100), straw compost and vermi-compost only, 560kg, 254kg, 372kg, 365kg and 372kg ha^{-1} $season^{-1}$, respectively.

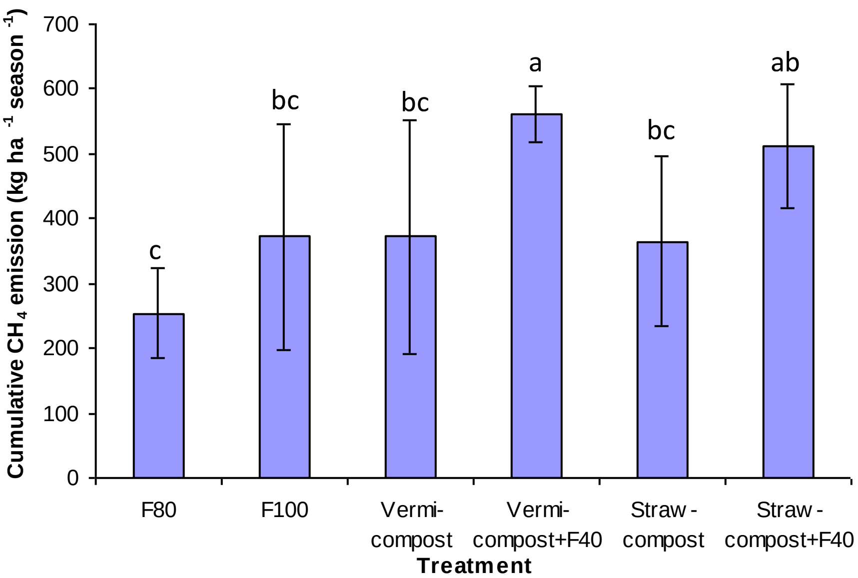
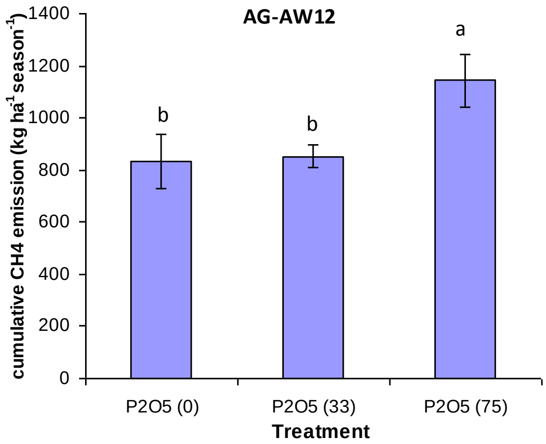
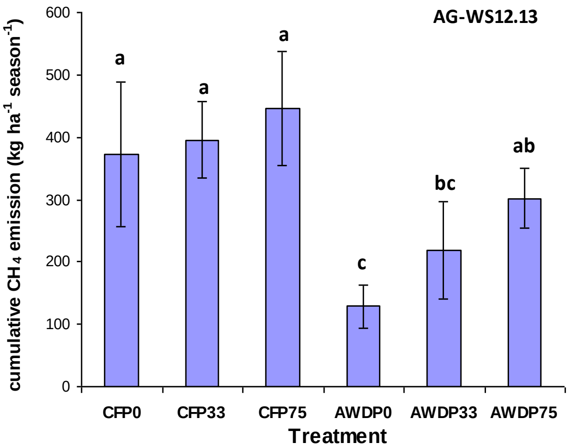


Figure 3: Effects of in-organic fertilisers, straw compost and vermi-compost on CH_4 emission from Summer Autumn rice season (2013) in CLRRI, Can Tho. Error bars indicate standard deviation (n=3). Different letters indicate significance ($p < 0.05$) of treatments. Error bar are standard deviations.

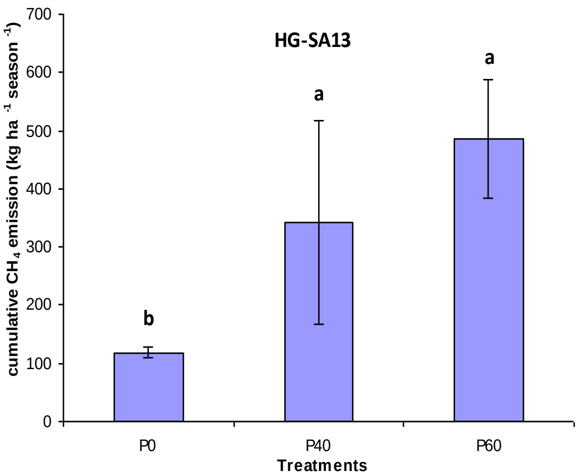
7.1.4 The effect of water and phosphorus fertilizer management on CH_4 emission

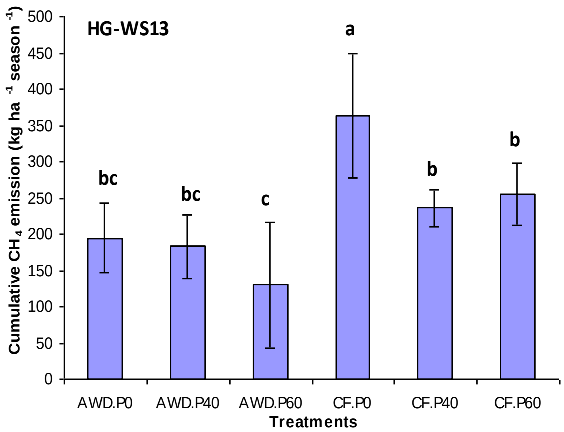
An Giang



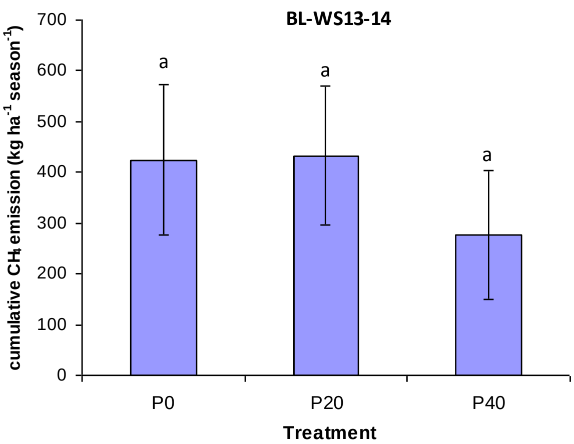


Hau Giang





Bac Lieu



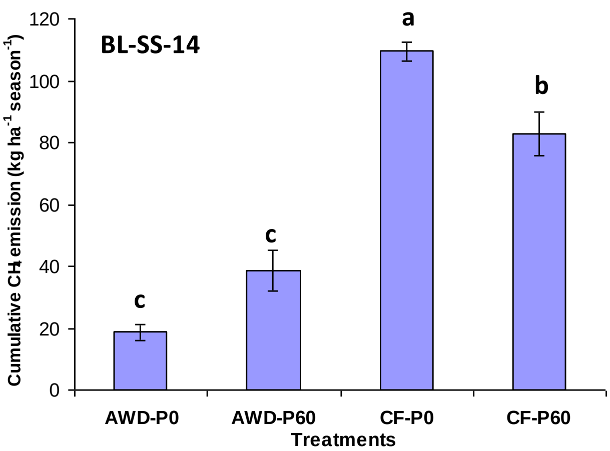


Figure 4: The effect of water and phosphorus fertilizer management on CH_4 emission. Error bars indicate standard deviation (n=3). Different letters indicate significance ($p < 0.05$) of treatments.

The series of field experiments were conducted in An Giang (alluvisol), Hau Giang (acid sulphate soil) and Bac Lieu (saline soil) to investigated the effect of phosphate fertilizer and water schemes on CH_4 emission from paddy rice field. The results showed that CH_4 emission was significant lower in AWD treatment compared to CF treatment in three study sites in An Giang, Hau Giang and Bac Lieu. CH_4 emission was increasing with increasing amount of phosphorus fertilizer in both An Giang (fig 4a) and Hau Giang (fig 4c). While the CH_4 emission difference among phosphorus fertilizer doses were not significant.

7.1.5 The effect of upland cropping on GHG emissions relative to rice-based systems

Though Viet Nam is the one of the world's top rice exporters, many of its farmers remain poor. The Vietnamese government has recently advocated that farmers should include upland crops within the rice rotation cropping system to improve profitability. Upland crops have a better water use efficiency compared to rice production and will be a suitable adaptation to climate change induced water shortages during the dry season. Dryland cropping will also reduce the emission of methane.

Methane fluxes were reduced 47% under mungbean as compare to rice in SS2013 at CLRRI (Fig. 5a). However, CH_4 emissions of rice field after mungbean could also reduced up to 81%. The over all CH_4 significant reduction in mungbean-rice system were 71% comparison to rice-rice system.

The beneficial effect of upland crop on CH4 mitigation was also extended to SA rice crop after sesame. CH4 emissions of rice field from sesame-rice system could also significantly reduced up to 63 % compared to it in rice-rice system. The over all CH4 significant reduction in mungbean-rice system were 49 % comparison to rice-rice system (Fig. 5b).

(a) (b)

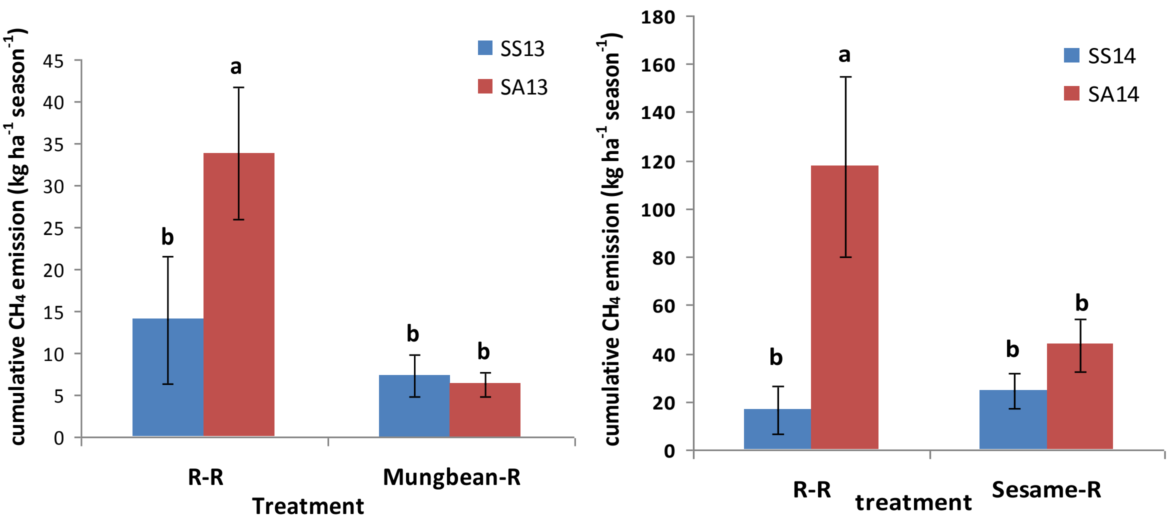


Figure 5: CH_4 emission as affected by cropping system at Cantho in SS 2013 (a) and 2014 (b). Error bars indicate standard deviation (n=3). Different letters indicate significance ($p < 0.05$) of treatments.

Soybean in rotation with rice reduced CH_4 emission around 76 % at Lang Giai-Bac Lieu in WS crop 2014 (Fig.6a). CH_4 emission was further reduced to 97 % when maize was introduced into rice based cropping system at Dinh Thanh-An Giang in SA 2014 crop (Fig.6b).

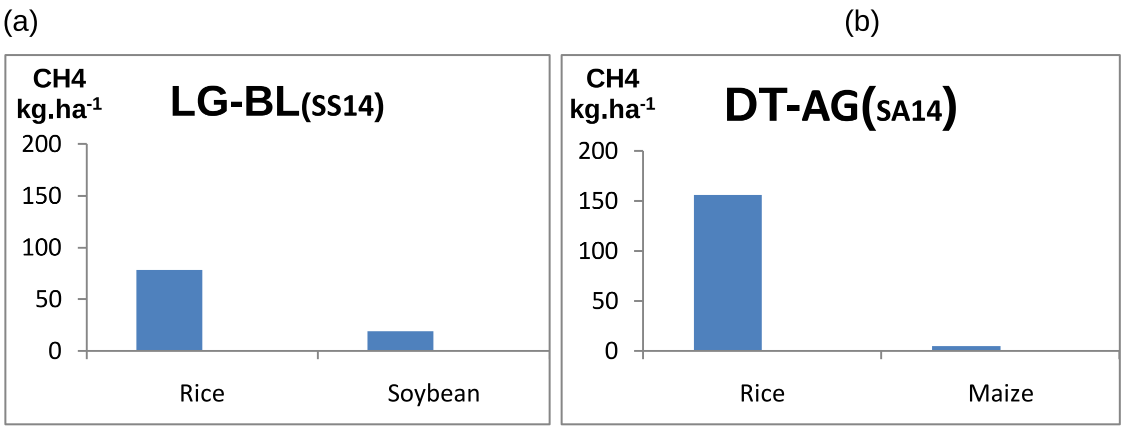


Figure 6: CH_4 emission as affected by cropping system at Lang Giai-Bac Lieu in WS2014 Fig.6 (a) and Dinh Thanh-An giang in SA 2014, Fig.6 (b).

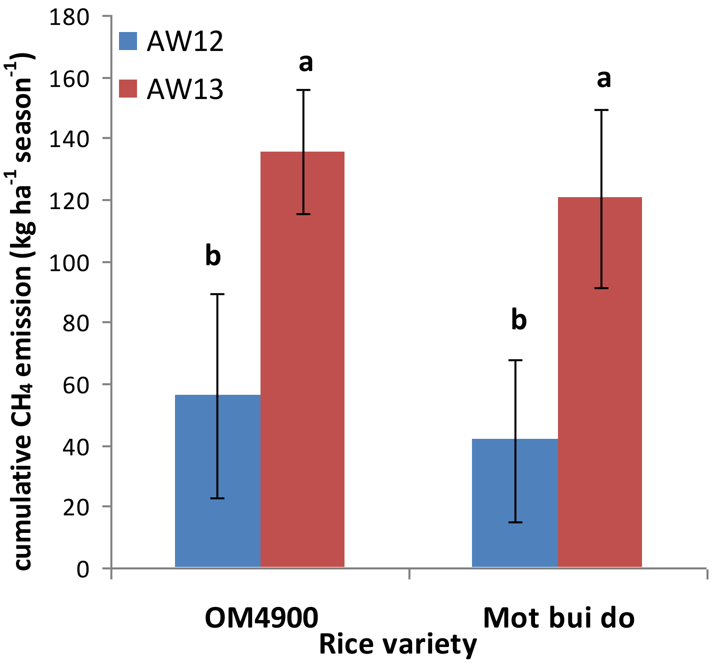


Figure 7: CH_4 emissions on saline soil as affected by rice varieties at Phuoc Long-Bac Lieu.

Error bars indicate standard deviation (n=3). Different letters indicate significance ($p < 0.05$) of treatments.

CH_4 emissions were also studied on rice-shrimp system under saline soil condition at Phuoc Long district-Bac Lieu province in Autumn-Winter 2012 (AW12) and Autumn-Winter 2013 (AW13). Improve rice varieties OM4900 and traditional rice Mot bui Do were cultivated on paddy with lime dosage of 2T/ha for soil reclaimation or without using lime. Results presented in Figure 7 showed that short duration rice variety OM4900 emitted similar CH_4 as traditional variety (Mot bui do) in both AW12 and AW 13 rice season.

7.2. Baseline GHG emissions studies at 4 benchmark sites

The site at An Giang province is charaterised by alluvial soils which are flooded from July to October. To protect the fields flood control have been constructed but the fields inside the dykes are regularly suffer from stagnant water. Stagnant flooding often occurs to a depth of 60 cm because of high rainfall and high water level in rivers and canals during July-October. A field trail was established to quantify the effect of P rates (P0 = 0, P1 = 32.5 and P2 = 75 kg P_2O_5/ha) and water management methods by AWD (draining out at maximum tillering stage and completely 10 days before harvesting) and by CF (continous flooding at 5 cm water depth). The CH_4 emission was significantly highest during flooding time 943 kg/ha (AW2012) then it was lower down to 404 kg/ha for WS 2012-2013 and finally only 24 kg/ha for SA 2013 (table 2).

In An Giang study site, CH4 was significantly higher in P_2O_5 (75) treatment than it in P_2O_5 (0) and P_2O_5 (33) treatments in AW12 rice season, 534 kg, 407 kg and 430 kg CH_4 ha^{-1} $season^{-1}$, respectively (table 2). A significant interaction was found between AW12 rice season and highest phosphate fertilizer dose (75kg P_2O_5 ha^{-1}) resulting in significantly highest CH4 emission in P_2O_5 (75) treatment compared to the rest treatments at all rice seasons (Fig 8).

Table 2: The effect of phosphate fertilizer and seasonal variation on methane emissions at An Giang

Phosphate fert dose	Seasons			Average of phosphate fert dose
	AW12	SA13	WS13	
P_2O_5 (0)	835.5 b	14.4 d	373.2 c	407.7 B
P_2O_5 (33)	851.9 b	44.2 d	395.2 c	430.4 B
P_2O_5 (75)	1143.0 a	14.4 d	446.0 c	534.5 A
Average of season	943.5 A	24.3 C	404.8 B	

Note: Different small letters indicate significance of treatments on interaction of season and phosphate fertilizer dose ($p < 0.05$), different capital letters indicate significance of treatments on average of season or average of phosphate fertilizer dose ($p < 0.05$).

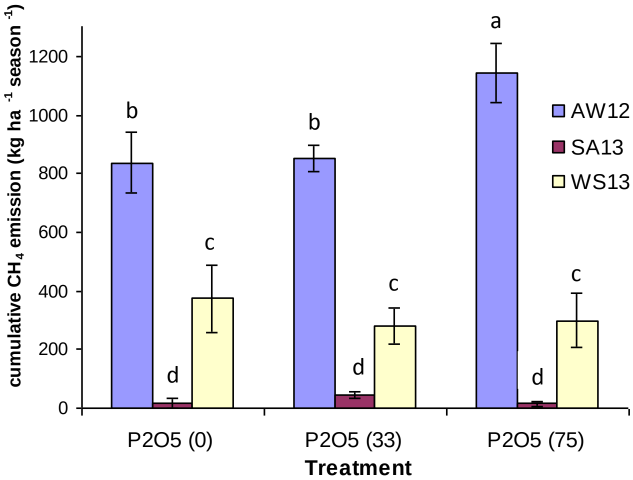


Fig 8: The effect of phosphate fertilizer dose and seasonal variation on methane emissions at An Giang. Error bars indicate standard deviation (n=3). Different letters indicate significance ($p < 0.05$) of treatments.

CH_4 emissions of two sucessive crops at Hau Giang were presented in table 3 where there was no significant different on cumulative CH4 emission between SA 13 and WS 13 rice season. Treatment amended 60 kg P_2O_5 ha^{-1} showed significant higher cumulative CH_4 emission compared to treatment without phosphate fertilizer amendment, 370 kg and 241 kg CH_4 ha^{-1} $season^{-1}$ (Fig 9).

Table 3: The effect of phosphate fertilizer and seasonal variation on methane emissions at Hau Giang.

Phosphate fert dose	Seasons		Average of phosphate fert dose
	SA13	WS13	
P_2O_5 (0)	117.8 c	363.3 ab	240.5 B
P_2O_5 (40)	342.0 ab	236.1 bc	289.1 AB
P_2O_5 (60)	485.2 a	255.2 bc	370.2 A
Average of season	315.0 A	284.9 A	

Note: Different small letters indicate significance of treatments on interaction of season and phosphate fertilizer dose ($p < 0.05$), different capital letters indicate significance of treatments on average of season or average of phosphate fertilizer dose ($p < 0.05$).

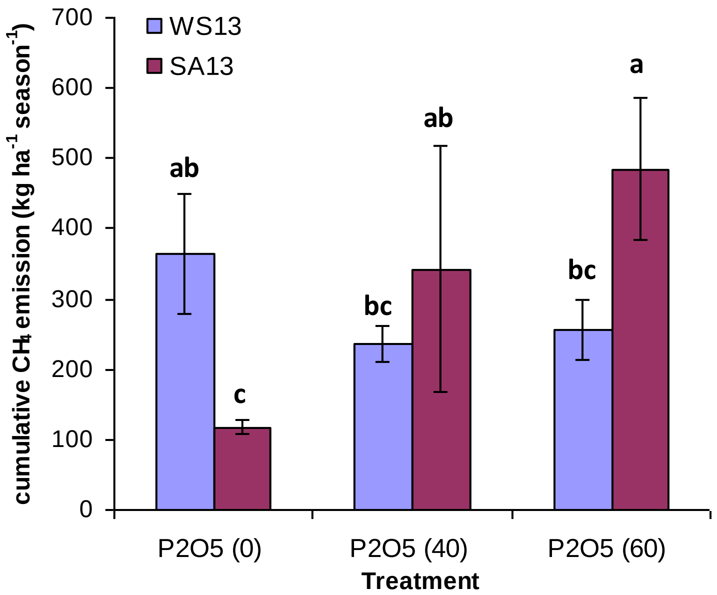


Figure 9: The effect of phosphate fertilizer dose and seasonal variation on methane emissions at Hau Giang. Error bars indicate standard deviation (n=3). Different letters indicate significance ($p < 0.05$) of treatments.

Experiments to study effects of P rates on rice yield and GHG emissions were conducted at Lang Giai-Bac Lieu site on 2013 Winter Spring rice season (WS13) and 2014 Spring Summer rice season (SS14) . Results showed that cumulative CH4 emission was significantly higher in WS13 than it in SS14, 330kg and 86 kg CH_4 ha^{-1} $season^{-1}$, respectively. P rates did not caused any significant difference on CH_4 emissions among treatments, 259kg and 157kg CH_4 ha^{-1} $season^{-1}$ (table 4).

Interaction between season and phosphate fertilizer dose was significance ($p<0.05$). Treatment amended zero phosphate fertilizer in WS13 showed significantly highest CH_4 emission compared to other treatments (Fig. 10).

Table 4: The effect of phosphate fertilizer and seasonal variation on methane emissions at Bac Lieu.

Phosphate fert dose	Seasons		Average of phosphate fert dose
	WS13	SS14	
P_2O_5 (0)	421.2 a	97.6 b	259.4 A
P_2O_5 (60)	239.7 b	74.5 b	157.1 A
Average of season	330.4 A	86.1 B	

Note: Different small letters indicate significance of treatments on interaction of season and phosphate fertilizer dose ($p < 0.05$), different capital letters indicate significance of treatments on average of season or average of phosphate fertilizer dose ($p < 0.05$).

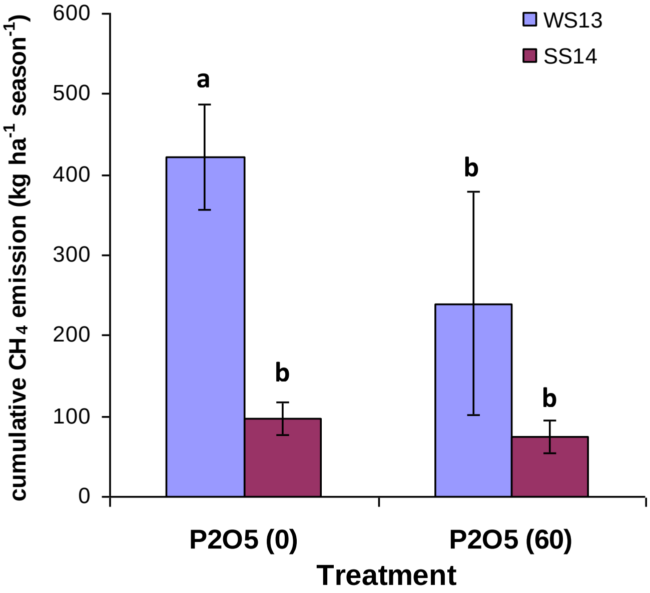


Figure 10: The effect of phosphate fertilizer dose and seasonal variation on methane emissions at An Giang. Error bars indicate standard deviation (n=3). Different letters indicate significance ($p < 0.05$) of treatments.

7.2. Effects of Agronomic practices on N_2O emission

7.2.1 Effects of straw and manure compost management from alluvial soils (CLRRI)

In WS 2012-2013 a field trial was monitored to quantify the effect of fertilisers and organic manure on the N_2O emission in CLRRI (Can Tho). The detail field layout and treatments description were described in 7.1.3. The N_2O emission was lowest in treatment amended vermin-compost only and highest in treatment amended straw compost plus inorganic fertilizer. The combined amendment of vermicompost or straw-compost with inorganic fertilizer showed significant higher N_2O emission compared to amendment of vermi-compost or straw compost only.

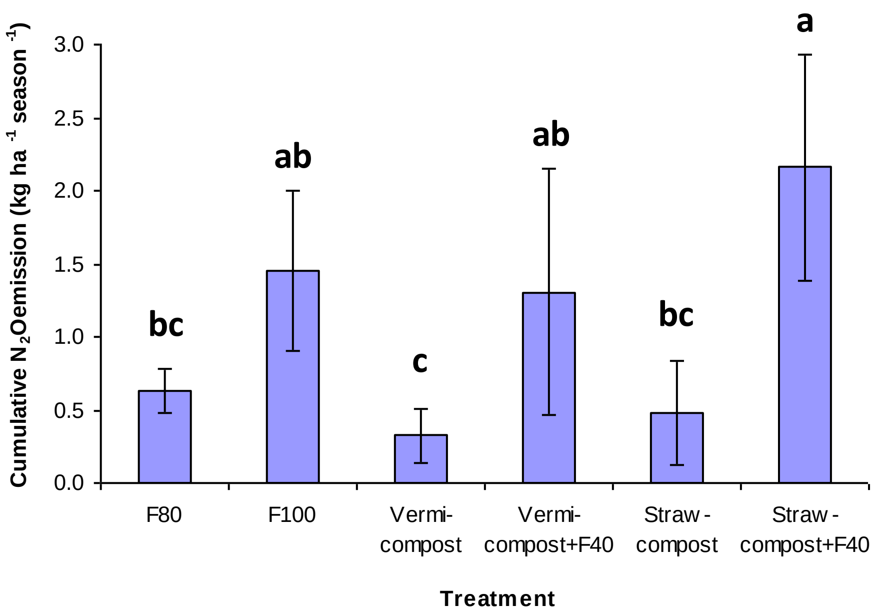
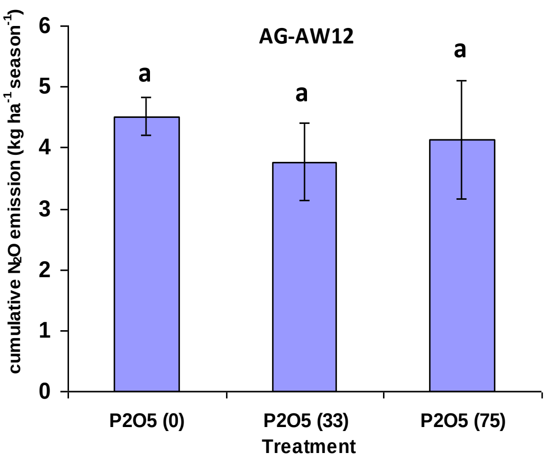
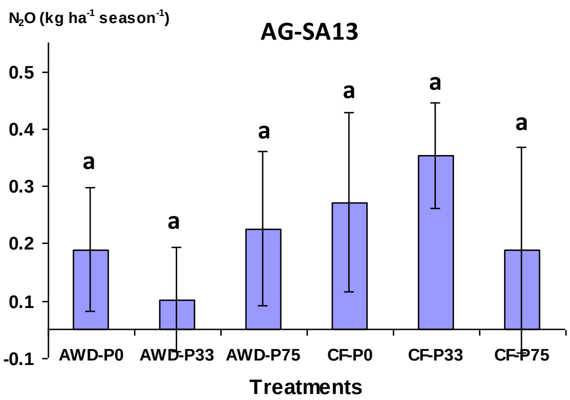


Figure 11: Effects of in-organic fertilisers, straw compost and vermi-compost on N_2O emission from Summer Autumn rice season (2013) in CLRRI (Can Tho). Error bars indicate standard deviation (n=3). Different letters indicate significance ($p < 0.05$) of treatments.

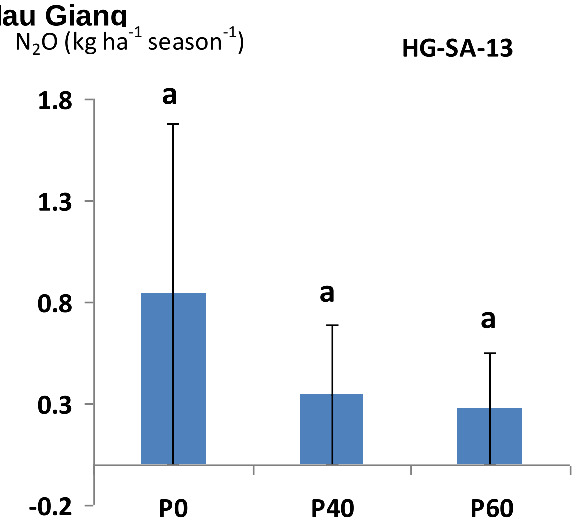
7.2.2 The effect of water and phosphorus fertilizer management on N_2O emission

An Giang





Hau Giang



Bac Lieu

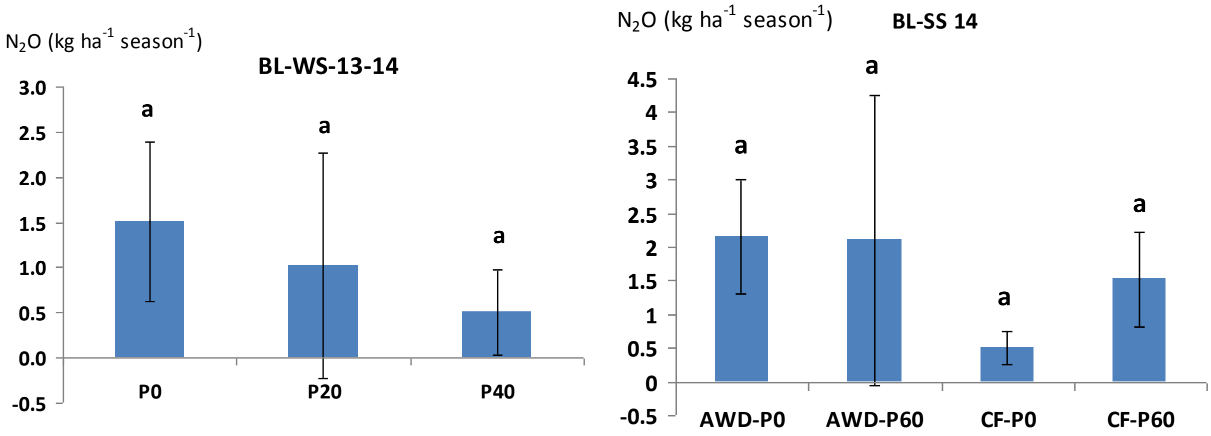


Figure 12: The effect of water and phosphorus fertilizer management on N_2O emission. Error bars indicate standard deviation (n=3). Different letters indicate significance ($p < 0.05$) of treatments.

The series of field experiments were conducted in An Giang (alluvisol), Hau Giang (acid sulphate soil) and Bac Lieu (saline soil) to investigated the effect of phosphate fertilizer and water schemes on N_2O emission from paddy rice field. The results showed that cumulated N_2O emission varied from 0.1 to 4.5 kg N_2O ha^{-1} $season^{-1}$. There were no significant differences on N_2O emission among different phosphate fertilizer dose as well as between AWD and CF treatments.

7.2.3 The effect of upland cropping on GHG emissions relative to rice-based systems

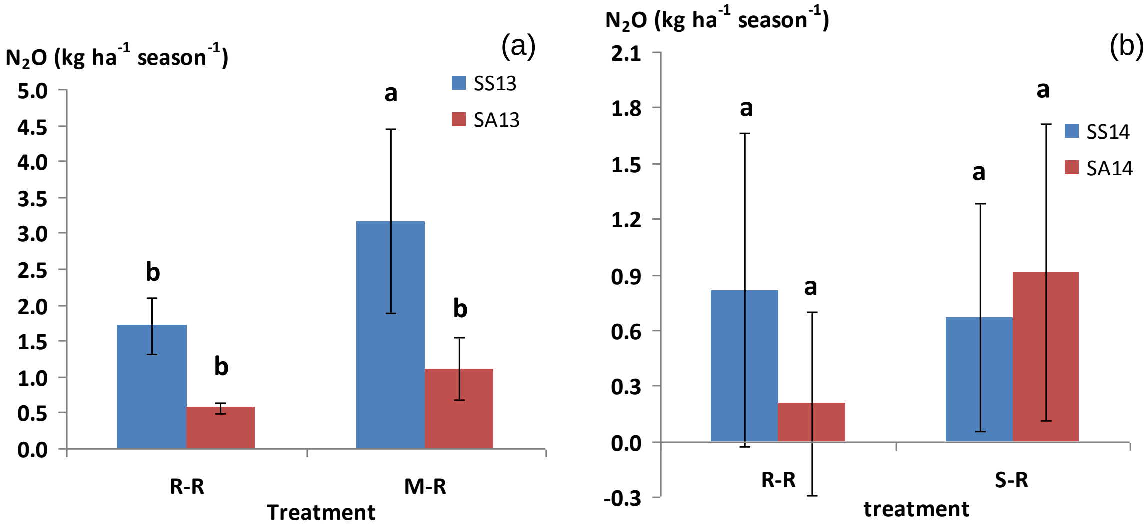


Figure 13: N_2O emission as affected by cropping system at CLRRI (Can Tho) in SS & SA 2013 (a) and at Thoi Lai (Can Tho) in SS & SA 2014 (b). Error bars indicate standard deviation (n=3). Different letters indicate significance ($p < 0.05$) of treatments.

N_2O fluxes significantly increased 85% under mungbean as compare to rice in SS2013 at CLRRI (Fig. 13a). While N_2O emissions not significantly increased in rice field after mungbean compared to rice in SA13 at CLRRI. The over all (SS13 + SA13) N_2O emission increased in mungbean-rice system were 88% comparison to rice-rice system.

There was not significant difference on N_2O emission between rice-rice system and sesame –rice system in both SS14 and SA14 at Can Tho study site (Fig. 13b).

8 Impacts

8.1 Scientific impacts – now and in 5 years

Over the past several years there has been significant investment in measuring GHG emissions from rice production system in Vietnam. A quick survey has shown there are at least 9 projects that have rice GHG measurement components on-going in Vietnam. These projects are collecting valuable data on impacts of various water, nitrogen, organic amendment and crop residues management on GHG emissions. Theme 6 –CLUES had cooperated with GIZ –Tra Vinh and WINROCK- Long An to measure GHG emission from paddies rice. Cantho University was supported by EDF and AusAID to carry out Vietnam Low Carbon Rice Project on at An Giang and Kien Giang province. Theme 6 was also participated 3 MRV workshops organised by the Institute of Agricultural Environment initially supported by WINROCK-Vietnam to formulate protocol/guidelines for study GHG emission from rice crop in Vietnam. GIZ-Bac Lieu had implemented AWD technique for rice cultivation to increase yied and GHG reduction. Numbers of Ph.D scholar from Cantho University who are carrying out thesis on GHG are increasing as well as numbers of publications. The Vietnamese has approved National Target Program on Climate Change Adaptation (NTPCCA) with the financial support around 2,000 billion VND in which CC mitigation will be studied to achieve committment of reduction 20 % GHG emission by 2020. Currently all study on GHG measurements in Vietnam use closed chamber for flux samplings as Theme 6 did.

8.2 Capacity impacts – now and in 5 years

GC-laboratory for GHG measurement has been set up at CLRRI under CLUES project. 8 researchers of Soil Science and Microbiology are capable of carrying out flux samplings by closed chamber method and measurement. Two Ph.D scholars of Cantho University are now conducting many experiments on GHG emissions from paddy rice. One MSc. student had been successfully completed his thesis on Carbon accumulation relating to methane and CO2 emissions from salt infected soil in Soc Trang province. Extension workers are quite aware of GHG emission after being trained and now they are actively directed low carbon rice production at Kien Giang, An Giang, Soc Trang, Tra Vinh, Long An and Vinh Long.

8.3 Community impacts – now and in 5 years

Climate change is being concerned in many provinces of the Mekong delta (MD). AWD technique and/or introduction upland crop (sesame, maize, mungbean) is campaigned to cope with water scarcity in Spring-Summer (SS) or early Summer crop to increase water use efficiency, reduce cost of rice production and GHG emission. Straw recycling as composting or biogas production has been extensively practiced by farmers thanks to straw collector besides its use in mushroom cultivation or feeding livestocks at CanTho, Long An, Kien Giang, Tra Vinh and Dong Thap province. Rice areas was reduced nearly 100,000 ha in Winter-Spring crop 2015 (Crop Department-MARD) in concordance with the restructuring agriculture to increase agricultural production efficiency. All the above reasons will definitely reduce GHG emission from paddy in the MD.

8.3.1 Economic impacts

AWD application in Winter-Spring crop could save 50 % irrigation cost and reduce 85 % methane emission as compare to CF (Tinh et al., 2014). Net profit in AWD was 350 USD higher than CF. Under the direction of MARD on restructuring agriculture to increase high profit for farmers, upland crops (maize, soybean, sesame...) are. Recent information of Thoi Lai district-Cantho city indicated that areas under sesame has expanded nearly 2 times from 800 to 1,500 ha simply because profit from sesame was much higher than rice (4-10 times).

8.3.2 Social impacts

By varying incomes from upland crops cultivation which will open up many opportunities for local people to have stable life at their homeland. They will not pour into city to find jobs which will produce chaotics in transportation and unsecure lives in industrial zones due to high population.

8.3.3 Environmental impacts

Recommendation of AWD for rice cultivation and introduction an upland crop in rotation with rice in SS crop to save water are salient features for CC adaptation. Reduction of GHG emission and molluscide pollution of soil and water resource are striking effects of AWD and upland crop.

8.4 Communication and dissemination activities

Data base of Theme 6 on GHG emission will be used in national MRV network. At least 3 journals will be published in 2015 on Effects of soil types, cultivation methods and cropping system on methane and nitrous oxide emission from paddy in the MD.

Act. 6.6:

Interacting with national agencies for GHG mitigation and inventories (e.g. Task Force for National Communication to UNFCCC)

6.1	Institute of Agricultural Environment	Methane emission data from Mekong delta	March 2015	Baseline records from MD

9 Conclusions and recommendations

9.1 Conclusions

CH_4 emission

- In alluvial soils at CLRRI (Can Tho), for both rice varieties OM576 (V1) and Jasmine85 (V2) there was no significant difference on cumulative CH_4 emission between the two transplanting densities T1 (15x15 cm) and T2 (20x20 cm), and also so for seeding rate with 100 kg/ha (S1) and 140 kg/ha (S2).
- In alluvial soils at in CLRRI (Can Tho) there was a significant difference between the soil tillage treatments, ploughing showed significant higher CH_4 emission compared to rotary tillage treatment, 329.0 and 170.4 kg ha^{-1} $season^{-1}$, respectively.
- In alluvial soils at CLRRI (Can Tho), the AWD treatment significantly reduced CH_4 emission (54%) compared to CF treatment
- In alluvial soils at CLRRI (Can Tho), the combined amendment of vermicompost and inorganic fertilizer showed significant higher CH_4 emission compared to amendment of inorganic fertilisers (F80; F100), straw compost and vermi-compost, 560kg, 254kg, 372kg, 365kg and 372kg ha^{-1} $season^{-1}$, respectively.
- CH_4 emission was significantly lower (46%, 40% and 70%) in AWD treatment compared to CF treatment in three study sites at An Giang, Hau Giang and Bac Lieu, respectively.
- CH_4 emission increased with increased amount of phosphorus fertilizer in both An Giang (flluvisol) and Hau Giang (acid sulphate soil). While there was no significant difference in the CH_4 emission between the phosphorus fertilizer doses at Bac Lieu study site (saline soil).
- Seasonal variations in methane emission were observed in the Mekong Delta. Methane emission from rice paddies were highest in Autumn-Winter and smallest in Summer-Autumn crop. Different soil types induced methane emission differently. Methane emissions increased in order deep flooded alluvial soil (An Giang)> shallow flooded alluvial soil (Cantho)> acid sulphate soil (Hau Giang)> saline soil (Bac Lieu, Ca Mau, Kien Giang).
- Introduction of upland crops into triple rice system reduced methane emission significantly. Mungbean or soybean reduced 75 % methane flux but sesame or maize could achieved up to 95 %. The beneficial effect of methane mitigation was also observed for sucessive rice crop on upland based about 30 %.

N_2O emission

- In alluvial soils at in CLRRI (Can Tho), the combined amendment of vermicompost or straw-compost with inorganic fertilizer showed significant higher N2O emission compared to amendment of vermi-compost or straw compost only.
- The cumulated N_2O emission varied from 0.1 to 4.5 kg N_2O ha^{-1} $season^{-1}$. There were no significant differences on N_2O emission among different phosphate fertilizer dose as well as between AWD and CF treatments in An Giang (alluvisol), Hau Giang (acid sulphate soil) and Bac Lieu (saline soil)
- The over all (SS13 + SA13) N2O emission increased in mungbean-rice system were 88% comparison to rice-rice system at CLRRI (Can Tho) study site. While there was

not significant difference on N2O emission between rice-rice system and sesame – rice system in both SS14 and SA14 at Thoi Lai (Can Tho) study site.

9.2 Recommendations

-AWD method is advisable to be applied on large scale to save water, increase benefit to farmers while reducing methane emission from rice cultivation.

-Sesame, maize, and legume crops are recommended to replace SS rice crop in triple rice system to save water and reduce methane emission from paddy.

10 References

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10.2 List of publications produced by project

-MSc dissertation of Cantho University by Ngo Thanh Cuong