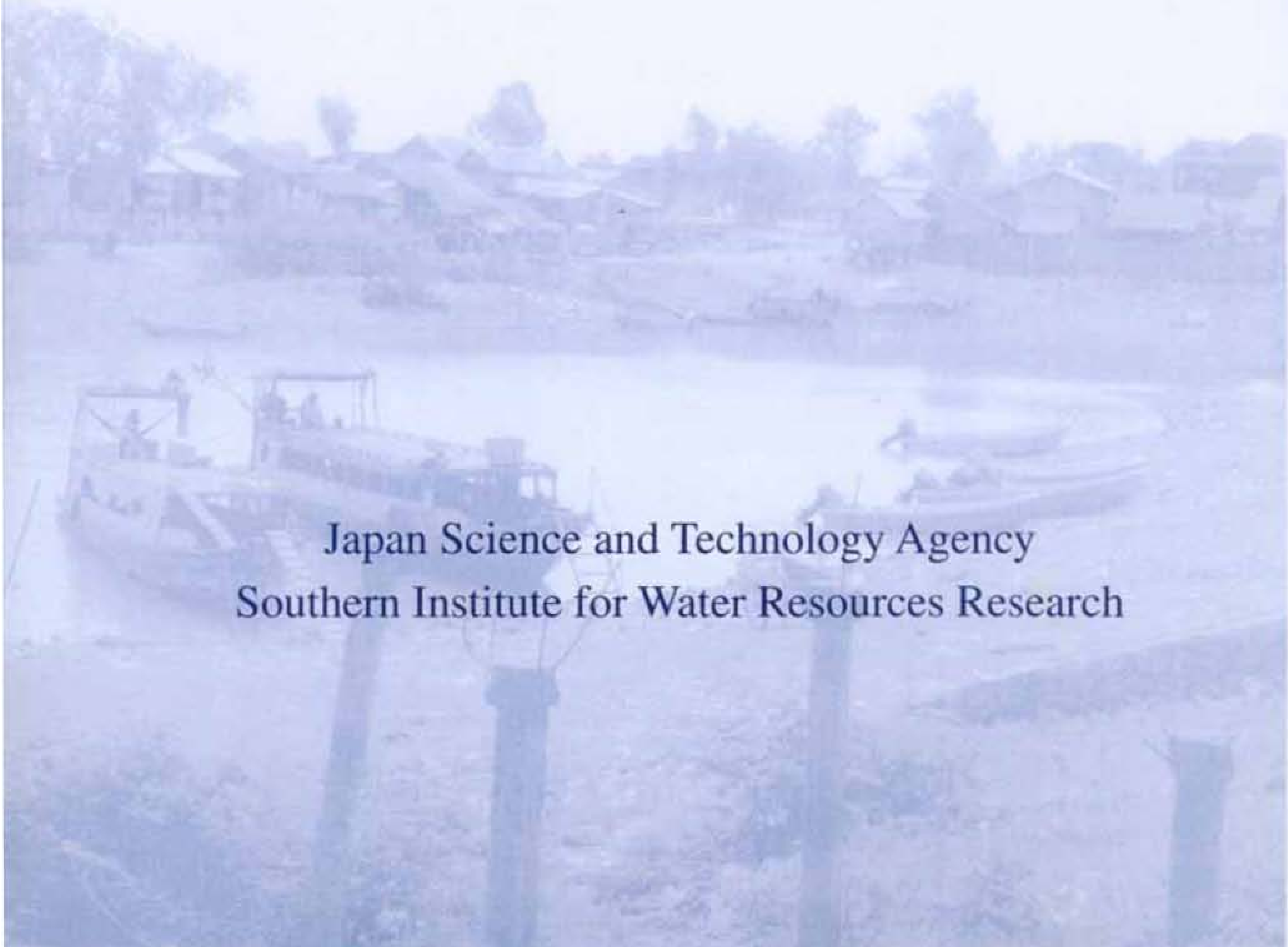
Proceedings of the International Symposium on Sustainable Development in the Mekong River Basin

Ho Chi Minh City
6th–7th October 2005



Japan Science and Technology Agency
Southern Institute for Water Resources Research

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A great deal of additional information on the Water Use and Management System of the Mekong River is available on the Internet.
It can be accessed through the website (http://mekong.job.affrc.go.jp/)

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Preface

The proceedings for the symposium of “Sustainable Development in the Mekong River Basin” have been collated to serve a number of important papers by the peoples working at basin development in the Mekong River Basin. These papers cover following themes of sustainable development.

1. Monitoring and Modeling of Water use and Management
2. Influence of Hydrological Cycle Change on Human Activity
3. Evaluation of the Influence of Water Use Change on Economic Development
4. Proposal for Sustainable Water Use System

The aim of the symposium is information exchanges about the Mekong Basin among riparian researchers, administrators and Japanese researches.

The symposium is organized by the JST (Japan Science and Technology Agency) CREST (Core Research for Environmental Science and Technology) research project, “Water Use and Management System of the Mekong River”. It is our great pleasure to have this symposium with the key note by CEO of MRC and heart full arrangement of the symposium hall by Southern Institute for Water Resources Research in Viet Nam.

I hope this symposium can contribute to improve the sustainable development and mutual understanding for direction for solutions of problems. The knowledge will give a useful guideline for sustainable development of the Mekong River Basin, now and in the future.

Hajime Tanji, Ph.D.
Chairman of the Organizing Committee for
The International Symposium on Sustainable Development in the Mekong River Basin

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A REGIONAL COOPERATION PROGRAMME FOR SUSTAINABLE WATER RESOURCES DEVELOPMENT OF THE MEKONG RIVER BASIN

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ABSTRACT

This paper will outline the Mekong River Commission's orientation to implement a programme for sustainable water resources development, which will help the region achieve the UN millennium goals of halving the poverty level by the year 2015 and improving the welfare of the Mekong Basin's people. It will discuss the potential for balanced and sustainable socio-economic development in the various water related sectors within the Lower Mekong Basin and explore how the MRC programmes, in conjunction with development partners, can make optimum use of the river's resources. The paper will highlight the challenges of dealing with trans-boundary issues, inter country cooperation and the need for inclusive dialogue with upstream partners. It will also examine available options for meeting the need to balance environmental, social and economic concerns using the tools available within the MRC.

BACKGROUND

The Lower Mekong River Basin (Cambodia, Lao PDR, Thailand and Viet Nam) is home to approximately 60 million people. There are over 100 different ethnic groups living within the basin's boundaries, making it one of the most culturally diverse regions of the world, but its people are also some of the poorest in the world, with many existing on less than one dollar per day. The population is also growing rapidly and is expected to reach between 80 and 100 million in the next 20 years.

In order to achieve the millennium goals of halving the poverty level by the year 2015 and improving the welfare of the Mekong Basin's people, it is vital to make optimum and sustainable use of the basin's biggest resource – its water. Tens of millions of people in the Mekong Basin rely on the waters of the river system to provide them with their primary source of nutrition and as well their livelihood.

Sustainable development of the economic potential of the Mekong river system for food, for power generation, for transportation and for tourism, is a key to fighting poverty and increasing people's welfare in the region. Today this development is still in its early stages and the water of the Mekong still offers an enormous untapped potential for balanced and sustainable water resources development, but this development must be approached with care.

Water resources development in a large, international river basin is not without risks and difficulties; but the MRC believes that the risks of non-development or of insufficient cooperation are even higher. More, but carefully planned developments and investments are needed in all water related sectors if escalating demands of the rapidly growing population are to be met.

In an increasingly global economy, to attain the goals of poverty alleviation and sustainable economic growth in the Mekong region, it is obligatory that regional integration and cooperation are of prime importance. Furthermore, since water does not recognise borders, it is also clear that for water related developments, regional cooperation at the scale of the whole basin is essential. Development in one country may have consequences in another country, and investments in one sector may affect other sectors. Therefore, there is a need for a joint water resources development programme at basin scale, owned and managed by the riparian countries themselves, in close cooperation with the donor community, investment institutions and civil society.

Since 5 April 1995 Cambodia, Lao PDR, Thailand and Viet Nam have been working together to promote and co-ordinate sustainable management and development of water and related resources in the Mekong Basin.

Subsequently the MRC has set up a dialogue mechanism with the two upstream countries: China and Myanmar.

STATUS OF THE WATER RESOURCES

The water resources of the Lower Mekong Basin are described in some detail in the MRC State of the Basin Report (MRC 2003). In strategic terms, important characteristics of Mekong water resources include the following:

- Abundance: Annual runoff averages around 475 km^3/year. Per capita resources currently stand at over 8500 m^3/person/year – compared with 2200 for the Nile; 1400 for the Rhine; 2265 for the Yangtze and 1700-4000 for the Ganges (WRI, 2003).
- Low consumptive use: Average annual withdrawals are estimated at around 60,000 million m^3, or 12% of total annual flows; the total volume of regulated storage in the basin (including the Upper Basin) for hydropower and irrigation is less than 20,000 million m^3 (less than 5% of annual flows); the per capita volume of water stored in the Lower Mekong Basin is estimated to be 230 m^3 per person, which is about nine times less than that of China (and 25 times less compared to the US (5800 m^3 per capita).
- High dependence on in-stream uses (particularly by the poor): The Mekong fishery is one of the largest inland fisheries in the world, estimated to be worth at least $US 2,000 million annually, and providing the major protein source for many people in the basin. Inland navigation is an important mode of transport for many areas where road access is limited
- Extreme seasonality: In most parts of the Basin, flows in the driest three months constitute less than 10% of total annual flows; while flows in the wettest three months make up over 50% of total annual flows (MRC DSF).
- Importance of the flood pulse for the ecology of the floodplain and the Mekong fishery: During the wet season, between 1 and 4 million hectares of floodplain are submerged, including the Tonle Sap Great Lake.
- Dry season water shortages: Dry season shortages occur as a result of the rainfall seasonality, concentration of extractions in the driest period and drought events during the onset of the wet season.
- Water quality: Water quality in the mainstream is generally good, and is rarely a constraint to water use. The exception is saline intrusion, acid sulphate drainage and pollution in intensively used areas of the Mekong Delta

A BASIN-WIDE DEVELOPMENT PROGRAMME

As an international river basin organisation, the MRC has identified four main roles it can play in the region:

- Development and investment facilitation
- Provision of a regional cooperation framework
- Environmental monitoring and protection
- Knowledge management and capacity development

During the past 10 years, with strong support from the international donor community, MRC has made considerable progress in implementing its 1995 agreement. It has achieved an impressive amount of work in terms of knowledge generation and dissemination, capacity building and development of powerful planning tools. Much of this has helped the member countries in their own strategies. MRC is now promoting a basin-wide development programme aiming at facilitating investments, both structural and non-structural, based on collaborative planning of win-win solutions at basin scale. It is important that such a development programme is owned and managed by the Mekong countries themselves, in close cooperation with the donor community, investment institutions and civil society.

The MRC is currently preparing its Strategic Plan 2006 – 2010, addressing in a holistic way the development needs in the areas of navigation, flood management, fisheries, irrigation, hydropower, environment management, watershed management, tourism, and capacity development. The orientation of the MRC Programme is to implement Integrated Water Resources Management (IWRM) at basin scale as a means to alleviate poverty and to enhance economic growth in the scope of the millennium goals.

The concept of Integrated Water Resources Development and Management is not new and has been promoted during the Earth Summit held in Rio De Janeiro in 1992. Later, the Global Water Partnership (GWP) defined IWRM as: “a process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.” This approach allows for a holistic view of the needs and interests of the countries sharing the river system. With this approach, the MRC believes a well-balanced, equitable and sustainable development process can be facilitated — for the mutual benefit of all Mekong riparian countries.

The MRC Programme focuses specifically on water resources, and can be seen as a contribution to the Greater Mekong Subregion Economic Cooperation Programme (GMS), promoted by the Asian Development Bank. The MRC programme is also enhanced by other regional initiatives such as the ASEAN Mekong Basin Development Cooperation, and the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP).

Joint planning, management and coordination of the MRC Programme is achieved in close cooperation with the National Mekong Committees (NMC) and the line agencies of the member countries. The role of the MRC, as an intergovernmental body, is to facilitate coordinated and balanced investments in the basin by supporting the countries at the level of strategic planning and programme implementation.

The MRC is now working to identify, plan and prioritise a broader range of development projects in cooperation with the donor community, investment institutions, and the civil society. MRC's role in the development process, as an International River Basin Organisation (RBO) owned by its member countries, is complementary to the role of investment banks and it plans to act as a promoter and facilitator of the development and investment process in the water sector in the region, encouraging and coordinating sustainable use and management of water and related resources for navigation, food production, energy production and domestic use.

The MRC Regional Cooperation Programme for Sustainable Water Resources Development of the Mekong River Basin is structured in the following sub-programmes:

- Basin Development Planning
- Water Use Management
- Environment Management
- Flood Management and Mitigation
- Navigation
- Fisheries
- Hydropower
- Agriculture, Irrigation and Forestry
- Tourism
- Integrated Capacity Building
- Information Management and Decision Support

The sub-programmes are further subdivided into priority subject areas or components under which the MRC projects will be implemented.

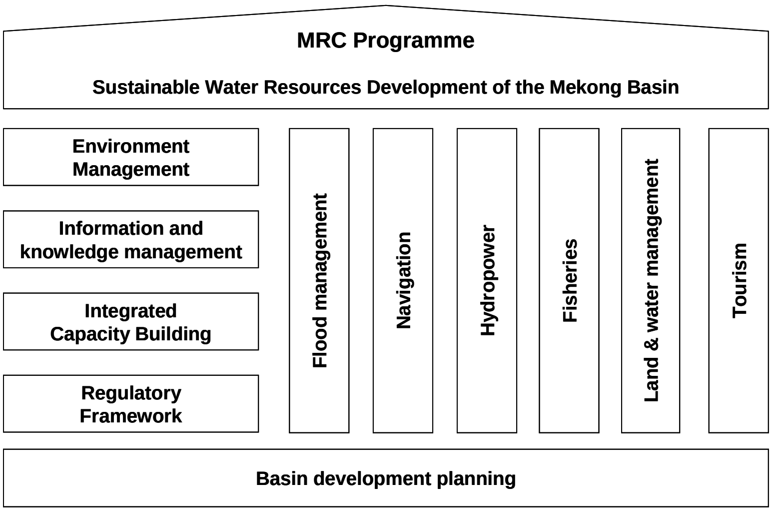

Figure 1. The Mekong River Commission's Programme Structure.

WATER FOR FOOD

Agriculture is still the dominant economic activity in the Lower Mekong Basin. It accounts for between 20% (in NE Thailand) and 52% (in Lao PDR) of GDP, providing food for 300 million people in the world. It provides livelihoods for around 75% of the LMB population and is an important source of export income. Irrigation is an integral part of the agricultural production systems. Wet season irrigation helps to secure the rice crop and dry season irrigation allows a second (sometimes third) crop and is increasingly important in the production of high value vegetables, fruit and industrial crops. As populations in the region are growing rapidly, irrigation is vital to food security as well as economic development. Thailand and Vietnam have already developed a substantial proportion of their irrigable land and water resources in the LMB.

There is still potential for expansion of irrigation, but more investment is also needed in the improvement of existing irrigation systems and management capacities aiming at increased irrigation efficiency and water productivity. During the wet season, water availability is far in excess of demand, but dry season water shortages are common, particularly in the Mun-Chi basin in Thailand and in the Delta region of Viet Nam, which is currently responsible for about 50% of that country's total food production. Intrusion of seawater into the Delta is becoming more and more an issue of concern, reducing the potential for irrigated rice production.

Table 1. Importance of agriculture to LMB economies (2002).

Country	Share of agriculture in GDP[a]	Growth in agricultural production[b]	Growth in agricultural value added[d]	Share of labour force in agriculture[e]	Net agricultural exports[f]
	% (2003)	% per year (2003)	% per year (2002)	% (2001)	US$ millions
Cambodia	37.2	9.8 (1.9)[c]	1.8	70	-282.1
Lao PDR	48.6	2.2	4.3	76	-41.1
Thailand	9.8	6.8	4.4	56	4,499.70
Viet Nam	21.8	3.3	3.0	67	966.7

Sources: a,b/ ADB (2004); c/ National Institute of Statistics, Cambodia; d/ ADB, 2003; e/ FAO; f/ FAO

(negative numbers indicate imports)

The MRC is monitoring land use changes in the four member countries, identifying problems and implementing technical surveys of irrigation practices to improve efficiency.

The Lower Mekong fishery is one of the most productive inland fisheries in the world, estimated at around three million tonnes per year, with a total value of around $US 2 billion. The basin provides a wide variety of breeding habitats for over 1300 species of fish, but this precious resource is under stress both from over-fishing and from an increasing population. The MRC programme incorporates strategies to manage the productive Mekong fisheries so as to sustain their high yield and economic output well into the future, through research and training; assessment of catches; aquaculture of indigenous species and management of river and reservoir fisheries

WATER FOR TRANSPORT AND TRADE

The Mekong River is an important gateway to trade centres in the Southeast Asia region and beyond. In 2001, trade valued at $4,700 million was transported throughout the LMB on the Mekong River and its tributaries, including the passage of an estimated $88 million of goods between Thailand and Yunnan. There are 25 major ports on the Mekong River and except for a 14 km stretch around the Khone Falls near the Lao-Cambodia border, almost the entire length of the river is navigable for nearly eight months of the year.

Flow regime exercises an important control on navigability, and changes in flow, either increases due to regulation or decreases due to diversions, will influence the viability of navigation. It is one of the MRC's prime mandates to promote freedom of navigation on the Mekong, and to increase social development and international trade opportunities using the navigation potential of the river system, however to fully realise the trade and transport potentials, a regional development approach is needed. Issues to be addressed include river navigation conditions;

ports; integration of navigation with other transport modes (particularly in the international context); physical and non-physical barriers to navigation; and environmental and safety concerns such as pollution.

WATER FOR POWER

The Lower Mekong River Basin has an estimated theoretical potential for hydropower development of about 30,000 MW (17,000 MW for the mainstream and 13,000 MW for the tributaries). However, only a small part of this potential has currently been developed (2000 MW or 7%). It is estimated that the hydropower potential of the Lancang basin (China) amounts to 23,000 MW, of which 13% (3,000 MW) is currently developed. Altogether, the Mekong Basin has an overall hydropower potential of 53,000 MW with an estimated development level of 9.4%.

Demand in the LMB is expected to grow by around 7% per year over the next 20 years, and there are substantial opportunities for trading of power between the countries in the region.

Hydropower options are included in the power development strategies of all the Mekong countries. There is thus still a large hydropower potential that could be developed in the Mekong region. Obstructions to meeting this potential include the lack of an effective regional transmission system, competition from other power sources, and resistance to hydropower development due to concerns about the impacts of dams on fish migration and the river flow regime.

Successful development of the region's hydropower potential will require a well-structured and integrated development programme.

Table 2. Energy in the LMB.

Country	Energy Demand 2000 (GWh)[1]	Electrification rate (%) in 2001[2]	Projected energy demand 2020 (GWh per year)[3]	Current installed capacity from all sources (MW)[4]	Hydropower Potential (GWh/year)[5]	Currently installed hydropower capacity (MW)[6]
Cambodia	381	4-80	5,700	143	36,300	11
Lao PDR	865	5-100	4,400	643.1	102,300	625.6
Thailand	96,781	802-100	328,000	22,888	26,100	2,936
Viet Nam	26,722	28-100	169,000	8,227	10,000	4,154
TOTAL	124,749	-	507,100	31,901.1	174,700	7,726.6

Notes: 1/ ADB, 2001; 2/ MRC, 1997; BDP, 2002; Meritec, 2004; MRC (2003b); 3/ ADB, 2001; 4/ MRC, 2001; 5/ MRC, 1997; 6/ MRC, 2001

WATER FOR RECREATION

The tourism industry is already making a significant contribution to the economies of the member countries. Being blessed with abundant historical and cultural heritage and unspoiled natural beauty, the Mekong River Basin has also a great potential to attract visitors from various parts of the world, generating more income from foreign exchange. Being a highly labour-intensive industry, tourism also plays a significant role in generating employment opportunities to localities where it is promoted, in a balanced manner, which also ensures necessary environmental protection.

THE NEED FOR PROTECTION

Floods are part of life in the Lower Mekong Basin. The annual flood pulse maintains the health of the fishery and the environment in general as well as being essential for irrigation. However floods also cause hundreds of deaths and millions of dollars worth of damage each year. In 2000, more than 800 people died, and the economic damage was assessed at more than US$400 million. In 2001, more than 300 people died, and the economic damage was assessed at more than US$100 million. Significant damages where also assessed in 2002. Sustainable development entails finding the balance between improving infrastructure and saving lives and possessions and maintaining the environmental benefits. As well as maintaining an accurate flood forecasting system and establishing an effective warning mechanism, The MRC has a strong role to play as a facilitator on trans-boundary issues regarding floods and flood protection.

As the population and infrastructure on the floodplain grows there is the potential for increasing loss of life and economic damage due to floods. Development of levees to protect crops and infrastructure as well as construction of elevated roads less subject to flood impact have the potential to unintentionally exacerbate flooding elsewhere in the floodplain. They can also block fish migration routes on the flood plain. To meet the requirements of a regional approach to flood management, the MRC has initated the development of a Regional Center for Flood Management and Mitigation in Phnom Penh, which is hosting the MTC Regional Flood Management and Mitigation Programme strongly supported by the donor community.

In terms of ecological health and water quality, the Lower Mekong Basin is in a fortunate position compared with similar river basins. With generally low levels of industrial activity in the basin at present, the two main immediate concerns about water quality are diffuse pollution due to poor catchment land management, and the potential for water quality emergencies arising from spillages or shipping accidents. Also in the Mekong Delta nutrient levels in the water are high and rising, presumably due to intensive agriculture and aquaculture and the wastewater produced by areas of high population density but this will soon change.

A fast-growing population, together with increased industrial and infrastructure development all place competing demands on resources. The MRC's Environment Programme is engaged in environmental monitoring and assessment programme, which, together with its work on environmental flow management, will provide environmental decision support for development options.

Deforestation is a significant environmental concern of all Mekong country governments. Concerns focus on the loss of biodiversity and livelihoods as the forests are cleared, as well as the potential impact of the land-use change on the rivers. The MRC is working to preserve the integrity of the watersheds of the four countries.

PLANNING AND DECISION-SUPPORT TOOLS

Integrated Water Resources Management and Development needs to be supported by databases and Geographical Information Systems (GIS) in order to store, analyze, and distribute hydro-meteorological data, land use data, socio-economic data, administrative data, infrastructure data, etc. Planning and decision-making require mathematical simulation models and Decision Support Systems (DSS). During the past five years, the MRC Secretariat has developed rich databases and powerful mathematical tools that will be updated through an effective international data management and exchange policy. The MRC now has a strong basin modelling and knowledge base and the ability to undertake environmental and trans-boundary analysis.

One of the MRC's objectives has been to strengthen the framework for trans-boundary environmental management by the four Lower Mekong Basin countries. The simulation tools allow for the analysis of a range of multi-sectoral development scenarios, which will help countries make informed decisions.

The scenarios are built up by describing:

- Available water resources, defined by the balance between the supply of water, determined mainly by climate, and current uses. Water use can be consumptive, as in irrigation, domestic and industrial use, or non-consumptive, as in fisheries and navigation.
- Trends that affect water use or availability, such as population growth, increased irrigation or climate change.
- Interventions, which may be physical - for example, dams, weirs and irrigation works - or non-physical, in the case of new management systems, tariffs, water use policies and laws.
- By looking at a range of scenarios, it is possible to build up a picture of how sensitive the river system is to particular types of change, and how different factors interact.

Scenario analysis is also being used to help countries reach agreement on how much water should be left in the Mekong in different places - the "minimum flow" that is mentioned in the 1995 Agreement on Cooperation for Sustainable Development of the Mekong Basin.

The outcomes of possible scenarios are evaluated using a combination of hydrological modelling, environmental and economic assessment tools and expert opinion. The basin models and Decision Support Framework (DSF) developed under the MRC's Water Utilisation Programme have been designed to give a detailed description of water availability and flows under different scenarios. When information about river flow is known, conclusions can then be drawn about how these will affect the environment and the communities that depend on natural resources.

The DSF includes three detailed simulation models; of the LMB subcatchments, the river network, and the unique floodplain system below Kratie (in Cambodia), including the Great Lake and Mekong Delta. These simulation models can provide detailed statistical information on the daily distribution of water anywhere in the land or rivers of the LMB, and salinity intrusion in the Mekong Delta for a period of up to 16 years.

One essential part of any development strategy is the people behind the planning. In the Mekong region, there is a strong need to develop the technical, institutional and legal water resources management capacity and expertise at various levels. The MRC is developing a regional training programme, involving a network of leading education and training institutions in the region and worldwide, which it expects to increase regional cooperation and integration. Capacity strengthening in all fields will lead to more effective integrated water resources development and river basin management.

REGIONAL COOPERATION AND CONFLICT PREVENTION

In an increasingly global economy, to attain the goals of poverty alleviation and sustainable economic growth in the Mekong region, regional integration and cooperation are of prime importance. Furthermore, since water does not recognise borders, it is also clear that for water related developments, regional cooperation at the scale of the whole basin is essential. Development in one country may have consequences in another country, and investments in one sector may affect other sectors.

The 1995 Mekong Agreement provides the legal framework enabling cooperation for sustainable development within the Mekong Basin. Part of the MRC’s new strategy will be to identify, categorise and prioritise projects, programmes and investment opportunities, to seek assistance for and then to implement them at basin level. But optimal and equitable development of the Mekong’s water resources requires collaborative planning and joint identification of investment priorities referring to basin-wide strategies in each water-related sector.

Joint management of water resources requires appropriate legal administrative procedures and tools, to be used both for development planning and for operational management of infrastructure. Since 1995, and with support of the Global Environment Fund and the World Bank, MRC member countries have been working on agreements on a series of procedures regarding their shared resources. These include agreements on data exchange, on water quality and on procedures for notification of water use, such as diversions of the mainstream and constructions of infrastructures on tributaries.

In any international river basin, there are inevitably potential areas of water related conflicts. MRC has an important role to play at the level of conflict prevention. With its knowledge base and cooperation mechanisms, MRC gets more and involved in the discussions relating to potential conflict areas or “hot spots”. The MRC governance bodies, the Joint Committee and the Council, are playing an increasingly active role in handling sensitive trans-boundary issues. In addition to the regular Joint committee and Council meetings, more than 40 trans-boundary meetings have been organized since 2002. There are also several bilateral and multi-lateral cooperation initiatives between the Mekong countries.

Concrete cooperation with upstream countries China and Myanmar, which are Dialogue Partners of MRC, is also increasing through joint activities on a number of subjects. Cooperation is possible in a pragmatic way through joint identification and implementation of projects in various areas of mutual benefit, such as navigation safety and trade facilitation, flood management, environment management and biodiversity conservation, and development of decision support tools. On 1 April 2002, the MRC and China signed an “Agreement on the Provision of Hydrological Information on the Lancang/Mekong River in Flood Season”. Through this agreement, China contributes effectively to MRC’s flood forecasting activities. Discussions on other possible joint activities are ongoing. This participation of the upstream countries in the MRC Programme for Sustainable Water Resources Development of the Mekong Basin, in a joint effort to alleviate poverty and increase economic welfare, is a factor of regional integration and is of mutual benefit for all countries sharing the Basin.

SOCIO-ECONOMIC DEVELOPMENT AND POTENTIAL ENVIRONMENT IN THE MEKONG DELTA, VIETNAM

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ABSTRACT

Mekong River Delta is one of the 7 key economic regions of the whole country, is an important agricultural production of Vietnam, which contributes more than 50% of food production; more than 55% of aquatic and fruit production; more than 61% of exported aquatic production of the country … Mekong River is considered as water resource of determine meaning to the existence and development of more than 16 million people and society in the Mekong Delta of Vietnam. There has been an encouraging progress in socio-economic development in the Mekong Delta over the past years, especially since the adoption of the policy of renovation. However, there remains and develops serious emerged environmental problems.

Through the steer view and socio-economic development thought of the Party and Government of Vietnam for the Mekong Delta, the objectives and development directions of socio-economic in the Mekong Delta to the year 2010, directions of adjustment on the production of agriculture, forestry and aquaculture till year 2010, the paper has analyzed and assessed the existing environmental problems in the Mekong Delta in different zones; defined serious environmental polluted areas and predicted the potential environment in the process of rapid socio-economic development in the Mekong Delta, especially prediction of the development of environment in the urban zone, industrial zone, agricultural development zone, coastal zones, flooding areas and the area affected by flood protection structures in the Mekong Delta.

Addressing in a harmonic way the linkage between socio-economic development and environmental protection toward sustainable development should be proceeded ahead.

GENERAL INTRODUCTION

The Mekong Delta is located at the South pole of Vietnam. The part which belongs to Vietnam is located at the downstream of the Mekong delta and is recognized with 3,971,232 ha in area, accounting for 12% area of the country, and average population in 2000 was 16,365 million people, accounting for 22% population of the country. Its population density is 412 persons/km2 which is 1.75 times higher than the average population density of the country (i.e. 236 persons/km^2). The entire country is covered with 9.3 million ha for farm land whilst 2.97 million ha among which is found at the Mekong delta, accounting for 32%. Farm land in the Mekong delta is 3-4 times larger than that in other deltas or plains. Hydrological regime of the Mekong delta suffers strong impacts from the hydrological regime of the Mekong river and tidal regime of the East sea.

The Mekong delta is the most important area of agricultural production in Vietnam, contributing over 50% food productivity, over 55% seafood products and fruits, and over 61% value of seafood exportation of the country, etc. The Mekong delta is characterized with:

- Its reputation of being the largest and most fertilized delta not only in Vietnam but also in the South East Asia;
- The largest and key area of the country for food and foodstuff production;
- The largest area of the country for aquaculture farming which accounts most national productivity and value of seafood products annually;
- Its great potentiality in livestock development for egg and meat supply for the locality itself, the entire nation, and for exportation.

Since 2001, the Government of Vietnam has had the directive of socio-economic development in making the Mekong delta a national key economic area (with reference to Deccision 173/2001/QÑ-TTg dated 06 November 2001). In accordance with such decision, the Mekong delta is one of the seven national key economic area. For the development, the Mekong delta should make use of its potentiality and advantages in geography, land resources, water resources, forest, sea, and labor force for further promotion on rice, seafood and agricultural product exportation. Water resources in the Mekong delta is considered as a top important factor of appropriate concerns to ensure sustainable environmental development and the growth of agricultural and aquaculture sectors, and at the same time, facilitate and accelerate the development of other sectors.

However, strong socio-economic development has caused several disadvantages for the environment and ecology of the Mekong at the present and in the future.

OUTLOOK AND DIRECTIVE ON SOCIO-ECONOMIC DEVELOPMENT FOR THE MEKONG DELTA

The direction on the development of the Mekong delta [7] indicated in the ninth Party Congress in 2001 is specified as follows:

"To continue to improve its role as a largest area for national rice, agricultural and seafood product exportation; to accelerate and improve production on food, vegetable, livestock, seafood and commodities; to promote processing industries and mechanics serving for agriculture, home craft and small scale industry, and services; to work out the construction of industrial parks using gas in the South West.

To make complete road system and navigation network; to improve and enlarge the National road 1A and open some new routes for transportation development in the South West; to improve national roads leading to respective provinces; to construct a bridge over Hau river and ensure the availability of bridges on such lines; to develop route systems for through traffic and rural transport; to construct strong bridges to replace foot bridges; to complete and improve river ports and airports; to make residential area planning and construction with appropriate infrastructure to accommodate thousand year flood prevention and salinity intrusion prevention."

The report on socio-economic development plan for the Mekong delta of the Government [5] identified its outlook and directive as follows:

- To accelerate industrialization, modernization; to continue to overcome existing shortcomings in the economy, gradually increasing economic growth and internal accumulation; to look for and make use of external resources to further promote and consolidate internal force and vice versa;
- To rapidly change the economic structure and labor allocation oriented to industrialization and modernization, making dynamic comparative advantages, improving economic affects and the compatitiveness on commodities and services of national and international markets and to promote exportation;
- For areas of annually flood prone, there should be combined solutions of "living with the flood" and the changing of economic structure oriented to industrialization and modernization and avoid being backward in compared with neighbor localities;
- For coastal area, the economy should be directed to the exploitation of benefits from the sea and coastal area and development of new industrial sectors. Economic structure shall be changed in accordance with the capacity of respective components in order to promote available resources.
- To prioritize infrastructure construction for areas of comparative advantages and areas of developed double infrastructure to accelerate production development, reducing the developed gap on living standard among respective localities; to gradually develop infrastructure for the socio-economics of the entire area;
- To make a distinct changes in human resources, human resources development; to focus on educational development and public awareness improvement; to produce a labor force of high qualification and appropriate allocation which is capable to obtain modern technology, to accommodate new industries, and being qualified and equipped with creativity ability to serve for industrialization and modernization;
- To effectively solve social critical issues; to create more job opportunities to the labors; to reduce unemployment rate in town and job deficit in rural area; to eliminate hunger and alleviate poverty and prevent being poor again; to consolidate and further improve public living conditions; to develop culture and information and public health care;
- To promote synchronized applications of advanced science and technology to daily production, socio-economic development in associated with ecological environment conservation for the common welfare of the public whilst flooding normally occur annually; and
- To promote socio-economic development in associated with stable politics, secured society, and improved the security of national defense.

DEVELOPMENT OBJECTIVE AS OF 2010 [5]

- GDP per capita in was USD 412 in 2001, USD 470-500 in 2005, and shall be USD 700-730 in 2010;
- Total export turn-over is estimated at USD 3 billion and shall be at USD 5.5 in 2010. Rice for exportation shall be stable at about 3.5-4 million tons. Export turn-over is estimated at USD 1.5 billion in 2005 and shall be at USD 2.5 billion in 2010;
- To create about 350-400 thousand jobs per year, averagely. Labors with trained skills and competence in 2005 shall be at 20% and shall be at 30-35% in 2010;
- There will be no household of hunger as of 2005; households of poverty shall be reduced to about 8% as of 2005 and to about 4-5% as of 2010;
- Households in rural area to be supplied with power shall be at 70-80% by 2005 and at 100% as of 2010. By 2005, 75% households of the city and 60% of the rural area shall be supplied with clean water, and respectively, 90% and 80% by 2010. There shall be no foot bridge as of 2005; and
- To increase the average value of agricultural, forestry, and aquiculture farming per hecta of agricultural farm land from USD 1,200 presently to USD 1,600 as of 2010.

DEVELOPMENT ORIENTATION

The population of the Mekong Delta in 1998 was 16 million and shall be increased to 21.1 million as of 2010. Farm land takes major account in land use (i.e. 73.29%); land for forestry takes an account of 11.12%; land for urban area increased 1.51%; and land for residential area decreased to 3.58%. GDP of the area in 2010 shall be VND 159,673 billion (including 41% from the city and 59% from the rural area). It is anticipated that incomings for treasury budget of the Mekong delta from 1995-2010 shall be VND 278,657 billion. Incomings for treasury budget from GDP in 2000 accounts 18.2% and shall be 23.4% in 2010. Expenses from treasury budget shall be increased, i.e. 20% of the budget shall be for the investment and development of social infrastructure [5].

ORIENTATION OF STRUCTURAL ADJUDGEMENT FOR AGRICULTURAL, FORESTRY, AND AQUICULTURAL PRODUCTION AS OF 2010 [4]

- To stabilize irrigated area for paddy field from 1.8-2 million ha to ensure the supply of 18-19 million ha of rice for local consumption and for exportation in accordance with national food security strategy and the export target of 3.5-4 million tons of rice per year;
- To reduce area for winter crop at coastal areas in the East and West sea for shrimp farming and other aquatic products of both salt and brackish water and of high export value;
- To promote rice farming in combination with tiger shrimp farming at coastal area effected with salt water (e.g. one shrimp farming season during dry period on paddy fields of winter crop);
- To encourage the development of plants for material to processing industry in order to replace exported material such as cotton, corn, and soya bean;
- To continue with the development of other plants which provide material for processing factories in the area such as sugar cane, pineapple, vegetables, beans, coconut, and fruits;
- To promote aquaculture farming in salt, brackish and fresh water, and mainly focus to tiger shrimp, blue clawed shrimp, fish of all kinds, and mollusca for national consumption and for export;
- To continue with the development of domestic animals, including specific concerns to animals which take the major part in the market, i.e. pig, poultry, cow for meat, cow for milk, etc.; and
- To develop forestry not only to have good protection of mangrove forest in the coastal area for ecological and environmental conservation but also to develop indigo forest for the environment of floodplain area and to earn income from making business.

CURRENT ISSUES ON ENVIRONMENT IN THE MEKONG DELTA

Area of urbanization (area I)

- High speed of urbanization and rapid increase of population whilst the infrastructure has not been developed accordingly;
- Environmental pollution due to waste water, exhaust gas and solid waste discharge from domestic use, activities from respective sectors of services, trading and commerce, health care, education, transportation, livestock, etc; and
- Pollution due to smoke, dust, noise, waste water, solid waste, and toxic waste discharge from industrial parks and home craft and small scale industry enterprises.

Coastal area (area II)

- Degradation of mangrove forest due to deforestation for shrimp farming;
- Degradation on aquatic resources;
- Degradation of biological diversification;
- Sea water pollution and water pollution at the coastal area due to the operation of ports and harbors, transportation, aquaculture farming, exploitation and processing;
- Erosion and deposition at the estuaries and coastal area; and
- Problems caused by natural disaster and flooding.

Area of agricultural development (area III)

- Salinity and alum intrusion;
- Pollution due to the utilization of chemicals and fertilizers in agriculture;
- Soil degradation due to intensive cultivation;
- Pollution of surface and ground water resources due to feces, solid waste, waste water from domestic use and waste water from livestock activities;
- Increase of water-born diseases due to polluted water resources; and
- Pollution due to smoke, dust, waste water and solid waste discharge from home craft and small scale industry enterprises which are located along the river.

Floodplain area (area IV)

- Clean water and water for domestic use in flood period;
- Collection and treatment of waste water for residential areas in the floodplains;
- Solid waste and waste from domestics in long flood period; and
- Burying dead people and treatment to dead animals for sanitation and environment conservation after flooding.

Area of severe pollution and environmental degradation

- Cities and towns (townships) and factories of large scale, industrial parks and export processing zones (Area I);
- Mangrove forest which were destroyed for shrimp farming (Area II);
- Estuaries and coastal areas under erosion and deposition (Area II);
- Home craft and small scale industry enterprises along the river (Area III);
- Floodplain areas during flood period and after recession; and
- Areas of salinity and alum intrusion.

POTENTIAL ENVIRONMENT IN THE MEKONG DELTA BY 2010

Potentiality, socio-economical and environmental effects of structure changing and adjustment of agricultural, forestry, and aquaculture farming production

- ➢ The positive change in development of agricultural, forestry, and aquaculture production shall create job opportunities to the labors. It is estimated that there shall be jobs provided to about 2 million people during 2001-2005, including 1.4 million people in aquatic sector, and to about 2.5 million people during 2006-2010, including 1.6 million people in aquatic sector;
- ➢ The supply of material for local industrial processing of agricultural, forestry and aquatic products shall result the development of some other sectors in rural area which use agricultural waste, products, and by-products for

product processing as well as the development of services for production and daily life, i.e. commerce, agricultural activity encouragement, credit, etc.;

- With natural characteristics, the Mekong delta has formed diversified ecology. It is the sensitive and vulnerable place where several kinds of animals and plants were grown up and settle their living. Currently, the Mekong Delta is facing up with several causes of environmental pollution due to objective factors in respective resources and due to subjective factors from production activities of the human beings, e.g. water pollution on the rivers and channels due to industrial and domestic waste, environmental pollution in residential area of those who moved out from flooding area and have to live with domestic animals whilst there are insufficient power, clean water and water closets are provided, pollution at area of aquaculture farming development in coastal area due to the lack of waste drainage system, environmental pollution at the floodplains after recession, and pollution due to forest fire, etc; and

Prediction of waste discharge in the Mekong Delta

According to the statistical data on 1 April 1999 [1], the population in the Mekong Delta is 16.132.024 people, in which 85% people in rural area and 15% from urban area. The prediction on population of the Mekong delta shows that there will be 21.1 million people by 2010, including around 5,275,000 people from urban area, accounting for 25% of the total population, and around 15.825.000 people from rural area, accounting for 75% of the total population.

Waste water

By 2010, the consumption and wastewater discharge is estimated in the following table:

Table 1: Prediction of wastewater discharge in the Mekong Delta up to year 2010

	Urban area	Rural area
Population	5,275,000	15,825,000
Consume water /day (litre)	120	100
Discharge 80%	96	80
Wastewater /day (m^3)	5,064,000	1,266,000
Wastewater/year (m^3)	1,704,360,000	462,090,000
Compared to the year 2000	4 times higher	1.5 times higher

According to the Rapid assessment of sources in 1993 made by WHO [10] for several developing countries, the daily untreated pollutants discharged by the human beings to the environment shall be as follows:

Table 2: pollutant discharge coefficient

No	Pollutant	Quantity (gr/person/day)	Average quantity (gr/person/day)
1	Total suspended solids (TSS)	70 – 145	107.5
2	BOD5	45 – 54	49.5
3	COD (dichromate)	72 – 102	87.0
4	Ammonia (NH4-N)	2.4 – 4.8	3.6
5	Total Nitrogen (N)	6 – 12	9.0
6	Total Phosphorus (P)	0.6 – 4.5	2.5
7	Oil without mineral	10 – 30	20.0

Thus, the volume and concentration of the pollutants from urban and rural areas in 2010 shall be:

Table 3: Prediction of volume and concentration of pollutants from urban and rural areas in 2010

No	Pollutant	Urban area		Rural area	
		Volume in 2010 (ton/day)	Concentration (mg/l)	Volume in 2010 (ton/day)	Concentration (mg/l)
1	Total suspended solids (TSS)	544.4	1,120	49,674.7	1,344
2	BOD5	250.7	516	22,873.4	619
3	COD (dichromate)	440.6	906	40,201.8	1,088
4	Ammonia (NH4-N)	18.2	38	1,663.5	45
5	Total Nitrogen (N)	455.8	94	4,158.8	112
6	Total Phosphorus (P)	12.2	25	1,109.0	30
7	Oil without mineral	101.3	208	9,241.8	250

Compared to Vietnamese standard (i.e. TCVN 5954 -1995) [9] , the concentration of the above parameters are tens to hundreds times higher (for type A and B).

Urban and even rural wastewater discharge without proper collection and treatment shall cause severe pollution to the environment and to surface water resources in particular whilst surface water is used for multi-purposes including water supply for domestic use.

According to the master plan, **industrial parks** in the Mekong delta shall take about 7,000 ha. However, it is predicted and anticipated that area for industrial parks in 2010 shall be less than 50% in compared with that in the master plan.

Based on the estimated water discharge volume in technical planning for industrial parks, it is anticipated that water discharge volume from the industrial parks in the Mekong delta in 2010 shall be 280,000 m3/day and night. Surveys made at the industrial parks in Ho Chi Minh City and the eastern south allows estimating the average volume of substances from waste water discharge in 2010 as follows:

Table 3: Prediction on average concentration of pollutants in waste water discharged from the industrial parks

Parameter	Average concentration found in the industrial parks from HCMC and the eastern south (mg/l)	Pollution loading from the industrial parks in the Mekong delta by 2010 (kg)
SS	253	70,840
BOD5	170	47,600
COD	271	75,880

Solid waste

By 2010, if it is estimated that each person from urban area discharges 0.75 kg solid waste per day, solid waste discharge from urban area of the Mekong delta shall be 15,825 tons/day or 5,776,125 tons/year; such discharge shall be 2 times higher than that of 2000. Among which, organic solid waste accounts for about 60% (equivalent to 3,465,675 tons) and 6% for toxic solid waste (equivalent to 346,568 tons/year). Such domestic solid waste shall cause severe pollution to the environment without proper management.

In the rural area, if each person discharges 0.5kg solid waste, the solid waste discharge from rural areas by 2010 will be about 7,912 tons/day or 2,888,062 tons/year. Such discharge shall be 2 times higher than that of 1999. In which organic solid waste accounts for about 80%. Besides, solid waste from agriculture is also significant.

In case 40 kg of solid waste per day is discharged from every ha of **industrial land**, it is estimated that by 2010 there shall be 140 tons of solid waste discharged per day or 51,100 tons/year, including 5,621 tons of toxic waste.

For the industries of medium and small scales: These industries are located scatteredly at different places in urban area, residential area, along the roads and navigation routes or within the traditional home craft villages, etc. They are equipped with manual technology, outdated equipment and machinery, small work-space, and limited investment capital. Most of the enterprises are not equipped with waste treatment system due to several causes: high cost, no power supply, large area needed, no proper treatment technology is equipped, no encouragement for waste treatment system investment. Therefore, these enterprises have caused pollution to the surrounding residential areas and it is very obvious with the tendency of pollution increase due to industrial waste and waste from home craft and small scale industries.

With the solid waste discharge factor of 15.4 tons for industries of medium and small scales (in accordance with the estimation made by ENTEC [2] for the survey on 365 enterprises of medium and small scales in Ho Chi Minh City), for about 121 State industrial manufactories under the management of the local authorities and 83,079 non-

State enterprises (as of 31/12/1999), industrial solid waste in the Mekong delta shall be 1,281,280 tons/year and 8,000,000 tons in 2010.

Exhaust gas

Industrial parks eliminate pollutants every day to the air, e.g dust, SO2, SO3, NOx, CO, VOC. Surveyed pollution factor at some industrial parks e.g. Bien Hoa, Suoi Dau, Hon Kho (Nha Trang), etc. shows 4.9 tons of dust/year, 12.6 tons of SO2/ha/year, 1.7 tons of NO2/ha/year; based on this, it is estimated that air pollution at the industrial parks in the Mekong delta by 2010 shall be 17,150 tons of dust, 44,100 tons of SO2, and 5,950 tons of NO2 per year.

In general, Environmental change tendency in the Mekong Delta is very much subject to the collection possibility and the intensity of treatment of domestic and industrial waste before they are discharged to the environment. In general, however, the current rapid speed of population increase and the development of different industries results the increase of waste volume and the degradation of environment in urban area since the management and treatment capacity of relevant authorities cannot keep pace with such development.

Prediction of environmental development in other different areas

In agriculture

The requirements of intensive farming, crop increasing, plan diversifying are increasing in the Mekong Delta. Fertilizers and pesticides are more and more used. Due to the variety of pesticides on the market (about 735 products), it is very difficult to manage the forbidden or limited to use, including high toxic and difficult to degrade products. Those still exist on the market. Besides, due to uncontrolled spraying pesticides, the number of people is influenced of poisons by eating agricultural products content residual of pesticides may possible increasing in coming years.

The rice monoculture and using new variety of rice with high yield and short growing life will lose the old variety with positive characteristics and suitable for the natural condition in the Mekong Delta such as the capacity of standing in the condition of inundation, acid sulphate soil, salinity soil, draught, …

The development of breeding in coming years will increase the volume of waste, causing adverse impacts on water and air environment, especially in flooding season. It is estimated that till 2010 the waste from breeding discharge to the environment will be 220,000 tons/day if it is not collected and treated. Besides, the waste also generates from the epidemic and dead animals.

Because of speed up industrial raising fish and shrimp for exportation, the area and yield for them will be increasing. The environment concerns:

- Increasing water pollution in ponds, lakes, fields due to excess food, pesticides, …
- Increasing catching disease capacity of fish and shrimp due to pollution environment
- Exhaustion of aquatic products due to catching fish by batteries, nets, mines, …

In coastal area

The coastal area is the area with potential of forest exploitation and aquaculture, therefore recent years it's exploited without organizing and planning. This area is more and more suffered negative impacts on the environment. Due to the construction of beach dykes crossing the mangrove forest, the mangrove forest inside the dyke has disappeared and that outside the dike has degraded, such as in Ben Tre, Tra Vinh, Ca Mau and Kien Giang provinces.

The structures for freshenization in the coastal area besides bring positive impacts, they cause adverse effects on the environments, and the results of observation shows that:

- Contamination of water in dry season because of closing of salinity prevention sluices
- Setting obstacles to the migration of shrimp and fish, causing decline of aquatic products
- Setting obstacles to the transportation of fresh water, sediments, and nutrients … impacts on the balance of mangrove forest ecosystem.

Mangrove forest is the receiving of most pollutants from the upstream. Increasing utilization of agricultural chemical, increasing of industrial activities in the upstream will increase toxic substances for the mangrove forest.

In flooding area

In the period of 1996 – 2010, the construction of population group and population line in the flooding area is one of the focuses of the programme. Some population groups surround by immense flood, such as Sa Rai, Vinh Hung, Thanh Loc, Tam Nong, Giong Giang, My An, …in these area, it has not yet been attached the special importance to drainage system in the design stage. Among all system has already constructed, only Sa Rai has pumping station, which can operate in both dry season and rainy season [6], but this pumping station has not yet designed enough capacity.

All the areas in side the dyke, therefore, seriously contaminated with organic matters and microorganisms, lacking of clean water for domestic use, in addition domestic wastewater has not treated, no way to escape and stagnant for 5 months long of the flood season. This is the cause for many waterborne diseases.

The inhabitant areas have not yet been planned with landfields or dumping grounds. The waste from breading farm, pigsties, and houses without collecting and treating is dumped directly to canals, rivers. The environment in this encirclement conditions will be more and more degraded.

Due to flood prevention of the Government, the people's levies are safer in the flooding area, more land for cultivation; the population in the flooding area will increase. As consequence, domestic waste, agricultural waste and chemical using for agriculture will be increased unless suitable management measures supported.

Environmental development due to impacts of flood protection structures

The flood protection structures have positive impacts on the flooding areas: decreasing area and time of flood, increasing agricultural productions. However, construction activities and operation of those flood protection structures is one of the reason causing changes of environment in the whole regions. The potential environmental changes have been predicted as follows [3]:

Direct impacts:

- Lower level of flood but flooding time longer in the downstream
- Increasing the dangerous level about human and property if those structures or the flood control measures are not meet the capacity requirements.
- Enrichment for ground water
- Significant impacts on aquatic source of income due to disordering their migration routine (because of salinity prevention sluice), damage habitat and water quality changes … resulted in decreasing yield at the river mouth, at shore and sea production.
- The impacts due to flood drainage canal excavation: disordering habitat, narrowing flooding area, increasing water temperature due to clearance of bank vegetation, increasing soil erosion and sedimentation, increasing flood in the downstream.
- Changing the ecosystem, decreasing agricultural development projects needing irrigation water
- Setting obstacles to wildlife
- Increasing salinity intrusion in dry season due to no reserved water in the depression to push salinity water out.

Indirect impacts:

- Improving transportation, increasing development opportunities in the flooding areas and feeling safety of living with flood protection structures. Those resulted in increasing population, infrastructures, agricultural production, deforestation, encroaching on wildlife, …
- Increasing utilization of fertilizers to compensate losing soil nutrients, increasing water contamination and depending on importing productions.

CONCLUSION AND RECOMMENDATION

Conclusion

Vietnam is directed toward sustainable development, and if she accepts the viewpoint of sustainable development, she should consider 3 factors: economic, society, and environment. Vietnam has its important role in international integration into environmental protection, taking part in most international Conventions and Agreement on environmental protections.

Mekong Delta has very important role in the industrialization and modernization of Vietnam. Company with socio-economic development the environmental protection should be in concern. The pressing environmental issues need to be integrated management in the Mekong Delta are:

- Degradation of natural wetland ecosystem
- Environmental issues due to flooding
- Salinity intrusion, acid soil and water
- Bank erosion, sedimentation in estuaries and coastal area
- Pollution due to wastewater, solid waste, dust, noise, … in the urban areas
- Pollution due to industrial waste from industrial zones, the industries of medium and small scales
- Pollution due to waste in the rural areas, and fertilizers, pesticides, …

The measures to minimize pollution and degradation are integrated managements including: pollution prevention, environmental improvement, raising awareness, and capacity building for management organizations. Those measures should be carried out periodically: to 2005, to 2010 and to 2020 focusing on objectives and contents prioritize for each period.

Recommendations

- The people's committee of provinces in the Mekong Delta should plan to invest for environmental improvement and protection for areas with severe pollution and degradation.
- The Government should promulgate policy and mechanism aiming at drawing investment and mobilizing capitals from different sources for environmental protection activities.
- Accomplishment of organization mechanism for environmental management from national level to local level. Strengthening human resources and investment on equipment for environmental monitoring, controlling and coerce to comply with environmental protection laws.
- Raising awareness on environmental protections for different classes: managers, peoples, teenage, and children.

For sustainable development in the Mekong Delta, sustainable development of agriculture – and rural development the following factors should be ensured [8]:

- Rural economic growing should be 3 times higher then the population increasing in the regions.
- Income of each farmer should be over the poverty line
- Changes in socio-economic should create jobs for people, especially women.
- The cultivated system should protect soil, surface and ground water and gene of plan variety
- Production technology and production organizing form should be suitable to infrastructures, finance capacity of the Government and farmers, appropriate to education level and customs belief of farmers.
- Economic associate with reinforcement of national defense and national security.

Study and research are required for mitigation solutions to respective areas. However, development of production and infrastructure in accordance with relevant planning shall also be one method contributing to forest and water resources protection, reducing causes of pollution particularly to the coastal and floodplain areas where millions of people are settling and earning their living.

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CANAL WATER POLLUTION OF CAN THO CITY IN THE MEKONG DELTA É

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ABSTRACT

Located on the Bassac River's bank, Can Tho is a City newly established on the basis of the same town. Crossing by a dense canal network, Can Tho is facing on water pollution problem due to domestic sources and industrial zones newly constructed. Using modelling approach it is presented in this paper the current situation of water canal pollution. The near future of this pollution picture is also predicted based on planning development activities.

INTODUCTION

Located on the Bassac River's bank, Can Tho is a City newly established on the basis of the same town and has been considered as the Capital of the Vietnam Mekong Delta . It consists of 4 districts, namely, Ninh Kieu, O Mon, Binh Thuy, Cai Rang, and all locate along the Bassac and Can Tho Rivers' banks. Population of the City is estimated of 548,220 in 2005 and 971,200 in 2010, respectively. The City is crossed by a dense network of creeks and canals (see figure 1), such as Binh Thuy, Cai Khe, Khai Luong, Tham Tuong where waste water is directly discharged to.

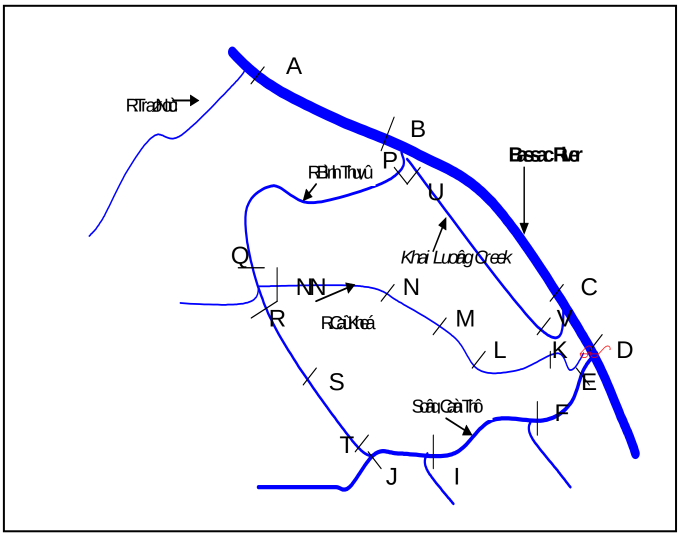

Figure 1: a) Can Tho area location map b) Schematization of Can Tho area in computation

Based on survey and statistical data, it is seen that waste water come mainly from domestic, fish and food processing, brewage, drug, hospital, fertilizer sources. As a newly established city and with rapid growth of population, drainage as well as sewage has become great concerns of authority. In addition, rapid urbanization in recent years brought about damages and overload to drainage and sewerage facilities, causing serious urban inundation along with water pollution. Therefore, water quality in Can Tho City is one of the most serious environmental issues, particularly in relation to development activities of the city.

With the purpose to identify water pollution issues and impacts of development scenarios of the city serving for EIA , a study using mathematical model on hydraulic regime and water pollution status was carried out [2].

CURRENT AND NEAR FUTURE SITUATION OF CANAL WATER POLLUTION OF CAN THO AREA

It is seen that all canals of Can Tho area are conneced to the Bassac River and all are strongly affected by semi-diurnal tide from the South China Sea. During a day there are two times when water level reaches highest and lowest values (see figures 2a and 2b for discharge). When tide changes the direction flow velocity becomes relatively zero, and consequently polluted water can not be diluted or spreads to other area. Water becomes more polluted during ebb tide and more clean during spring tide.

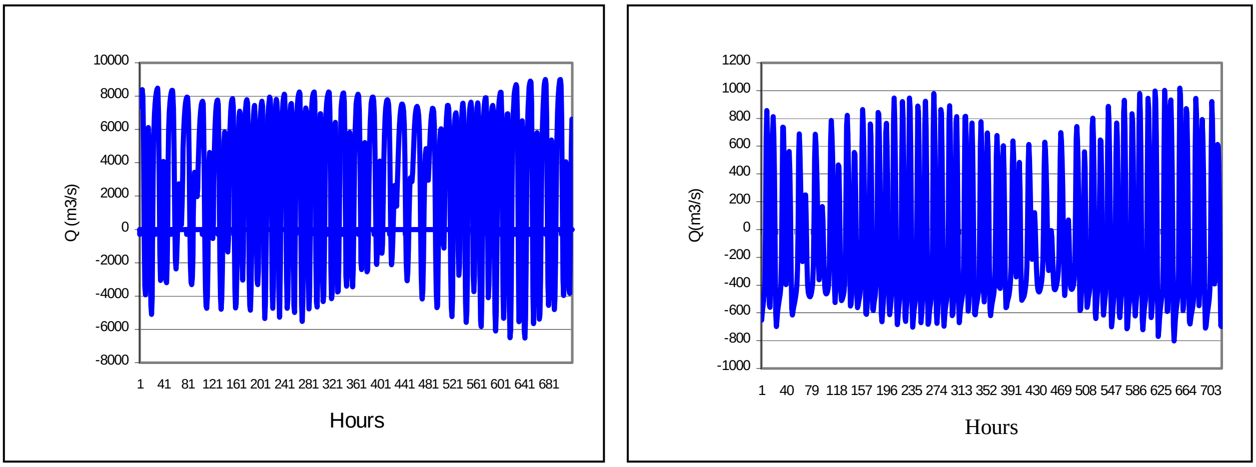

Figure 2: a) Discharge at point D on the Bassac River (April); b) Discharge at point E on the Can Tho River (April)

Based on scheme of drainage pipeline system of the city, discharging points of wastewater are mainly located along the Can Tho River (from E to F on fig. 1b), the Cai Khe creek (from N to K), the downstream part of the Khai Luong creek, between A and B on the Bassac River, and from S to T on the Tham Tuong creek (see fig. 1b). Due to organic materials is dominant in the wastewater; BOD_5 was used as indicator for canal water pollution. The water quality model [1] briefly illustrated in below appendix was used for BOD computation.

Scenarios in simulations

It is given in table 1 data corresponding to five scenarios used in simulation:

Scenario No.1 denoted by **PA_2005:** the current status of wastewater in 2005

Scenario No.2 denoted by **PA_2010**: wastewater status estimated for 2010

Scenario No.3 denoted by **XL100**: wastewater status estimated for 2010 with primary treatments of sources in order BOD_5 in all sources are less than 100mg/L.

Scenario No.4 denoted by **XL50**: wastewater status estimated for 2010 with full treatments of sources in order BOD_5 in all sources are less than 50mg/L.

Scenario No.5 denoted by **PA_2020** : wastewater status estimated for 2020 with primary treatments of sources in order BOD_5 in all sources are less than 100mg/L and with load increased at 1.5 times compared to that of 2010.

Table 1: data for five scenarios in simulation

Scenarios	PA_2005		PA_2010		XL100		XL50		PA_2020	
	Load (m3/d)	BOD mg/L	Load (m3/d)	BOD mg/L	Load (m3/d)	BOD mg/L	Load (m3/d)	BOD mg/L	Load (m3/d)	BOD mg/L
Can Tho River	4964	430	6658	378	6658	100	6658	50	9987	100
Cai Khe Creek	15367	354	20060	299	20060	100	20060	50	30090	100
Th. Tuong Creek	3088	439	3800	384	3800	100	3800	50	3800	100
Khai Luong Creek	3264	151	3984	163	3984	100	3984	50	3984	100
Binh Thuy Creek	3264	84	3984	84	3984	84	3984	50	3984	84
Tra Noc Creek	13337	84	21481	84	21481	84	21481	50	21481	84
Bassac River	14748	120	38896	120	38896	100	38896	50	38896	100

Due to tidal variation, computed BOD is seen oscillation with time as seen in figures 3 a, b.

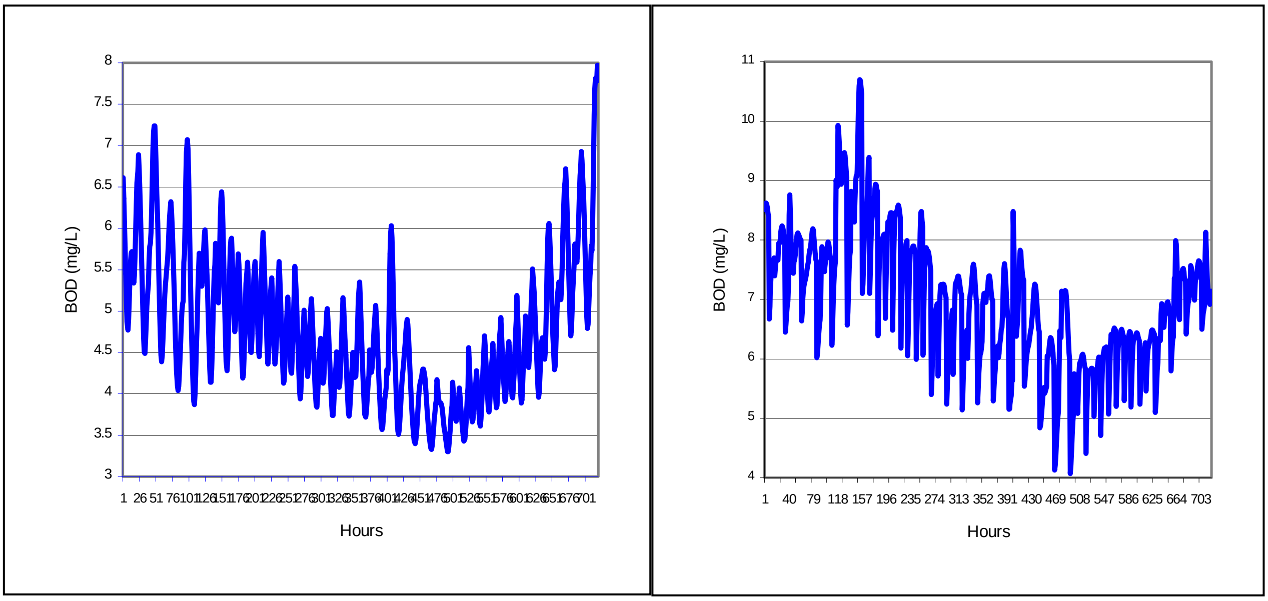

Figure 3: a) Variation of BOD at point A on the Bassac River and b) at point E on the Can Tho River

Simulations of the dry season are carried out with hydraulic data of 2000 and river water can be considered clean if BOD_5 in river water is less than 5mg/L. For simulation purpose the hydraulic schematization covers the whole delta but only rivers and canals of Can Tho area are received polluted wastewater.

It is noted that due to variation in time of BOD only maximum and average values are used to estimate pollution status of river water. Table 2 below shows results of computed BOD corresponding to five mentioned scenarios.

Table 2: Computed BOD max (BODmax) and BOD average (BODbq) corresponding to 5 scenarios

Unit mg/L

Scenarios		PA_2005		PA_2010		PA_XL100		PA_XL50		PA_2020	
River	Location	BODmax	BODbq	BODmax	BODbq	BODmax	BODbq	BODmax	BODbq	BODmax	BODbq
Bassac River	A	8.24	5.1	8.02	5.02	7	4.61	5.14	3.9	7.02	4.63
	501	11.98	5.68	15.57	5.52	13.05	4.96	6.82	4.06	13.06	4.99
	504	10.55	6.29	7.63	5.74	6.54	5.04	5.12	4.1	6.56	5.08
	C	18.09	6.99	10.07	5.97	6.74	5.14	5.17	4.14	6.79	5.18
	D	12.28	6.93	8.56	5.98	6.44	5.14	5.01	4.14	6.46	5.18
Tham Tuong Creek	R	11.84	5.52	11.35	5.48	6.88	4.76	5.16	4	6.89	4.78
	S	56.83	8.54	43.86	8.66	23.16	5.69	23.16	4.43	23.16	5.71
	T	30.31	7.79	24.68	7.67	15.02	5.47	15.02	4.34	15.02	5.5
Khai Luong Creek	U	22.29	8.11	14.18	6.52	8.14	5.33	6	4.23	8.17	5.36
	6447	28.3	10.99	18.2	7.78	9.9	5.82	6.14	4.45	9.92	5.85
	6448	39.23	13.86	31.78	9.34	13.74	6.4	7.44	4.71	13.76	6.44
	6449	47.6	17.28	23.92	8.82	11.27	6.2	6.46	4.62	11.3	6.24
	V	29.71	12.27	26.63	7.7	11.82	5.78	6.49	4.43	11.83	5.82

Table 2 (continued)

Scenarios		PA_2005		PA_2010		PA_XL100		PA_XL50		PA_2020	
River	Location	BODmax	BODbq	BODmax	BODbq	BODmax	BODbq	BODmax	BODbq	BODmax	BODbq
Cai Khe Creek	K	21.9	9.2	24.07	8.88	10.73	6.01	8.52	4.54	12.62	6.45
	6411	22.16	9.94	24.52	9.79	10.86	6.28	8.39	4.66	12.78	6.85
	6412	22.75	10.43	25.39	10.37	11.08	6.46	8.02	4.74	13.07	7.1
	6413	23.51	10.88	26.52	10.93	11.33	6.63	7.93	4.82	13.39	7.34
	L	25.74	11.22	28.95	11.37	11.96	6.76	8.03	4.88	14.45	7.53
	6415	27.04	11.39	30.8	11.58	12.5	6.82	7.52	4.91	15.17	7.62
	M	27.69	11.41	30.8	11.61	12.49	6.83	7.47	4.91	15.16	7.63
	6417	26.63	11.23	28.92	11.48	12.07	6.79	7.39	4.89	14.34	7.57
	N	25.47	11.05	26.77	11.27	11.45	6.72	7.15	4.86	13.48	7.48
	6419	22.86	10.8	23.72	11.03	10.66	6.65	6.96	4.83	12.59	7.38
	6420	20.67	10.64	22.39	10.92	10.25	6.61	6.82	4.82	12.04	7.33
	6421	19.46	10.55	21.18	10.88	9.87	6.6	6.71	4.81	11.53	7.31
	6422	18.82	10.49	20.05	10.89	9.5	6.6	6.61	4.81	11.04	7.31
	6423	18.28	10.44	19.33	10.9	9.28	6.6	6.53	4.81	10.8	7.32
	6424	17.79	10.4	18.71	10.91	9.19	6.61	6.46	4.82	10.68	7.33
	6425	17.46	10.36	18.48	10.91	9.12	6.6	6.41	4.82	10.59	7.32
	6426	17.33	10.31	18.33	10.89	9.07	6.6	6.37	4.81	10.53	7.31
	6427	17.23	10.26	18.23	10.86	9.04	6.59	6.32	4.81	10.48	7.3
	6428	17.13	10.21	18.12	10.82	9.01	6.58	6.28	4.81	10.44	7.28
	6429	17.02	10.14	18	10.76	8.98	6.56	6.25	4.8	10.39	7.26
	6430	16.9	10.07	17.86	10.69	8.93	6.54	6.22	4.79	10.34	7.23
	6431	16.78	9.97	17.72	10.59	8.89	6.51	6.2	4.78	10.28	7.19
	6432	16.66	9.87	17.55	10.47	8.84	6.47	6.18	4.76	10.22	7.13
	6433	16.52	9.75	17.36	10.34	8.78	6.43	6.15	4.74	10.14	7.07
	6434	16.36	9.61	17.12	10.18	8.71	6.38	6.13	4.72	10.04	7.01
	6435	16.16	9.47	16.85	10.02	8.63	6.33	6.1	4.7	9.94	6.94
	6436	15.95	9.32	16.55	9.84	8.54	6.28	6.08	4.68	9.82	6.86
	6437	15.71	9.17	16.22	9.66	8.44	6.22	6.05	4.65	9.69	6.78
	6438	15.47	9.01	15.91	9.47	8.35	6.16	6.03	4.63	9.57	6.7
	6439	15.23	8.84	15.59	9.27	8.25	6.1	6	4.6	9.44	6.61
	NN	13.17	6.09	13.55	6.12	7.73	5.03	5.37	4.12	8.67	5.17
Binh Thuy	1986	9.28	6.17	7.25	5.65	5.84	4.98	5.14	4.08	5.87	5.02
	1987	7.63	5.12	7.8	5.02	6.85	4.61	5.16	3.92	6.86	4.63

Table 2 (continued)

Scenarios		PA_2005		PA_2010		PA_XL100		PA_XL50		PA_2020	
River	Location	BODmax	BODbq	BODmax	BODbq	BODmax	BODbq	BODmax	BODbq	BODmax	BODbq
Can Tho River	E	10.7	7.14	11.31	6.33	6.5	5.21	5.3	4.17	6.78	5.29
	2005	10.83	7.25	11.61	6.52	6.67	5.25	5.31	4.19	6.96	5.35
	2006	24.3	7.37	22.06	6.72	8.6	5.3	5.32	4.21	9.37	5.42
	2007	11.99	7.43	11.74	6.83	6.71	5.33	5.34	4.23	7.05	5.46
	2008	12.14	7.42	13.25	6.84	6.73	5.33	5.37	4.23	7.31	5.47
	2009	14.16	7.38	12.94	6.82	6.64	5.33	5.42	4.23	7.18	5.46
	2010	29.32	7.3	16.79	6.75	7.51	5.31	5.49	4.23	7.71	5.44
	2011	27.2	7.2	42.87	6.67	12.4	5.3	6.64	4.22	12.61	5.41
	2012	13.27	7.07	17.26	6.54	7.59	5.27	5.65	4.21	7.76	5.37
	F	11.9	6.9	13.69	6.37	6.93	5.23	5.74	4.19	7.13	5.31
	2015	10.76	6.65	10.92	6.13	6.39	5.16	5.88	4.16	6.54	5.23
	I	11.12	6.36	7.93	5.81	6.36	5.07	6.06	4.12	6.38	5.11
	J	8.96	5.95	7.56	5.64	6.24	5	6.24	4.17	6.24	5.03

For visualization data in table 2 can be graphically shown, for example as in figures 4 and 5 for the Bassac River

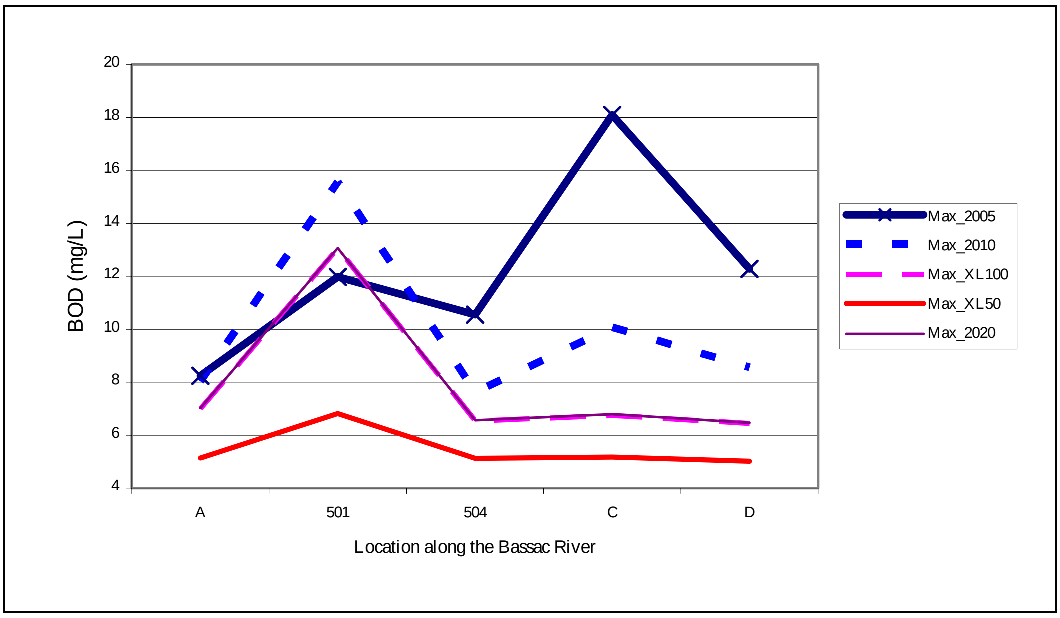

Figure 4: Max BOD along the Bassac River corresponding to 5 scenarios during April

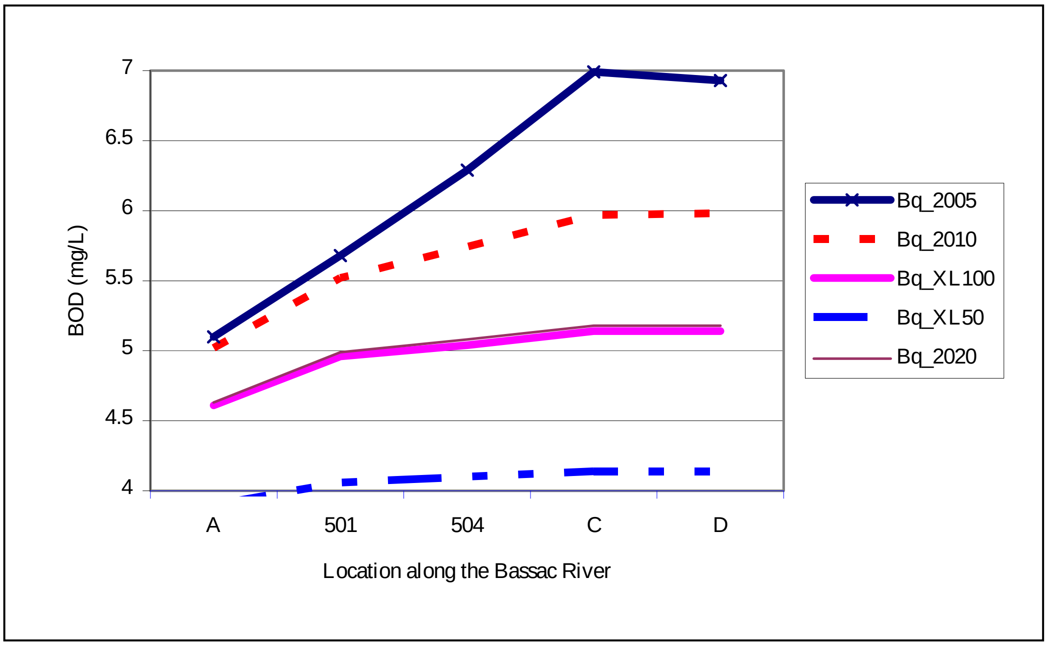

Figure 5: Average BOD along the Bassac River corresponding to 5 scenarios during April

Remarks on the computed results

From table 2 (and figures 4 and 5) some following remarks can be drawn:

+ Due to tidal effect it should be used average values of BOD for assessment of water pollution status.

+ River water becomes most polluted when flow changes direction, therefore if possible the waste water should not be discharged to rivers and canals at this moment.

+ Waste water without any treatment discharged to the Bassac River will make the water of this river worsen in regard to quality.

+ Although waste water load of 2010 of the Can Tho area is greater than that of 2005 but due to primary treatments are applied before discharging, in average the river water quality is not much worsen.

+ With regard to river water pollution level of the Can Tho area the following ranking of rivers and canals can be made: Tham Tuong, Cai Khe and Khai Luong Creeks.

+ If primary treatments before discharging can be made in order BOD_5 in all sources is less than 100mg/L, then in average, river water of the Can Tho area can be considered clean except at time when tidal flow changes direction.

+ The reduction of BOD5 in all sources to 50mg/L can guarantee clean status of rivers and canals of the Can Tho area (provided that no other sources from the outside areas).

+ Can discharge more waste water to the Cai Khe Creek and the Can Tho river but the volume is not greater than 1.5 times of that of 2010 and provided that primary treatments before discharging can be made in order BOD_5 in all sources is less than 100mg/L.

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APPENDIX

GENERAL TO A MATHEMATICAL MODEL FOR BOD/DO

Rivers and canals are the natural collectors of rain runoff from large drainage areas and often of the direct or indirect discharges from industrial and domestic sources. But rivers have been also the principal suppliers of fresh water to cities, agriculture and industry. Thus, while the maintenance of satisfactory water quality is necessity, river pollution has been often a serious problem.

The presence of DO (**D**issolved **O**xygen) in river water is essential for aquatic life and provides a refreshing taste in the drinking water. Therefore, its maintenance above a desirable level is one of the major objectives of control strategies.

Organic materials entering the river consume oxygen as they decompose. As the initial consumption exceeds the oxygen uptake from the atmosphere, the DO level goes through a minimum before it bounces back.

Because almost domestic and a number of industrial sources are often the major contributors to the organic loads discharged into rivers, so the water quality model for river mainly deals with BOD (**B**iochemical **O**xygen **D**emand) and DO computation. Application of this model allows the users to assess or to compute in a given situation the BOD and DO distribution or the required BOD removal efficiency from the treatment system.

Below is a brief of the BOD and DO model developed by Dac N.T. (the first author of this paper)

For water quality problem in river and canal network it is customary to use one-dimensional mathematical model, of which the hydrodynamic component is considered given from observations or from hydraulic model using one-dimensional Saint-Venant equations consisting of continuity and momentum equations. These equations are solved numerically by Preissmann implicit finite difference scheme and of which the solutions are flow parameters and velocity [1].

The variation of BOD and DO in the river is mathematically described by the following transport-dispersion equations:

a) *For BOD with concentration B*:

$$\frac{\partial B}{\partial t} + U\frac{\partial B}{\partial x} = E\frac{\partial^2 B}{\partial x^2} - (K_1 + K_3 + \frac{q}{A})B + \frac{qB_q}{A} \qquad (1)$$

b) *For DO with concentration D*:

$$\frac{\partial D}{\partial t} + U\frac{\partial D}{\partial x} = E\frac{\partial^2 D}{\partial x^2} + K_2(D_s - D) - K_1 B + \frac{q(D_q - D)}{A} \qquad (2)$$

where: Bq, Dq: concentrations of BOD and DO, respectively, in lateral flow q; Ds: saturation concentration of dissolved oxygen in water; K_1: BOD removal rate constant; K_2: re-aeration constant; K_3 :BOD removal constant due to settling; U: mean flow velocity; E: dispersion coefficient.

It is noted that in (1) if K1 = K3 = 0 one has an equation expressing salinity.

The equations (1)-(2) correspond to a general form:

$$\frac{\partial S}{\partial t} + U\frac{\partial S}{\partial x} = E\frac{\partial^2 S}{\partial x^2} - \sigma S + \varphi \qquad (3)$$

where: $\sigma > 0$ and φ are known coefficients; S: concentration of BOD or DO (or salinity).

Equation (3) is solved numerically by the two-step method in which during one time steps firstly the pure transport equation

$$\frac{\partial f}{\partial t} + U\frac{\partial f}{\partial x} + \sigma f = \varphi \qquad (4)$$

is solved, of which along the characteristic lines dx/dt = U solutions are:

$$f(x,t) = (f_0 - \frac{\varphi}{\sigma})\exp(-\sigma t) + \frac{\varphi}{\sigma} \qquad (5)$$

where f_o is concentration at intersection between characteristic line and straight line t = n.Δt.

Successively, the dispersion equation :

$$\frac{\partial S}{\partial t} = E\frac{\partial^2 S}{\partial x^2} \qquad (6)$$

is then solved by finite difference method leading to solving a tridiagonal equation system with initial condition taken from (5). The solutions of (6) will be those of (3) during a time step.The computation of BOD-DO/salinity in the flood plains and in a system with structures also included in the model but not mentioned in this paper (see [1], Nguyen Tat Dac 1987).

AN EVALUATION OF PRESENT EXPLOITATION, UTILIZATION AND QUALITY OF SHALLOW GROUNDWATER IN SAND DUNES IN CAU NGANG, DUYEN HAI DISTRICTS AND TRA VINH TOWN, TRA VINH PROVINCE

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ABSTRACT

Shallow groundwater in sand dunes has been an important source of freshwater for people living in coastal areas of Tra Vinh province for a long time. Today, the demand for freshwater to supply agricultural production and household consumption is increasing. The result is increasing pressure on the quality and quantity of this resource. Present exploitation, utilization and quality of shallow groundwater in sand dunes in Cau Ngang, Duyen Hai Districts and Tra Vinh town were evaluated in order to recommend measures for appropriate utilization and management of groundwater in sand dunes that can contribute to agriculture development while protecting the health of people in the case study areas. Ninety households were interviewed (30 households/district and town). Water samples were taken from 18 cement–walled and earthen wells in six research sites (three well sites) in April, June and August 2003 to analyze for total ammonia nitrogen (NH_{3T}), nitrate nitrogen (NO_3^-), total iron (Fe_T), *Escherichia coli* and total Coliform, Arsenic (As), and pesticide residues (Thiodan and Basudin).

Results from the study indicate that shallow groundwater in sand dunes in the case study areas is currently overexploited. There is no agency monitoring the exploitation of the resource. If this situation continues, the degradation of shallow groundwater and a shortage of freshwater in sand dunes will be unavoidable. Shallow groundwater in sand dunes in the case study areas is mainly used for watering cash crops. In addition, it is also an important source of freshwater supply for domestic consumption for between 81 and 94 interviewed households, especially in the dry season.

Generally, the quality of shallow groundwater in sand dunes in the case study areas meets the Vietnamese standard for groundwater (TCVN 5944 - 1995) and drinking water (TCVN 5501-1991). However, there are some parameters such as total Iron, Nitrate, As, *Escherichia coli* and total Coliform that did not meet the standards in the second (June 2003) and third (August 2003) stages of sampling, especially in Truong Long Hoa village, Duyen Hai district.

INTRODUCTION

Tra Vinh Province is situated in the southern plain region of the Mekong Delta, with the soil a mixture of sand and mud silt deposits. Tra Vinh has many sand dunes and has three water regions: saline, brackish and fresh water, making agriculture and aquaculture the main economic lifeblood of the Province. It is bordered on the North and Northwest by Vinh Long, on the Southwest by Soc Trang, and on the Southeast by the South China Sea.

Tra Vinh is facing a shortage of clean freshwater supply for agricultural production and household consumption due to saline intrusion and pollution of surface water. Shallow groundwater in sand dunes has been an important source of freshwater for people living in coastal areas of Tra Vinh province. This research evaluates the present exploitation, utilization and quality of shallow groundwater in sand dunes in Cau Ngang and Duyen Hai districts and Tra Vinh town, Tra Vinh province. The aims are to recommend measures for appropriate utilization and management of groundwater in sand dunes, to contribute to agriculture development whilst protecting the health of the people in the study areas. The specific objectives of the study are:

- To assess the need for clean water and the importance of shallow groundwater in sand dunes for domestic consumption and agricultural production in Cau Ngang and Duyen Hai districts, Tra Vinh town, Tra Vinh province;
- To evaluate the present management, exploitation and utilization of shallow groundwater in sand dunes in the studied areas; and
- To analyze and evaluate quality of shallow groundwater in sand dunes, to assess to the effects of agricultural production and household activities on quality of shallow groundwater in sand dunes in the studied areas.

MATERIALS AND METHODOLOGY

Study sites

The study was conducted at Truong Long Hoa village, Duyen Hai District, Long Son Village, Cau Ngang District, and Ward No. 8, Tra Vinh Town. Figure 1 shows the position of Tra Vinh province and the study sites

Figure 1. The position of Tra Vinh province and the study sites

Data Collection Methods

Rapid Rural Appraisal (RRA) technique was used to collect information about current management, and exploitation of shallow groundwater in sand dunes in the studied areas.

Questionnaire surveys were conducted at Truong Long Hoa village, Duyen Hai District, Long Son Village, Cau Ngang District, and Ward No. 8, Tra Vinh Town (30 households per village/town) to collect information related to current agricultural development and practices, and the needs of freshwater for household consumption and agricultural production in the study areas.

At Truong Long Hoa village, Duyen Hai district, three water samples were taken from earthen wells on the sand dunes labeled TLH1, TLH2. TLH3, and an other three water samples were taken from earthen wells next to the sand dunes labeled TLH4, TLH5 and TLH6. At Long Son village, Cau Ngang district, three water samples were taken from earthen wells for watering agricultural crops, labeled LS1, LS2, LS3, and an other three water samples were taken from cement- walled wells for household consumption, labeled LS4, LS5 and LS6. At Ward No.8, Tra Vinh Town, three water samples were taken from earthen wells for watering agricultural crops, labeled W81, W82, W83, and an other three water samples were taken from cement- walled wells for household consumption, labeled W84, W85 and W86 to analyze for total ammonia nitrogen (NH_{3T}), nitrate nitrogen (NO_3^-), total iron (Fe_T), *Escherichia coli* and total Coliform, Arsenic (As), and pesticide residues (Thiodan and Basudin). However, samples analyzing for pesticide residuals were only taken in August, 2003.

Data Analysis Methods

Water samples were analyzed at the Environmental Quality Laboratory, Department of Environment and Natural Resources Management, College of Agriculture, and Advanced Laboratory of Cantho University using APHA[1] methods

Excel Microsoft Program was used to run descriptive statistics, and SPSS software was used to analyze One-way ANOVA to compare the different concentrations of analyzed water quality parameters from different sampling cycles and sites.

RESULTS AND DISCUSSIONS

The importance and management of shallow groundwater in sanddunes in the study areas

About 13.5 percent or 10.5 million of Vietnamese people rely on groundwater for their daily water needs. It is estimated about 80 percent of the population in the coastal provinces in the Mekong Delta are dependent on groundwater for their domestic consumption. In Tra Vinh province, there are about 41,512 tube wells, 14,465 cement-walled wells, 13 cleanwater supply centers for rural areas, and 199,149 jars for rainwater storing. These water supply systems provide about cleanwater for about 466,523 among 910,652 people (51 %) living in rural areas of the province (Department of Science, Technology and Environment Tra Vinh Province [2]).

Results from this study indicated that there were only about 50 deepwells in Truong Long Hoa village, Duyen Hai district. However, 100 percent of interviewed households accessed to clean water supply because households with deepwells allowed other households access to the clean water from their deepwells. In the rainy season, water from earthen wells is used for bathing and washing clothes and rainwater is used for drinking and cooking. In addition, about 90 percent of interviewed households still used water from shallowwells for watering their cashcrops. The average depth of the shallowwells is about 3,6 m (ranging from 1 to 4 m) and the width from 2.5-3.5 m. Each household digs about 4-5 shallowwells to get enough water for watering their cashcrops in the dry season.

In the past, all people living on sand dunes in Tra Vinh province replied completely on shallow groundwater in sanddunes for drinking, cooking and bathing. Due to shallow groundwater resources depletion, they have accessed to other water supply sources. Hence, only poor people or those living in areas where freshwater is not available from other sources, still rely on shallow groundwater in sand dunes .

In Long Son village, Cau Ngang district, 65.6 percent and 16.6 percent of interviewed households are still using water from cement-walled wells, and earthen wells for drinking and cooking, respectively. The depth of the cement-walled wells is about 3- 7 m. For watering the cash crops, 53.1 percent of interviewed households used freshwater from earthen wells, 37.5 percent from canals, 6.3 percent from deepwells and 3.1 percent from cement-walled wells.

In Ward No.8, Tra Vinh town, results from the questionnaire interviews indicated that 65.6 percent of households used water from cement-walled wells, 18.8 percent from deepwells and 15.6 percent from earthen wells for cooking and drinking. In addition, 56.3 percent of interviewed households used water from earthen wells , 37.7 percent used water from cement-walled wells for bathing and clothwashing. Shallow groundwater in sanddunes is the main water supply for watering cashcrops in Ward No.8, Tra Vinh town. 76.7 percent of interviewed households used water earthen wells and the rest 23.3 percent used cement-walled wells for watering cashcrops. Figures 2 and 3 show earthen wells and cement-walled wells in the study areas.

Figure 2. Earthen wells for watering cashcrops in the study areas.

Figure 3. Cement- walled wells for domestic consumption and watering cashcrops in the study areas.

Agricultural Section under Village People Committee is the administrative body managing the use of water resources in village level. However, its management is focused mainly on deep groundwater. The utilization of shallow ground water in sand dunes is still openly accessed. The number of wells changes from season to season. In the dry season (from May to November), farmers dig earthen wells to get freshwater for watering the cash crops. About 4 -5 wells per household. The size of each well is 2.5 to 4.0 m width and 2.1 to 3.0 m depth. The shallow ground water in sand dunes is recharged by rainwater. Hence, the depth of water column in the wells varies from season to season depending on rainfall . The highest water column occurs in October and lowest one happens in May. In the areas where farmers practice rotation of rice and cash crops, in the dry season farmers dig earthen wells for watering the cash crops; in the rainy season, they fill up the wells for rice planting together with land in the field.

Water quality of shallow groundwater in sand dunes in the study areas

Chemical parameters

Total ammonia Nitrogen (N-NH_{3T})

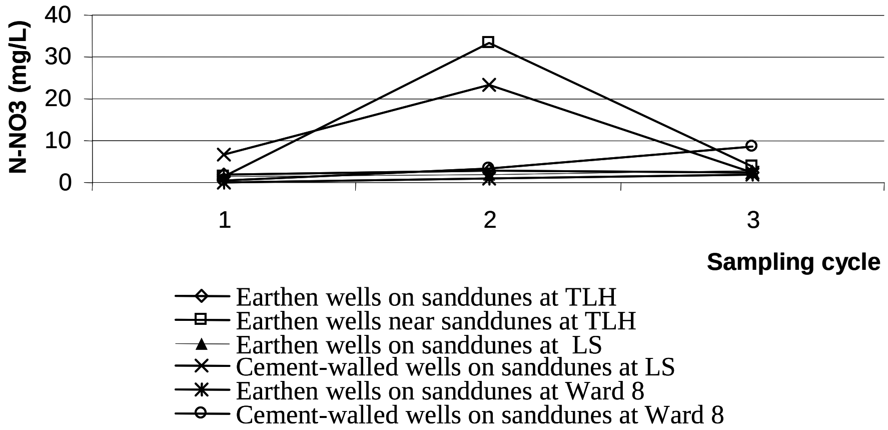

Figure 4. Changes of total ammonia nitrogen (N-NH3T) concentrations in water samples taken from the study areas

From Figure 4 we can see that concentrations of N-NH_{3T} in the study areas were lowest in the first sampling cycle (April 2003) because it is the end of the dry season in the Mekong Delta. The highest concentrations of N-NH_{3T} were found in the second sampling cycle (June 2003), early raining season in the Mekong Delta. The high concentrations of N-NH_{3T} in the second (June 2003) and the third sampling cycle (August 2003) in the study areas may be explained by the results of run-off water bringing nutrients from land to the shallow groundwater. Results of one –way ANOVA analysis showed that there is significant difference ($P<0.05$) in N-NH_3 concentrations in earthen wells near sanddunes at Truong Long Hoa village, earthen wells and cement- walled wells at Long Son village, and earthen wells at Ward No. 8, Tra Vinh town in the first, second and third sampling cycle. In addition, concentrations of N-NH_3 in cement- walled wells at Ward No. 8, Tra Vinh town were higher than the Vietnamese standard for groundwater (TCVN 5944- 1995) of < 3mg/L.

Nitrate Nitrogen (N-NO_3)

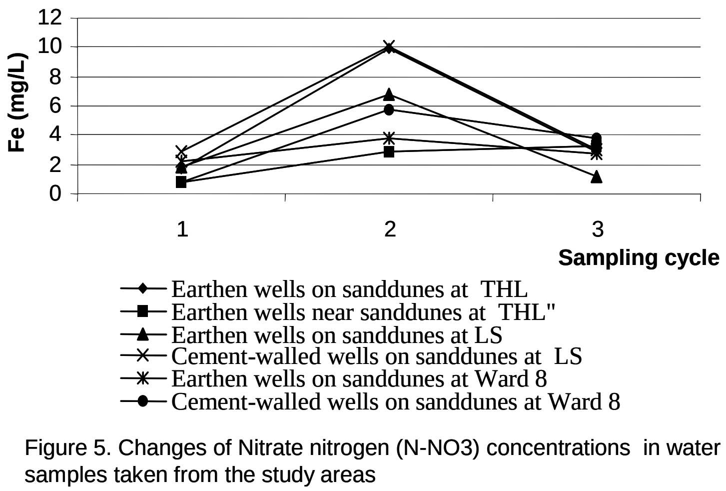

Figure 5. Changes of Nitrate nitrogen (N-NO3) concentrations in water samples taken from the study areas

From Figure 5 we can see that concentrations of N-NO_3 in the study areas were also lowest in the first sampling cycle (April 2003). The highest concentrations of N-NO_3 were found in the second sampling cycle (June 2003) and then the third sampling cycle (August 2003). However, Results of one-way ANOVA analysis showed that there is no significant difference ($P<0.05$) in N-NO_3 concentrations in water in shallow groundwater in sanddunes in the study areas in three sampling cycles. There is only significant difference in N-NO_3 concentrations in cement-walled wells at Ward No. 8 in three sampling cycles. The results from our study are different from those from Dinh [3]. According to Dinh [3], Nitrate nitrogen concentrations in shallow groundwater in sand dunes at Tra Vinh- Da Loc, Hoa Thuan- Hoa Loi- Hiep Hoa, and Vinh Kim- Cau Ngang in the dry season are higher than in the rainy season. The difference can be explained by the fact that the wells studied by Dinh [3] are cement-walled wells with covers on the top, therefore, run-off water can't discharge directly into the wells. According to Ahm et al [4], in the dry season, water is not saturated in soil , oxygen will oxidize NH_3 in soils to form NO_3 that will be ended up in ground water. Results from monitoring quality of shallow groundwater from the period of 1992- 1995 by the Department of Minerals and Geology [5] showed that concentrations of NO_2^- and NO_3^- in shallow groundwater in Tra Vinh province were highest in October, the end of the rain season, especially in areas near dense population densities or intensive agriculture. In general speaking, concentrations of NO_3 in shallow groundwater in the study areas are low, only three wells (TLH6, LS1 and LS4) among 18 sampled wells had NO_3^- concentrations in the second sampling cycle higher than Vietnamese Standard for groundwater quality (TCVN 5944-1995) of 45 mg/L .

Total iron (Fe_T)

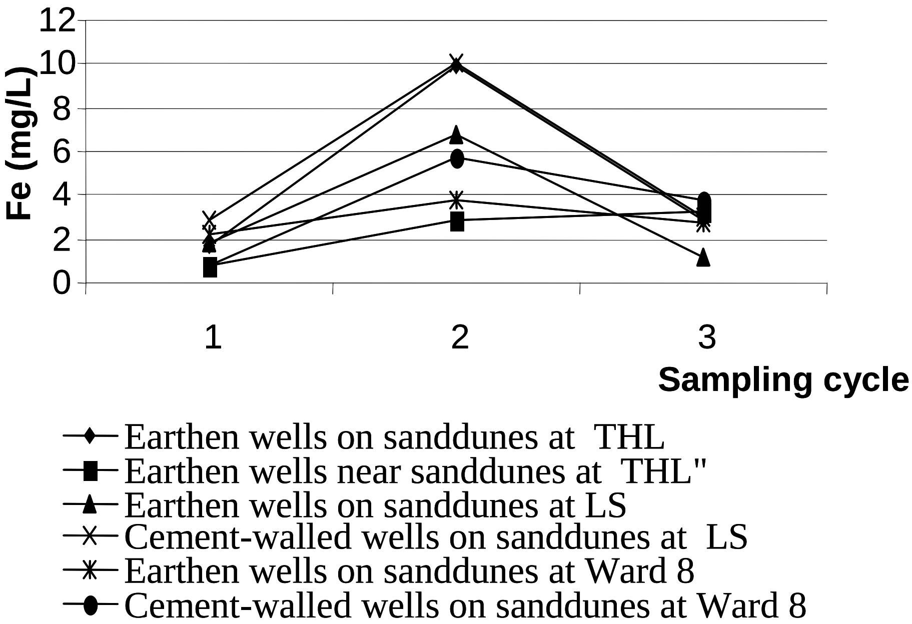

Figure 6. Changes of Total iron (FeT) concentrations in water samples taken from the study areas

From Figure 6 we can see that concentrations of Fe_T in the study areas were lowest in the first sampling cycle (April 2003) and highest in the second sampling cycle (June 2003). In addition, the concentrations of Fe_T were high in cement- walled wells on sanddunes at Long Son village and earthen wells on sanddunes at Truong Long Hoa village. Concentrations of Fe_T in water from these wells are higher than Vietnamese standard for groundwater quality (TCVN 5944-1995) of 3-5 mg/L. Results of one-way ANOVA analysis showed that there is no significant difference ($P<0.05$) in Fe_T concentrations in water in shallow groundwater in sanddunes in the study areas in three sampling cycles. Results of the study are different from those obtained by Dinh [3]. According to Dinh [3], Concentrations of Fe_T in shallow groundwater on sanddunes at Tra Vinh- Da Loc, Hoa Thuan- Hoa Loi- Hiep Hoa, and Vinh Kim- Cau Ngang were high in the dry season and low in the rainy season. The difference can be explained by the fact that the wells studied by Dinh [3] are cement-walled wells with covers on the top, therefore, run-off water can't discharge directly into the wells.

Biological parameters
Ecoli (MPN/100 mL)

Results of analysis for *Ecoli* (MPN/100 mL) in water samples taken from the study areas in sampling cycle 1 (April 2003), sampling cycle 2 (June 2003) and sampling cycle 3 (August 2003) are presented in Figure 7.

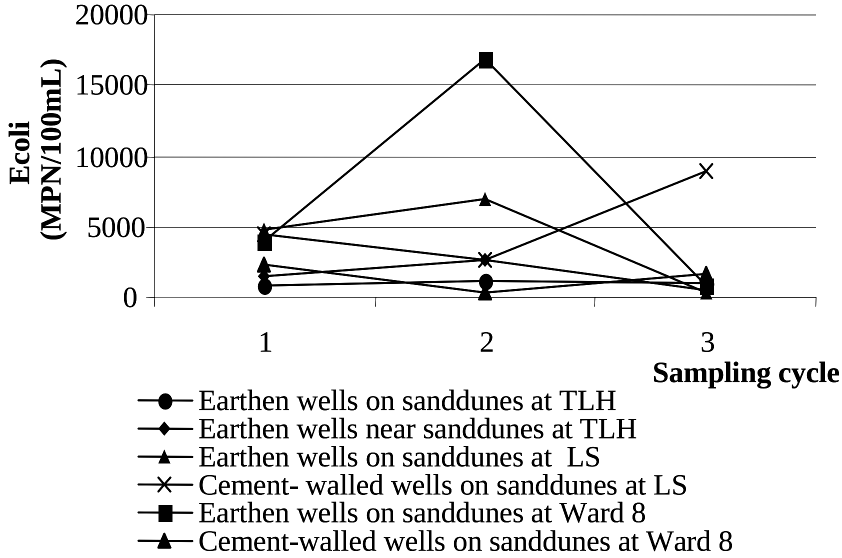

Figure 7. Changes of Ecoli (MPN/100 mL) in water samples taken from the study areas

From Figure 7 we can see that number of Ecoli is rather high in water from earthen wells on sand dunes at Ward No. 8, and earthen wells on sand dunes at Long Son village. However, results of one-way ANOVA analysis showed that there is no significant difference ($P<0.05$) in *Ecoli* numbers in water in shallow groundwater in sanddunes in the study areas in three sampling cycles.

Total Coliform (MPN/100 mL)

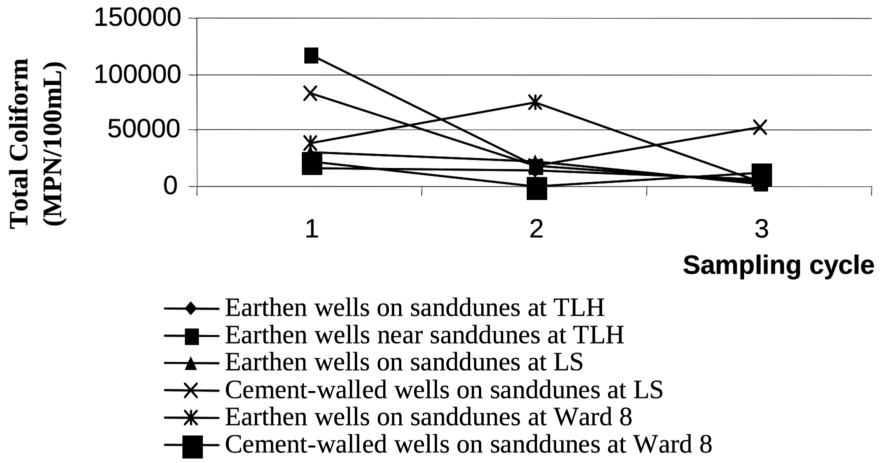

Figure 8. Changes of Total Coliform (MPN/100 mL) in water samples taken from the study areas

From Figure 8 we can see that Total Coliform (MPN/100 mL) were very high in water samples taken from earthen wells near sand dunes at Truong Long Hoa, cement- walled wells at Long Son village and earthen wells at Ward No.8, Tra Vinh town. Total Coliform (MPN/100 mL) in water from these wells are higher than Vietnamese standard for groundwater quality (TCVN 5944-1995) of 3 MPN/100 mL. Results of one- way ANOVA analysis indicated that there is no significant difference ($P<0.05$) between different sampling sites in the three sampling cycles. However, there is a significant difference in total Coliform (MPN/100 mL) between earthen wells and cement-walled wells at Ward No.8, Tra Vinh town. Water from these wells is not only used for watering agricultural crops but also for household consumption that may have negative effects on human health , especially intestine diseases.

Heavy metal and pesticide residuals

Arsenic (As) concentration

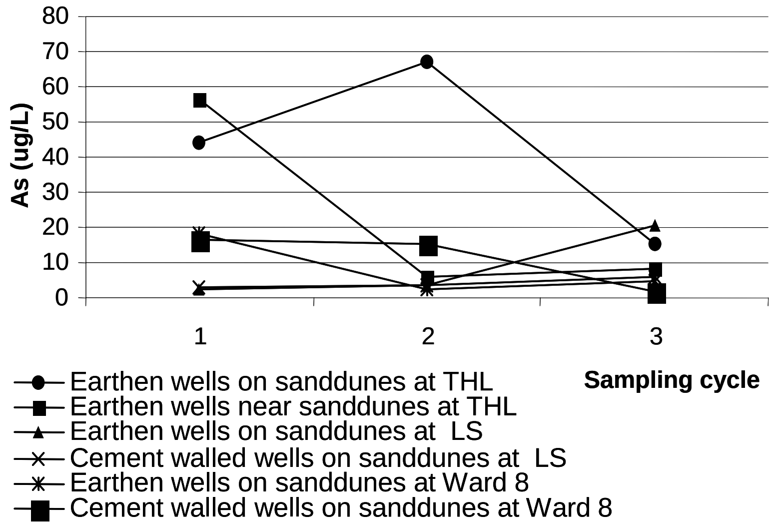

Figure 9. Changes of As concentration (μg/L) in water samples taken from shallow water wells in the study areas

From Figure 9 we can see that As concentrations in shallowwells on and near sand dunes at Truong Long Hoa is very high in all sampling cycles. In addition, As concentrations in shallowwells in the dry season are higher than in the rainy season. However, results of one- way ANOVA analysis indicated that there is no significant difference ($P<0.05$) in As concentrations in the six sampling sites in three sampling cycles.

It is worth to mention that the total iron (Fe_T) were also higher in shallow groundwater in sand dunes at Truong Long Hoa village. According to Gustafsson and Tin [6], areas in low-lying sediments, acid sulphate soils, we can find inorganic Arsenic as Arsenite ($H_2AsO_3^-$/ $H_3AsO_3^-$; As (III)) which is stable in reducing conditions and Arsenate ($H_2AsO_4^-$/ $HAsO_4^-$; As (V)) which is the dominant species in under oxidizing conditions Arsenate (As(V)) is expected to be very sparingly soluble in most soil environments, because of a very efficient inner- sphere complex adsorption mechanism on Fe and AI oxides. Arsenite (As(Ill)) may also be adsorbed, but to a significantly lesser extent. Furthermore, As(III) adsorption decreases with decreasing pH within the pH range of interest for acid sulphate soils. Arsenite, therefore, is the most soluble of the different inorganic As species.

Pesticide residuals

Results of analysis for pesticide residuals indicated that Basudin was not detected in the study areas. However, Thiodan was found at concentration of 0.32 μg/L and 0.15 μg/ in earthen wells on sanddunes at Truong Long Hoa village and Long Son village, respectively. Cultivation of cash crops (watermelon, gourd, pumpkin, bitter melon…) is the main agricultural activities in Truong Long Hoa village. In Long Son village, besides above cash crops, farmers are also planting rice. They spray pesticides for cashcrops more than for rice cultivation. The common pesticides used are Thiodin, Badan, Reagent, and Basudin.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Shallow ground water in sand dunes is still an important freshwater source for people in the study areas. 56-90 percent of interviewed households use Shallow ground water in sanddunes for watering agricultural

crops (3- 5 wells/household) and 81-94 percent use water for cooking, drinking and bathing (1 well/ household) .

2. There is no local governmental body to manage Shallow ground water in sanddunes . The use of the resource is open access. Awareness of local people on protection of shallow ground water in sanddunes is low. They do not know fully about the impact of poor water quality on human health.
3. Generally speaking, the quality of shallow ground water in sand dunes in the study areas still meet Vietnamese standards for groundwater quality (TCVN 5944-1995) and Vietnamese standards for drinking water quality (TCVN 5501-1991), However, concentrations of some parameter such as Fe_T , N-NO_3^- , As, *Ecoli* and total Coliform are higher than the standards in the rainy season, especially at Truong Long Hoa village, Duyen Hai district.
4. Wastes from domestic and agricultural activities are the main cause for pollution of shallow ground water in sanddunes in the study area

Recommendations

1. The cleanwater, sanitary and rural environment program should focus on cleanwater supply for people living in the coastal areas in the Province.
2. Monitoring program for quality and utilization of shallow ground water in sand dunes should be carried out to protect human health and sustainable use of the resource.
3. Shallow ground water wells that supply water for domestic consumption should have a cover on their tops, and the land around the earthen wells should be elevated to stop run-off water discharge directly into the wells.
4. Provide help for farmer to build proper toilets, plant trees and grasses on bared land on sand dunes and proper use of organic fertilizers to protect the water sources from pollution.
5. Run an environmental program to increase awareness of people on protection of environment and shallow ground water in sand dunes

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ESTIMATION OF IRRIGATION WATER AND RICE YIELDS USING CROPWAT MODEL IN LAO PDR

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ABSTRACT

In Lao PDR, the population is growing rapidly and is expected to continue growing, which will inevitably lead to an increase in food demand. To maintain self-sufficiency in food supply, one option is to raise the unit yield. According to the Ministry of Agriculture-Forestry, Lao PDR, the total rice harvested area in 2002 was about 3% of the total land and the irrigated rice area was about 11% of the total rice harvested area. The rainfed yield was 3.5 ton/ha for lowland rice and 1.8 ton/ha for upland rice, and the irrigated yield was 4.5 ton/ha. Thus, the low proportion of irrigated rice area resulted in unsustainable food supply. For stable food supply, the key is determining the area of rainfed paddy that could be irrigated. Therefore, estimation of the water requirements and evaluation of the effects of installing irrigation are extremely important. The study area was the KM35 Irrigation Project Site at Savannakhet Province. The area was divided into 13 segments. Using the CROPWAT model, irrigated water into the paddy at each area of KM35 was estimated for the 2004 rainy season. In the estimation process, yield response coefficient ky was modified, and also, the partition height was taken into consideration. The estimated volume of irrigation water for the entire KM35 site was 7% of the active capacity of the reservoir. Irrigation days were from 26 to 43 (34 on average). From the relation between partition height, hardpan depth and actual yield, it was revealed that actual yield had a positive correlation to partition height, most likely due to the reserved water up to the partition height, and a negative correlation to hardpan depth. The relation to irrigation days indicated the opposite results to those of actual yield. In the case of KM35, total irrigation volume in the rainy season was minimal. When the supplementary irrigated rice yield is higher than the rainfed yield, this indicates that supplementary irrigation is available for raising the unit yield. In addition, even if part of the area is irrigated in the dry season, further increases can be expected within the year. Because this model did not take into consideration groundwater level or the effects of fertilizers, it is necessary to include these factors for improved accuracy when estimating dry season irrigation.

INTRODUCTION

In Lao PDR, evaluation of the food supply is very important from the perspective of the country's rapid population growth (UN, 2004), and inevitable increase in food demand. On the other hand, water and land resources are not expected to change dramatically. In determining the methods for maintaining self-sufficiency in food supply, expansion of harvested areas is not possible because the land is almost fully used, but raising the unit yield is a viable option.

A favorable method for raising the rice yield per unit is through irrigation. According to the Ministry of Agriculture-Forestry, Lao PDR, the total rice harvested area in 2002 was 738,104 ha, which is about 3% of the total land. Irrigated rice area was about 11% of the total rice harvested area, and the remaining 89% was rainfed paddy area. The rainfed yield was 3.5 ton/ha for lowland rice and 1.8 ton/ha for upland rice, and the irrigated yield was 4.5 ton/ha. Thus, the low proportion of irrigated rice area resulted in unsustainable food supply. For stable food supply, the key is determining the area of rainfed paddy that could be irrigated. Therefore, estimation of water requirements and evaluation of the effects of installing irrigation are extremely important.

STUDY AREA

The KM35 Irrigation Project Site (KM35) of Savannakhet Province in Lao PDR was selected as the study area (Fig. 1). In 2002, the province's rice harvested area was the largest in Lao PDR and its production accounted for about 20% of the total (Fig. 2), demonstrating the importance of Savannakhet Province for rice production.

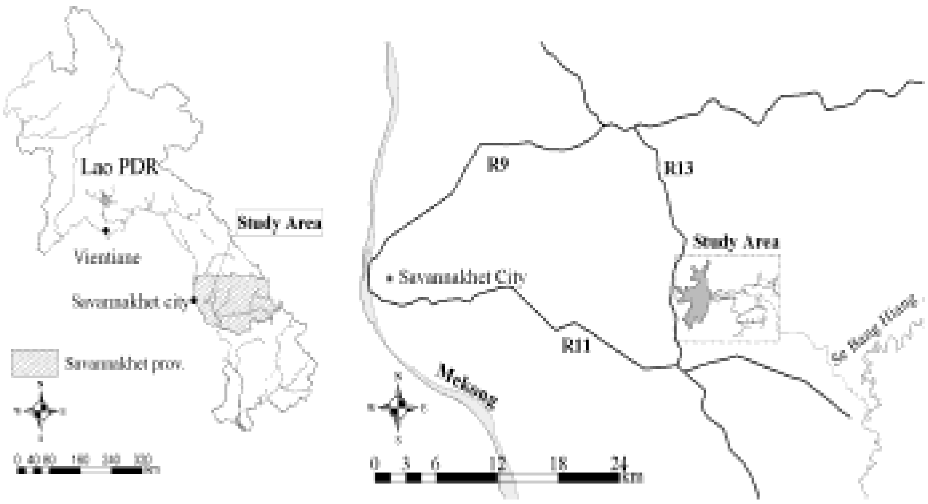

Fig. 1: Location of the study area

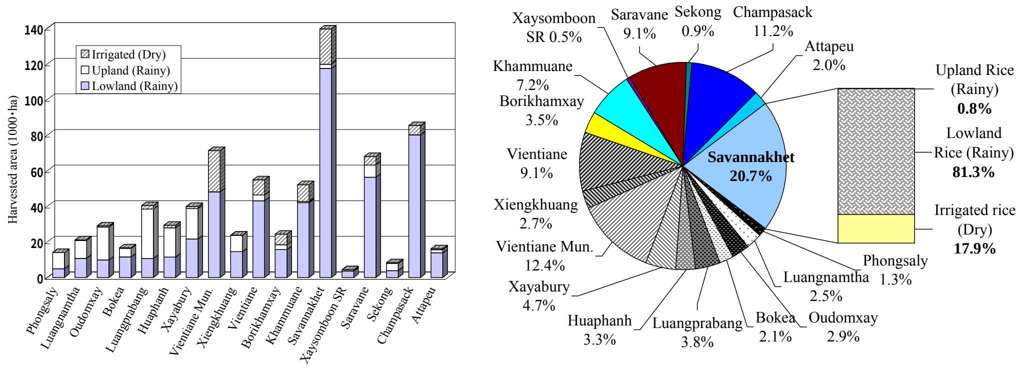

Fig. 2: Harvest area and yield of Lao PDR

KM35, located 35 km from Savannakhet City, was constructed under the Japan International Cooperation Agency (JICA) in 1996. The field belongs to a branch of the Se Bang Hiang River, which is a tributary of the Mekong. Total cultivating area is 950 ha with a reservoir having 8.9×10^6 m^3 of active capacity and 31.0 km^2 of catchment area. During the planning stage, 950 ha was allocated for cultivating paddy rice with supplementary irrigated water in the rainy season, and 550 ha was allocated for paddy rice and 400 ha for upland crops with irrigation water in the dry season (JICA, 1992). However, the area was not completely irrigated every dry season due to water shortage, the high cost of fertilizers and the breakdown of some canals. Average annual rainfall from 1993 to 2002 was about 1,500 mm at Kengkok Station near KM35: approximately 85% was in the rainy season from May to September and the rest was in he dry season (MRC, 1993-2002). Thus, rice cultivation was impossible without irrigation water.

Fig. 3 shows the details of KM35. There are two main canals, three secondary canals on the left side, four secondary canals on the right side, and several tertiary canals on each side. In this study, the field was divided into 13 areas: 5 areas on the left canal side and 8 areas on the right canal side. Table 1 shows each area, the partition height, hardpan depth and rainy-season rice yield in 2004.

Table 1: Hardpan depth, partition height, yield and area

Number	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Hard Pan Depth (cm)	13.9	14.8	10.2	10.9	10.6	11.7	11.0	11.9	10.0	9.5	10.5	10.6	11.8	
Partition Height (cm)	16.1	17.7	21.9	18.9	18.3	16.1	20.4	20.0	22.3	30.3	22.6	24.1	20.9	
Actual Yield (t/ha)	3.65	2.40	3.86	2.46	2.74	2.79	5.95	3.36	3.96	3.91	2.57	4.89	3.17	
Area (ha)	39	62	71	109	87	47	18	83	89	50	99	144	52	950

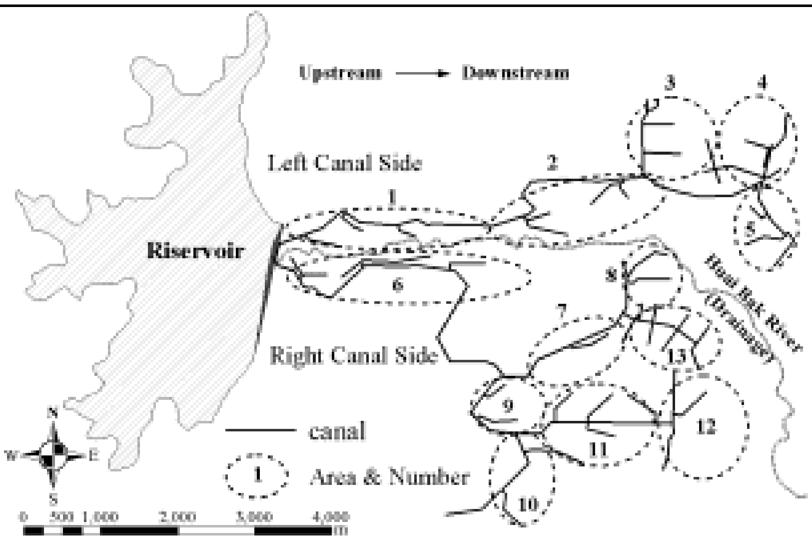

Fig. 3: KM35 divided into 13 areas

METHODOLOGY

A model based on CROPWAT by the Food and Agriculture Organization of the United Nations (FAO) was used in this study. Partition height was taken into consideration and the yield response coefficient was modified. Using this model, rainfed yields were estimated first. Then, calculations were performed to determine how much supplemental water was irrigated to produce the actual yields in each area, respectively. All data was collected in the rainy season of 2004. For the calculation, meteorological data, except for rainfall, was collected from the Savannakhet Weather Station. Rainfall data was collected from the Kengkok Station closer to the field.

Crop Evapotranspiration

Crop evapotranspiration can be calculated from the following equation (Richard, 1998):

$$ETc = \left(Kc + Ke\right)ETo \tag{1}$$

$$ETa = \left(Ks \bullet Kc + Ke\right)ETo \tag{2}$$

where ETc and ETa are crop evapotranspiration, standard and adjusted for water stress, respectively, ETo is reference crop evapotranspiration, Ks is water stress coefficient, Kc is crop coefficient, and Ke is evaporation coefficient. Then, ETo is evapotranspiration from the hypothetical reference surface, and is calculated from the FAO Penman-Monteith equation as follows:

$$ETo = \frac{0.408\Delta\left(R_n - G\right) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (3)$$

where R_n is net radiation at the crop surface, G is soil heat flux density, T is mean daily air temperature at 2-m height, u_2 is wind speed at 2-m height, e_s and e_a are saturation and actual vapor pressures, respectively, Δ is slope vapor pressure curve and γ is psychometric constant. Each parameter is determined from meteorological data sets. In Eq. 1, Kc is given from FAO, Ks is calculated from water stress as explained below, and Ke is determined by the soil condition.

Yield Decrease

CROPWAT is suitable for upland crops, but paddy rice differs in cultivating style. Paddy rice cultivated on lowland is generally framed in by partitions. These partitions can store rain or irrigated water in an amount up to its height, which protects the rice plants against drought for a while. For this reason, the effect of the partition height was taken into consideration. Water content is determined by the sum total of rainfall, irrigation water, evapotranspiration, runoff above the partition and deep percolation from the hardpan. If the water content decreases across the surface, some water deficit will occur. The rice can use water until the water deficit reaches the Total Available Water. However, when the water deficit exceeds the capacity of Readily Available Water, water stress is generated. The water stress is determined by Ks estimated from the following equation:

$$Ks = \frac{TAW - Dw}{TAW - RAW} \quad (4)$$

$$Dw,\ i = De, i\text{-}1 - Pi - Ii + ETa, i + DPi \quad (5)$$

where Dw is the water deficit, TAW and RAW are total and readily available water, respectively, P is rainfall, I is irrigated water, DP is deep percolation, and *i* is the day number. When water stress reaches the rice plant, the evapotranspiration must be decreased from non-stressed ones. This decrease means that the rice plant could not produce its potential yield, which is only possible without water stress. The yield decrease is estimated from the following equation:

$$\text{Yield Decrease} = Yp - Ya = Ky \bullet \left(1 - \frac{ETa}{ETc}\right) \bullet Yp$$

$$Yp = 4.50 \text{ ton/ha} \quad (6)$$

where Ya is actual yield, Yp is potential yield under non-water-stress conditions, and Ky is yield response coefficient. The value of Yp was the maximum rice yield of Savannakhet Province, and was obtained from statistical data.

Determination of Ky

The yield response coefficient Ky was adjusted to the measured actual yields (Table 2). According to FAO (Doorenbos, 1986), Ky value of rice plants is 1.4, 3.0 and 0.4 for each stage, vegetative, flowering and yield formation, respectively. Using these values, the estimated yield of KM35 under rainfed conditions ranged from 3.15 to 3.24 ton/ha. On the other hand, the measured minimum yield was 2.40 ton/ha at Area 2. The FAO values were not suitable in the case of KM35; therefore, Ky was adjusted to approximately equalize the yield between the actual and rainfed estimation at Area 2.

Table 2: Ky value and growing stage

Stage	Establish-ment	Vegetative	Flowering	Yield Formation	Ripening
Period (days)	15	65	15	35	20
Ky	2.3	↗	4	↘	1.4
Ky from FAO	1.3	↗	3	↘	0.4

Estimation of Irrigated Water

From actual yield data, irrigated water volume is adversely estimated from Eqs. (1) through (6) and the following equation:

$$\mathrm{Ya} = \frac{\sum Xi}{n} \bullet \mathrm{Yp}$$

$$Xi = 1 - \mathrm{Ky}\left(1 - \frac{\mathrm{ETa}, i}{\mathrm{ETc}, i}\right) \qquad (7)$$

where n is 150 days for the total rice planting period. The daily irrigation volume is determined to fulfill the above equations. The schedule depends on the water deficit. The daily irrigation volume is constant during the entire period, but is changed for each area.

RESULTS AND DISCUSSION

The results of the estimation are shown in Fig. 5 and Table 3. The rainfed yield from each area is estimated under conditions of no rain and ranges between 2.23 and 2.52 ton/ha. Irrigation water was supplied to harvest the actual yield of each area individually. Irrigation water supplied to Areas 2, 4 and 10 was almost zero. When the actual yield exceeded the potential yield such as in Areas 7 and 11, its irrigation water was supplied to harvest the entire potential yield.

Table 3: Results of estimation

Number	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Rainfed Yield (t/ha)	2.23	2.35	2.52	2.40	2.36	2.22	2.50	2.48	2.52	2.52	2.52	2.52	2.53	2.44(avg)
Irrigation (mm/day)	3.0	0.1	3.0	0.1	0.8	1.2	5.5	2.0	3.2	3.1	0.1	5.5	1.5	29.1
Total Irrigation (mm/season)	131	4	90	4	30	50	172	69	96	86	3	144	48	927
Irrigation Days	43	42	30	37	39	43	31	35	30	28	29	26	32	34 (avg)
Area Irrigation (m^3/day)	1,170	62	2,130	109	696	564	990	1,660	2,848	1,550	99	7,920	780	20,578
Total Area Irrigation (10^3 m^3/season)	51.09	2.48	63.90	4.36	26.10	23.50	30.96	57.27	85.44	43.00	2.97	207.36	24.96	623.39

The total irrigation water volume of each area is the sum of the estimated daily irrigation in this rainy season. In the estimation, irrigation days were 26 to 43 (34 on average), total daily irrigation water volume was about 20,000 m^3 per day, and the total volume of the whole rainy season was about 623,000 m^3. The seasonal total was about 7% of the active capacity of the reservoir.

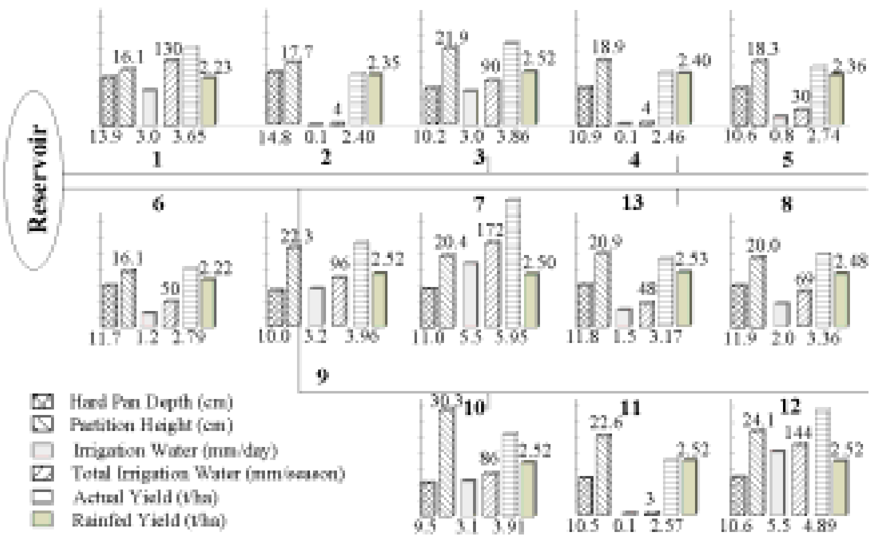

Fig. 5: Results of estimation

The relation between actual yield and partition height, hardpan depth, is shown in Fig. 6. It was revealed that actual yield had a positive correlation to partition height, and a negative correlation to hardpan depth. It is assumed that the positive correlation to partition height is due to the partition reserving water up to its height. However, the hardpan had the opposite result, even though it was able to save water under the soil as well as the partition. On the other hand, the relation of partition and hardpan to irrigation days is shown in Fig. 7, which reveals that irrigation days were negative for partition height, and positive for hardpan depth. In terms of the partition height alone, the reason is the same as explained above. For the hardpan depth, it was shown that a greater volume of irrigation water was required for deeper hardpan, presumably because it was more difficult for deeper hardpan to maintain RAW.

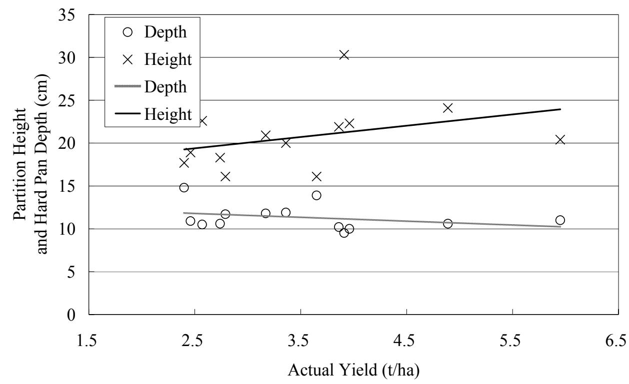

Fig. 6: Relation between actual yield, partition and hardpan

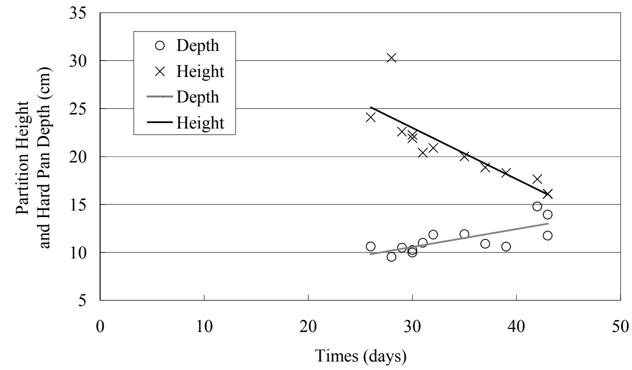

Fig. 7: Relation between irrigation days, partition and hardpan

CONCLUSION

In the case of KM35, it was revealed that total irrigation volume in the rainy season was minimal, only 7% of the active capacity. Furthermore, a correlation between actual yield and partition height was shown. When the supplementary irrigated rice yield is higher than the rainfed yield, this result indicates that supplementary irrigation is available for raising the unit yield. In addition, even if part of the area is irrigated in the dry season, further increases can be expected within the year.

Because this model did not take into consideration groundwater level and the effects of fertilizers, it is necessary to include these factors for improved accuracy when estimating the dry season irrigation.

ACKNOWLEDGEMENTS

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IN-SITU INVESTIVAGATION OF WATER QUALITY IN THE HAU RIVER ESTUARY

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ABSTRACT

The Hau River estuary is a part of the Lower Mekong Delta, Vietnam. The total catchments area of the study site is about 490 km^2. During the flow season, the tides severely intrude into the river and the interior channel systems. The phenomenon not only affects irrigation development but also domestic water supply. Salt water worsens water quality and damages crop-lands. In recent years, salinity measurement has not been made full enough and systematically due to the budgetary limitation. To investigate the hydrodynamic behavior along the Hau River, field investigation of water quality will be carried out from the beginning of 2005 April.

INTRODUCTION

The Mekong Delta covers an area of 45,000 km^2, of which 39,000km^2 or 87% of the whole delta lies within the border of Vietnam. Mekong Delta hereafter refers to the delta in Vietnam. The Mekong Delta is 12% of total land area of Vietnam. About 16 million Vietnamese, or one in every five, live in the delta. The delta covers 4.9% of the entire Mekong River Basin (795,000 km^2) or 6.4% of the Lower Mekong River Basin (606,000km^2).

The Mekong Delta is where the economy has responded quickly to the government's "open door (Doi moi)" policy. The economy of the delta, the major agricultural production area of Vietnam, is oriented towards the primary sector. The delta shares 27% to the total GDP of Vietnam, some 40% of agricultural production, and a half of rice production in the country. Paddy production is at 11 millions tons, nearly 740kg/capita (despite the high population density of nearly 400 people/km^2), making the Mekong Delta the largest producer compared to other river basins in Vietnam. Rice and fishery products contribute significantly to the nation's export earnings. The delta contributes approximately 85% of rice for export. During the dry season saline water from the South China Sea and the Gulf of Thailand move upstream along the rivers and canals of the Mekong Delta. The salinity intrusion into the Mekong Delta is very complicated. The highest salinity is usually observed in April. Currently, 1.77 million ha of delta lands are affected by saltwater intrusion, which not only affects irrigation development but also domestic water supply. Salinity worsens water quality and damages crop-lands. The most severe situations occur during the low flow reason when there is not enough flow to prevent seawater intrusion. Strong tidal waters encroach up to 50-70 km. The existing abstraction increases in the delta. The area affected to increase to 2.2 million ha, if preventive measures are not taken up (MRC [3]).

Therefore, the goal of the study is to investigate thoroughly the flow structure in the Hau River. Detailed results of field investigation of water quality as well as water level are reported in this paper.

STUDY AREA AND FIELD MEASUREMENT

The Hau River estuary (9^0 33’-10^0 46’N, 105^0 00’- 106^0 42’E) is a part of the Lower Mekong Delta (see Fig.1). The total catchments area of the study site is about 490 km^2.The Hau River located in the monsoon tropical semi-equatorial climate zone, the climatic regime in the Hau River is dominated by the two monsoon seasons: the north-east (dry season, from December to April) and the south-west (rainy season, from May to November) (Nien [2]). The measuring length is about 40 km. The maximum and minimum water depth are 15m and 5.2m, respectively.

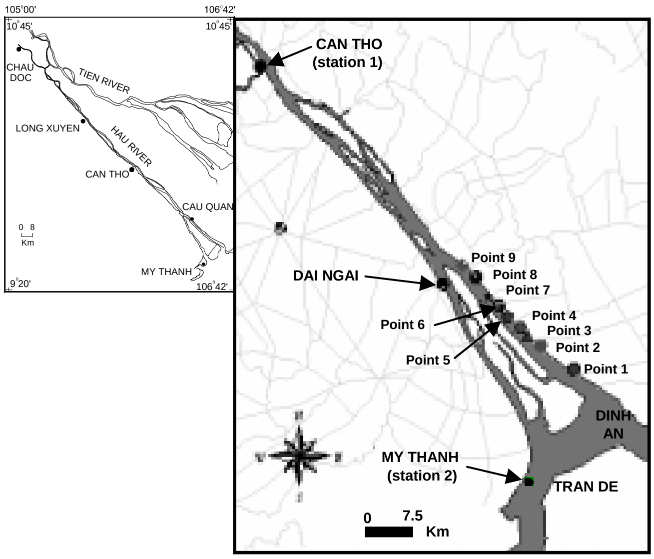


Fig. 1. Location map of the Hau River estuary

Photo 1. Setting up of Compact-CT sensor

Table 1. Location of measuring points by using TPM Clorotec and Compact-CT sensors.

Location of measuring points on 6th April 2005 by using TPM		Location of measuring points on 10th April 2005 by using TPM		Location of Compact -CT sensors	
P1	09^{o}39’11’’N, 106^{o}11’57’’ E	P1	09^{o}36’37’’N, 106^{o}16’50’’ E	B43	09^{o}45’25’’N, 106^{o}06’30’’ E
P2	09^{o}40’56’’N, 106^{o}10’10’’ E	P2	09^{o}38’36’’N, 106^{o}13’48’’ E	B41	09^{o}44’29’’N, 106^{o}07’40’’ E
P3	09^{o}42’49’’N, 106^{o}08’51’’ E	P3	09^{o}39’33’’N, 106^{o}12’35’’ E	B37	09^{o}41’56’’N, 106^{o}09’36’’ E
P4	09^{o}44’27’’N, 106^{o}07’32’’ E	P4	09^{o}40’09’’N, 106^{o}11’55’’ E	B27	09^{o}37’29’’N, 106^{o}13’53’’ E
P5	09^{o}45’28’’N, 106^{o}06’21’’ E	P5	09^{o}41’10’’N, 106^{o}10’11’’ E	** Setting up for long time period (up to June 2006).	
P6	09^{o}46’29’’N, 106^{o}04’55’’ E	P6	09^{o}42’02’’N, 106^{o}09’51’’ E		
P7	09^{o}45’27’’N, 106^{o}04’10’’ E	P7	09^{o}42’56’’N, 106^{o}09’04’’ E		
P8	09^{o}47’27’’N, 106^{o}03’38’’ E	P8	09^{o}44’32’’N, 106^{o}07’45’’ E		
P9	09^{o}49’09’’N, 106^{o}01’11’’ E	P9	09^{o}45’25’’N, 106^{o}06’30’’ E		
P10	09^{o}50’54’’N, 105^{o}59’01’’ E	*			
P11	09^{o}51’49’’N, 105^{o}58’11’’ E				
P12	09^{o}52’43’’N, 105^{o}57’15’’ E				

* P - Measuring points in study site; ** B - The navigation buoy (see Fig. 1 & photo 1)

Measurements were carried out by using TPM Chlorotec (ALEC Electronics Co., Ltd.) to measure salinity, turbidity, water temperature, chlorophyll-a, and water depth. Unfortunately, almost values of turbidity exceed the maximum range of turbidity equipment, therefore this parameter is not shown here. Acoustic Doppler Current Profilers (ADCP) meter was also used to measure the velocity and its direction at several transects and longitudinal sections. In the Mekong delta the lowest flow season usually belongs to April each year; therefore, field investigation of water quality was carried out at the beginning of April, from 6th to 10th April 2005 along the measuring line that can be seen in the Fig. 1. The measuring methods are both towing and profiling by the use of TPM meters. In additional, Four COMPACT-CT sensors also were setup to measure the continuous data of salinity and temperature. Based on the buoy for navigation purpose (mostly located in the center of river), we located these sensors with the buoy (at the buoy N°43, 41, 37, 27, in seaward respectively, see photo 1). Further more, tidal level at the river mouth can be observed in My Thanh station (called station 2), and the upstream discharge can be observed in Can Tho station (station 1) (see Fig. 1). The coordinate system of measuring points in longitude and latitude can be found in the table 1.

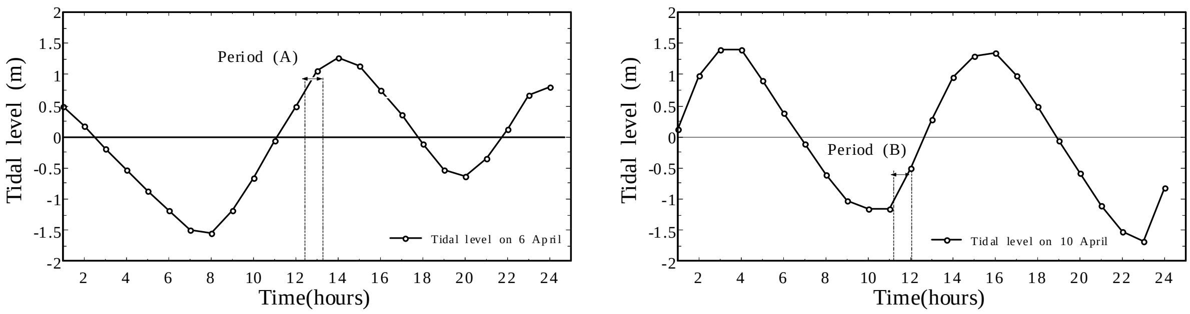
RESULTS AND DISCUSSIONS

Water quality variation

Tides in the South China Sea are predominantly semi-diurnal with non-uniform amplitude. Each day the tide has two crests and two troughs, the height of each crest and trough varies from day to day during about 15 days periods. Two troughs more significantly change as compare with the change of two crests during each a half of month tide period. The amplitude can be up to 2 m, with a phase lag of the borderline of two troughs is a half of tide period. When one trough decreases down, the other trough increases gradually from day to day, and vice versa (Le, [1]).

In order to simulate the water quality phenomena in the Dinh An estuary (see Fig. 1), in term of tidal level from the sea, we would better to use water level at Tra Cu station (near the Dinh An mouth). However, this parameter is not available in the Tra Cu station. To get rip of this situation, we have to use the water level at My Thanh station for simulation.

Water level variation at the My Thanh station should be used for analysis (see Fig. 2). Fig. 2a) is the water level measured on 6th April while water level on 10th April was measured in Fig. 2b). Further more, observation period is also shown in Fig. 2. Period (A) corresponds to the high tide condition; where as period (B) corresponds to the low tide condition. In the figures below, it should be noted that, the lag time of tidal level between 6th and 10th is about 2 hours. Due to this problem, it will cause the changes of salinity intrusion in different periods.

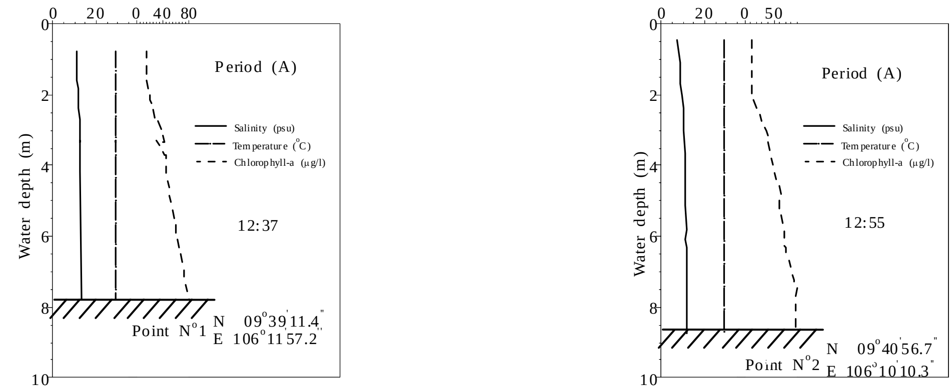


a) On 6th April 2005 b) On 10th April 2005

Fig. 2. Time variation of water level at My Thanh station.

The Mekong River delta is also very sensitive with the East wind (gio Chuong) due to the direction of estuaries North East or East. In the dry season, salinity intrusion length may be extended 8-10 km further due to the strong wind (Nien, [2]).

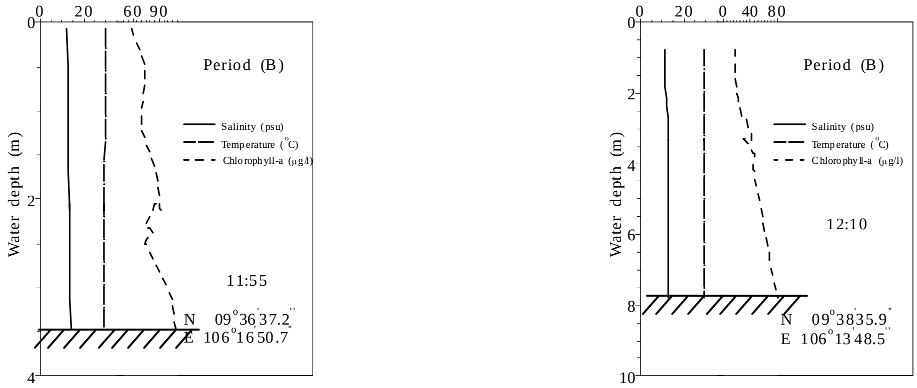
Water quality profiles are shown for period (A) and (B), in the Fig. 3 and Fig. 4, respectively. It can be seen in the Fig. 3 (a) that the temperature distribution is almost constant from the surface to the bottom. The profile of salinity distribution shows slightly linear increase from the surface to the bottom. Contrary to these quantities, chlorophyll-a illustrates the significant increase from the surface to the bottom. All of water quality parameters in Fig. 3 (b) show the same behavior profile with the Fig. 3(a).



(a) Point N°1 (b) Point N°2

Fig. 3. Water quality parameters throughout of water depth at the measuring point N°1 & N°2 on 6th April 2005 during period (A).

During the investigation of period (B) on 10th April, the basic characteristics of profile in Fig. 4 are similar with period (A) in Fig. 3, eventhough the values of salinity and chlorophyll-a are a little bigger than one in Fig. 3. The reason why the measuring points on 10th April are the closer to the sea as compared with the measuring points on 6th April.



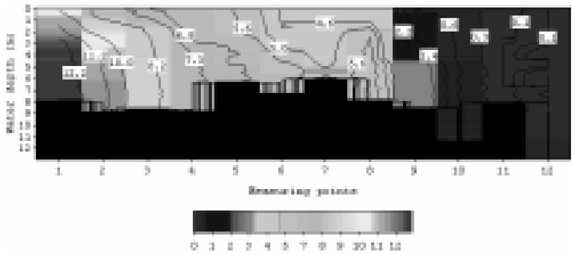
(a) Point N°1 (b) Point N°2

Fig. 4. Water quality parameters throughout of water depth at the measuring point N°1 & N°2 on 10th April 2005 during period (B).

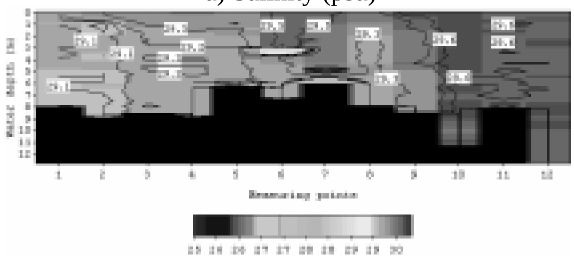
It is more comprehensive to see water quality parameters by plotting longitudinal profile as well as vertical one (Tanaka, [4]), represented in Fig. 5, in which the abscissa indicates the measuring points (see Fig. 1). In Fig. 5 (a) the contour line indicates that the reduction of salinity concentration from the river mouth to the further measuring points upward to upstream. It also agrees with the tidal regime from the high tide to low tide. Further more, in Fig. 5(b), the temperature distribution is almost constant from the surface to the bottom (temperature values range from 29.11 to 30.2). It may be caused by the situation of shallow water in the Hau River.

Contour lines of chlorophyll-a also illustrates the same behavior of reduction concentration from the river mouth to the upstream measuring points. Nearly the water surface, the value of chlorophyll-a is not very high, where as the chlorophyll-a is very high from near the bottom.

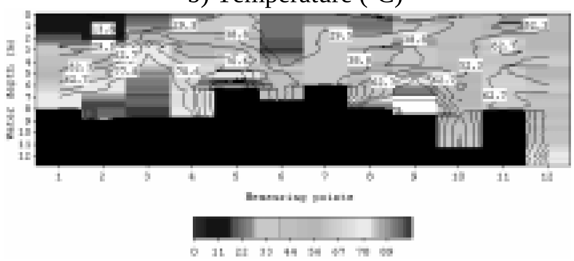
On the other hand, by using towing method, variation of water quality along the Hau River can be seen in the Fig. 7 corresponding to the high tide to low tide (from 12:37 to 16:40 on 6th April 2005).



a) Salinity (psu)

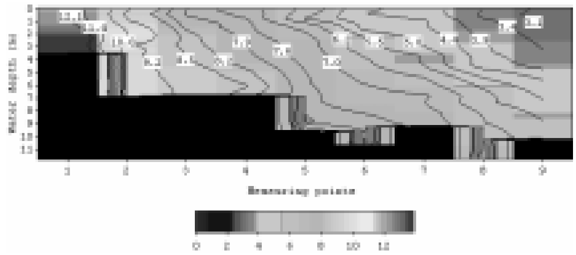


b) Temperature (°C)

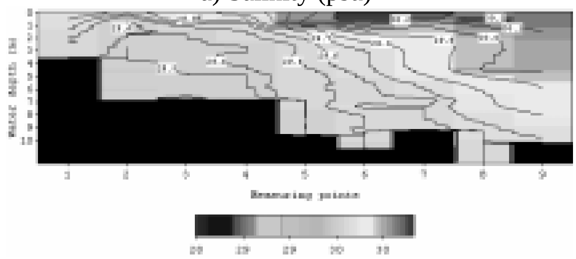


c) Chlorophyll-a (μg/l)

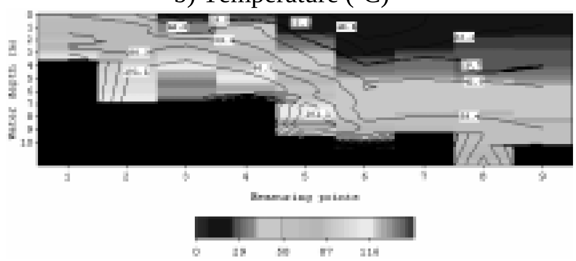
Fig. 5. Water quality profile during period (A) on 6th April 2005



a) Salinity (psu)



b) Temperature (°C)



c) Chlorophyll-a (μg/l)

Fig. 6. Water quality profile during period (B) on 10th April 2005

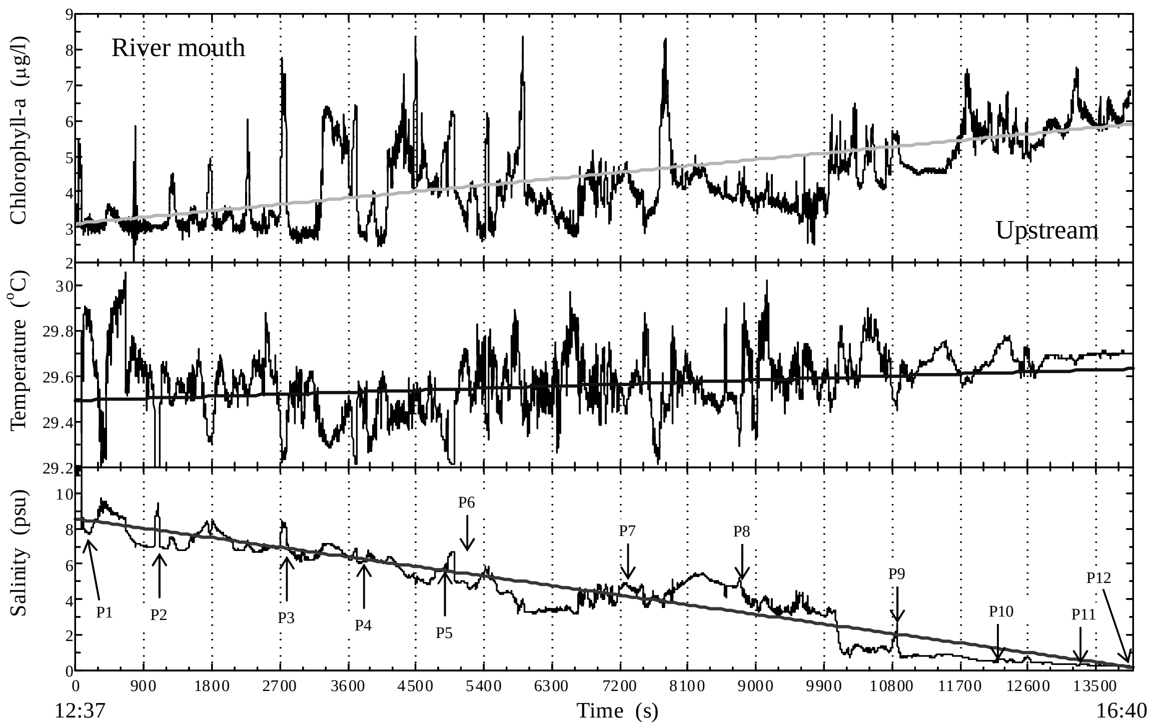
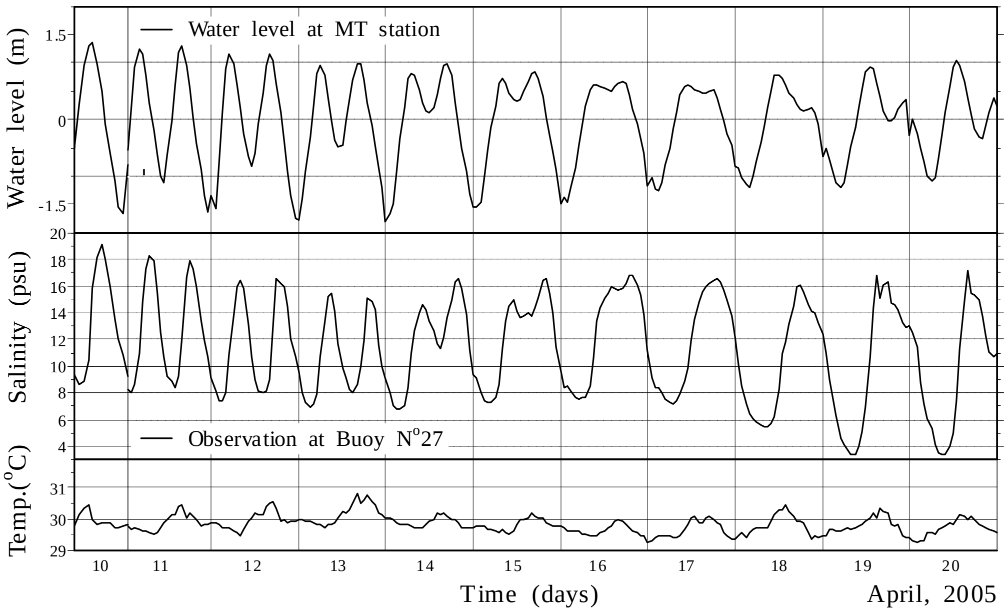


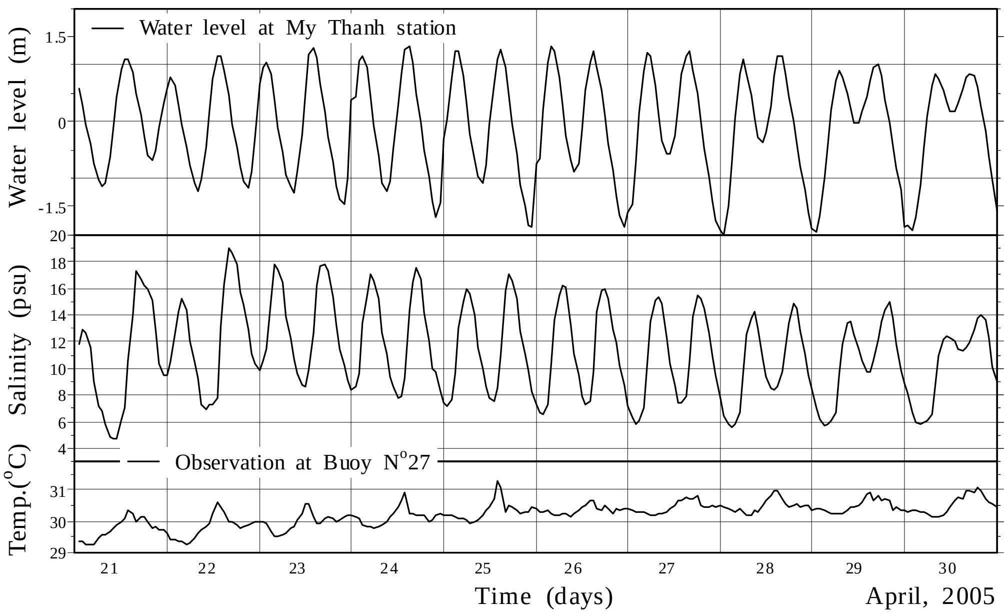
Fig. 7 Time variation of water quality on 6th April 2005 by using towing method

From the Fig. 7, we can see that the tendency of salinity decreases from the river mouth to the upstream, where as temperature distribution is almost constant, in which P_1, P_2 to P_{12} are correlative measuring points as seen in Fig. 5. We suppose that temperature distribution may be caused by the shallow water of the estuary and strong East wind from the South China Sea. In contrast, chlorophyll-a has an increased trend during that period from the river mouth to upstream.

Time variation of Salinity and Temperature

Setting up the Compact-CT the Compact-CT sensor in the navigation buoy, we can get the time variation of salinity and temperature. In order to understand the time variation of such parameter, a correlative time variation of water level has been drawn in Fig. 8.





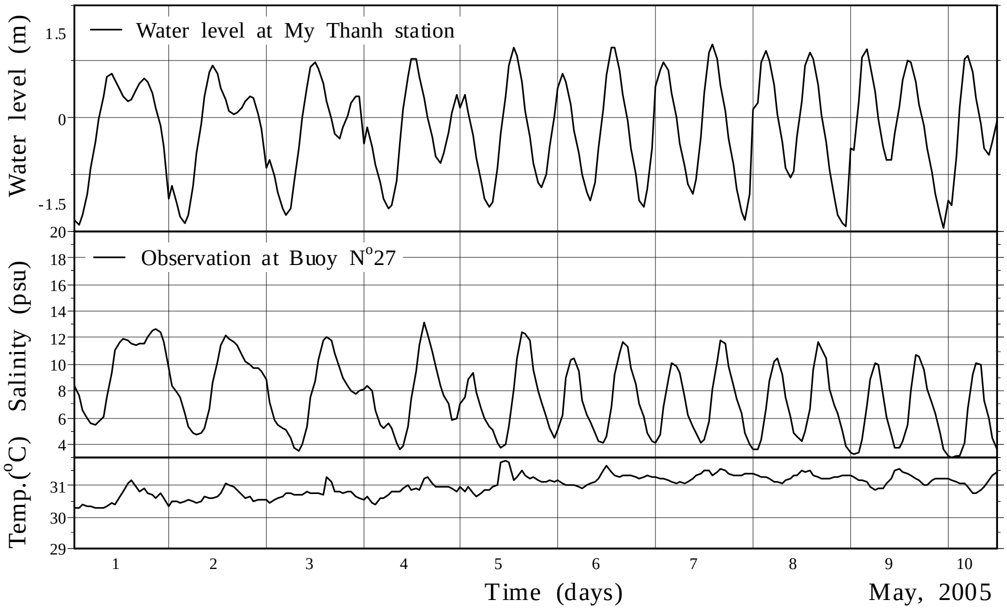
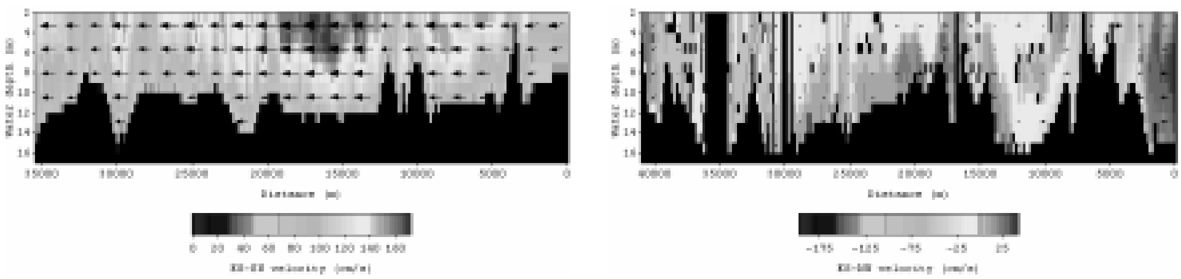


Fig. 8. Time variation of salinity and temperature at the buoy N° 27 (sensor 4) from 10th April to 10th May 2005

From Fig. 8, it is clear to see that the time variation of salinity varies with the general trend of water level, in each day the salinity also has two crests and two troughs. There is a decrease of salinity after 1 month of measurement. It may be caused by the dilution of fresh water from the upstream. From the correlation between time variation of water level and salinity, the crests and troughs of salinity are always later than crests and troughs of water level about 1.8 to 3.5 hours, respectively.

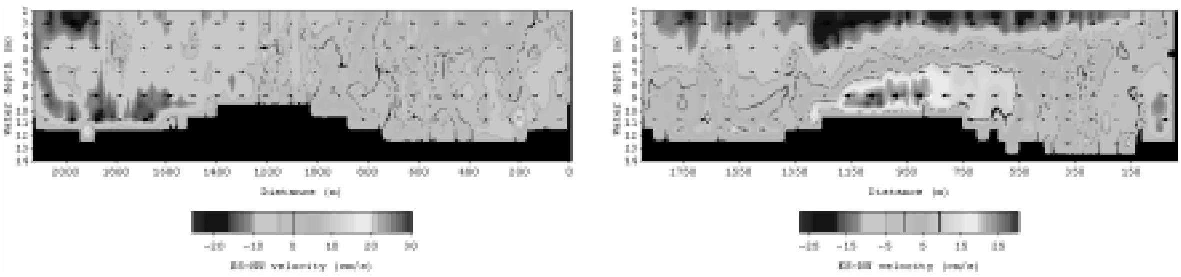
Velocity and its direction along the Hau River

One more important parameter for calibration and verification process is the river flow's velocity and its direction. In the field observation, we use ADCP to measure this parameter at both some cross-sections and longitudinal sections.



a) From low tide to high tide (11:32 ÷ 14:07) b) From high tide to low tide (14:11 ÷ 17:34)

Fig. 9. Velocity distribution at the longitudinal section on 6th April 2005



a) At high tide period (13:08 ÷ 13:26) b) At low tide period (16:04 ÷ 16:21)

Fig. 10. Velocity distribution at the cross-section on 8th April 2005

In the Fig. 9, the velocity magnitude and its vector of velocity in the river flow's direction are plotted at the longitudinal section during the measuring day of 6th April. It should be noted that the flow direction of the Hau River does not coincide with the North/South (N/S) or East/West direction (E/W). By and large, in this case we should use the maneuver in order to project N/S and E/W velocity components into the river flow direction by using Winriver 1.06 software. The Fig. 9a) is plotted to show the velocity in the period of low tide to high tide, where as the Fig. 9b) is plotted to describe one in the period of high tide to low tide. In these figures we can see that the vector of velocity of river flow agrees with the movement of tidal level.

In the same vein, the Fig. 10 shows the distribution of the velocity and its direction at the one transect measured on 8th April. The same behavior also can be seen as the Fig. 9a) and b).

CONCLUSIONS

In the present study, water quality parameters during the field investigation at the beginning of dry season in the Hau River, Vietnam were reported. The following conclusions can be obtained:

(1) Due to the strong tides from the South China Sea while very slow flow in the up stream sources, the incursion of saltwater into the Hau River was well-mixed in the vertical direction.
(2) The temperature distribution was almost constant both vertical profile and longitudinal profile, it may be caused by the shallow water in the Hau River as well as the strong East wind from the South China Sea.
(3) Velocity and its direction during high tide and low tide agree with the tidal regime. These parameters may be very important for calibration and verification process when simulating the water quality phenomena intruded from the South China Sea.
(4) Because of the complexity of cross-section and bathymetry in the bottom of river, it should be carefully considered the effect of morphological change to the water quality in the Hau River when simulating that phenomena.

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INTEGRATED MODELLING OF LOWER MEKONG BASIN FLOODPLAINS - USEFUL TOOL FOR IMPACT ASSESSMENT?

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OLLI VARIS

ABSTRACT

Lower Mekong Basin (LMB) floodplains in Cambodia and Vietnam are important part of the Mekong ecosystem. The ecosystem is driven by the monsoon floods of the Mekong River. This pulsing system together with large floodplain, rich biodiversity, and high annual sediment and nutrient fluxes from Mekong makes the area very productive. Livelihoods of people living in and around the floodplains, especially in Cambodia, are strongly dependent on the natural resources and thus, flood pulse and water quality from upstream. As a part of "Lower Mekong modelling project" under Mekong River Commission, an integrated modelling system has been developed for the LMB to assess the impacts of planned developments on the lake's ecosystem and riparian communities. Understanding of the ecosystem functioning and tools for predicting the development impacts are essential for integrated water resources management (IWRM), as well as for sustainable basin wide planning, and national and regional policy making. Can the integrated modelling, where EIA 3D model system is combined with socio-economic study, support IWRM, basin wide planning and policy making? In this paper the model system is described and this key question discussed.

CARBONIZATON OF *MELALEUCA* IN VIET NAM BY JAPANESE STYLE CHARCOAL MAKING METHOD

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ABSTRACT

To improve a quality of Melaleuca charcoal and achieve high performance of charcoal making, a combined system (SSY-1 type) of Japanese style charcoal kiln and essential oil collector using heat energy generated from the charcoal kiln was constructed. Improvements on the classical Japanese soft charcoal kiln (black charcoal kiln) were tested as follows. In order to keep the quality of charcoal high, the refining pipe and water tank for hotwater making was assembled inside of carbonization room to control the speed of rise in temperature which affects the quality of charcoal. Furthermore, a device of an essential oil collector by using heat energy generated from a charcoal kiln was designed to use heat energy effectively. The characteristics of soft charcoals of melaleuca obtained from the kiln were analyzed. For comparison, charcoals obtained from Vietnamese kiln were compared. Melaleuca charcoals have several superior characteristics than present soft charcoals, such as high fixed carbon content, heat generation amount and low volatile content. As for difference between the kilns, SSY-1 type kiln showed lower yield of charcoal and costs longer carbonization term, however, charcoals obtained from it showed higher value than those of Vietnamese kiln in most analyses, refining degree, hardness, fixed carbon content and ash content.

INTRODUCTION

Charcoal making is a traditional practice all over the world, however there are few researches on the subject. In addition, the problem that the quality of the charcoal depends on the location of materials inside the kiln has not been solved yet. This problem affects the yield and quality of charcoal. The major cause of the problem is the difference of heat convection inside the kiln. Hence the primary objective of this study was to find a way to maintain high quality.

During the carbonization process, much of the heat from carbonizing wood is emitted to outside the charcoal kiln. However, there is no way to use such heat energy. Efficient utilization of the heat energy generated by the carbonization process is one of the most important subjects in carbonization studies. Heat can be used as energy for many purposes such as making hot water. Although a way to use the heat energy generated from the charcoal kiln must be found, there are no previous studies on the kiln used for the heat generator of charcoal kilns. The second objective of this study is to build a system that uses the heat energy generated from a kiln.

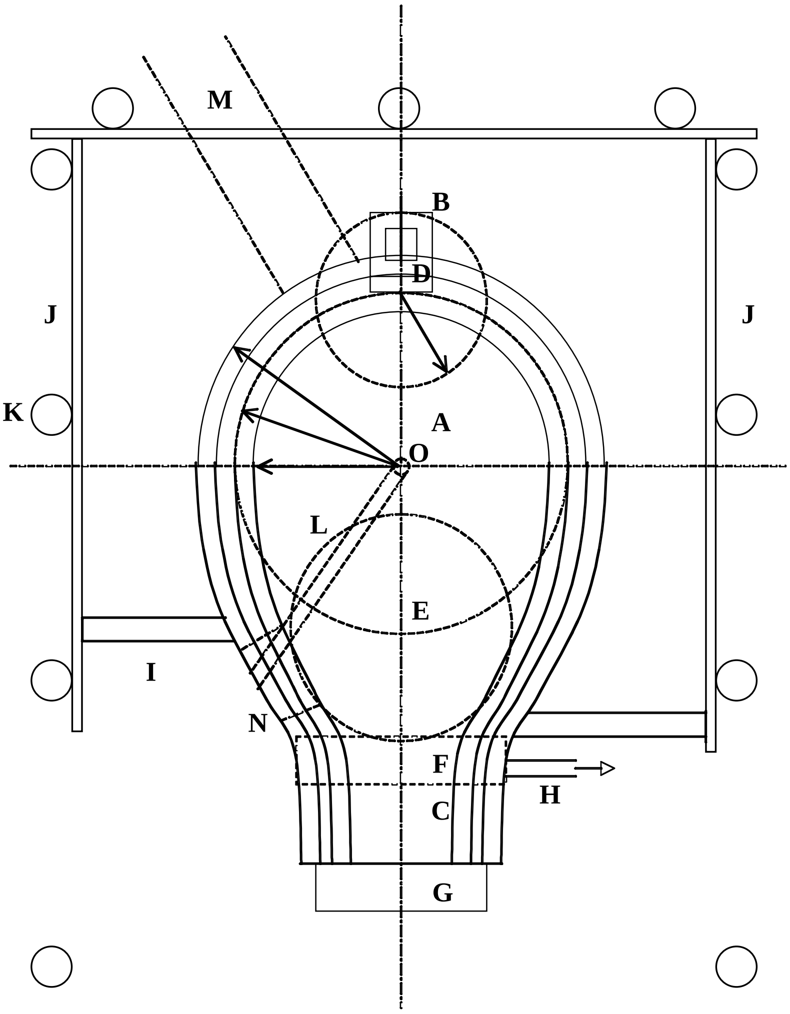
In order to solve the above problems, the apparatus combined with charcoal kiln and essential oil collector (SSY-1 type kiln) was manufactured in trial.

In this presentation, we would like to show the process of SSY-1 type kiln construction and the results of the analyses of the charcoals obtained from it.

SSY-1 TYPE KILN

SSY-1 type kiln is a combined system (SSY-1 type) of improved Japanese style charcoal kiln and essential oil collector using heat energy generated from the charcoal kiln. Figure 1 shows the plan of SSY-1 type kiln.

In the carbonization room of the charcoal kiln part the hotwater-making tank was equipped and the carbonization room was connected only to the upper part of the fireplace because of setting up the tank. This layout in the kiln might affect the charcoal-making. The first effect is that the tank will hinder the temperature increase.



O: center of carbonization room, A: carbonization room, B: chimney, C: fireplace,
D: center of entrance of chimney, E: cross of the centerline and the circle (diameter: 909mm),
F: hot water tank , G:entrance of fireplace , H: connecting pipe to hot water storage tank,
I: rock wall, J: holding wall made of wood, K: pillar for roof, L: refining pipe,
M: trench to drain water from charcoal kiln, N: entrance of carbonization room

Figure 1 Plan figure of a charcoal kiln

The volume of the tank is approximately 0.5 m^3 and water is continuously supplied to the tank from the storage tank. This mechanism might cause heat loss of the charcoal kiln and a slower temperature increase. However, it is considered that a slower temperature increase is effective for producing good-quality charcoals[1)]. Hence, this might have a good effect on the quality of charcoal. The second effect is on the route of heat within the kiln. In this layout, heat generated in the fireplace will be led only from the upper part of the fireplace. Heat will go along the ceiling and reach the back wall of the kiln. Thereafter, a part of the heat will circulate to the front side of the kiln, because the entrance of the chimney is set at the bottom of the kiln. The logs near the fireplace that generally hardly burned, however, will be protected because of the water tank between the carbonization room and fireplace. Hence the temperature in the kiln might be kept equal everywhere compared with existing kilns. A uniform distribution of heat produces uniform quality of charcoals and the reduction of loss of materials near the fireplace might increase the total yield of charcoal.

Besides the hotwater tank, the refining pipe assembled in the bottom of the carbonization room also will play an important role to make the temperature in the carbonization room uniform. Generally, the temperature at the top of the carbonization room is higher than that at the bottom, which is why low-quality charcoals are produced at the bottom of usual kilns. However, airflow from the bottom through the refining pipe accelerates pyrolysis at the bottom of the carbonization room and makes the temperature in the carbonization room more uniform than in existing kilns. A refining pipe through the carbonization room as shown in this kiln has never been designed for this type of charcoal kiln before. This new approach yields good-quality charcoals.

The kiln built in this experiment provides more products than existing kilns. First, hot water is available from this kiln. In this experiment, hotwater was made in the hotwater-making tank as a precursor of steam for the essential oil collector and once stored in the hotwater storage tank. The hot water storage tank in this experiment is an open top drum that has three pipes, two of which are connected to the hotwater-making tank and the other is connected to the essential oil distiller. Although the storage of hot water in the hotwater storage tank is a demerit in view of the water temperature decrease rather than direct injection to the essential oil collector, the hotwater storage tank acts as a safety bulb of the hotwater-making tank in the essential oil collecting system and simplifies the structure of the essential oil collecting system. The hotwater storage tank also makes it easy for water to be put into and taken out of the essential oil collecting system. Hot water made in the hotwater-making tank moves to the hot water storage tank and can be easily taken from the open top of the hotwater storage tank. Water supply to the essential oil collecting system can be easily reversed putting water from the top of the hot water storage tank.

As for the chimney, longer chimney produces a higher yield of pyroligneous liquor[2)]. Hence, three long bamboo chimneys were applied in this experiment. Smoke exhausted from the kiln is cooled and condensed as pyroligneous liquor inside of the chimney. Bamboo is harder to heat than stainless steel, so smoke generated from the kiln might be cooled faster in the chimney made of bamboo than that of stainless steel. This increases the yield of pyroligneous liquor in hot places such as tropical areas. Besides, bamboo is more readily available than stainless steel in Vietnam. Furthermore, plural chimneys are effective to increase the yield of pyroligneous liquor.

In the place where this combined system of charcoal kiln and essential oil collector was constructed, trees of genus Melaleuca, for example Melaleuca cajuputi and M. leucadendron, are planted and essential oil are collected from them. Essential oil of M. cajuputi and M. leucadendron are widely used commercialy. This system enables charcoal- making from wood and essential oil collection from leaves to be performed simultaneously in the same place.

CHARCOALS OBTAINED FROM SSY-1 TYPE KILN

Charcoal making process

SSY-1 type kiln

Charcoal making in novel combination kiln was only finish work of kiln making, but schedule was similar to that of ordinary charcoal making. At first, fuel wood was burned in the fireplace until the temperature of chimney exhaust reached at 80-82^{o}C. Then, big entrance of fireplace was closed gradually and carbonization of logs

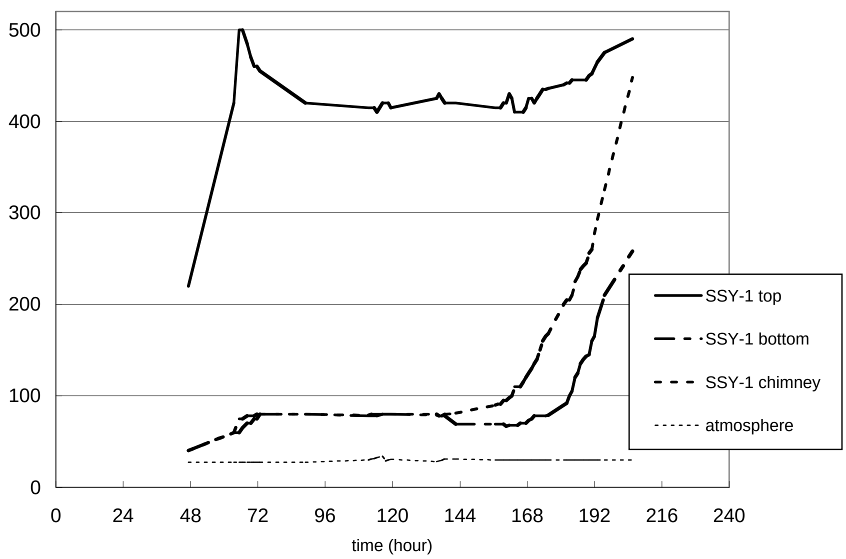


Figure 2 Temperature changes inside of the SSY-1 type kiln

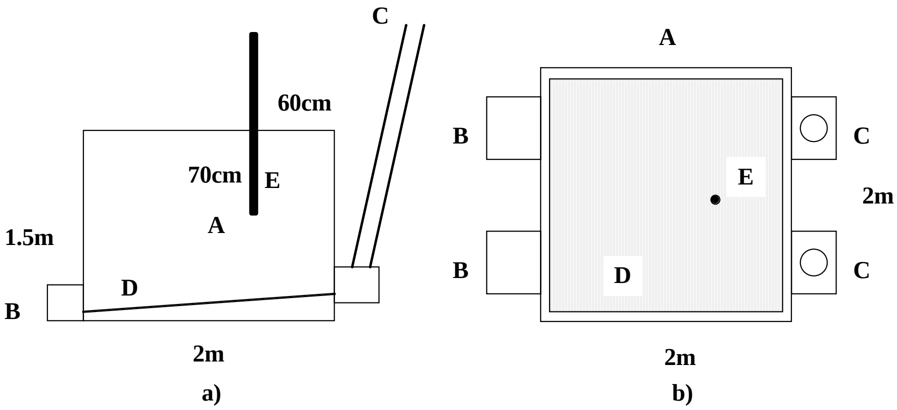


Figure 3 Plan of Vietnamese kiln a)section, b)view from the top

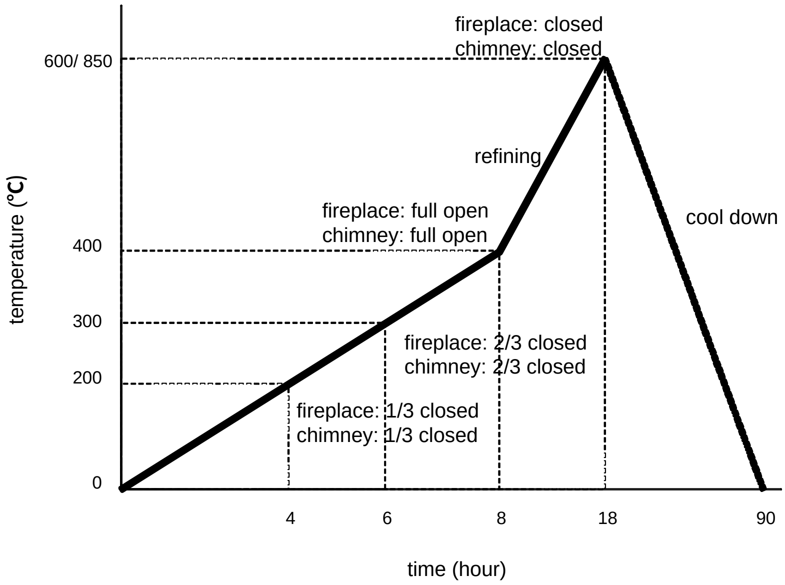


Figure 4 Charcoal making schedule with Vietnamese kiln

controlled by opening and closing of chimney and small entrance of fireplace.

During carbonization, water tank set in the fireplace was filled with water to supply hot water and promote heat circulation inside of the carbonization room. Refining pipe equipped in the bottom of carbonization room was not used in this experiment. Figure 2 shows temperature change inside of the SSY-1 type kilns.

Vietnamese kiln

Charcoal kiln designed and built in Thanh Hoa station of FSSIV suburban area of Ho Chi Min City by FSSIV were used in this experiment. Figure 3s show the plan of Vietnamese kiln. Its size was 2m (length) x 2m (depth) x 1.5m (height) and had two fire places and chimneys in the bottom of the kiln. Six square meters of materials (1.6 tons of melaleuca) could be treated at one time of charcoal making. Iron mesh was spread on the floor of carbonization room and was slanted lower in the direction of fireplace and higher in the direction of chimney. One thermocouple was set inside of the kiln and the temperature at the point of 70cm from the ceiling could be measured. In case of charcoal making, the ceiling of the kiln was shut with iron sheet and covered with sand.

Cut logs were built on the floor of the carbonization room, however direction of the logs were not arranged equally as Japanese soft charcoal making [3)]. Logs were just arranged for the sake of filling the gap between logs. Subsequently, the other logs were laid on the built logs to fill the gap between the built logs and the ceiling. After the loading of the logs, the ceiling were closed and covered with sand.

Figure 4 shows the charcoal making schedule. At the beginning of the charcoal making, fuel woods were burned in the fire place. When the temperature inside of the kiln reached at 200°C, one third of the fireplace and chimney closed, Regularly, the temperature reached at 200°C in 4 hours. In the next 2 hours, the temperature reached at 300°C. One third of the fireplace and chimney were also closed at that time. The temperature reached at 400°C in 2 hours and the fireplace and chimney were opened fully at that temperature. Full open of the fireplace and chimney promote to increase the temperature inside of the kiln. When the temperature reached at 600 and 850°C, respectively, fireplace and chimney was closed fully and fire inside of the kiln was extinguished. After 3 days of cooling, the kiln was opened and charcoals at the bottom, middle and top part of the kiln were taken out separately.

Charcoal obtained after the closing of fireplace and chimney at 600°C and 850°C were named 600 and 850, respectively. The part of the kiln, top, middle and bottom was hyphenated together after temperature. In total, 6 specimens were analyzed in this experiment.

Charcoal analyses

Refining degree and hardness

Refining degree of the charcoals were measured with refining degree meter (FA56, Sanyo electric). Hardness value of the charcoals were measured with Miura hardness tester .

Bulk density

Small piece of the charcoal was put into water and boiled until when charcoal sank under water. Then, charcoal was taken out from water and water on the surface of the charcoal was wiped with paper towel. Before drying up of the charcoal, charcoal was put into the mess cylinder that contained water that volume was measured in advance. The increase of volume of water after charcoal input was estimated as volume of charcoal. Charcoal was taken out from water and dried up in the oven kept at 105°C. After for 1 day, weight of charcoals was measured. Specific gravity was calculated by dividing the oven dried charcoal weight by the volume.

Fixed carbon, ash, volatile and heat generation

Fixed carbon, ash, volatile and heat generation of charcoals were measured by Sunkoh Environmental research center co. , ltd..

Fixed carbon content of charcoals were measured only about all charcoals obtained from SSY-1 type kiln and two charcoals obtained from Vietnamese kiln, 600-top and 850-top. As for the other charcoals, fixed carbon contents were not measured because of low refinement values.

BET surface area, total pore volume and pore size distribution

BET surface area, total pore volume and pore size distribution were measured with automatic surface area analyzer (Nova 4000, Quantachrome Instruments). About 0.05g of sample was put into the cell and measurement of adsorption amount of nitrogen after sample degas. Obtained data were analyzed with software, (AS-1, Quantachrome Instruments)

Results and discussion

Yield

In this experiment, total amount of the charcoals obtained at 600°C and 850°C reached 250 to 300kg and their yields ranged between 16 ~ 19 % (Table 1). Regularly, yield of soft charcoal obtained from Japanese soft charcoal kiln is about up to 20 % [4], hence, these values are similar to those of Japanese soft charcoal kiln. In detail, charcoals obtained from bottom parts showed the highest yield in the both temperature, 600°C and 850°C and their value were up to 40 % of the total obtained charcoals.

From SSY-1 type kiln, 105kg of charcoals were obtained from 1,300kg of logs. (Table 1) Yield was about 8.1 % and lower than those of Vietnamese kiln and reported yield of Japanese soft charcoal kiln. Generally, there is inclination of temperature, higher at the top and lower at the bottom [5]. To avoid loss at the top by burning, logs are set in the carbonization room in the form of upside down [3]. However, small pieces of melaleuca was set in the top of carbonization room to form the ceiling of the carbonization room in this experiment. These small pieces are easily burned and might cause lower yield of charcoal.

Table 1 Yield, refining degree, hardness and bulk densities of charcoals

kiln	sample	yields (%)	refining degree	hardness	bulk densities (g/m^2)
SSY-1 type kiln	front		6.6	3.5	0.55
	center	8%	6.6	9.5	0.45
	back-top	in total	6.4	5.5	0.38
	back-middle		6.3	4.5	0.55
	back-bottom		6.4	6.5	0.56
Vietnamese kiln	600-top		6.6	5.5	0.43
	600-middle	16-19%	8.4	5.5	0.48
	600-bottom	in total	-	1.5	0.47
	850-top		6.5	2.5	0.46
	850-middle	16-19%	6.5	3.5	0.47
	850-bottom	in total	-	4.5	0.42

Refining degree, hardness and bulk densities

Table 1 shows the refining degrees, hardness and specific gravities of the charcoals obtained in this experiment. All charcoals obtained from SSY-1 type kiln showed similar refining degree and ranged between 6.4 and 6.6. These values were a little lower than literature data [6)]. In this experiment, temperature inside of carbonization room reached at only about 500oC (Figure 4) and was lower than the temperature that soft charcoal kiln usually reached. Hence, refining degrees were remained lower value. However, these results suggests that heat distribution of SSY-1 type kiln is uniform and uniform charcoal can be produced with this kiln.

On the contrary, refining degrees of the samples obtained from Vietnamese kiln categorized into three groups. First group, 600-top, 850-top and 850-moddle showed similar results as those of SSY-1 type kiln and ranged their refining degree between 6.3- 6.6. The second group, 600-middle showed lower, refining degree, 8.4. The refining degrees of the third group, 600-bottom and 850-bottom, could not be measured because of high electric resistance. These results suggest that heat distribution inside of Vietnamese kiln was not uniform and location in the kiln has influence of charcoal quality. In addition, higher carbonization temperature contribute to increase refining degree of charcoal obtained from middle part of the kiln, but it did not increase refining degrees of charcoals in the bottom.

Hardness values of the charcoals obtained in this experiment were not uniform and ranged between 1. 5 and 9. 5 (Table 1). Hardness value of major Japanese soft charcoals obtained from oaks such as *Quercus serrata* and *Quercus acutissima* ranged between 8 and 10 [6)]. Though hardness value of most charcoals obtained from both SSY-1 type kiln and Vietnamese kiln were lower than those of Japanese soft charcoals, charcoal that showed its hardness value was 9.5 was obtained from SSY-1 type kiln in this experiment. This indicates that harder charcoal production is possible by using SSY-1 type kiln. Hardness value was dependent on carbonization methods [6)]. Further research will be required for melaleuca charcoal production method.

Bulk densities (g/cm^3) of the charcoals showed similar values and ranged between 0.381 and 0.556 (Table 1). Bulk density of Japanese soft charcoal reported to be ranged between 0.40 and 0.75 [7)]. Values of the charcoals obtained in this experiment were similar to those of Japanese soft charcoals.

Fixed carbon, ash, volatile and heat generation

Fixed carbon contents of the charcoals ranged between 79.60 and 87.14 (Table 2). Generally, soft charcoals ranges its fixed carbon content between 66 and 80 % [7)], but fixed carbon contents of all charcoals, except for 850-top, over 80 %. Though carbonization temperatures were low, fixed carbon contents over those reported in the literature. These results indicate that charcoal of melaleuca is equal to the other soft charcoals. In addition, all charcoals obtained from SSY-1 type kiln, except for back-bottom, showed their fixed carbon contents more than 85 % and one charcoal, SSY-1 front, showed its fixed carbon content more than 87 %. As for charcoals obtained from Vietnamese kiln, maximum fixed carbon content was 81.17 % (600-top). Fixed carbon content was not improved by increase of the carbonization temperature from 600^{o}C to 850^{o}C. Fixed carbon content of the charcoals

Table 2 Results of industrial analyses of the charcoals (air dry base)

kiln	sample	content of fixed carbon (%, a.d. base)	ash (%, a.d. base)	volatile (%, a.d. base)	heat generation amount (cal/g, a.d. base)
SSY-1 type kiln	front	87.14	3.15	7.61	7770
	center	86.51	3.23	8.26	7810
	back-top	84.45	5.15	7.49	7440
	back-middle	85.62	4.96	6.66	7490
	back-bottom	82.47	5.26	9.12	7270
Vietnamese kiln	600-top	81.17	5.94	10.37	7340
	850-top	79.6	9.72	7.36	6880

from SSY-1 type kiln were higher than those of Vietnamese kiln. These results suggest that fixed carbon content of charcoal can be improved by carbonization with SSY-type kiln.

Ash content of the charcoals from both kilns ranged between 3.15 and 9.72. These values are higher than reported in previous report [8]. Melaleuca is reported to contain high content of silicon [9] and this may cause high ash content in the charcoal. Another possible reason of high ash content is bark of melaleuca logs. Melaleuca logs were covered with thick bark and it was not debarked in advance of carbonization in the series of experiments. Bark of melaleuca are easily burned and make space in the carbonization room. In case of charcoal making, inside of carbonization room must be filled fully with materials as much as possible to prevent space. Space in the carbonization room helps burning of material and causes ash generation rather than carbonization. Add to effect of bark, size of material also affects ash content in the charcoals obtained from SSY-1 type kiln. As mentioned in the previous report about kiln construction, small pieces of melaleuca was filled in the carbonization room to form the ceiling of it. They are easily burned in case of carbonization and also generate ash. From these possible causes, the charcoals in this experiment showed higher ash content.

Though the charcoals contained high content ash, SSY-1 type kiln could suppress of ash content. The charcoal obtained from SSY-1 back middle showed maximum ash content, 5.26, but it was less than minimum ash content of the charcoal obtained from Vietnamese kiln, 5.94 (600-top).

Generally, volatile contents in soft charcoals are reported as between 12 and 25 %, however all charcoals obtained in this experiment showed lower volatile contents, between 6.66 (SSY-1 back middle) and 10.37 (600-top). These results respond to high fixed carbon content and suggest that melaleuca charcoals are suitable for a fuel.

Amounts of heat generation are shown in Table 2. SSY-1 center showed maximum amounts of heat generation and achieved 7810 cal/kg (air dry base). Amounts of heat generation of soft charcoal is about from 6900 to 7500 [7]. Hence melaleuca charcoal can generate higher amount of heat than other soft charcoals and is suitable for good fuel. In addition, SSY-1 type kiln can generate higher heat generation amount charcoal than Vietnamese kiln. Heat generation amounts of all charcoal, except for SSY-1 back bottom, were higher than those of Vietnamese kiln.

In summary, melaleuca charcoal are good for fuel because of high contents of fixed carbon, high amounts of heat generation and low contents of volatile. In addition, carbonization equipment affect on charcoal quality. SSY-1 type kiln can produce higher quality charcoal than Vietnamese kiln by increasing good points of melaleuca charcoal, high fixed carbon content and heat generation amount and suppressing short point of it, high ash content.

Surface area and total pore volume

Table 3 shows surface area and total pore volume of the charcoals measured by BET method. Generally, surface area of soft charcoals ranged between 380 and 420m2/g [7]. Charcoals obtained from both kilns showed lower surface area.

Though surface area of the charcoals were not uniform, charcoals obtained from Vietnamese kiln showed higher surface area than most charcoals obtained from SSY-1 type kiln. All charcoals obtained from Vietnamese kiln showed over 200m^2/g of surface area. On the contrary, surface area of SSY-1 back top only over more than 200 m^2/g and those of the other charcoals were less than 200m^2/g. One possible cause of lower surface area of the charcoals obtained from SSY-1 type kiln is lower carbonization temperature than Vietnamese kiln. Carbonization

Table 3 Surface area and total pore volume of the charcoals (air dry base)

kiln	sample	Surface area (m^2/g)	Total pore vol. (cc/g)
SSY-1 type kiln	front	91.60 ± 40.37	0.076 ± 0.027
	center	102.45 ± 40.17	0.153 ± 0.002
	back-top	275.35 ± 1.27	0.152 ± 0.001
	back-middle	130.22 ± 5.23	0.093 ± 0.003
	back-bottom	102.63 ± 40.81	0.080 ± 0.036
Vietnamese kiln	600-top	222.14 ± 43.09	0.097 ± 0.052
	850-top	254.32 ± 24.25	0.160 ± 0.013

temperature is higher in Vietnamese kiln (Figure 4) . Temperature is higher at the higher position in SSY-1 type kiln (Figure 2) . Among the charcoals obtained from SSY-1 type kilns, samples collected upper area in the carbonization room, SSY-1 back top and SSY-1 back middle, showed higher surface area than the other samples. This result is corresponding to the results of surface area analyses of Vietnamese kiln charcoals. However, this hypothesis does not agree with the results that SSY-1 type kiln charcoals showed similar refining degrees as Vietnamese kiln charcoals. Another possibility is ash in the charcoals. Melaleuca contain high content of ash and it might fill pore in the charcoals and decrease surface area. Further studies, such as microscopic studies on inorganic composition distribution, will be required.

Contrary to surface area, total pore volumes of most charcoals are higher than charcoal of *Quercus serrata* and similar to charcoal of *Pinus densiflora* [10]. Lower surface area and higher total pore volume indicates that melaleuca charcoal has wider pore than the other soft charcoals.

Acknowledgement

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A SYSTEM DYNAMICS MODEL FOR ASSESSING WATER RESOURCES AND SOCIO-ECONOMIC CHANGES: THE CASE OF THE CIANJUR WATERSHED, WEST JAVA - INDONESIA

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ABSTRACT

A model including socio-economic factors has recently received much attention because social and economic activities have great influence on water quality. In this paper, a system dynamics model (SDM) for the purpose of assessing water resources and socio-economic changes is developed based on the statistical database that includes hydrological, economic, and social data. The SDM has six sectors: the agricultural, the industry, the land use, the population, the water resource, and the water quality sector. Cianjur Prefecture (West Java, Indonesia) is used for the case study to calibrate the SDM. Cianjur Prefecture is a part of the Citarum River watershed, the largest watershed in West Java, and there is concern about the impacts of economic development on the water resources. In the field investigations conducted in 2003 and 2004, total nitrogen (TN) and total phosphorus (TP) concentration was measured, and information such as fertilizer application was investigated by the interview with farmers. The statistical database consists of the data such as population, land use area, agricultural production, hydrological data, and Gross Domestic Production (GDP) for the period 1988 to 2002. The SDM is calibrated using the statistical data and simulates total population, the area of the irrigated paddy field, and agricultural Gross Regional Domestic Production (GRDP) with a relative error of 2.6%, 13.2%, and 6.4%, respectively. The results of sensitivity analyses are fairly good. The SDM simulates the socio-economic factors and the nutrient concentration together in a single model and is a support system for policymaking.

INTRODUCTION

Nutrients from excess fertilizers and domestic and industrial wastewater have degraded water quality of rivers and lakes in an agricultural watershed. Many watershed management models have been developed for sustaining water resources, and a model with socio-economic factors has recently received much attention because social and economic activities have great influence on water quality. One of the methods covering socio-economic factors and water resources is system dynamics. Simonovic [1] developed WorldWater model and showed that there were a strong relationship between the world water resources and future industrial growth of the world. Kato *et al.* [2]

developed a model with social factors using system dynamics that simulated the change of population and land use in an agricultural watershed in Japan.

In this paper, a system dynamics model (SDM) for assessing water resources and socio-economic changes is developed using the statistical database. Cianjur Prefecture (West Java, Indonesia) is used for the case study to calibrate the SDM. Field investigations were conducted in 2003 and 2004 to collect the total nitrogen (TN) and total phosphorus (TP) concentration and so on. Statistical data such as population, land use area, agricultural production, hydrological data, and Gross Domestic Production (GDP) are collected for the period 1988-2002 to create a database. The SDM is developed and calibrated based on the statistical data and the data obtained from the field investigations. Lastly, scenario application and possible use of the SDM in other watersheds are discussed.

STUDY AREA AND DATABASE

Study area

Cianjur Prefecture is located in the Citarum River watershed, West Java, Indonesia (Figure 1). The Citarum River flows from the urban areas of Bandung (population 2 million) to Jakarta, the capital of Indonesia; its watershed is the largest in West Java. There are three major dams for agricultural and hydroelectric purposes in the river, and its water is used for municipal purposes, as drinking-water, and for agricultural and industrial purposes in the downstream of three major dams. There are not enough wastewater treatment facilities in the watershed, and most of the domestic sewage and industrial and agricultural wastewater directly flows into the river and water quality is heavily polluted (Hart *et al.* [3]). There is concern about the impacts of further economic development on the water resources.

The area of the Cianjur watershed is 425 km^2. Human population is about 490,000. Land is mainly used for agricultural use such as paddy field and the plantation of tea.

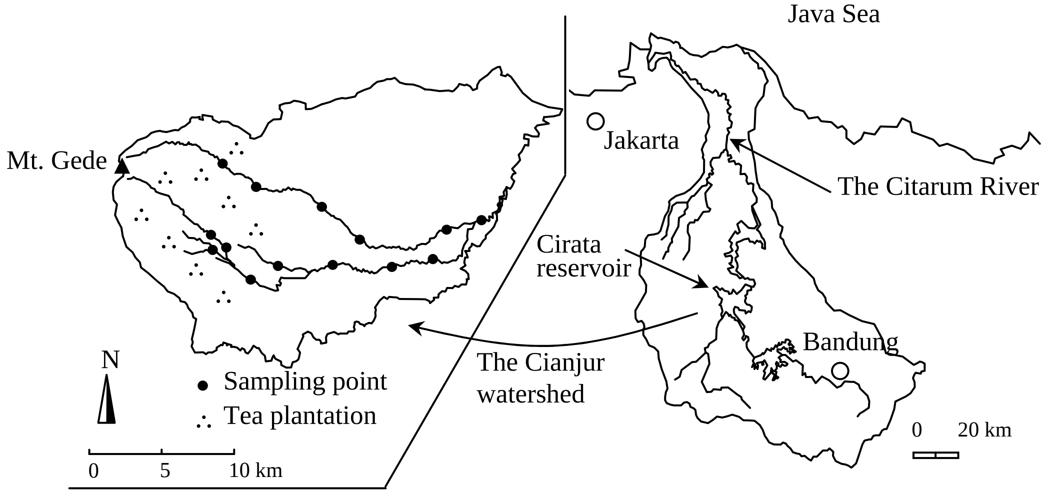

Figure 1. Location of the Cianjur watershed.

Field investigation

Field investigations were conducted in 2003 (August) and 2004 (January, September, and December) and water was sampled at 14 sampling points each time (Figure 1). The results are shown in Table 1.

Table 1. The TN, TP, and COD concentration in the Cianjur watershed (mg/L).

	TN	TP	COD
Maximum	4.20	0.80	25.45
Minimum	0.40	0.02	0.82
Average	1.89	0.18	6.39

The data of chemical fertilizer application were obtained from the interview with farmers. They generally grow rice crops two or three times and grow vegetables once per year and use fertilizers each time. The fertilizer application rates of nitrogen and phosphorus are 20 - 115 and 15 kg ha^{-1} $crop^{-1}$, respectively.

Database

We use the statistical data for the period 1988 to 2002 and the data obtained from field investigations. The Statistics Bureau of Cianjur Prefecture government publishes annual reports (Cianjur Prefecture [4]). The database includes: population (demographical data and working population), land use area (irrigated paddy field, rain fed paddy field, corn, bean, vegetable, fruit, tea, palm, coffee, rubber, forest, and residential area), production (rice, corn, bean, vegetable, fruit, tea, palm, coffee, and rubber, and wood), hydrological data (rainfall, runoff, TN concentration, and TP concentration), GDP (total, agricultural, and industrial) and Gross Regional Domestic Production (GRDP) (total, agricultural, and industrial). The tendency of data are as follows:

Increase tendency: Population (total, agricultural, and industrial), the area of plantation (tea and palm)
Decrease tendency: Vegetable production area, rubber production area

We should consider that these parameters for Cianjur Prefecture are greatly influenced by the same parameter for Indonesia. For example, Indonesia GDP affects strongly Cianjur GRDP (Figure 2); there was an economic crisis in 1997 and both Indonesia GDP and Cianjur GRDP decreased. We create causal loops based on the tendency of the data.

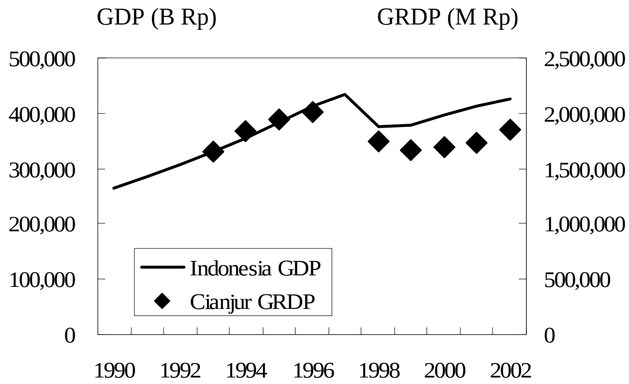

Figure 2. Indonesia GDP and Cianjur GDRP for the period 1990 to 2002.

SYSTEM DYNAMICS MODEL WITH SOCIO-ECONOMIC FACTORS

System dynamics model

System dynamics is a method created by Forrester [5] and is used to understand the way all the elements in a system interact with one another. System dynamics models have been used in many areas, and watershed management planning and water resources planning as well.

Kato *et al.* [6] developed a system dynamics model for simulating the population and land use changes in the Cidanau watershed, Indonesia. The model simulated the population and land use changes fairly well and predicted the effluent nutrient load in the watershed over ten years. In this paper, based on the model, a SDM is newly developed to evaluate the impact of economic development on water quality. Many new factors and causal loops are introduced. The SDM is comprised of six sectors: the agriculture sector, the industry sector, the land use sector, the population sector, the water resource sector, and the water quality sector. Figure 3 shows the framework and the representative factors used in the SDM. The SDM simulates population, the area for representative land use, TN, TP, and GDP.

The elements (“stock”, “flow”, and variable) and their relationships are illustrated in Figure 3; a square represents “stock” and a circle represents variable. A stock is the accumulation that is changed over time by inflows and outflows, and a flow is the rate of change of a stock (Meadows *et al.* [7]). Each stock is changed by the rates of flow. Each arrow means an increase or decrease effect on each factor, and has an equation to calculate the effect.

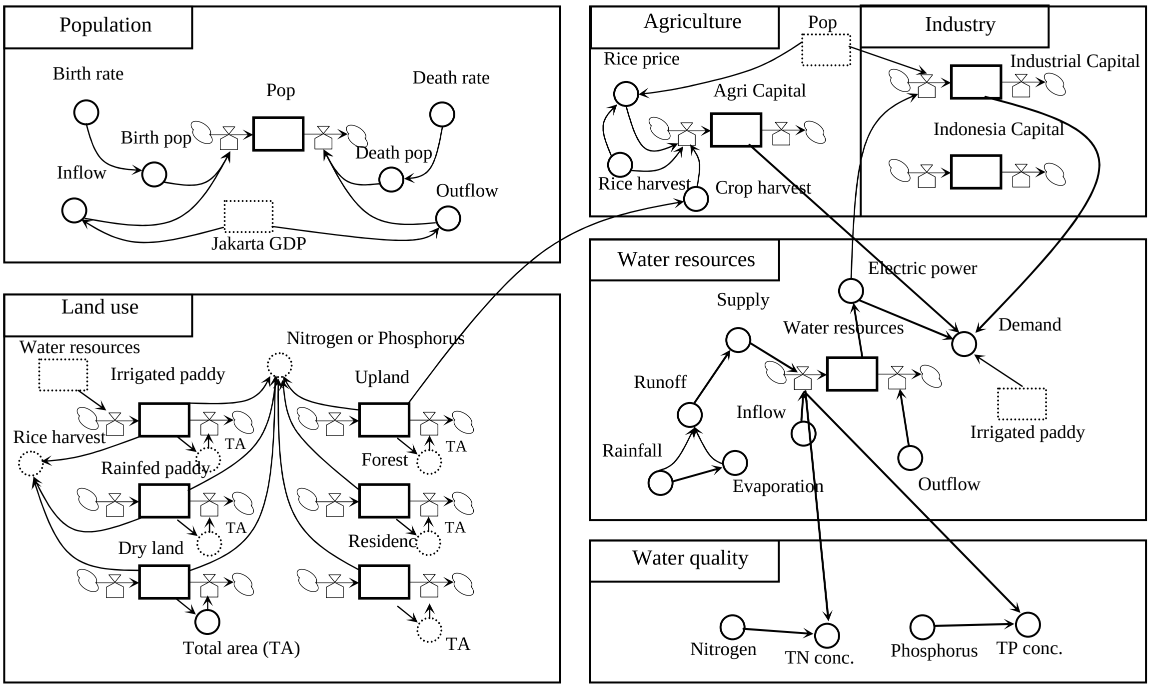

Figure 3. The SDM for the Cianjur watershed.

Figure 4 shows the agricultural capital loop and industrial capital loop in the model. For example, when the agricultural capital loop is a positive loop, a part of the capital is used for investment and increases the land use area. The increased area increases production. A part of the profit (price) increases the capital. In addition, population and Indonesia GDP, or economic states in Jakarta, influence the crop price.

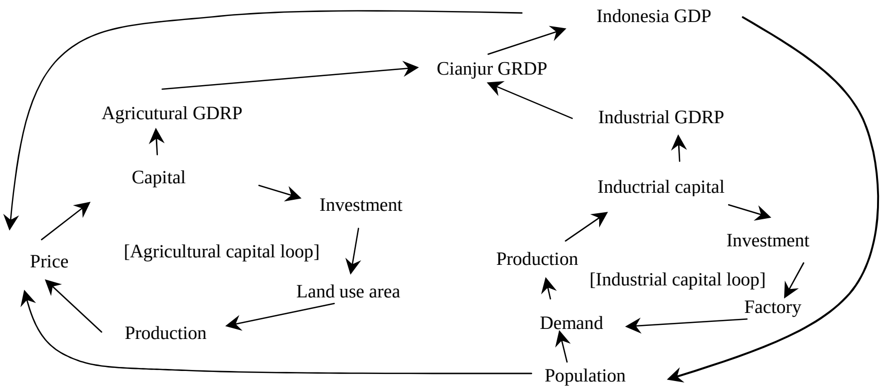

Figure 4. The agricultural capital loop and the industrial capital loop

Figure 5 shows the water flow in the SDM. Runoff is determined by rainfall and the runoff rate. Nutrients are originated from farmlands, or effluent of fertilizers, and domestic sewage. The nutrient concentration is calculated using nutrient load and runoff.

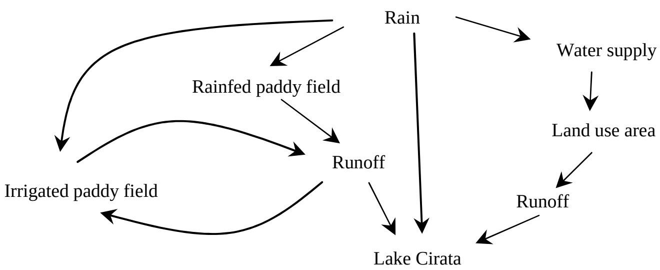

Figure 5. The water flow in the SDM.

After the SDM is calibrated manually, the relative errors between the statistical data and the calculated values are shown in Table 2. The errors are 2.6% for the total population, 13.2% for the irrigated paddy field, and 6.4% for the agricultural GDRP. Pekalangan is an Indonesian traditional farmhouse with farmland in the back yard.

Table 2. The list of the relative errors.

Pop (Age)	0 - 10	10 - 20	20 - 30	30 - 40	40 - 50	50 - 60	60 +	Total
Error (%)	12.1	1.7	6.6	6.4	7.2	13.4	10.6	2.6
Area	Rainfed Paddy	Forest	Irrigated Paddy	Pekalangan	Plantation	Upland		
Error (%)	47.3	9.2	13.2	7.6	23.5	21.4		
GDP	Agi GDP	Indus GDP						
Error (%)	6.4	34.3						

Sensitivity analysis

Sensitivity analysis is used to determine the degree to which a model is "sensitive" to changes in the value of the parameters of the model and to changes in the structure of the model (Breierova and Choudhari [8]). Sensitivity analysis for the SDM is conducted to reveal the influence of each variable to the parameters of the SDM. Principal elements are selected and are changed from -20% to 20% with intervals of 10% (Table 3).

For example, the increase of the birth rate has the effect of increasing population, the area of the paddy field, GDP, and TN; the decrease of the rice price has the effect of decreasing the area of the paddy field, GDP, and TN. These results suggest that the sensitivity of the SDM is relatively reasonable because the calculated values follow the tendency of the statistical values.

Table 3. Sensitivity analysis (%).

		Birth Rate	Death Rate	Inflow Pop.	Outflow Pop.	Irrigated Paddy	Plan -tation	Upland	Forest	Rice Price	Crop Price	Other Price	Rain -fall
Total Population	-20	-7.86	1.98	-0.11	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	-10	-3.95	0.98	-0.06	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10	3.97	-0.97	0.06	-0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	7.98	-1.94	0.11	-0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Paddy Area	-20	-0.002	0.00	0.000	0.000	-3.46	0.00	0.00	0.00	-0.002	-0.004	-0.01	-0.07
	-10	-0.001	0.00	0.000	0.000	-1.73	0.00	0.00	0.00	-0.001	-0.002	-0.01	-0.03
	0	0.000	0.00	0.000	0.000	0.00	0.00	0.00	0.00	0.000	0.000	0.00	0.00
	10	0.001	0.00	0.000	0.000	1.73	0.00	0.00	0.00	0.001	0.002	0.01	0.03
	20	0.002	0.00	0.000	0.000	3.46	0.00	0.00	0.00	0.002	0.004	0.01	0.07
GDP	-20	-9.74	3.69	-0.21	0.50	-0.001	-0.08	-1.76	0.00	-2.17	-5.45	-10.07	0.00
	-10	-4.94	1.83	-0.11	0.25	0.000	-0.04	-0.88	0.00	-1.08	-2.73	-5.04	0.00
	0	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10	5.09	-1.79	0.11	-0.25	0.000	0.04	0.88	0.00	1.08	2.73	5.05	0.00
	20	10.34	-3.55	0.21	-0.49	0.001	0.08	1.76	0.00	2.17	5.46	10.11	0.00
TN	-20	-1.27	0.37	0.00	0.00	-3.07	0.00	0.00	0.00	-0.04	-0.08	-0.18	45.21
	-10	-0.51	0.18	0.00	0.00	-1.53	0.00	0.00	0.00	-0.02	-0.04	-0.09	18.39
	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10	0.76	-0.18	0.00	0.00	1.15	0.00	0.00	0.00	0.02	0.04	0.09	-13.79
	20	1.52	-0.36	0.00	0.00	2.68	0.00	0.00	0.00	0.04	0.08	0.18	-23.75

CONCLUSIONS

A system dynamics model is developed for assessing water resources and socio-economic changes in the Cianjur watershed, Indonesia. The characteristic of the SDM is that the SDM simulates the changes in population and land use area, TN and TP, and GDP together in a single model. After calibration, the results of the simulation and sensitivity analysis are fairly good.

Because it is necessary for policy makers and stakeholders to find some effective scenarios that can achieve both economic development and the preservation of water resources for sustainable development, next step is to develop integrated scenarios and to forecast water quality under the scenarios using the SDM. The TN and TP outputs of the SDM are a tendency; therefore, a hydrologic model should be combined if the exact values are needed. The SDM evaluates scenarios for economic growth and environmental conservation and is a support tool for policy making in a watershed.

In addition, in this paper, the SDM is calibrated for an area in Indonesia; however, the SDM can be used for other watersheds by developing a database for the targeted watersheds. In that case, it is also necessary to reconsider some factors in the SDM. As there is the stock for the area of plantation in the SDM for the Cianjur watershed, there are characteristic factors for the targeted watershed. One of the strong points of system dynamics is that it is relatively easy to add or delete a factor in a model.

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RELATIONSHIP BETWEEN FLUCTUATION OF WATER LEVLE AND FISH CATCHES OF *HENICORHYNCHUS SPP.* AND *CHANNA MICROPELRES IN* KAMPONG THOM PROVINCE IN KINGDOM OF CAMBODIA

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ABSTRACT

Inland fisheries resources in Cambodia are maintained by high productivities in flooding areas around Tonle Sap Lake adjusting to Mekong River (MRC 2004). In a system of Tonle Sap Lake and Mekong River, Cambodian inland fisheries products are approximately 400, 000 tones per year which is the world's fourth largest inland fisheries production (MRC 2004). The inland fisheries also contribute more than 75% of animal protein intake in this country. It could be said that the inland fisheries resources are very important for food security in Cambodia.

Recently catch amount of large and medium sized fishes in Tonle Sap Lake has declined and there is a great concern of over exploitation (MRC 1999). In addition, the average sizes of small sized fishes have also shrunk and this would be derived from over fishing (MRC 2004). Struggling to cope with these problems, it could be important to grasp reasons of decline of fish stock in quality and quantity.

In previous studies, a total catch including all species were used for analyses, however, this may cause misunderstanding mechanisms of stock decline due to stock volume should be examined by species. In this paper, we used catch data sorted by species for establishing models to find fluctuation mechanisms of fish catch.

We made two models for *Henicorhynchus spp* and *Chhana microleptes*, respectively. These are major species of fish catch in large-scale fisheries in Kampong Thom province. According to our results, the catch fluctuation of *Henicorhynchus spp* was caused from a fluctuation of water level at Chak Tomuk in an early period of rainy season affecting the spawning and the mortality of larva and juvenile. The catch fluctuation of *Chhana microleptes* was formed by a decrease of the fish stock resultant from fishing pressures of small-scale fishermen and the fluctuation of the water level in the early period of rainy season affecting the fishing activities of small-scale fishermen.

INTRODUCTION

Cambodia hold a rich aquatic living resources which sustained a unique hydrologic system of Mekong river and Tonle Sap Lake.[1] The system of Mekong river and Tonle Sap Lake flood every year, and this flooding events seems to sustaining high productivities of Mekong river basin. Cambodian inland fisheries products are approximately 400, 000 tones per year which is the world's fourth largest inland fisheries production.[1] This inland fisheries products contribute more than 75% of animal protein intakes in this country.[2] It could be said that the inland fisheries resources are very important for food security in Cambodia. However, there are worries that high fishing pressure and changes of water utilization derived from dam constriction could put negative impact to aquatic resources in the Mekong river basin . [1,3]. And rational countermeasures for sustainable development of aquatic resource use are required. Thus, to elucidate the impacts from the hydrologic system changes to aquatic resources has the highest priority in Cambodia.

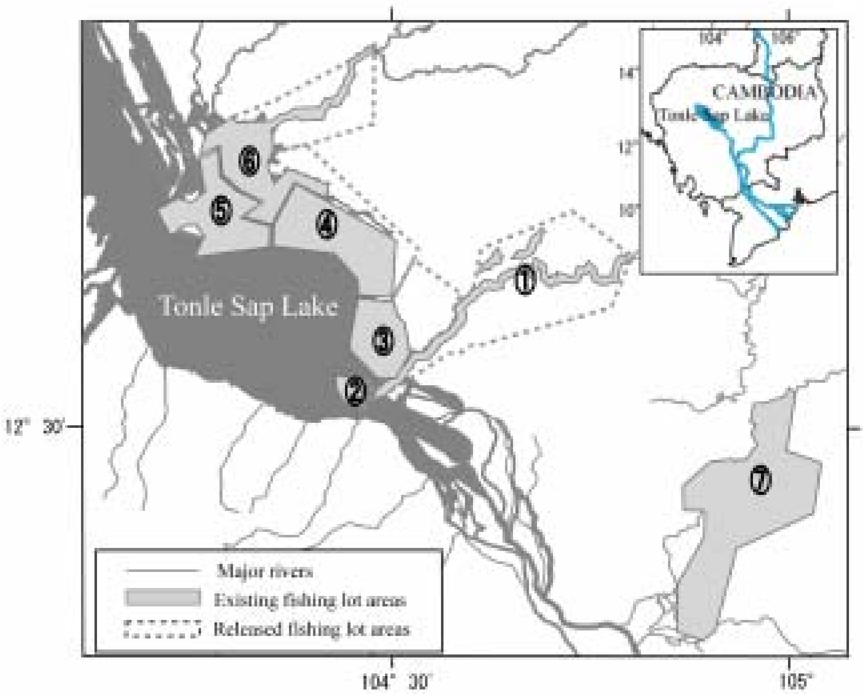


Figure. 1 Map of the Fishing Lots in Kampong Thom province: In the fishing lots1,2,6,7 locat in rivers, operating Barrage traps. In the fishing lots 3,4,5,6 locate in the lakes, operating Arrow-shaped bamboo fence traps. In 2000 , Cambodia Government reduced fishing lot areas which are described by broken line.

Mekong River Commission (MRC) reported that correlation between yields of DAI fishing in Tonle Spa River and max water level in Tonle Sap Lake.[4] This is the singular report regarding the hydrologic system and fish yields of Mekong river basin. However, the fishery yield usually composes of many fish species which have different biological characteristics one another. And, each fish resource is affected differently from a hydrologic change. Therefore, the impact from hydrologic changes to fishery resources should be evaluated by species and/or species groups which hold similar biological features, especially in reproductive biology.

In Cambodia, two fish groups are historically recognized by their migration and reproductive behaviors, one called as "White fish" which is highly migratory species group and another called as "Black fish" which is sedentary features. White fish is mostly caught by back net at riverine areas (including Lot areas) around Tonle Sap Lake and , and Black fish is yield by large size set net (in Cambodia it called as Fishing Lot fence System) at Tonle Spa Lake and its flooding areas.

Cypriniformes including Henicorhyncus spp are majority species of White fish and Chhana species are major species of Black fish. So, we collected catch data by species and fishing effort data of large-scale fishing in Kampong Thom province. And using the catch data of *Henicorhynchus spp* (Riel: Khmer name) and *Chhana microleptes* (Chhdor: Khmer name), we estimated CPUEs and elucidated the relationship between CUPEs and the hydrologic cycle mechanisms of Mekong river and Tonle Spa Lake.

MATERIALS AND METHODS

Catch data and Fishing effort data

In Cambodia, there are three categories of fishing; large, middle and small scale fishing, which are identified based on the fishing license system and fishing gear by Cambodia low. In this study, we treated only large scale fishing data because we can obtain reliable statistical data of large scale fishing only.

Nine years from 1994-95 to 2003-04 except for 1998-99 fishing catch data of *Henicorhynchus spp* (Riel) and *Channa micropeltes* (Chhdor) in Kampong Thom province had been compiled on research reports of Kompong Thom provincial office, Department of Fishery (DOF) and MRC projects.[5,6]

Data of number of gears had been collected by DOF annual reports [7]. Numbers of Barrage traps and Arrow-shaped bamboo fence traps were used as fishing efforts for Riel and Chhdor, respectively (Fig.1and 2).

CPUE

Catch per unit of efforts (CPUE) of Riel and Chhdor were calculated from the catch and fishing effort data mentioned before. CPUE of Riel ($CPUE_{RIEL}$) was calculated through dividing catch data by number of Barrage traps. CPUE of Chhdor ($CPUE_{CHHDOR}$) was calculated through dividing catch data by number of Arrow-shaped bamboo fence traps. When some trends of CPUE are observed, CPUE was defined into TREND CPUE and Detrended CPUE

Water level data

Two kinds of daily water level data were used as hydrologic characters. One was daily water level data of river at interflow point of Tonle Sap River and Mekong River collected another was daily water level inside of Tonle Sap Lake. Both data are collected by Department of Hydrology, Cambodia. Based on these data, we calculated following hydrologic parameters for both rive and Tonle Sap lake, Max water level of river, Starting date of water level, Stability index of water fluctuation.

Max water level in the river was defined as maximum of water level during September-October. Starting date of water level rising in the river was a date of inflection point of regression quadratic curve of water level during March1 – July 31. Stability index of water fluctuation in the river was standard deviation of residual error during 120 days after Starting date of water level rising in the river. The residual error was calculated by following equation; $e_{Str+t} = WL_{Str+t} - WL'_{Str+}$, WL_{Str+t}, is observed water leverl of day t , WL'_{Str+t} is estimated water level at day t from regression quadratic curve of water level. Max water level in Tonle Sap Lake was defined as maximum water level during September-October. Index of Starting Date of water level rising in Tonle Sap Lake was date when water level in Tonle Sap Lake reach at 2m depth.

Data analysis

Correlations between CPUE (or Detrend CPUE) and each hydrologic parameters were evaluated. According to the results of correlation analyses, hydrologic parameter holding high regression coefficient with CUPEs were used for composing multiple regressions for CPUE back calculation. In back calculation of CPUE, we used a dummy variable, because width of fishing areas for large scale fishing had been drastically shrunk at 2000 due to a political reason. A dummy variable from 1994-95 to 1999-00 was zero and it from 2000-01 was one.

RSELUTS

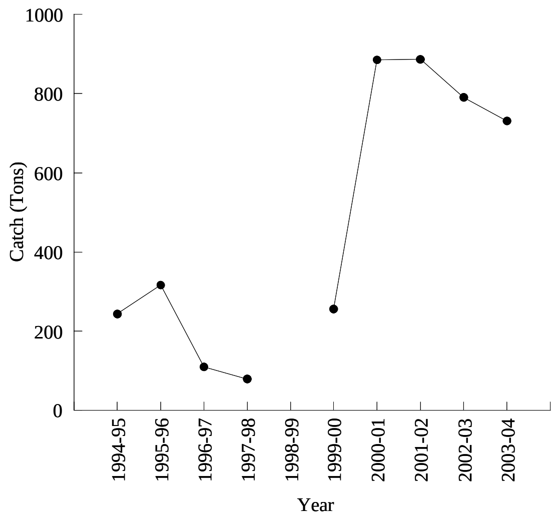


Figure.2 Catch data of Riel of large-scale fisheries between 1994-95 and 2003-04 Source: data from1994-95 to 1996-97 obtained from Diep Loeung *et al.* 1998, data in 1997-98 obtained from Van Zalinge *et al.* 1999, data in 1998-99 obtained personally from a former provincial fisheries office data supervisor of project for the Management of the Freshwater Capture Fisheries of Cambodia in Kampong Thom province, data from 2000-01 to 2003-04 obtained from Provincial Fisheries Office in Kampong Thom provice. Note: Data in 1999-00 was not found.

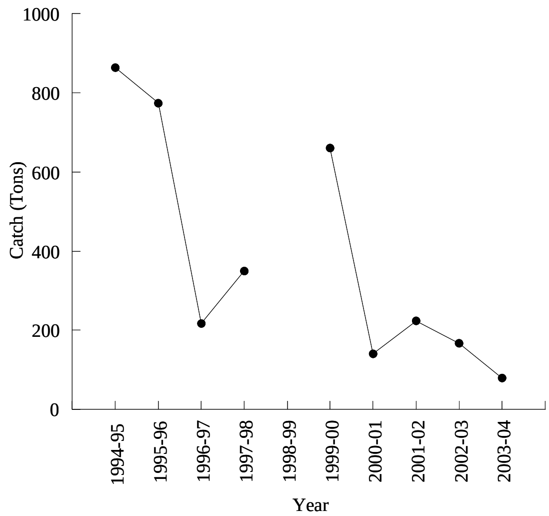


Figure. 3 Catch data of Chhdor of large-scale fisheries between 1994-95 and 2003-04 Source: data from1994-95 to 1996-97 obtained from Diep Loeung *et al.* 1998, data in 1997-98 obtained from Van Zalinge *et al.* 1999, data in 1998-99 obtained personally from a former provincial fisheries office data supervisor of project for the Management of the Freshwater Capture Fisheries of Cambodia in Kampong Thom province, data from 2000-01 to 2003-04 obtained from Provincial Fisheries Office in Kampong Thom provice. Note: Data in 1999-00 was not found

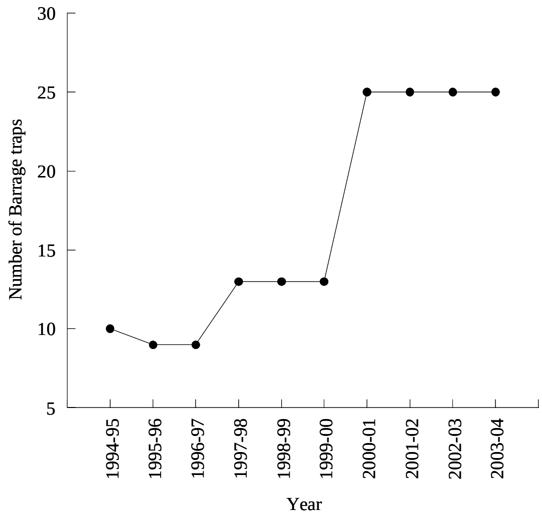


Figure.4 Number of Barrage traps of large-scale fisheries in Kampong Thom province between 1994-95 and 2003-04. Source: data from fisheries statistics published annually by statistical and planning office in Department of Fisheries

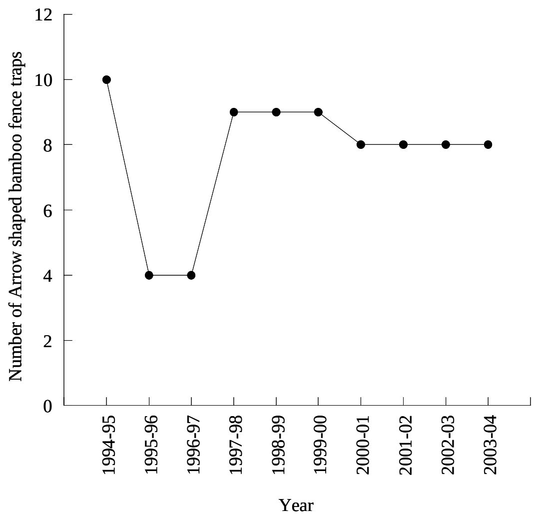


Figure.5 Number of Arrow-shaped Bamboo fence traps of large-scale fisheries in Kampong Thom province. Source: data from fisheries statistics published annually by statistical and planning office in Department of Fisheries

Catch data and Fishing effort data

The catch of Riel from 2000-01 was two times of that from 1994-95 to 1999-00 (Fig. 2). Catch data of Chhdor from 1994-99 to 2003-04 decreased gradually (Fig.3). Number of Barrage traps after 2000-01 increased constantly (Fig.4). Number of Arrow-shaped bamboo fence traps were stable from 1994-95 to 2003-04, excepting 1995-96 and 1996-97 (Fig.5). Number of Arrow-shaped bamboo fence traps in 1995-96 and 1996-97 were approximate half of other years.

No trend was observed in $CPUE_{RIEL}$, but it held high fluctuation (Fig.6). Downward trend of $CPUE_{CHHDOR}$ was revealed (Fig.7). According to the downward trend, the $CPUE_{CHHDOR}$ divided into Detrend $CPUE_{CHHDOR}$ and Trend $CPUE_{CHHDOR}$. Detrend $CPUE_{CHHDOR}$ was used for estimation of correlation with hydrologic parameters. Trend $CPUE_{CHHDOR}$ was used as explanatory variable for models of $CPUE_{CHHDOR}$.

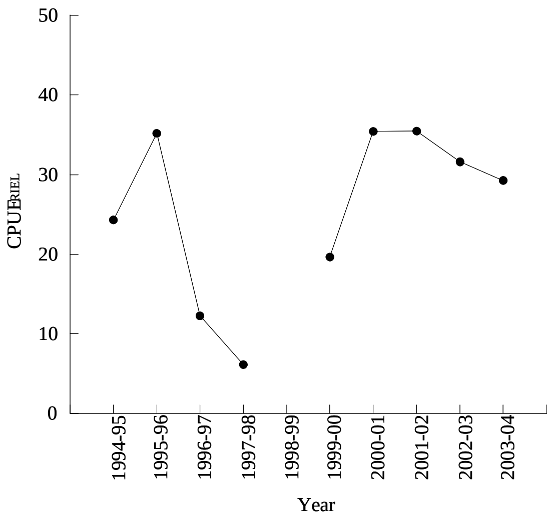


Figure.6. CPUERIEL of large-scale fisheries in Kampong Thom between 1994-95 and 2003-04 without 1998-99. Note: CPUERIEL in 1998-99 was not calculated because of the absence of catch data in 1998-99.

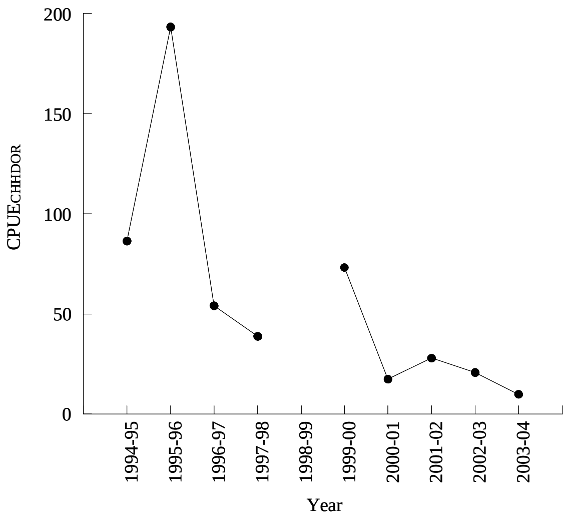


Figure.7 CPUECHHDOR of large-scale fishery in Kampong Thom between 1994-95 and 2003-04 without 1998-99. Note: CPUECHHDOR in 1998-99 was not calculated because of the absence of catch data in 1998-99.

CPUEs

No clear correlation between $CPUE_{RIEL}$ and Max water level in the river was observed (r^2=0.04, Fig.8). $CPUE_{RIEL}$ and Starting date of water level rising in the river correlated negatively, excepting 1999-00 (r^2=0.42, Fig.9) Negative correlation between $CPUE_{RIEL}$ and Stability index of water fluctuation in the river was identified (r^2=0.41, Fig.10). There is not definite correlation between Detrend $CPUE_{CHHDOR}$ and Max water level in Tonle Sap Lake (r^2=0.02, Fig11). Detrend $CPUE_{CHHDOR}$ and Index of starting date of water level rising in the river correlated negatively (r^2=0.41, Fig.12). Model 1 which included explaining variables of Starting date of water level rising in the river and Stability index of water fluctuation explained 59% of the interannual variation of $CPUE_{RIEL}$ (Table. 1, Fig. 13). Model 2 which contained a dummy variable for considering release of fishing lot areas in addition to explanation variables of the model 1 explained 78% of the interannual variations of the $CPUE_{RIEL}$ (Table. 1, Fig. 14). The model 2 explained the interannual variations larger than the model 1. Model 3 which included explaining variables of Index of starting date of water level rising in Tonle Sap Lake explained 45% of the interannual variation of $CPUE_{CHHDOR}$ (Table. 1, Fig. 15). Model 4 which included the dummy variable in addition to explanation variables of the model 3 explained 90% of interannual variations of $CPUE_{CHHDOR}$(Table. 1, Fig. 16). The model 4 explained interannual variations of $CPUE_{CHHDOR}$ larger than the model 3.

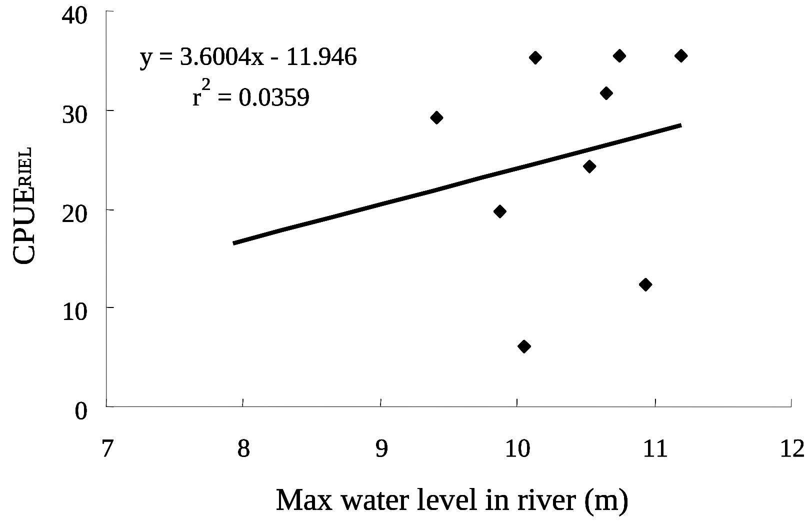


Figure.8 Relationship between CPUERIEL and Max water level in river from 1994-95 to 2003-04, except 1998-99.

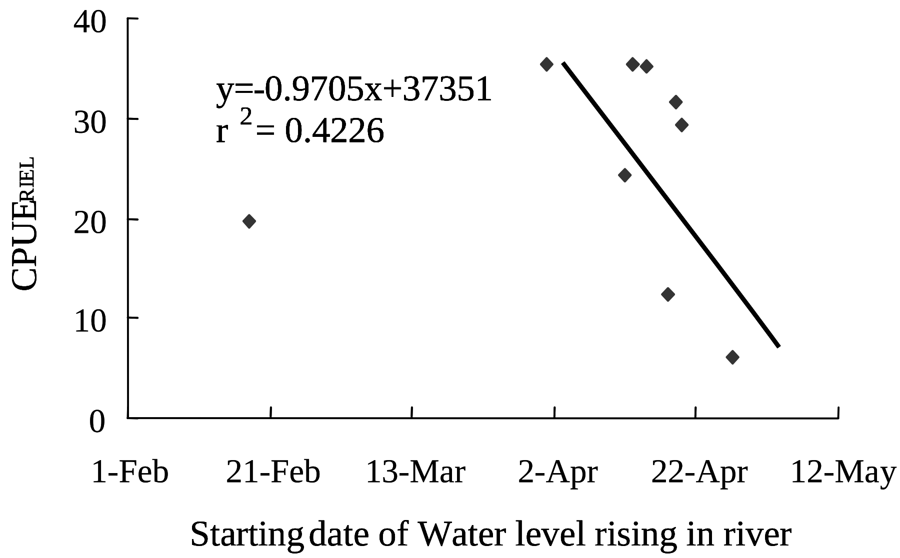


Figure.9 Relationship between CPUERIEL and Starting date of water level rising in river from 1994-95 to 2003-04 without 1998-99, Note: 1999-00 was treated as outlier.

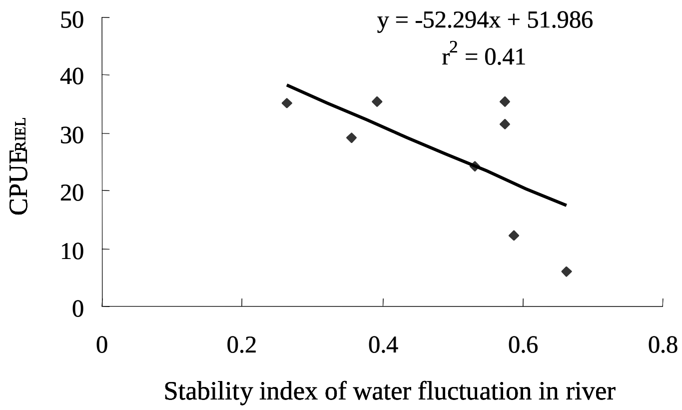


Figure.10 Relationship between CPUERIEL and Stability of water fluctuation in river from 1994-95 to 2003-04 without 1998-99 and 1999-00. Note: 1999-00 was removed because of the results of correlation analysis in Figure.9.

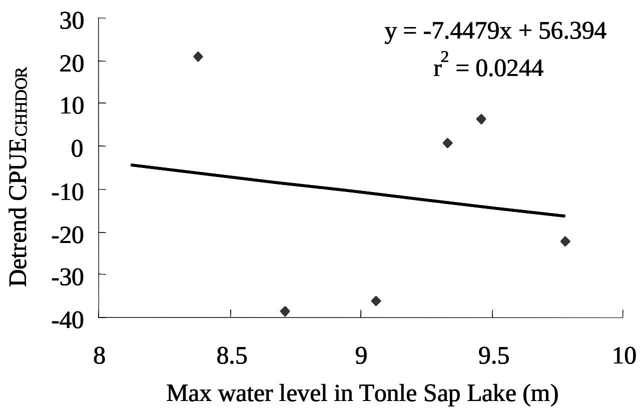


Figure.11 Relationship between Detrend CPUECHHDOR and Max water level in Tonle Sap Lake from 1996-97 to 2002-03 without 1998-99

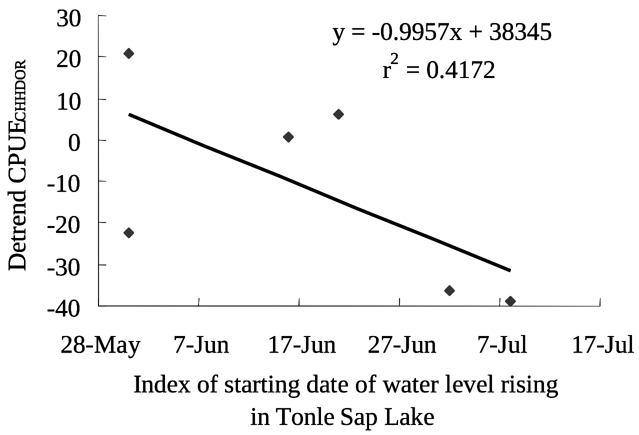


Figure.12 Relationship between CPUECHHDOR and Index of starting date of water level rising in Tonle Sap Lake from 1996-97 to 2002-03 without 1998-99

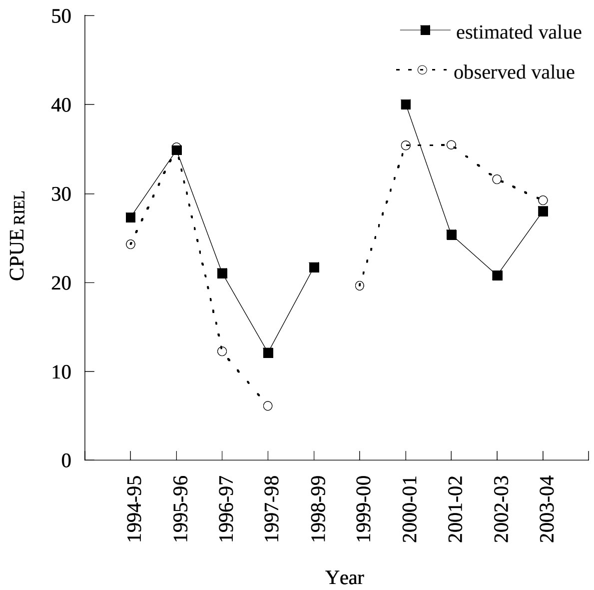


Figure 13. Comparison between estimated value by model and observed value for CPUERIEL from 1994-95 to 2003-04. Note: Estimated value in 1999-00 was lacking because the explaining variables in 1999-00 could not be used as a result of the correlation analysis in Fig.9. Observed value in 1998-99 was not calculated because of the absence of catch data in 1998-99.

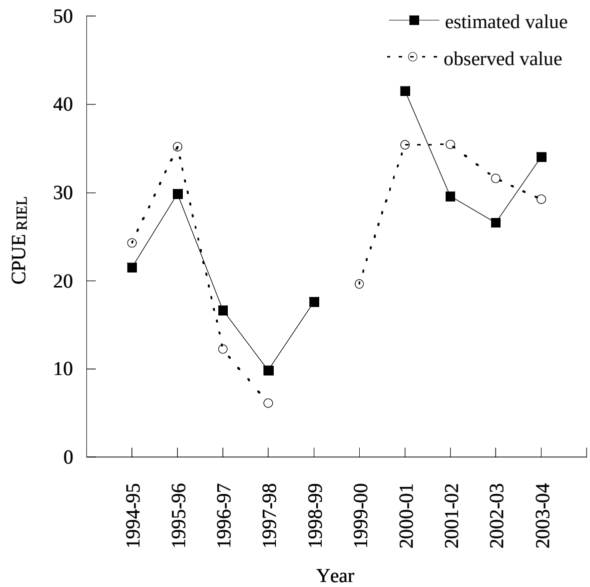
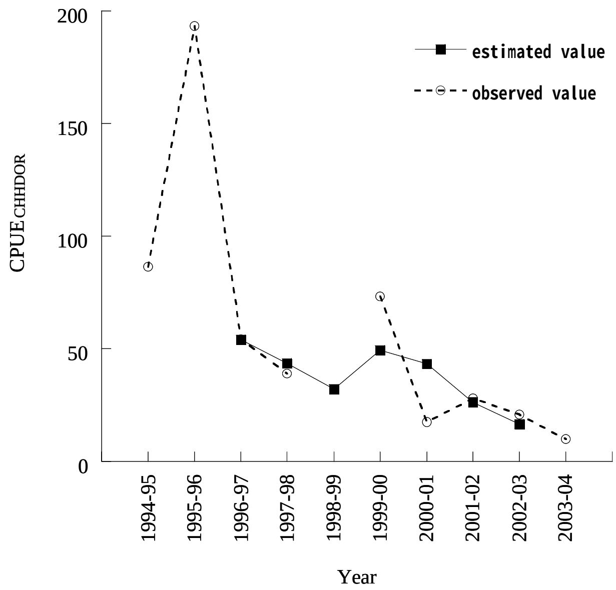


Figure.14 Comparison between estimated value by model including a dummy variable and observed value for CPUERIEL from 1994-95 to 2003-04. Note: Estimated value in 1999-00 was lacking because the explaining variables in 1999-00 could not be used as a result of the correlation analysis in Fig.9. Observed value in 1998-99 was not calculated because of the absence of catch data in 1998-99.



Figue.15 Comparison between estimated value by model and observed value for CPUECHHDOR from 1994-95 to 2003-04. Note: Estimated value in 1994-95, 1995-96 and 2003-04 were lacking because these explaining variables calculated from water level data were missing. Observed value in 1998-99 was not calculated because of the absence of catch data in 1998-99

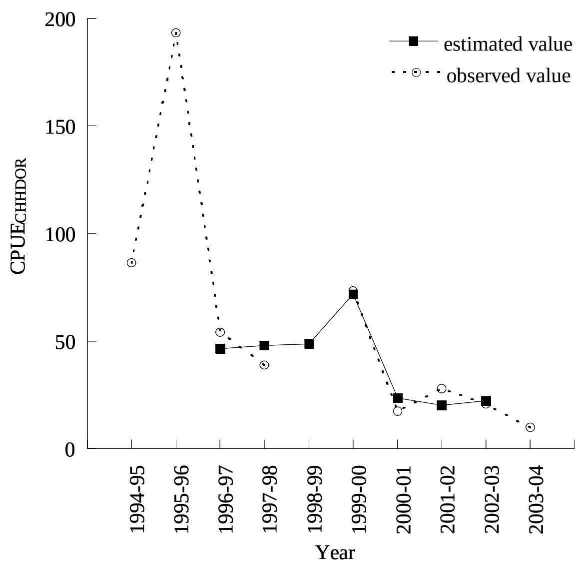


Figure.16 Comparison between estimated value by model including a dummy variable and observed value for CPUECHHDOR from 1994-95 to 2003-04. Note: Estimated value in 1994-95, 1995-96 and 2003-04 were lacking because these explaining variables calculated from water level data were missing. Observed value in 1998-99 was not calculated because of the absence of catch data in 1998-99.

Table 1. Model results

No.	Equations	d.f.	R^2(adj.)
1	$CPUE_{RIEL} = 76.68 - 0.70Str - 36.29Stb$	8	0.59
2	$CPUE_{RIEL} = 60.58 - 0.46Str - 36.37Stb + 9.90Dum$	8	0.78
3	$CPUE_{CHHDOR} = 24.91 + 0.992Tre - 0.53Sta$	6	0.45
4	$CPUE_{CHHDOR} = 107.57 - 0.56Tre - 0.41Sta - 53.05Dum$	6	0.90

Str: period from March 1 to Starting date of water level rising in river
Stb: Stability index of water fluctuation during wet season in river
Tre: Trend CPUECHHDOR
Sta: period from May 1 to Index of starting date of water level rising in Tonle Sap Lake
Dum: a dummy variable which equals zero if year is from 1994-95 to 1999-00 and one if year is after 2000-01
R2: coefficient of determination between estimated value by model and observed value

DISCUSSION

Comparing trends of catch and gear numbers, both of the catch of Riel and number of Barrages increased in 2000-01 year (Fig.2, 4). So, increase of number of Barrage could be major cause of increase of the catch of Riel. In the case of Chhdor, the catch showed a downward trend constantly, in spite the number of Arrow-shaped bamboo fence traps were stable (Fig.3, 5). Hence decreasing of the catch of Chhdor could suggest of resource exhaustion. No downward trend of $CPUE_{RIEL}$ was shown, and a stock of Riel would not be exhausted (Fig.6). On the contrary a stock of Chhdor seems to be decreasing because of the downward trend of $CPUE_{CHHDOR}$ (Fig.7). These results can indicate the importance for evaluation resources by species.

The difference of the trends between $CPUE_{RIEL}$ and $CPUE_{CHHDOR}$ would be derived from the biological differences and different usage as fisheries resources. Riel spawns a lot of eggs and the stock magnitude of the year depending on the mortality during early life history. On the contrary, Chhdor spawns relatively little eggs and the stock size depending on the number of spawners. Besides, many Riel are caught at small size (young age), but many Chhdor are yielded after grown up at elder age (2-4 years old). These differences would derive the different impacts from hydrologic events. This can also highlight the importance the stock evaluation by species.

In the previous study, max water level in Tonle Sap Lake seems singular hydrological parameter relating fisheries catch and resources. In this study, the date of water level rising and the stability of water level rising during early rainy season in the river were supposed to affect on the Riel stock. And date of water level rising at Tonle Sap lake and maximum water level which closely related the width of flooding area were related on the Chhdor stock. These differences can indicate the difference in the impacts from drastic hydrological changes by dam constriction in Mekong river system. We treated quite restricted data of Kampong Thom province. So it is difficult to evaluate whole fishing catch and stock status of Riel and Chhdor inhabiting around Tonle Sap Lake. However, if we obtain information of number of fishing gears sorted by types and location, our models would be adjustable to calculate the fishing catch and to elucidate the impact of future hydrologic changes around Tonle Sap lake, at least Riel and Chhdor. And our results imply the importance of compilation of biological and fisheries data and information by species, by gears and by areas for sustainability of fisheries and conservation of aquatic resources.

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DRIFT OF LARVAL AND JUVENILES FISH IN THE MEKONG MAIN STREAM NEAR PHNOM PENH

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ABSTRACT

Analysis of drift of larval and juvenile fish in two rivers, the Mekong upstream and the Tonle Sap Rivers near Phnom Penh of Cambodia were made. Samplings were undertaken with the bongo-net from June to October during raining season. Larval fish densities differed to times of day and months. Highest densities of *Pangasius* spp. and *Henicorhynchus* spp., was detected 71555 larvae/1000m^3 in June and 28695 larvae/1000m^3 in July, larvae densities and numbers of fish species were decreasing from August to October. We identified 155 species belonging to 15 orders and 28 families; we found 133 species in the Mekong River and 72 species in the Tonle Sap Rivers. The major of spawning period for more than 1/3 fish species of Cambodian Mekong is beginning at first and the middle of the flood season, the diversity declined towards from August to October.

INTRODUCTION

Most Mekong fish spawn at the onset of the rainy season in May or June (Poulsen *et al*. 2001). Previous studies have shown that higher flood levels during the flood season is higher number of many fish species spawn and migrated (Chea T. R and Touch S. T 2001) [1], (Chea T. R *et al.* 2002) [2] (K.G. Hortle 2003) [4]. It is assumed that floods are important for ecological events in the life cycle of many fish species.

For most species fish the exact spawning grounds have not been identified. This is especially true for species spawning in the mainstream of the Mekong or large tributaries. However many fish spawn in the mainstream between Kratie and Stung Treng in northern Cambodia. After spawn eggs, larvae and juveniles fish drift downstream to nursery areas associated with the large floodplain around the Great Lake and along the Tonle Sap, Bassac and the Mekong Rivers. The knowledge about the ecology of eggs and larvae of freshwater fish is a great importance to the establishment for protection measurement and management rule of populations. So, the objectives of this research are to identify of larval and juveniles fish collected from the Tonle Sap and the Mekong Rivers, to examine the orders, families and species compositions of larval and juveniles fish in both rivers, and to determine abundance of larvae and juvenile fish (larvae/1000m^3) during study period.

METHODS

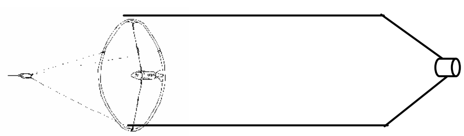

Figure1: the bongo- net used for collection fish larvae and juveniles in the Mekong and Tonle Sap Rivers

Sampling location: samples were collected at the Mekong upstream and the Tonle Sap Rivers near Phnom Penh

Sampling period: sampling were collected from June to October

Sampling times: sampling were collected everyday, four times per day at (06:00, 12:00, 18:00 and 24:00 hours) in both Rivers.
Sampling collection: samples were collected by bongo-net with 1m diameters mount; 5m length; 1mm mesh size and set down 2m from water surface.
Identification of larval fish:
For fish larvae and juvenile has been used reference of (Rainboth 1996) [6]; (Chevey 1930) [3]
Counting and sub-sampling:

All larvae in each sample were counted. Sometimes a sample consisted of several thousand tiny larvae mixed with lots of organic material. In such cases, we resorted to sub-sample. Sub-sample was carried out in the following manner:

Weigh the total sample.
Take three sub-samples from different parts of the sample.
Weight each sub-sample individually.
Identify all species in the sub-sample and count them.
Estimate the number of larvae in the full sample according to the following formula:

$$N_{tot} = \left(\frac{N_1}{W_1} + \frac{N_2}{W_2} + \frac{N_3}{W_3} \right) \times \frac{W_{tot}}{3}$$

Ntot: Number of larvae fish in the samples
N1: Number of larvae fish in the sub-sample 1
N2: Number of larvae fish in the sub-sample 2
N3: Number of larvae fish in the sub-sample 3
Wtotal: Weight of larvae fish in the sample
W1: Weight of sub-sample 1, W 2: Weight of sub-sample 2, W 3: Weight of sub-sample 3
Flux velocity was measured in the both rivers by mean a flow meter by the expression:
$V = ((n*f)/999999/t$; $V1 = [((n*f)/999999)*\phi^2 *\pi]/4$
Where: V= flux velocity (m/s); V1= volume, n = number turns of flow meter; f = calibration factor of flow meter (26.873); t = time of exposure.

Results:
4.1 Families composition
4. 2. Order composition

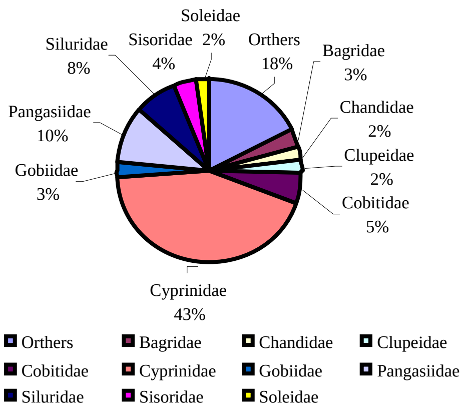

Figure1. Families composition in the

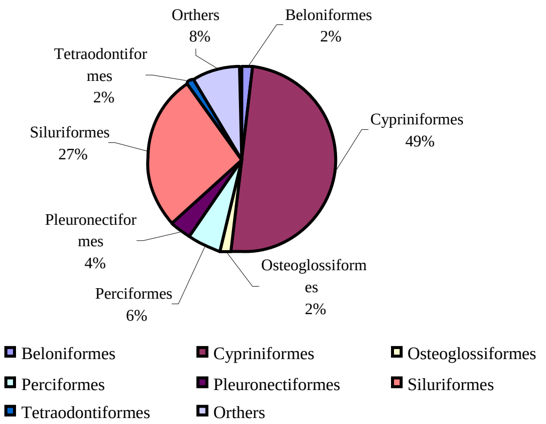

Figure 2. Orders composition in the Mekong River

A total of 869 samples (small jars) have been analyzed from two rivers (580 samples from the Mekong and 289 samples from Tonle Sap Rivers. From the Mekong and the Tonle Sap rivers, we identified 155 species belonging to 15 orders and 28 families, and we found 133 species in the Mekong River and found 72 species in

In the Tonle Sap Rivers the 3 highest-ranking orders identified in accordance to species richness were: Cypriniformes, 66 species (49%), Siluriformes 36 species (27%) and Perciformes 8 species (6%).

In the Mekong river the most species-rich were families Cyprinidae (57 species), Siluridae (10 species), Pangasiidae (13 species), Bagridae and Gobiidae for each species (4 species), Cobitidae (7 species). Most of the remaining families were only represented by a small number of each species.

4.3 Temporal variation of families and species

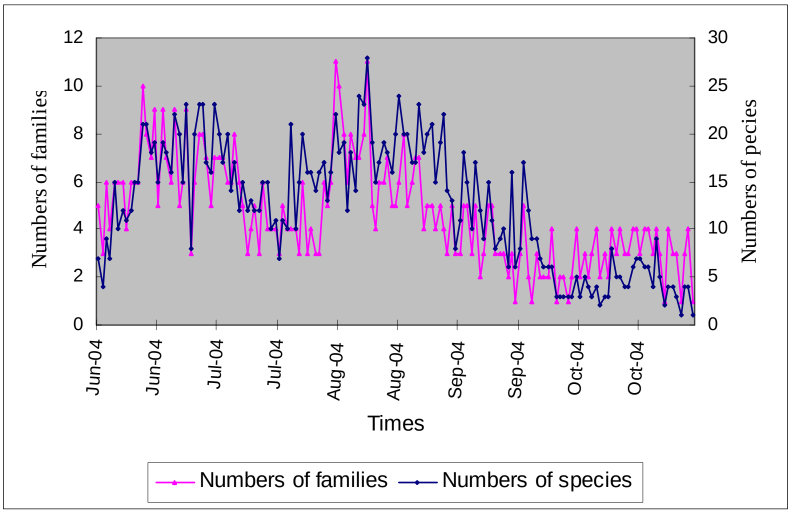

Figure 3. Temporal variation of families and species larval fish in the Mekong River

In the Mekong river, the highest number of species encountered in one day was 28 species (on 10/08/04), and the lowest number for one day was 1 species (27/10/04). From these graphs, we can also see that species diversity declined towards the end of the study period. This indicates that the major spawning period of more than 1/3 of species fish of Cambodian Mekong is beginning at first and the middle of the flood season. These results are also reflected in the Mekong 2002 for larvae study.

4.4. Temporal variation of densities larval fish in the Mekong River

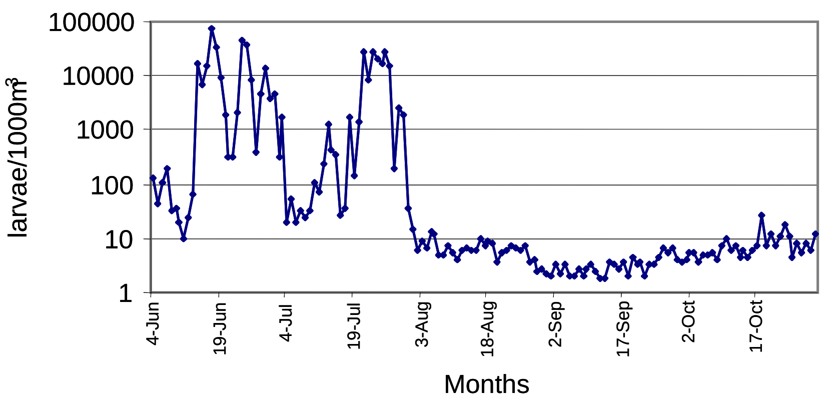

Figure4. Temporal variation of densities larval fish in the Mekong River

The highest density of larvae fish was found in the upstream Mekong occurred between June and July (71555 larvae/1000m^3) in June and 28695/1000m^3 in July.

Discussion

The results show that most fish larvae and juveniles collected from the Mekong and the Tonle Sap, the family Cyprinidae was the most abundant (1/2 of total numbers of species). Orders represented by the highest number of species were Cypriniformes, Siluriformes and Perciformes. Most of species belonging to these orders are mainstream spawners. Several species only occurred in very low quantities in the samples. These results are similar to the findings of previous studies (Chea TR & Toch ST 2001; Chea TR e*t al*. 2002). More than 1/3 fish of Cambodian Mekong spawn at the beginning and middle of the flood season. The highest density of *Pangasius* spp. and *Henicorhynchus* spp. occurred between June and July, the diversity declined towards from August to October.

Acknowledgments

I would like to thank the Assessment of Management Capture Fisheries for financial support, Dr. Kent G. Hortle for his advice and technical assistance.

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BEHAVIOR OF NUTRIENTS IN NATURAL RIVER AND SHRIMP FARMING AREA IN BAC LIEU PROVINCE, MEKONG DELTA

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ABSTRACT

Extensive shrimp farming occupies more than 95% area for aquaculture and nearly half of total natural area in Ca Mau peninsular. Therefore, it could have a large impact on the natural water environment, and the shrimp farming practice in return, may become impacted through positive-feed-back. To assess these possible impacts, we have been conducting a large scale survey in Bac Lieu province. For water sampling, seven main water inlets and 4 representative shrimp farming zones in Bac Lieu were selected. Water quality and isotopic composition of some components in water and sediment were examined. The correlations between water quality, shrimp farming techniques with harvest efficiency have also been analysed. Some preliminary results have been emerged after the 1st stage of survey. There are signals that natural water quality is impacted by shrimp farming activities, both in canals inside shrimp farming zones and main water inlets.

INTRODUCTION

Viet Nam has 3,260 km coastal line and its climate is very convenient for shrimp farming development. In Viet Nam, shrimp farming is paid due attention due to its high export value and currently, it becomes a key industry that brings high profit to the Mekong delta in general and to Bac Lieu province in particular.

However, the shrimp farming industry encountered many difficulties on maintaining stable production…The problems can be from shrimp seed quality, the availability of natural food source for shrimp, water quality and pond management practices…, among those, pond water quality is considered most important factor since it is the main reason that leads to shrimp disease and mass shrimp dead. Therefore, the saying “farming shrimp means farming water” becomes the most important lesson for farmers when first step into this industry.

Ca Mau province has a total area of 500,000 ha of which shrimp farming occupies 220,000 ha. Bac Lieu province extends over 250,000 ha of which shrimp farming occupies over 110,000 ha[6]. These two provinces have the highest proportion of land used for shrimp farming (nearly 50% of natural area).

Shrimp farming practices are classified in 3 types [2]: (1) intensive farming with stocking density over 25 shrimps m^{-2}; (2) semi-intensive farming with stocking density between 10-25 shrimps m^{-2}; (3) extensive farming with stocking density under 10 shrimps m^{-2}. For intensive and semi-intensive farming man-made feeds are supplied to the shrimps and aeration systems and chemicals are normally used. For extensive farming, there is almost no feeding and chemical treatment is very limited, except for the addition of lime to maintain suitable pH. Water quality of the rivers and canals in the area is expected to be worsen because of increasing release of waste water, itself correlated with ever increasing shrimp farming activity.

In the Ca Mau peninsula and many other coastal settings of the Mekong delta extensive shrimp farming occupies over 95% of the total shrimp farming area and this proportion is still increasing due to ongoing conversion from intensive to extensive farming. While extensive shrimp farming practices could have a large effect on the quality of natural waters, because of limited water treatment, they in turn depend on the quality of natural waters to fill the ponds.

This work was started to better understand biogeochemical processing of waste waters from fish ponds. Understanding the underlying biogeochemical processes will assist in developing approaches leading to an improvement of water quality for shrimp farming and thus contributes to a sustainable development of aquaculture in the region.

OBJECTIVES

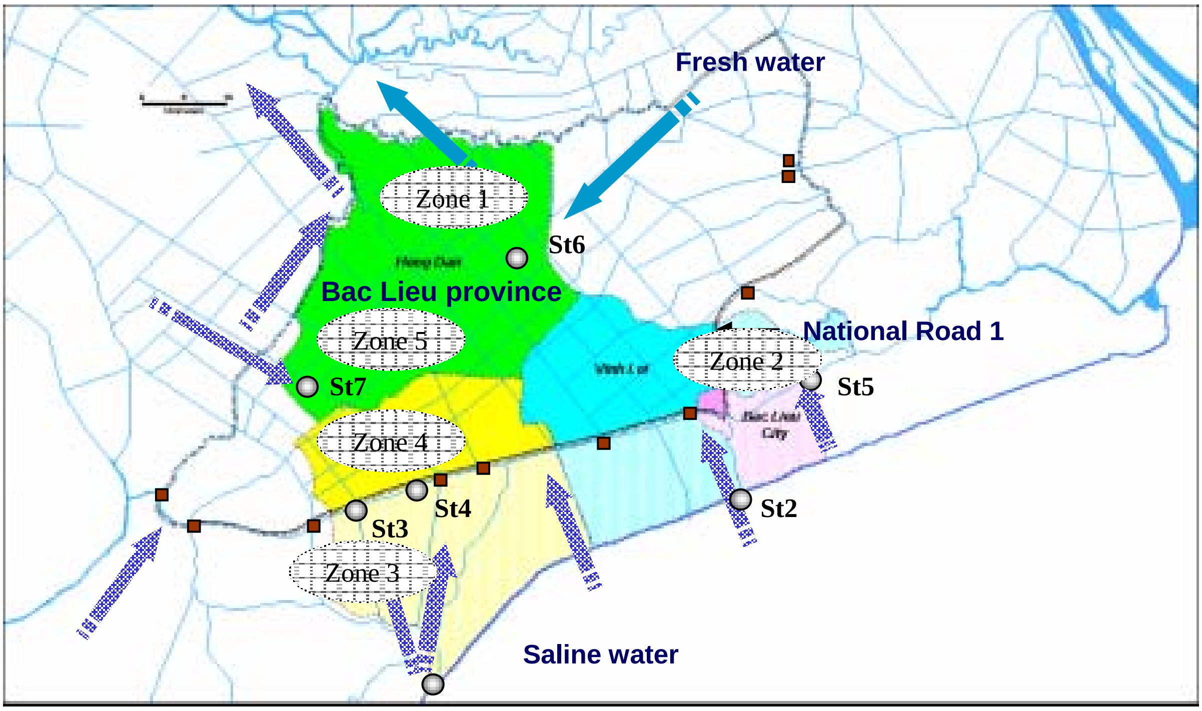
Study the level of organic pollution in natural water bodies impacted by shrimp farming activities and assess capacity for self purification

Assess the biogeochemical processing of C and N in waters and sediments affected by shrimp farming

Study the impact of auto-polluted supply waters on extensive shrimp farming industry

RESEARCH METHODOLOGY

Map of sampling area



Saline water — Fresh water

Sluice gates to regulate the sea water intrusion to the upper zone (north of National Road 1)

Sampling sites for primary supplying water sources

Major shrimp farming areas where studied ponds and its (secondary) supplying canals were selected and sampled

St1: Ganh Hao River Mouth
St2: Nha Mat River Mouth
St3: Cay Gua Sluice Gate (transitional zone)
St4: Su Son Sluice Gate (transitional zone)
St5: Nam Can Sluice Gate (transitional zone)
St6: Quan Lo Phung Hiep canal – at Ninh Quoi village (fresh water source)
St7: Cho Hoi canal

Research activities

Monitoring water quality (all year round) of main water inlets for shrimp farming areas and waste water discharged from shrimp farming areas:

Sampling sites (see the map above):

+ River mouths (=end-members which are the main water supplies for the whole area):

1. Sampling site 1 **(St1)**: Ganh Hao river mouth in Dong Hai district
2. Sampling site 2 **(St2)**: Nha Mat river mouth, in Nha Mat sub-district, Bac Lieu town.

+ Sluice gates separating regions north of National Road 1 from regions south of it. National Road 1 plays a role as a levee along which many sluice gates were constructed to regulate salt water intrusion to the northern areas of the road. Shrimp farming also occurs to the south of road but less intensively than in the north:

3. Sampling site 3 **(St3)**: Su Son sluice gate in Gia Rai district (this sluice gate opened all year round).
4. Sampling site 4 **(St4)**: Cay Gua sluice gate Gia Rai district (this is a middle sized sluice gate, opened all year round)
5. Sampling site 5 **(St5)**: Nam Can sluice gate in Hung Thanh sub-district, Vinh Loi district, (this sluice gate is opened and closed according to a provided plan to regulate the water supply to upper regions)

+ Fresh water from the Mekong River:

6. Sampling site 6 **(St6)**: Quan Lo-Phung Hiep canal at Ninh Quoi sub-district, Hong Dan district

+ Waters from upcountry (run-off waters that are sulfuric acid rich in the rainy season + saline water from the Gulf of Thailand)

7. Sampling site 7 **(St7)**: Cho Hoi canal, Phong Thanh Nam sub-district, Phuoc Long district, this canal is connected with Huyen Su canal in Thoi Binh district, Ca Mau province

Sampling plan and method: (See the table below)

Sampling sites	**ID**	**Description of the sites**	**Location (District)**	**Sampling frequency**	**Parameters**
Ganh Hao	St1	River mouth	Dong Hai	Sampled at both low tide and high tide for each campaign. Two campaigns a month (only at spring tide)	Temperature, pH, salinity, DO, COD, alkalinity, ammonium, nitrate, N total, P total, C/N ratio, POC, PON, ^{13}DIC, ^{13}POC, ^{15}PON (in water samples);
Nha Mat	St2	River mouth	Bac Lieu		
Cay Gua	St3	Sluice gate in the transitional zone	Gia Rai		
Su Son	St4	Sluice gate in the transitional zone	Gia Rai		
Nam Can	St5	Sluice gate	Vinh Loi		
Quan Lo Phung Hiep canal (Ninh Quoi)	St6	A fresh water source supplied to Bac Lieu province	Hong Dan	One sample /campaign (since no tide influence here)	
Cho Hoi canal	St7	Saline water from neighbor province	Phuoc Long	Two campaigns a month (only spring tide).	

Assess water quality inside the shrimp farming zones and the dependency of shrimp farming practice on water quality (Phase 1: From April 2004 to March 2005)

Four major shrimp farming zones in Bac Lieu were selected, in each zone, 2 shrimp farming ponds were selected; the water quality in those 2 shrimp ponds and in the intake canal was examined.

Sampling plan and method:

Location	Sampling sites	ID	Description	Sampling frequency	Parameters
Zone 1	Ut Huan canal	C1	Supply canal for SP1 & SP2	Once a month (only at spring tide)	Temperature, pH, salinity, DO, COD, alkalinity, ammonium, nitrate, N total, P total, C/N ratio, POC, PON, ^{13}DIC, ^{13}POC, ^{15}PON (in water samples); C/N ratio, ^{13}POC, ^{15}PON (in mud samples).
	Le Van Dang	SP1	Shrimp pond 1		
	Pham Van Nho	SP2	Shrimp pond 2		
Zone 2	Ut Hen canal	C2	Supply canal for SP3 & SP4		
	Nguyen Viet Thanh	SP3	Shrimp pond 3		
	Huynh Van Ngon	SP4	Shrimp pond 4		
Zone 3	Dinh Thanh canal	C3	Supply canal for SP5 & SP6		
	Nguyen Hoang Ben	SP5	Shrimp pond 5		
	Nguyen Minh Duc	SP6	Shrimp pond 6		
Zone 4	Nam Phuoc canal	C4	Supply canal for SP7 & SP8		
	Tran Tan Phuoc	SP7	Shrimp pond 7		
	Tran Dang Khoa	SP8	Shrimp pond 8		

PRELIMINARY RESULTS (REPRESENTATIVES)

During the survey, all sampling sites were properly sampled, except Nam Can sluice (this sluice gate was closed during sampling time and there was no water exchange from the shrimp farming area inside and main river).

Behavior of ammonium

Ammonium is a useful primary indicator of waste water release in aquatic systems. It is the inorganic nitrogen component released during the ammonification process by heterotrophic bacteria consuming dissolved organic compounds.

Ammonium in main water supplies

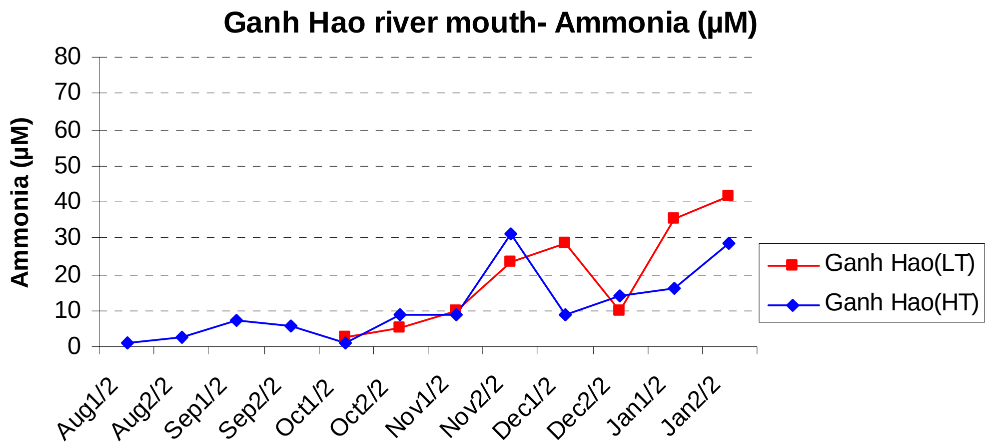


Figure 1: Ammonium(µM) in Ganh Hao river plume at high tide (blue) and low tide (red).

Ganh Hao River is a large river with a catchment area equivalent to the area of two provinces (i.e about 5000 km^2 or more). During 6 months from August 2004 to January 2005, the ammonium concentration of water in Ganh Hao river mouth was always less than 40 µM (Figure 1). The ammonium concentration increased from October to

January. From November to December, many ponds were harvested and pond waste waters were drained off to nearby rivers. Furthermore, from December to January many ponds were renovated resulting in large amounts of mud being washed into adjacent rivers and canals. These activities clearly lead to increase of ammonium in river water. The ammonium concentration at high tide was frequently lower than that at low tide. The water at high tide is upcoming seawater and thus relatively unpolluted, while at low tide the effect of waste water release from the aquaculture areas becomes significant. Although ammonium in the marine end-member was originally low, it rose toward the end of the shrimp cropping period when also shrimp pond renovation was ongoing. Thus, also the marine end-member can become polluted by waste water discharged from aquaculture activities.

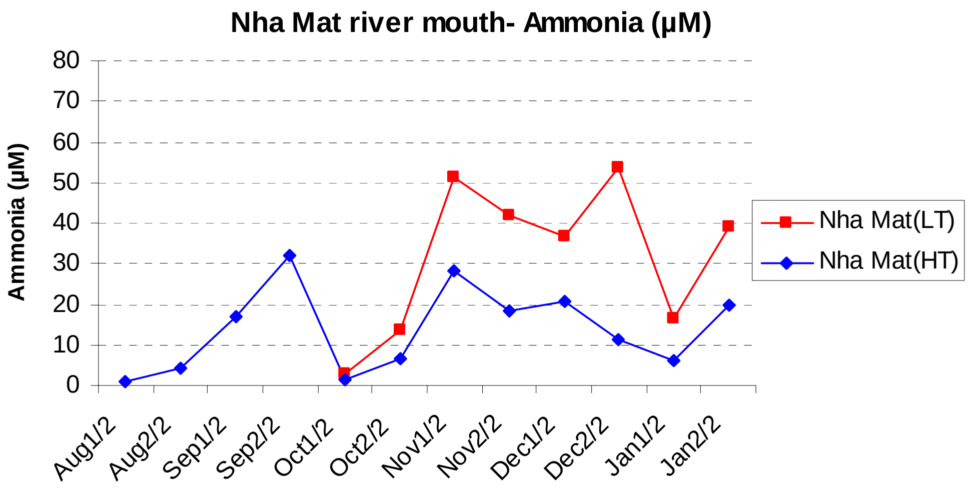


Figure 2: Ammonium (µM) in Nha Mat river plume at high (in blue) and low tide (in red).

Nha Mat River is a small river and its catchment area occupies only a part of Bac Lieu district (i.e. 200 km^2). The maximum ammonium concentration in Nha Mat river mouth was 53 µM (Figure 2). In general, ammonium at this river mouth was higher than in the case of Ganh Hao River. Nha Mat river is much narrower than Ganh Hao River and therefore its capacity of dilution for added waste water can be expected to be lower. The trend of ammonium, however, is also similar to the one observed for the one in Ganh Hao river. Both show a close dependency on pond cropping activity. The only difference is that most of shrimp farming in this area is of the intensive type so cropping began and finished earlier than in the other areas.

Both, for the Ganh Hao river mouth (Figure 1) and the Nha Mat river mouth (Figure 2), but especially for the latter, water at high tide had lower ammonium compared to low tide, reflecting that the upstream shrimp farming areas released ammonium.

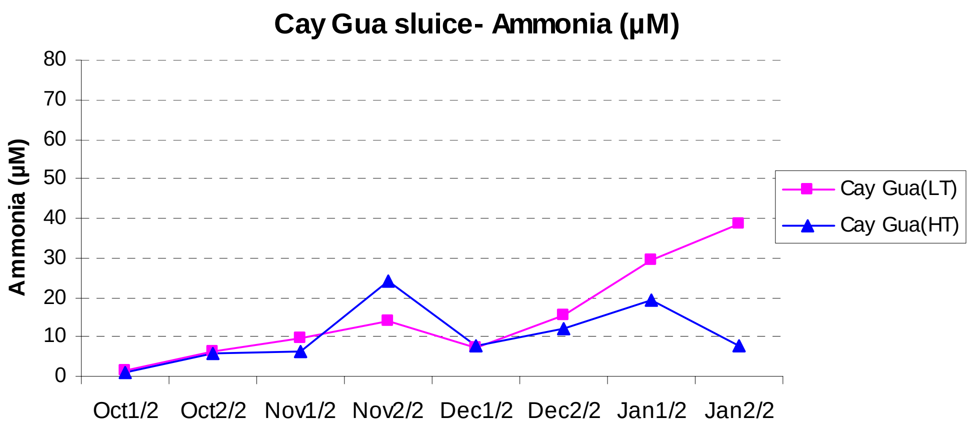


Figure 3: Ammonium (µM) at Cay Gua sluice gate during high (in red) and low tide (in blue).

The ammonium concentration at Cay Gua sluice was below 40 µM and the trend of ammonium variations was more or less similar to those of Ganh Hao and Nha Mat river mouth. Until December there was no clear difference between low tide water and high tide water.

Ammonium concentration in shrimp farming ponds

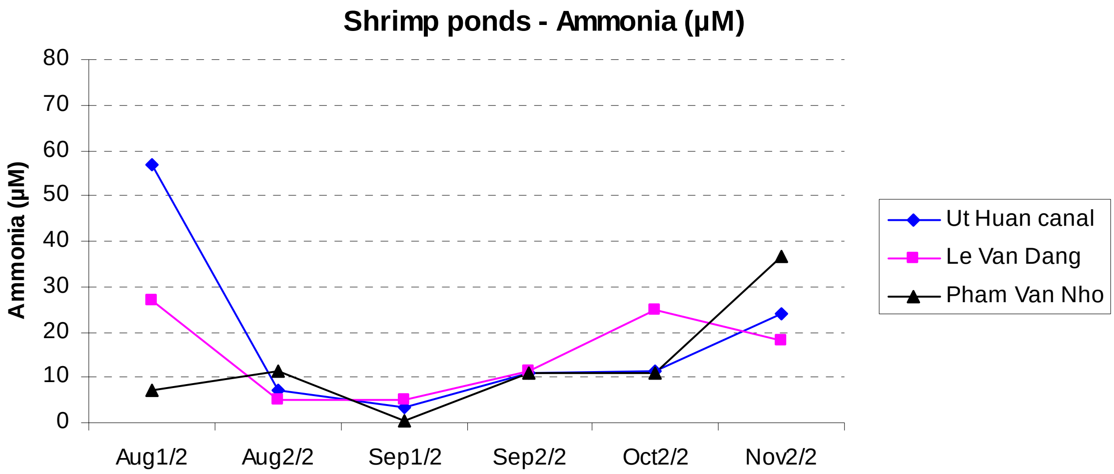


Figure 4: Ammonium (µM) in shrimp ponds and its supplying canal (Zone 1).

In Zone 1, sampling campaigns were conducted from the beginning of the crop (August) until the ponds were drained for shrimp harvest at the end of November. Ammonium concentration is high at the first sampling campaign in the canal and in the pond of Mr. Le Van Dang because he fertilized his pond few days before. But from the second sampling campaign afterward, ammonium concentration increased in both ponds and also in the canal (Figure 4). This trend appears in all other shrimp ponds and intake canals indicating that these became increasingly polluted toward the end of the crop.

Behavior of ammonium vs. nitrate and DO

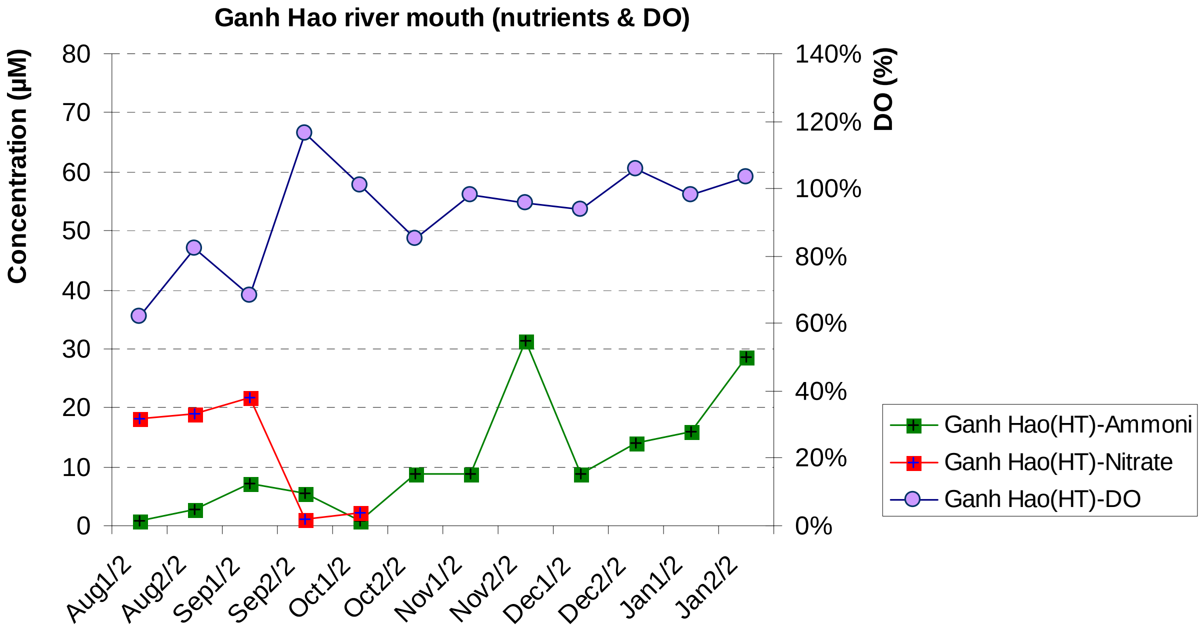


Figure 5: Ammonium (µM), nitrate and dissolved oxygen in Ganh Hao river mouth.

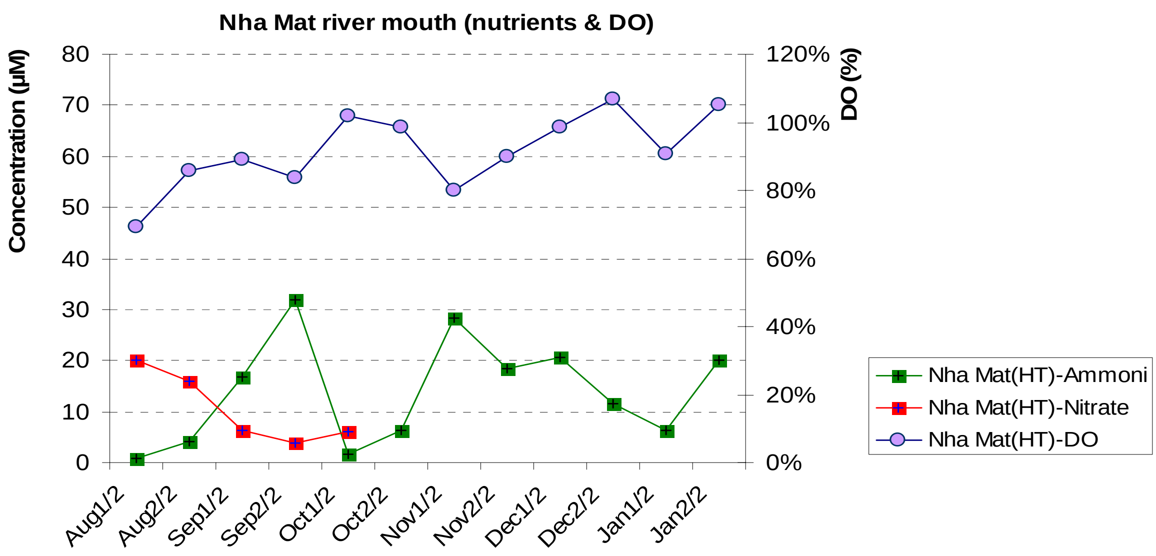


Figure 6: Variations of ammonium vs. nitrate and DO in Nha Mat river mouth.

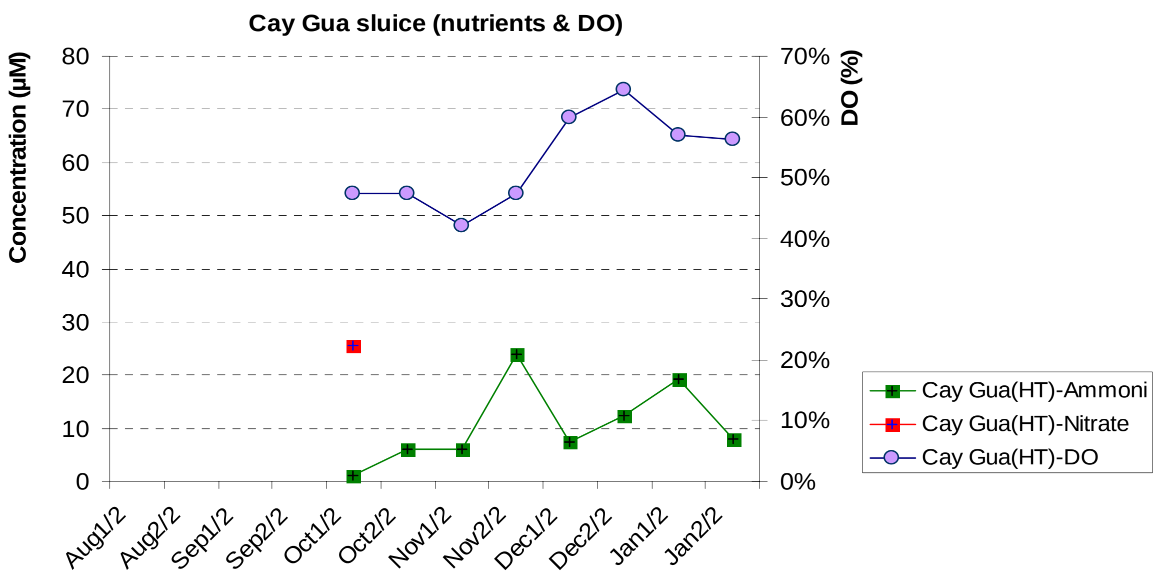


Figure 7: Ammonium (µM), nitrate and dissolved oxygen at Cay Gua sluice gate.

Dissolved oxygen concentrations (DO) often exceeded saturation level. Figures 4, 5, 6 and 7 suggest that nitrate and ammonium concentration had opposite behavior with dissolved oxygen concentration, i.e nitrate and ammonium increased when DO decrease and vice versa. This fact indicates that significant phytoplankton activities occurred in those water bodies, reflecting some degree of euptropication. The greater the phytoplankton activity, the more nitrate and ammonium was consumed and the more oxygen was released to water.

Behavior of phosphate

Behavior of phosphate in main water supplying sources

In the marine environment the ratio between phosphor, nitrogen and carbon normally stays around a certain value called "Red-field ratio". Phosphate variations in Ganh Hao river mouth (Figure 8), Cay Gua sluice (Figure 9) show its dependence on the timing of shrimp farming crop. Phosphate concentration increased towards the end of farming crop (from August to November), decreased when farming crop finished (in December) and increased rapidly when most of shrimp ponds was subjected to pond renovation (in January) to prepare for the next crop.

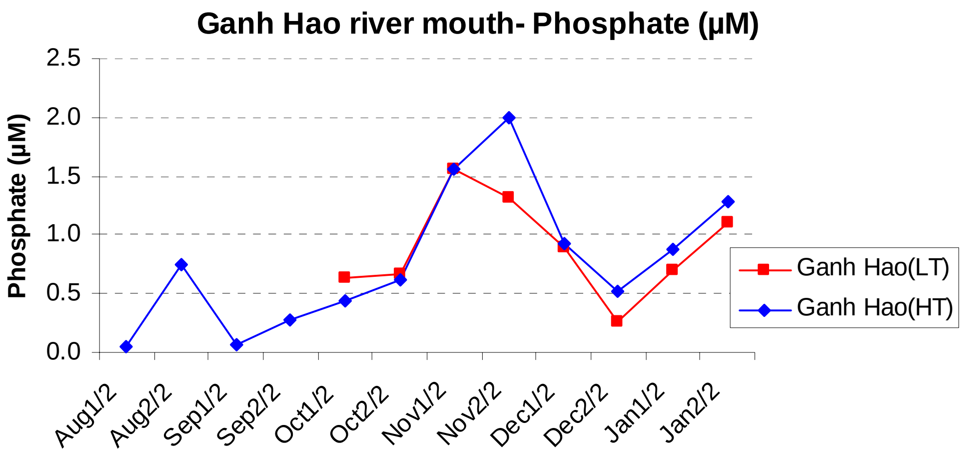


Figure 8: Phosphate (µM) at Ganh Hao river mouth

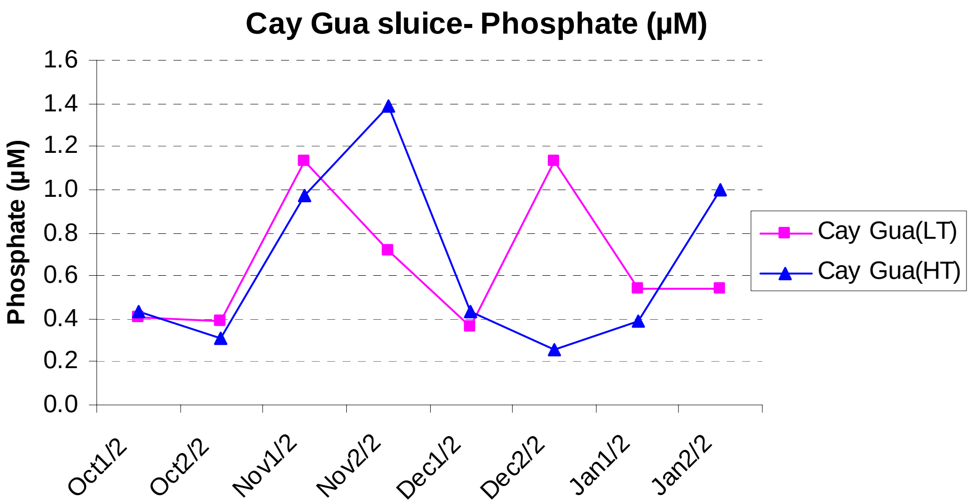


Figure 9: Phosphate (µM) at Cay Gua sluice

Isotopic composition of dissolved in organic carbon (DIC)

Isotopic composition of DIC vs. ammonium

Processes which influence the DIC isotopic composition are photosynthesis (DIC becomes enriched in ^{13}C) and respiration (DIC becomes enriched ^{12}C) [3]. Phytoplankton growth consumes ammonium (and/or nitrate), while ammonium is released as a result of cell breakdown and mineralisation. Intensive mineralization with release of ^{13}C-depleted CO_2 and ammonium might therefore result in an inverse relationship between both parameters. However, no such relationship was observed.

Isotopic composition of DIC vs. salinity

In natural waters DIC generally shows an enrichment in ^{13}C from fresh water to seawater[4]. In Bac Lieu province this seems to be the case (Figure 10), suggesting that simple mixing between a marine and a fresh water end-member was the major process in control. However, in local canals (i.e. inside shrimp farming areas) isotopic composition showed no relation with salinity (Figure 11). This indicates that here, heterotrophic bacterial respiration was significant and kept δ^{13}C-DIC low, even at high salinity.

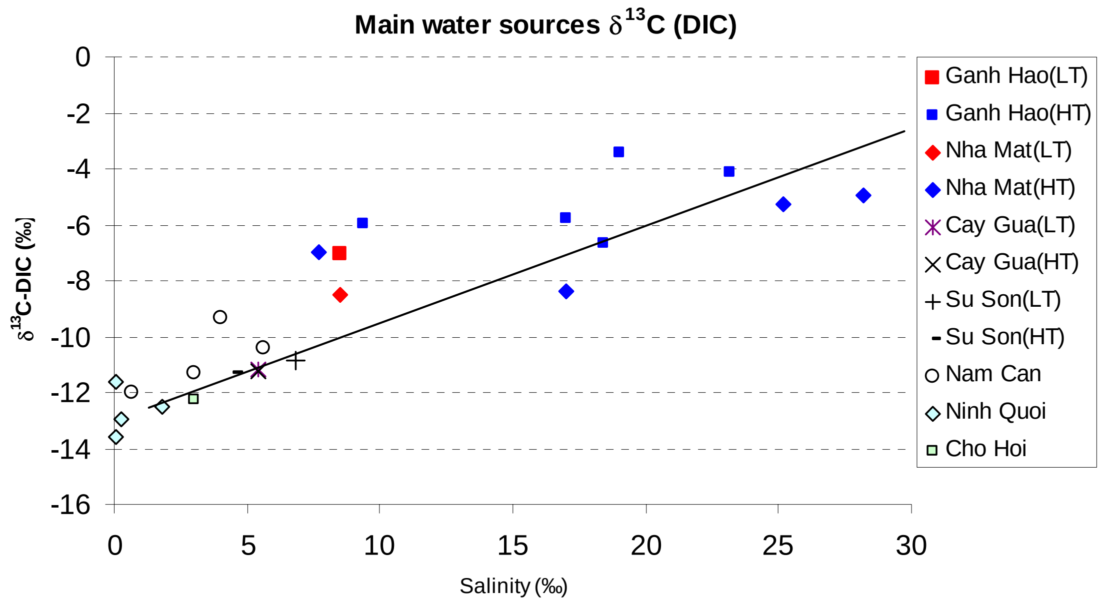


Figure 10: Isotopic composition of dissolved inorganic carbon vs. salinity in main water sources.

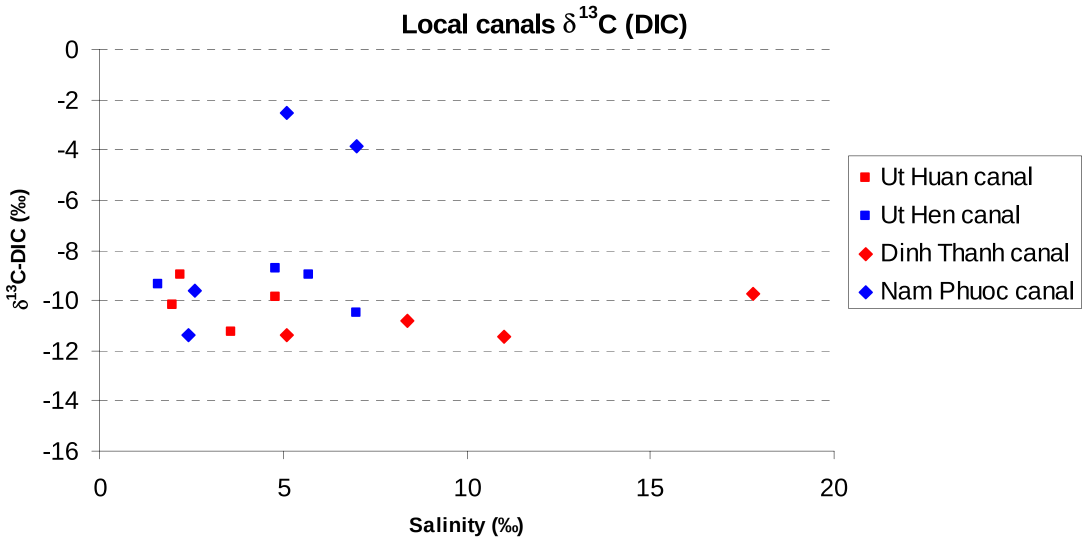


Figure 11: Isotopic composition of dissolved inorganic carbon vs. salinity in local canals.

PRELIMINARY CONCLUSIONS

The water quality of natural rivers was deteriorated towards the end of 2004, because of increased waste disposal and mud disposal at the end of cropping and of pond renovation. Sampling needs to be continued to monitor the river water quality in this area for the rest of the year and for a subsequent year to examine temporal, seasonal evolution, keeping in mind that shrimp farming is extending continuously.

Although the studied parameters rarely exceeded the (national[5] and international[1]) allowable levels, some preliminary results indicate that the water environment inside shrimp farming fluctuated significantly and becoming less healthy during cropping. As a result the water quality inside the overall shrimp farming area is impacted by shrimp farming activities which in return may become impacted through positive feed-back.

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EFFECT EVALUATION OF FRESH WATER DISCHARGE AGAINST SALINITY INTRUSION AT LOWER MEKONG RIVER

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ABSTRACT

In the Mekong River region, fresh water use becomes difficult during dry season, especially from February to May, when fresh water flow decreases and salty water intrudes upstream. The size and the type of the salinity intrusion are affected by fresh water discharge, tidal fluctuation, wind and etc., and the fresh water discharge is the only factor that can be changed artificially by the upstream water resources development. In this research, we have studied the effects of the fresh water discharge on the salinity intrusion into the distributaries of the Mekong River by the field observation and numerical simulation. At first, time series of the river discharge and the salinity concentration were decomposed into quasi-steady component and the fluctuating component, and the correlations among them were examined. An obvious correlation was observed between two quasi-components of discharge and salinity, but the peak of the salinity was one month earlier than the bottom of fresh water discharge. No obvious correlations were observed between two fluctuating components. Next, the dispersion coefficients were calculated for 25 cases, that is, 5 cases at 5 locations based on the field-measured data. The result showed that the coefficients were larger than we had expected, and that they were scattered widely even observed at the same location. The reasons are considered to be that depth and velocity could not be measured precisely near riverbanks, and that the dispersion coefficient is easily affected by the riverbed and velocity distribution. Finally, we solved the convection-diffusion equation numerically. During the calibration process, constant magnitude of dispersion coefficient was assumed through the river course. However, large difference was remarked between measured and calculated values after May. The reason was attributed to the weakened diffusion effect corresponding to the weakened monsoon wind. The magnitude of the dispersion coefficient was reduced to 60 percent of the firstly-assumed one after May. After the modification they agreed well, and it could also explain the reason why the bottom of fresh water discharge was preceded one month by the peak of salinity. In order to change fresh water discharge, the water level at My Thuan was changed by adding constant value. Various fresh water discharges caused various salinity intrusions showing the quantitative relations between salinity and fresh water discharge.

INTRODUCTION

Many water resources development projects have been planed along the Mekong river. China has several plans to construct dams in the upper reach of the Mekong river, and Lao has a plan to construct Nam Theun 2 dam in the Nam Theun river. Cambodia will consume much more water corresponding to future increase of population, and Vietnamese provinces will also increase their water demand. These projects will surely affect the fresh water discharge of the Mekong river, and the serious effects may be brought to the lowest areas along the Mekong river in Vietnam.

In dry season, especially from February to May, fresh water discharge decreases and saline water goes upstream. Along the lower Mekong river, fresh water intake becomes difficult during these months. Salinity intrusion is the most serious problem for Mekong delta in Vietnam, and Vietnamese research institutes have carried out many investigations and studies[1), 2)]. They have also developed numerical models that can simulate flow movement and saline water movement[3), 4)]. However, as for the longitudinal dispersion coefficient, which is a core of numerical model, it cannot be given without calibration process, during which parameters are changed gradually until measured and calculated values fit well. The magnitude of the longitudinal dispersion coefficient can be calculated theoretically on the assumption of uniform flow. Therefore it is not clear whether this calculation method is applicable to a tidally fluctuating flow.

In this study, the objectives are firstly to investigate features of the longitudinal dispersion coefficient, and secondly to seek a relation between fresh water discharge and salinity intrusion, which is the main subject of this study. At the same time, we will also analyze the relation between water levels and fresh water discharge for new findings.

STUDY AREA AND AVAILABLE DATA

Study area is the lower reach of the My Tho River including the Tieu but not the Dai, and is shown in **Fig.1**. Along the river course, there are three main intakes, Xuan Hoa (XH), Vam Giong (VG), and Long Hai (LH), and they send irrigation water to Go Cong Irrigation district that consists of 37,400 ha of paddy fields. Available data of water level are measured at My Thuan (MT) bridge and at Vam Kenh (VK) river mouth. Both points are national benchmarks, and water levels of the Mekong river are measured in every hour. Besides, we can use water level measured by Southern Institute of Water Resource Research (SIWRR) and Go Cong Irrigation company. These data were measured at XH and VG every 20 minutes from March to May in 2004, but the bases of water levels are not same with that of national benchmark.

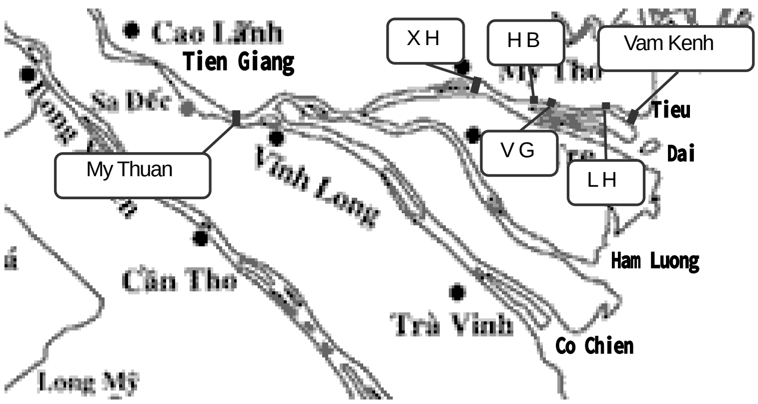

Fig. 1 Study Area (from HP 5) of Mekong Delta in Vietnam)

The salinity was measured by SIWRR at Hoa Binh (HB) and at VK along the Tieu river. The daily maximum and minimum salinity were measured from January to June in 2002 and in 2003. However, the data of 2002 is considered to have some errors because there are no significant differences between maximum and minimum values in January. We also measured salinity, velocity distribution, and river cross-sections by use of TPM and ADCP in cooperation with SIWRR in March 2004. Salinity and discharge were measured every 20 minutes at 5 locations, Dong Tam (DT) bridge, XH, VG, LH and VK, and river cross-sections were measured every 4km from the river mouth to XH along the Tieu river. However, we could measure salinity and discharge only for several hours. The study period is only half year, that is, from January to June in 2003, because all data needed are available only in this period. Besides, other data measured at March in 2004 are also used to calibrate parameters of numerical model and to calculate longitudinal dispersion coefficients.

NUMERICAL MODEL

Study area is a river course from MT bridge to VK river mouth, but we have only precise cross-sections from VG to VK. Therefore, same cross-section of VG is used for the river reach from VG to MT bridge. A single canal is assumed without considering other distributaries, which are the Dai, the Harmluong and the Cochien rivers. It means that river discharge and salinity are meaningful only in the Tieu river, and only salinity is meaningful in the upstream reach. At the river mouth, the river was prolonged 3 km and widened to have a width of 10 km. This additional part is the transition that connects the Tieu river with the Southern China sea.

Simulation of Flow Movement

We confirmed the mixing type of the salinity intrusion is the strong mixing through the field observation in the Tieu river. In such case, we may calculate flow as a non-density current because the upper layer moves together with lower layer. The Saint-Venant equations, which consist of continuity and momentum equations, were used as the governing equations. Water levels at MT and VK measured at the national benchmarks were used as the upstream and downstream boundary conditions.

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=0 \qquad (1)$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+gA\frac{\partial h}{\partial x}=gA(S_0-S_f) \qquad (2)$$

Where, A: cross-sectional area, Q: discharge, t: time, x: distance, g: gravitational acceleration, h: depth, S_o: channel slope and S_f: friction slope

A modified finite difference method based on the 2 step Lax-Wendroff method was applied to the numerical model. The increment of distance is 1km, and the time step is 1 minute. We confirmed that the influence of the initial conditions disappeared within 3 or 4 days after start of calculation. **Figure 2** shows the measured and calculated discharges at three locations after calibrating coefficients. In spite of the simplified river course, we can see that flow movement is fairly well simulated.

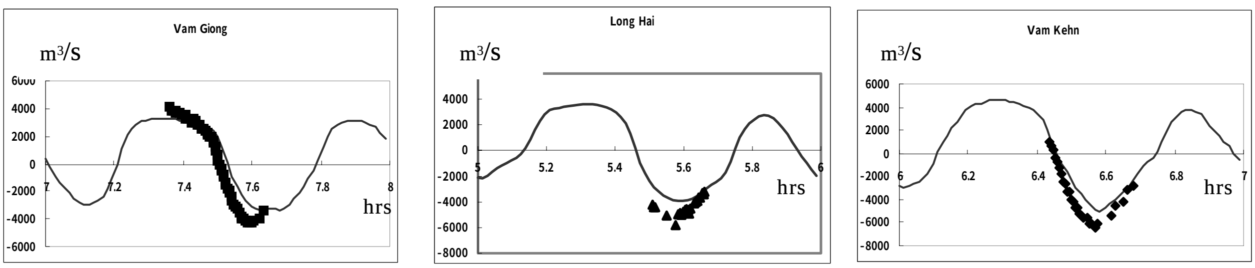

Fig. 2 Comparison of measured and calculated discharges March in 2004

Simulation of Saline Water

As the mixing type is strong mixing, the phenomena of salinity intrusion can be described by the convection-diffusion (dispersion) equation shown bellow.

$$\frac{\partial(AS)}{\partial t}+\frac{\partial(QS)}{\partial x}=\frac{\partial}{\partial x}\left(AD_L\frac{\partial S}{\partial x}\right) \qquad (3)$$

Where, S: salinity concentration, D_L: longitudinal dispersion coefficient

In the above equation, to decide the magnitude of the dispersion coefficient is a big problem. In many former studies, the magnitude of the coefficient is decided based on the calibration process comparing measured and calculated values. In this study we used the formula method as well as the usual calibration method, and we compared two values obtained by two methods. The formula method uses an analytical formula with river cross-section and velocity distribution. Salinity concentration was calculated explicitly at every time step just after calculating flow movement using calculated discharge and cross-sectional area. Zero salinity concentration was given at the upstream boundary MT, and a constant salinity concentration of 30 ppt was give at the downstream boundary VK. The calibration process is explained in detail later.

CORRELATION BETWEEN FRESH WATER DISCHARGE AND SALINITY CONCENTRATION

Regression Curves of Water Levels and Flow Rates

Salinity intrusion is surely affected by the river discharge, but they are scarcely measured, especially in a tidal river. On the contrary, water levels are often measured continuously. Numerical model explained above can calculate flow rate anywhere within the reach by giving water levels as boundary conditions. We will firstly check the correlation between river discharge and water levels' difference. The time series of them are composed of seasonal component, half monthly component and half daily component. We tried to extract seasonal components of discharge and water levels' difference by obtaining cubic regression curves.

(a) WL's difference between MT and VK (b) River discharge at Hoa Binh

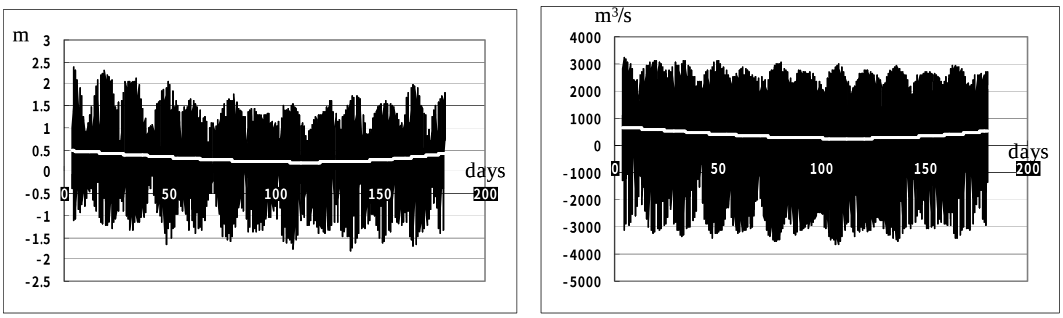

Fig. 3 Extraction of seasonal components from time series of water levels' difference and river discharge

Figure 3 (a) shows the time series of water level (WL) s' difference between MT and VK, and its cubic regression curve. Figure 3 (b) shows river discharge at Hoa Binh (HB), and its cubic regressive curve. Daily change of WLs' difference and river discharge are 1.5 ~ 3.5m and $4000m^3/s$ ~ $6000m^3/s$, respectively. On the contrary, seasonal change of WLs' difference and river discharge are 0.2 ~ 0.5m and $250m^3/s$ ~ $700m^3/s$, respectively. Seasonal changes are about one tenth of daily changes. The regressive curve for the river discharge is almost equal to the averaged river discharge and it can be regarded as the fresh water discharge. Figure 4 (a) and (b) show the daily averaged WLs' difference and daily averaged river discharge and their regressive curves. The difference between the daily averaged and the regressive curve shows short-term variable component, and we can realize that it has 14-day cycle.

(a) WL's difference between MT and VK (b) River discharge at Hoa Binh

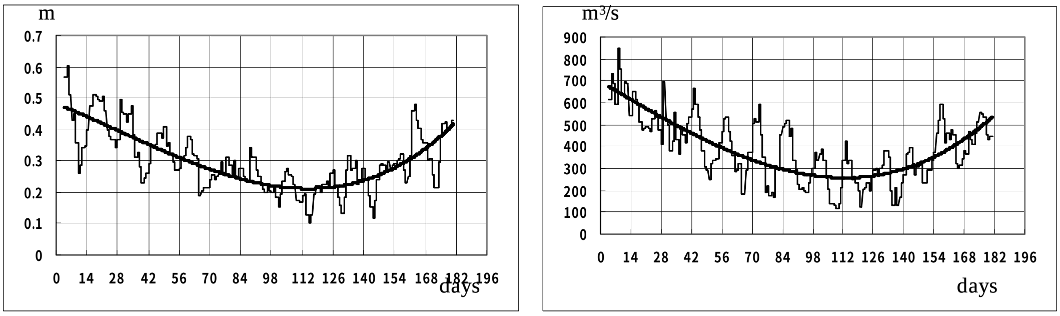

Fig. 4 Daily averaged WLs' difference and daily averaged river discharge

Regressive Curves of WLs' Difference and River Discharge

Figure 5 shows three regressive curves (MT, HB and VK) for river discharges, one regressive curve (MT-VK) for WLs' difference and its square root (Root). All these curves are normalized by making its minimum value unity.

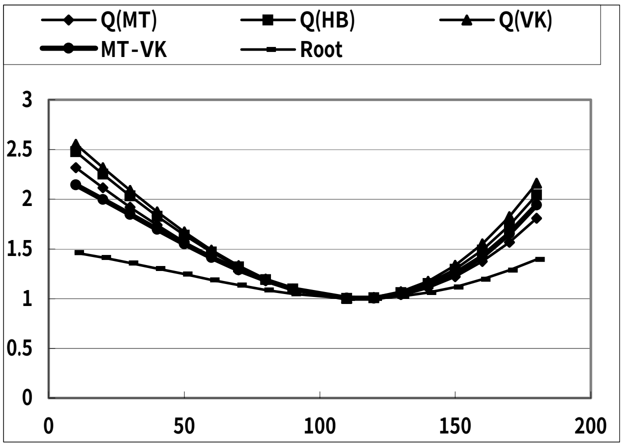

Fig. 5 Regressive curves

There is no significant difference between four thick regressive curves. However, thin square root curve is obviously different from other four curves. It means that the averaged river discharge is proportional to the averaged WLs' difference. In case of the steady flow, mean velocity is proportional to the square root of WLs' difference, and river discharge is also proportional to the square root if cross-sectional area is constant. We can see an interesting relation between regressive curves.

We can also see that the date of minimum river discharge perfectly coincides with that of minimum WLs' difference, that is, on around 20th April (112 days).

Regressive Curves for Maximum and Minimum Salinity Time Series

Figure 6 (a) shows regressive curve for maximum salinity, and (b) for minimum salinity. We analyzed data from the February to June, because January's data are judged to be measured improperly. Upper thin line shows observed salinity and thick line is its cubic regressive curve. The difference between upper thin and thick lines is shown by lower thin line. We called the difference the short-term component. We can see that the regressive curves have their peaks on around 10th March (70 days) for maximum salinity, and on around 25th March (85 days) for minimum salinity. In both cases, the dates of peak are more than one month earlier than the date of minimum discharge. As for the short-term components for both cases, it is difficult to find 14- day cycle.

Correlation between Salinity and River Discharge

At first, we checked correlations between maximum and minimum salinities observed at VK. Figure7 (a) shows the correlation between daily maximum and minimum salinities, and (b) shows correlation between short-term components of maximum and minimum salinities. We can see strong positive correlations for both cases.

(a) Maximum salinity (b) Minimum salinity

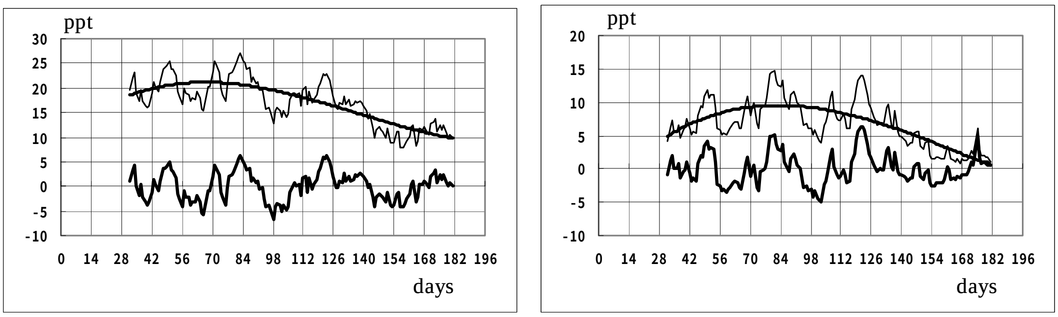

Fig. 6 Regressive curves for salinity time series (at VK)

a) between Max and Min salinities (b) between short-term components

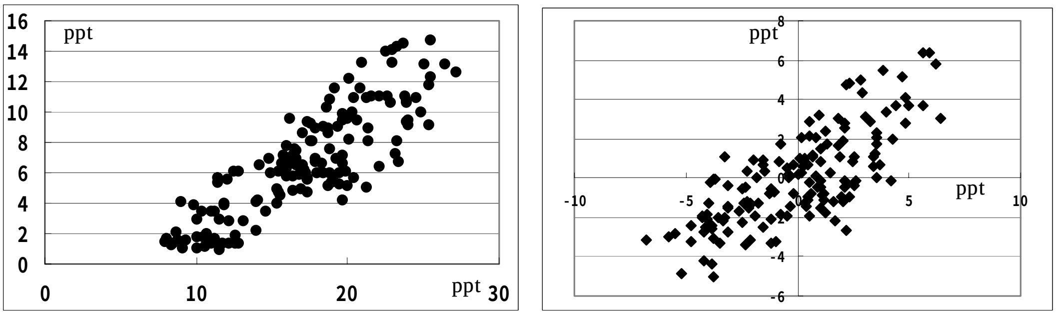

Fig. 7 Correlation between maximum and minimum salinities in a day

Figure 8 (a), on the other hand, shows correlation between short-term components of maximum and minimum salinities. We cannot see any correlation between two components. Short-term components in Fig. 8 (a) are observed in the same day, but even if the observed day was shifted, not any correlation was observed. Figure 8 (b) shows correlation between short-term component of maximum salinity and maximum distance of water movement in a day. The maximum distance is the water volume divided by cross-sectional area. In this calculation, the cross-sectional area was assumed to be 5,500m^2 at VK. We could neither see any correlation even if the observed day was shifted. As for the correlations between salinity and river discharge, we could arrive at a conclusion that there is a strong correlation between long-term components, but no correlations between short-term components.

(a) salinity and discharge (b) salinity and maximum distance

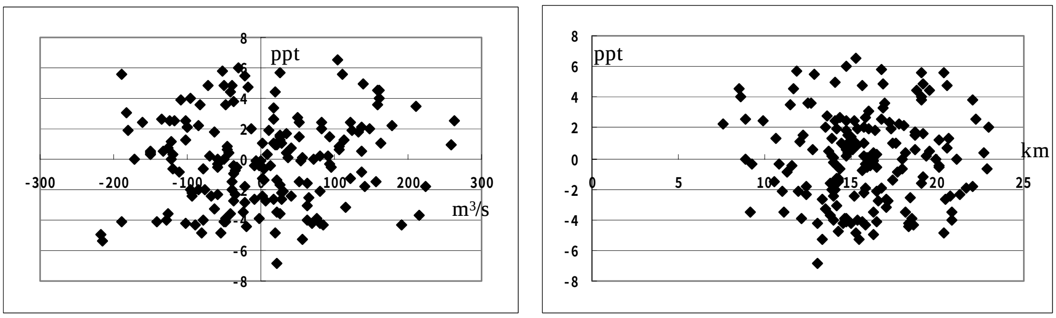

Fig. 8 Correlation between short-term components

Longitudinal Dispersion Coefficient

In case of the strong mixing, salinity diffusion is mainly caused by longitudinal dispersion. The longitudinal dispersion is some kind of diffusion caused by cross-sectional velocity distribution, and the magnitude is overwhelmingly larger than that of molecular diffusion or turbulent diffusion. The magnitude of longitudinal dispersion coefficient (D_L) can be calculated by following formula, if cross-section and transverse velocity distribution are known. However, this formula is derived on the assumption that flow is uniform.

$$D_L = -\frac{1}{A}\int_0^B q''' dy \int_0^y \frac{1}{K_y h} dy \int_0^y q''' dy \tag{4}$$

where, $q'''=U'''h$, U''': difference between velocity and mean velocity, K_y: turbulent diffusion coefficient to y direction

We have already measured cross-sections and velocity distributions at five locations, that is, at VK, LH, VG, XH and DT by ADCP. River flow is strongly affected by tidal movement, and there remain some questions whether this formula is applicable to the tidal flow. However, it is useful to know the magnitude of such coefficients. Table 1 shows values of longitudinal dispersion coefficients for 25 cases (5 cases×5 locations). Table 1 (a) shows $D_L/U_* R$ and Table 1 (b) shows D_{LO} (=$D_L/VR^{5/6}$), in which R is hydraulic radius and V is mean velocity.

Table 1 Longitudinal dispersion coefficient at 5 locations

(a) $D_L/U_* R$

VK	LH	VG	XH	DT
1,075,468	893	83,852	20,747	35,713
5,678,918	5,006	233,529	11,610	35,086
766,373	3,200	26,911	13,990	33,737
15,368	2,236	67,110	43,755	40,154
194,571	8,917	5,272	2,639	34,361

(b) D_{LO} (=$D_L/VR^{5/6}$)

VK	LH	VG	XH	DT
87,535	73	6,825	1,689	2,907
462,223	407	19,008	945	2,856
62,377	260	2,190	1,138	2,746
1,250	182	5,462	3,561	3,268
15,837	726	429	215	2,797

From Table 1, we can see that calculated values are very scattering except those at DT bridge. At the river mouth VK, especially, the maximum value is 400 times larger than the minimum value. According to the study by Fischer, the value of $D_L/U_* R$ is 7,710 at the Missouri river. It means that values in Table 1 are also very large. Following reasons may be considered for the above results. Firstly, the formula itself is very sensitive to the velocity distribution. Secondly, the velocity distribution must be steady, but we used momentary velocity distribution measured by ADCP. And thirdly, we could not get precise cross-sections and velocity distributions near riverbanks, and it might be the most decisive factor. When we used D_{LO} =300 ~ 500 for numerical simulations described in the next part, we could get good results. As for the longitudinal dispersion coefficient, much study is needed.

RELATION BETWEEN FRESH WATER DISCHARGE AND SALINITY INTRUSION

The magnitude of salinity intrusion mainly depends upon three factors, that is, fresh water discharge, tidal fluctuation and monsoon wind. Among them, we tried to examine only the effect of fresh water discharge by solving the convection-diffusion equation numerically with other factors unchanged. At first, we made a numerical model that can reproduce the present situation, and then fresh water discharge was changed to examine the effect.

Reproduction of Present Salinity Intrusion

In the numerical model, we assumed that the longitudinal dispersion coefficient is the function of mean velocity V and hydraulic radius R, and shown by the following relation.

$$D_L = D_{LO} V R^{5/6} \tag{5}$$

The upstream boundary condition is water level at My Thuan, and the downstream boundary condition is also water level at Vam Kehn. The increment of distance Δx=1 km, and time step Δt=1 minute. Data of water level is hourly data; therefore, hourly data were interpolated using Spline Interpolation. Figure 9 shows observed and simulated salinity at Hoa Binh.

(a) D_{LO}=300 (b) D_{LO}=500

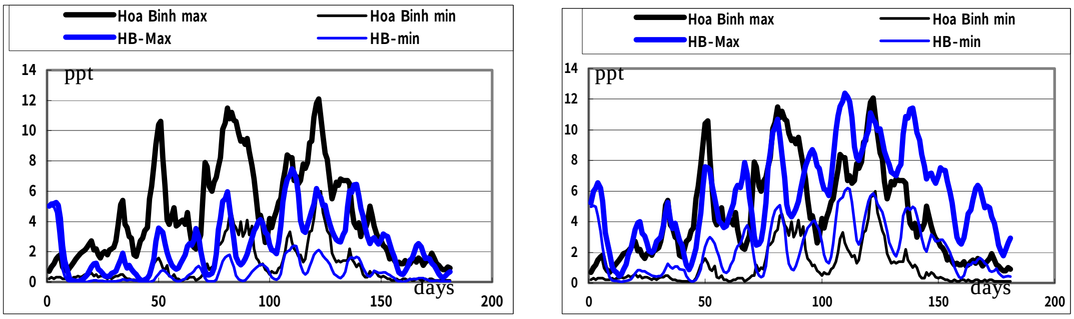

Fig. 9 Observed and Simulated maximum and minimum salinity (at Hoa Binh)

Figure 9 (a) shows the comparison between observed and simulated salinities when D_{LO}=300, and (b) shows the comparison when D_{LO}=500. We can see that simulated one is closer to the observed one before 120 days when D_{LO}=500, and closer to observed one after 120 days when D_{LO}=300. It is hardly possible to explain the above results only by the fresh water discharge. Considering the one-month time lag observed during the former regressive analysis, we could arrive at the conclusion that the value of longitudinal dispersion coefficient decreased. Figure 10 shows result when the value of the coefficient is changed from D_{LO}=500 to D_{LO}=300 at 120 days. The reason for the decrease of D_{LO} might be the influence of the monsoon. In May, strong east wind of monsoon during dry season is weakened and changes its direction. Weakened monsoon also weaken the mixing of saline water. However, we have not enough data to quantify the effect of monsoon on longitudinal dispersion coefficient.

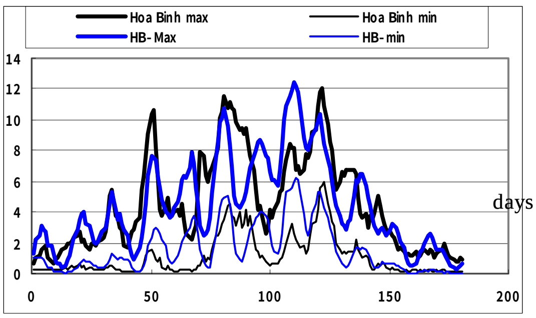

Fig. 10 Comparison in case of D_{LO}=500→300 at 120 days

Salinity Concentration and Fresh Water Discharge

The fresh water discharge was changed implicitly by changing water level at My Thuan by adding +1, +3, +5, -5 cm, but other factors were unchanged. The outputs of the numerical model are the time series of maximum and minimum salinity concentrations, and their regressive curves. Figure 11 (a) shows recession curves of maximum salinity, and (b) shows recession curves of minimum salinity. The 'Observed' means regression curve obtained from the time series of measured salinity, and 'M+0' means regression curve obtained from numerical simulation without WL changes.

(a) Maximum salinity (b) Minimum salinity

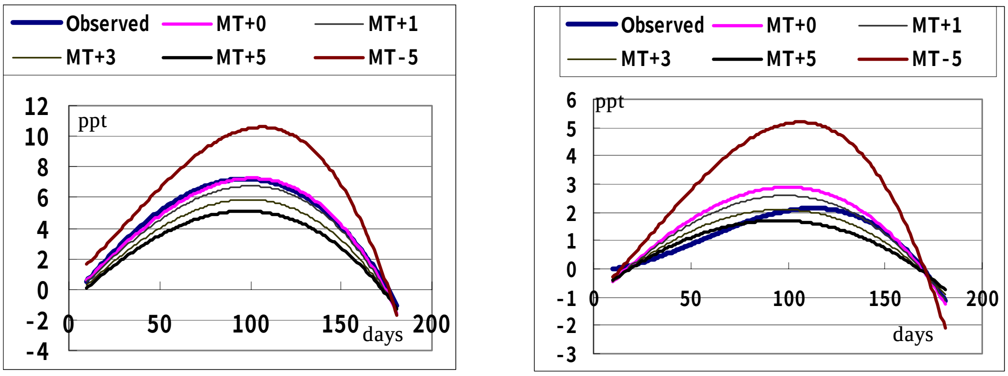

Fig. 11 Regressive curves when My Thuan WL is changed（at Hoa Binh）

The quasi-steady component of regressive curve is meaningful only during 20 days to 160 days, because salinity concentration may become negative out of this period. The logarithmic expression of salinity, for example, may be a suitable method to avoid negative salinity, but as our concern is focused on the period of high salinity, we continued analysis based on the results shown in Fig.11. The comparison of two regressive curves of 'Observed' and 'MT+0' is some kind of check whether numerical simulation is properly carried out or not. In case of the maximum salinity (a), 'Observed' and 'MT+0' are very close each other, but in case of minimum salinity (b), we can see 1ppt difference during first half period. As it is difficult to realize the relation between salinity and fresh water discharge from Fig. 11 only, two kinds of relation, that is, fresh water discharge vs. WL at MT, and maximum salinity concentration vs. WL at MT are shown in Fig. 12 (a) and (b). Three lines mean their relations on 50 days, on 100 days and on 150 days. We could get similar relationship for minimum salinity concentration, but is not shown here. Figure 12 shows relation between salinity concentration and fresh water discharge through the aid of WL at MT. Figure 13 shows direct relation between salinity and fresh water discharge.

(a) Fresh water discharge (b) Maximum salinity concentration

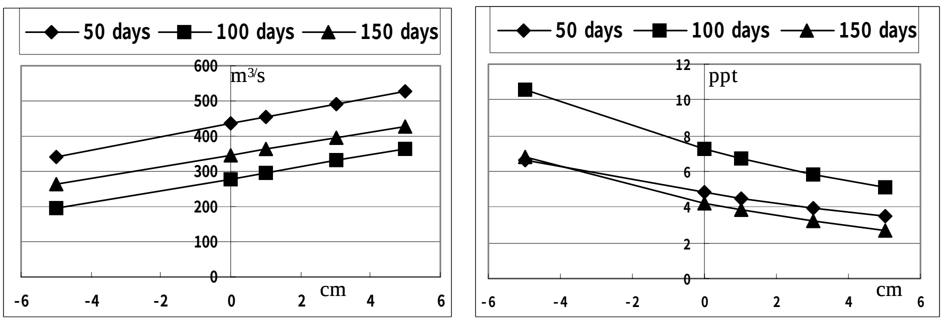

Fig. 12 Salinity vs. WL and fresh water discharge vs. WL

In Figure 13, the axis of abscissa shows fresh water discharge (m^3/s) and the axis of ordinates shows salinity concentration (ppt). From this figure we can realize that the salinity concentration becomes smaller with the passage of time even if fresh water discharge is same. The reason is considered to be that the longitudinal dispersion is weakened corresponding to the weakened monsoon east wind. Figure 13 shows that the maximum salinity concentration increases by 0.015 ~ 0.033ppt, in average, 0.024ppt corresponding to the decrease of unit fresh water discharge $1m^3/s$. and that minimum salinity concentration increases by 0.015 ~ 0.02ppt corresponding to the decrease of unit fresh water discharge.

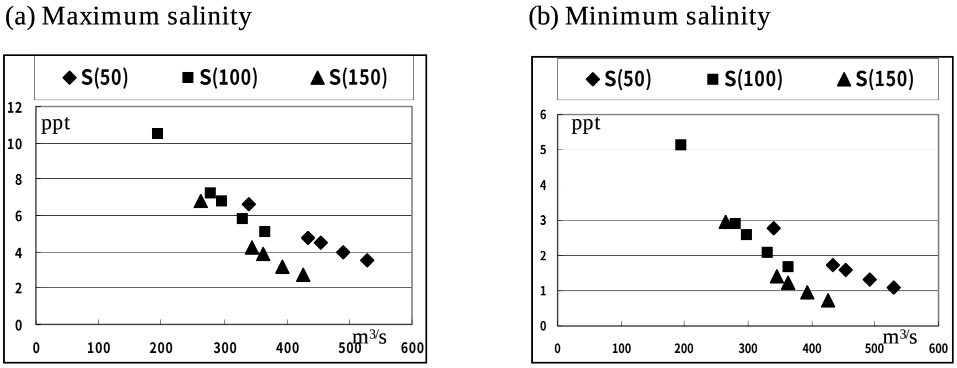

Fig. 13 Relation between salinity and fresh water discharge (at Hoa Binh)

CONCLUSIONS

Through this study, following results are obtained. Firstly, quasi-steady components are extracted from severely fluctuating time series data such as river flow, salinity concentration and water levels' difference. Through extraction of such quasi-steady components, we could easily find the relationship between them. As the result, it was found that the fresh water discharge is proportional to the averaged WLs' difference. This result seems to be against the fact that the discharge of the steady flow is proportional to the square root of the WLs' difference, if cross-sectional area is same. It was also found that the peak of salinity comes one month earlier than the bottom of fresh water discharge. As for the longitudinal dispersion coefficient, calculated values were very large and scattering. From this result, we realized that precise measurement of water depth and velocity distribution is crucial especially near riverbanks. From the numerical simulation, we ratiocinated that the dispersion is weakened corresponding to the weakened monsoon east wind after May. And finally, we could show the relation between salinity and fresh water discharge at Hoa Binh. However, all above results must be examined carefully because the results are obtained various kinds of assumptions.

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THE WATER QUALITY ISSUES OF THE MEKONG RIVER AND LOWER MEKONG BASIN

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ABSTRACT

The Mekong River flows through 6 countries with the upper part of Mekong River basin covering area of China and Myanmar while the lower part covering most area of Lao and Cambodia, one third of Thailand and one-fifth of Viet Nam, which is called Lower Mekong Basin (LMB) with an area of about 606,000 km^2 covering 80% of total basin. The surface water resource in the LMB is very abundant and has played an extreme important role for economic development and life of local inhabitants. The development of production, population growth, poor infrastructure system together with complex natural conditions keep threatening to make problem for water quality in the LMB, especially in cities, resident centers with high density of population and very poor waste water treatment system. At present, potential pollution sources along the river have not caused any large scale problem for the Mekong River due to its high flow and localized nature. Available data of Water Quality Monitoring Network (implemented since 1985 under coordination of the Mekong River Commission - MRC) showed that there has not been any concerned water quality issue for the Mekong River in terms of physical - chemical characteristics, nutrient, organic matter. Results from the Water Quality Diagnostic Study (BURGEAP, 2003) also indicated that there is no sign for pollution of pesticides or industrial contamination in the Mekong River. However, there have been local pollution problem. For example at the Stung Chrall drainage canals located in the south of Phnom Penh, Cambodia the water has low dissolved oxygen (DO) concentration from 1.5 mg/L to 4.2 mg/L, total Phosphorous is up to 0.45 mg/L. In Vientiane, the water at Houa Khoua drainage canal has DO values low from 2 to 4 mg/L, total Phosphorous always high from 0.1 to 0.8 mg/L. At Ban Som, upstream of Mun River, Thailand, the water has high conductivity values (EC), especially in the dry months with EC values up to 250 mS/m (salinity about 1.5 g/L) which is not so high for irrigation but have caused difficulties in domestic use. In the Mekong Delta, where there is a large area of acid sulfate soil of about 1.6 million ha, the acidic water with low pH down to 3 - 4 is one obstacle for local inhabitants in this area. In the Delta, high density of population and development of agriculture and aqua production can be seen as sources for high nutrient concentration in canal water. The annual median values are about 0.1 mg/L for total Phosphorous, and higher than 0.75 mg/L for total Nitrogen.. To improve the water quality situation in the LMB, and to protect the Mekong River for long term sustainable development, cooperation activities among countries in the region should be taken.

INTRODUCTION

Table.1 Approximate figures of the Mekong River Basin

Country	Catchment Area		Average Flow	
	km^2	%	m^3/s	%
China	165,000	21	2,410	16
Myanmar	24,000	3	300	2
Thailand	184,000	23	2,560	18
Lao PDR	202,000	25	5,270	35
Cambodia	155,000	20	2,860	18
Viet Nam	65,000	8	1,660	11
Total	795,000	100	15,060	100

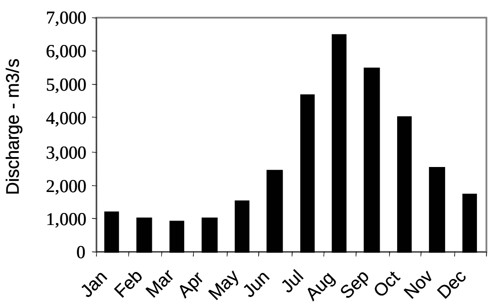
Source: MRC, 2001

The Mekong River originates from the Tibet Plateau and passes through border of China, Myanmar, Lao, Thailand, Cambodia and Viet Nam. The basin covers a catchment area of approximate 795,000 km^2. The Mekong River is ranked as among the river of the world as number six based on its annual discharge of 475 x 10^9 m^3 and as number twelve based on its length of 4,880 km. The following table shows the main characteristics of the basin

The upper part of basin covers area of China and Myanmar while the lower part covers most area of Lao and Cambodia, one third of Thailand and one-fifth of Viet Nam, which is called Lower Mekong Basin (LMB) with an area of about 606,000 km^2 covering 80% of total basin.

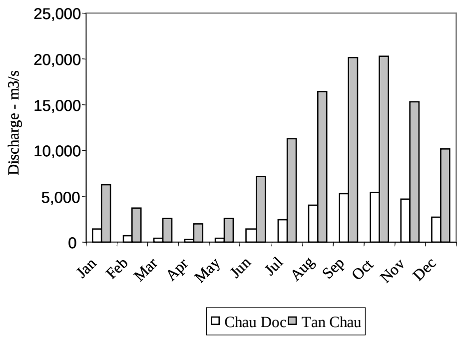
In the LMB, there is a tropical climate with two monsoon seasons – the dry season starting from December to May and rainy season starting from June to November. The mean annual rainfall in the basin ranges from 1000 to 4000 mm, in the LMB this figure is of 1,700 mm. The discharge in the Mekong River is affected by the pattern of the annual rainfall distribution in the basin. Water level in the river starts to rise after the onset of the rain in May and attains the peak level in August or September at upstream area while in September or October at downstream area. After this, water level starts falling rapidly until December, afterwards slowly recedes and reaches the lowest level in late April. Average monthly flows at stations in upper part of LMB (Chiang Sean) and at two branches of Mekong (Tan Chau) and Bassac (Chau Doc) flowing to the Delta, Viet Nam presented in the Fig.1&Fig2 showed this trends.

The abundance of the Mekong River water source has played an important role for the economy development of riparian countries where local inhabitants' life are closely tied with the Mekong River.



Source: MRC, 2003

Fig.1 Average monthly flows - Chiang Sean



Source: SIWRP, 2001

Fig.2 Average monthly flows at Tan Chau & Chau Doc

WATER USES OF THE MEKONG RIVER AND THEIR POTENTIAL IMPACTS ON THE ENVIRONMENT

The water of the Mekong River has been used for many purposes in riparian countries. Followings are major water uses in LMB and their potential impacts on water environment.

Domestic use

The water of the Mekong River is a main source to serve for domestic purposes of local inhabitants in the LMB. The 57 million population of the LMB is predominately rural with about for 80% of population living in rural area and relying on natural resources for their livelihoods. The population is largely concentrated in the capital cities such as Phnom Penh (Cambodia) or Vientiane (Lao), resident centers such as resident centers in the Mekong Delta. In most of cities, towns and other resident centers located along the rivers, canals, there has been no treatment of domestic wastewater which drain directly into water bodies. In cities, there is not a separate drainage system for storm water and domestic wastewater. Domestic wastewater from areas with high density of population and poor infrastructure system have been sources to make receiving water bodies polluted.

Agriculture

In the LMB, the agricultural sector keeps a very important role for economy development of riparian countries. In the Delta, Viet Nam the land used for agriculture takes almost 84% of area, while in Thailand this figure is 79.3% and in Lao and Cambodia these figures are lower 14% and 23.4%, respectively. Total irrigated area in the LMB is 3,276,876 ha (in 2000) which takes a large part up to 80-90% of water abstraction in the basin either by the storage of receding flood water at the end of rainy season or the diversion of water from river and stream. Rice production has significantly increased in recent years (Table.2). Income from agriculture keeps a very high portion in total income.

Table 2. Rice production the LMB

Country	Period	Rice production (1,000 tone)
Cambodia	1993 - 2000	2,221 - 4,041
Lao PDR	1995 - 1999	1,417 - 2,094
Northeast Thailand	1997 - 2001	8,168 - 9,497
MK Delta	1995 - 1999	12,832 - 16,281

Source: MRC, 2003

The intensive crop and pressure on increase of yield requires a great application of fertilizers and pesticides in agricultural production. The increase of these agro-chemicals is inevitable [Table.3]. It may become a significant contamination source for surface and ground water in the LMB. The increase of fertilize may lead to eutrophication, degrading water quality, damaging aquatic ecosystems, etc.

Table 3**.** Use and total of fertilizer in LMB (from 1989 -1999) and pesticides

Country	Fertilizer (kg/ ha) of agr land	Total for fertilizers use (1000 tones)	Pesticides use (1000 tones)
Cambodia	0.1 - 2.1	0.3 - 7.9	
Lao PDR	0.4 - 8.5	0.3 – 8.1	
Thailand*	39.8 - 100.1	818.8 – 1801.7	40,606 - 47,681 (1994-1995)
Viet Nam*	88.2 - 263.2	563 - 1934.6	32,745 –33,019 (1996-1997)

Source: FAO 2001

Note: '*' data are for the whole country rather than for just the territory within basin

Aquaculture

The Mekong River is one of the most diverse and abundant fisheries in the world with the yield of the Mekong capture fishery of about 1.5 million tones per year. The Mekong River and other surface water sources in the LMB as streams, canals are very good habitat for aquaculture. Fish cage culture has been developed very much recently. Total freshwater aquaculture production in LMB has risen from 60,000 tones in 1990 to 255,000 tones in 2001. Due to profits of production, fertilizers, chemicals, biological products have been used freely, which may lead to damage water habitat. An estimate showed that the natural and synthesized food amount for 1 ha of raising shrimp is about 4.5 tone/year and about 25% of this amount - 1.1 tones is decomposed. Decay of redundant food leads to severe pollution of aquaculture habitat if there is no measure for changing water of the pond within suitable period. The discharge of water from these ponds could make the receiving water bodies to be polluted.

Water uses for industries, navigation and many other fields may be pollution sources in the future, however, at present they are not severely threatening sources.

WATER QUALITY ISSUES OF THE MEKONG RIVER AND THE LMB

Soon recognizing the water quality would become a concerned factor for water use of the Mekong River, the Mekong River Commission (MRC) (before 1995 called Interim Committee for Co-ordination of Investigation of the Lower Mekong Basin) has launched a project of Water Quality Monitoring Network in the LMB (WQMN) since 1985 with participation from riparian countries. The data obtained from 1994 to 2004 by WQMN were used for assessment of water quality of the Mekong River and the LMB.

Nutrients and organic matters

Nutrient compositions in water consist of compounds of nitrogen and phosphorous. Main sources of this contamination come from wastewater of dense resident areas and agriculture production. High concentration of nutrient will make water eutrophic with blooming algae, consequently, the substantial reduction of dissolved oxygen content in the water, causing death of fish and many other aquatic creatures. High organic matter is also a characteristic of domestic wastewater which is not treated and discharged into water bodies.. This situation is very common in the region, especially in capital cities as Phnom Penh or Vientiane. Survey in the Environment Risk Assessment project implemented in 2003 indicated that at the Stung Chral canal located in south of Phnom Penh, Cambodia the wastewater has very high nutrient concentration with total Phosphorous from 0.5 up to 5 mg/L (Fig.3) and dissolved oxygen variation from 1 up to 6 mg/L and often lower than 5 (Fig.4).

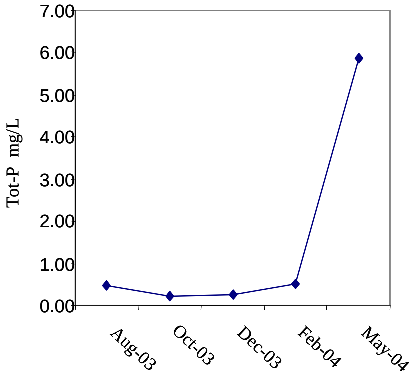


Fig.3 T-P variation in Stung Chral, Phnom Penh

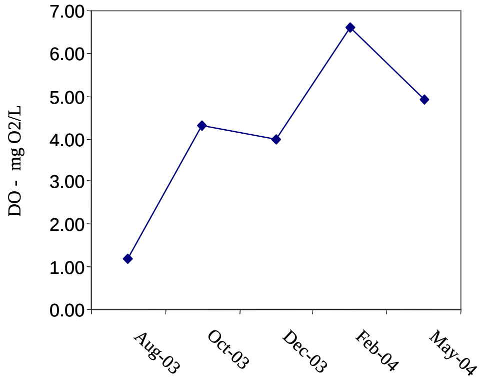


Fig.4 DO variation in Stung Chral, Phnom Penh

At Houa Khoua in Vientiane, Lao, where the wastewater from city flows to Thatluong Swamp before entering to the Mekong River, data colleted by WQMN showed that annual median values of total Phosphorous are always higher than 0.1 mg/L which is considered as the level for slight impairment of water bodies in terms of nutrient (Fig.5). DO values less than 4 mg/L take about 40% of total values (Fig.6). As most other towns or cities in the LMB, wastewater in Vientiane has not been treated before discharging to the Mekong River.

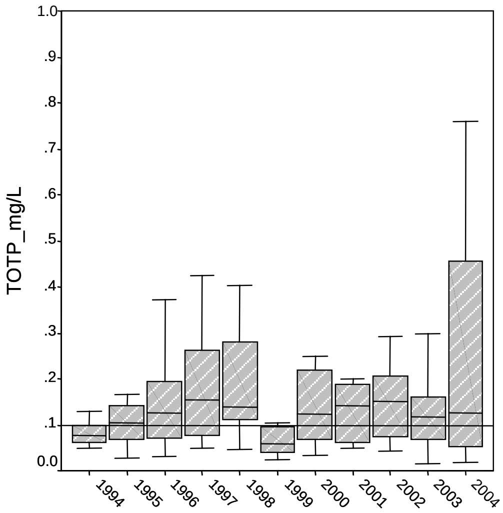


Fig.5 T-P variation at Houa Khoua

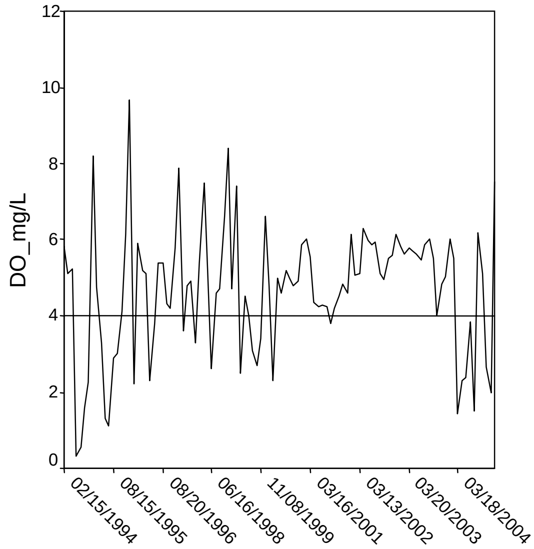


Fig.6 DO variation at Houa Khoua

In the Mekong Delta, data showed that nutrient concentration is little high with annual median values of total Phosphorous higher than 0.1 mg/L at some locations as Ngan Dua or Vinh Thuan in the Ca Mau Peninsula (Fig.7) and 1.0 mg/L for total Nitrogen at Kien Binh in the Plain of Reeds and at My Xuyen in Ca Mau Peninsula (Fig.8). The main reason for this is that the high application of fertilizer for rice production and wastewater from high density of population in these places where the people are often leaving along canals and discharge most wastes into canals.

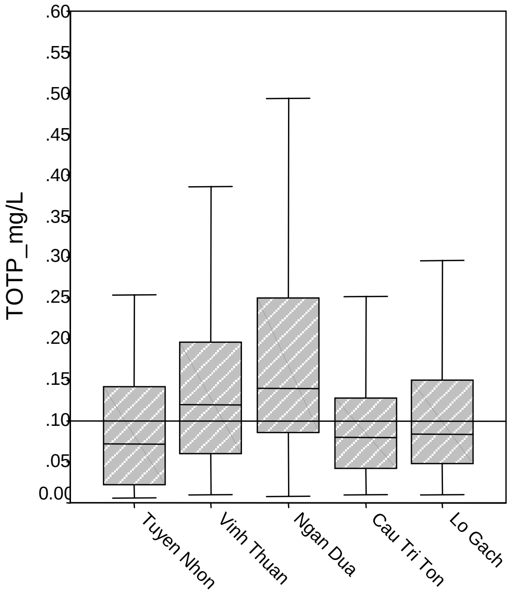


Fig. 7 T-P variation in the Mekong Delta

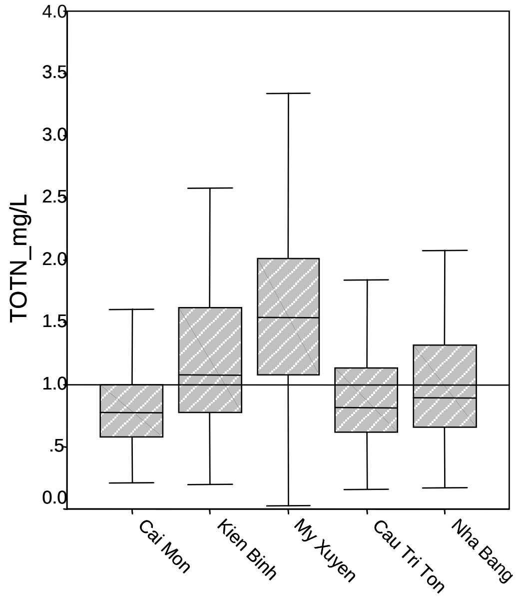


Fig.8 T-N variation in the Mekong Delta

However, the organic matters are not high with COD values often lower than 6 mg O_2/L while the Viet Nam National Standards for class A requested COD less than 10 mg O_2/L. The yearly median concentration of dissolved oxygen (DO) in the Mekong Delta is about 6 mg/L. This means that the organic pollution in the Mekong Delta is not much concerned in general.

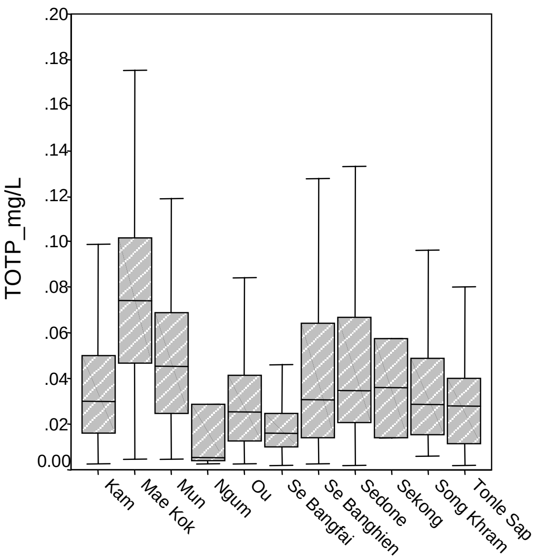


Fig. 9 T-P in tributaries of Mekong River

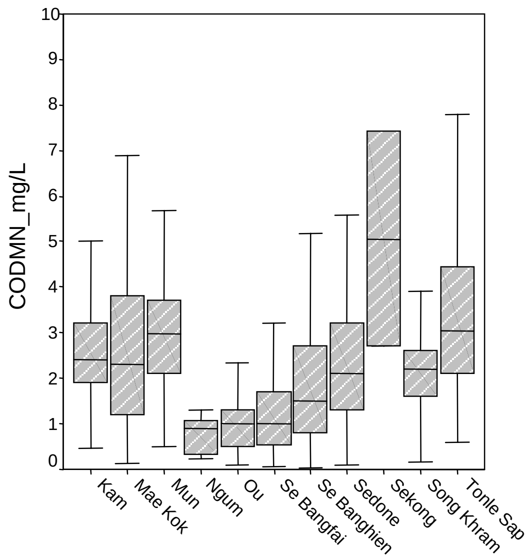


Fig.10 COD in tributaries of Mekong River.

The contribution of nutrient and organic matters from tributaries to the Mekong River are low. Data collected over main tributaries of the Mekong River in the WQMN showed that the median values of total Phosphorous often less than 0.1 mg/L (Fig.9), and total Nitrogen less than 1.0 mg/L which indicates that the contribution of those compositions to the Mekong River from tributaries are small in terms of concentration.

The median values of COD (Fig.10) and DO from tributaries are about from 1 to 5 mg O_2/L and from 6 to 8 mg O_2/L, respectively. These values indicate that the content of organic matters is low, meaning that potential pollution from tributaries to the Mekong River is very low.

Yearly median values of all stations in the Mekong River of WQMN from upstream to downstream areas indicated that the content of nutrient are still low with total phosphorous and total nitrogen is far below 0.1 mg/L and 1.0 mg/L, respectively (Fig.11&Fig.12).

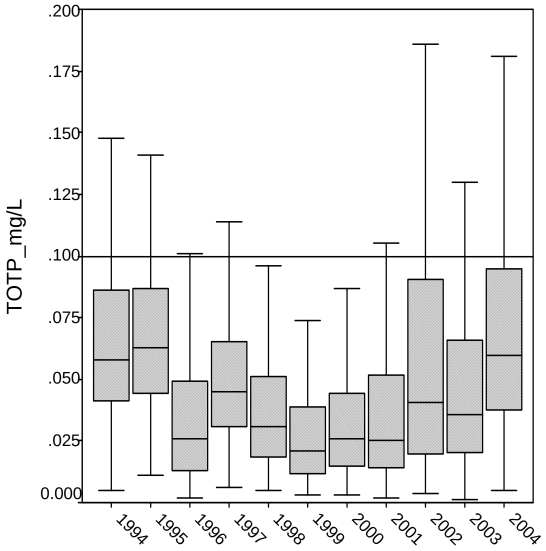


Fig. 11 T-P in the Mekong

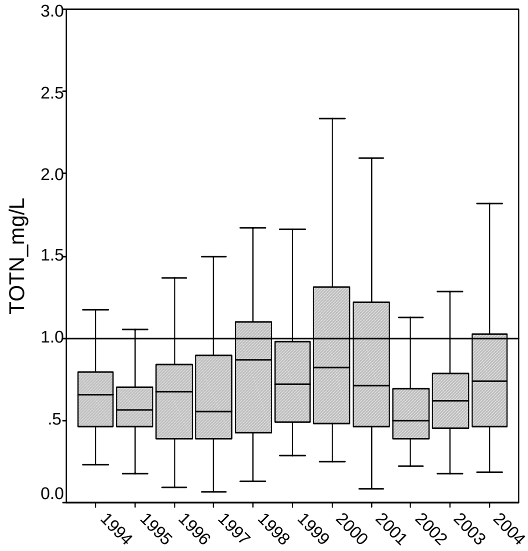


Fig.12 T-N in the Mekong

Trend over the years is not clear for total nitrogen, however, there seems an increase over past five years for the total phosphorous, although this increase is very small.

The Mekong River yearly median concentration values for dissolved oxygen and COD vary from 6.5 to 7.5 mg/L and 1.5 to 3.5 mg/L, respectively, which indicate that there is no sign for organic pollution in the Mekong River

Trace metals in rivers and streams mainly come from the erosion of earth cover, or by human activities such as mining, wastewater from industries, etc. Most metals in rivers are transported via adsorption on particulate matter. So, concentration of dissolved metals in the water is usually low. Some results investigated in 2001 and 2002 at Tan Chau, My Thuan (Mekong River) and Chau Doc, Can Tho (Bassac River) showed the variation of copper (Cu) from 0.002 to 0.009 mg/L, lead (Pb) from 0.002 to 0.008 mg/L and cadmium (Cd) less than 0.001mg/L. In the project of Water Quality Diagnostic Study implemented in 2003 and 2004 by Burgeap, France, dissolved and non-dissolved pollutants such as organic matter, pesticides, PAHs, PCBs, heavy metals were analyzed in the water at some places in the Mekong River and found that neither pesticides nor industrial contamination were detected. This indicates that toxicity of the Mekong River is quite low.

In general, there has not been any concerned water quality issue for the Mekong River in terms of physical-chemical characteristic, nutrient, organic matter and toxicity

At present, there is no influence from tributaries to the Mekong River, however, the direct discharge from large cities located along the Mekong River as Phnom Penh or Vientiane may have caused the local impact to the Mekong River which even though is very slight but has been found as in the following example at Takhmao station (Phnom Penh, Cambodia) in the Bassac River.

In the Mekong River, day time dissolved oxygen (DO) concentrations at most of places are high due to turbulence. However, there are some places along the river where it may be affected by domestic wastewater from dense resident area and the variation of DO parameter can show this impact as in Phnom Penh City with population of about 1.2 millions people located on the right bank of the Mekong and Tongle Sap River (Fig.13). The run-off and domestic wastewater of the city drains to the wetland areas in the north and the south of city, one part drains directly to the Tongle Sap and Bassac River. Considering stations around Phnom Penh, DO concentration at Takhmao location about thirty km downstream of Phnom Penh City on the right bank of the Bassac River has lowest annual median DO value (Fig.14) in comparison to other stations in the Mekong River. One of reasons to make low DO content can be the decomposition of organic matters which come from wastewater. The content of organic matters can be expressed roughly by the Biological Oxygen Demand (BOD) or Chemical Oxygen Demand (COD) values. When there is a contrary relation between DO and BOD or COD contents, it means that there may be impacts of organic matters to the water quality in this place. At Takhmao station, the higher values of COD is also observed (Fig 15). It can be explained that in the south of Phnom Penh, the wastewater from the wetland area is drained to the Bassac River above the Takhmao location to make the river water affected with low DO concentration and high COD concentration.

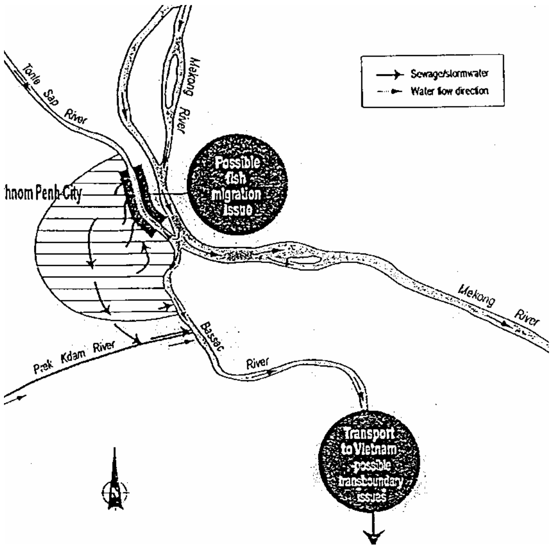


Fig.13 Location of Phnom Penh (Hart, 2001)

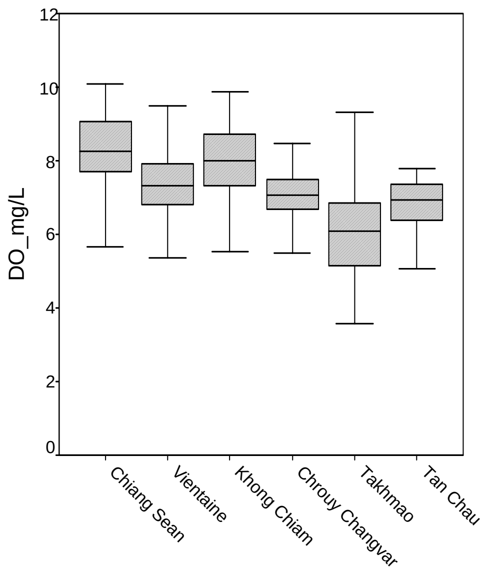


Fig. 14 DO variation in the Mekong River

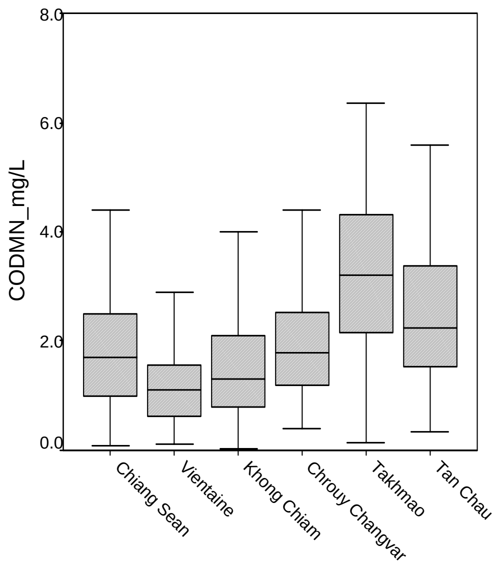


Fig.15 COD variation in the Mekong River

This impact is very small but it can be distinguished with other places in the Mekong River. About 25% of DO values at Takhmao station are below 5 mg O_2/L (Fig.16). If looking at the monthly mean variation of DO concentration (Fig.17), we can see that DO concentrations are always low in the dry season (January – April, November and December) but not in the wet season (from May to October) at Takhmao place. At Phnom Penh the monthly discharge of the river in the dry season is about from 2000 - 4000 m^3/s about 10 times lower than in the rainy season then in dry season, pollution possibility is higher than in the rainy season (low DO values).

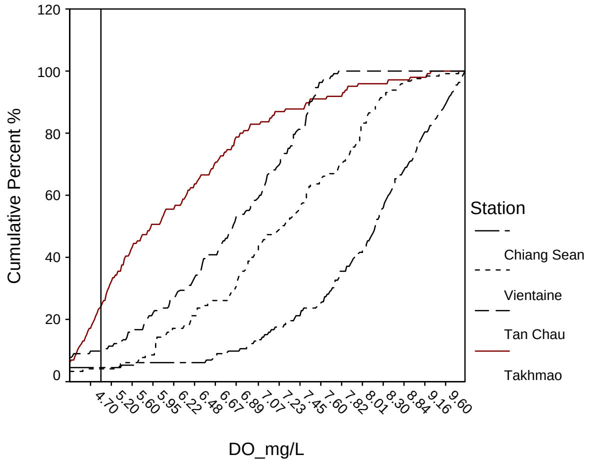


Fig.16 DO cumulative in the Mekong River

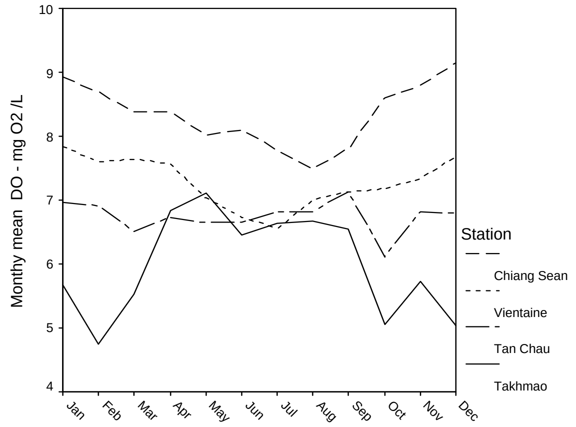


Fig.17 Mean DO curves in the Mekong River

The Phnom Penh and Vientiane cities have been recognized as potential sources to cause the transboundary water quality issues to downstream area (Bari Hart,2001). At present, this impact is still very low to the Mekong River as showed at Takhmao station.

Salinity issues

Salinity intrusion in the dry season is one of the biggest obstacles for living conditions of local inhabitants and water demand for economic development in the Mekong Delta, Viet Nam. The Delta with an area of 3,978,600 ha (5% of Mekong Basin) is almost affected by salinity intrusion, except for two provinces connecting with boundary of Cambodia. The salinity intrusion depends on some following major factors: climate conditions, tidal regime, and water use in upstream areas and abstraction at the sites. These factors are changed with both periodic and random characteristics, in other hand, they are also changed temporal and spatial, thus the assessment process of salinity intrusion in the Delta is very complicated. The maximum length of salinity intrusion occurs when upstream flow is lowest in April. The 4 g/L salinity limit can come upward about 25-30 km from river mouth as for the year 2000 (Fig.18).

Source: SIWRP, 2001

Fig.18 Variation of salinity in the Mekong Delta, Viet Nam, 2000

To prevent salinity intrusion, local authorities have constructed damps, sluices. However, if operation regime of these constructions is not proper there will be some rising problems for protected areas such as hindering navigation, restriction of water movement causing water polluted, etc, especially in the dry season when the constructions need to close to prevent salt water. In recent years, the economy of riparian countries has developed fast thus water demand also increases, especially in the dry season the water use raised up leading to increase of salinity intrusion in the Delta which cause many problems for production and living conditions as well.

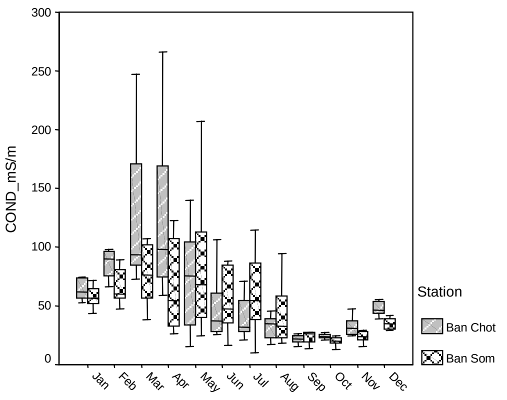


Fig. 19 EC variation in Mun, Chi rivers

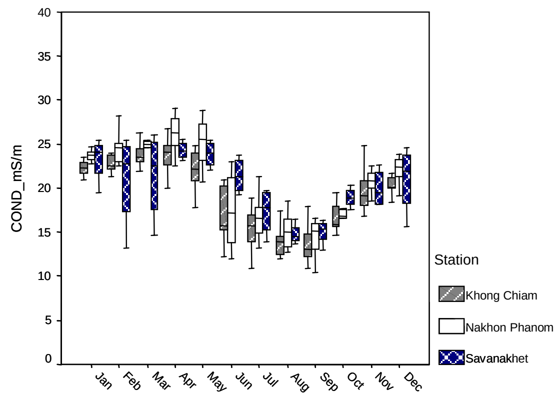


Fig. 20 EC variation in the Mekong River

In upper part of Mun, Chi river basin, Thailand, at some locations as Ban Som or Ban Chot the salinity is very high with the conductivity values up to 1000 mS/m and monthly median values up to 100 mS/m due to local salinized structure in this area (Fig.19). However, the salt load coming from this area to the Mekong River is very little due to very high dilution effect of the Mekong River. Variation of conductivity values at Khong Chiam station in the Mekong River where the Mun River joins with the Mekong River is the same form with those at Nakhon Phanom, upstream and Savanakhe, downstream location of Khong Chiam (Fig.20) The salinity of upper part of Mun, Chi rivers is up to about 7.0 g/L and causes a lot of problems for local inhabitants in domestic uses and agriculture production in this area.

Acidic water in the Mekong Delta

The acidic water that is caused by acid sulfate soil and is one of concerned issues in terms of water quality for local inhabitants in the Mekong Delta, Viet Nam where there is a large area of acid sulfate soil about 1.6 million of ha in which there is 0.5 million of severe acid sulfate soil. The oxidization process of acid sulfate soil is presented as follows:

$$FeS_2 + 7/2\,O_2 + H_2O = Fe^{2+} + 2\,SO_4^{2-} + 2H^+$$
$$Fe^{2+} + 1/4\,O_2 + H^+ = Fe^{3+} + 1/2\,H_2O$$
$$Fe^{3+} + 3H_2O = Fe(OH)_3 + 3\,H^+$$

The integrated reaction for this process is: :

$$FeS_2 + 15/4\,O_2 + 7/2\,H_2O = Fe(OH)_3 + 2SO_4^{2-} + 4H^+$$

Released acid will react with alumosilicates forming solved products such as aluminum sulphate and other secondary minerals as kaolinites. In the beginning of rainy season, these products will be washed out to canal making canal water acidified with pH less than 5 and high concentration of toxic ions such Al^{+3}, Fe^{+2},etc. The acidic water can be one main obstacle for production and living conditions of local inhabitants in this area. One example for this situation, we can look at the variation of pH value at station Thoi Binh in Chac Bang canal in Ca Mau Peninsula, Mekong Delta . At this site, the canal water has low pH down to 3, and low pH often occurs in the rainy season from May to September (Fig 21& Fig22) and this situation happens every year. The acidic water appears in the 3 parts of the Mekong Delta that is Plain of Reeds, Long Xuyen Quadrangle and Ca Mau Peninsula. It has causes a lot of problem for local inhabitants when the canal water is main source for production and domestic use. However, there is no impact from this water to the Mekong River due to localized nature of this issue.

CONCLUSION

Available water quality data from the WQMN showed that in general, there has not been any concerned water quality issue for the Mekong River in terms of physical- chemical characteristics, nutrient, organic matters and toxicity.

At present, the impacts from tributaries to the Mekong River is not found. However, the cities and centers with high density of population located along the river may be significant potential pollution sources for the Mekong River which is considered as tranboundary water quality issues (Bari Hart, 2001). Even though, this impacts at present is still very low, however, it was found in Takhmao, Bassac River.

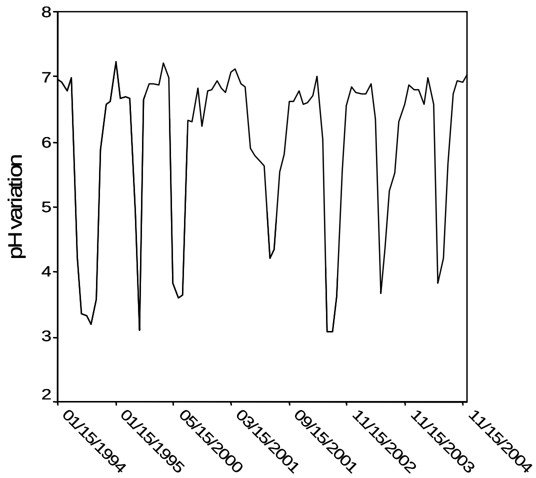


Fig.21 Yearly pH at Thoi Binh station

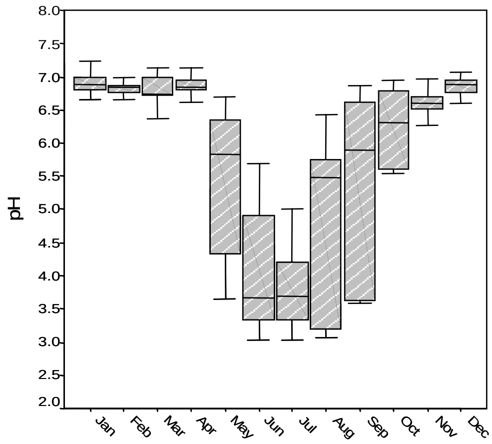


Fig.22 Monthly pH at Thoi Binh station

Although the source of surface water is abundant in LMB, local inhabitants, especially in the utmost countryside area, are still suffering with a number of water problems in terms of freshwater lacking, pollution water, salinity intrusion, acidic water, etc, due to hydro-meteorological and natural conditions of basin and impacts caused by human activities.

In the LMB where countries share river basin, the development activities for one country can influence another country on water resources in terms of water quantity and water quality as well. The cooperation of countries in the LMB is extreme importance for utilization and sustainable development of water resource of the Mekong River. The WQMN being implemented in the LMB with participation of four riparian countries is a good example for this cooperation and an effective tool to manage the water resource in terms of water quality.

Acknowledgements

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FLUCTUATION OF NUTRIENT CONCENTRATION IN THE MEKONG RIVER, VIENTIANE − LAO PDR

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ABSTRACT

The water of the Mekong River and its tributaries is vital water resources for people in Lao PDR as well as in the riparian countries. The nutrients carried by the river also play a significantly important role for the agricultural and fishery production in the region. Although the nutrient concentrations might vary depending on the seasons and the rainfall events, there have been only few observations of the water quality in the river with high frequency such as weekly or more so far. The purpose of this study is to explore the seasonal variation of nutrient concentrations and loads in the main stream of the Mekong River. The water samples were taken directly from the surface of the river water at two sampling points in Vientiane. The sampling was carried out twice a week at one point and once a month at another point during the period from January to December 2004. The samples were analyzed for nitrate-nitrogen, nitrite-nitrogen, ammonium-nitrogen, total-nitrogen, phosphate-phosphorus and total-phosphorus, as these elements are necessary nutrients for crops and fishes. Nitrogen concentrations at both points were generally low during the study period. At the point where a frequent sampling was carried out, nitrogen concentrations in the form of nitrate, nitrite, and ammonium ranged from 0.07 to 0.39 mg/L, from 0.0021 to 0.0068 mg/L, and from 0.01 to 0.23 mg/L respectively. 18.6 percent of the samples showed total phosphorus concentration exceeding USEPA recommended concentration of 0.1 mg/L. Most of the nutrient concentrations increased in May and Jun possibly because accumulated nutrient loads in the basin during the dry season were leached by the first runoff in the beginning of the wet season and reached the river. The nitrogen and phosphorus loads flowing in the Mekong River at Vientiane in 2004 were calculated to be 58,207 and 11,773 tons per year, respectively. The obtained data in the present study indicated that the water in the Mekong River is of good quality, maybe due to lower population density and absence of industrial and large-scale agricultural activities in the upstream area of the sampling points.

Keywords: the Mekong River, nutrient, nitrogen, nitrate, ammonium, phosphate, phosphorus, load

INTRODUCTION

The Mekong River is the longest river in the Southeast Asia with its length of approximately 4,800 km. It originates at the northeast rim of the Tibetan plateau, flows through several riparian countries including the Mekong Delta in Vietnam and reaches the South China Sea.

It is estimated that about 35 percent of all the water in the Mekong River originates from watersheds in Lao PDR. The Mekong River and its tributaries are vitally important water resources for agriculture as well as other sectors such as domestic use, transport, fishery and industry in Lao PDR. The nutrients carried by the river also play a significantly important role for the agricultural and fishery production in the region. It is said that annual floods have provided a lot of nutrients to the Mekong Delta.

In Lao PDR, recent population increase causes rapid enlargement of city areas. Because the construction of sewage systems cannot follow the rapid expansion of the city areas, it is often observed that municipal wastes are directly flowing into nearby rivers or canals. The population increase in the country also leads to rapid expansion of arable land. The area of the land for slash and burn agriculture in the basin is increasing. The expansion of arable land and the consequent deforestation must affect the water quality in the Mekong River.

Although the nutrient concentrations might vary depending on the seasons and the rainfall events, there have been only few observations of the water quality in the river with high frequency such as weekly or more so far. To seek the best management for sustainable agriculture and the total watershed management plan, better understanding of the current condition of the fluctuation of nutrient concentrations and loads in the Mekong River is necessary. The purpose of this study is to explore the seasonal variation of nutrient concentrations and loads at Vientiane. River water samples directly taken from the river were analyzed for major nutrients. The seasonal variation in the nutrient concentrations and loads are shown and the causes of the variation are discussed in this paper.

METHODS

Sampling points

Sampling points where water samples were taken from the river were selected at Vientiane. Vientiane Capital City, the largest city in Lao PDR, is located in the central part of the Mekong River basin along the left bank of the river. It has a population of 616,000 (in 2001) and an area of 3,920 km^2 with an average population density of 157.1 people/km^2. The locations of the sampling points are shown in Figure 1. Water samples were collected from the Mekong River at 2 sampling points. One point is located at Kaoliao water treatment plant, which is at the upstream of Vientiane (Kaoliao). Another point is located at the Department of Meteorology and Hydrology (DMH), which is about 2.5 km downstream from Kaoliao point.

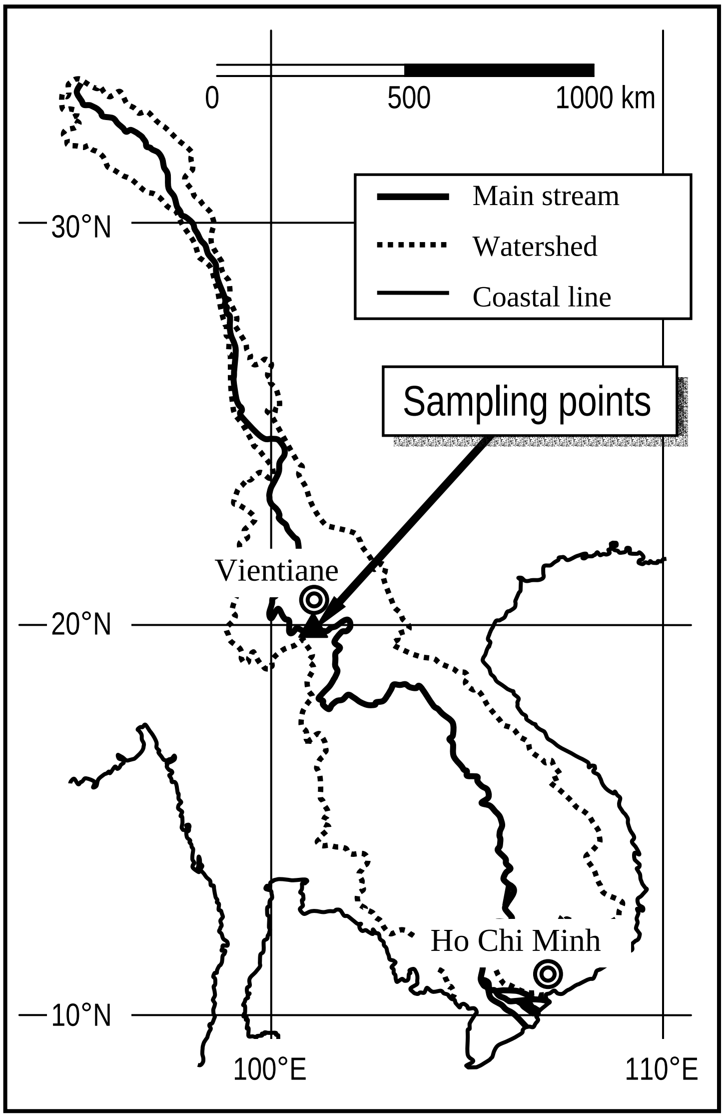

Figure 1. The locations of the sampling points.

Samples were directly taken from the river near the left bank. The river water around 0.5 m below the water surface was sampled by using a bucket with a nylon rope (about 10 m in length). The samples were immediately transferred to a 500 ml clear plastic bottle at the sampling points. The sampling was carried out basically twice a week at Kaoliao from January to December 2004 and monthly at DMH from March to December 2004.

Analytical methods

After the sampling, pre-treatment was quickly conducted to prevent the possible quality change in the samples. The samples were placed in a cooler box while being transported to the laboratory and kept at 4 °C until being analyzed. Before the analysis water samples were filtered through a filter paper (Whatman) for some parameters as shown in Figure 2. The water samples were analyzed for six parameters, i.e. total nitrogen (TN), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), ammonium-nitrogen (NH_4-N), total phosphorus (TP) and phosphate-phosphorus (PO_4-P) in the laboratory at Irrigation Engineering Department, National University of Laos, Vientiane Capital City. NO_3-N, NO_2-N, NH_4-N and PO_4-P concentrations were analyzed by Cadmium Reduction Method, Diazotization Method, Salicylate Method and Ascorbic Acid Method, respectively, using a spectrophotometer, Hach Model DR/4000U and a digester, Model TNP-1.

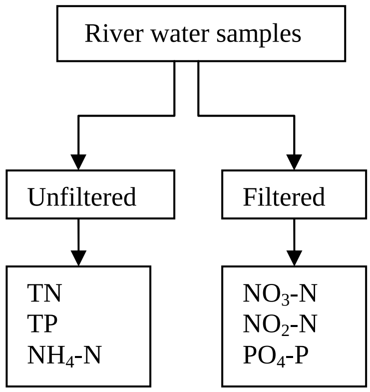

Figure 2. Scheme of sample analysis.

RESULTS

Changes in nutrient concentrations

Fluctuations of nitrogen concentrations at Kaoliao and DMH are shown in Figures 3 and 4, respectively. NO_3-N concentrations varied in the range between 0.07 and 0.39 mg/L at Kaoliao and between 0.10 and 0.35 mg/L at DMH. The lowest NO_3-N concentrations at both points were recorded in December. The highest NO_3-N concentrations at Kaoliao were recorded in the beginning of May and in the middle of June. The mean and the range of the NO_3-N concentration at each point are given in Table 1. As shown in Table 2, the NO_3-N concentrations at both points were quite low when they were compared with the maximum concentration for drinking water recommended by The

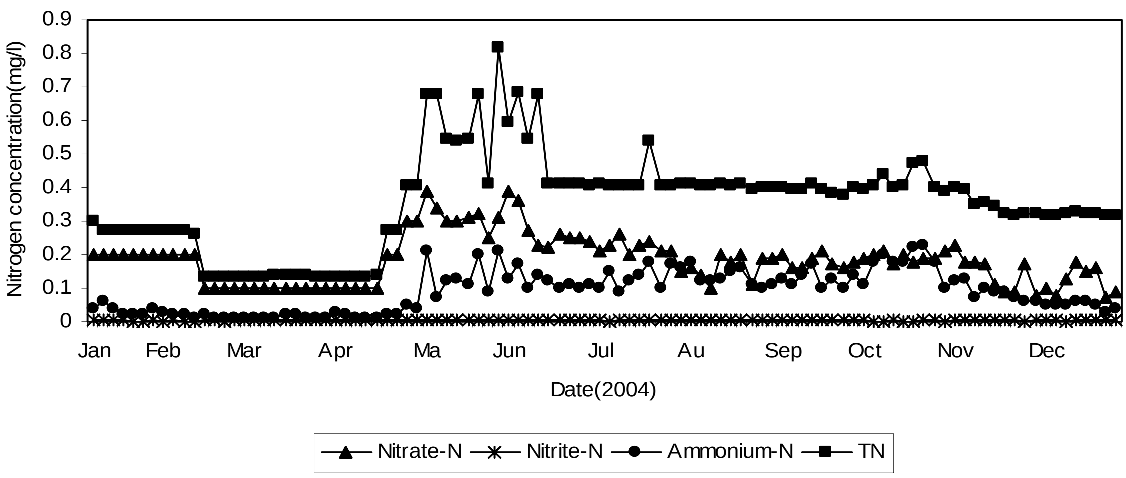

Figure 3. Changes in nitrogen concentrations at Kaoliao.

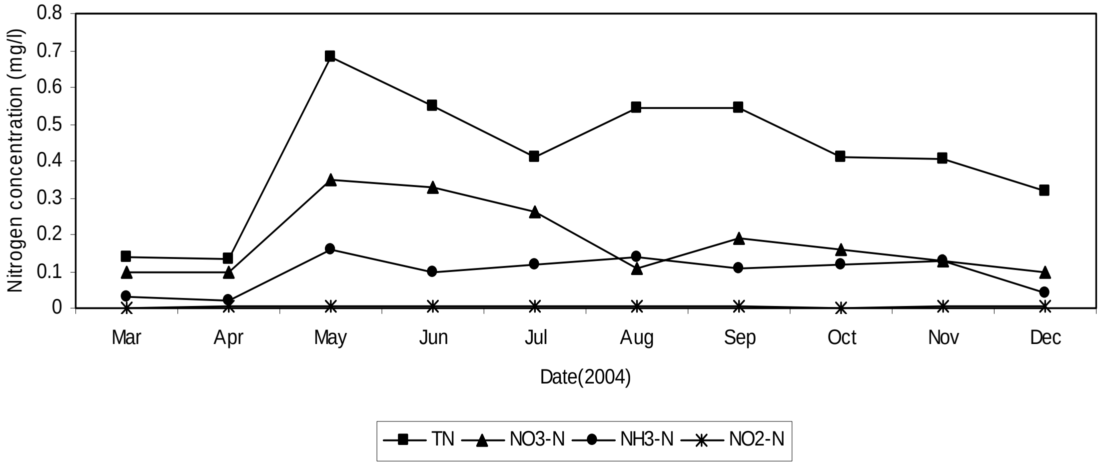

Figure 4. Changes in nitrogen concentrations at DMH.

United States Environmental Protection Agency (USEPA) [1] and World Health Organization (WHO) [2].

Table 1. Means and ranges of nutrient concentrations at Kaoliao and DMH.

Parameter	Kaoliao (upstream)		DMH (downstream)	
	Mean	Range	Mean	Range
NO_3-N (mg/L)	0.17	0.07 - 0.39	0.18	0.10 – 0.35
NO_2-N (mg/L)	0.0034	0.0022 - 0.0068	0.0032	0.0021- 0.0045
NH_4-N (mg/ L)	0.09	0.01 – 0.23	0.10	0.02 – 0.16
TN (mg/L)	0.36	0.13 – 0.82	0.41	0.14 – 0.68
PO_4-P (mg/L)	0.05	0.02 – 0.12	0.05	0.02 – 0.06
TP (mg/L)	0.07	0.03 – 0.16	0.08	0.04 – 0.13

NH_4-N concentrations varied in the range between 0.01 and 0.23 mg/L at Kaoliao and between 0.02 and 0.16 mg/L at DMH. The NH_4-N concentration sometimes exceeded the maximum concentration for drinking water recommended by USEPA [1] and WHO [2]. Before May, the NH_4-N concentrations at both points were consistently low and ranged between 0.01 to 0.03 mg/L. The period when the low NH_4-N concentration was observed coincided with the period when relatively low NO_3-N concentrations were observed. After October, the NH_4-N concentration showed a gradual decrease until the end of the study period, with occasional fluctuations at Kaoliao.

Table 2. Means of nutrient concentrations at Kaoliao and DMH compared with the maximum limits recommended for drinking water and domestic uses.

Parameter	Mean of measured values		Recommended values	
	Kaoliao	DMH	USEPA[1]	WHO[2]
NO_3-N (mg/L)	0.17	0.18	10	50
NO_2-N (mg/ L)	0.0034	0.0032	1.0	3.0
NH_4-N (mg/ L)	0.09	0.1	0.1	1.5
TN (mg/ L)	0.36	0.41	-	-
PO_4-P (mg/ L)	0.05	0.05	-	-
TP (mg/ L)	0.07	0.08	0.1	-

NO_2-N concentration was uniformly lower than 0.01 mg/L during the study period. However, the NO_2-N concentration at Kaoliao in late April and May seemed to be higher than that during other periods.

TN concentrations were generally low at both sampling points. The mean and the range of the TN concentration at each point are shown in Table 1. The highest TN concentration was recorded as 0.82 mg/L at Kaoliao on May 28. Except for this date, the TN concentration stayed less than 0.75 mg/L, which is the concentration recommended by Australia and New Zealand Environment and Conservation Council guideline [3] for aquatic ecosystems. The TN concentration was higher in May and Jun than that in other months. After Jun, the TN concentration showed a gradual decrease.

Fluctuations of phosphorus concentrations at Kaoliao and DMH are shown in Figures 5 and 6, respectively. PO_4-P concentration was uniformly lower than 0.20 mg/L. As shown in Table 1, the mean of the PO_4-P concentration of the measured 102 samples at Kaoliao was 0.05 mg/L, which was a relatively high value when it was compared with the mean Global Environmental Monitoring System (GEMS) value (0.025 mg/L). The lowest PO_4-P concentration was recorded at Kaoliao in March.

TP concentrations at both sampling points were low. As shown in Table 1, the mean TP concentration at Kaoliao was 0.07 mg/L (102 samples) and that at DMH was 0.08 mg/L (10 samples), which were relatively low values when they are compared with the mean TP concentrations in other major rivers in southern Asia. About 18 % of the samples had the TP concentrations exceeding the USEPA recommended concentration of 0.1 mg/L. At Kaoliao, the highest TP concentration of 0.16 mg/L was recorded in September and the lowest TP concentration was recorded in March.

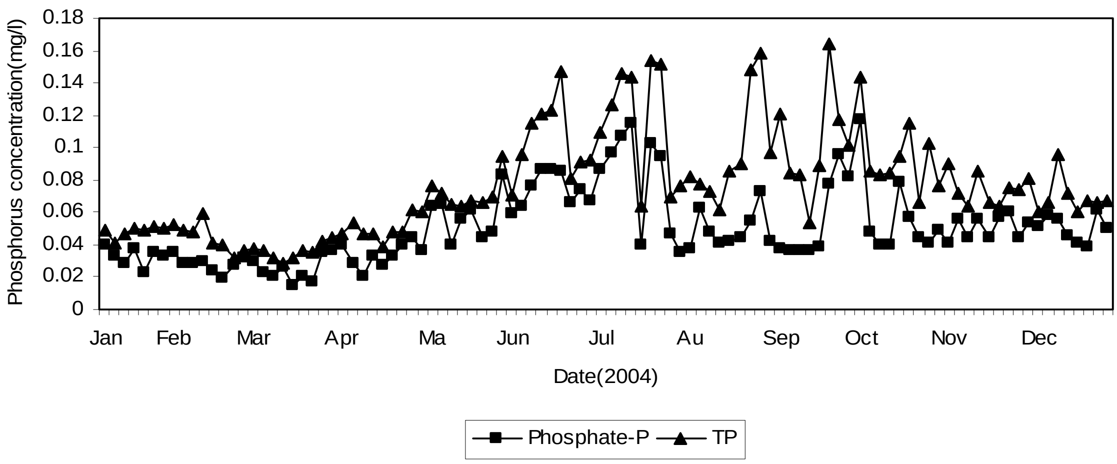

Figure 5. Changes in phosphorus concentrations at Kaoliao.

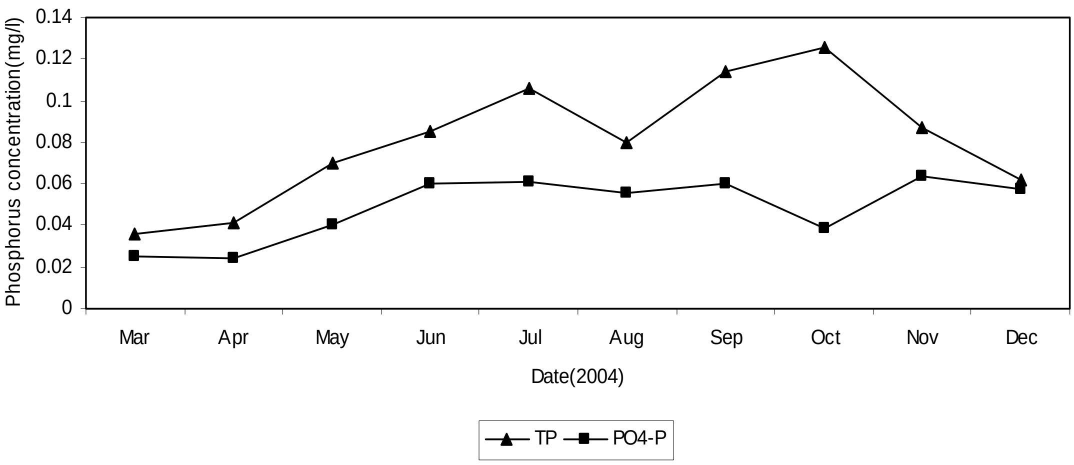

Figure 6. Changes in phosphorus concentrations at DMH.

Nutrient loads

Figure 7 shows the changes in the daily discharge during the study period which was provided by water way sector, Ministry of Communication, Post and Construction at Vientiane Capital City, Lao PDR. The discharge varied in the range between 659 and 13,800 m^3/s during the study period. The highest discharge was recorded in September, which was lower than the highest discharge in 2003.

Figures 8 and 9 show the calculated amount of nutrient loads of nitrogen and phosphorus in each month. Nitrogen and phosphorus loads at both sampling points were low from January to April. Both of the loads began to increase in May at both points. Monthly nitrogen and phosphorus loads rose to peaks in September at both points. The amounts of nitrogen and phosphorus carried by the river at Kaoliao in September were calculated to be 10,264 and 2,351 tons, respectively. On the other hand, the amounts of nitrogen and phosphorus passed through DMH in September were 17,251 and 3,460 tons, respectively. After September, the monthly loads decreased until the end of the study period.

DISCUSSIONS

Concentrations of nitrogen and phosphorus varied seasonally and the concentrations increased in May, the early stage of the wet season. It is suggested that the first runoff after the dry season took the accumulated nutrient loads from the basin to the river and brought about the sharp increase of the nutrient concentrations in the river water. The flush of the stream bed sedimentation which accumulated during the low flow season might also contribute to the sharp increase of the nutrient concentrations in the river water.

After Jun, nitrogen concentrations at both sampling points showed a gradual decrease until the end of the study period, with occasional fluctuation at Kaoliao. It is considered that the accumulated nutrients in the basin had been diluted by plentiful water during the flood season. On the contrary, phosphorus concentrations at both sampling points continued to increase until October when the phosphorus concentrations reached their maximum values.

As shown in Tables 1 and 2, the measured data in the present study

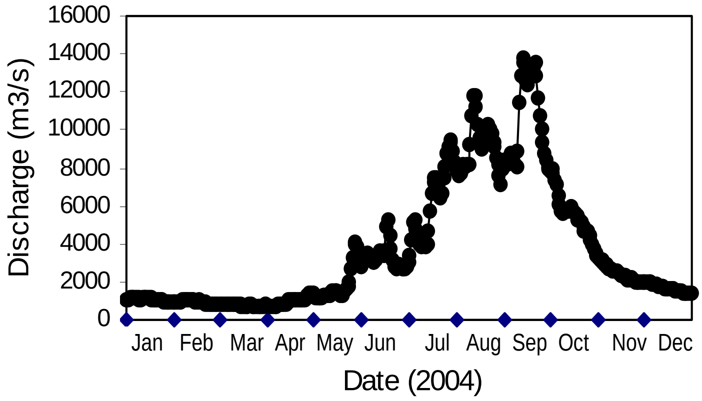

Figure 7. Changes in daily discharge at DMH.

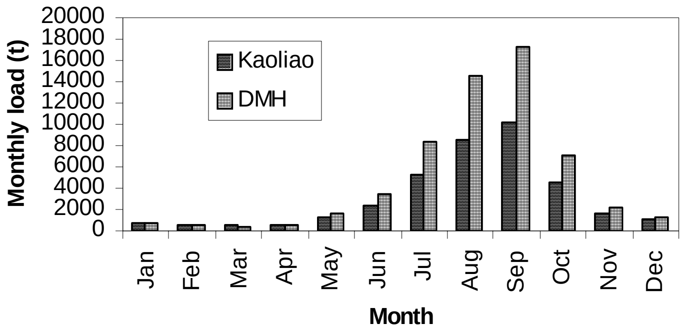

Figure 8. Monthly load of TN.

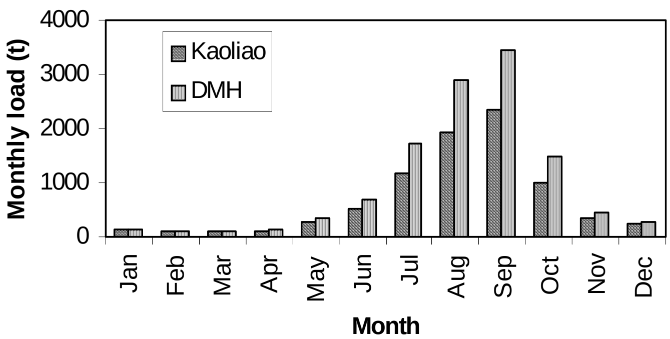

Figure 9. Monthly load of TP.

showed that the water in the Mekong River is of quite good quality. It is probable that lower population density and absence of industrial and large-scale agricultural activities in the upstream of the sampling points account for the normal state of the water quality in the river.

The seasonal changes in the nutrient loads were governed by the changes in the discharge, clearly due to a large amount of discharge carrying the nutrients. TN and TP loads in the Mekong River were calculated using frequent data to be 37,000 and 8,000 tons per year, respectively, at Kaoliao. On the other hand, TN and TP loads were calculated roughly to be 58,000 and 12,000 tons per year, respectively, at DMH, which is located about 2.5 km downstream from Kaoliao. The nutrient loads during the study period were generally low compared to the loads calculated by Iida *et al*. [4] at Kaoliao for 2002.

CONCLUSIONS

Nutrient concentrations at both Kaoliao and DMH sampling points sharply increased in May, probably because the first runoff after the dry season took the accumulated nutrient loads from the basin to the river and the stream bed sedimentation which accumulated during the low flow season was flushed by the first runoff. After June, nitrogen concentrations showed a gradual decrease until the end of the study period. On the contrary, phosphorus concentrations continued to increase until October when the phosphorus concentrations reached their maximum value. The nutrient concentrations measured in the present study during the period from January to December 2004 showed that the water in the Mekong River is of quite good quality, maybe due to lower population density and absence of industrial and large-scale agricultural activities in the upstream area of the sampling points. The changes in the nutrient loads were governed by the changes in the discharge, clearly due to a large amount of discharge carrying the nutrients. Nitrogen and phosphorus loads in the Mekong River were calculated to be 37,000 and 8,000 tons per year, respectively, at Kaoliao in 2004.

ACKNOWLEDGEMENTS

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MODELING OF RADIATION SHADE FUNCTION OF RIPARIAN COVER

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ABSTRACT

Recently multi functionality of riparian vegetation attract the attention of scientists of river engineering, ecological, botany field. Riparian vegetation is closely related to river front ecosystem and has environmental control functions; 1) production of organic matter such as insects or litter fall, 2) stream temperature control by radiation shade, 3) purification of water quality by surface flow trapping. Usually riparian vegetation area is only about 5% of total watershed area; however it is important as the connection of terrestrial zone and water zone.

In this study, stream temperature control function of riparian vegetation was focused. In a river with luxuriant riparian vegetation, direct solar radiation is reduced by the crown of trees, thus the stream temperature is kept low, and excessive growth of algae is prevented even during low discharge periods. Therefore, the decline of riparian vegetation strongly affects the river thermal environment, which also has a large impact on the ecological systems. In developing countries, riparian vegetation decreased rapidly by legal or illegal logging, because riparian vegetation was easy to use and transport by water. In such area, excess logging made serious increase of stream temperature until original species of fish or insect in the area can not live in.

In this study, a model that relates stream temperature with riparian vegetation was developed. The Nam Song River, which is a tributary of the Nam Ngum River flowing through the Vientiane Metropolis, was selected for field study. Meteorological data (air temperature, relative humidity, wind speed) were used, and the sink or source terms of the heat transfer equation were estimated from that data. NDVI remote sensing data was used for seasonal change of LAI (leaf area index) Simulations were made with several cases of riparian vegetation density, showing that river water temperature is more sensitive to river discharge change in the case of low density condition

INTRODUCTION

Recently, the multiple functions of river corridors have attracted the attention of biologists and environmental river engineers. In a river with luxuriant corridor vegetation, direct solar radiation is reduced by the crown of trees, thus the stream temperature is kept low, and excessive growth of algae is prevented even during low discharge periods. As the stream temperature is kept low, any rapid increase of immigrant plants, which seize the habitats of conventional plants, is prevented, and as a result, the biodiversity of the habitats is retained (Swift & Messer, [1]).

Temperature is an important parameter in stream water quality. Human activity raises or lowers natural stream water temperatures due to impoundments, industrial use, irrigation and global warming (Bartholow, [2]; LeBlanc et al., [3]). Water temperature affects nearly every physical property related to water quality management and, unfortunately, a change of water temperature is often undesirable. Therefore, control of stream water temperature becomes a prerequisite for maximum utilization of water resources (Yoshida et al., [4]).

The Mekong River, a major international river flowing thorough six countries, had had relatively pristine conditions in the last centuries. However, the habitats of river biota and fish are now threatened by serious changes to river environments resulting from the rapid expansion of human activities. In lower Mekong area, riparian vegetation decreased rapidly by legal or illegal logging, because riparian vegetation was easy to use and transport by water (Fig.1). In Laos especially, located in mountainous area, the riparian forest are being logged by farmland development or fire agriculture. The decline of river riparian vegetation strongly affects the river thermal environment, which has a large impact on the ecological system (Stanford & Ward, [5]).

In this study, a model that relates stream temperature with riparian vegetation was developed. The Nam Song River, which is a tributary of the Nam Ngum River flowing through the Vientiane Metropolis, was selected for field study. Meteorological data (air temperature, relative humidity, wind speed) were used, and the sink or source terms of the heat transfer equation were estimated from that data. NDVI remote sensing data was used for seasonal change of LAI (leaf area index) and seasonal change of vegetation shade was calculated from LAI value.

STUDY AREA

The Nam Song River, having a 1800 km^2 catchment area and 100 km length, is a tributary of the Nam Ngum River (Fig. 2). The Nam Song Diversion Dam (1500 km^2 catchment area) was constructed in 1996 to divert water from the Nam Song basin to the Nam Ngum reservoir.

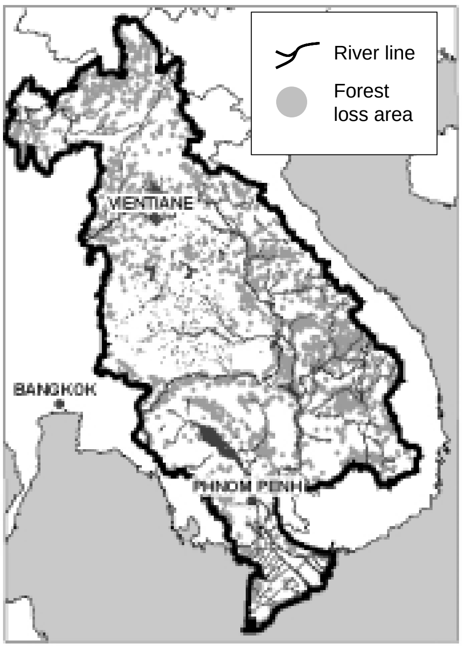

Figure 1. Forest loss area in lower Mekong basin from 1993 to 1997

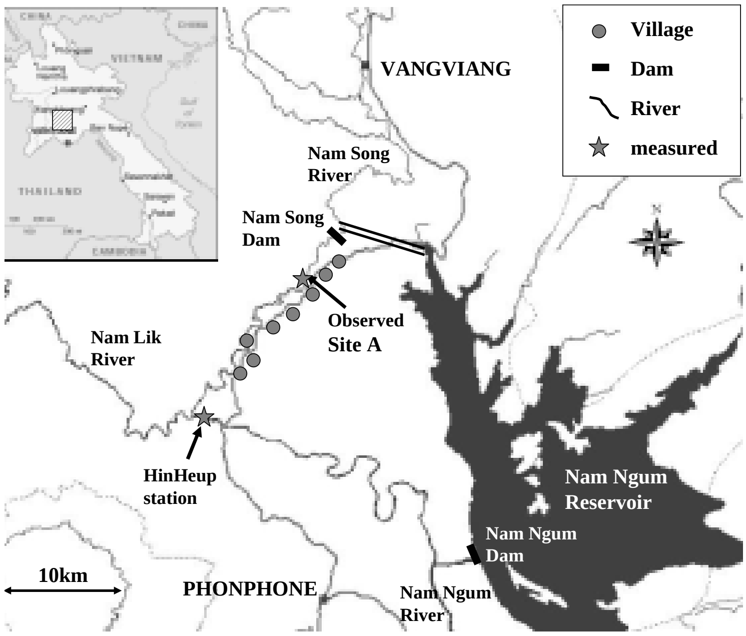

Figure 2. Location of study area

Downstream of the Nam Song Dam, there are eight villages consisting of approximately 4000 people along the riverbanks. In the dry season, the water release discharge from the Nam Song dam decreased from 10.0 m^3 s^{-1} to a minimum of only 2.0 m^3 s^{-1} (as shown in Fig. 3, estimated by Yoshida et al., [6]); the dry season discharge decrease made a large impacts on the fisheries and domestic water quality. The decline of the fish catch was a serious loss to local villages, and the river downstream of the dam now has a very reduced number of species. The local peoples had utilized the forest resources along the river before dam construction. However, now many kinds of crops are transplanted along the riverbank to improve their living instead of fishery. The reduction of the corridor vegetation density also accelerated the environmental decline of the Nam Song River (Roel & Sean, [7]). In this study area, the actual stream temperature was observed 4 km downstream from the Nam Song dam and daily meteorological data at the Hinheup station was available.

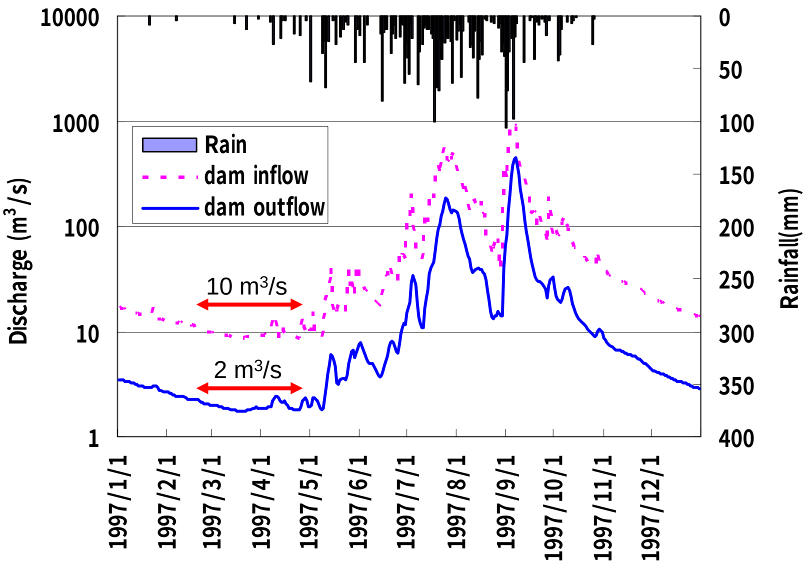

Figure 3. Hydrograph at the Nam Song diversion dam (1997).

MODELING OF SEASONAL CHANGE OF RIPARIAN VEGETATION SHADE

Estimation of solar radiation

To predict the stream temperature, the heat gained or lost from a parcel of water should be calculated as it passes through a stream segment. This is accomplished by simulating the various heat flux processes that determine that temperature change. These physical processes include convection, conduction, evaporation, as well as long wave radiation (heat to or from the air), direct solar radiation (short wave), and radiation back from the water. So first, solar radiation, which is basal parameter, should be calculated. To calculate solar radiation, the radiation at the outer edge of the Earth's atmosphere was calculated.

In this study, the FAO (Food and Agriculture Organization of the United Nations, [8]) method was employed to estimate hourly solar radiation from meteorological data (air temperature, relative humidity, wind speed). The extraterrestrial radiation R_a, for each day and each hour of the year and for different latitudes can be estimated from the solar constant as follows:

$$R_a = \frac{12(60)}{\pi} G_{sc} [(\omega_2 - \omega_1)\sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)(\sin(\omega_2) - \sin(\omega_1))] \tag{1}$$

$$dr = 1 + 0.33\cos\left(\frac{2\pi}{365} J\right) \tag{2}$$

$$\delta = 0.409\sin\left(\frac{2\pi}{365} J - 1.39\right) \tag{3}$$

$$\omega_1 = \omega - \frac{\pi \Delta t}{24} \tag{4}$$

$$\omega_2 = \omega + \frac{\pi \Delta t}{24} \tag{5}$$

$$\omega_s = \arccos[-\tan(\varphi)\tan(\delta)] \tag{6}$$

where R_a is hourly extraterrestrial radiation [MJ m^{-2} h^{-1}], G_{sc} is the solar constant = 0.082 [MJ m^{-2} min^{-1}], dr is the inverse relative distance Earth–Sun, φ is latitude [rad], δ is solar declination [rad], J is the number of the day in the year, ω_1 is solar time angle at beginning of period, ω_2 is solar time angle at end of period, ω is solar time angle at midpoint of hourly period [rad], ω_s is the sunset hour angle [rad], Δt is calculation time step [h].

The solar time angle at the midpoint of the period is:

$$\omega = \frac{\pi}{12}[(t_s + 0.06667(L_z - L_m) + S_c) - 12] \tag{7}$$

$$S_c = 0.1645\sin(2f) - 0.1255\cos(f) - 0.025\sin(f) \quad (8)$$

$$f = \frac{2\pi(J-81)}{364} \quad (9)$$

where t_s is standard clock time at the period's midpoint (e.g. 7.5 for between 07:00 and 08:00), L_z is the longitude of the centre of the local time zone, degrees west of Greenwich (e.g. 255° for Bangkok), L_m is longitude of the measurement site, S_c is seasonal correction for solar time [hour]. Of course, $\omega < -\omega_s$ *or* $\omega > \omega_s$ indicates that the sun is below the horizon and Ra is zero.

The solar radiation R_s can be calculated with the Angstrom formula, which relates solar radiation to extraterrestrial radiation and relative sunshine duration:

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a \quad (10)$$

$$N = \frac{24}{\pi}\omega_s \quad (11)$$

where R_s is solar or shortwave radiation [MJ m^{-2} hour^{-1}], n is actual duration of sunshine [h], N is maximum possible duration of sunshine or daylight hour [h], a_s *and* b_s are the Angstrom coefficients. Depending on atmospheric conditions (humidity, dust) and solar declination (latitude and month), the Angstrom coefficients will vary. In this study, the FAO recommended values, a_s=0.25 and b_s=0.5, were used. Sun-Earth relation was schematized in Fig.4

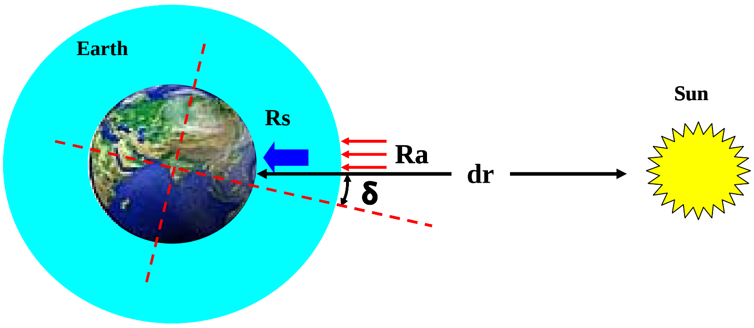

Figure 4. Scheck of Sun-Earth relation.

Fig.5 shows the calculated solar radiation and that observed from 5 Aug to 30 Dec 2004 at Vientiane Meteorology station (102.5°E, 18°N). There were relatively large margins of error in some radiation peaks of rainy day; however, overall the daily trend had good agreement with observed values. In this study, to express the solar radiation reduction due to cloudy skies, relative sunshine duration (n/N) was used in equation (10) during all daylight hours, because only daily sunshine data was available. Using the hourly data of cloud cover would have improved the accuracy of estimation, but the data were unavailable.

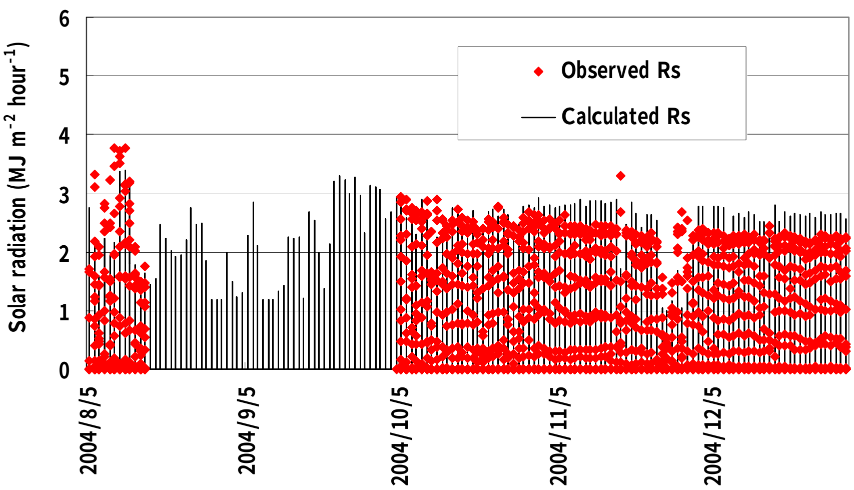

Figure 5. Comparison of observed and calculated R_s (5 Aug to 30 Dec 2004).

Estimation of shade parameter of riparian vegetation

To evaluate the stream temperature regulation function of the riparian vegetation, the vegetation shade parameter V_{shade} should be estimated. At first, characteristics of the riparian vegetation such as height V_h, density V_d and vegetation offset V_o from the stream were analyzed from GIS land cover data (1 km resolution), provided by the Global Mapping Project (Fig.6) and field survey data. The Global Map land cover GIS data contains the information on vegetation height and density (e.g. evergreen: height >2 m, density >60%).

Table1 shows the estimated present condition of the rirarian vegetation, which was evaluated as an average value along the main stream from the GIS definition and was modified by field survey). The vegetation density was the same, 60%, for both the right and left banks. However, the right bank vegetation which was better sunlit in the morning was more luxuriant.

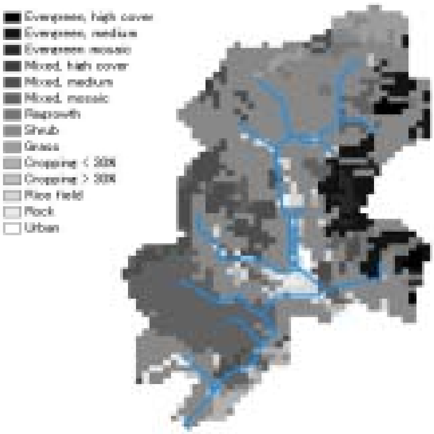

Figure6. GIS land cover data of Nam Song river watershed

Table1. Characteristics of river corridor vegetation.

	V_h (m)	V_d (%)	V_o (m)
Left bank	7.0	60.0	10.0
Right bank	10.0	60.0	7.0

V_h : vegetation height; V_d : vegetation density; V_o :vegetation offset from the stream

From the vegetation characteristics, the local sunrise/sunset time and hourly sun angle, the vegetation shade ratio that considers the sunlight filtered out by the vegetation were calculated (Fig.7). The watershed-scale radiation shade model was proposed by Chen [9] and considered complex vegetation shading and topographic effects. In this study, a simplified model was proposed to enable application at a large-scale resolution (1-km mesh). In the 1-km resolution analysis, topographic effects were neglected because 1 km is too much longer than the vegetation offset distance.

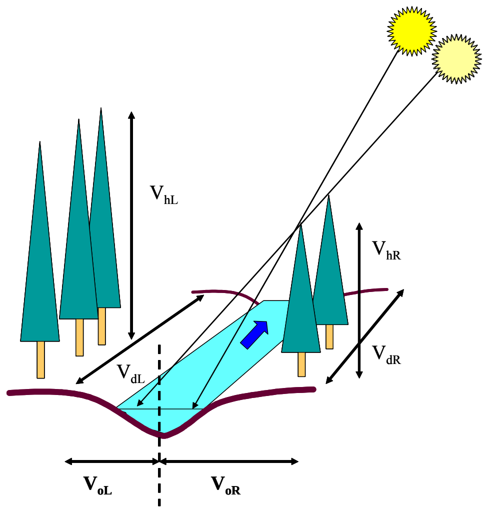

Figure7 Sketch of the shade ratio calculation from sun angle and vegetation data

Shadow length of the vegetation tree was estimated as follows;

$$S_{length,L} = \left| V_{hL} / \tan(\omega) \right| \quad (-\omega_s < \omega < 0) \qquad (12)$$

$$S_{length,R} = \left| V_{hR} / \tan(\omega) \right| \quad (0 \le \omega < \omega_s) \qquad (13)$$

where S_{length} is Shadow length of the riparian tree, V_{hL} and V_{hR} is vegetation height of left and right side bank.

Shined water surface width was calculated by;

$$W_{shined,L} = \max\left(0, V_{0L} + W/2 - S_{length,L}\right) \quad \left(-\omega_s < \omega < 0\right) \tag{14}$$

$$W_{shined,R} = \max\left(0, V_{0R} + W/2 - S_{length,R}\right) \quad \left(0 < \omega < \omega_s\right) \tag{15}$$

where W_{shined} is shined water surface width, V_{oL} is vegetation offset distance, W is water surface width.

The vegetation shade ratio was calculated as:

$$V_{shade} = E_{VL} \cdot V_{dL} \cdot \left(W - W_{shined,L}\right)/W \quad \left(-\omega_s < \omega < 0\right)$$
$$= E_{VR} \cdot V_{dR} \cdot \left(W - W_{shined,R}\right)/W \quad \left(-\omega_s < \omega < 0\right) \tag{16}$$

where V_{shade} is vegetation shade ratio, E_V is radiation shade coefficient of vegetation and V_d is vegetation density along the stream.

E_V changes seasonally according to the luxuriance of vegetation leaf and can be estimated from LAI (leaf area index) depend on Beer's low;

$$R_{s,out} = R_{s,in} \cdot (1 - E_V) = R_{s,in} \cdot (1 - \exp(-\beta \cdot LAI)) \tag{17}$$

where $R_{s,out}$ is solar radiation under the canopy, $R_{s,in}$ is solar radiation above the canopy, LAI is leaf area index and β is extinction coefficient. Although irradiance generally decreases as one descends from the canopy of a tropical forest, there is a great variation from point to point. Therefore architecture of tree crowns and patterns of leaf arrangement should affect extinction coefficient. In this study, β=0.52 was employed which estimated for typical tropical trees (Kitajima [10]).

LAI is defined as the leaf area per unit ground area. LAI can be estimated from the NDVI (normalized difference of the vegetation index), because NDVI represent the relative seasonal changes in vegetation rather than vegetation amount. There is a significant relationship between NDVI and LAI. Assuming that NDVI/LAI relationship is liner (Wardley et al [11]); and the maximum NDVI value in a season correspond to the maximum LAI of vegetation cover (Justice [12]). LAI can be inferred from NDVI as follows;

$$LAI_i = LAI_{\max} \cdot \left(NDVI_i - NDVI_{\min}\right)/\left(NDVI_{\max} - NDVI_{\min}\right) \tag{18}$$

where *max*, *min* and *i* are the maximum, minimum and period values, respectively.

Figure 6 shows the NDVI data which was used for LAI analysis produced by USGS (U. S. Geological Survey). In this area, NDVI value increase from July to November (rainy season) and decrease from November to July(dry season), depend on the rainfall amount.

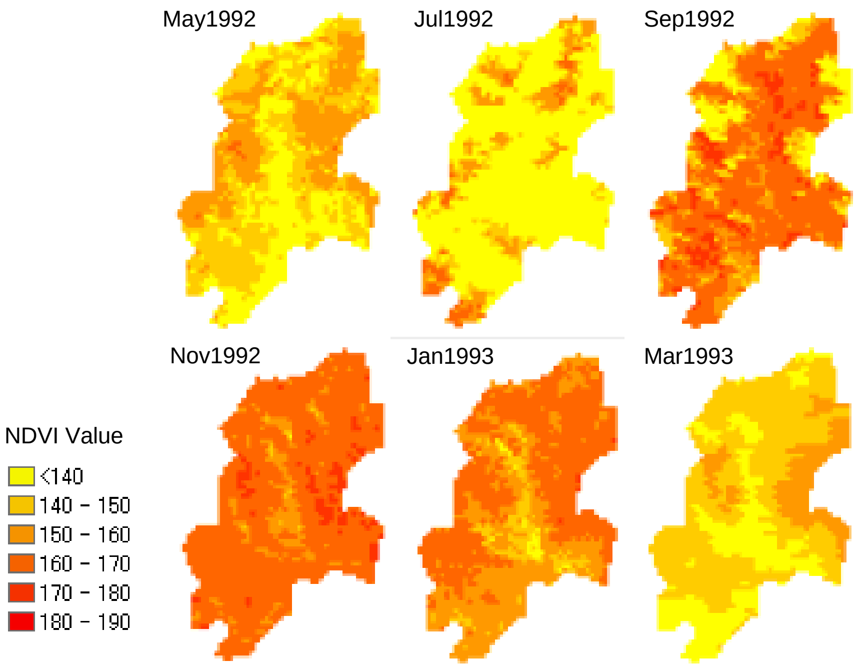

Figure 6. Seasonal change of NDVI 1992-93 (Data source: USGS)

Figure 7 shows calculated LAI value of deciduous and evergreen trees from NDVI data. The result shows both deciduous and evergreen tropical tree in this area is luxuriant in the summer. Leaves of deciduous trees drop on July and exuberate again on September. Plot values shows estimated LAI from NDVI data and seasonal LAI change models of deciduous and evergreen tree are shown in solid line.

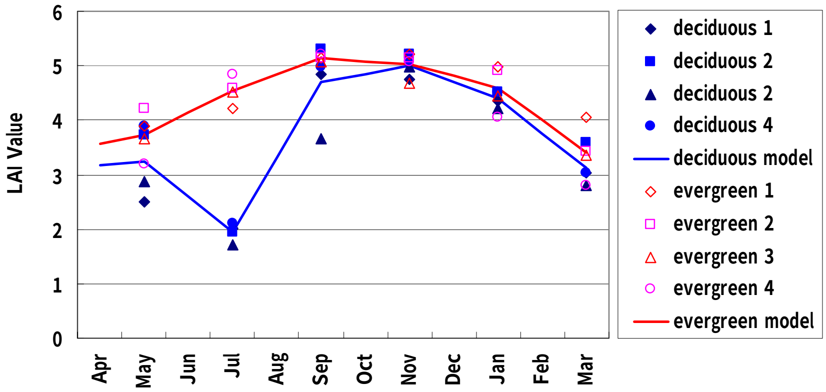

Figure 7. Seasonal change of LAI 1992-93

Figure 8 shows the analyzed result of the daily change of shade ratio. Vegetation shaded time was longer in the afternoon due to the luxuriant right bank vegetation and the value was zero around noon.

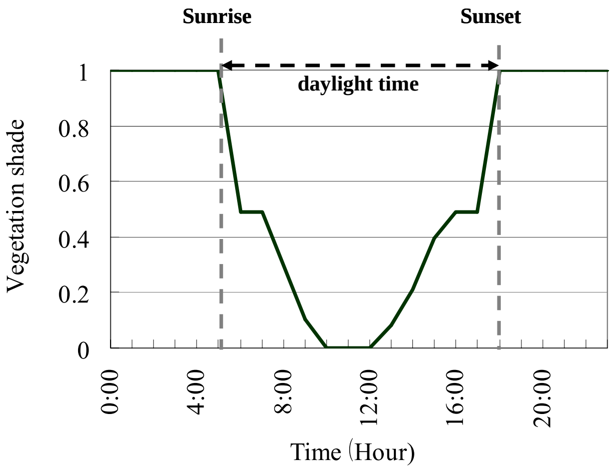

Figure 8. Daily change of Vegetation shade ratio (20 Mar 2004)

STREAM TEMPERATURE ANALYSIS

In this study, the one-dimensional heat advection–dispersion equation including the heat exchange with the atmosphere was used. When applied to an open channel of variable cross section and flow rate, the heat transport equation takes the form:

$$A\frac{\partial T}{\partial t}+\frac{\partial (QT)}{\partial x}=\frac{\partial}{\partial x}\left(AD_L\frac{\partial T}{\partial x}\right)+\frac{WS}{\rho Cp}+\frac{G}{\rho Cp} \quad (19)$$

where T is water temperature, x is distance, t is time, D_L is a dispersion coefficient in x direction, S is a source or sink term which includes heat transfer with the surrounding environment, A is cross-sectional area, W is surface width, Q is flow rate, G is the lateral heat advection term by lateral inflow. For numerical testing, dispersion values (D_L) of 20–200 $m^2\ s^{-1}$ were applied assuming several river conditions (Bashar & Stefan, [13]), but increases of D_L did not change the model simulation results because of the relatively high velocity of flow and the low longitudinal temperature gradient along the modeled stream, indicating that the system was advection dominant. Therefore D_L was set equal to zero in the model.

Equation (19) can be used to predict water temperatures in steady flow streams that are well mixed and have no significant transverse temperature gradients; the main variation is in the flow direction. Stream cross-sectional area A and width *W* are a function of stream flow rate *Q*, ρ is the density of water, and *Cp* is the specific heat of water.

The source or sink term *S* expresses the heat transfer rate with the surrounding environment:

$$S = S_a + S_b \tag{20}$$

with

$$S_a = H_s + H_l + H_e + H_c \tag{21}$$

where S_a is the net heat exchange rate between the water and the air, S_b is the net heat exchange between the water and the streambed, H_s is the net short-wave (solar) radiation, H_l is the net long-wave radiation, *He* is the evaporative heat transfer, H_c is the convective heat transfer.

H_s is the net solar radiation. Solar radiation is a measured weather parameter, and net shortwave radiation is expressed as the difference between measured incoming and reflected radiation:

$$H_s = (1-\alpha)Rs(1-V_{shade}) \tag{22}$$

where α(= 0.06 was employed) is the reflection parameter at the water surface, R_s is solar radiation and V_{shade} is vegetation shade ratio estimated by corridor vegetation analysis.

H_l is the net long-wave radiation and can be expressed as:

$$H_l = \sigma\left(\varepsilon_a T_{K,a}^4 - \varepsilon_w T_{K,s}^4\right) \tag{23}$$

where σ is the Stefan-Boltzmann constant, $T_{K,a}$ is air temperature (degrees Kelvin), $T_{K,s}$ is the water surface temperature (degrees Kelvin), ε_w (= 0.97) is the long-wave emissivity of the water surface (Edinger et al., [14]), and ε_a (= 0.78 was employed depending on the estimation of Iziomon et al., [15]) is the emissivity of the atmosphere. Note that Ts can be replaced by T assuming a well mixed condition and in the field, T was measured at the middle point of depth, near the river shore.

The evaporative heat transfer He can be estimated by the relation as follows:

$$H_e = -\rho L\, f(Wind)(e_s - e_a) \tag{24}$$

$$f(wind) = 0.0296 + 0.00637\ Wind_z \tag{25}$$

where e_a is the vapour pressure of the air, e_s is the saturated vapour pressure at the water surface temperature, *L* is the latent heat of water vaporization (= 2.45 MJ kg^{-1}), *f*(*wind*) is a wind function using wind velocity, $Wind_z$ is wind velocity at *z* height and *z* is vertical height (Gulliver & Stefan, [16]). Measured wind speed data was observed at 2 m height at the Hinheup station.

H_c is the convective heat transfer which may be expressed as follows:

$$H_c = 0.61\frac{P}{1000}\rho\ \ L\ \ f(wind)(T_a - T_s) \tag{26}$$

where T_a is the air temperature, *P* is atmospheric pressure and *f(wind)* is same function of evaporative heat transfer.

The net heat exchange between the water and streambed S_b is expressed as:

$$S_b = -k\frac{\partial T_b}{\partial z} \tag{27}$$

where *k* is the thermal conductivity of the streambed materials, T_b is the streambed temperature and *z* is vertical distance into the streambed. Usually the riverbed heat conduction term S_b can be assumed to be negligible except under the extreme shallow flow condition (Honzo & Stefan, [17]). And in this study S_b was neglected because the flow depth was not so shallow and riverbed temperature data was not available.

The lateral advection term *G* can be calculated as follows:

$$G = \rho C p q_l (T_g - T_w) \tag{28}$$

where q_l is lateral inflow discharge per unit distance [$m^3\ s^{-1}\ m^{-1}$] and T_g is lateral flow temperature. Usually lateral flow is supplied from groundwater. In this study, q_l was estimated by a rainfall–runoff model, which was analyzed in a previous study (Yoshida et al., [4]). The grand water temperature is almost same as the annual average air temperature and does not change so much. Therefore if the observed data was not available, T_g can be replaced as annual average air temperature (Bartholow, [2]).

Equation (19) was solved by the implicit Crank-Nikolson scheme using dt = 3600 s and dx = 1000 m.

RESULTS AND DISCUSSIONS

For model verification, the stream temperature was simulated with a present 60% riparian vegetation density. Figure 9 shows the results at the observation point located 4 km downstream from Nam Song dam, 1–31 March 2004. The daily variations of stream temperature were almost in agreement with observed values; however, some maximum values were lower than the observed ones. This is because daily average wind speed data and sunshine duration data were used during the same day period; it should improve if hourly data were available.

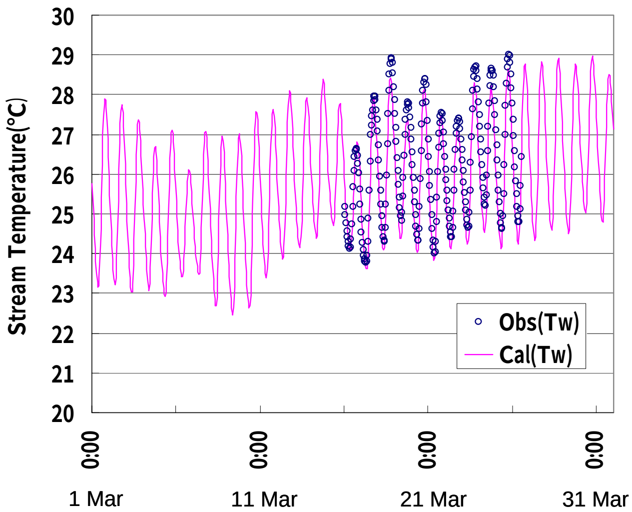

Figure 9. Comparison of observed and calculated stream temperature (March 2004)

Figure 10 shows the long term change of input discharge data and simulated stream temperature from 1 March to 30 July 2004. Left side vertical axis and solid line shows stream temperature and right side vertical axis and dashed line shows inputted discharge at upstream end. The fluctuation of stream temperature was big when the discharge of river was small and it was not sensitive when discharge was large. Therefore dry season stream temperature, which was easy to be affected by external environment changes, is more important for assessment of river thermal condition. In addition, riparian vegetation shades also decrease in dry season from Fig.7, which is also the reason of high altitude fluctuation.

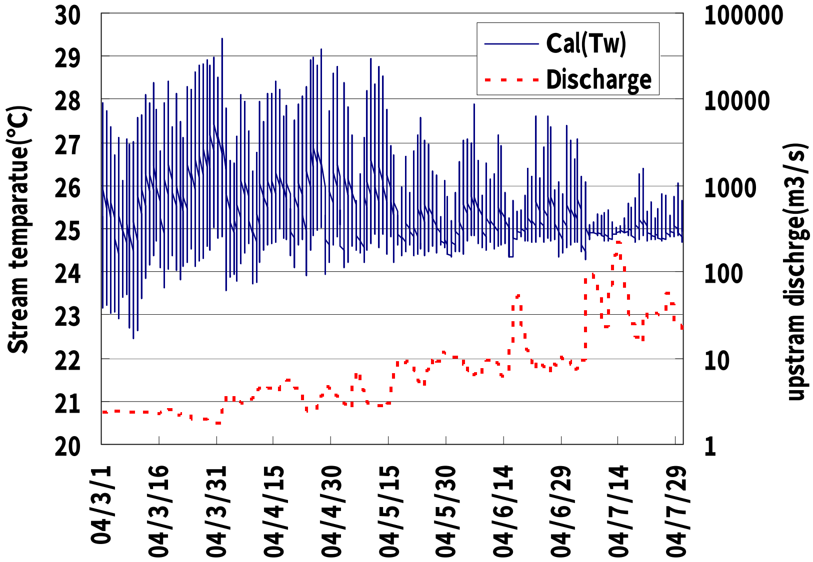

Figure 10. Changes of stream temperature and input discharge

Using the model, sensitivity analysis of stream temperature against to the discharge change was conducted. Stream temperature was simulated with different riparian vegetation densities (40%, 60% and 80%) and discharges (10 m^3 s^{-1} for the pre-development of diversion dam and 2 m^3 s^{-1} for the present condition). Simulation results for 21–31 March 2004 are shown in Fig. 11(a)–(c). In the 10 m^3 s^{-1} discharge cases, the simulation results were within the one degree range in all vegetation density cases. However, in the 2 m^3 s^{-1} cases, stream temperatures increased by approximately two degrees as the vegetation density decreased. When vegetation density was high, stream temperature was not so sensitive to river discharge change. On the other hand, stream temperature was very sensitive to the discharge change when density was low. Therefore adequate management of river corridor vegetation is important to prevent the undesirable change of the river thermal environment.

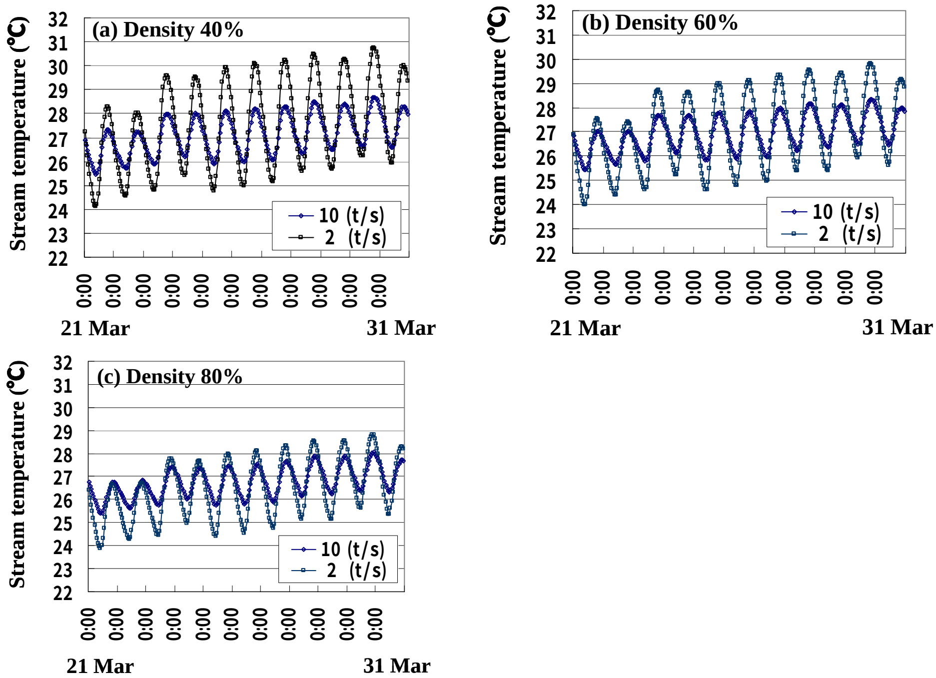

Figure 11. Effect of density and discharge changes to the stream temperature (density: 40, 60 and 80%; discharge: 10 and 2 m^3 s^{-1}; at site A)

CONCLUSION

In this study, firstly solar radiation was estimated considering daily and seasonal changes. Daily vegetation shade change was calculated from vegetation height, density and offset distance, and it was combined with a stream temperature analysis model. NDVI remote sensing data was used for seasonal change of LAI (leaf area index) and combined with vegetation shade model. The model was applied to the Nam Song River to simulate the effect of corridor vegetation on stream temperature. From the long term analysis, the fluctuation of stream temperature was big when the discharge of river was small and it was not sensitive when discharge was large. Therefore dry season stream temperature, which was easy to be affected by external environment changes, is more important for assessment of river thermal condition. Simulation results using different vegetation density showed that stream temperature was higher and more sensitive to discharge change when the vegetation density was lower. Discharge change will occur with any water resource development. Therefore, the change in a river's thermal environment must be assessed before the development, and adequate management of river riparian vegetation is important to prevent the undesirable change of the river thermal environment.

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WATER SOURCE COMPONENTS COMPUTATION, NEW DEVELOPMENT AND WIDERING APPLICATIONS

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ABSTRACT

Since formatting in the first time the problem of water source components in 1996 there is a rapid development in method for solving the problem with strictly satisfying the conservation law, in assessment of power of water sources, ages of water sources and their variation in space etc. Computation of water sources components is widely and successful applied in environment problems in water quality (salinity, acid water, pollution) and in the integrated management of water resources for different objects (river basin, inundated zones, aquaculture in sea shore zones...).This paper will show brifly this research.

INTRODUCTION

Every water system as a set of rivers, channels and inundated plains always is acted by many water sources: precipitation, flows from upper basins, sea water, waste water, polluted waters etc. At some point M in a water system and at arbitrary time t, each i water source has its portion $p_i(M,t)$.

We can definite p_i as follows: At coordinates (M,t) we take an arbitrary volume dw and dw_i is the portion volume of i water source then:

$$p_i(M,t) = \frac{dw_i}{dw} \tag{1}$$

For one dimensional problem (1D) we can introduce the mean value for wet cross section A as

$$\overline{p_i}(x,t) = \frac{1}{A}\int_A p_i(M,t)dA \tag{2}$$

and A is the wet section area.

We also use the mean value across water discharge as follows

$$\tilde{p}_i(x,t) = \frac{Q_i}{Q} = \frac{1}{Q}\int_A p_i(M,t)udA \tag{3}$$

where Q – discharge

u – velocity at arbitrary point *M* in cross section

Between $\tilde{p}_i$ and $\overline{p_i}$ there is the relation

$$\tilde{p}_i(x,t) = \alpha_i(x,t)\overline{p}_i(x,t) \tag{4}$$

Where α_i is coefficient concerning the nonuniform distribution of velocity and water source portion in cross section

$$\alpha_i = \frac{1}{Q\overline{p}_i}\int_A p_i udA \tag{5}$$

Similarly for two horizontal dimensional problem ($2D_h$) the mean value of i water sources portion along the depth $\overline{p}_i(x,y,t)$

$$\overline{p}_i(x,y,t) = \frac{1}{h}\int_{z_0}^{z_0+h} p_i(x,y,z,t)dz$$

and then

$$\tilde{p}_{i,x}(x,y,t) = \frac{1}{q_x}\int_{z_0}^{z_0+h} p_i(x,y,z,t)u_x(x,y,z,t)dz = \alpha_{i,x}\overline{p}_i(x,y,t)$$

$$\tilde{p}_{i,y}(x,y,t) = \frac{1}{q_y}\int_{z_0}^{z_0+h} p_i(x,y,z,t)u_y(x,y,z,t)dz = \alpha_{i,y}\overline{p}_i(x,y,t)$$

Where: z_0: the bed level
h: the depth of flow
q_x, q_y: specific water discharge (discharge per one width unit) in x and y direction correspondingly.

The coefficients α_i, $\alpha_{i,x}$, $\alpha_{i,y}$ may be greater than 1 (when the distribution of p_i and velocity are similar) and less than 1 (when they are in contrary direction) and are equal 1 (if the distributions are uniform). In this paper it concerns only the one-dimensional problem (1D, $1D^+$). The governing differential equation has following form, see [1], [2], [4], [5],[7]:

$$\frac{\partial p_i}{\partial t} + \alpha_i v \frac{\partial p_i}{\partial p_x} - \frac{1}{A}\frac{\partial}{\partial x}\left(DA \frac{\partial p_i}{\partial x} \right) + R_i = 0 \qquad (6)$$

Where: D: is dispersion coefficient (follows the Fischer' formula)
R_i: source or sink (volumetric) for i water portion, for example if there is a lateral flow q then

$$R_i = \frac{q}{A}\left(p_{iq} - p_i \right)$$

Note that the equation (6) is the same as form of solute transport one, in which the variable of solute concentration (C) is replaced by the variable of water source component (p_i).

It is important that the following mass conservation condition should be satisfied:

$$\sum_{i=1}^{n} p_i = 1 \qquad \text{with} \qquad 0 \le p_i \le 1 \qquad (7)$$

where n – number of water sources in the system.

Boundary and initial conditions of the problem for water source components are given as in hydraulic problem and solute transport one [1],[2],[4],[5]; more over it is exist the conditions inside water system such as pollution water bodies (acid water, waste water, badly movable water bodies etc..).

Equation (6) together with Saint Venant Equations (8), (9), as follows

$$\frac{\partial \omega}{\partial t} + \frac{\partial Q}{\partial x} - q = 0 \qquad (8)$$

$$\frac{1}{g}\frac{\partial v}{\partial t} + \frac{\alpha v}{g}\frac{\partial v}{\partial x} + \frac{\partial z}{\partial x} + kv|v| = 0 \qquad (9)$$

will form governing equations, from which p_i , Q, Z can be solved.

SOLVING WATER SOURCE COMPONENT PROBLEMS

As is well-known, the governing equations (6), (7) and (8) can be solved according to two steps as follows:

Step 1: Solving Saint Venant Equations; and

Step 2: Solving the equation of water component using hydraulic characteristics at the step 1. The method of solving the equation of water component is the same as solving the solute transport equation.

Nowadays, there are many softwares with high quality that can be used to solve these equations, for examples MIKE11 (DHI), DUFLOW (Holland), KOD (Nguyen An Nien), SAL (Nguyen Tat Dac), VRSAP (Nguyen Nhu Khue), etc. Recently, in KOD.WQPS software by Nguyen An Nien, ten water components can be calculated simultaneously [6]. This gives great advantages for users when analyzing complicated water systems.

SOME FURTHER DEVELOPMENTS OF WATER SOURCES COMPONENTS COMPUTATION

Intensity of water sources influence

If we take mean value of water source component for enough long time interval T (for example for a month) $\overline{p_i}(x)$ and simultaneous mean value of discharge $\overline{Q_i}$ for the same interval of time, then the intensity I_i of i water source at the point x is defined as of I_i divided to $\overline{Q_i}$

$$\overline{I}_i(x, t_0, T) = \frac{\overline{p_i}(x, t_0, T)}{\overline{Q_i}(x, t_0, T)} \qquad (10)$$

$\overline{I_i}(x)$ is known as the proportion of i water source to an unit of its discharge (m^3/s; 10 m^3/s; 100 m^3/s...).

Relative intensity of two water sources

It is known as relation between intensities of water source i and k

$$\overline{N}_{ik}(x,t_0,T) = \frac{\overline{I}_i(x,t_0,T)}{\overline{I}_k(x,t_0,T)} \qquad (11)$$

$\overline{N}_{ik}$ give comparison of rate of influence for two water source simply speaking it gives us to know influence of an discharge unit of water source i is equal how many discharge unit of water source k. For example, one m^3/s from Dau Tieng reservoir release has effect on water quality of Saigon River as 15 m^3/s of Tri an reservoir release at Thi Tinh, 7 m^3/s at Binh Loi etc. This relative intensity allows us to choose effective measure for managing water system.

Relation of influence of the same water source but with different propagation lines

For estimating of influence of sea water from different river mouths at some place in water system we introduce the proportion $I_{Sk,l}(x,t)$ between instantaneous sea water components from mouth k $p_{S,k}(x,t)$ to $p_{S,j}(x,t)$ from the mouth j.

$$I_{Sk,j}(x,t) = \frac{p_{Sk}(x,t)}{p_{Sj}(x,t)} \qquad (12)$$

We also introduce the mean value

$$\overline{I}_{Sk,j}(x,t_0,T) = \frac{p_{Sk}(x,t_0,T)}{p_{Sj}(x,t_0,T)} \qquad (13)$$

where suffix S is marked for sea water.

The values $I_{Sk,j}$; $\overline{I}_{Sk,j}$ allow us to compare influence of sea water from different river mouths. We also may take value of the role of each river mouth in combination of set of river mouths (usually in mean values).

$$\overline{J}_{Sk}(x,t_o,T) = \frac{\overline{p}_{Sk}(x,t_0,T)}{\sum_l \overline{p}_{Sj}(x,t_0,T)} \qquad (14)$$

This is significant information for choosing measures for restricting sea water influence (when necessary to prevent salinity intrusion) or increasing sea water intake (for aquaculture).

SOME APPLICATIONS OF WATER SOURCE COMPONENTS COMPUTATION

The computation of water source components meets many applications in water resources and environmental management. Some of them are following.

Salinity intrusion

If salinities at river mouths are constants $\overline{S}_k$ then with sea-water components $p_{Sk}(x,t)$ we immediately calculate the salinity at cross-section x at time t as follows

$$S(x,t) = \sum_k p_{Sk}(x,t).\overline{S}_k \qquad (15)$$

If salinities at river mouths are different then we introduce a normal salinity S_0 (for example $S_0 = 100 g/l$, and at each river mouth we can consider the sea water comprises two components, one component with normal salinity $p_{Sk}(x_{bk},t) = S(x_{bk},t)/S_0$ and other is fresh water to dilute normal salinity to existent one $p_{fk}(x_{bk},t) = 1 - p_{Sk}(x_{bk},t)$ - where x_{bk} are ordinates of cross-sections at river mouth k. Salinity at cross-section x at time t can be determined as follows

$$S(x,t) = S_0 \sum P_{Sk} \qquad (16)$$

We also have other formula

$$S(x,t) = S_0\left(1 - \sum p_{fk}(x,t)\right) \qquad (17)$$

If the formula (15), (16) allow us to know the influence of each river mouths to salinity at research point then the formula (17) gives information about role of dilution of each fresh water source. This information is very useful for setting measures for salinity intrusion prevention.

Propagation of polluted water

Studying rate of portion of polluted waters p_{pk} (the suffix p indicates pollution), we have

$$p_p(x,t) = \sum_k p_{pk}(x,t) \qquad (18)$$

and we have information about each polluted source k. Also we can suggest suitable location to place factories or points discharging polluted water sources…

We also may receive mean value of polluted water according to the diluting fresh water sources *l*.

$$p_p(x,t) = 1 - \sum_l p_{fl}(x,t) \qquad (19)$$

The formula (19) expresses the role of component fresh water in diluting polluted water sources. From this information we can chose suitable water sources to dilute polluted ones.

Environment management for aquaculture [4]

Satisfying water supply quantitatively and qualitatively for aquaculture is very important. Computation of water sources components allows to know salinity distribution, portion of clean sea water each operation of releasing and in taking water, component of in taking released water from other ponds, component of released water from diseased shrimp ponds in water system, rate of dilution of polluted water etc. All of them are basis for planning and effectively managing water source for aquaculture.

CONCLUSION

Computation of water source components, which deals with resolving differential equations, diversifies tools for doing research of problems of water quality and quantity. It allows resolving not only mass transmission problem, but also details of role of water sources in systems. All these elements serve for effective integrated management of water resources.

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THE PRESENT CONDITION ON WATER RESOURCES DEVELOPMENT IN NORTHEASTERN REGION OF THAILAND

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ABSTRACT

Water shortage situation has become a serious problem in the northeastern region of Thailand. Although there are efforts to solve this problem from the past several governments to the present government, the developed water resources are still insufficient to meet current requirement. The government actually began to develop water resources through the Royal Irrigation Department (RID) which is a major agency to take responsibility on this matter. Therefore the study and survey on water resource development was conducted by RID in cooperation with local and foreign agencies.

The above-mentioned problem has the essential effects on developing the country and using a great cost for implementation. Since 1965, RID carried out the study and survey in order to formulate a way to develop water resources in the northeastern region from foreign fund in term of technical cooperative and financing support. Besides, the study was periodically reviewed by RID and other government agencies concerned. Meanwhile, the government allocated several thousand million from the government budget and foreign loan or grant for an alleviation of water shortage in the northeastern region.

Due to the limited potential site, the northeastern region has the differential characteristics from other regions both in topography and in climate that these characteristics are impacts of water resource development. Moreover, the deforestation in upstream and inappropriate land use have directly effects on the better living standards for the people in this region who has the average income lower than other regions, and the economics and security of the whole country.

This paper is to present condition and counter measure against the shortage of water, to review the past data, policy, implementation, including the current situation and problem or obstacle of water resources development in the northeastern region, and to revise and identify an appropriate direction of future water resources development.

DESCRIPTION OF THE NORTHEASTERN REGION

Topography

The northeastern region contains 19 provinces, covering an area of 105.52 million rai based on the administrative zone or about 103.52 million rai based on the basin zone, which is equivalent to one- third of the whole country area, This region has not a plenty of nature resources as compared with other regions.

General topography is upland at 100-300 m.MSL, its area is gently undulating and slope towards the southeast. A large number of people in the region are cultivators. Rice is a major crop with an area of 46.13 million rai, or approximately 53.97 % of the total area growing rice in the country (85.47 million rai). Other crops are cassava, kenaf, maize, etc.

There are 3 main rivers in this region:

1. Kong river is located on the north and east parts of the region, its length is about 850 km. from the Thai-Lao borderline, the river flows Loei, Nong Khai, Nakhon Phanom, Mukdahan and Ubon Ratchathani provinces. Kong river is a large river and has a significant for developing the countries in Southeast Asia Region.
2. Chi river is located on the central part of the region, the river rises in the Petchabun range at Chaiyaphum, Loei and Phetchabun provinces. It flows Khon Kaen, Maha Sarakham, Kalasin, Roi Et, Yasothon provinces for some 1,000 km. to its confluence with the Mun river at Muang and Varinchamrat districts in Ubon Ratchathani province.
3. Mun river is located on the lower part of the region, the river rises in the range at Nakhon Ratchasima. It flows Buri Rum, Surin and Si Saket provinces for some 890 km. to its confluence with Kong river at Kong Chiem district, Ubon Ratchathani province.

Shown in figure 1: Rivers in the Northeastern Region

Soils

The large area is classed as upland, soils are sandy clay which aren't hygroscopic and low productive. Besides, some areas are saline soils which are obstacles to water resources development and cultivation in this region. The results of feasibility study on appropriate soils for cultivation in this region which conducted by the Department of Land Development, it was found there is an appropriate area for growing rice about 23.18 million rai, but the people actually grow rice with an amount of 46.13 million rai. It means they grow rice in an unsuitable land that is a cause of low productivity when compared with other regions.

Rainfall

An average rainfall quantity of the whole region is about 1,319 mm/year, and the major part has an average rainfall of 1,100 - 1,300 mm/year. Minimum average rainfall is about 800 mm/year at the west of Chaiyaphum province, and maximum average rainfall is about 2,900 mm/year at Nong Khai and Nakhon Panom provinces.

The period of wet season starts in May to October, the rainfall quantity is equivalent to 89.3 % of annual rainfall quantity. The remaining 6 months are winter and dry seasons; rainfall quantity is equivalent to 10.7 %. If any year, the rainfall quantify is lower than the average level, or the wet season lasts shortly, the drought and the water shortage problems will occur, especially in the west and central parts of the region. Besides, this region has a high change of rainfall quantity as compared with others.

From the statistic of rainfall in 1965-1998, found 40 % of the whole region is an area with an average rainfall lower than 1,200 mm. These areas are in Nakhon Ratchasima, Chaiyaphum, Khon Khen, Maha Sarakham and Burirum provinces.

Shown in figure 2: Quantity of Rainfall in the Northeastern Region

Runoff

Due to the upland and undulating areas, so there are many small rivers flow into Mun, Chi and Kong rivers. The water quantity and inflow are varied by their size and topography characteristics.

Chi river	Catchment area of 49,476 sq.km. and quantity of average annual runoff at its confluence with Mun river about 11,244 mcm./year
Mun river	Catchment area of 69,700 sq.km. and quantity of average annual ran off at its confluence with Kong river about 19,500 mcm./year (excluding the water quantity of Chi river)
Kong river	Catchment area of 46,460 sq.km. and quantity of average annual runoff about 30,769 mcm./year

The water level statistics from the stations in this region, some notices are as follows:

A. Branch with the water quantity lower than 10 sq.km. will have some inflows when raining, and no inflow in dry season.
B. Basin with the catchment area not over than 1,000 sq.km. will have inflows only in wet season for the period of 4-6 months, and continuously decrease and empty in dry season.
C. Basin with the catchment area over than 1,000 sq.km. will have inflows all times, especially large river branches of Mun, Chi and Kong rivers.

In past, the deforestation and cultivation in upstream were the cause of inflow changes, erosion and sedimentation, the canals become shallow or flooded suddenly. From these situations, it is concluded that the construction of small reservoir in the area with low inflow or without inflow after dry season (December – May), will cause a lack of water. If they haven't formulated the plan for appropriate water use, they wouldn't have enough water to use throughout the dry season.

Groundwater

In this region, there is groundwater pumping for agriculture and consumption use. For drinking water, the drilling survey and the study on the quantity of groundwater were carried out by the government agencies and the international institutes since 1942. The government has promoted groundwater for domestic use since 1945. However, the groundwater in irrigation system is still limited due to the low potential for development in both water quantity and quality.

Land use and population

The Department of Land Development has studied on land use in this region by using information from an artificial satellite. Type of land use in 2000 are concluded the following:

Type of land use	Million rai	Percentage of the region's area
Paddy field	46.30	43.88
Field crop	17.85	16.92
Fruit trees and tree crops	0.28	0.26
Idle land	3.38	3.20
Grass land	1.62	1.53
Floodplain	0.49	0.47
River, reservoir	1.85	1.75
Urban and community	2.95	2.80
Forest	30.80	29.19
Total	**105.52**	**100.00**

As mentioned in the preceding data, the cultivated area covers 64.43 million rai (comprising paddy field, field crops and tree crops), the forest and national park areas of 30.8 million rai, and the wild animal preservation area of 7.10 million rai, the remaining area is the national conservation forest. It means that 70% of land use is for cultivation and farm holding land. The remaining areas are forest and upstream areas which are idle land due to an inappropriate soil.

The main reason of cultivation extension is the population growth. From the population statistic in 1950, a total of population is about 6.5 million person, holding land of 22.6 million rai. In 2001, number of population increase to 21.49 million person and farm holding land for agriculture about 61.5 million rai.

From the increasing population, the quantity of water use increases relatively; meanwhile, the balance of natural resources has been changed. In this region, the cultivation in large area is depended on rainfall. The area nearby the river will receive impacts from the uncertainty of water quantity, such as flood and water shortage in dry season. Shown in figure 3: Land Use in the Northeastern Region

EXISTING WATER RESOURCES DEVELOPMENT

The government has carried out the water resources development to alleviate water shortage that is divided into 3 areas:

Irrigation agriculture area

It means an area to be irrigated from the large and medium scale projects for agricultural purpose both in wet and dry seasons. Up to the present, RID has completed the construction of reservoirs, diversion dams in large and medium scales, totalling 270 projects with an irrigation area of 3.14 million rai. However, the large and medium scale irrigation projects shall be constructed in the potential areas by considering the increase of productivity and an economic outcome.

River bank area and natural water sources

River bank area and natural water resource receive the water from an electric pumping project which the local people take part in sharing the electric cost for water pumping. Besides, the distribution system is the concrete canals having the construction of pumping stations along Kong, Chi and Mun rivers, totalling 992 projects and irrigable area of 1.44 million rai. Additionally, RID has several pumping projects to help the people who got damage from uncertain rainfall in wet season and their requirements. However, the limitation of the pumping project is a sufficiency of water quantity, especially in dry season.

Rainfed area

Rainfed area is an area which is unable to receive irrigation water from projects as mentioned above. A large area is located far from water sources, therefore the development of small scale project in this region was carried out by the 10 government agencies since 1977. For RID's responsibility is to the construction of small scale irrigation projects in the region, 4,224 projects completed or about 45% of all projects in the country. The small scale irrigation project consists of small reservoir and weir, an objective is to supply water for domestic use, livestock, agriculture and others in dry season.

Although, the construction uses a high invest cost for the implementation as described above, it is found the water supply in this region isn't still meet the people's requirement.

STUDY OF THE POTENTIAL FOR DEVELOPING AN IRRIGATION AREA

From the study of water resource development projects was reviewed on the water storage by reservoir and weir, the distribution system by pipelines, the diversion between basin branches including branches in Kong basin. It is found that these can supply the supplementary water for the cultivation area of 9.10 million rai as shown the followings:

Large and medium scale irrigation projects

RID has studied and formulated the plan for large and medium scale irrigation projects in the potential areas of the northeastern region, comprising 113 projects of reservoirs and weirs, with the supplementary storage of 1,885 mcm. for the cultivation area of 1.71 million rai.

Pipe irrigation project

Pipe irrigation project was studied by RID in order to help the people and cultivation area in upland where is unable to get the water by gravity. Pumping the water from small and medium reservoirs which theirs capacity not less than 2 mcm both in existing and proposed in the construction plan, the total will be 147 projects of 0.70 million rai.

Increasing an efficiency of water source and irrigation water use

The Department of Energy Promotion and Development has studied increasing an efficiency of water source and irrigation water use in the northeastern region, comprising the distribution system by pipelines and canals from the water sources developed or improved, such as reservoir, weir, gate, excavation and swamp. Besides, the diversions between basin branches or branches in Kong basin are included. There are 357 projects studied, with an additional capacity of 340 mcm. and the cultivation area of 1.70 million rai.

Kong-Chi-Mun project

Kong-Chi-Mun project is a large scale project studied by the Department of Energy Promotion and Development in order to help the cultivation area in this region. In present, the project was transferred to RID's responsibility. This project pumps the water from Kong river for a supplementary water and an extension of service area in Chi and Mun basins. The construction of weirs or large drainage channel with pumping station and canals in Chi and Mun rivers makes a possibility of water supply for the cultivation area of 4.98 million rai. Moreover, RID provides the promotion on participatory irrigation management, and transferring the responsibility for water management to local administrative organization agencies.

PROPOSED STRATEGIC PLAN ON WATER RESOURCES DEVELOPMENT

There are limited opportunities for increasing the total volume of water stored in large and medium scale reservoirs, owing to the low surface runoff and shortage of new storage sites. The greatest potential for future investment in water resource development lies in the rehabilitation and up-grading of existing project, construction of new water storages and increase water management efficiency. To support the plan, the following programs are proposed:

Excavation of existing swamp, canal and natural marsh in each village

- The existing swamp, canal and marsh which are shallow or unable to store enough water for the dry season, it will be excavated a time per year as planned.

Construction of village pond

- Village having no swamp, canal and marsh shall be considered to construct a village pond in suitable area with enough the water storage for domestic consumption throughout a year, especially in the dry season.

Irrigation with pipe system

- To widely distribute the water from source into agricultural area, especially in non-irrigated area
- To ensure adequate water quantity for agriculture
- To supply water into farm pond

Study and formulate the water resources development plan in basin level

- To give a priority to studying the basin having a problem and water shortage. Besides, water demand, topographical characteristics and water quantity in each basin will be considered as a suitable area for construction of the water resources development project.
- To formulate activities for water utilization to be consistent with live storage

- To formulate agricultural system (crops, livestock and fishery) to be consistent with land potential and efficiency of water use

Construction of on-farm pond

- Due to water shortage in dry season, an on-farm pond will be excavated to store the water for the consumption use in dry season and as the supplementary source in non-irrigated areas.
- To promote farmer's participation with government agencies for irrigation work

Construction of small scale reservoir

- RID will consider constructing small scale reservoirs in suitable areas by using a year for construction period. The construction of small scale reservoirs can be carried out in various regions more than the current plan.
- The above mentioned construction, the completed reservoirs would be transfer to water user groups for management and operation by themselves. For the RID will cooperate in operation and maintenance.

Construction of medium scale reservoir

- Medium scale reservoir will be mainly constructed for agricultural purpose; each project will take a construction period of 3-5 years. The construction of medium scale reservoirs can be carried out in various regions more than the current plan.

Construction of large scale reservoir

- Large scale reservoir will be mainly constructed for agricultural purpose and others; its capacity is varied by basin size. The construction period will take several years depending on project scale. RID has prepared outline plans for a number of large reservoirs within the Mun and Chi river basins but such is subject to significant problems, principally relating to environment and resettlement. RID accelerates to review the feasibility study and environmental impact assessment of projects in order to get an approval and put in the implementation plan.

Establishment of water user organization

- To set up water user organization and to promote participatory irrigation management in local level and water source operation.
- To transfer knowledge of on-farm system, water a plant and period, appropriate and efficient water use.
- To provide an organization for water management in national, basin and local levels with the responsibility for formulating policy, supervising and coordinating with other concerned agencies in conducting the water management plan in various basins.

Promotion of short term crop instead of paddy rice and improvement of agriculture in irrigated area

- To promote and publicize the farmer to grow a short term crop instead of paddy rice to avoid the risk of water limitation by supporting inputs, such as seeds and fertilizer.
- To permanently improve the agricultural system in an irrigated area by changing from paddy field to integrated agriculture and orchard. It is depended on the farmer's decision for formulating a production plan, besides government agencies will provide a credit to farmer.

Deforestation protection and conservation

- To conserve and protect a forest trespass in upstream
- To rehabilitate the deteriorated forest in upstream and to reforest plentifully in short time.

Water Resources Development Project and Irrigation Area in Northeastern Region

Project	Kong River Basin			Chi River Basin			Mun River Basin			Northeastern Region		
	Number of projects	Capacity (mcm)	Area (mil.rai)	Number of projects	Capacity (mcm)	Area (mil.rai)	Number of projects	Capacity (mcm)	Area (mil.rai)	Number of projects	Capacity (mcm)	Area (mil.rai)
The current water resource development project												
1. Large & medium scale irrigation projects	91	917.22	0.688	72	4,636.29	1.122	107	3,642.32	1.330	270	9,195.83	3.140
2. Small scale irrigation project	972	250.07	0.608	1,349	227.44	0.637	1,903	337.97	1.059	4,224	815.48	2.304
3. Electric pumping project	304	-	0.421	445	-	0.688	243	-	0.327	992	-	1.437
4.Water resource development by the office of Accelerated Rural Development	198	156.98	0.163	445	90.54	0.172	231	73.94	0.267	610	321.45	0.602
total of current projects (with distribution system) 1+3	395	917.22	1.109	517	4,636.29	1.810	350	3,642	1.657	1,262	9,195.83	4.577
total projects (without distribution system) 2+4	1,170	407.050	0.771	1,794	317.98	0.809	2,134	412	1.326	4,834	1,136.93	2.906
Grant total	1,565	1,324.27	1.880	2,311	4,954.27	2.619	2,484	4,054	2.983	6,096	10,332.76	7.483
Water resource development project in development plan												
1. Large & medium scale irrigation project	64	652.14	0.860	44	416.30	0.400	5	816.65	0.448	113	1,885.09	1.708
2. Pipe irrigation project	64	-	0.259	40	-	0.149	43	-	0.297	147	-	0.704
3. Irrigation efficiency improvement project												
- Case of water source development	151	149.52	0.506	53	120.48	0.393	126	70.01	0.498	330	340.01	1.397
-Case of diversion between branches	11	-	0.01	6	-	0.017	10	-	0.115	27	-	0.143
-Case of diversion between branches in Kong river basin	-	-	0.039	-	-	0.043	-	-	0.082	-	-	0.164
4. Kong - Chi - Mun project	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	4.98
The total of all projects in development plan	290	801.66	1.674	143	536.78	1.002	184	886.66	1.440	617	2225.10	9.096
The total of potential development project (with distribution system)	685	1,719	2.783	660	5,173.07	2.812	534	4,528.98	3.097	1879	11,420.93	13.673

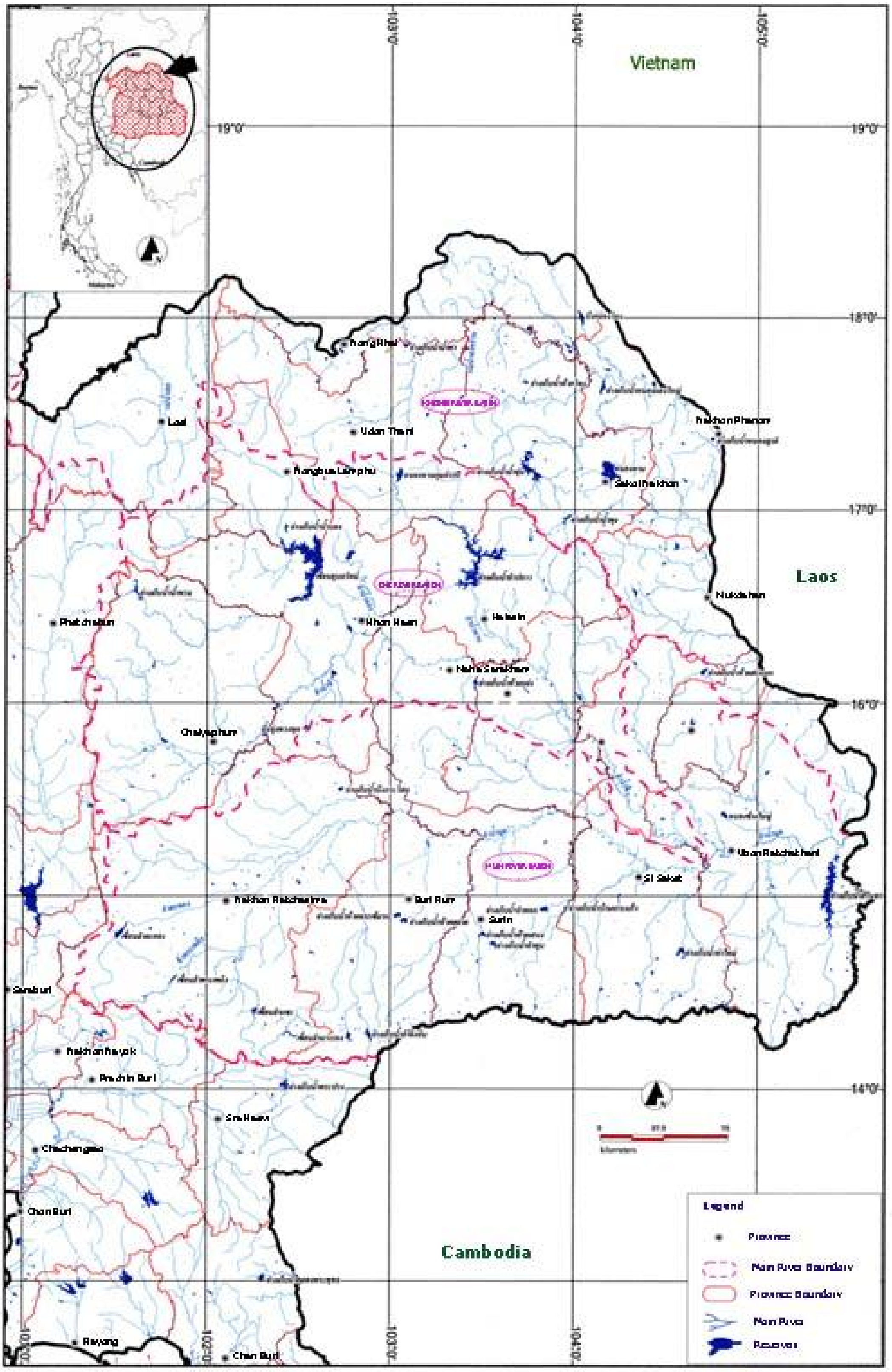


Figure 1 : River Basins in the Northeastern Region

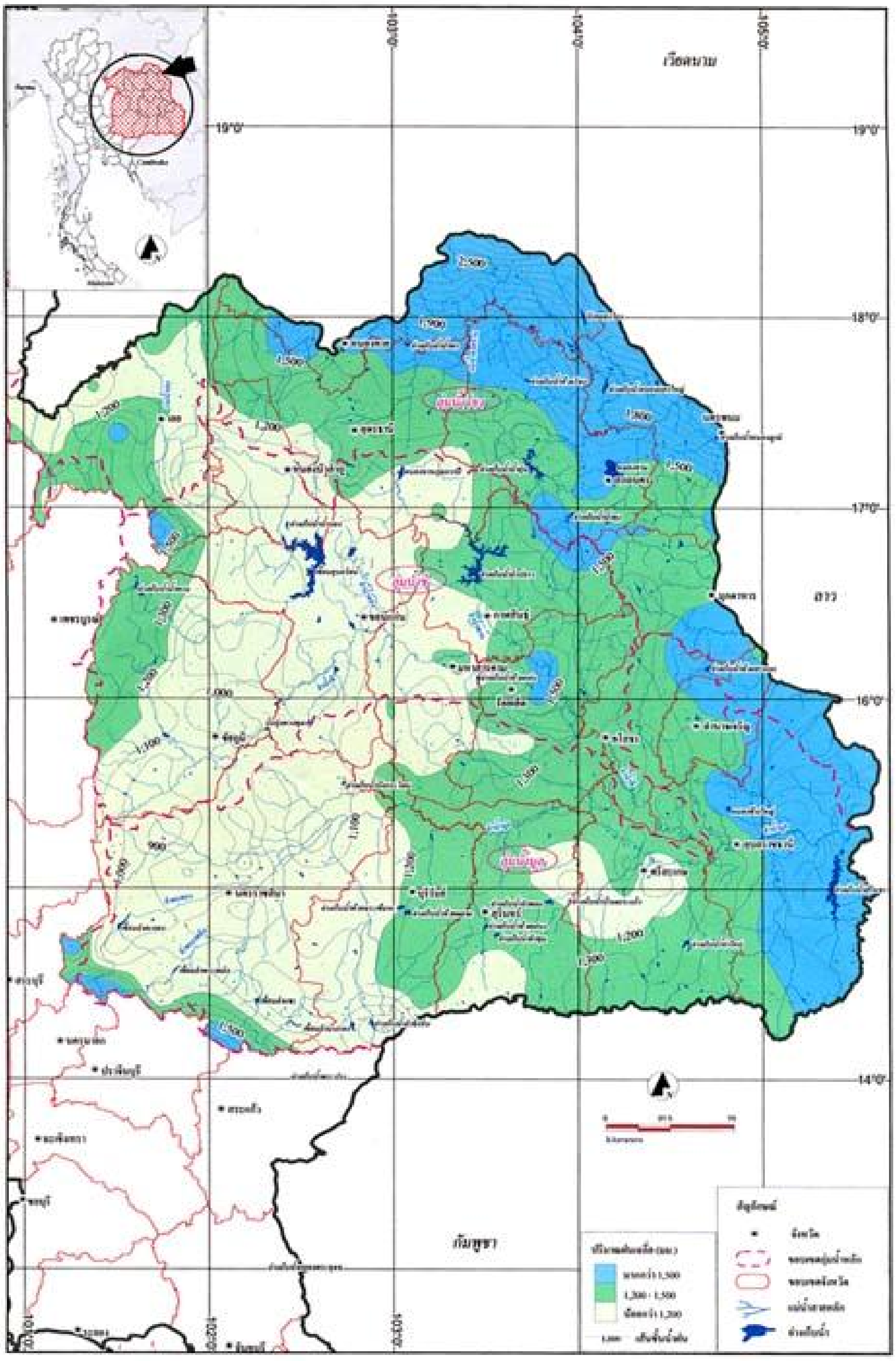


Figure 2 : Quantity of rainfall in the Northeastern Region

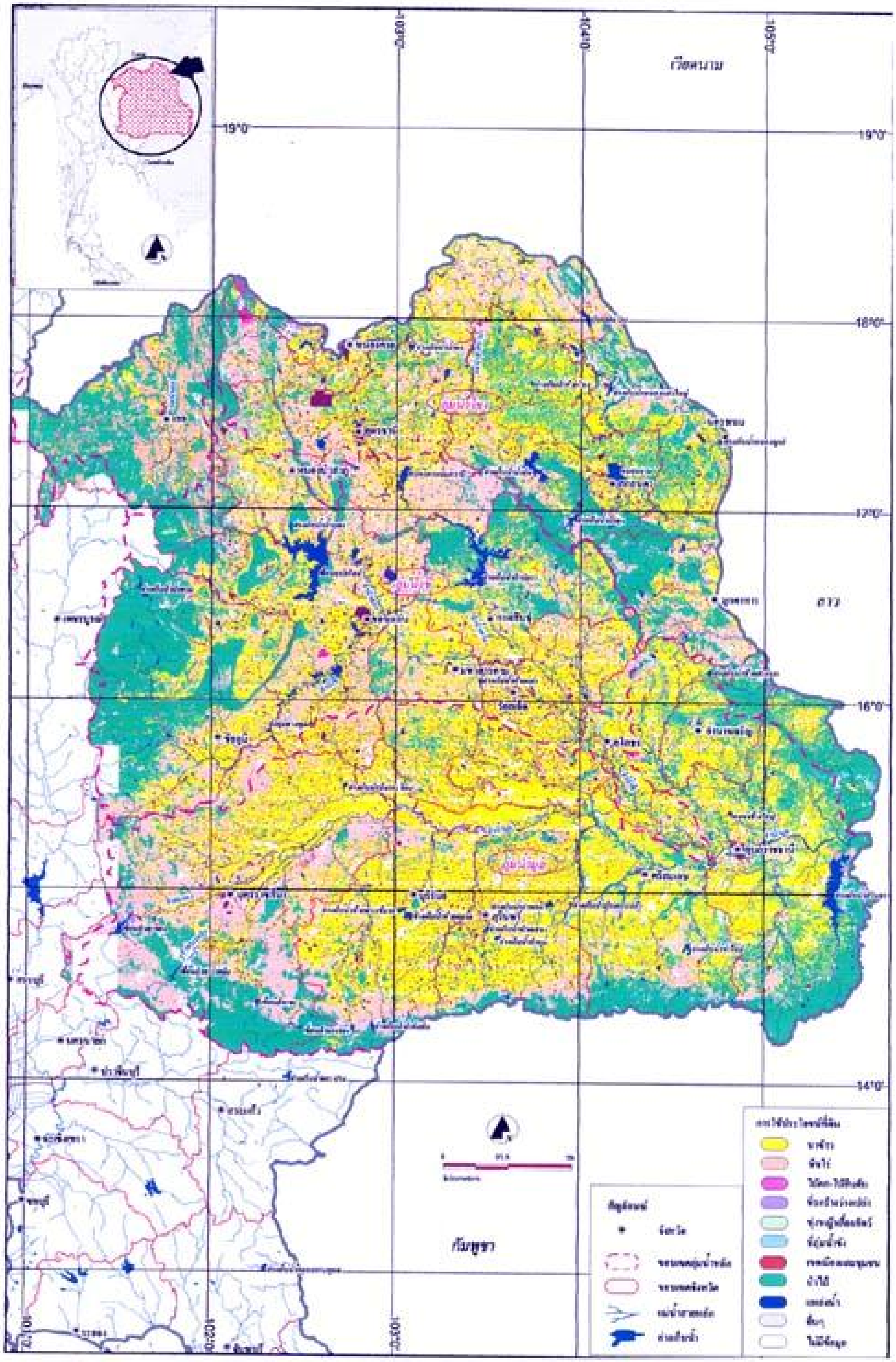
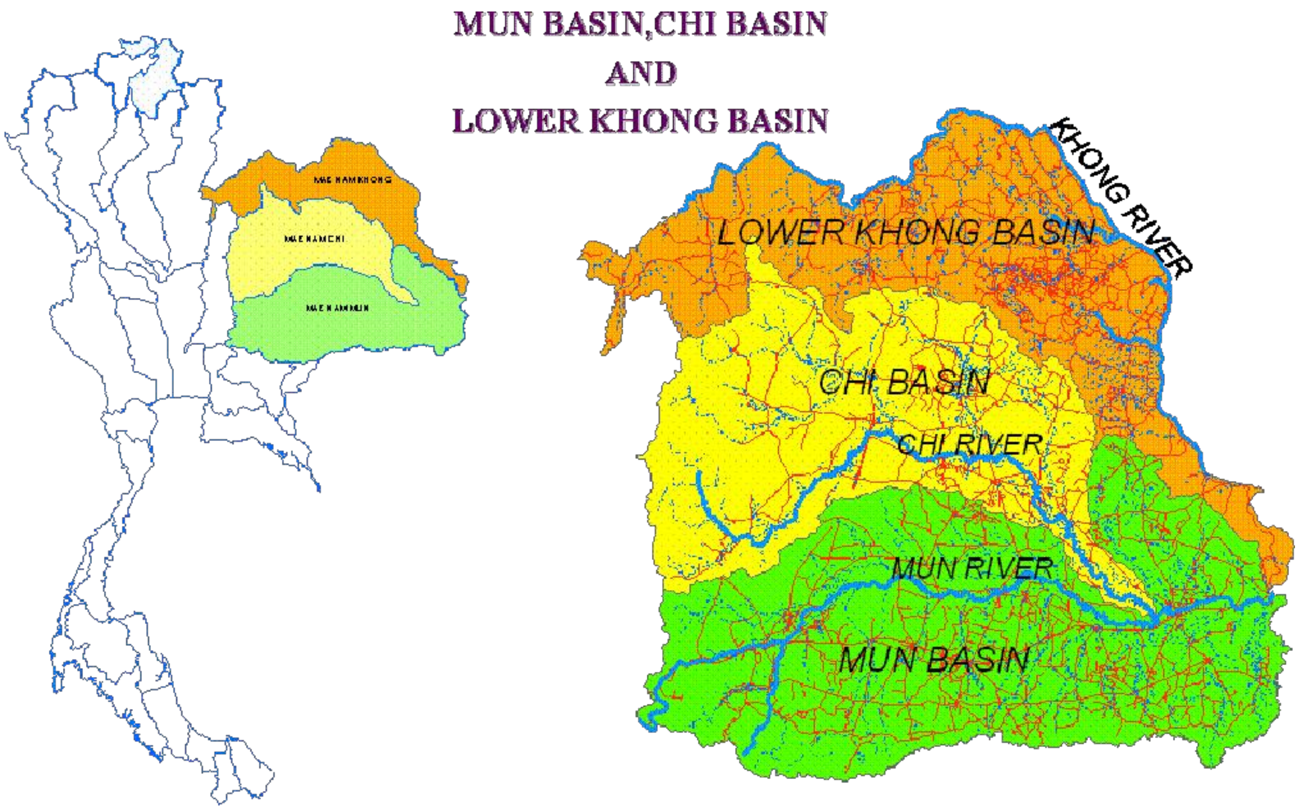
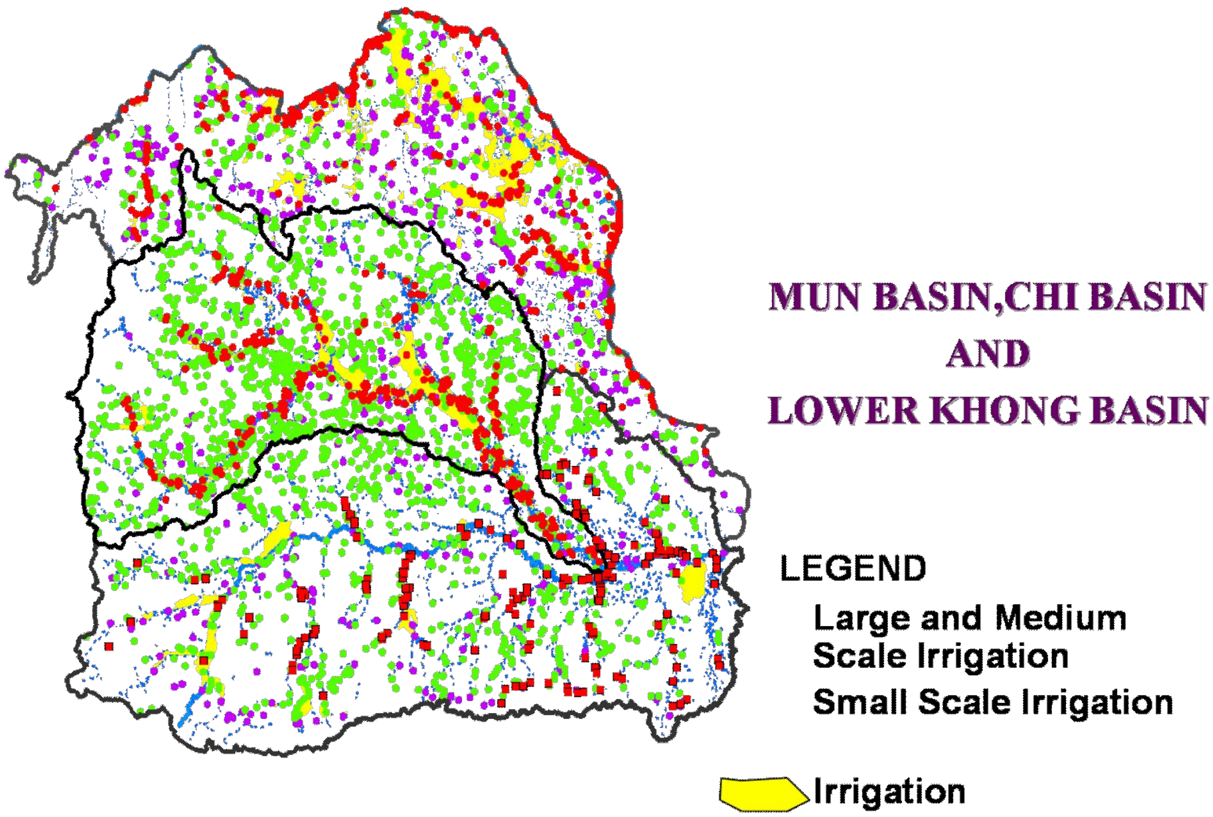


Figure 3 : Land Use in the Northeastern Region


MUN BASIN,CHI BASIN
AND
LOWER KHONG BASIN
KHONG RIVER
LOWER KHONG BASIN
CHI BASIN
CHI RIVER
MUN RIVER
MUN BASIN


MUN BASIN,CHI BASIN
AND
LOWER KHONG BASIN
LEGEND
Large and Medium
Scale Irrigation
Small Scale Irrigation
Irrigation

STUDY ON THE MANAGEMENT AND OPERATION OF LARGE-SCALE SURFACE IRRIGATION SYSTEMS IN THE MEKONG DELTA, VIETNAM (THE CASE STUDY IN GO CONG IRRIGATION SYSTEM)

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ABSTRACT:

Within some past decades, the production of agriculture has increased quickly in Mekong delta. One of main reason of this success is the large scale surface irrigation systems have been developed to supply fresh water resources and flood control for paddy rice such as Go Cong Irrigation system, Quan Lo Phung Hiep Irrigation system, South Mang Thit system,... However, the conflicts of water utility have occurred when the diversity of plants and aquaculture has become a necessary requirement for the sustainable economic development of Mekong delta in recent years. The problems need to be addressed the relationship of impacted factors aim to look for the reasonable solution in the management and operation of these irrigation systems to develop sustainable water resources in the Mekong delta.

BACKGROUND

Within some past decades, the production of agriculture has increased quickly in Mekong delta. One of main reason of this success is the irrigation systems have been developed to supply fresh water resources for paddy rice such as Go Cong Irrigation system, Quan Lo Phung Hiep Irrigation system, South Mang Thit system,... However, the conflicts of water utility have occured when the diversity of plants and aquaculture has become a necessary requirement for the sustainable economic development of Mekong delta in recent years. The problems need to be addressed the relationship of impacted factors aim to look for the reasonable solution for the operation of irrigation systems in the Mekong delta. In the Table 1 has shown the Irrigation and drainage systems have been developed in the Mekong Delta .

Table 0-1: The large scale Irrigation systems have been developed in the coastal zone of Mekong Delta during 1995 - 2005

No.	Name of the Irrigation systems	Location	Service area (ha)	Functions
1	Go Cong	Tien Giang	54,000	Fresh water supply, salinity control
2	Tiep Nhat	Soc Trang	53,910	Fresh water supply, salinity control
3	South Mang Thit	Vinh Long, Tra Vinh	225,682	Fresh water supply, salinity control
4	Quan Lo – Phung Hiep	Soc Trang, Bac Lieu	178,888	Fresh water supply, salinity control
6	Nhat Tao Tan Tru	Long An	13,320	Fresh water supply, salinity control
7	Ba Lai	Ben Tre	50,800	Fresh water supply, salinity control
10	Ba Rinh – Ta Liem	Soc Trang, Can Tho	30,944	Fresh water supply, salinity control
12	Huong My	Ben Tre	17,000	Fresh water supply, salinity control
16	Ke Sach	Soc Trang, Can Tho	32,000	Fresh water supply, salinity control

Tieu and Dai rivers are main branches of Tien River, which are affected by the salinity intrusion from East sea tide. Salinity intrudes to My Tho about 50 to 60 km far from the river mouths every year. Go Cong Irrigation system with 54,000 ha of rice has obtained freshwater and control salt water from these branches (Fig.1). The study will concentrate on the way to operate floodgates during the dry season.

Figure 1: Go Cong Irrigation system

OBJECTIVES

The study aims:

- To understand more detailed physical and chemical processes of salinity intrusion when the change of the water flow regime from dry to wet season.
- To suggest the reasonable solution for the operation of Irrigation system in Mekong delta.

FIELD OBSERVATION

The relation of Q – H curve

In Go Cong Irrigation system, almost structures aim to serve for drainage and salinity control. Two headworks used to supply freshwater in the dry season those ara Xuan Hoa and Vam Giong. In February Vam Giong sluive will be closed and after that Xuan Hoa will be closed in March when salt water is over 4‰. The relation curves of Q~H have been established for Xuan Hoa and Vam Giong sluices aim to estimate the discharge.

The relation curved will be divided into two stages such as up and down tide lines to describe for the tidal flow status. The figure 2 showed the Q & H curves of upstream water level at Xuan Hoa sluice. The coefficients of R^2 are rather high. The water level varied from 0.55 – 0.8 m while the values of discharges were within the range of 25 – 150 m^3/s.

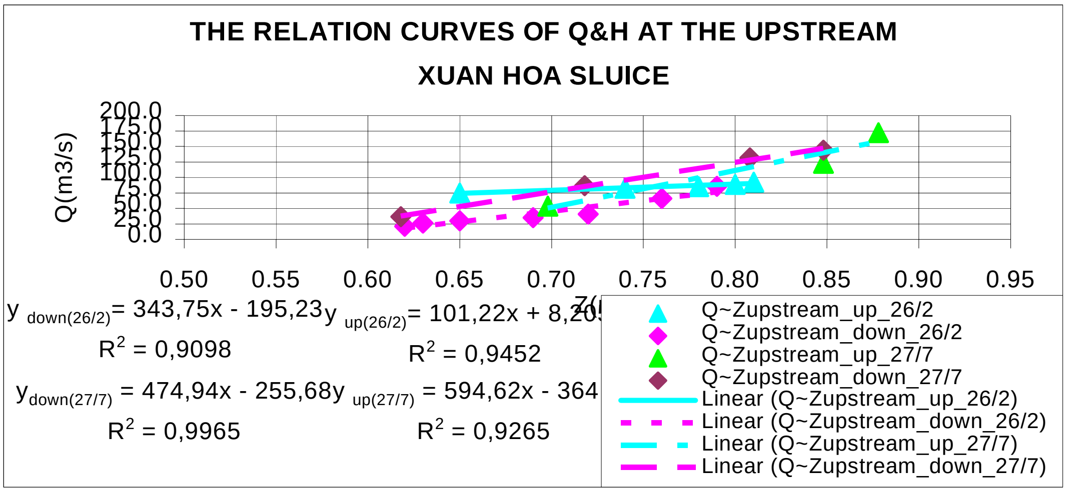

Figure 2: The relation curves of Q&H at the upstream Xuan Hoa sluice

The relation between salinity and tidal variation

Two measurement periods have been carried out in March and May 2004 with 7 days for each time. The first period of 03 – 10 March 2004 has measured along Tien River about 60 km from Dong Tam Bridge to Tieu rivermouth. TPM device used to measure the distribution of salinity by installed sensors. The figure 3 has shown the variation of salinity versus time and depths at Dong Tam Bridge in 07 March 2004. The difference of salinity was not clear at the depths however, it varied strongly with time. In fig.4 the variation of salinity with time at Vam Kenh station. Saline concentration has increased when water level of tide rised after 2 hours later respectively.

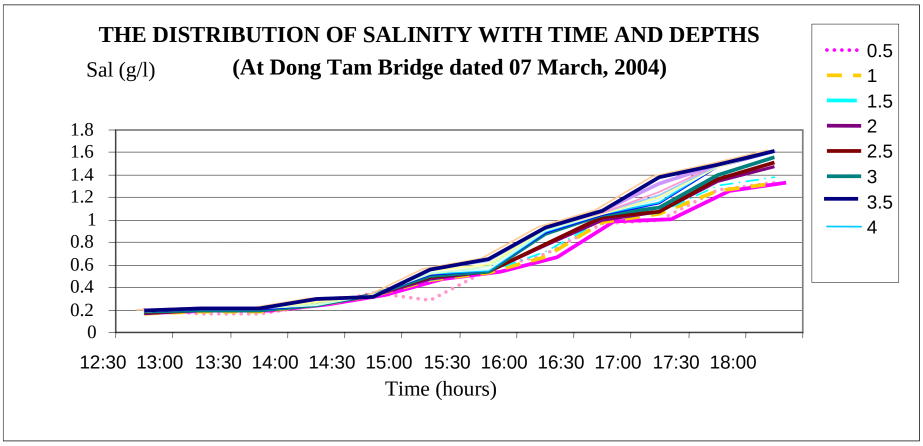

Figure 3: The distribution of salinity with time and depths at Dong Tam Bridge

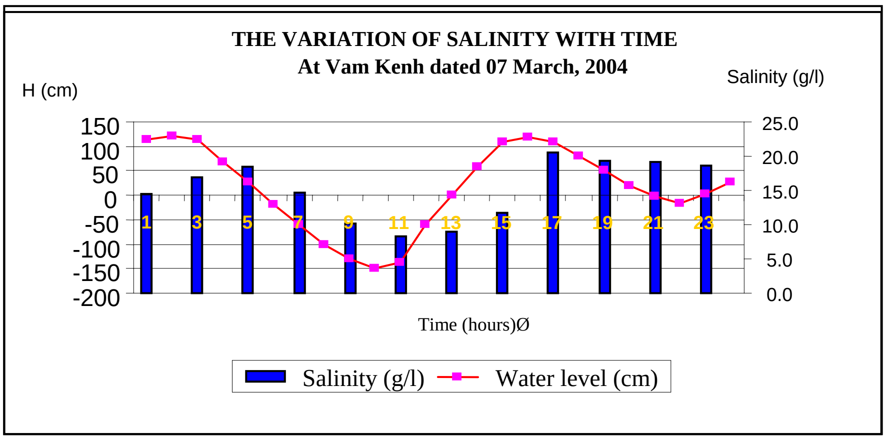

Figure 4: The variation of salinity with time at Vam Kenh station.

The distribution of water flow

ADCP (Acoustic Doppler Current Profiler) device used to measure the cross sections and water flow of Tien River. The velocity of water flow is about 2m/s at the river mouth meanwhile it is about 2.5 – 3m/s at Xuan Hoa. The cross sections of Vam Kenh and Xuan Hoa have been demonstrated in figures 6 and 7. They have also shown the sedimentation of river bed at near river mouth when the level of river bed in Vam kenh is shallower than in Xuan Hoa.

CROSS SECTION OF TIEN RIVER AT VAM KENH

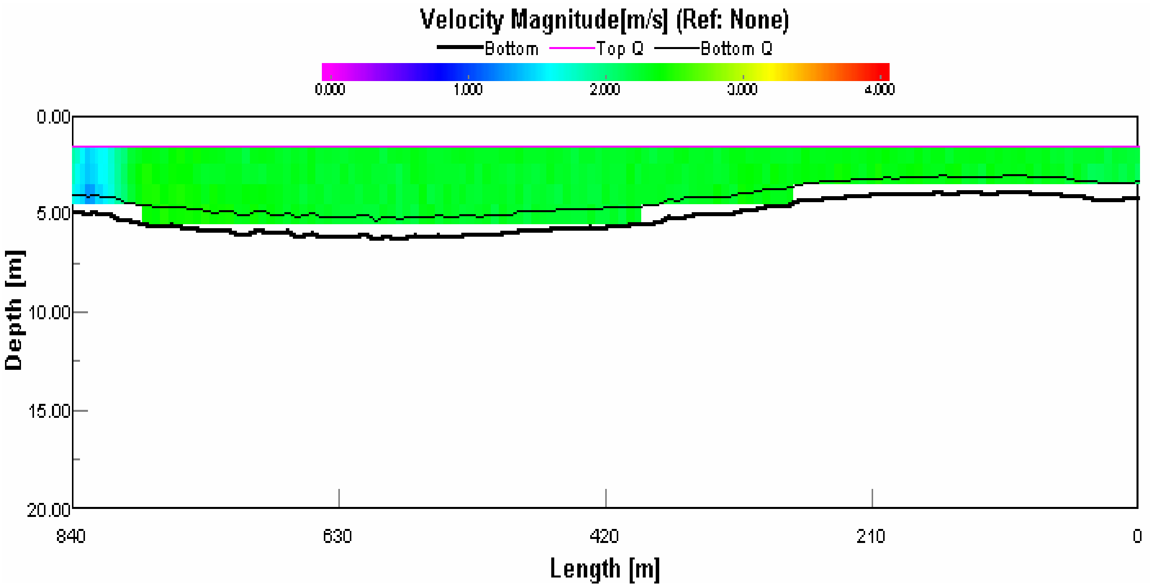

Figure 5: Profile of velocity distribute on the cross section of Tien River at Vam Kenh

CROSS SECTION OF TIEN RIVER AT XUAN HOA

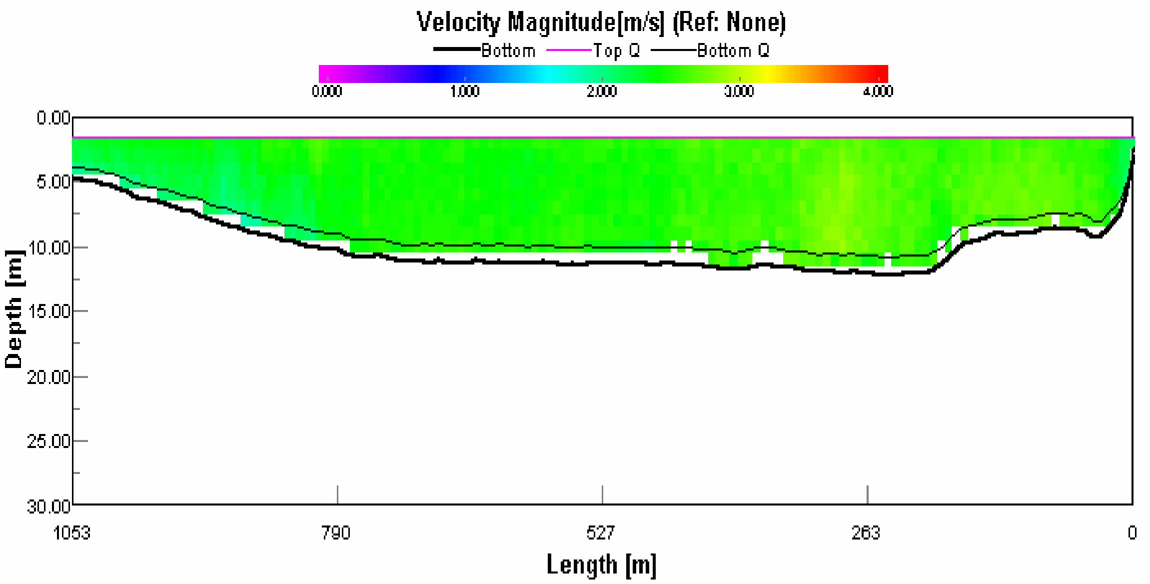

Figure 6: Profile of velocity distribute on the cross section of Tien River at Xuan Hoa

SALINITY INTRUSION MODEL AND OPERATION PROCEDURE

In order to find the reasonable solution for the operation procedure, it must base on the hydraulic models in almost the irrigation system in Mekong delta. The outputs need to be water distribution and flood gate operation to control salinity and inundation. This study has used MIKE 11 (Dannish Hydraulic Institute) as a tool to simulate this procedure.

Schemation of river network

In order to implement the procedure of the operation of Go Cong irrigation system, the river network has been schematized as in figure 8. This scheme includes 61 branches and 8 boundaries. All cross section of canals have been input the modl how to close as the reality of study area.

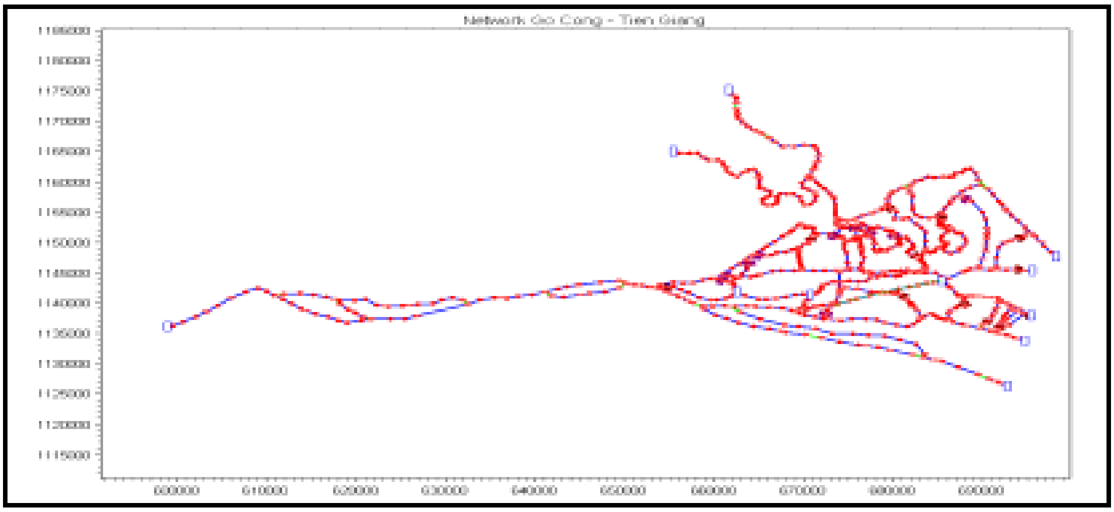

Figure 7: Schemation of Go Cong irrigation system by MIKE 11

Rules of the operation of flood gates

The operation of floodgates has based on two rules

– Operated by the hydraulic control of the tidal variation how to keep required water level after the floodgates.
– Operated by the salinity control and water supply when the upstream volume is higher than the water resource of tide from estuary.
–

Simulation of water level control in the dry season 2004

The conditions when operate flood gates

The floodgates open when

- The difference of water level between upstream and downstream of the gate ≥ 0.1m
- The water level in the field <0.85

When concentration of salt water >2g/l, all flood gates will be closed as follows:

- Xuan Hoa sluice will be closed from 5 March, 2004 to 30 April, 2004
- Vam Giong sluice will be closed from 1 Feb., 2004 to 30 April, 2004.

Boundaries

- Discharge boundaries: The water requirement of case study area about 1l/s/ha has been input by the distributed source or outflow along the irrigation canals. The outner discharge boundary is at My Thuan.
- Water level boundaries: the scheme includes 8 water level boundaries at My Thuan, Tan An, Ben Luc, Dai rivermouth (Binh Dai station), Tieu rivermouth (Vam Kenh station), Vaico rivermouth, Gia Thuan sluice, Rach Bun sluice and Tan Thanh sluice.

Parameters of model

Manning coefficient is the sensivity for calibration of model around 0.022 to 0.033

Time series

The measurement data in the case study area includes water level at Xuan Hoa sluice and Vam Giong sluice from Feb., 2004 to April, 2004.

The results of the model

Water level: The simulated values are rather fit with the measured values at the upstream and downstream of Xuan Hoa sluice as in figures 8 & 9.

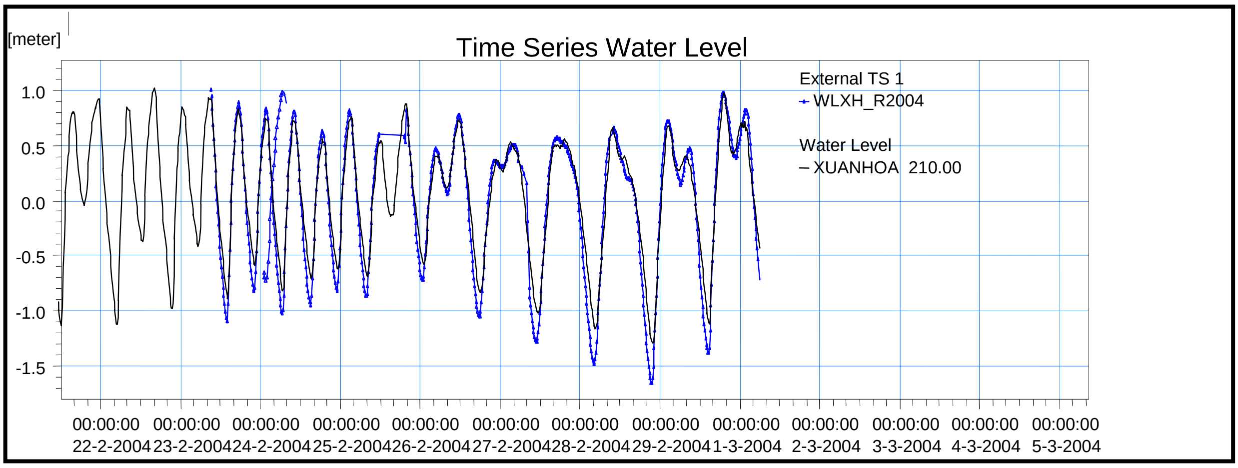

Figure 8. The simulation of water level in the upstream of Xuan Hoa sluice in the dry season of 2004

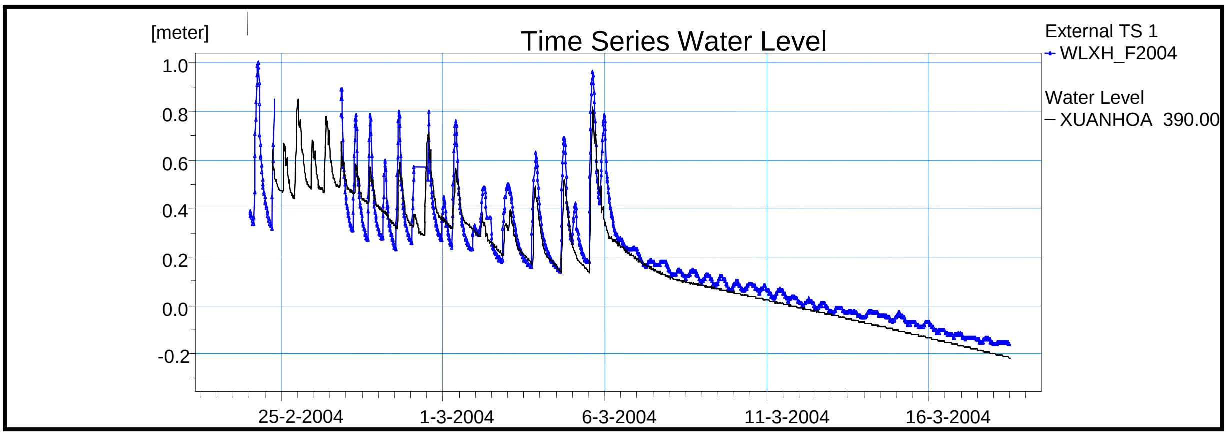

Figure 9. The simulation of water level in the downstream of Xuan Hoa sluice in the dry season of 2004

Simulation of salinity control in the dry season of 2004

Based on the simulation of hydraulic, the simulation of salinity control was calculated from AD module.

The requirements for the operation of flood gates

In the cases of floodgates in the system such as Xuan Hoa, Vam Giong, Long Uong, No.3, they will be only opened when the water level in field > 0.85 m and the difference of water level between up and downstream ≥ 0.1 m as weel as the salt concentration of river water ≤ 2g/l. In the other cases, they are closed.

Boundaries

- The constant values are equal 30 g/l at the river mouths and equal 0 g/l at other boundaries.
- Water and discharge boundaries: same as hydraulic model in the dry season of 2004.

Time series

Observed data in the case study area include the salinity at Long Hai, Vam Giong, Xuan Hoa and Dong Tam. The calibration have been carried out as follows:

- Water levels from 1/2/2004 to 30/4/2004 at Xuan Hoa and Vam Giong
- Salinity from 08 – 10/03/2004 along Tien River from from Dong Tam to Vam Kenh river mouth.

Dispersion coefficient

D = 1500 in the river and other canals are D=100.

The result of the simulation

Water level: The simulated values are rather agrred with the measured values in the study area at the upstream and downstream of Xuan Hoa sluice in Fig.10.

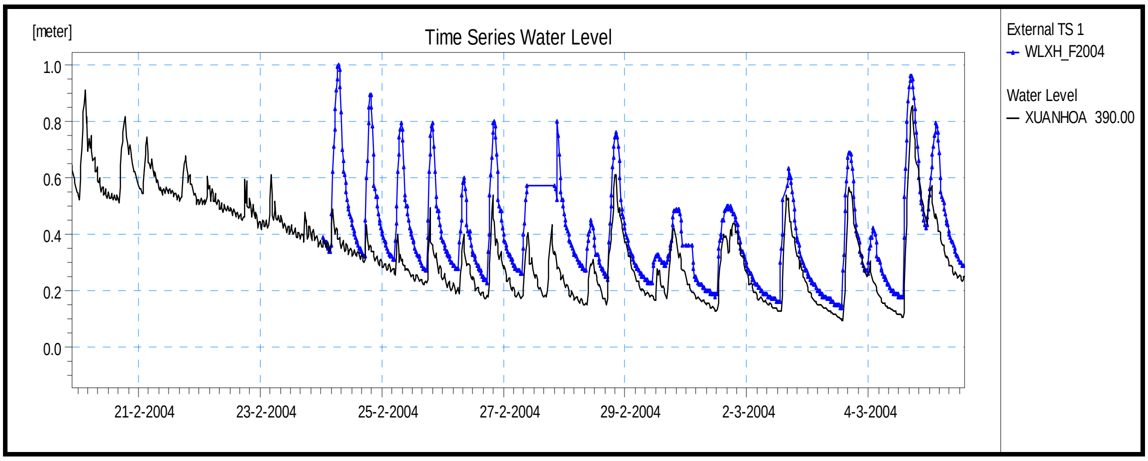

Figure 10. The simulation of water level at the downstream of Xuan Hoa sluice in the dry season of 2004

Salinity concentration: The differences of salinity between simulated and measured are rather small at the upstream of Xuan Hoa sluice as in Fig.11.

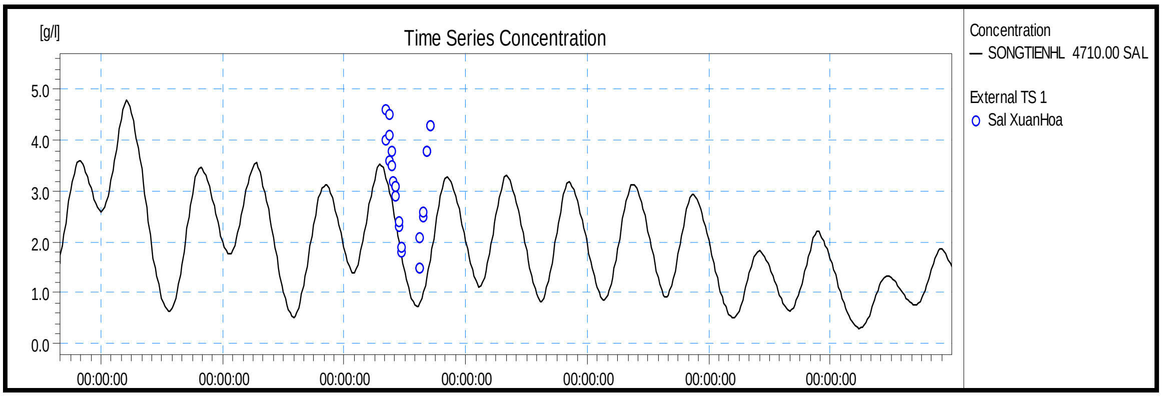

Figure 11. The simulation of salinity at Xuan Hoa sluice in the dry season of 2004

– The procedures of flood gates to get the fresh water during the dry season in Fig.12.

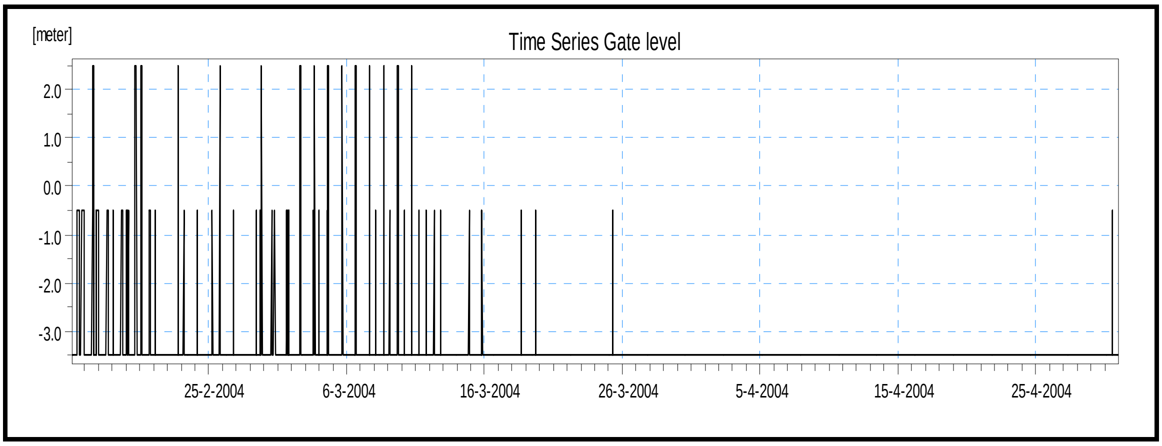

Figure 12. The simulation of the operation procedure of Xuan Hoa gate in the dry season of 2004 by AD model.

Implementation the guide of the operation for flood gates

From the result of the simulation, the guide of operation procedure for flood gates in the tables 4-1 and 4-2 as follows:

Table 0-1: The guide of the operation procedure in the dry season of 2004 (based on the result of HD model in 2004)

STT	**Sluices**	**The operation procedure**		
		Irrigated	Closed	Drained
1	Xuan Hoa	from 1/2/2004 to 5/3/2004	from 5/3/2004 to 30/4/2004	
2	Vam Giong		from 1/2/004 to 30/4/2004	
3	No.3	From1/2/2004 to 5/3/2004	from 5/3/2004 to 30/4/2004	

Table 0-2: The guide of the operation procedure in the dry season of 2004 (based on the result of AD model in 2004)

STT	**Sluices**	**The operation procedure**		
		Irrigated	Closed	Drained
1	Xuan Hoa	1-26/2, 1-12/3, 14/3, 15/3, 18/3, 19/3, 25/3	27/2, 13/3, 16/3, 17/3, 20-24/3, 26/3-29/4	
2	Vam Giong		from1/2/004 to 30/4/2004	
3	No.3	½-8/3, 11-12/3, 16-19/3, 21-22/3, 31/3-11/4, 13-14/4, 18-23/4, 29/4	9-10/3, 13-15/3, 20/3, 23/3, 26-30/3, 12/4, 15-17/4, 24-26/4,28/4, 30/4	

CONCLUSION

The model has described rather exactly water level, and discharge as well as salinity the salinity intrusion into main branches of river. It has also suggested the schedule of operation procedure of sluices to get fresh water for irrigation in the study area. However in order to implement the accurate schedule, it needs more detailed topography map with large scale and measured data at the sites in field for validation of the model. Nevertheless from the scenarios, the model can simulate the operation procedure of floodgates in the system. This is necessary to help managers and decision makers know how to give decision in the imergency cases.

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WATER BALANCE MODEL FOR THE WEST BARAY IRRIGATION SYSTEM SIEM REAP, CAMBODIA

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ABSTRACT

This paper describes the estimation of total water balance from West Baray reservoir to its irrigated paddy fields. For the calculation of the total water balance, two main models are calculated. The first model is the water balance of the reservoir. The inputs to the model are water level of the reservoir, lake evaporation, precipitation combined with area-volume curve of the reservoir. The outputs are inflow and outflow of the reservoir. The supply from the reservoir to paddy fields is computed from the outflow. The second model is the water balance of paddy fields. Based on this model, the water requirement in paddy fields is derived. To calculate the water requirement, reference evapotranspiration is needed. The reference evapotranspiration is simulated for monthly time series using the FAO Penman-Monteith model. Since there is no drainage network in the irrigation system, surface drainage and runoff are not included in the calculation of the water balance, and seepage is considered negligible in the flat floodplain area. The evapotranspiration, rice variety, soil type and irrigated area are used to simulate water consumption in paddy fields. The inflow and outflow of the reservoir is computed from 2000 to 2004, while the water balance of paddy fields is simulated for only 2002 and 2003 due to the limitation of data. Finally, the two models are connected to produce the total water balance from the reservoir to paddy fields. The amount of total outflow from the reservoir is estimated and the total water consumption for dry season cultivation is also determined. The consistency of the two terms is found to be around 29 million cubic meters. This can be said the amount of water loss by conveyance efficiency is compensated by floodwater storage in the field. The West Baray reservoir contributes about 80% of the total dry season irrigation while around 20% of the total water use is from the storage of dike system.

INTRODUCTION

Angkor, the capital city of the Khmer empire, was one of the world's great architectural achievements. This most beautiful and mysterious historic site is famous not only for its artistically significant architecture, but also for its water management infrastructure. The West Baray irrigation system is one of the successful projects in water resources development during the Angkorean period, the golden time of the Khmer civilization. The irrigation scheme was developed in 1050 under the reign of Udayadityavarman II (Une and Egawa, [1]). The system is characterized by a reservoir combined with a dike system in the floodplain of the Tonle Sap Great Lake and an irrigation system (Figure 1.a). The reservoir is supplied by a tributary of the Great Lake, the Siem Reap river, in rainy season. The water is distributed to irrigation area in dry season. A small dike system was constructed in the Tonle Sap floodplain for retarding and storing floodwater. The stored floodwater is used as an additional water source for dry season cultivation.

In this research, we attempt to study water management of the West Baray irrigation system by analyzing water use in the irrigation system and uncover effectiveness of the system, which will play a vital role in the study of the Tonle Sap Great Lake system in our future research.

WEST BARAY IRRIGATION SYSTEM

The man-made West Baray reservoir is perfectly rectangular and perfectly aligned to the compass. It was constructed on the land inclining gently south-west. The elevation of land at north-east corner is about 20 m MSL (mean sea level) and south-west is around 12 m MSL with a difference of 8 m. Its east-west embankment is 7950 m long while north-south one is 2110-2145 m. This ideal rectangular reservoir is enclosed by an earth dike of 16 m high on the south-west side and 7-8 m high on the north-east (Une and Egawa, [1]). The West Baray dike was elevated by using excavated soil at both sides of the levee (Groslier, [2]). When the reservoir is charged, outside ditch is used to collect infiltration water. The reservoir is presently capable of storing water up to 53 million cubic meters (MCM) at water level of 19.6 m MSL.

Around the West Baray reservoir, there is only one outlet structure connected to the 2.7 km main canal MC. The canal can evacuate a flow of 9 m^3/s (JICA, [3]). There are 8 secondary canals SC (Figure 1.b), totally 59.2 km long, and operating through 23 sluice gate regulators equipped with wooden planks. 79 tertiary canals with a total length of 150 km are connected to the secondary canals by a concrete regulator structure at each of its head (WAPCOS and MOWRAM, [4]). There is no drainage system at the beneficial area of this enormous irrigation system. When a heavy rainfall occurs, the irrigation canal system is used as the drainage system.

In rainy season, from June or July, a weir gate named French weir gate is closed and water is diverted to the West Baray reservoir via the feeder canal passing through a regulation. The maximum flow capacity of the feeder canal is estimated at 14 m^3/s with a length of 6 km (JICA, [3]). When water level at the West Baray reservoir reaches 25 m reading or 19.6 m MSL, the French weir gate is opened to release water to downstream of the Siem Reap river, and the regulator is closed to stop inflow from the Siem Reap river. The water from the reservoir is supplied to irrigation area from November to May/June.

The dike system in the floodplain of the Great Lake plays a significant role as storing floodwater for dry season irrigation. Normally, the water is used for dry season rice during the first month of cultivation. When the water finishes, water from the West Baray reservoir is supplied.

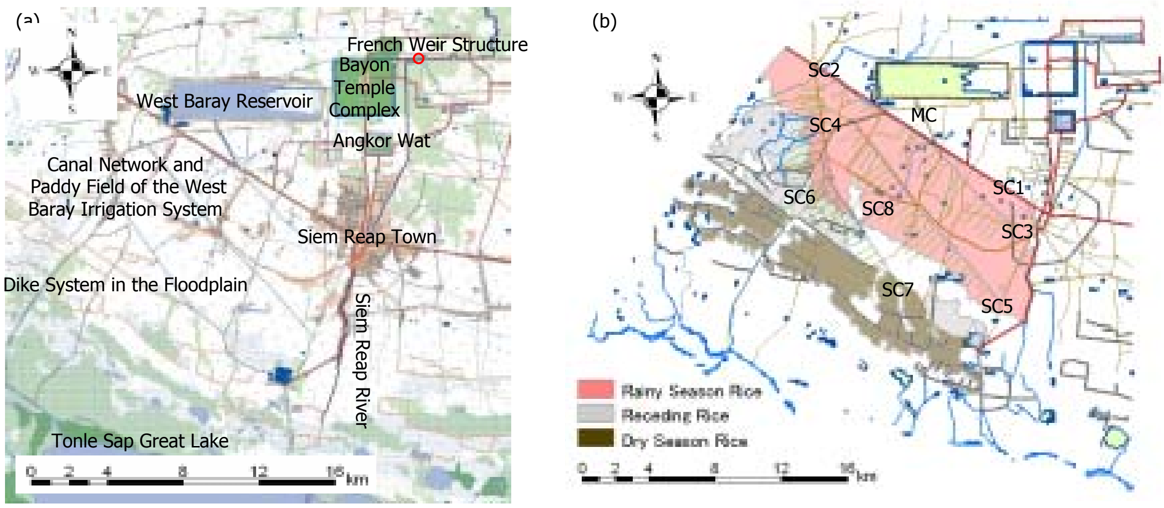

Figure 1- Components (a) and cultivating (b) pattern of the West Baray irrigaion system

Three kinds of rice, rainy season rice, recession rice and dry season rice are grown in the command area of the West Baray reservoir (Figure 1.b). In order to save water for irrigation, land preparation operation of all types of rice is usually done in rainy season. The cultivation patterns and time of growing of these rice varieties are described below:

- Rainy Season Rice: Land preparation of rainy season rice is usually done in June or July, and then land is kept dry. At the same time, nursery is prepared. In July, farmers start transplanting or spreading. The harvesting time is generally in December. Rainy season rice is grown on non-flooded area between the rainy season shoreline of the Great Lake and national road 6.
- Recession Rice: Farmers start plowing at the first and/or second shower of rainy season rain, especially in May. Then, the land is left inundated during flood season. When flood subsides in December, farmers start spreading. Harvesting time of recession rice is at the end of February or at the beginning of March. Receding rice is grown in northern part of a dike named Dike 78, which is flooded in rainy season due to expansion of the Great Lake.
- Dry Season Rice: Land preparation of dry season rice is operated in May or June, before the flood of the Tonle Sap arrives, normally from 15 to 30 days after land preparation of receding rice in northern part of

Dike 78, and then the field is inundated. Farmers spread rice seed in January or February depending on the withdrawal of flood. The dry season rice is generally harvested in April. For the first month of dry season cultivation, the floodwater stored by dike system is used. For the rest of growing period, water from the West Baray reservoir is supplied.

The rice yield in the cultivation area of the West Baray is very low and varies from village to village. It ranges from 2.95 t/ha to 0.77 t/ha. Yields are low because of soil problems and unpredictable combinations of drought and flood, and crop failure are also common.

CALCULATION APPROACH

To analyze water use patterns in the paddy field of the West Baray irrigation system, two main models are calculated; one is a water balance model of the supplying reservoir and another is a water balance of irrigated paddy field. The following sections discuss the procedure of calculating the inflow and outflow of the West Baray reservoir and simulation approach of water requirement of paddy rice.

Water Balance of the West Baray Reservoir

The daily water level in the West Baray reservoir is the most important hydrological data in the study of the water balance of the reservoir. The data of water level of the reservoir are available from 1993-1997 and 2000-2004. Since the data during 1993-1997 are not available daily for the whole years and it is not possible to interpolate for missed data, the calculation of the inflow and outflow of the reservoir is estimated for only 2000-2004. The equation of inflow and outflow of the West Baray reservoir in cubic meter is

$$I_j \text{ or } O_j = V_j - V_{j-1} - (P_j - E_j) \qquad (1)$$

where I_j is inflow in j day, O_j outflow in j day, V_j and V_{j-1} storage volume of reservoir in j and j-1 day, P_j volume stored by precipitation in j day, and E_j volume lost by evaporation in j day.

The inflow and outflow of the West Baray reservoir is computed according to the following steps:

- Estimate the daily increment of capacity by using the change of reservoir water level, and water level and volume curve of the reservoir.
- Estimate the daily increment of capacity based on storage by rainfall and loss by evaporation.
- Estimated inflow and outflow is the difference of the above-mentioned two terms.

In the computation of the inflow and outflow of the reservoir, some assumptions are made:

- During inflow period, it is assumed there is no outflow, and vice versa.
- Infiltration is not taken into account.

Generally, the inflow period is from June/July to October/November and the outflow duration lasts from November/December to May/June. There is only one outlet around the reservoir, so outflow from the reservoir is the supply to the irrigated paddy field.

Variation of Water Level of the West Baray Reservoir

The availability of the water level of the West Baray reservoir is not daily consecutive. A linear interpolation technique is applied to the whole series of data for filling the gap of missing data.

Since there is no regulation on the operation of the reservoir, the specific date of inflow and outflow is determined by the period of variation in the minimum and maximum water level in the reservoir. In other words, the inflow period is the period when the water level rises from the minimum to the maximum level of each year, while the outflow period is the time interval when water level falls from the maximum to the minimum level of each year.

To eliminate errors caused by intermittent time series of data and wind and wave effect in the calculation, the inflow and outflow of the reservoir is computed by an irregular time interval technique. The concept is based on the falling and rising slope of water level in the reservoir for certain time period. This means the change of storage is simulated for the time interval in which water level rises or falls in the same slope.

Relation of Water Level, Area and Volume of the West Baray Reservoir

The water level, area and volume curve of the West Baray reservoir is based on three datasets; a bathometric survey of the reservoir conducted by JICA in 1997, a topographic survey of the reservoir carried out by MOWRAM in 2004, and digital elevation model (DEM) of the reservoir derived from satellite photos.

In this study, the average of the three datasets is used in the computation of the inflow and outflow of the West Baray reservoir. The second order of polynomial regression is applied to the averaged data series (Figure 2). The equation of area A and the equation of volume V as a function of water level Z can be obtained as below:

Area curve equation: $A = -0.10\,Z^2 + 5.06\,Z - 48.13$ ($R^2 = 0.987$)

Volume curve equation: $V = 0.96\,Z^2 + 23.13\,Z + 139.01$ ($R^2 = 0.999$)

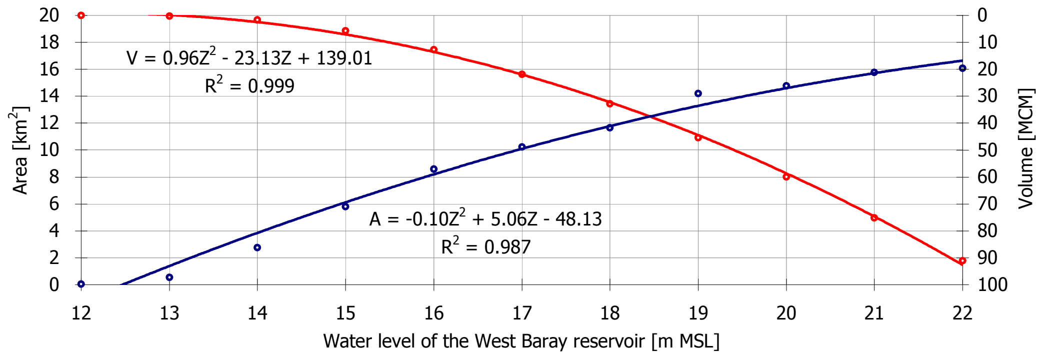

Figure 2- Water level, area and volume curve of the West Baray reservoir

Storage by Precipitation and Loss by Evaporation

Two main components affecting the result of calculation of the inflow and outflow of the reservoir are precipitation and evaporation. Reception area of rainfall and evaporation area is fixed as the maximum area of 16.07 km^2 at the water level of 22 m MSL. The water surface area of the West Baray reservoir varies with the water level, but the rainfall reception area and evaporation area (including soil evaporation area) are kept as a constant in this calculation.

The evaporation data is available only in 2000 and 2004. For the calculation of inflow and outflow of the West Baray reservoir for 2000-2004, interpolated data are used for missing data.

It is not really facile to directly estimate evaporation from a large open water surface like a lake, a pond or a reservoir. For the simulation, this parameter is estimated by the ratio of reservoir and pan evaporation rates. It is believed that there is about 30% more evaporation from the small area of a pan than from a large reservoir or a lake because of extra heat taken in through the pan's side (Linacre, [5]). The value of factor of lake evaporation E_o by pan evaporation E_p is about 0.77 (Veihmeyer, [6]). However, true values of the coefficient is said to vary from 0.6 to 0.8.

$$\frac{E_o}{E_p} = 0.77 \tag{2}$$

where E_o is lake evaporation [mm day^{-1}] and E_p pan evaporation [mm day^{-1}].

Water Balance of Paddy Field

To understand the West Baray system as a whole and to fully explore the opportunities, possibilities and constraints of developing a new rice-based system for the Tonle Sap Great Lake, farming system and water use patterns of the West Baray irrigation system are to be identified.

The water balance equation in the paddy field expresses the change in the amount of water stored in a control volume during a defined time period as equal to the amount of water entering the volume during the time period, the inflow, minus the amount leaving the volume during that time period, the outflow. The inflow to the field consists of total supplies through precipitation, irrigation, seepage inflow and surface runoff inflow, while outflow is composed of water leaving the field through evapotranspiration, percolation, surface runoff outflow and seepage outflow. The field storage constitutes ponded water and soil moisture. The water balance model of paddy field was developed based on the following equation:

$$\Delta D + \Delta W = (P + IR + S_{in} + R_{in}) - (ETc + I + S_{out} + R_{out}) \tag{3}$$

where D is ponded water depth, W soil moisture, P precipitation, IR irrigation, S_{in} seepage inflow, R_{in} surface runoff inflow, ETc crop evapotranspiration, I percolation, S_{out} seepage outflow, R_{out} surface runoff outflow. All terms in the water balance equation are expressed in cubic meter.

For the purpose of model calculations, field storage (standing water and soil moisture) is kept unchanged for the whole growing period. This means that the amount of inflow (supply) must be approximately equal to the outflow (consumption). The assumption of various types of factors that may affect the water balance model is discussed here.

In the West Baray irrigation system, there is no drainage system. The total water supply is totally used by the paddy field. This means that surface drainage or runoff can be assumed as nil.

The slope of irrigation area is relatively gentle, so seepage is considered negligible in such a flat area.

Two sources of water supply, the West Baray reservoir and the storage of floodwater by dike, are used for irrigation term.

In sum, the major elements of supply are precipitation (mainly for wet season cultivation), the West Baray reservoir water (receding rice and dry season rice) and floodwater storage (mostly for dry season rice). The consumptive use principally consists of crop evapotranspiration and percolation.

Data of agricultural soil type is not available for this study. Literature review and existing information propose that agricultural land of the study area is alluvial paddy with sandy clay loam soil. The infiltration is assumed around 5 mm/day and the total porosity of the type of soil is 0.398 (Rawls et al., [7]).

Crop Evapotranspiration

The crop evapotranspiration is one of the most important factors for the evaluation of water consumption in the paddy field. The crop evapotranspiration needs include two components: water for maintaining physiological processes that lead to plant development and growth, and water to compensate for evaporation from the soil.

In this study, the FAO Penman-Monteith method is used for estimating the reference evapotranspiration ETo. The crop evapotranspiration ETc will be produced from the reference evapotranspiration ETo by single crop coefficient approach. The FAO Penman-Monteith method is derived from the original and very sophisticated Penman-Monteith equation. The FAO Penman-Monteith equation is a simple representation of the physical and physiological factors governing the evapotranspiration process. The method presents a straightforward computation procedure and requires only standard meteorological data of air temperature, humidity, radiation and wind speed.

$$\mathrm{ETo} = \frac{0.408\,\Delta(R_n - G) + \gamma \dfrac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \tag{4}$$

where ETo is reference evapotranspiration [mm day^{-1}], R_n net radiation at the crop surface [MJ m^{-2} day^{-1}] obtained by equation (11)-(19), G soil heat flux density [MJ m^{-2} day^{-1}] given by equation (8), T mean daily air temperature at 2 m height [°C], u_2 wind speed at 2 m height [m s^{-1}] expressed by equation (7), e_s mean saturation vapor pressure [kPa], e_a actual vapor pressure [kPa], e_s - e_a saturation vapor pressure deficit [kPa], Δ slope vapor pressure curve [kPa °C^{-1}] given by equation (6), γ psychrometric constant [kPa °C^{-1}] calculated from equation (5).

The psychrometric constant γ is given by

$$\gamma = \frac{c_p P}{\varepsilon\lambda} = 0.665 \times 10^{-3}\, P = 0.665 \times 10^{-3} \times 101.3 \left(\frac{293 - 0.0065 z}{293}\right)^{5.26} \tag{5}$$

where γ is psychrometric constant [kPa °C^{-1}], P atmospheric pressure [kPa], λ latent heat of vaporization = 2.45 [MJ kg^{-1}], c_p specific heat at constant pressure, 1.013310^{-3} [MJ kg^{-1} °C^{-1}], ε ratio molecular weight of water vapor/dry air = 0.622 and z elevation above mean sea level [m].

For the calculation of evapotranspiration, the slope of the relationship between saturation vapor pressure and temperature Δ is required. The slope of the curve at a given temperature is expressed by

$$\Delta = \frac{4098 \times \left[0.6108 \times \exp\left(\dfrac{17.27\, T_{mean}}{T_{mean} + 237.3}\right)\right]}{(T_{mean} + 237.3)^2} \tag{6}$$

with Δ slope of saturation vapor pressure curve at air temperature T [kPa °C^{-1}], T_{mean} mean air temperature [°C], exp[..] 2.7183 (base of natural logarithm) raised to the power [..].

Wind speeds measured at different heights above the soil surface are different. Surface friction tends to slow down wind passing over it. Wind speed is slowest at the surface and increases with height. To adjust wind speed data obtained from instruments placed at elevations other than the standard height of 2 m, a logarithmic wind speed profile is used:

$$u_2 = u_z \times \frac{4.87}{\ln(67.8 \times z - 5.42)} \tag{7}$$

where u_2 wind speed at 2 m above ground surface [m s^{-1}], u_z measured wind speed at z m above ground surface [m s^{-1}], z height of measurement above ground surface [m].

Complex models are available to describe soil heat flux. Because soil heat flux is small compared to R_n, net radiation, particularly when the surface is covered by vegetation and calculation time steps are longer than 24 hours, the monthly soil heat flux G can be computed by

$$G_{month,i} = 0.07\,(T_{month,i+1} - T_{month,i-1}) \quad \text{or, if } T_{month,i+1} \text{ is unknown,} \quad G_{month,i} = 0.14\,(T_{month,i} - T_{month,i-1}) \tag{8}$$

with G soil heat flux [MJ m^{-2} day^{-1}], $T_{month,i}$ mean air temperature of month i [°C], $T_{month,i-1}$ mean air temperature of previous month [°C], $T_{month,i+1}$ mean air temperature of next month [°C].

The vapor pressure deficit is the difference between the mean saturation e_s and the actual vapor pressure e_a for a given time period. For monthly calculation, the saturation vapor pressure e_s is computed from equation (10) using the maximum temperature T_{max} and minimum temperature T_{min} averaged over the time period, and similarly the actual vapor pressure e_a is computed with equation (11) using maximum temperature T_{max}, minimum temperature T_{min} and mean relative humidity RH.

As saturation vapor pressure is related to air temperature, it can be calculated from the air temperature. The relationship is expressed by

$$e^o(T) = 0.6108 \times \exp\left[\frac{17.27 \times T}{T + 237.3}\right] \tag{9}$$

where e°(T) is saturation vapor pressure at the air temperature T [kPa], T air temperature [°C], exp[..] 2.7183 (base of natural logarithm) raised to the power [..].

The mean saturation vapor pressure can be expressed by

$$e_s = \frac{e^o(T_{max}) + e^o(T_{min})}{2} \tag{10}$$

The actual vapor pressure can also be calculated from T_{max} [°C], T_{min} [°C] and RH [%] by:

$$e_a = \frac{RH}{100}\left[\frac{e^o(T_{max}) + e^o(T_{min})}{2}\right] \tag{11}$$

The net radiation R_n is the difference between the incoming net shortwave radiation R_{ns} and the outgoing net longwave radiation R_{nl} where R_n, R_{ns} and R_{nl} are measured in [MJ m^{-2} day^{-1}].

$$R_n = R_{ns} - R_{nl} \tag{12}$$

The net shortwave radiation resulting from the balance between incoming and reflected solar radiation is given by

$$R_{ns} = (1-\alpha)\,R_s = (1-\alpha) \times \left(a_s + b_s \frac{n}{N}\right) \times R_a \tag{13}$$

where R_{ns} is shortwave radiation [MJ m^{-2} day^{-1}], α albedo or canopy reflection coefficient, which is 0.23 for the hypothetical grass reference crop, R_s the incoming solar radiation [MJ m^{-2} day^{-1}], n actual duration of sunshine [hour] and recorded with a Campbell Stokes sunshine recorder, N = 24/πxω_s the maximum possible duration of sunshine or daylight hours [hour], ω_s the sunset hour angle in radians [rad] given by equation (17), R_a extraterrestrial radiation [MJ m^{-2} day^{-1}] given by equation (14). When no actual solar radiation data are available and no calibration has been carried out for improved a_s and b_s parameters, the values a_s = 0.25 and b_s = 0.50 are recommended.

The extraterrestrial radiation R_a for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year by

$$R_a = \frac{24 \times 60}{\pi} G_{sc} \times d_r \times \left[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)\right] \tag{14}$$

with R_a extraterrestrial radiation [MJ m^{-2} day^{-1}], G_{sc} solar constant = 0.0820, [MJ m^{-2} min^{-1}], d_r inverse relative distance Earth-Sun [-], ω_s sunset hour angle [rad],φ latitude [rad], δ solar decimation [rad].

The inverse relative distance Earth-Sun d_r and the solar declination δ are given by

$$d_r = 1 + 0.033 \times \cos\left(\frac{2\pi}{365} J\right) \tag{15}$$

$$\delta = 0.409 \times \sin\left(\frac{2\pi}{365} J - 1.39\right) \tag{16}$$

where J is the number of days in a year between 1 (1st January) and 365 or 366 (31st December).

The sunset hour angle ω_s is given by

$$\omega_s = \arccos\left[-\tan(\varphi) \times \tan(\delta)\right] = \frac{\pi}{2} - \arctan\left[\frac{-\tan(\varphi) \times \tan(\delta)}{X^{0.5}}\right] \tag{17}$$

where $X = 1 - [\tan(\varphi)]^2 \times [\tan(\delta)]^2$

Net longwave radiation R_{nl} can be estimated from

$$R_{nl} = \sigma\left[\frac{T_{max,K^4} + T_{min,K^4}}{2}\right] \times (0.34 - 0.14 \times \sqrt{e_a}) \times \left(1.35 \frac{R_s}{R_{so}} - 0.35\right) \tag{18}$$

where σ is Stefan-Boltzmann constant 4.903 10^{-9} [MJ K^{-4} m^{-2} day^{-1}], $T_{max,K}$ maximum absolute temperature during the 24-hour period [K=°C + 273.16], $T_{min,K}$ minimum absolute temperature during the 24-hour period [K=°C + 273.16], e_a actual vapor pressure [kPa] given by equation (11), R_s solar radiation [MJ m^{-2} day^{-1}] expressed by equation (13), R_{so} clear-sky radiation [MJ m^{-2} day^{-1}] obtained by equation 19, σT^4 Stefan-Boltzman law.

The calculation of the clear-sky radiation R_s when n = N is required for computing net long wave radiation.

$$R_{so} = (0.75 + 2 \times 10^{-5} \times z)\, R_a \tag{19}$$

with z station elevation above sea mean level [m], R_a extraterrestrial radiation [MJ m^{-2} day^{-1}] given by equation (14).

Rice Growth Stage and Crop Coefficient

As mentioned above, there are three types of rice growing in the West Baray irrigation system, rainy season rice, receding rice and dry season rice. In general, rice plant growth can be divided into three agronomic stages of development, vegetative, reproductive and ripening (Moldenhauer and Slaton, [8]). For the purpose of calculation, the length of rice growing (Doorenbos and Pruitt, [9]; IRRI, [10]) and the crop coefficient Kc (Allen et al., [11]) of each development stage were modified based on other rice varieties. Finally, below growing durations and crop coefficient are adopted (Figure 3):

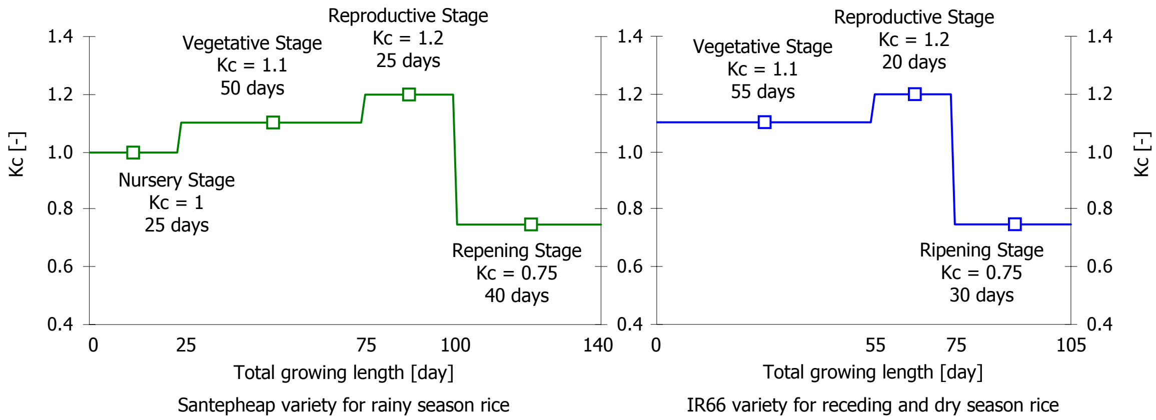

Figure 3- Rice growing stage and crop coefficient

RESULTS AND DISCUSSION

The two developed water balance models are able to estimate inflow and outflow of the West Baray reservoir and water consumption in paddy fields at a specific time period. The analysis of the results of the models is presented and discussed as follows:

Water Balance of the West Baray Reservoir

The water balance model of the West Baray reservoir was computed from water level in the reservoir, lake evaporation, and precipitation combined with area-volume curve of the reservoir. The daily inflow and outflow of the West Baray reservoir is depicted in figure 4.

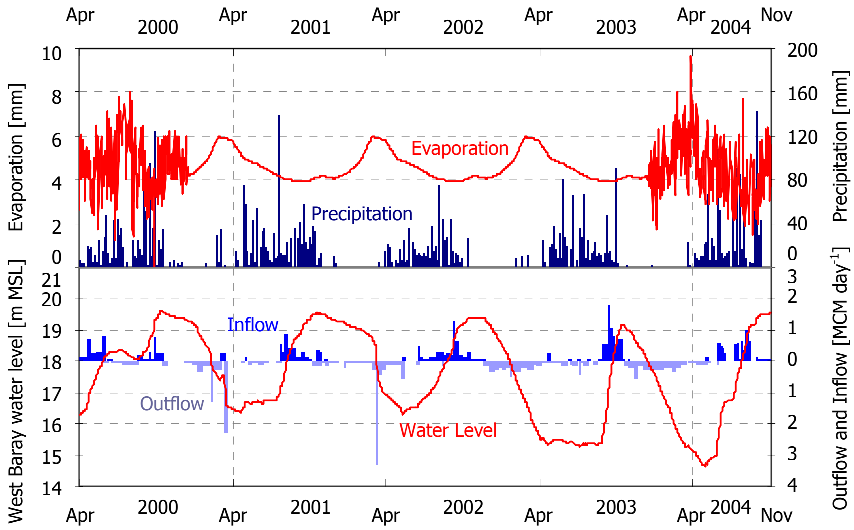

Figure 4- Simulated inflow and outflow hydrograph of the West Baray reservoir

In average, rainfall contributing to the total inflow (inflow from Siem Reap river plus rainfall) of the West Baray reservoir is about 28% (figure 5.a), while about 20% of the total outflow (outflow to irrigation system plus reservoir evaporation) is the loss by evaporation (figure 5.b).

The average total supply to irrigation system is 31.15 MCM which accounts for 59% of the total effective capacity (52.75 MCM), while leftover capacity is 9.54 MCM or 18% of live storage. In the recent years, the leftover volume has gradually decreased. This indicates that water use patterns of the West Baray irrigation seem improved.

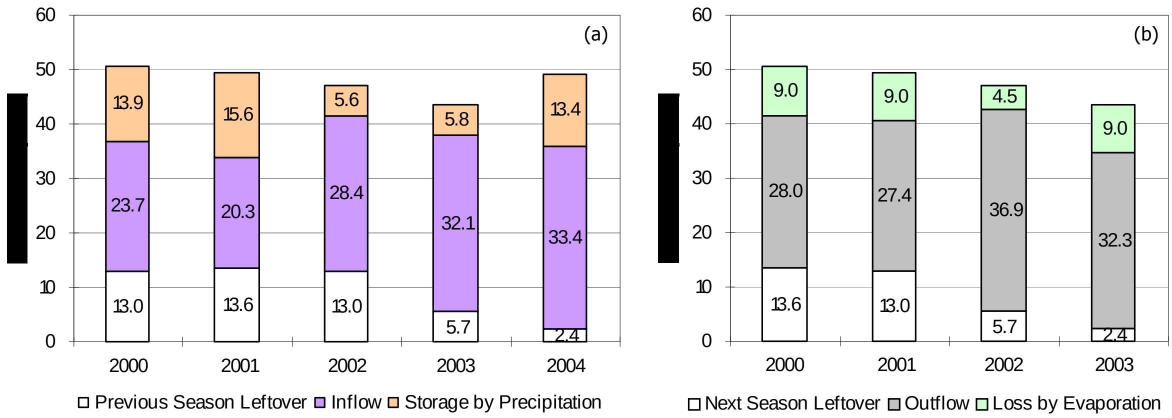

Figure 5- Storage (a) and supply (b) pattern of the West Baray reservoir

Water Balance of Paddy Field

The monthly average daily reference evapotranspiration was simulated from basic climatologic data, minimum and maximum temperature, air humidity, sunshine and wind speed, and are shown in figure 6. For general weather condition in the West Baray irrigation system, average daily reference evapotranspiration ETo is found 4.5 mm/day while average daily pan evaporation E_p is 4.6 mm/day.

The water balance of paddy field was simulated on two consecutive growing years, 2002 and 2003. The average daily crop evapotranspiration of rainy season rice ETc_{rainy}, receding rice $ETc_{receding}$ and dry season rice ETc_{dry} are found 4.25 mm/day, 4.24 mm/day and 4.61 mm/day, respectively. The average total crop evapotranspiration of rainy season rice (140 days) $ETc_{tol\text{-}rainy}$, receding rice (105 days) $ETc_{tol\text{-}receding}$ and dry season rice (105 days) $ETc_{tol\text{-}dry}$ are 596 mm, 445 mm and 484 mm, respectively.

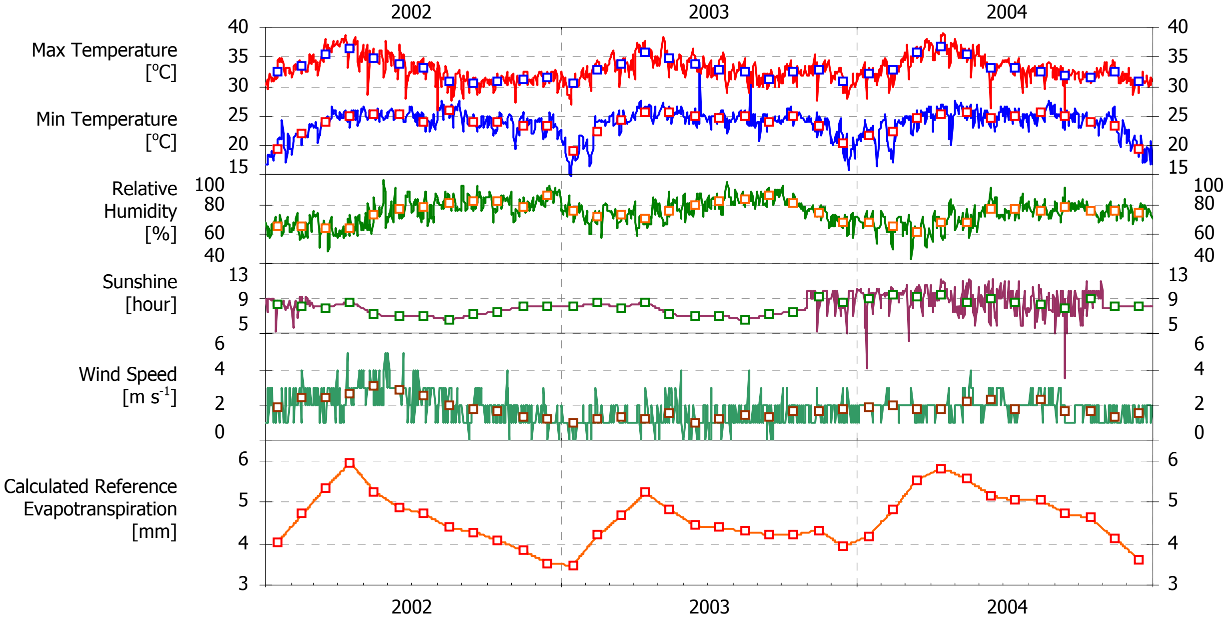

Figure 6- Meteorological data and simulated reference evapotranspiration

The average total water consumption of rainy season rice (4098 ha), receding rice (994 ha) and dry season rice (1832 ha) are 1296 mm (53.11 MCM), 970 mm (9.65 MCM) and 1009 mm (18.49 MCM), respectively. Furthermore, the average annual consumptive use of water for paddy cultivation is 3275 mm (81.24 MCM), out of which 1525 mm (37.83 MCM) or 47% is crop evapotranspiration. The total supply from storage of floodwater is 6 MCM. The average total water consumption in paddy fields for dry season cultivation (receding rice and dry season rice) is about 28 MCM (figure 7). In addition, the average water supply from the reservoir for dry season irrigation is found 29 MCM.

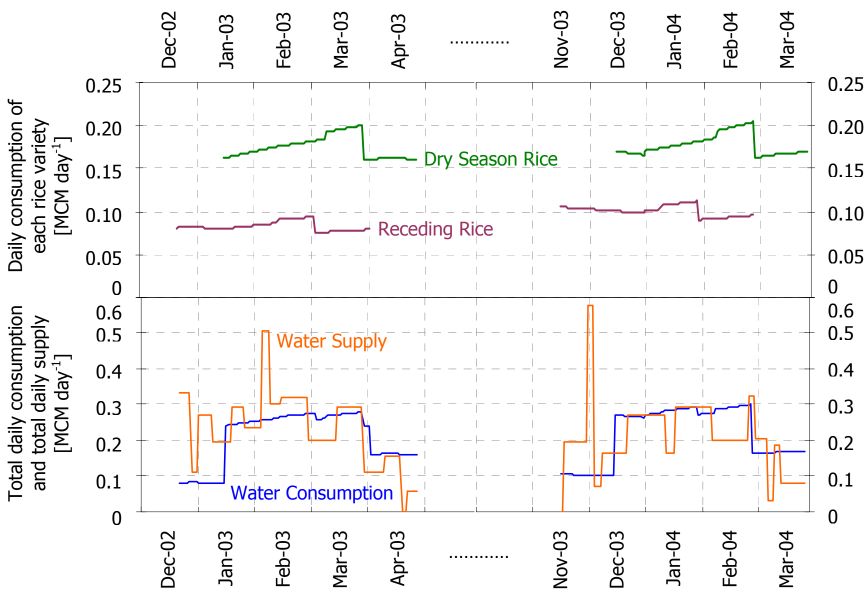

Figure 7- Water consumption in the paddy field and water supply from the reservoir

The consistency of the average total water consumption and average total water supply in dry season cultivation (2002-2004) is found. This indicates that the amount of water loss by conveyance efficiency is compensated by floodwater storage in the fields. The West Baray reservoir contributes approximately 80% of the total irrigation while around 20% of the total water use is from storage of the dike system.

CONCLUSIONS

The methods used to simulate the water balance model of the reservoir without model calibration were outlined. The water balance components of the paddy fields were also described. Lastly, the two models were connected to produce the total water balance model from the supplying reservoir to the consumptive paddy fields. The West Baray reservoir plays a key role in securing water supply in the event of water scarcity in the area. The water stored in the dike system is an additional water source for dry season cultivation.

The West Baray irrigation system can be used as a representative of other irrigations around the Tonle Sap Great Lake area; the system can be applied to areas around the lake where the slope is gentle to the lake and there is a tributary as a supplying source to the reservoir and small dikes for storing floodwater must be developed near the lake. If there is no tributary, pumping stations for supplying water to the reservoir must be installed near the lake shoreline.

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EVALUATION OF EFFECTIVE WATER MANAGEMENT IN PUMP IRRIGATION PROJECT ALONG THE MEKONG RIVER BASIN IN LAO.P.D.R

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ABSTRACT

In pump irrigation scheme, water must be used effectively since the high cost of energy is inputted. In Laos, pump irrigation is intensively introduced to stabilize and increase rice production, however many schemes have been complained about poor performance. This study deals with 3 pump projects of Kao Leo 2, Ton Hen and Pak Khagnoung in order to compare irrigation performances from the view points of engineering and socio-economy. To judge the scheme performance, 6 indicators are examined. These indicators include Water Productivity (WP), Irrigation Effectiveness (IE), Relative Water Supply (RWS), Energy Consumption (EC), Irrigation Service Fee Collection (ISFC), and the function of Water User Groups (WUGs). The results indicate that higher performance is observed in Ton Hen project, while 2 typical poor performances are found in Kao Leo 2 and Pak Khagnoung projects. Kao Leo 2 project suffers from insufficient water for cultivation due to poor distribution between up and down stream areas. Pak Khagnoung project faces low effectiveness of water use due to the lowest of WP and IE. This is considered as serious situation since it will effect on cost recovery of the project investment.

INTROCUTION

Food production shortages in the Mekong River basin will become more serious as the population is increasing. In Laos, although self-sufficient in rice production was attained in 2000, it still remains unstable as there still has been an imbalance in the supply and demand for rice at the regional level. Thus, securing and increasing rice production with emphasis on irrigation development is one of the top priorities for agricultural and rural development of the country.

Irrigation is the major agricultural technique applied in Laos. In particular, pump irrigation has been intensively implemented to stabilize rice production in rainy season and to increase production in dry season. Most pump schemes have been installed along the Mekong River and its tributaries from central to the south of the country. Up to 2004, the designed areas under pump irrigation schemes account for 145,942 ha which occupied for more than 60% of total irrigation areas compared with other schemes in the country as shown in Figure 1 (MAF [1]). According to the Nippong Koei [2], the government initiated a radical measure to increase rice production by distributing more than 8,000 pump units along the Mekong River and its major tributaries, especially in 3 main plains of Vientiane, Savannakhet and Khammuan Provinces. This project boosted the paddy production remarkably increase from 1.4 million tones in 1996 to 2.2 million tones in 2000, and then the government declared the rice self-sufficiency.

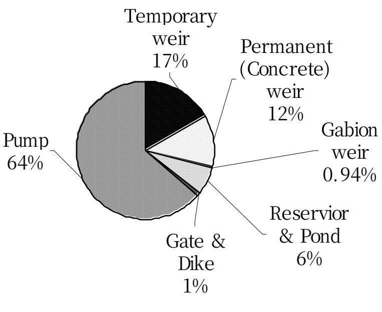


Figure 1: Dry-Season Areas by Irrigation Type in 2003

Despite their apparent attractiveness in terms of potential productivity, pump irrigation schemes become to have several problems. Most schemes have poor performance and operate below capacity due to the lack of proper lesson on management. After 2000, farmers in pump scheme refused growing rice in dry season. As a result, dry-season planted areas were gradually decreasing from 102,000 ha in 2001 to 84,000 ha in 2002 and 81,000 ha in 2003. Finally, many schemes become totally abandoned. Therefore, pump project assessment is needed to be identified the problems to trial out solution for improving and sustaining the projects.

In Laos, poor performance of pump irrigation system is a main concern of the increasing operation cost. The main cause identified is poor water management resulting to water delivery losses and inefficient water allocation (Sanyu Consultant Inc [3]). As consequence, farmers have refused growing rice under pump schemes because of inadequate water, high cost of water fee, and low return. Thus, effective and proper management is one of the most important factors in keeping pump irrigation project well operation and bring scheme to sustainable level.

Several previous literatures have assessed the performance of irrigation system. Watanabe et al. [4] studied water balance in Japan by focusing on water budget and water requirement in paddy field plots. This study is important in that average water requirement of rice for growing under stable supply was estimated at 220 to 280 grams per gram of water (0.22-0.28 kg/m^3). HEC [5] proposed that pump irrigation system was an appropriate option to develop and increase rice production along the left bank of Num Ngum River in Laos compared with gravity system. Besides, the difficulties of management capcity in irrigation schemes in Laos were identified (Siliphong et al. [6]). There have been numerous papers addressing irrigation water use, water distribution and efficiency (Rainer et al. [7], Merriam and Keller [8], Boss [9], Tomozo et al. [10], and Sato and Goto [11]).

In this study, the performances of water management in 3 pump schemes: *Kao Leo 2*, *Ton Hen* and *Pak Khagnoung* are compared. The objective is to identify pump project problems and to evaluate the effectiveness of water use and water distribution from the view points of engineering and socio-economic aspects.

STUDY AREA

The study was conducted in 3 pump irrigation schemes: Kao Leo 2, Ton Hen, and Pak Khagnoung Projects, located along Mekong Rivers and its major tributaries as shown in Figure 2. Kao Leo 2 project was constructed in 1983 under Australian government support. A project area of 1,000 ha is located at Vientiane city next to Wattay airport. However, the area is not completely planted every dry season due to irrigation water problem. Only 379 ha were planted in the dry season of 2003-04 and 90% was classified as paddy areas and 10% was vegetable areas such as sweet corns, peanuts, cauliflowers and cabbages. The water is supplied from Mekong River by *Inclined Axial Flow Pump* with capacity of 586 l/s x 4 units and distributed by a main canal, 3 secondary canals and 24 tertiary canals.

Ton Hen pump project was initiated by the Lao government in 1987. From 1992 to 1994, SIRAP continued to develop this project by promoting agricultural production and organizing WUGs to manage scheme. Since then project has been in good technical condition and it was handed over to the farmer's groups. The project area is located at Ton hen and Ban Ven villages in Savannakhet province with total service areas of 500 ha. Around 357.5 ha were planted in the dry season of 2003-04. Water is pumped up from Se Bangfai River by *inclined axial flow pump*, 555 l/s x 2 units, and delivered through a main canal, 2 earth secondary canals, and 49 tertiary canals.

Pak Khagnoung pump project was constructed in 1992 under EU support and is was transferred to MAF in 1997. It is now under responsibility of irrigation district office. Total project area is 402 ha, but only 138 ha were planted in the dry season of 2003-04 because farmers complain about the low yield. Water is lifted by *inclined axial flow pump* (355 x 4 units), located on the left bank of Num Ngum River in Pak Khagnoung village, around 16 km away from Vientiane city to the north. The distribution network consists of a main canal, 3 secondary and 22 tertiary canals.

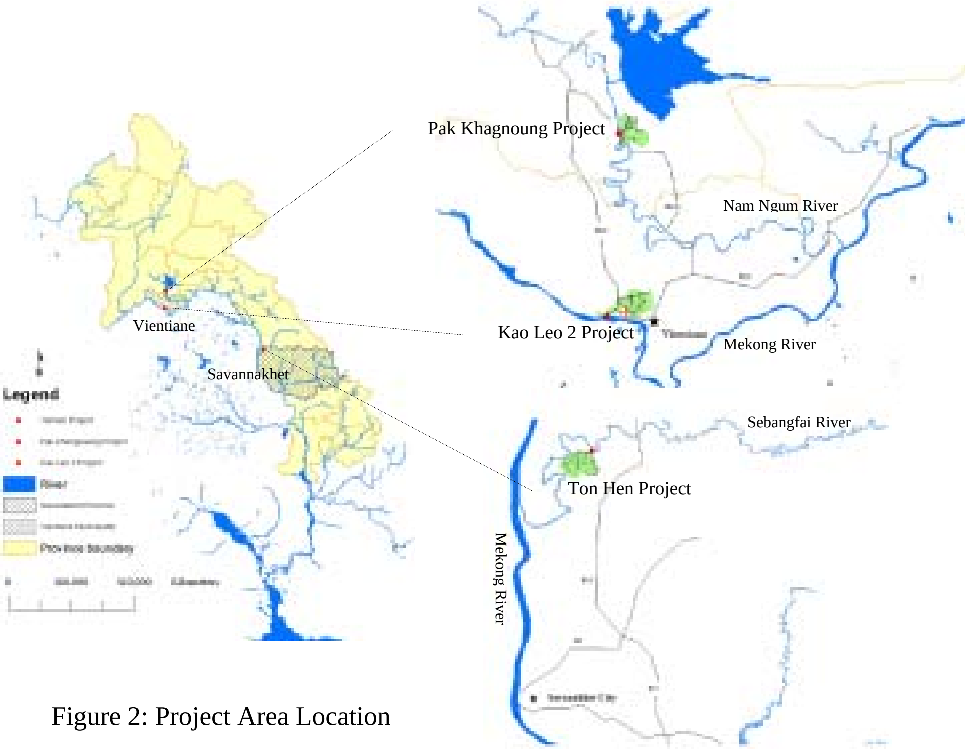


Figure 2: Project Area Location

DATA COLLECTION AND METHODOLOGY

The first survey was conducted during rainy season of 2003 within 11 pump projects in Vientiane, Khammuan and Savannakhet provinces to collect general information relating to pump project problems. The second survey was carried out during dry season of 2003-04 to observe the project sites and to collect more detailed data regarding scheme operation and maintenance in 3 pump projects. To evaluate pump irrigation performance, irrigation facilities: pumps, canals, water gates and other irrigation structures are initially evaluated. Then 6 indicators are analyzed in order to compare performance among 3 schemes. These indicators include:

Water Productivity (WP)

Greater of production with the same amount of water use is the broadest objective of irrigation management (Chambers [12]). Water Productivity, WP (kg/m^3), is defined as follows.

$$WP = \frac{\text{Production}}{\text{Water Supply}} \qquad (1)$$

Where, Production : Amount of paddy which could be harvested in a cultivation season (kg)
Water Supply : Volume diverted or pumped from river (m^3)

Irrigation Effectiveness (IE)

It is an indicator to determine how effective the farmers or projects manage the irrigated water by comparing the actual planted areas to the ideal land areas determined by the theoretical water requirement (Buarapha [13]).

$$IE = \frac{\text{Actual Planted Areas}}{\text{Potential Irriagted Areas}} \qquad (2)$$

Where, Actual Planted Area : Land areas that the farmers grow crops (ha),
Potential Irrigated Area : Land area (ha) that farmers should have been able to cultivate based on the amount of seasonal irrigated water and the theoretical water requirements, which can be estimated as.

$$\text{Potential (Max.) Irrigated Area} = \frac{E * Q}{P * WR} \qquad (3)$$

Where, E : Energy used during whole season operation (Kwh), Q : Pump capacity (m^3/hr),
P : Pump power (Kw), and WR : Water requirement (m^3/ha/season)

Relative Water Supply (RWS)

It is one of the strongest indicators to measure performance of water use in irrigation scheme. It was applied for many studies about irrigation management in the past, especially in Sri Lang ka, India, Indonesia and Philippine. RWS can be defined as the ratio of water supply at the head work and water demand from the system (Uphoff et al. [14]).

$$RWS = \frac{\text{Water Supply}}{\text{Water Demand}} \qquad (4)$$

Where, Water Supply : Volume diverted or pumped from river (m^3),
Water Demand : Volume of water to avoid undesirable water stress (m^3)

Energy Consumption (EC)

The purpose of effectiveness management is the achieving the lowest cost per cubic meter of water. The lower of EC indicates the lower operation cost with the same amount of water use. The estimation of EC (kwh/m^3) is considered as follows.

$$EC = \frac{\text{Electricity Use}}{\text{Water Supply}} \qquad (5)$$

Where, Electricity Use : Amount of energy used to operate pumps for that season cultivation (Kwh),
Water Supply : Volume diverted or pumped from river (m^3)

Irrigation Service Fee Collection (ISFC)

The percentage of ISF collected indicates the satisfaction of farmers to scheme performance. In well function scheme, the percentage of ISF collection is usually high. The ratio of ISF collection can be estimated as.

$$\text{ISF Collection} = \frac{\text{Collected Amount (kip)}}{\text{Total Amount (kip)}} \qquad (6)$$

Where, Collected Amount : Amount of ISF that actually collected from farmer in that cultivation season (kip),
Total Amount : Amount of ISF that expected to be collected based on total planted areas (kip)

WATER SUPPLY AND WATER DEMAND ESTIMATION

Water supply is the volume diverted from the river by pump at headwork of irrigation system. The volume of daily water supply, WS (m^3), is calculated as: WS (m^3/day) = Effi. * Q * T_{op} (7)
Where Effi. : Current pump efficiency (%), obtained from previous studies such as Thanasak [15] for Kao Leo 2 project, and from evaluation report by Buarapha for Ton Hen and Pak Khagnoung projects. Q: Pump capacity (m^3/hour). T_{op}: Pump operated hours per day.

Table 1 shows the estimation of water supply among 3 schemes based on current pump efficiency and actual operated hours. Due to the time and hours of operation is different during the season, daily operation hours is divided into 3 stages. According to pump operators, around 7 days is needed to repair each pump for 1 time in Kao Leo 2 project. The results showed that the total water supply is 4.723 MCM for Kao Leo 2 project, 5.690 MCM for Ton Hen project, and 2.920 MCM for Pak Khagnoung project. It is observed that although pumps have higher capacity and were operated longer hours in Kao Leo 2 project, lower volume of water supply was obtained compared with Ton Hen project due to the low efficiency and poor condition of pumps.

Table 1: Water Supply Estimation of 3-Pump Schemes

Project	Pump Unit	Q (m^3/hr)	Effi. (%)	Daily Operation (hour/day)			Not Operation Days (Pump Repairing Days)	Total Water Supply (MCM/ season)
				Stage 1*	Stage 2*	Stage 3*		
Kao Leo 2	1	2,109.6	26	0	0	0	- not operating (broken)-	4.723
	2	2,109.6	37	12	12	21	7+7+7=21days	
	3	2,109.6	26	12	12	21	7 days	
	4	2,109.6	32	12	12	21	7+7=14 days	
Ton Hen	1	1,908	65	16	14	16	0	5.690
	2	1,908	60	16	14	16	0	
Pak Khagnoung	1	1,278	65	12	0	12	0	2.920
	2	1,278	60	12	12	0	0	
	3	1,278	63	0	12	12	0	
	4	1,278	63	0	0	0	- not working -	

Note: Stage 1* is during nursery and land Preparation period, Stage 2* is after transplanting or applying fertilizer period, and Stage 3* is flowering and grain setting period.
Total operation days are 153 days for Kao Leo 2 project, 150 days for Ton Hen project, and 152 days for Pak Khagnoung project. MCM: Million Cubic Meters.

The result of daily water supply is demonstrated in Figure 3. The peak volume of water supply is at the beginning and the late of cultivation stages (Nov. to Jan. and Mar. to Apr.) in Ton Hen project, while the quantity of water supply is almost the same for the whole season in Pak Khagnoung project. In Kao Leo 2 project, the peak lifted volume is observed at the late of cultivation stage. However, the volume cannot reach peak capacity level due to the frequent breakdown of pump.

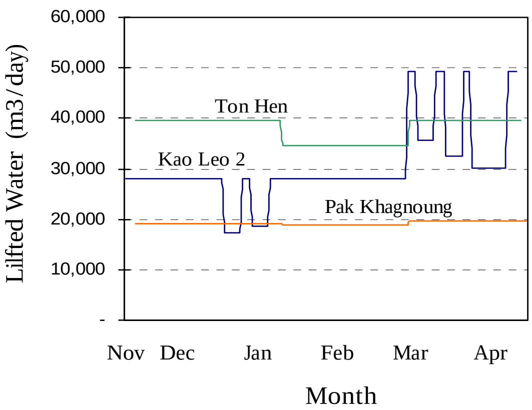


Figure 3: Daily Water Supply

Water demand is the volume of irrigation water requires avoiding undesirable water stress for the system. Water Demand, WD (m^3), can be determined as: WD (m^3) = WR * PA * CD (8)
Where, WR: Water Requirement (l/s/ha), PA: Planted Areas (ha), and CD: Cultivation Days
Cultivation days and planted areas data were directly obtained from the sites through interviewing project staff and farmers. The unit of water requirement is obtained from water management hand book (Lao-Australian Irrigation Project [16]) for Kao Leo 2 project and from data which has been used by scheme operators for Ton Hen and Pak Khagnoung projects. The result of water demand estimation is demonstrated in table 2.

Table 2: System Water Demand Estimation

	Kao Leo 2 Project	Ton Hen Project	Pak Khagnoung Project
Unit water requirement (l/s/ha)	1.49	1.54	1.65
Cultivation days	140	150	140
Actual planted areas (ha)	379	357.5	136.2
Total water demand (MCM)	6.82	7.15	2.72

WATER USER GROUP'S PERFORMANCE

It is difficult to measure performance of WUGs since there is no specific definition. In this study, the group performance is compared through investigating 30% of total farmers including project staff for each project. The farmers were interviewed in up-, middle-, and down-stream areas concerning their difficulties and their dissatisfactory with irrigation water use and the function of the groups. The group activities and farmer's participation in social works such as regular meeting on agricultural production, irrigation water management, and cleaning canals are also taken into consideration for investigation.

Figure 4 shows the percentage of farmers who are not satisfied with the function of the groups. Higher percentages are observed in Kao Leo 2 project, especially in middle- and down-stream areas. Most farmers mentioned about the weakness of water and gate operators that they lack of responsibility to mange and distribute water to each farm block. Water is flood in up stream, but shortage in down-stream areas. When water shortage occurred, farmers have to take water from canals by themselves and this has lead to the confliction among farmers between up and down streams.

Most interviewed framers complained about water not available in time and insufficient for cultivation as shown in Figure 5. Larger percentages are found in Kao Leo 2 project, especially in down stream areas. While few farmers were found in Ton Hen and Pak Khagnoung projects who complained about irrigation water.

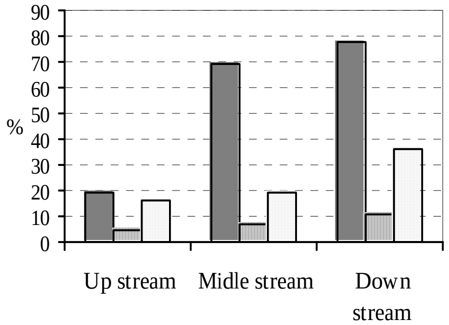


Figure 4: Percentage of farmers who are unsatisfied with WUG Perfromance

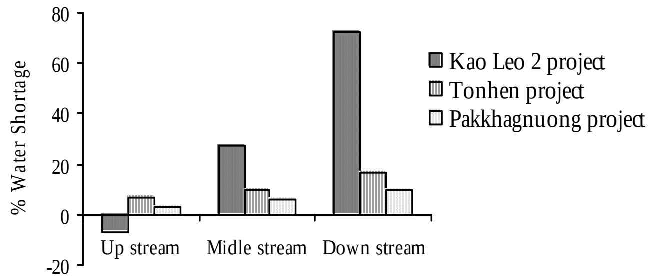


Figure 5: Percentage of farmers who complain about water shortage for cultivation

In terms of WUG structure, the size of responsible areas is largely different among each WUG in Kao Leo 2 project, ranging from 8 ha -75 ha. On the other hand, it is not so much different in Ton Hen and Pak Khagnoung projects. It is observed that larger size of WUG has rather poor performance and is hard for management, especially collecting water fee.

RESULTS AND DISCUSSION

Table 3 and Figure 6 indicate the comparison results among Kao Leo 2, Ton Hen and Pak Khagnoung Projects. Higher irrigation performance is observed in Ton Hen Project. Because the project consumed less energy with 0.10 Kwh/m^3 and it has the highest WP of 0.23 kg/m^3 and IE of 0.62. Around 72% of total project areas were planted during the dry season of 2003-04, and most of these areas (95%) could be harvested. More than 80% of total ISF was collected although ISF rate is higher as twice of Kao Leo 2 project. In addition, the condition of irrigation facilities including pumps, water gates and canals were still in good condition due to regular maintenance. The ratio of non-functional water gates is calculated at 0.03 or 3%.

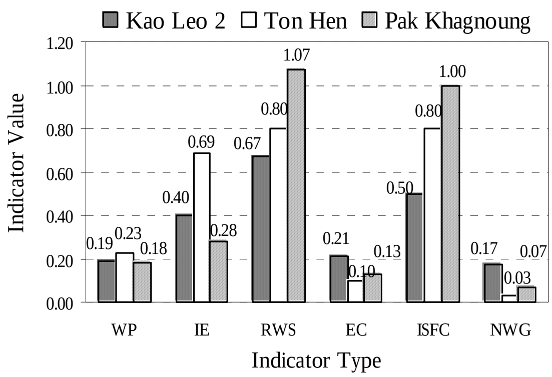
On the other hands, the lowest of RWS (0.67) is evaluated in Kao Leo 2 project though the project consumed largest energy of 0.21 Kwh/m^3 and pump were operated longer hours. WP is also significant low as 0.19 kg/m^3 because of water shortage and not available in time, resulting large paddy areas (40% of planted areas) damaged. Poor condition of pump, water gates and other irrigation facilities are also observed. From these reasons, only half of total ISF was collected even though its rate is lower than other 2 projects.

In Pak Khagnoung project, although RWS is highest (1.07), low effectiveness of water use is evaluated. Project has lowest ratio of WP (0.18 kg/m^3) and IE (0.28). This occurred because small areas, around 30% of project area, were planted compared with volume of lifted water and designed capacity of pump. According to the interview, small fields were grown because farmers complained about the low yield of rice which is difficult for them to invest dry-season cultivation due to the low return and unprofitable. In addition, the project also set up the highest rate of ISF to 437,000 kip/ha compared with others projects and this is also the reason of high investment cost.

Table 3: Comparison results of 3 projects

Results	Kao Leo 2 Project	Ton Hen Project	Pak Khagnoung Project
Total Project Areas (ha)	1,000	500	402
Potential Irrigated Areas (ha)	958.19	518.34	486.05
Actual Planted Areas (ha)	379	357.5	136.2
Harvested Areas (ha)	232.87	340.77	136.2
Yield (tones/ha)	3.81	3.74	3.07
Unit Water Requirement (l/s/ha)	1.49	1.54	1.65
Cultivation Days	150	140	150
System Water Demand (MCM)	6.822	7.150	2.724
Water Supply (MCM)	4.558	5.697	2.920
Energy Used (Kwh)	957,450	552,900	384,368
ISF rate (kip/ha)	150,000	337,000	437,500
ISF Collected Amount (%)	50.79	80.28	100

Note: Potential Irrigated Areas is calculated by following equation 3
$US 1 = 10,380 kip (rate of March, 25th, 2005)



WP : Water Productivity (kg/m^3)
IE : Irrigation Effectiveness
RWS : Relative Water Supply
EC : Energy Consumption
UEC : Electricity Consumption (Kwh/m^3)
ISFC : Irrigation Service Fee Collection
NWG : Non-functional Water Gate

Figure 6: Comparison Results

CONCLUSION AND RECOMENDATION

The government has clear policy on promoting and expanding of dry-season cultivation areas by focusing on improvement irrigation management. In this study, problems and performance of pump irrigation systems are identified. It is summarized that pump irrigation projects being used along the Mekong River basin in Laos face 4 main problems: (1) Problems of irrigation facilities (poor condition of existing structures and shortage of pump spare parts), (2) Weakness of organization (water user group and project organization), (3) Low collection of Irrigation Service Fee (ISF), and (4) Increase of energy costs.

According to the comparison study on effective water management among 3 schemes, high performance is evaluated in Ton Hen project where Water Productivity and Irrigation Effectiveness are highest. Few farmers complain about irrigation water and performance of WUGs, and hence high percentage of ISF is collected. Meanwhile, 2 typical poor performances are found in Kao Leo 2 and Pak Khagnoung projects. Kao Leo 2 project suffers from insufficient water for cultivation due to inefficient in management and water distribution. Majority farmers complain water shortage in down stream, while water is flooding in up stream. This problem has significant effect on large areas which could not be harvested. As a consequent, farmers are not willing to pay water fee and project become deficit. In the case of Pak Khagnoung project, water supply is sufficient; however the project faces low effectiveness of water use. Few areas were cultivated, while large volume of water is supplied. Decreasing in planted areas is considered as the serious situation since there will be an effect on cost recovery of the project in the future.

In accordance with the country policy on improving irrigation performance and increasing cost recovery of medium and large scale irrigation projects in low land areas, the effective irrigation water management has to be more increased. The study proposed that further detailed field observation should be conducted in Kao Leo 2 project in order to improve efficiency of water use in each water use zone and water distribution between up-and down-stream areas. Re-organizing WUG into same size of responsible areas is probably easy way to manage and control water to the field. In Pak Khagnoung project, introducing diversification crops would be effective solution to increase planted areas. These kinds of crops consume less amount of water and produce comparable incomes for the farmers in order to reduce electricity fee. Irrigation water fee rate has to be also classified in accordance with crop type and agricultural activities such as fish pond.

Acknowledgements

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HYDROLOGIC ANALYSIS AND FLOW FORECASTING OF THE UPPER MEKONG DELTA

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ABSTRACT

The prediction of flood resulting from heavy rain over a catchment is one of the major problems in applied hydrology, particularly in the Mekong Delta where flood inundation is the serious constraint for the peoples' life and activities. This paper discribed a realtime flow forecasting model which consists of combination of a Tank Model and an ARMA time series model for the Lower Mekong River Basin from Chiang Saen to Kompong Cham. It also disscusses a storage model of the Tonle Sap Lake. The "3*4+1- type" Tank Model was employed to calculate the runoff of the Mekong River and its sub catchments. The ARMA time series model was applied to the residuals of the Tank Model application in order to obtain 1 day to 5 days ahead flow forecasting after the present day based on the available data of the present day. The inflow to the Tonle Sap Lake was also estimated by the "3*4+1- type" Tank Model, whereas outflow of the lake was formulated based on the relationship between storage volumes and water level of the Lake surface. The simulated results from the Tank Model were considered sufficiently well. The combination of the ARMA to the Tank Model was found effective to improve flood forecasting at the outlets point of each sub-catchment. The established storage model for the Tonle Sap Lake could calculate satisfactorily well for simulating the outflow and the seasonal water balance of the Tonle-Sap area.

INTRODUCTION

Flooding of Mekong River has remained a major problem for human settlements and rural infrastructures, and cause serious damage to agricultural production in the low-lying area of Mekong Delta every year. The accuracy of flood prediction gives important information for flood control planning and other related water resource management.

To achieve the accurate flood forecasting, many methods have been developed to apply for suitable watershed. In the real situation, data availability is subject to those methods. Times series prediction encompasses a wide range of application domains. Based on data availability, this study was proposed two application methods of time series model, in which only one method was applied for flood forecasting.

The objectives of this study are, first, to establish the combination models, the Mekong Runoff Model and the Auto-Regressive and Moving-Average (ARMA) model for flood forecasting, and second to estimate the total inflow/reverse flow of the Tonle Sap Lake by Storage Function Model. These models were also used for evaluating the impact of inflow into the Mekong Delta, Cambodia.

Since the early 1960s, several advanced models have been developed for the Mekong River to simulate hydrological processes, such as flood control, water balance and related water resources development, by various organizations and consultants. Carbonnel et al. (1962~63) conducted a project research on sedimentology and hydrology of Tonle Sap Lake. Though it still provides useful data and information, the up-to-date topographic, hydraulic and hydrologic data are necessary for accurate calculation of water balance in the present condition.

In addition to this, Kite G. (2000) applied SLURP model (Semi-Distributed Land-Use Runoff Process) with Muskingum-Cunge method to estimate runoff of the Mekong River from Yunnan (China) to the South China Sea in Vietnam, based on data obtained from internet and some public institutions (MRC's).

Despite, many hydrological models have been developed and applied for the Mekong River for flood forecasting (Al-Soufi R.W. 2000), but these are still not sufficient to guarantee good warning information for sustainable development in the region.

Tawatachi T. (2001) applied a simple tank model (4 tanks in one column) combined with autoregressive (AR) model for flood forecasting in the Pasak River of the Chao Phraya River watershed.

In this paper, the modified series tank model "3*4+1- type" was employed to calculate the total runoff from the Lower Mekong Basin from Chiang Sean to Kompong Cham. ARMA model was used to estimate the expected error from the Tank model to obtain the final flow forecasting. The "3*4+1- type" model was used also to estimate the inflow from the Tonle Sap Lake catchments. Outflow of the lake was performed based on the relationship between storage volumes and water level of the Lake surface.

CATCHMENT CHARACTERIST ICS

The Mekong River is one of the world's 12 largest rivers, and rated as the 14th by volume and discharges measured at Pakse in Laos PDR. It varies from 1,600-57,800 m^3/s, with mean annual discharges around 15,000 m^3/s and mean discharges between June and September of about 20,000 m^3/s (according to Kite G. 2000). It covers the drainage area of 795,000 km^2 with length 4,500 km. The river starts in Tibet at elevation of 5,000 m of China and flows through Myanmar, Thailand, Lao, Cambodia and Viet Nam before reach the South China Sea. The Lower Mekong Basin covered about 609,000 km^2 in four riparian countries, Cambodia, Laos, Thailand and Vietnam (77% of the Mekong total catchment) from Chiang Saen (the borders of Myanmar, Thailand and Lao at altitude of 500 m) to the Sea in Vietnam. The Mekong River absorbs an abundant of tributaries inflow along its main stream.

The Tonle Sap Lake is the largest freshwater lake in Southeast Asia and is important source for agricultural production and fishery in Cambodia. From May to the end of October, when the water level of the Mekong river is high, water flows through the Tonle Sap River and fills the Lake up to six times its normal size, from about 2500 km^2 to 15,000 $km^{2,}$ and the volume of the lake also increases from about $2.53*10^{18}*m^3$ to $173.95*10^{18}*m^3$ depending on the flood intensity (Sothea K. et al 2003). During the year, the lake's water level varies from 1 meter above the mean sea level in the dry season to 9 meters in the rainy seasons. Data were available for 39 rainfall and 12 stream gauging stations spread across the modeling catchments for the Mekong runoff model and 14 rainfall and 2 stream gauging stations for the Tonle Sap Lake Model. The outline of study area in the Lower Mekong Basin is shown **Figure 1**.

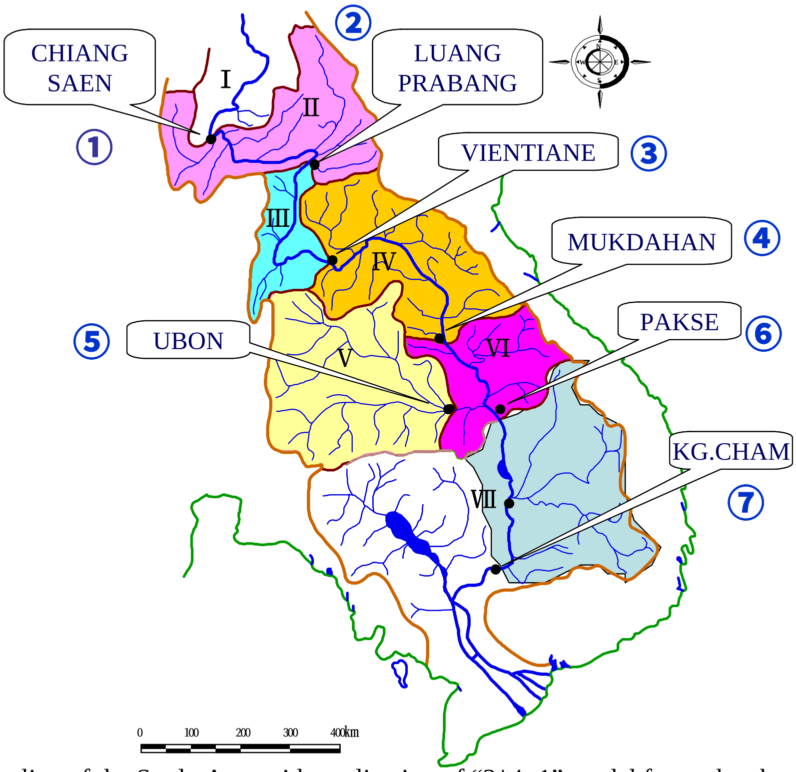


Figure 1 The outline of the Study Area with application of "3*4+1" model for each sub-catchment

DESCRIPTION OF MODEL AND ITS APPLICATION

The "3*4+1- type" Tank Model

Sugawara (1961) proposed the 4*4 type Tank Model to be applied for the watershed having dry season. In a non-humid basin, some parts are wet and the remaining parts are dry. To approximate the continuing change of wet area, the basin is divided into four zones of tank columns (S1, S2, S3, S4) from the lowest to the highest part. Tatano tried to apply the 4*4 type model for the Lower Mekong River Basin. According to Tatano's application, the "4*4-type" Tank Model had a tendency to show too much increase in stored water in the lowest tank of the nearest column to the river. Therefore, the modification of the model structure from the "4*4" to "3*4+1- type" model was examined. The geometric ratio of the S1, S2, S3, and S4 areas ranges from r=2 to r=3, which are also used as the model parameters. The "3*4+1- type" model consists of 13 storage tanks with four columns, in which each column has three storage tanks. The coefficient for the hole sizes and hole heights are the model parameters. For simplicity in model calibration, the same set of parameter values can be adapted in every column. To separate the channel flow from the slope water moment, an OPEN BOOK scheme was employed, in which catchment is presented as a quadrangle with a straight channel. **Figure 2** is illustrated the concept of "3*4+1-type" with channel routing sub-model.

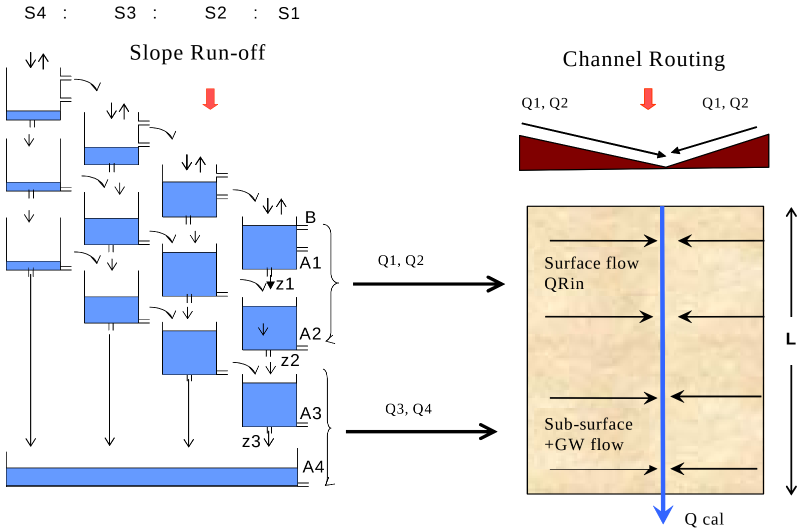


Figure 2 The "3*4+1-tye" model with channel routing sub-model

Based on Tatano's experience, the "3*4+1" Model, together with the Kinematic wave for channel routing sub-model, was employed to calculate the runoff from the drainage area of 471,995 km^2 from Chiang Sean to Kompong Cham. In this study, the whole drainage area was divided into six sub-catchments (II~VII), and one Tank Model was applied to each sub-catchment, as shown in Figure 1. Model calibration was done for the year 1995 through the trial-and-error approach, and the data for 1996~97 were used for model validation. **Figure 3** shows the obtained hydrograph of the catchment outlet at Mukdahan (a) and Kompong Cham (b).

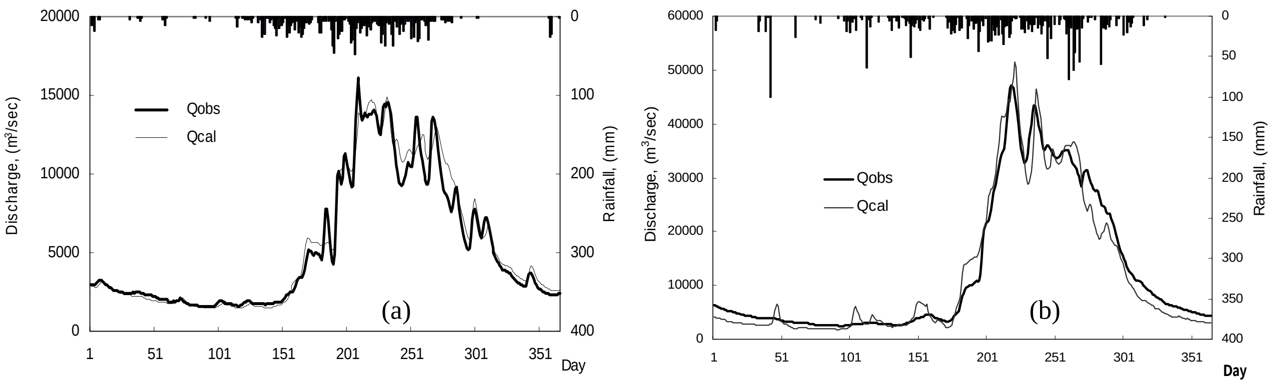


Figure 3 The simulated runoff hydrographs in sub-catchments (a) at Mukdahan, (b) at Kompong Cham

The Autoregressive and Moving-Average model (ARMA)

The ARAM time series model was applied to the residuals (different between calculated and observed discharges) of the Tank model application, in order to forecast 1day to 5 days ahead flow forecasting after the present day based on the available data. By using the Box-Jenkins (1970) approach, the basic equations of the ARMA model with autoregressive parameters (p) and moving average parameter (q) for flow forecasting in time step *t* are written as follows:

$$Z_{t+1} = \phi_1 Z_t + \phi_2 Z_{t-1} + \phi_3 Z_{t-2} + \dots\dots\dots\dots + \phi_p Z_{t-p+1} + e_{t+1} - \theta_1 e_t - \theta_2 e_{t-1} - \theta_3 e_{t-2} - \dots\dots\dots - \theta_q e_{t-q+1} \quad (1)$$

for 1 day ahead

$$Z_{t+2} = \phi_1 Z_{t+1} + \phi_2 Z_t + \phi_3 Z_{t-1} + \dots\dots\dots\dots + \phi_p Z_{t-p+2} + e_{t+2} - \theta_1 e_{t+1} - \theta_2 e_t - \theta_3 e_{t-1} - \dots\dots\dots - \theta_q e_{t-q+2} \quad (2)$$

for 2 days ahead

where, Z_{t+1} is dependent variable at time *t+1*(which corresponds to residuals from Tank Model); Z_{t-p+1} is independent variable from the previous time *t-p+1*; e_t is the white noise factor value; e_{t-q+1} is error estimated from the previous time *t-q+1*; and ϕ and θ are model parameters.

The application of combination of ARMA with Tank models

The residual obtained from the Tank Model is the time series to be analyzed by AMRA model. Though rainfall forecast is also necessary in real flood forecasting, this analysis assumed future rainfall can be perfectly forecast, and used the rainfall records as input to the Tank Model. Then, the combination of ARMA time series model to Tank Model was finally obtained the final flow forecasting in each sub-catchment reach. The procedure of this analysis is summarized in **figure 3**.

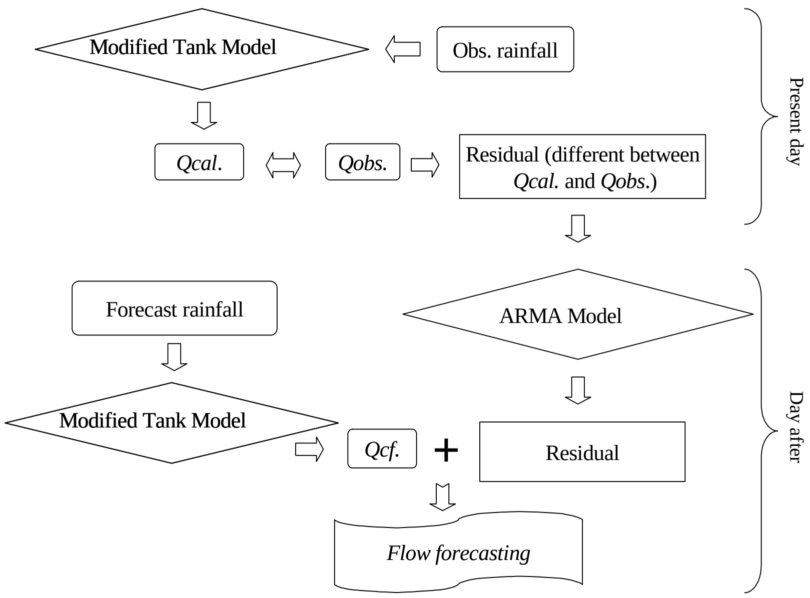


Figure 3 The procedure of the flood forecasting

The evaluation criteria for evaluating model performance of the goodness-to-fit between the calculated and observed flow was defined as follows:

1. Mean Relative Error (MRE):

$$MRE = \frac{1}{N}\left|\frac{Q_{obs} - Q_{cal}}{Q_{obs}}\right| \quad (3)$$

2. Model Efficiency (ME)

$$ME = 1 - \frac{\sigma_{\varepsilon}^{2}}{\sigma_{z}^{2}} \qquad (4)$$

where, N is the number of data points; Q_{obs} is the observed discharge (m^3/s); and Q_{cal} is the calculated discharge (m^3/s); σ_{ε} is standard deviation applied for time series (conversion of remaining error); σ_z is white noise standard deviation (standard error).

Two conceptual application methods for flood forecasting were defined in this study; ARMA application for the whole catchment (1) and sub-catchment wise ARMA application (2). The method (1) is a simple application, in which ARMA model is applied to the whole catchments reach. The method (2) is a repetitive application, in which the ARMA model is applied to each sub-catchment utilizing the available observed discharge data of the upper sub-catchment. The two application methods are presented in **Figure 4**. **Figure 5** presents the results of flow forecasting from 1 to 5 days ahead at Ubon and Pakse sub-catchments, based on the use of method (1).

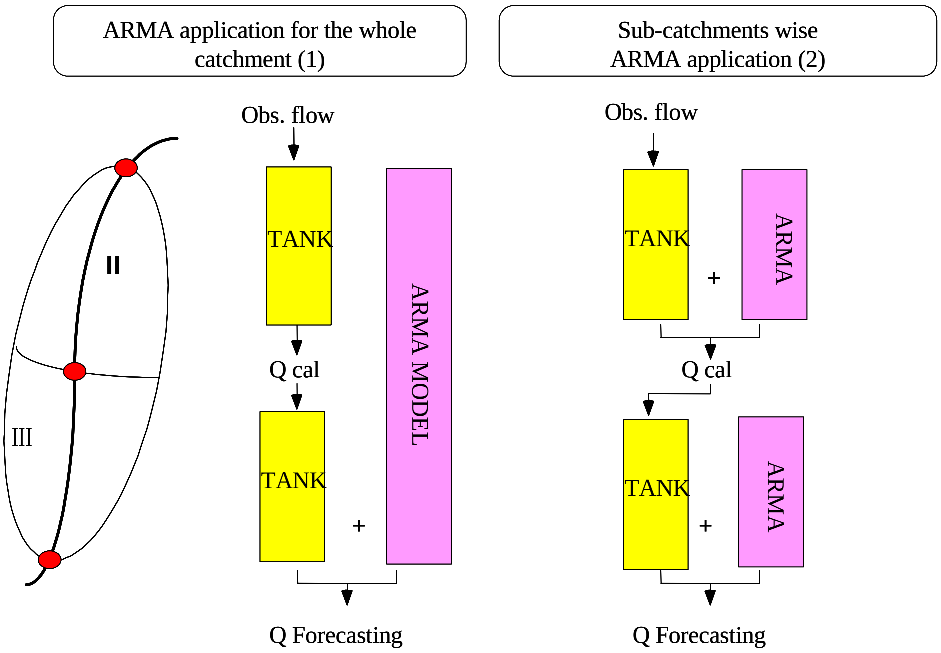


Figure 4 The application methods for flood forecasting

Discussion

The parameter values and model performances of Tank Model and the combined Tank and ARMA models are summarized in **Table 1** and **Table 2**, respectively. In Table 1, the Tank Model application is considered reasonable for model simulation, in which its mean relative errors are ranging from 0.07 to 0.3. Table 2 shows that, for 1 day to 5 days ahead forecasting, the combined Tank and ARMA models were found better performances than Tank Model application alone. Based on this performance, the better results produced from ARMA time series model depends on the good estimation of the residuals from the Tank Model.

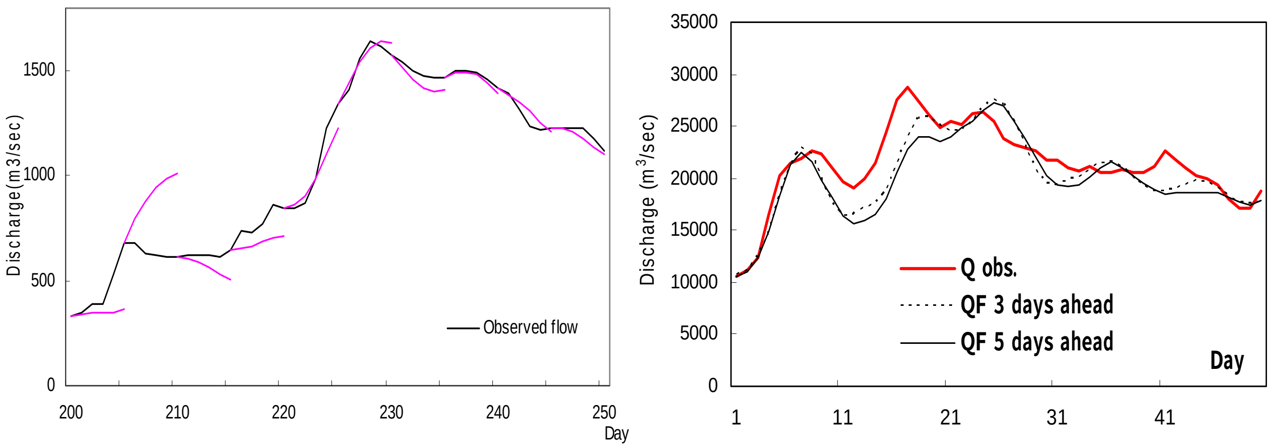
The method (1) does not take into account the use of present discharge data of the upper sub-catchments. In Figure 5, the rising parts of forecast hydrographs were having different shape against its observed flow hydrograph. Therefore, the use of method (1) for flow forecasting is needed to be improved. However, to improve of flood forecasting results, method (2) which utilizes the present discharge data at the upper sub-catchments for ARMA model is expected to produce more accurate results for flood forecasting.

Table 1 Summary of parameter values and Tank Model performances

Sub-catchment	II	III	IV	V	VI	VII
Area, km^2	79000	31000	92000	50000	104000	115995
Upper flow coefficient *(B)*	0.15	0.40	0.45	0.06	0.41	0.55
Overland flow coefficient *(A1)*	0.12	0.20	0.20	0.05	0.31	0.50
Infiltration coefficient *(Z1)*	0.25	0.50	0.31	0.06	0.20	0.05
Root zone coefficient *(A2)*	0.05	0.06	0.12	0.03	0.10	0.05
MRE , % (Tank Model)	8.83	7.38	8.50	30.80	7.15	28.0

Table 2 Summary of parameter values and ARMA model performance

Sub-catchment	Flow forecasting point	Mean Relative Error (TANK+ARMA) ,%					
		MRE (%) (Tank Model)	Forecasting Day				
			1day	2days	3 days	4 days	5 days
SubII	②	8.83	2.74	4.44	5.30	5.79	6.04
SubIII	③	7.38	2.01	2.94	3.61	4.08	4.43
SubVI	④	8.50	3.17	5.57	7.30	8.37	9.02
SubV	⑤	30.80	1.80	3.80	5.86	7.89	9.81
SubVI	⑥	7.15	2.98	4.39	5.14	5.50	5.66
SubVII	⑦	28.00	2.56	3.90	8.20	8.90	10.60



(a) Flow forecasting hydrographs at Ubon (V)

(b) Flow forecasting hydrographs at Pakse (VI)

Figure 5 Hydrographs of forecasting flow of 1 to 5 days ahead at (a) Ubon and (b) Pakse sub-catchments

The Tonle Sap Storage Model

The Tonle Sap Lake area was divided into the catchment area and the lake surface. The 3*4+1 model was employed to calculate the total inflow from the two sub-catchments (Pursat and Sen), where daily data records of discharge, water level in 1995 to 1996 and rainfall for the same period are available. Outflow/reverse flow of the lake was estimated based on the relationship between storage volumes and water level of the lake surface. From the digital elevation data, the relationship curve between storage volumes and water levels was established. The storage change of the Lake was calculated from the water balance of the lake, and then converted to daily change in water level. **Figure 6** shows the catchment's modeling and the procedure of the Tonle Sap Lake Storage Model. The daily change of storage volume was maintained the mass balance equation between the inflow and out flow of the lake:

$$\frac{H^{t+1}-H^{t}}{\Delta t}\frac{W^{t+1}+W^{t}}{2}=\frac{(Q_{in}^{t+1}+Q_{in}^{t})-(Q_{out}^{t+1}+Q_{out}^{t})}{2}+W^{t}(R-ET_{a}) \qquad (5)$$

where, *t*, *t+1* are the beginning and end of the time step; *H* is water level of the Lake (m); Q_{in} is inflow into the lake (m^3/s); Q_{out} is outflow/reverse flow of the lake (m^3/s); *W* is storage area of the Lake (m^2); *R* is net rainfall (mm); ET_a is evapotranspiration (mm). The ET_a used in this model was calculated using Penman-Moneith method of FAO version for pan evaporation. The *H* and *W* were estimated based on the relationship between storage volume and water level of the lake. In this study, DEM of the Tonle Sap Lake was used for *W(H)* function analysis.

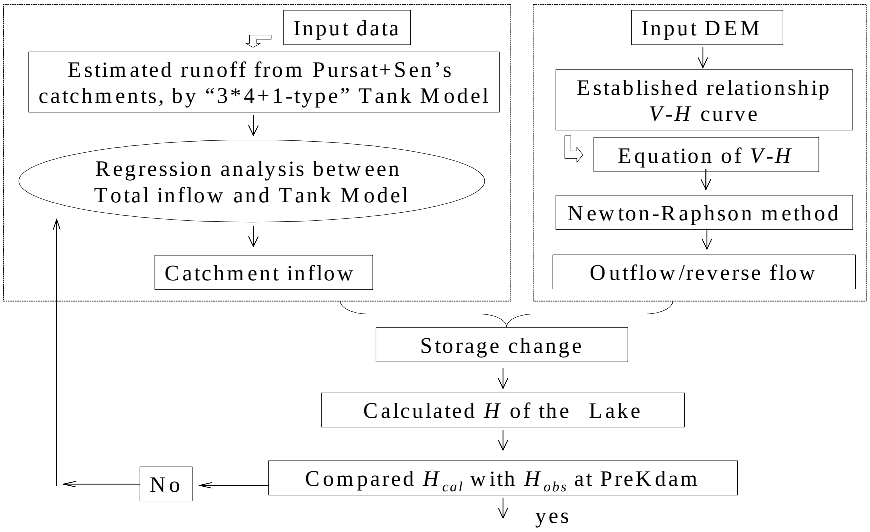


Figure6 The procedure of catchment's modeling and the Tonle Sap Storage Model

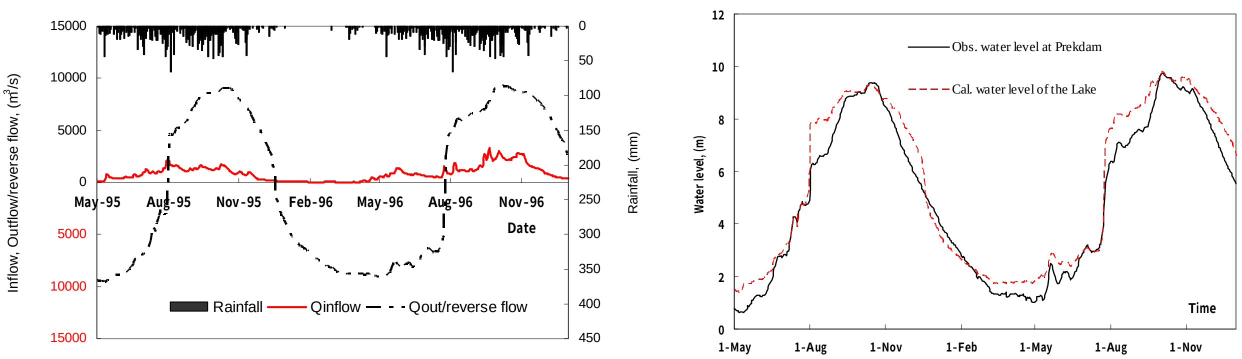
Estimation of outflow/reverse flow of the Lake

The Tonle Sap River is flowing between its lake and the Mekong River at Phnom Penh and the flow direction changes depending on the water level of the Mekong River. The calculation in this case was considered as gravitational drainage, in which outflow /reverse flow of the Tonle Sap Lake can be obtained by Manning equation:

$$Q = \frac{AR^{2/3}}{n}\sqrt{\frac{H_1 - H_0}{L}} \qquad (6)$$

where, Q is outflow/reverse flow (m^3/s); A is cross-sectional area (m^2); R is hydraulic radius (m); H_1 is water level in side the reach (m); H_0 is water level outside the reach (m); L is distant between two key stations (m); n is Manning coefficient. Cross-section of the river was assumed as trapezoidal for open channel flow

By using the Newton-Raphson's iteration method, **Figure7** are shown the calculated total inflow and outflow/ reverses flow **(a)** and water level **(b)** of the Tonle Sap Lake, compared to water level at Prekdam station.



(a) Calculated inflow/reverse flow of the Lake (b) Calculated water level of the Lake

Figure 7 The outcomes of the Tonle Sap Lake Storage Model

CONCLUSION

The establishment of the "3*4+1-type" Tank Model for estimating runoff of the Mekong River having distinct dry season was considered well satisfactory for this stage.

However, the 3*4+1 model is considered to have a capacity of representing the watershed properly and to be used as an effective toll for flood forecasting and estimating inflow to the Mekong Delta. The combination of ARMA model was also found effective to improve flood forecasting at the outlets point of each sub-catchment.

The accuracy of time series model for flood forecasting is fundamental to many decisions-making, related to flood warning system in the region. Consequently, to improve the capacity of flood forecasting with more accurate results, the method (2) will be taken into account for next analysis.

The results of the Tonle Sap Lake model were proved to be a better way for local drainage analysis. It is also suitable to evaluate the change in water level of the Lake and rivers for various activities, related to navigation, fisheries and floodplain management.

For more accurate modeling of flood forecasting, it is crucially important to collect long historical data on rainfall, discharge and water level records as well as channels geometric information.

ACKNOWLEDGEMENTS

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HYDROLOGICAL EXTREME EVENTS IN LAO PDR

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ABSTRACT

In Lao PDR, flood and drought are the two main hazards. Their occurrences are irregular but they are closely associated with anomalies both meteorological and hydrological extreme events.Large flood can be occurred immediately after severe drought or low flow events. Several examples can be cited: Extreme low flow of the Mekong river in 1965, followed a large and catastrophic flood in 1966; severe drought in 1977, followed by another large flood in 1978. In small scale, the inter annual variability is also very important. In conclusion, natural hazards continuously occur and shape the environment on which our societies depend, but there is a lot that scientific knowledge and appropriate public policy can do to prevent human disaster resulting from them.

INTRODUCTION

Geographically setting, the Lao People's Democratic Republic is a landlocked country, situated in the heart of the Southeast Asia countries. The total country's area is 236800 km^2, around 80% lie with the Mekong basin and the remaining 20% drains through VietNam directly to the South- China Sea. The major tributaries of the Mekong, all have significant watershed and there are hundreds of small streams with mostly have a torrential regime during the rainy season usually called dry rivers. The climate is basically tropical monsoon, with distinct wet season from May through October, a cool dry season from November through February and a hot dry season in March and April. This is a typical characteristic of the climate observed with a rainfall distribution of about 80% from May to October representing the annual rainfall.

Flood and drought are the main natural disasters resulting directly from the hydrological extreme events. These two phenomena can be expected to occur every year, if no flood, drought can occur at some region in the country and in some year, both can be observed, drought at beginning of the rainy season, and flash flood at the end of the monsoon. As the majority of the population live in rural area and their living depends on agricultural production, they are the most vulnerable from natural disasters. In an effort to reduce the impact of the natural disasters in the future, the Lao Government is focusing on natural disaster management issues, prioritizing the need for early warning systems and natural disaster preparedness for communities, establishing an emergency group that consisted of representative of ministries and other organizations, to manage and solve the problems encountered. The following sections will provide some information about the hydrological extreme events observed in Lao PDR since the end of the 19th century.

IDENTIFICATION OF THE EXTREME EVENTS

The Mekong water levels(flood events)

Based on a very long term record data of the Mekong water level at Vientiane gauging station from 1895 to 2002, the maximum gauge height reading of 12.71 m observed on 4 September 1966 was a largest flood in magnitude and duration. However, 43 years before, a large flood occurred in 1924 with a peak of 12.68 m was also a catastrophic event. The peak height reached 12.60 m on 19 August 2002 was the third highest point reached since it overflowed and flooded all of urban Vientiane in 1966. During the large flood in1978, the plain of Champasack province has suffered severe damage in agricultural production and public properties where the maximum water level of the Mekong at Pakse reached 14.70 m on 17 August with a corresponding of maximum peak flood discharge 58000 cubic meters per second.

Due to periodic flooding conditions, six flood prone areas were identified as seen in figure 1; Vientiane, Borikhamxay, Khammuane, Savannakhet, Champasack and Attapeu provinces. Table 1 summarized the Mekong discharge at Pakse with a total drainage of 545000 square kilometers and is considered an important outlet of the Mekong mainstream. Annual discharge variation can be seen in figure 2. Table 2 and 3 for Sekong river event.

The Mekong extreme low flow events

Statistics on the extreme low flow of the Mekong at Vientiane since 1895 have shown that the lowest of 6.67 m on 7 August 1992 was considered as the absolute low flow event for Vientiane municipality. For the other years the minimum water levels were recorded below:

In 1902 the gauge height was 7.89 m with a discharge 10400 m^3/s

In 1906 the gauge height was 7.18 m with a discharge 9080 m^3/s

In 1992 the gauge height was 6.67 m with a discharge 7559 m^3/s

Tributaries

Three river categories are chosen for identification:

- Small size catchment: Nam Lik at Kasy in Vientiane province with drainage area DA= 374 km^2.
- Medium size catchment: Nam Ngiep and Nam Sane at Borikhamxay province with drainage area DA = 4270 km^2 and 2230 km^2 respectively.
- Large size catchment: Nam Sekong at Attapeu province with a drainage area DA = 10.500 km^2 and its important tributary Sekhamane with DA = 4454 km2.

Nam Lik at Kasy

From 1987 – 2002, the annual peak discharge more than 300 m3/s was observed in August 1995 and severe flooding occurred at Kasy district(see figure 3). In downstream of Nam Lik severe flood was also observed in August – September 1995 resulting the combined effect from Nam Ngum in the Vientiane plain.

Nam Ngiep and Nam sane

From figure 4 and 5 the river flow variations occurred between 4 – 5 years of intervals. These rivers are in the Borikhamxay province where flooding condition are frequently observed.

Sekong at Attapeu

From figure 6 it is clear to observe a ten year-return period of severe flooding conditions, particularly the 1996 flood was considered as the most severe and catastrophic due to the flashy condition from Sekong and Sekhamane.

In addition to these three categories of rivers as selected, the hydrological extreme events occurred in 2002 have catastrophic impacts in Viengphoukha district in northern region and severe damage on Nam Phao hydro-electric plant in central region, due to the extreme heavy rainfall.

RIVER FLOWS AND ENSO EVENTS

ELNINO has direct impact on weather conditions and river flow variations in Lao PDR during the pass decades.

Strong ENSO events in 1982/83

Extreme heavy rainfall with more than 500 mm/day was observed on the 25/26 June 1983 at Paksong in the Southern province. Severe flood from Sedone River with property damages were reported. As it happened at the beginning of the transplantation season, damages on rice crop were not important.

Drought during ELNINO 1987/1988

Severe drought occurred in Northern region and rainfall much above normal in Central and Southern regions in 1987, the beginning of the event. In 1988 drought conditions effected all provinces. Extreme low flow was occurred throughout the country.

The 1991/92 ENSO events

In 1991 the annual precipitation was above normal and flooding conditions were observed in Southern province.

In 1992 the situation was completely different, low rainfall and very low River runoff for all rivers. Even the Mekong mainstream, the lowest water level at 6.67m of the annual minimum was observed at Vientiane and the lowest annual discharge was only 24600 m3/s observed at Pakse.

Recent ELNINO 1997/1998

In 1998 dry condition prevails throughout the country, in some region precipitation was only 50% of normal. Low flow conditions occurred in several rivers. Annual discharge of Mekong river was only 72% of the average(1961-1998)

IMPACTS FROM HYDROLOGICAL EXTREME EVENTS

From example of a prolonged dry condition 1992/1993, the annual electricity production of Nam Ngum 1 and Xeset, a total loss was estimated about 80 millions U.S dollars (according to the EDL report)

Nam Ngum 1 with deficit 68.822.877 U.S dollars

Xeset with deficit 11.756.650 U.S dollars

For flood, damages were annually reported since the large flood in 1966.

CONCLUSION

In Lao PDR, flood and drought are the two main hazards. Their occurrences are irregular but they are closely associated with anomalies both meteorological and hydrological extreme events.

Large flood can be occurred immediately after severe drought or low flow events. Several examples can be cited: Extreme low flow of the Mekong river in 1965, followed a large and catastrophic flood in 1966; severe drought in 1977, followed by another large flood in 1978. In small scale, the inter annual variability is also very important. In conclusion, natural hazards continuously occur and shape the environment on which our societies depend, but there is a lot that scientific knowledge and appropriate public policy can do to prevent human disaster resulting from them.

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EROSION OF MEKONG BANK IN CAMBODIA

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ABSTRACT

The objective of the project is to determine the mechanical and physical characteristics of soil surface of the banks. The study site is called Koh Chorram situated in Chrouy Taek village, Kingdom of Cambodia, along the Mekong river at about 40 km northeast of Phnom Penh capital. To observe the flow direction of groundwater, the installation of five bore-holes has been made perpendicularly the river. The depth of the boring is 35m, the spacing of every boring is 100 m. The sampling of these five borings was taken to the laboratory to determine type and characteristic of soil in different depths (6m, 18m, 21m, 27m, 35m). The study of geotechnical condition of the Mekong river bank showed that from the soil surface to the depth of 8 m the soil type is a non plastic sandy silt, from 8 m to 24 m it presents sandy clay plastic. By using Geo-slope software, we find the safety factor (FS) 0.699 for ordinary method, 0.678 for Bishop method, 0.712 for Janbu method. We see that the safety factor of bank slope is lower than 1.5 (limit value of safety factor), therefore this slope is unstable without taking account the interstitial pressure, in that case we must protect our slope by using the géotextile or constructing retaining walls.

OBJECTIVE

The Mekong river plays a major role on physical geography and on the economy of countries that it crosses. The erosions of Mekong banks have caused the change of the original ground surfaces and the depth of river bed. The main objective is finding the causes and mechanism of Mekong bank's destructions and aiming to analysis of perturbation of water river; to collapse terrains causing by flow actions; and to slope stabilities under the phenomenon cycle of Mekong regimes.

HYDROLOGY OF MEKONG RIVER

The Mekong river has got a distance of 4880 kilometers from Tibet's plateau up to China sea. It ranks the 12th for its length and the 21st for its surface in the world. During the rain season, the water level goes up from June or July to November or December with the discharge of 85% to 90% of annual flow. At the end of November, the discharge decreases from 20 to 30% of annual flow. The Mekong river flows from Yunnan's province of China across Myanmar, Lao PDR, Thailand, Cambodia and Vietnam. After the sites researches, the natural resources in the Mekong catchment's areas are still in good condition except in some regions only. The Mekong river allows the population, vegetables, plates and ecosystem to grow up with its flood and low water cycle. The annual flow of Mékong is about 475×10^9 cubic meters coming from the main sources as presented in Table 1.

Table 1. Approximate distribution of MRB water resource by country or province.

	Yunnan Province PRC	Myanmar	Loa PDR	Thailand	Cambodia	Vietnam	MRB
Catchments Area as % of MRB	22	3	25	23	19	8	100
Average flow(m^3/sec) from area	2410	300	5270	2560	2860	1660	15060
Average flow as % of total	16	2	35	18	18	11	100

The Mékong river crosses Cambodia from the North to the South in distance of 480 kilometers, and provides 86% of Cambodia surface with its water regimes. Every year, its flood about 450 × 10^9 cubic meters streaming into the plain and the Tonlé Sap reservoir before going into the sea of China. The annual discharge of Mekong river in Cambodia is about 300 × 10^9 cubic meters distributing to its hand reservoirs, and about 500 × 10^9 cubic meters flowing out China's sea, Figure 1.

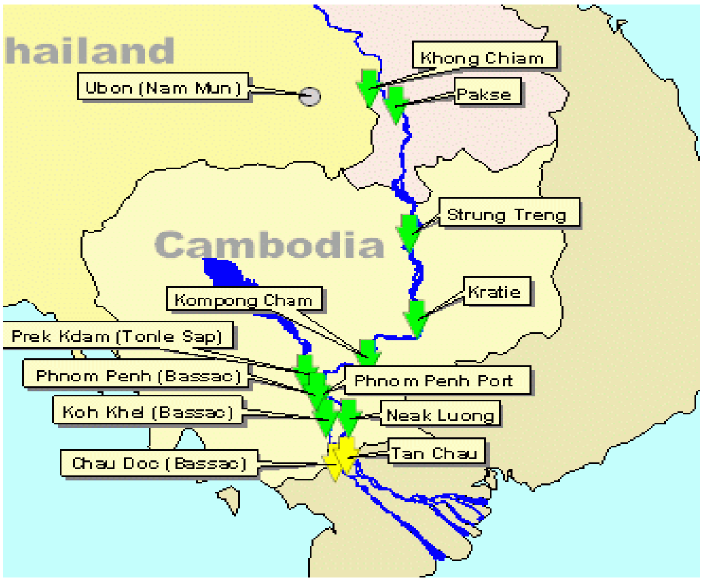

Figure 1. The Mékong River in Cambodia.

Nearly 25% of the Cambodia's Mékong water comes from the Tibet plateau and from China, 50% from the North-east of Thailand and Loa PDR, 20% from North-east of Cambodia and regions near Laos and Vietnam, and the rest about 10% comes from nine small rivers in Cambodia flowing into Tonlé Sap basin. Once, its highest flood level 23 meters, about 66700 m^3/s, in 1939 in Kratie province of Cambodia. The alarm level was 22 meters, Figure 2.

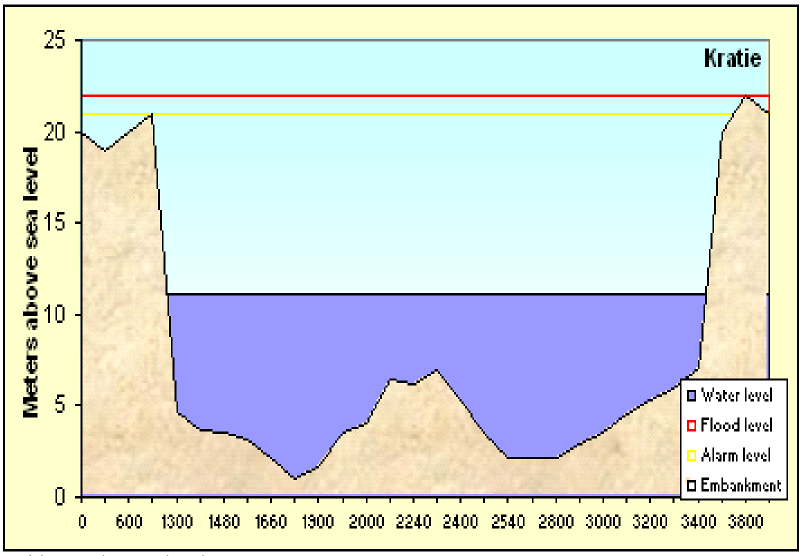

Figure 2. Schematic profile with actual water level.

After sites researches, the erosion of many natural banks along the Mékong begins from upstream to downstream. These bank erosions due to human activities, boat's ports, cultivated fields especially due to surface runoff during the rain season.

CHOICE OF SITE EROSIONS

After the sites studies along the Mekong river from Kratie to Phnom Penh, one enormous collapse zone is situated in village CHROUY TAEK of Kandal province, see Figure 3. Every year, this site has caved-in about 20 to 30 meters along the actual banks into water river. Sine 30 years, the total collapse sites is about 500 meters in distance forcing many people in place to move from the dangerous zones, see Figure 4. Consequently, the sedimentation has formed its size about 1 kilometer at downstream of collapse zones. The depots due to the ground erosion have formed a big sand island at the bottom of Mékong river disturbing water circulation during the humid season, see Figure 5.

Figure 3. Collapse zones in village CHROUY TEAK.

Figure 4. Houses moved from dangerous sites.

Figure 5. Big sand island at the bottom of Mékong.

SAMPLING AND WATER MEASURING

a) Taking soil sample

At Chroy Taek, the caved-in banks are vertical and depth. The installation of big rotary is difficult and impossible. So, the soil sampling at erosion banks were done by hands digging a hole to take a soil sample with PVC tubes of 10 cm diameter and 20 cm height, see Figure 6. The soil samples were taken at 4 different stratums (2m, 6m, 8m, 10m) in 3 ranks of 20 meters from each other:

Figure 6. Soil sampling at site erosions.

The sampling is used for the test of grading and shearing at different depths. The result of laboratory test for hole I-1 is given below:

Table 2. Sieve analysis of sample I-1.

Total mass of sample before washing		365.45g	
Total mass of dry sample		117,43g	
d (mm)	Mass of soil retained on each sieve (g)	Percent of soil retained (%)	Percent passing (%)
5	2.43	0.66	99.34
2.5	4.63	1.27	98.73
1.25	5.4	1.48	98.52
0.63	6.07	1.66	98.34
0.315	6.77	1.85	98.15
0.16	7.51	2.06	97.94
0.08	117.43	32.13	67.87

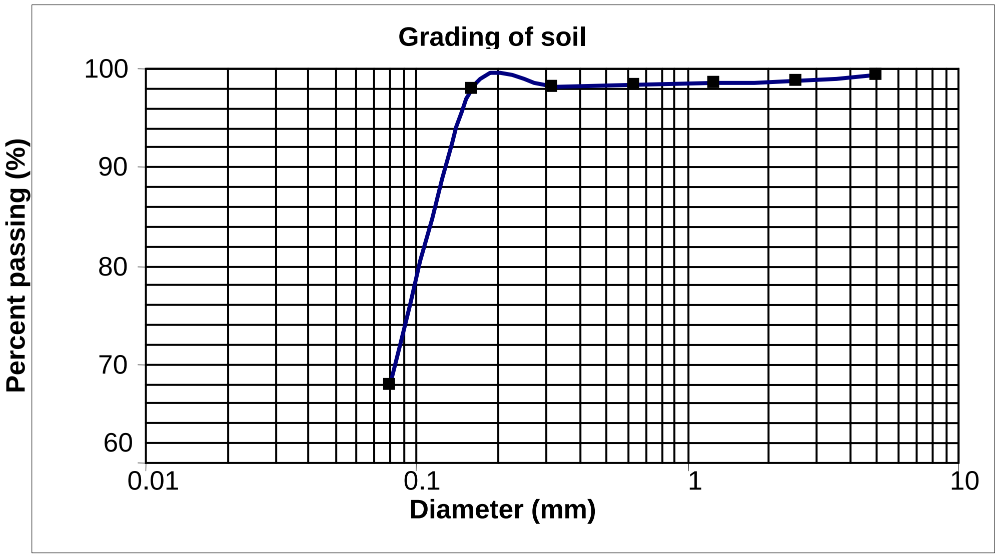

Figure 7. Curve of soil grading of sample I-1.

Table 3. Shear test of sample I-1.

No.	Unit	1	2	3
Volume of cutting shoe	cm^3	132.72	132.72	132.72
Mass of cutting shoe	g	168.58	168.58	168.58
Mass of cutting shoe and humid soil	g	343.9	340.71	353.07
Bulk specific density	g/cm^3	1.32	1.30	1.39
Average of bulk specific density	g/cm^3	1.34		
Mass of container	g	28.12	27.67	27.99
Mass of container and humid soil	g	68.98	80.91	58.42
Mass of container and dry soil	g	65.47	78.85	55.02
Moisture content	%	9.40	4.02	12.58
Average of moisture content	%	8.67		
Vertical stress	kPa	48	96	144
Tangential stress	kPa	43	86	126
Cohesion	kPa	2.00		
Angle of internal friction		40.85		

b) Observing the flow direction of groundwater

The direction of ground water at the collapse sites are defined by 5 bore-holes perpendicular to the river and situated 100 meters from each other. The water level in the bore-holes was measured 3 times a day: 6h00, 12h00 and 18h00, Figure 8. The sampling of these five borings was taken to the laboratory to determine type and characteristic of soil in different depths (6m, 18m, 21m, 27m and 35m). The result of laboratory test is given below:

Figure 8. Bore-holes and measuring ground water level.

c) Measuring of Mekong water level

The water level in Mekong river is daily measured 3 times a day at the same period as in bore-holes by using wood post graduated putted in the river, Figure 9. The water level in the bore-holes and in the Mekong river have been drawn as histogram as presented in Figure 10.

Figure 9. Wood post graduated in river.

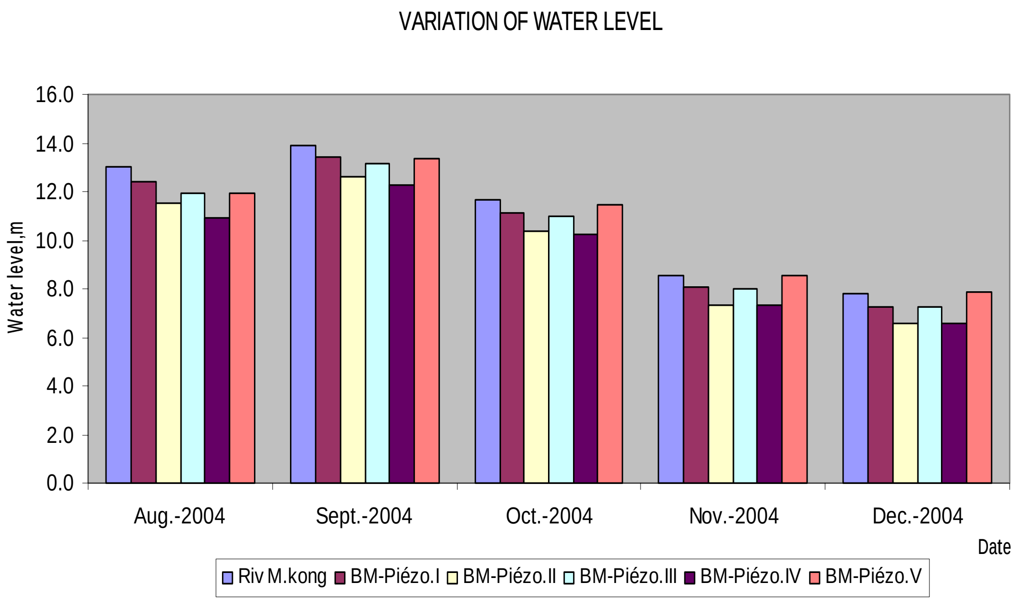

Figure 10. Relation between ground water level and Mekong regimes.

d) Interpretation of water level result

The variation of the water level in the boring corresponds to the variation of the water level in the river, so we can say that, when the water in the river goes up, the level in the boring goes up also. The curve indicated the flow direction of the groundwater shows that: during the rainy season the water of river nourishes ground water or the watertable.

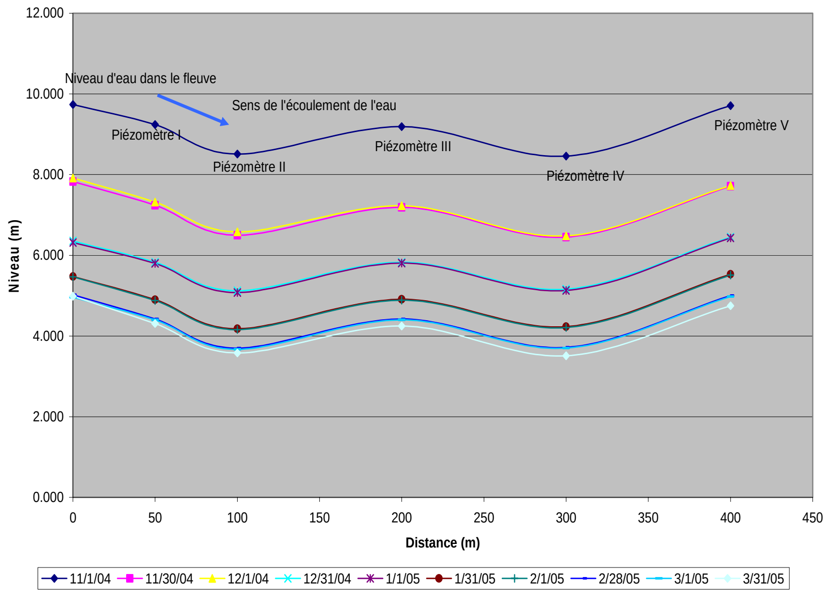

Figure 11. Direction of groundwater .

CROSS SECTION OF MEKONG RIVER

The transversal section of Mekong was defined by ADCP instrument. The measuring was done at 8 meters on the left and 9 meters on the right of erosion sites studied. The length of river section is about 2884 meters. The water depths are variable from 2 to 4 meters on the left side, but from 16 to 20 meters on the right side, see Figure 12. The flow direction heads for the North to the South with the water speed about 0.3 to 0.6 m/s, see Figure 13. The maximum velocity is about 0.7 m/s, see Figure 14. The discharge is variable according to the depth about 1900 to

6400 cubic meters/ sec along the section measuring. The maximum discharge obtained is about 6475.6 cubic meters/ sec.

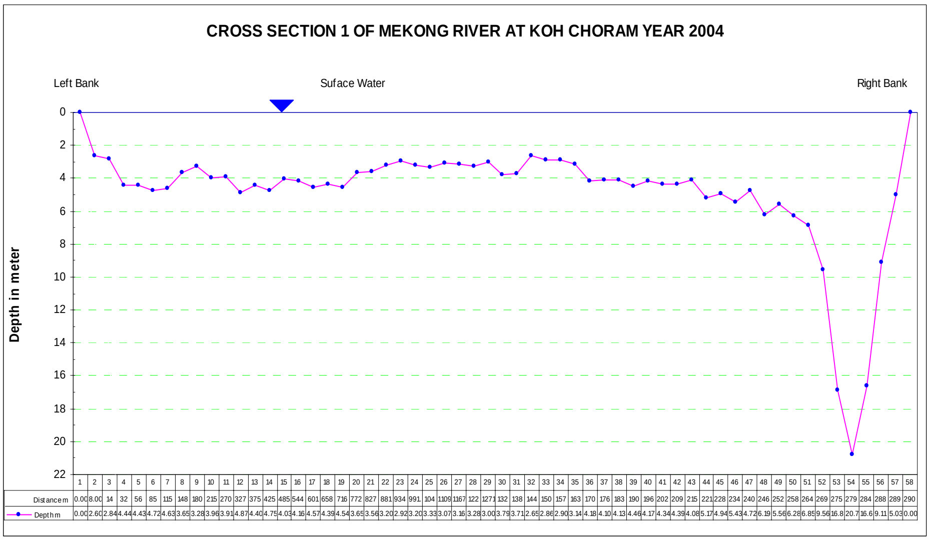

Figure 12. Cross section of Mekong river at KOH CHORAM year 2004

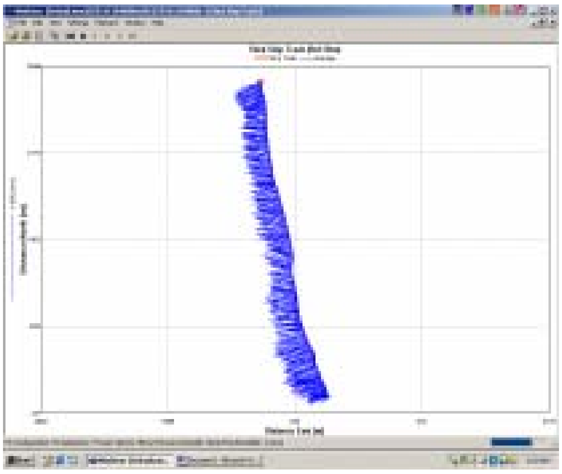

Figure 13. Flow Direction at studied section.

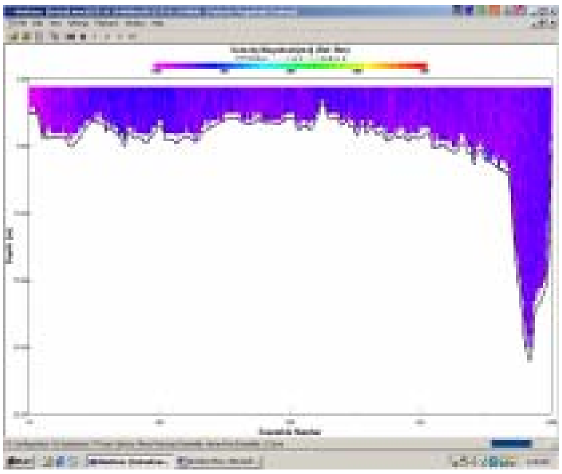

Figure 14. Velocity magnitude of water river, m/s.

CONCLUSION

The study of geotechnical condition of the Mekong river bank showed that from the soil surface to the depth of 8m the soil type is a non plastic sandy silt (soils characteristics $\gamma = 16.6$ kN/m^3, $\varphi = 37^o$ and C = 6.5 kN/m^2), from 8m to 20m it presents sandy clay plastic (soils characteristics $\gamma = 15.5$ kN/m^3, $\varphi = 26^o$ and C = 19 kN/m^2). By using Geo-slope software, we find the safety factor (FS) 0.699 for ordinary method, 0.678 for Bishop method, 0.712 for Janbu method. We see that the safety factor of bank slope is lower than 1.5 (limit value of safety factor), therefore this slope is unstable without taking account the interstitial pressure, in that case we must protect our slope by using the geotextile or constructing retaining walls.

At the place where we has been researched on the reason of the bank collapsed, it has several factors that influence the bank such as:

- The mechanical and physical characteristics of soil are very weak, the research area contains the light soils that alter themselves easily under the climate influence.
- The human activities destroy the structure of soil, such as the big waves of the boats, the sand exploitation.

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RESEARCH ON RIVER BED EROSSION AND SEDIMENTATION PREDICTION BY MIKE21C MODEL AT TAN CHAU – HONG NGU AREA, IN THE MEKONG RIVER (LMR) (*)

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ABSTRACT

In the last few decades, bank erosion and sedimentation have caused much damage for the LMR especially at Tan Chau-Hong Ngu reach. Therefore the bank revetment of 612 m long has been constructed in 2002-2003 to reduce such damages, but its effect needs to be considered. In the other hand, the river bed changes at the reach recently results in the sedimentation at the entrance of Hong Ngu channel causing the obstruction of navigation and increases erosion at Long Khanh channel especially at Long Thuan commune – Hong Ngu district. The research on riverbank erosion and sedimentation at the concerned area is urgent to consider the Tan Chau bank revetment effect and, at the same time to suggest suitable solutions to reduce erosion at Tan Chau and Long Khanh channel, to reduce sedimentation at Hong Ngu channel entrance. This paper introduces the erosion and sedimentation prediction and suitable alternative suggestion for the concerned area carrying out by the MIKE21C model, the Danish Hydraulic Institute two-dimensional software.

INTRODUCTION

The Lower Mekong Delta (LMD) river system has suffered from riverbank erosion and sedimentation almost everywhere (see Figure 1). According to the nearest statistic data there are numbers of bank erosion and sedimentation areas influenced LMD social-economic development. These areas involve 19 locations of high erosion rate (greater than 10 meters per year), 56 locations of medium erosion rate (5-10 meters per year), 59 locations of low erosion rate (less than 5 meters per year); 19 areas of high sedimentation rate (10-40 meters per year), 5 areas of medium sedimentation rate (5-10 meters per year) and 7 areas of low sedimentation rate (less than 5 meters per year). Most serious sedimentation and erosion problems is on the LMR (with 16 locations of high erosion rate and 19 areas of high sedimentation rate).

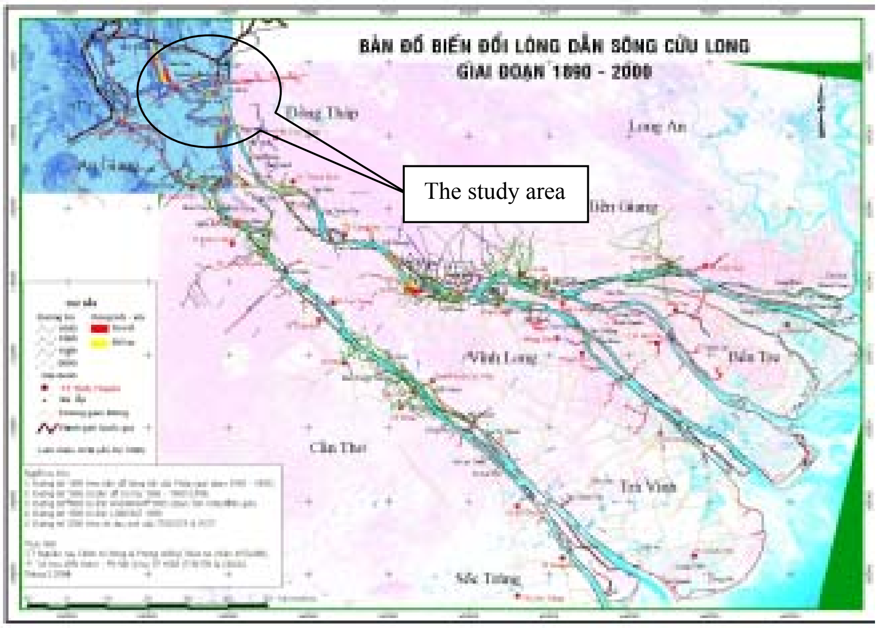


Figure 1. The river erosion and sedimentation in the Lower Mekong River, period 1890-2000 and the study area

One of the most noticeable sedimentation and erosion areas that caused huge damages in the LMR is Tan Chau-Hong Ngu reach (see Figure 2). The reach has been eroded for more than 20 years. Except the lost of infrastructure such as city, high store buildings, offices, schools, hospital, road, high voltage power line … collapsed and cost hundreds of billion Vietnamese Dong, this area was also suffered from calamities such as the river bank collapse in February 1988 caused 22 fatalities at Tan Chau Town; the river bank liding in 1992 at Hong Ngu Town caused 10 fatalities and 8 casualties. Therefore the bank revetment of 612 m long has been constructed in 2002-2003 to reduce such damages, but its protection capacity needs to be considered. In the other hand, the river bed changes at the reach recently results in the sedimentation at the entrance of Hong Ngu channel causing the obstruction of navigation and increasing erosion at Long Khanh channel especially at Long Thuan commune – Hong Ngu district.

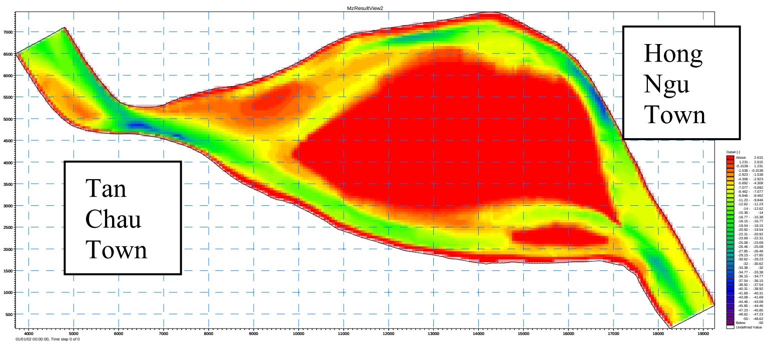


Figure 2. Tan Chau – Hong Ngu reach in the LMR

The riverbank sliding prediction had been done previously by SIWRR with empirical and semi-empirical formulas that have not yet ensured high accuracy. The mitigation measures have not been checked their effects by physical models due to lacking of fund. Moreover, the mathematical model to solve the problems of riverbank erosion prediction and/or structure's effects has not been carried out [2]. Hence the research on riverbed erosion and sedimentation prediction in the Lower Mekong River at Tan Chau-Hong Ngu reach by mathematical models (MIKE11 and MIKE21C) is significant.

CALCULATION RIVERBED EROSION AND SEDIMENTATION BY THE MIKE21C MODEL [1]

MIKE21C model setup

There were only surveyed topographic data in 2002, 2003, 2004 therefore a period 2002-2003 was selected for model calibration and period 2003-2004 for verification. The boundary conditions were discharges at Tan Chau station, water level at Hong Ngu (simulated data from MIKE11ST). Sediment grain size d=0.25 mm was used for the simulation area.

Model Calibration

Hydrodynamic parameters

+ Discharge distribution, water level calibrations

Methodology to adjust discharge distribution and water level were changing the resistance factor from 2D resistance matrix. Results of discharge distribution calibration were presented in Table 1 and Figure 3.

Table 1. Discharge distribution comparison of simulation with observation, dry season 2003

Date	Discharge distribution						Data type
	Total		Hong Ngu		Long Khanh		
	Q(m3/s)	%	Q(m3/s)	%	Q(m3/s)	%	
3/2003	4008	100	1825	45.5	2183	54.5	Obs.
6h PM 3/15/2003	3716	100	1807	48.6	1909	51.4	Calc

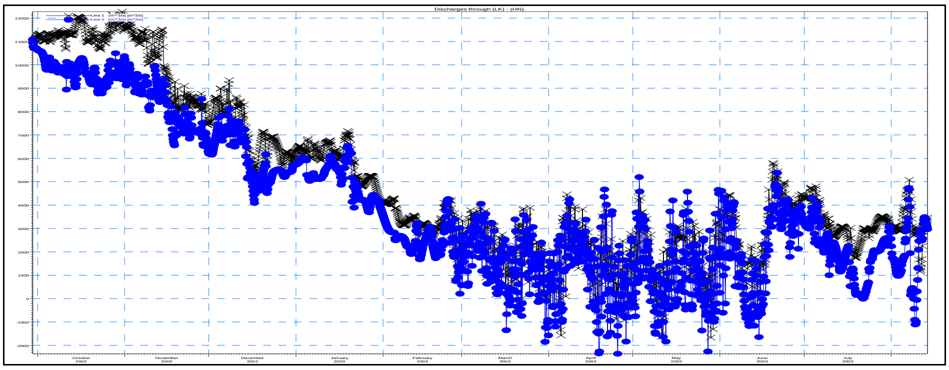


Figure 3. Discharge distribution calibration result in 2003

Morphology parameters

+ Sediment transport model

The selected sediment model was the one which had the most similar results between simulation and computation of sediment discharges. The results proved that Engelund & Fredsoe model was the most suitable model when comparing simulated suspended sediment data of various models at Tan Chau.

+ Plan form

Declare number of bank erosion. Adjust α, β, γ parameters to have erosion rates similar to observation data obtained from satellite images.

+ Check bathymetry

The last step in calibration processes was to check the river bed level suitability between simulation and observation. Figure 4 presented computed and observed river bed levels, period 2002-2003, at some cross sections in Tan Chau, Long Khanh and Hong Ngu channels.

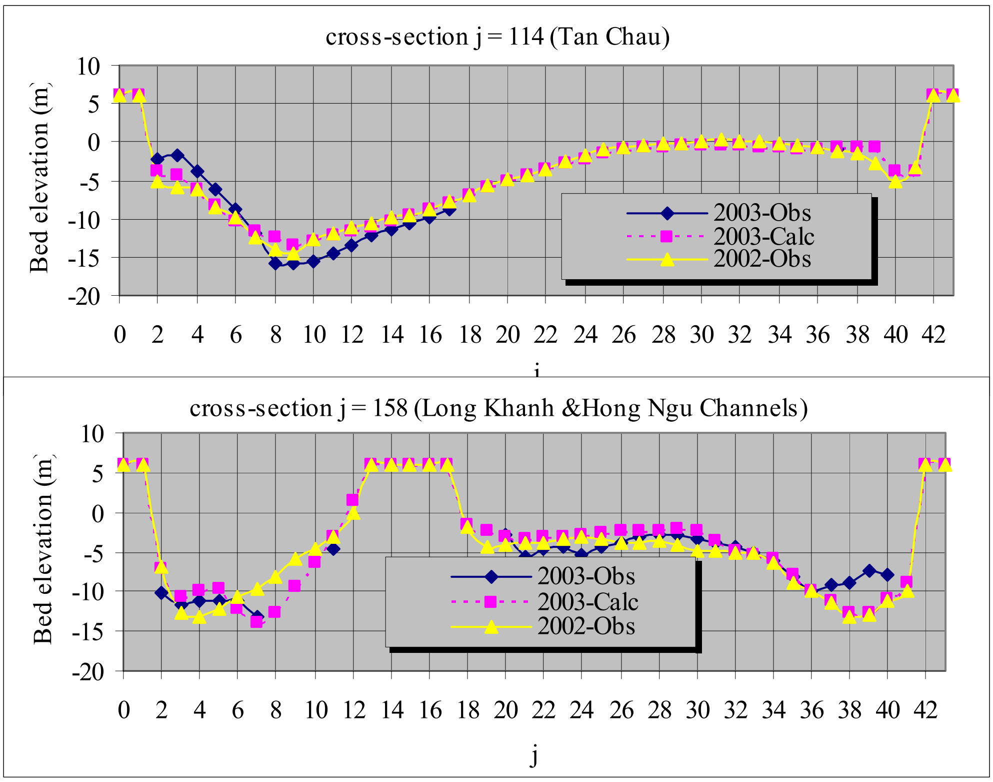


Figure 4. River bed level comparison between observed and simulated data at some cross sections

Model Verification

Discharge distribution calculating from MIKE21C was compared to the observed ones seeing the acceptability (see Table 2 and Figure 5).

Table 2: Discharge distribution at Hong Ngu and Long Khanh channels in 2004

Date	Discharge distribution						Data type
	Total		Hong Ngu		Long Khanh		
	Q(m3/s)	%	Q(m3/s)	%	Q(m3/s)	%	
6/10/2004	19536	100	9145	46.8	10391	53.2	Calc.
6/10/2004	19546	100	9185	47.0	10361	53.0	Obs.

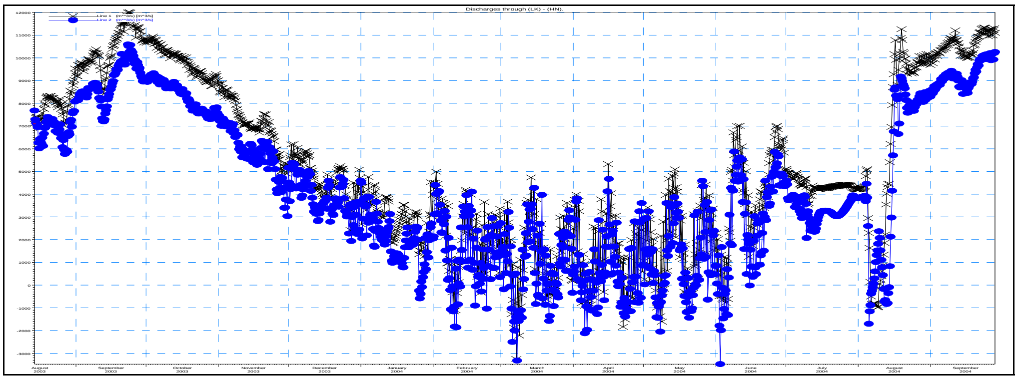
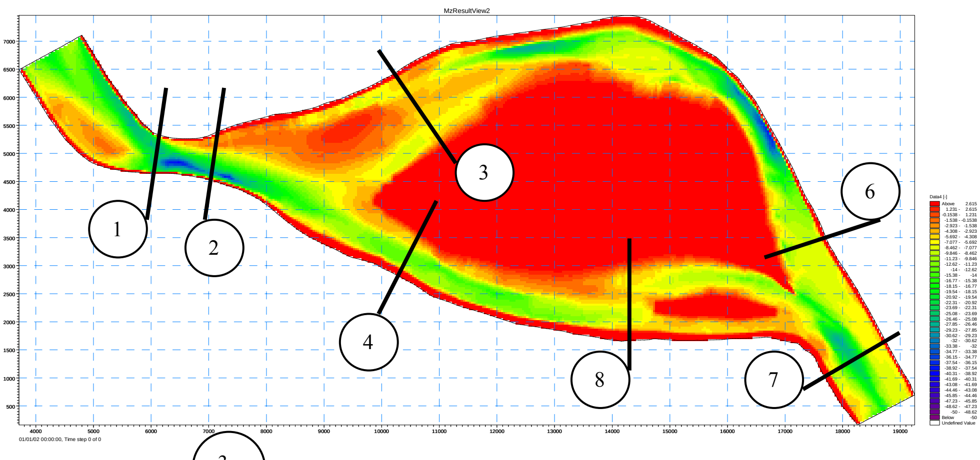


Figure 5. Discharge verification result in 2004

Checking the velocity distribution were carried out at some cross sections at Tan Chau-Hong Ngu reach (with cross section locations shown in Figure 6) to see the differences, presented in Figures 7. Results were acceptable as regard to velocity distribution shape although the velocity magnitudes were somewhat different from the observed ones. Yet the bed level trends, period 2003-2004, were pretty suited thus model parameters calibrated could be use to predict erosion and sedimentation at the concerned area.



Notes (3) Velocity distribution - surveyed cross sections, 2004

Figure 6. Cross section location for checking velocity distribution, 2004

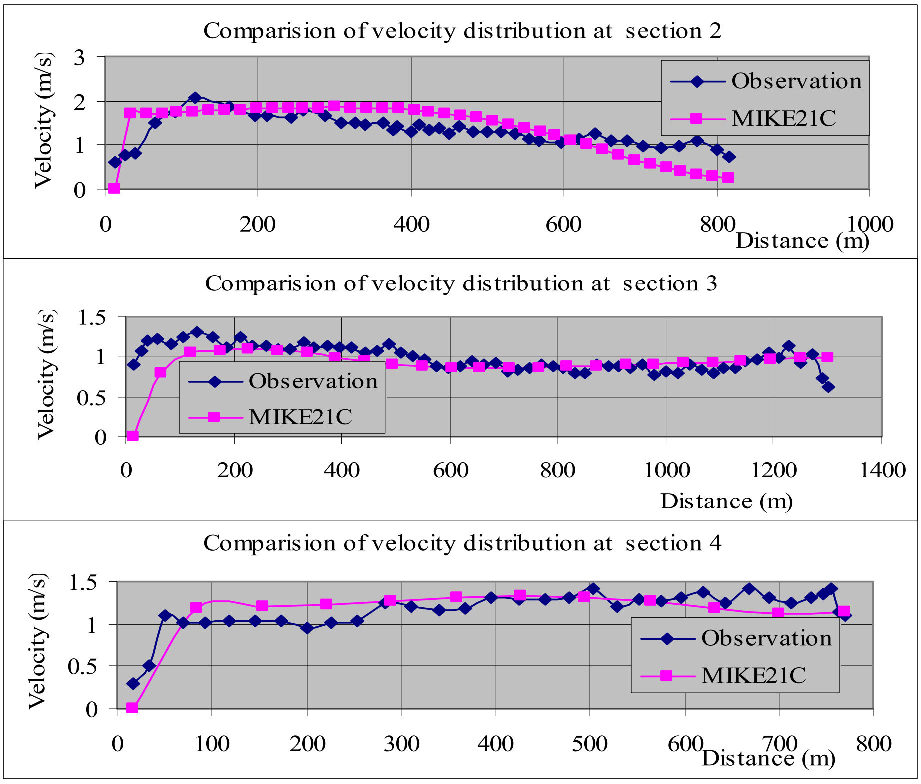


Figure 6: Comparisons of velocity distribution at some cross sections, 2004

Model application - Erosion and sedimentation prediction at Tan Chau-Hong Ngu reach

Define hydrograph for prediction

To predict erosion and sedimentation it was necessary to take typical hydrograph time series which represented flood events in the Lower Mekong River, thus 3 years 1998-1999-2000 were selected to be low, medium and high flood years continuously.

Prediction results

River bed topography of July 2004 was employed to simulate the bed changes period 2005-2007. Discharge distribution simulation expressed the development trends of Long Khanh channel, from 54% in 2004 to 59% in 2007, and degradation trend at Hong Ngu channel. As discharge increasing at Long Khanh channel, bank erosion is increasing, thus vice versa reducing discharge and bank erosion at Hong Ngu channel.

The bathymetric changes, after Tan Chau revetment installation, were expressed the sedimentation and erosion in longitudinal and cross sections (see Figure 7). The longitudinal sections (k=4, 8, 12) downstream of Tan Chau bank revetment were seriously eroded especially after historic flood. In the cross sections, the toe of revetment was eroded also (see Figure 8).

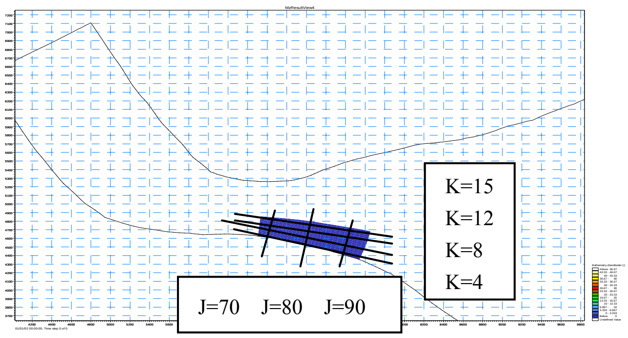


Figure 7. Section locations checking at Tan Chau revetment

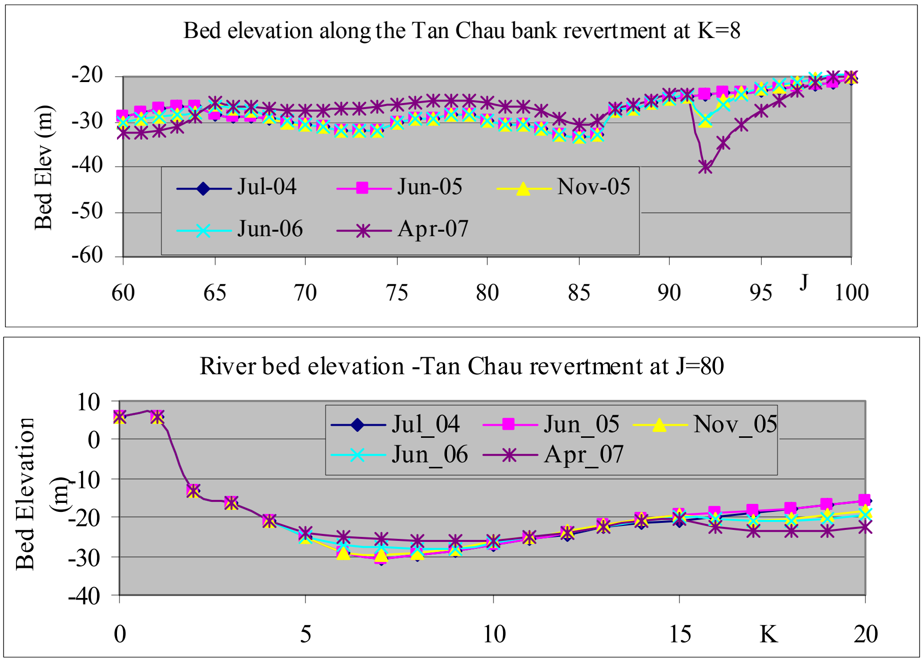


Figure 8. Prediction of erosion at downstream end and toe at Tan Chau revetment

Erosion and sedimentation mitigation measures at Tan Chau-Hong Ngu reach

+ Alternative A2

In 1996 the discharge distribution at the reach was Long Khanh 31%, Hong Ngu 59% and Cai Vung 10%. At that time, Hong Ngu channel was facing serious erosion and Long Khanh channel was pretty stable. Because of morphologic changes discharge distribution now (2004) are nearly the same for Hong Ngu and Long Khanh channel. This is an advantage morphology to stabilize discharge distribution so as not stimulate degradation at Hong Ngu and development at Long Khanh channels [3] [4] . The content of this alternative is to stabilize discharge distribution (50% each) for Hong Ngu and Long Khanh channel by river bed stabilization (by revetment) at the entrances of Hong Ngu and Long Khanh channels, extending Tan Chau revetment so as not to be eroded it downstream part and constructing three impermissible groynes to convert flow to erode a part of bar which is obstructive the Hong Ngu channel entrance. The three groyne dimensions and positions along with river bed bathymetry were presented in Figure 9. Discharge distribution prediction at Hong Ngu and Long Khanh was expressed in Figure 10. It's clear to recognize that the A2 alternative has got effectiveness and met the requirement

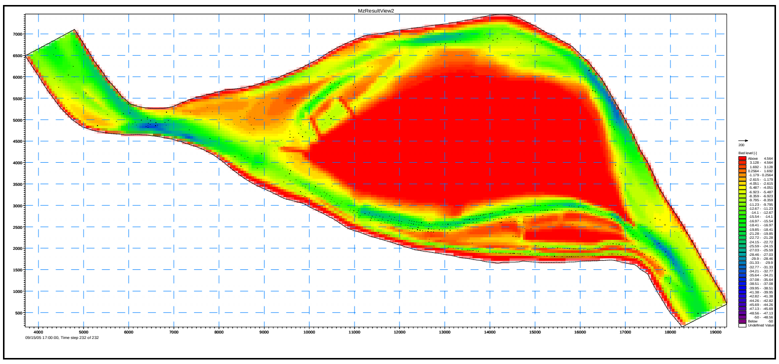


Figure 9. Groyne system to stabilise discharge distribution at Hong Ngu and Long khanh channels

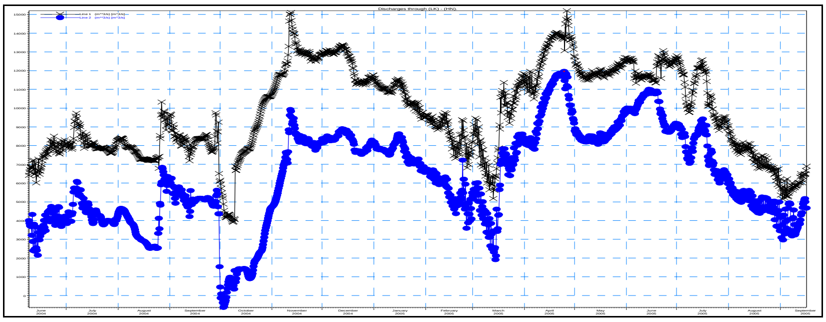


Figure 10. Discharge distribution prediction at Hong Ngu and Long Khanh channels

+ Alternative A3

To adjust discharge distribution of Hong Ngu and Long Khanh channels and to stabilize the bar at Hong Ngu channel entrance, alternative A3 contains alternative A2 adding a direction wall in front of Tan Chau site. The wall dimensions and positions along with three groynes, river bed bathymetry was presented in Figure 11. The discharge redistribution was mentioned in Table 6. It's true that the direction wall has improved flow discharge to have a better result.

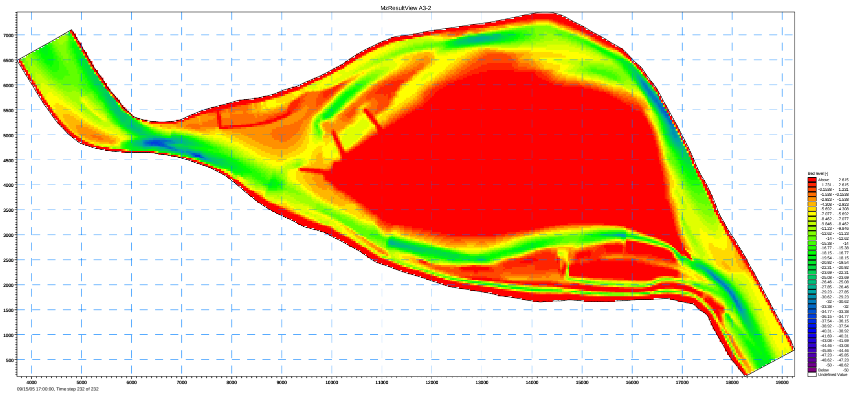


Figure 11. Locations and dimensions of impermeable groynes and direction wall, alternative A3

Table 3. Discharge redistribution at Hong Ngu and Long Khanh at different alternatives

Date	Discharge redistribution - Alternative A2					
	Total		Hong Ngu		Long Khanh	
	Q(m3/s)	%	Q(m3/s)	%	Q(m3/s)	%
(2005)-1998	15885	100	6144	**39**	9741	**61**
(2006)-1999	25097	100	10990	**44**	14107	**56**
(2007)-2000	27199	100	13037	**48**	14162	**52**
Date	Discharge distribution - Alternative A3					
	Total		Hong Ngu		Long Khanh	
	Q(m3/s)	%	Q(m3/s)	%	Q(m3/s)	%
(2005)-1998	15858	100	6117	**39**	9741	**61**
(2006)-1999	25125	100	10990	**44**	14135	**56**
(2007)-2000	26130	100	12967	**49.6**	13163	**50.4**

+ Bank erosion rates with and without engineering alternatives.

Results of bank erosion period 2005-2007 had no significant differences for alternatives. Bank erosion at Thuong Phuoc and Hong Ngu are decreasing and the one at Long Khanh are increasing. Those are fitted with actual processes of the two channels.

+ Other alternatives

Due to the time limit, there are not many alternatives given. However, considering the two alternatives A2 and A3, it's true that we can adjust discharge distribution by various alternatives such as changing the dimensions and directions of the groynes or direction wall. This is also possible to reduce bank erosion rate at Long Thuan by other measures.

DISCUSSIONS

1) There were different between calculation and simulation bed level values for the calibration 2002-2003 and 2003-2004 periods. However the variation trends of erosion and sedimentation were reflected well the actual processes. On the other hand, the differences of the bed levels for the two periods were not remarkable therefore it's difficult to calibrate precisely. More over, the accuracy of surveyed bathymetry was questionable for the surveyed purposes in these periods were not for the one of MIKE21C model.

2) The simulation and observation velocity distributions still had differences. One of the causes was the bathymetry had been carried out in July, 2004 while the observation of discharge data had not been issued therefore those data had been established from co-relation method for the model calculation, thus the results could not be high accuracy.

3) There was no helical flow observed data for calibration. It's necessary to employ the transverse velocity components at different cross sections (by ADCP measurement and additional software) for better calibration.

4) The prediction results which are whether fitted well enough the reality or not depend on the hydrograph proper. If the hydrograph is changed the results will be changed. Therefore it's needed to try and check the various hydrograph combinations to find the most suitable hydrographs for erosion and sedimentation prediction.

Note (*): This paper finished with the assistant of National basic research in Natural Science
Ghi chó : (*) - C«ng tr×nh hoµn thµnh víi sù hç trî cña ch-¬ng tr×nh nghiªn cøu c¬ b¶n trong khoa häc tù nhiªn.

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STRATEGIC ORIENTATION FOR SUSTAINABLE DEVELOPMENT IN VIETNAM (VIETNAM AGENDA 21)

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ABSTRACT

To achieve sustainable development as stated in the Resolution of the 9th National Communist Party Congress and in accordance with the international commitments, on 17 August 2004, the Prime Minister adopted “The Strategic Orientation for Sustainable Development in Vietnam” (Vietnam Agenda 21). The Strategic Orientation for Sustainable Development in Vietnam provides a framework strategy including major directions for ministries, sectors, localities as well as concerned organizations and individuals to implement and cooperate to ensure the country's sustainable development in the 21st century.

INTRODUCTION

Sustainable development is an inevitable tendency in the development process of human society. Thus, the agenda for each development period of the history has been worked out as a result of consensus and collective efforts of nations in the world. The both Earth Summits in Rio de Janeiro in 1992 and in Johannesburg in 2002 discussed action programmes to implement sustainable development in the 21st century. It was strongly affirmed at these two Summits that: To achieve sustainable development, there should be an integration of three important elements - economic growth, social development and environmental protection. These are also the three pillars of development that are always combined and strengthened for each other.

The concept of “sustainable development” came into being in movements for environmental protection in early 1970s. In 1987, in report “Our Common Future” by the UN’s World Commission on Environment and Development, “sustainable development” was defined as “ the development that satisfies the needs of the current generations without compromising the capacity of future generations to satisfy their own needs”.

At the Earth Summit on Environment and Development held in 1992 in Rio de Janerio (Brazil) 179 participating countries adopted the Rio de Janerio Declaration on Environment and Development, which was composed of 27 basic principles and Agenda 21 on solutions for sustainable development for the whole world in the 21st century. It was recommended by the Summit that specific conditions and characteristics should be taken into account during the formulation process of Agenda 21 at national, sectoral and local levels. Ten years later, at the World Summit on Sustainable Development held in 2002 in Johannesburg (The Republic of South Africa), 166 participating countries passed the Johannesburg Declaration and the Plan of Implementation on Sustainable Development. The previously-stated principles were reaffirmed and the commitment to continue full implementation of the Agenda 21 on sustainable development was made in the Summit

Since the Earth Summit on Environment and Development in Rio de Janerio in 1992, 113 countries in the world have formulated and implemented their National Agenda 21 on sustainable development and 6,416 local Agenda 21, and at the same time, these countries have also developed independent set-ups to implement the programme. A number of countries in the region such as China, Thailand, Singapore and Malaysia have already developed and implemented their Agenda 21

The government of Vietnam sent high ranking delegations to the mentioned conferences and made commitment to implementation of sustainable development. Sustainable development has become viewpoints of the Party and directions and policies of the Government and was affirmed in the Resolution of the 9th National Communist Party Congress as: “Fast, effective and sustainable development, economic growth in parallel with the implementation of social progress and equality and environment protection” and "Socio-economic development along with environmental improvement, ensuring harmony between artificial and natural environment, and preserving bio-diversity".

To achieve sustainable development as stated in the Resolution of the 9th National Communist Party Congress and in accordance with the international commitments, on 17 August 2004, the Prime Minister adopted "The Strategic Orientation for Sustainable Development in Vietnam" (Vietnam Agenda 21).

The Strategic Orientation for Sustainable Development in Vietnam provides a framework strategy including major directions for ministries, sectors, localities as well as concerned organizations and individuals to implement and cooperate to ensure the country's sustainable development in the 21st century. The Strategic Orientation for Sustainable Development raises the challenges facing Vietnam, sets out orientations, policies, legal instruments, priority activities that need to be implemented in the 21st century. It will not replace existing strategies, overall planning, plans, but serves as a basis to concretize the Socio-economic development strategy in the period 2000-2010, National strategy for environmental protection until 2010 and the visions towards 2020 and to build 5-year plan 2006-2010 and overall development strategies, planning and plans for sectors, localities with a view to acquiring close, reasonable, harmonious combination of economic development, social progress and equality and environment protection and ensure the country sustainable development. During implementation process, the Strategic Orientation for Sustainable Development will be regularly reviewed and adjusted to be in line with each stage of development. On the basis of the existing planning system, the Strategic Orientation for Sustainable Development in Vietnam focuses on the priority activities that need to be selected and implemented in coming 10 years.

PART 1
SUSTAINABLE DEVELOPMENT, VIETNAM'S INEVITABLE PATH

Sustainable development during the past years

1. Achievements: For 18 years of the renovation process, Vietnam has gained great achievements in socio-economic development and environment protection.
    - a. Economic development: Economic growth rate is high and relatively stable.
    - b. Social development: The state investment in social areas has been ever increasing, of which a special priority has been given to hunger elimination and poverty alleviation, employment creation, education and training, vocational training, health care, prevention and fighting against social evils. The living standards of the people in both urban and rural areas have been visibly improved.
    - c. Utilization of natural resources and environment protection

    The activities related to protecting environment, raising awareness of environment protection for individuals and organizations have been ever expanded and improved in quality, thus, resulting in more reinforced environment management, more appropriate exploitation and more thrifty utilization of natural resources, better prevented and controlled environment pollution, degradation and environmental incidents, considerably recovered and improved environment quality in some areas.
2. Remaining shortcomings
    - a. Awareness

      The views on sustainable development have not yet clearly and consistently been expressed in the system of state policies and regulatory instruments. Planning and plans on socio-economic development and policies on environment protection have not yet been closely combined and reasonably integrated during the formulating process.
    - b. Economic perspective

      Most of the investment has poured into the works serving the immediate benefits, little remained for regeneration of natural resources and environment protection. The economic growth has relied mainly on extensive development meanwhile the natural resources are limited and have been exploited to the ceiling of permitted limits. The development targets of the natural resources consuming industries are in conflict and have not yet appropriately been combined.
    - c. Social perspective

      The increasing pressure of the population growth, ever serious shortage of jobs, high ratio of poor households are big obstacles to the sustainable development. The quality of the human resources is still low. The consumption pattern of the people relies on consuming extensive amount of materials and energy, releasing much more waste and toxic substances. Some social evils such as drug addiction, prostitution, corruption have yet to be effectively prevented, threatening social stability.
    - d. Utilization of natural resources and environment protection

The arbitrary exploitation and wasteful utilization of natural resources, resulting in deteriorated environment and unbalanced eco-systems has been very common. The rapidly increasing urbanization rate has led to excessive exploitation of underground water sources, contamination of surface water sources, air pollution, and accumulation of solid waste. The regions which are plentiful in bio-diversity, forests, marine and coastal environments have yet to be properly protected and have been excessively exploiting.

Major objectives, views, principles and priority activities for the sustainable development in Vietnam:

1. Objectives

The overall targets in the strategy for socio-economic development in the period 2001-2010 are: "Bring the country out of the less developed state; Visibly improve the material, cultural and spiritual life of the people; form a firm foundation so that Vietnam basically become an industrialized country by the year 2020. Strengthen the human resource, scientific and technological capacity, infrastructure and economic potentials, national defense and security; basically establish socialist oriented market economic structure; improve the position of the country in the international arena".

The views on the development is confirmed in the strategy as follows "Rapid, effective, efficient and sustainable development, economic growth is accompanied with the implementation of social progress, equity and environment protection"; "Socio-economic development is closely bound to environment protection and improvement, ensure the harmony between artificial and natural environment, preserve bio-diversity".

2. Main principles

- Human beings are the center of the sustainable development
- Economic development is the central task
- Protection and improvement of environment quality are to be considered as inseparable factor from the development process
- The development process must equally satisfy the needs of the current generations without causing obstacles for the life of future generations
- Science and technology is the foundation and momentum for the country's industrialization, modernization, quick, strong and sustainable development
- The sustainable development is the cause of the whole party, authorities at all levels, the ministries, sectors and localities, agencies, businesses, social organizations, population communities and the whole people
- Establishment of independent and autonomous economy is tightly attached to the international economy integration on basis of self-initiatives.
- Social-economic development, environment protection should be closely combined with guarantee of national defense and security as well as social safety and order.

3. Priority areas

The Strategic Orientation for Sustainable Development specifies 19 priority areas 5 of which are in economic field, 5 in social and 9 in natural resources and environment area.

PART 2
PRIORITY ECONOMIC AREAS FOR THE SUSTAINABLE DEVELOPMENT

1. Maintain rapid and sustainable economic growth rate

- Continue to accelerate economic renovation
- Shift the economy which relies mainly on extensive development into the one which relies mainly on in-depth development on basis of effective application of advanced science and technology
- Shift the economy characterized by extensive exploitation and utilization of raw materials into one characterized by more skillful goods processing capacity
- Thoroughly save resources in the development process, effectively and efficiently utilize scare natural resources, and control the consumption
- Establish an accounting system of environment economy

2. Transform production and consumption patterns towards environmentally friendly direction

- Restructure production activities and services for consumption towards using less energy and materials and discharging less waste especially toxic waste at the same time.
- Take necessary measures towards appropriate consumption; Build up a consumption culture which is civilized, rich in national identity, harmonious and close to the nature
- Apply some economic instruments (such as consumption tax) to regulate inappropriate consuming behaviors

3. Implement the "Clean industrialization" process
   - Accelerate the process of substituting advanced and environmentally sound technologies for obsolete, energy-intensive ones.
   - Economically use natural resources, effectively control pollution and manage wastes; Priority should be given to environmentally friendly sectors and processes
   - Prevent and strictly tackle pollution resulted from production, trading and services
4. Agricultural and rural sustainable development
   - Complete the legal system, and uniform policies on the agricultural development; protect natural resources and agricultural and rural environment
   - Make rural development planning, appropriately encourage the urbanization of rural areas. Speed up restructuring process of the economy, breeds of plants and domestic animals, make use of the rural labour force. Promote processing industry. Expand production and markets for clean agricultural products.
   - Promote the land transition in areas where land is widely scattered. Work out and implement programmes on land productivity raising and appropriate utilization of water sources in localities. Further consolidate and complete the existing technical service system in agriculture, forestry, animal husbandry and aqua-culture.
   - Promote wide application of bio-technology and preservation of gene pools of local plant and animal. Develop production of organic and biological fertilizers, fertilizers with slow dissolubility for the development of ecological agriculture.
5. Sustainable development of regions and localities

   Priority should be firstly given to development of focal economic areas which can make break-through, on the other hand, must pay attention to support regions under state of less development and more difficult circumstances in order to reach a certain balance in spatial development. Attract wide participation of organizations, unions, and all strata of the people in selection and implementation of development approaches in their localities.

PART 3
THE PRIORITY SOCIAL AREAS FOR THE SUSTAINABLE DEVELOPMENT

1. Great attempts should be made to eliminate hunger, alleviate poverty and speed up the implementation of social progress and equity

   Efforts should be focused on the following urgent issues: Eliminate hunger and alleviate poverty; Shorten the gap in socio-economic development level between rural and urban areas, mountainous and plain areas; Support the ethnic minorities in socio-economic development activities and environment protection; Empower positions of women in activities concerned socio-economic development and protection of natural resources and environment; Create conditions for vulnerable social groups to integrate into communities.
2. Continue to reduce population growth rate and create jobs for the working force

   Firmly maintain reduction in birth rate and improve the population quality in physical, intellectual and spiritual; Transit the economic structure towards increase in proportion of the industrial sector, construction and services; Improve processing degree of products to create more jobs and expand labour markets.
3. Orientate the process of urbanization and population migration towards the sustainable development of urban areas, appropriate allocation of population and labour forces for each region

   Review the overall planning to ensure the sustainable urban development; Minimize impacts on eco-environment caused by the urbanization process; Implement comprehensive economic development strategy.
4. Improve education quality in order to raise intellectual level, professional skills and qualifications and match requests of the country's development

Reform curricula, content, education and training methods; Carry out education on environment protection and sustainable development, on that basis, mobilize the whole people to participate in the implementation of sustainable development.

5. Develop healthcare services in terms of quantity and quality, improve working conditions and living environment sanitation

To achieve the above targets, the following activities should be prioritized to be implemented: meet the people's basic needs on healthcare; develop reserve medical system, prevent and combat contagious diseases; alleviate detrimental impacts caused by environment pollution on the public health; Focus on protection of mother and children's health.

PART 4
PRIORITY AREAS IN UTILIZATION AND PROTECTION OF NATURAL RESOURCES AND POLLUTION MONITORING ESSENTIAL FOR THE SUSTAINABLE DEVELOPMENT

1. Prevention of land deterioration, effective and sustainable utilization of land resources

Priority activities are as follows:

- Supplement, amend and further perfect policies and laws on land ownership. Plan and manage land resources utilization of all land users
- Regulate population allocation and migration among regions, areas with a view to reducing population pressure on land resources
- Apply combined technical measures (e.g.: agricultural, biological, chemical, mechanical...) and invest in in-depth intensive farming
- Raise public awareness of appropriate and thrifty utilization of land resources

2. Water environment protection and sustainable utilization of water resources

Priority activities are as follows:

- Continue to formulate policies, legal documents, provisions and technical procedures on utilization, protection and management of water sources
- Formulate and implement programmes, projects on combined management of river basins, upstream areas and underground water
- Promote application of wastewater treatment technologies, encourage utilization of clean technologies in production process in order to reduce amount of emission and reuse wastewater
- Raise awareness of population communities about appropriate and thrifty utilization and protection of water resources

3. Appropriate exploitation and thrifty and sustainable utilization of mineral resources

To achieve the objective of sustainable development, thrifty and effective use of mineral resources, the following activities should be implemented:

- Use economic and administrative instruments and legal provisions to strictly and more effectively enforce mineral law; Perfect the organization system of mineral resource management at central and local levels.
- Formulate consistent planning on utilization of mineral resources and environment protection; Organize mineral exploitation procedures in appropriate manner, avoid the state that prior exploitation of easy to extracted mines leaving behind the difficult to extractor ones, which have bad impacts on supervision, evaluation and planning of mineral exploitation. Restrict and prohibit in near future spontaneous and arbitrary mines exploitation.
- Renovate and renew exploiting, winnowing and processing technologies in order to acquire full collection of mineral content and protect environment; Apply advanced technologies for ores with low mineral content in order to thoroughly utilize amount of minerals in mines, at the same time, reduce volume of waste soil and stone, narrow coverage of dumping sites.
- Raise public awareness of appropriate and thrifty utilization and protection of mineral resources.

4. Protection of marine, coastal and island environments and promote marine resources

Priority activities to be implemented:

- Formulate a strategy for marine economic development, resources and environment management under the principle of sustainability; Establish a cross sectoral mechanism for the unified management of sea and coastal areas.
- Promote offshore fishing and properly adjust coastal fishing; Progressively develop aquaculture in coastal brackish and brine water in harmony with environment; Develop fishery logistics system; Diversify economies for job generation.
- Establish and efficiently manage marine and coastal protected areas; Strongly promote research and application of technologies for marine and coastal environmental protection and responses to marine environmental accidents.

5. Forest protection and development

Priority activities to be implemented:

- Strengthen the State management system of equitable use and protection of forest resources, involving active participation of community.
- Assist people in planting and protecting forests, effectively using the forest land assigned; Facilitate ecological agricultural-forestry development, agro-forestry farms, and enhance services for agricultural expansion.
- Study and apply new techniques and technology in forestry.

6. Air pollution reduction in industrial and urban areas

Priority activities to be implemented:

- Environmental impact assessment must be undertaken on all socio-economic and development projects in order to prevent possible causes of air pollution
- The effectiveness of energy use, power generation of thermal power stations and power facilities should be improved. Clean sources of energy should be promoted.
- Clean materials and technology are encouraged to use in production establishment; Strictly prohibit import of and rapidly reduce the use of obsolete equipment which causes serious pollution.
- Awareness on environmental protection in general, and in the working environment in particular, should be raised for entrepreneurs, trade unions and workers.

7. Solid waste and toxic waste management

Priority activities to be implemented:

- Develop and promulgate the pollution control plans at national, sectoral and local levels for active prevention, treatment, recovery and approach to control of environmental pollution due to solid, liquid, air and toxic wastes.
- Construct hygienic landfills in medium and large cities; Progressively promote the application of recycling technology for waste reusing.
- Reduce solid waste from the source by encouraging the application of clean and environmentally-friendly technology.
- Promote community education and awareness raising programmes; Encourage people to actively participate in waste collection, treatment and management activities in medium and large cities in order to prevent disorderly discharging waste, particularly toxic waste in streets.

8. Biodiversity conservation

Priority activities to be implemented: Improve policies and legislation related to bio-diversity conservation; Regularly review bio-diversity action plans to align it with national socio-economic plans and strategies.

9. Implement measures for mitigating climate change, limiting its negative impacts, preventing and controlling natural disasters

Priority activities to be implemented:

Promote propaganda, dissemination and awareness raising for public community; Strengthen and improve capacity of hydrometeorology; Improve quality of hydrometeorology forecasts to meet the requirements of socio-economic development and environmental protection, primarily for preventing and controlling natural disasters.

PART 5
SUSTAINABLE DEVELOPMENT IMPLEMENTATION ARRANGEMENTS

Improve the leading role of the Government in the implementation of sustainable development

1. Institutional development: The following three issues need addressing:
    - Complete the system of legal documents on sustainable development.
    - Operate sustainable development mechanism as a linkage of ministries, sectors, and localities, incorporating environmental considerations into socio-economic issues when making development decisions.
    - Establish organizations in charge of sustainable development.
2. Improve capacity for environmental management: Improve the capacity of state management agencies at all levels in terms of environmental management is one of the focal tasks in order to realize sustainable development in Vietnam.
3. Apply financial tools for sustainable development
4. Establish sustainable development evaluation indicator system: Progressively foster the development and application of a system of sustainable development evaluation indicators.
5. Public education and awareness raising of sustainable development
6. Formulate sectoral and local sustainable development strategic orientations

Involve the whole society's participation in sustainable development

1. Overall advocacy: Sustainable development is the cause of all people.
2. Activities by main social groups for accelerating sustainable development:
    a. Women;
    b. Teenagers and young people;
    c. Farmers;
    d. Workers and Trade Unions;
    e. Businessmen;
    f. Ethnic minorities groups;
    g. Intellectuals and scientists

International cooperation for sustainable development

Priority activities to be implemented in international cooperation to achieve sustainable development are: Continue to implement renovation policies; involve individuals and international organizations in implementation the Strategic Orientation for Sustainable Development in Vietnam; Enhance international cooperation in the UN Committees on sustainable development.