

# EFFECTS OF CLIMATE CHANGE AND LAND SUBSIDENCE ON WATER MANAGEMENT ZONING IN TIDAL LOWLANDS CASE STUDY TELANG I, SOUTH SUMATRA

EFFETS DU CHANGEMENT CLIMATIQUE ET AFFAISSEMENT DU SOL  
ZONAGE DE GESTION DES EAUX DE MARÉE DANS LES BASSES TERRES  
ÉTUDE DE CAS TELANG I, AU SUD DE SUMATRA

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## ABSTRACT

Water management zoning in tidal lowlands is an approach to design and implement proper water management. Water management zoning is defined as the determination of zones that have similar water management characteristics, based on their physical characteristic. The impacts of climate change and land subsidence on water management zoning deserve careful analysis, since they may have an important influence on success of agriculture in tidal lowlands.

This study is dealing with the effects of climate change - especially sea level rise - and land subsidence on water management zoning in tidal lowlands. Results of this study may be useful to support development of lowlands, particularly in Indonesia, including of measures to be taken to deal with climate change and land subsidence. Data for the study were based on the conditions in the Telang I area, South Sumatra. Hydrodynamic modelling by using DUFLOW in combination with the Model Builder of ARCGIS was used in this research.

Land subsidence in Telang I was calculated or modelled in compartments of soil in each layer. Samples were taken from two locations representing category A and B or B/C hydro-topographical conditions of the standard classification of tidal lowland areas in Indonesia (secondary block P8-12S and P6-3N). Results show that land subsidence has a relation with the groundwater fluctuation that varies in the area from 3 - 7 mm/year. In low areas where the groundwater level is near the surface land subsidence is about 3 mm/year, while for higher areas it is about 7 mm/year. Land subsidence during the reclamation period was higher than the present subsidence, about thirty years after reclamation.

It can be concluded that the impacts of climate change and land subsidence on water management zoning in future will be significant. Land subsidence has more impact on water management zoning than sea level rise. The impacts can be positive and negative for the development of the tidal lowlands of the study area, as well as of similar areas in Indonesia. Water management zoning in the wet season is primarily dependent on the tidal fluctuation and rainfall, which is also related to the hydro-topographic conditions, tidal irrigation and drainability. Sea level rise and land subsidence make the potential of tidal irrigation larger and significant. The area with tidal depth of 0 - 25 cm or > 25 cm will increase. This change in water management zoning from dryland crops in the present condition to tidal irrigated wetland

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rice and from tree crops to dryland crops due to the reduced potential of drainage by gravity.

Preventive efforts to control land subsidence are needed to overcome negative impacts which may occur in future, while for climate change there needs to be wider concern to minimize or to reduce its rate. Therefore, structural and non structural measures are needed.

KEY WORDS: Sea level rise, land subsidence, water management zoning, hydraulic modelling, GIS modelling

## SYNTHÈSE ET CONCLUSIONS

Zonage de la gestion de l'eau dans les basses terres est l'une des stratégies à concevoir et à mettre en œuvre la gestion adéquate de l'eau. Zonage de la gestion de l'eau est définie comme les zones de certaines régions qui ont la gestion des eaux similaires en fonction de leurs caractéristiques physiques. Les impacts du changement climatique et les affaissements de terrain sur le zonage de la gestion de l'eau méritent une analyse attentive, car ils peuvent avoir une influence importante sur la réussite du secteur agricole dans les plaines.

Cette étude est consacrée aux incidences du changement climatique - en particulier l'élévation du niveau de la mer - et les affaissements de terrain sur la gestion de l'eau de zonage dans les basses terres de marée. Les résultats de cette étude peuvent être utiles pour soutenir le développement des basses terres, en particulier en Indonésie, y compris des mesures à prendre pour faire face au changement climatique et l'affaissement du sol. Les données pour cette étude sont fondées sur les conditions dans la zone I Telang, au sud de Sumatra. Modélisation hydrodynamique à l'aide de DUFLOW en association avec le constructeur de modèles d'ARCGIS a été utilisée dans cette recherche.

Affaissements de terrain dans Telang I a été calculée ou modélisés dans des compartiments de sol dans chaque couche. Les échantillons ont été prélevés à deux endroits représentant de catégorie A et B ou B / C des conditions hydro-topographiques de la Classification type des zones de plaine de marée en Indonésie (secondaire bloc P8-12S et P6-3N). Les résultats montrent que l'affaissement du sol a une relation avec la fluctuation des eaux souterraines qui varie dans la région du 3 - 7 mm / an. Dans les zones basses où la nappe phréatique est proche de la surface de l'affaissement du sol est d'environ 3 mm / an, tandis que pour des zones plus élevées, il est d'environ 7 mm / an. Affaissements de terrain au cours de la période de récupération a été plus élevé que la subsidence actuelle, près de trente ans après la remise en état.

Il peut être conclu que les impacts du changement climatique et les affaissements de terrain sur la gestion de l'eau de zonage à l'avenir seront importants. Affaissements de terrain à plus d'impact sur la gestion des eaux de zonage de l'élévation du niveau de la mer. Les impacts peuvent être positifs et négatifs pour le développement de la plaine de marée de la zone d'étude, ainsi que des zones similaires en Indonésie. Zonage, la gestion de l'eau dans la saison des pluies est principalement dépendante de la fluctuation de la marée et des précipitations, qui est également lié aux conditions hydro-topographiques, l'irrigation des marées et drainabilité. L'élévation du niveau de la mer et l'affaissement du sol font le potentiel de l'irrigation des marées plus grandes et importantes. La zone de la profondeur à marée de 0 - 25 cm ou > 25 cm va augmenter. Ce changement de gestion de l'eau de zonage à partir de cultures des zones arides dans l'état actuel de riz des zones humides de marée irriguées et des cultures d'arbres des terres arides cultures en raison de la réduction du potentiel de drainage par gravité.

Les efforts de prévention pour contrôler l'affaissement du sol sont nécessaires pour surmonter les impacts négatifs qui pourraient survenir à l'avenir, tandis que pour le changement climatique il faut être plus large souci de minimiser ou de réduire son taux. Par conséquent, des mesures structurelles et non structurelles sont nécessaires.

MOTS CLÉS: élévation du niveau de la mer, les affaissements de terrain, zonage, la gestion de l'eau, modélisation hydraulique, la modélisation SIG.

## INTRODUCTION

Lowland, flood prone areas can be found all over the world, along the coasts, in river floodplains and as inland depressions. Generally these are by their nature sensitive areas with a high ecological value. Due to their physical conditions and environmental value they are basically unsuitable for development. However, due to the in many cases strategic location and/or suitability for agricultural production there is often a tremendous pressure to develop these areas for various types of land use (Schultz, 2008).

This study is dealing with the impacts of climate change and land subsidence on water management zoning in tidal lowlands. Water management zoning is defined as the determination of zones that have similar water management characteristics, based on their physical characteristic. The most important parameters for water management zoning are tidal irrigation (irrigability) and potential for drainage (drainability).

Focus was on three main aspects i.e. sea level rise, land subsidence and changes in water management zoning in tidal lowlands. Results of this study may be used to support development of lowlands in general and particularly to support tidal lowland development in Indonesia, including of measures to be taken to deal with climate change and land subsidence.

## THE IMPORTANCE OF LOWLANDS IN INDONESIA

Due to regional developments an increasing number of worlds' population is living and working in flood prone areas, in particular in lowlands area. There are no indications that this tendency will change. In the rural areas we may observe improvements in agricultural production and an increase in the value of crops, farm buildings, water management facilities and infrastructure. Due to urbanisation and industrialisation and the improvement in the standard of living the value of property, buildings and infrastructure has significantly increased and will further increase in future. Especially in flood prone and lowland areas in South and East Asia including Indonesia we may observe a very rapid growth of urban areas. In order to cope with this growth for new urban areas very often reclamation has taken place of low-lying areas in the neighbourhood of the existing urban area (Schultz, 2008).

Indonesia has large lowland areas with an estimated acreage of about 34 million ha, out of which about 20 million ha is tidal lowland. The other 13.4 million ha concern predominantly non-tidal lowlands along rivers and inland swamp areas. Tidal lowlands have been reclaimed since more than 100 years by local people known as Buginese and Banjarnese. The main motivation was to find new living space because of the limitation of further expansion possibilities in the village of origin (Collier, 1980). They have settled along the eastern coast of Sumatra (Riau, Jambi, South Sumatra and Lampung), and along the western and southern coast of Kalimantan (Manuwoto, 1986). The Government schemes in the tidal lowlands were mainly reclaimed in the 1970s. One of the important original objectives of the government for this reclamation was transmigration of farmers from the overcrowded isles of Java, Bali and Madura to the isles of Sumatra, Kalimantan and Papua (Ministry of Public Works, 1984).

Almost 4 million ha of the tidal lowlands have been reclaimed, partly by spontaneous settlers (2.5 million ha) and partly by the Central Government (1.5 million ha). Detailed distribution of lowlands in Indonesia in each province sponsored by Government is shown in Figure 1. These reclaimed areas generally have a good potential for agricultural development, with a rice crop in the wet season and a second rice crop, or a dry food crop in the dry season.

### **Problem definition**

For tidal lowlands, sea level rise is particularly important, as it will increase flooding and restrict drainability of low-lying areas. It is predicted that water management in tidal lowland

schemes is affected by sea level rise as an impact of climate change and also will influence hydro-topography, drainage capability (drainability) and salinity intrusion. Land subsidence will also have significant impacts to soil development as well as hydro-topography and drainage capability. These impacts will directly affect the land suitability and water management zoning. To overcome this problem, it is needed to predict the effects of climate change and land subsidence on water management zoning in tidal lowland areas.

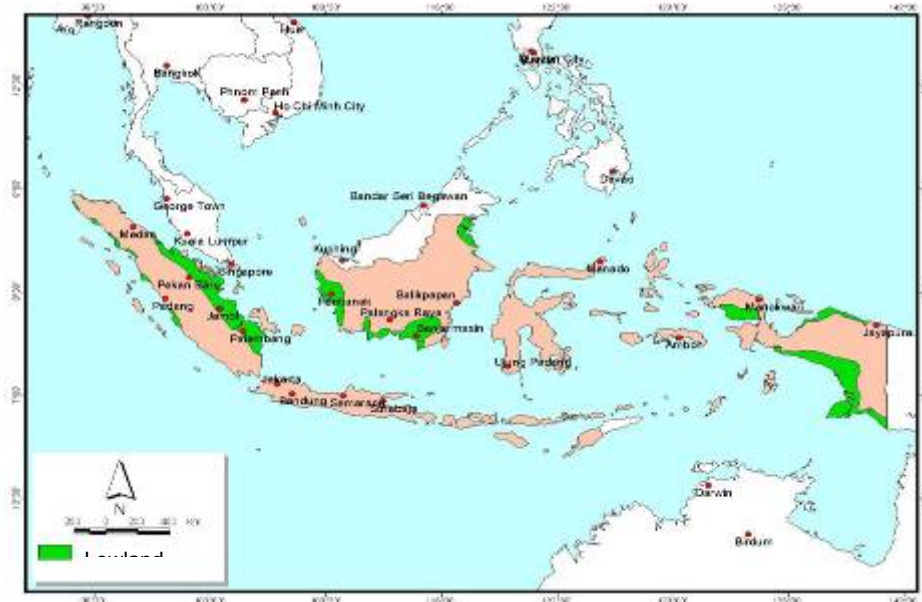


Figure 1. Lowlands distribution in Indonesia (re-drawn from Euroconsult, 1993)

## OBJECTIVES OF THE RESEARCH

The objectives of this research were (Rahmadi, 2009):

- to set up a water management zoning model for tidal lowlands by using spatial analyses with GIS and remote sensing techniques, based on the present situation;
- to evaluate the possible impacts of climate change and land subsidence on water management;
- to recommend approaches for future development of tidal lowlands.

## LOWLAND DEVELOPMENT IN INDONESIA AND GOVERNMENT POLICY

The Government of Indonesia wants to maintain food self-sufficiency, among others in rice. Nearly all rice in Indonesia is produced on Java, one of the most densely populated rice growing areas of the world. However, in Java there is continuous loss of fertile agricultural land for residential and industrial development. It is estimated that the rate of the loss of agricultural land at Java is about 30,000 ha/year (Soenarno, 1993). They have been identified as new development areas for the future.

### Potential of lowlands in Indonesia

Being located in the coastal zone, the lowlands are often characterised by waterlogged conditions, and shallow to deep peat overlying unconsolidated, and often (potentially) acidic clays. Main natural habitats were originally swamp forest and peat swamp forest, along with mangrove in brackish and marine areas.

From the Nationwide survey on coastal and near-coastal lowlands, an indicative assessment on land suitability for low cost agricultural development was conducted on Sumatra, Kalimantan and Papua (Euroconsult, 1984). 24.6 million ha were surveyed, of which 5.6 million ha or 23% were classified as suitable for development. Some of 64% of the remaining lowlands was classified as unsuitable for agricultural development due largely peat formations and low drainability. These areas would have to be kept as conservation areas.

### **Government policy on lowland development**

One of the important original objectives of the government schemes that were mainly reclaimed in the 1970s was transmigration, implying the reclamation of tidal lowland areas, primarily on the isles of Sumatra, Kalimantan and Papua in order to settle farmers from the overcrowded isles of Java, Bali and Madura, as well as for security at the border and for balancing the development (Ministry of Public Works, 1984).

In the recently formulated policy of the Indonesian Government, one of the main objectives of tidal lowland development and management is to contribute to the required increase in food production (Suriadikarta et al., 2001; Suprpto, 2002; Schultz, 2006).

Effort to keep the existing lowland (including peat and/or swamp forest) area as natural conservation areas based on their characteristics is also included in the present government policies. The umbrella of legal aspects of lowlands development is Law No. 7/2004 on Water Resources, by providing the legal basis for water resources development. Lowland development is one of the explicitly mentioned objectives of the law.

## CLIMATE CHANGE AND LAND SUBSIDENCE, THEIR POSSIBLE EFFECTS TO TIDAL LOWLAND WATER MANAGEMENT

Climate change as formulated by the Intergovernmental Panel on Climate Change (IPCC) refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer (Intergovernmental Panel on Climate Change (IPCC), 2007). This description differs from that of the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere (Bernstein et al., 2007).

The rise in global mean sea level is accompanied by considerable decadal variability. For the period 1993 to 2003, the rate of sea level rise has been estimated from observations with satellite altimetry as  $3.1 \pm 0.7$  mm/year, significantly higher than the average rate. The tide gauge records indicate that similar large rates have occurred in previous 10-year periods since 1950. It is unknown whether the higher rate in 1993 to 2003 is due to decadal variability or an increase in the longer-term trend.

### *Impact of climate change on Indonesia*

The global climate is a very complex system and climate change will interact with many other influences. However, in Indonesia, it will make many of the existing climatic problems worse. The following is described based on United Nations Development Programme Indonesia and Indonesian Country Report (United Nations Development Programme (UNDP), 2007). The El Niño-Southern Oscillation (ENSO) is found as one of dominant global factors causing extreme climate events in Indonesia and is often related to droughts and La Niña to floods. Moreover, El-Niño is considered as one of the overriding control factors in major forest/land fire and haze occurrence and frequency.

### Changes in seasons and rainfall

In most of Sumatra, comparing the periods 1961 - 1990 and 1991 - 2003, the onset of the wet season is now 10 to 20 days later and the onset of the dry season is now 10 to 60 days earlier.

Similar shifts have been seen in most of Java. These patterns seem likely to continue. In the future, parts of Indonesia, particularly regions located south of the equator, could have longer dry seasons and shorter but more intense wet seasons with the kind of changes in the rainfall pattern (Naylor et al., 2007).

### Sea level rise

As a result of the expansion of seawater and the melting of glaciers and polar ice caps, global warming could result in an average rise in sea level between 0.12 and 0.58 m in a century (Intergovernmental Panel on Climate Change (IPCC), 2007). The rate of increase varies with the location, i.e. between 0.1 and 6 mm/year, depending also on changes in the ocean currents. It is also described that at the equator zone sea level rise is not that much as at Antarctic or Arctic zone, or in other words it will not be higher than the global sea level rise. However, ocean conditions such as warmer temperature, salinity, decreased pH are dominant in the equator zone, although in the study area this is still hard to detect due to limited data (Figure 2). Information from the field shows a similar trend, especially salinity intrusion now periodically occurs in this region. According to recent observations by the National Oceanic and Atmospheric Administration (NOAA) satellite, Indonesia has an average sea level rise of 4.9 - 6.6 mm/year National Oceanic and Atmospheric Administration - Laboratory for Satellite Altimetry (NOAA-LSA), 2007) (Figure 3). In this study the global sea level rise of 2 mm/year has been used.

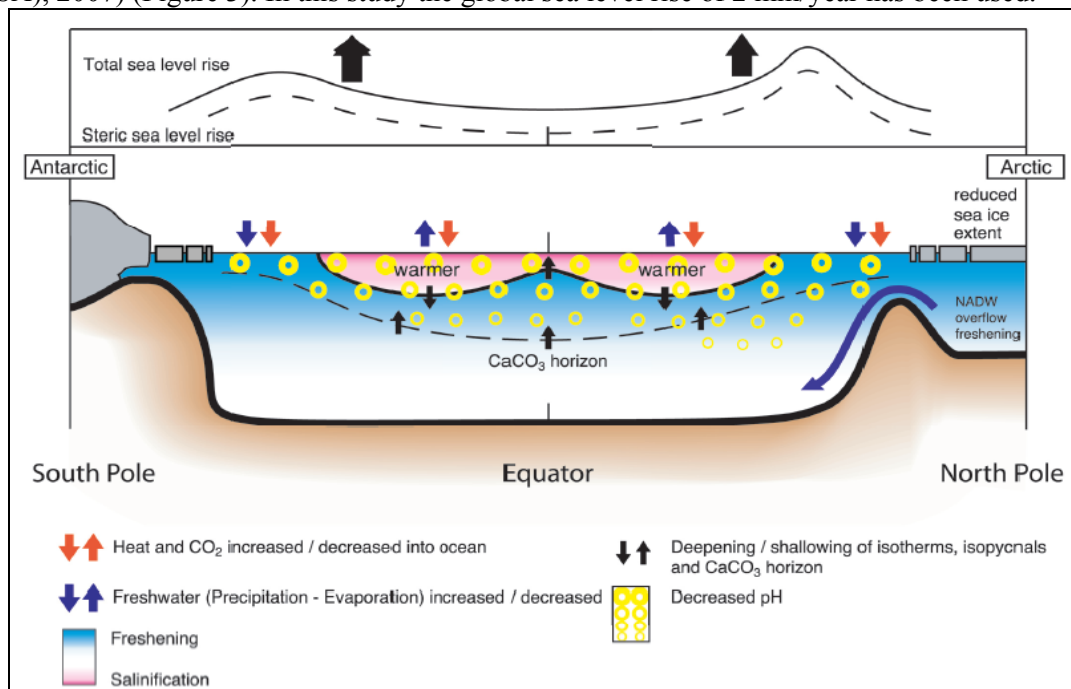


Figure 2. Schematic view of observed changes in the ocean state (Bindoff et al., 2007)

### Climate change and its general effect to water management in lowlands

The direct impacts of human activities on the coastal zone have been more significant over the past century than impacts that can be directly attributed to observed climate change (Scavia et al., 2002; Lotze et al., 2006; Schultz, 2008). The major direct impacts include drainage of

coastal wetlands, deforestation and reclamation, and discharge of sewage, fertilisers and contaminants into coastal waters as presented in Figure 4. Compared to the conditions when tidal lowlands were reclaimed for agricultural purposes, due to climate change different water management conditions will develop with as a consequence that water management zoning of the areas will have to be modified.

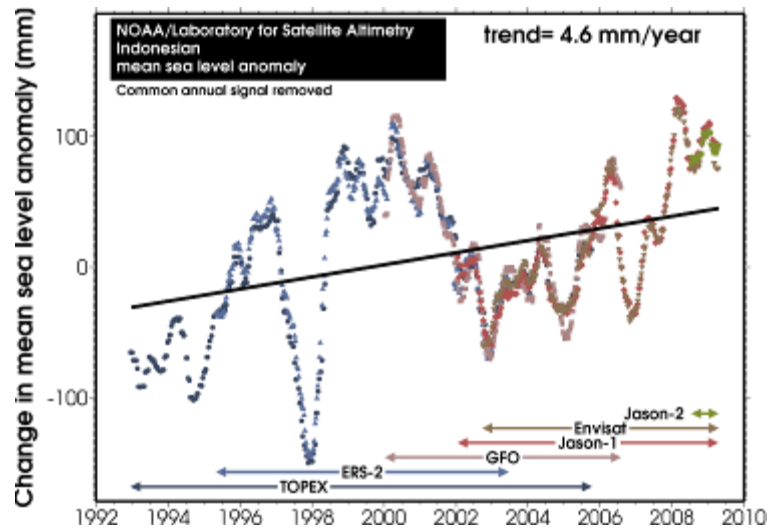


Figure 3. Average sea level rise per year in Indonesia (National Oceanic and Atmospheric Administration - Laboratory for Satellite Altimetry (NOAA-LSA), 2007)

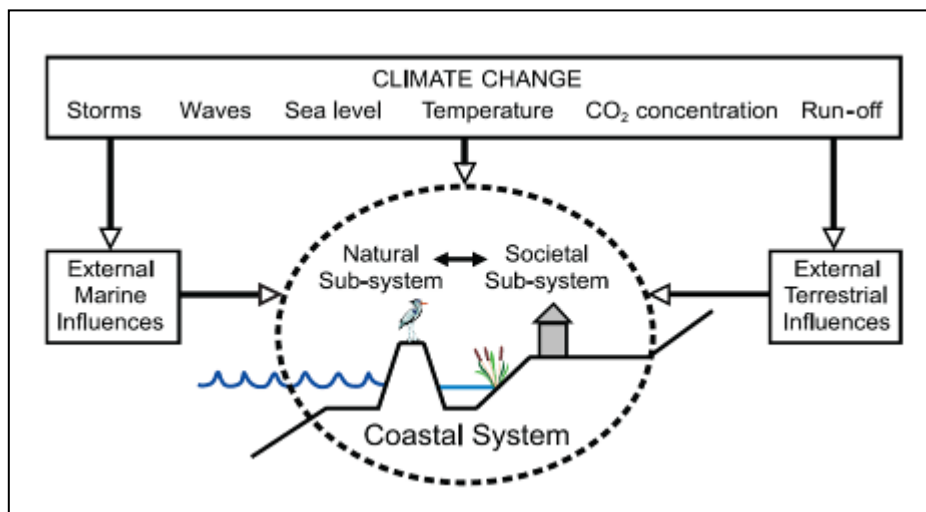


Figure 4. Climate change and the coastal system (Nicholls et al., 2007)

#### Effects of climate change on water management in lowlands in wet and dry season

Especially in tidal lowland areas, sea level rise and rainfall pattern will play an important role for future water management, as influence of upstream discharge is reduced by the tidal influence due to its location in the near coastal zone. In this research, the effect of sea level rise has been analyzed together with land subsidence.

The hydro topographical condition is defined as the elevation of the fields relative to actual high canal water levels at the nearest drainage or intake point, and is usually expressed in the number of tidal irrigations that can be applied. It provides a simple categorisation of the tidal irrigation potential and soil and water management conditions at field level.

Hydro-topography is classified as follows (after Euroconsult, 1993; Suryadi, 1996):

- *category A*: tidal irrigated areas, in both wet and dry season;
- *category B*: tidal irrigated areas, only in the wet season;
- *category C*: areas just above ( $\leq 0.50$  m) the average high water level in wet season;
- *category D*: water levels independent from tidal influence.

With land subsidence and sea level rise there will be significant change in hydro-topographic categories. This situation is caused by change of inundation depth of tidal irrigation, for example from category C to B, caused by the fact that it can be irrigated during the wet season, or from category B to A as before it could only be irrigated during the wet season, but with sea level rise it can be irrigated during the wet and the dry season.

### **Land subsidence and its impacts**

Land subsidence can be defined as the phenomenon of the irreversible reduction in the pore space in the soil, resulting in a drop of the surface level as a result of physical ripening of the topmost layer, oxidation of organic material and compression of the subsoil (De Glopper, 1973). When reclaiming tidal lowlands, one has to estimate the possible land subsidence, because this will affect the design and operation of the water management systems. Land subsidence is not constant in time and not uniform in space.

Land subsidence is very important in relation to the soil and water management system of lowland areas. Land subsidence will directly influence drainability of the area since the level of the land surface becomes lower than in the previous condition. Effects of land subsidence will influence all related infrastructure, especially hydraulic structures (as well as embankments) may have to be re-evaluated and adjusted.

Groundwater level fluctuations play an important role in land subsidence in tidal lowland areas. Drop of the groundwater level to the lower part of the soil especially occurs when there is no or limited rainfall, or during a dry period. The deeper the groundwater level the faster soil ripening (clay soil) takes place, which causes land subsidence. Land use will also play an important role in affecting land subsidence in relation with the groundwater table management. For rice fields it is the aim to maintain the groundwater as shallow as possible depending on the growing stages. For dryland crops such as corn or soybean, the groundwater table is kept 0.4 - 0.6 m below surface. Shrinkage and subsidence take place since there is soil ripening in the topmost soil. This situation will significantly increase when rice would be replaced by tree crops where the groundwater table is kept more than a metre below surface.

### **CASE STUDY TELANG I, SOUTH SUMATRA**

The Telang I scheme (26,680 ha) is located in the coastal swamp plains north of Palembang in South Sumatra Province. Administratively Telang I is located in the Muara Telang Sub District in Banyuasin District. It is bordered by the Musi River (East), Selat Jaran and Sebalik rivers (South), Anak Telang and Telang rivers (West and North). It takes 1 to 2 hours by speedboat via the Musi River to reach primary canals P10 and P3 (also called main canals, used as well for navigation). The north part of Telang I is still covered by mangrove forest and functioning as protected swamp forest.

The Telang I scheme is divided into secondary block units of 460 ha gross that consist of the farmlands of 128 families (KK). The 4,000 m by 1,150 m units are separated by village roads and housing areas on one side and greenbelts on the other side. Each family was allocated a plot of 2.25 ha divided in a 0.25 ha home yard, 1.0 ha first farm holding next to the home yard and a 1.0 ha second holding at the far end of the tertiary unit bordering the green belt. The home yards are located along the secondary canals (SPD) and village roads. Location of Telang I is



shown in Figure 5.

The climate at Telang I is tropical monsoon, hot and humid throughout the year with maximum temperatures ranging from 29 - 32 °C, minimum temperatures from 21 - 22 °C and humidity between 84 - 89%. The wet months (over 200 mm rainfall per month) occur during November - April and the average driest month is August (less than 100 mm rainfall per month). Average annual rainfall is about 2,400 mm. According to the classification of Oldeman the agro-climate is C-1, with 5 to 6 consecutive wet month (rainfall over 200 mm) and 0 - 1 dry months (rainfall less than 100 mm).

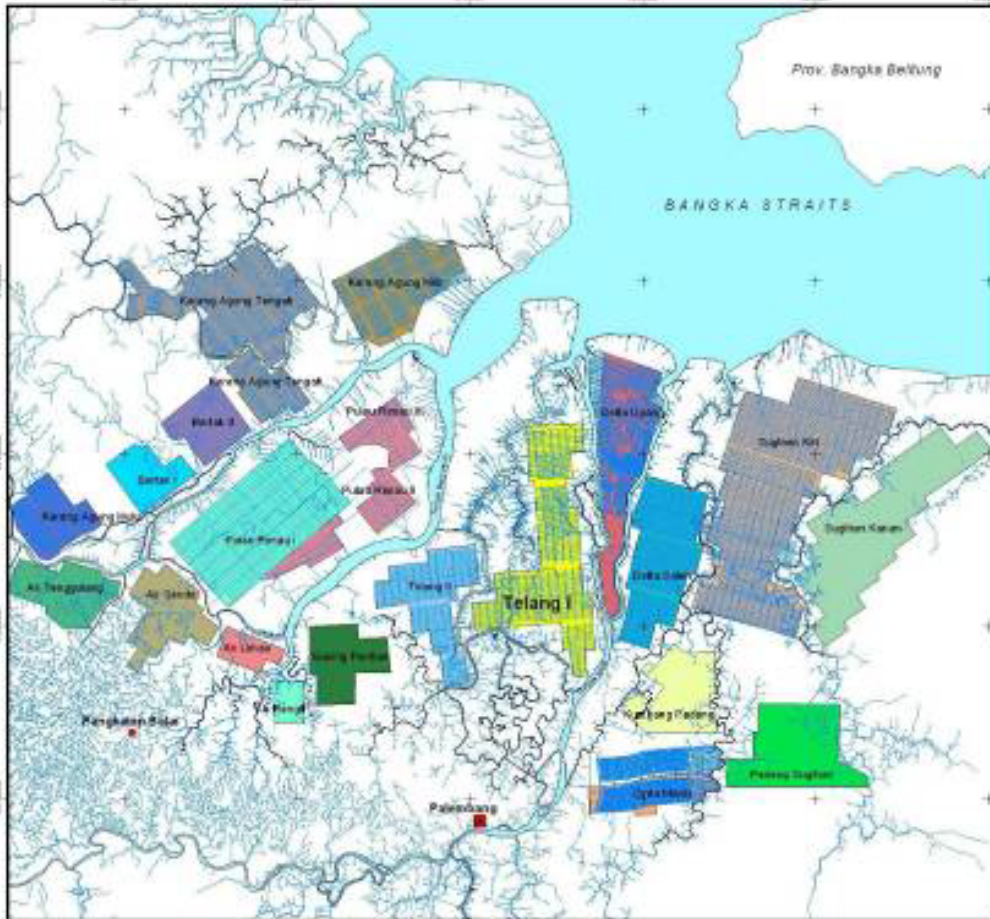


Figure 5. Telang I and tidal lowland reclamation schemes in South Sumatra

Water levels in the Musi and Telang rivers are mainly influenced by daily variations of the tides and less by seasonal effects. The tidal pattern of Bangka Strait in front of the coast of South Sumatra Province is of a mixed type. During spring tides the pattern is diurnal and during neap tides the pattern is semi-diurnal. The extreme wet season high water level (HWL) is 2.50 m+MSL at sea and 2.30 m+MSL in Musi River at Telang I. The extreme dry season HWL is 2.15 m+MSL at sea and 2.00 m+MSL in Musi River at Telang I. The mean HWL in the wet season is 1.75 m+MSL and in the dry season 1.60 m+MSL both at the sea and in the Musi River at Telang I. The mean low water level (LWL) in the wet season is 0.75 m-MSL at sea and 0.50 m-MSL in the Musi River at Telang I. For the dry season the mean LWL is 1.00 m-MSL at sea and 0.80 m-MSL in the Musi River at Telang I. The tidal range at sea is 1.40 m during neap tide and 3.50 m during spring tide.

#### Soil

Soils in Telang I have tidal swamp characteristics, are still to some extent organic and may

contain at some places potential acid sulphate layers at various depths. Moderately deep peat (over 0.40 m) can still be found in the northern part of Telang I, in primary block P3. The suitability of the shallow peat soils resembles that of the tidal swamp clay soils, though with increased risk of organic acidities (stagnant water) and water shortage (high permeability). At depths of less than 0.50 m potential acid sulphate soil layers or pyrite soils are not found anymore in the area. Pyrite at depths between 0.50 - 0.75 m has largely been oxidized, usually in the lower areas. Potential acid sulphate soil layers may still be found at depths below 0.50 m.

### *Topography*

The macro topography is generally flat or gently sloping towards the natural drainage outlets. At micro level, the topography is very irregular and disturbed as a result of reclamation activities. Topographical conditions of Telang I are shown in Figure 6.

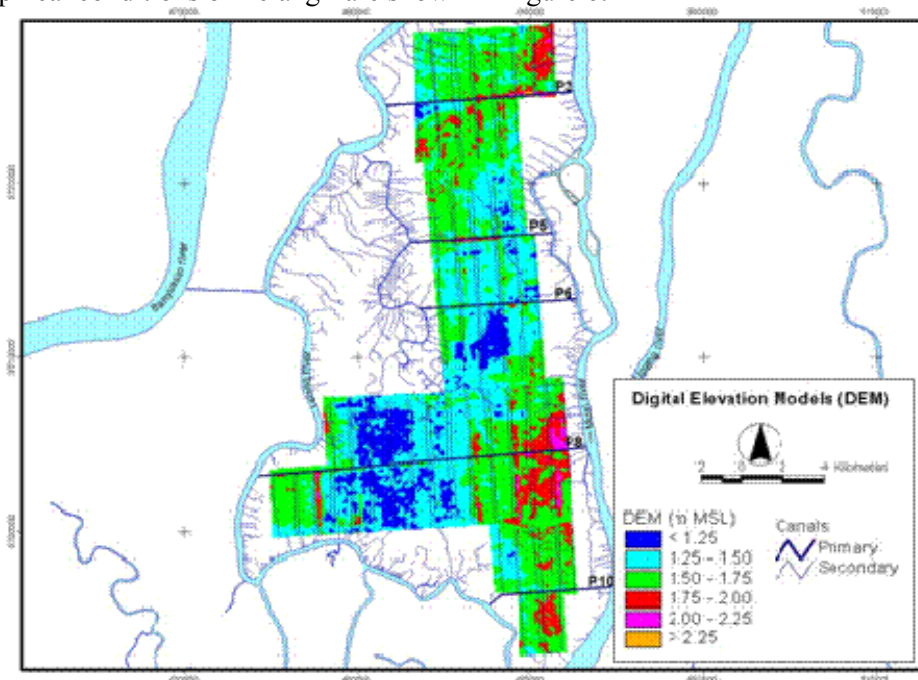


Figure 6. Topographic condition in Telang I (Citra Lahan Utama, 1994)

### *Land use*

During 1990-1995, 15% of the area was covered with shrubs and remained unutilized. This mainly concerned land at the fringes and in the lowest, poorly drained areas. Both drainage constraints and security aspects may have played a role. During undeveloped areas, pigs always damaged the crops and were perceived as a serious pest. Farmers managed over the years to develop techniques that better suited with tidal swamp conditions and land utilization was on the rise. Many farmers also developed lands near the river, in addition to their own land. Land use of the area is presented in Figure 7 which is based on the survey in 2003.

### *Hydro-topography*

The overall hydro-topography of Telang I can be assessed by analyzing relations between tidal water levels, the hydraulic infrastructure and field levels. Actual and predicted water levels in the tidal rivers and open primary canals are relatively well known. Predicted high water levels are higher than present water levels in the primary canals as there is much storage in the fields and canals. Increased flood and water control storage will reduce the actual water levels such

that they will approach predicted levels.

### Water management system in Telang I

The water management system in Telang I comprises primary, secondary and tertiary canals. The four primary canals have intervals of 4 - 8 km. Tertiary canals were originally constructed at 400 m spacing with an open connection at one side only to a secondary canal (SDU). In the up-grading of the Telang-Saleh scheme (1994 - 1997), tertiary canals were (re-)constructed at 200 m spacing and connected at both sides to the secondary canals, to allow a better water circulation, to optimize the supply and drainage in the low rice area (at the northern part of primary canals 5 and 6), and to drain the higher tree crop areas (at the southern part of primary canal 3). The tertiary canals with 200 m spacing are equipped with tertiary structures at both ends of the canals. During the project Land and Water Management Tidal Lowlands (LWMTL) (2004 - 2006) tertiary canals in the secondary blocks at primary canal 8 in (P8-12S and P8-11S) were also brought at 200 m spacing and equipped with movable fibre glass flap gate as well as at block P6-3N. With these structures water management can be implemented properly.

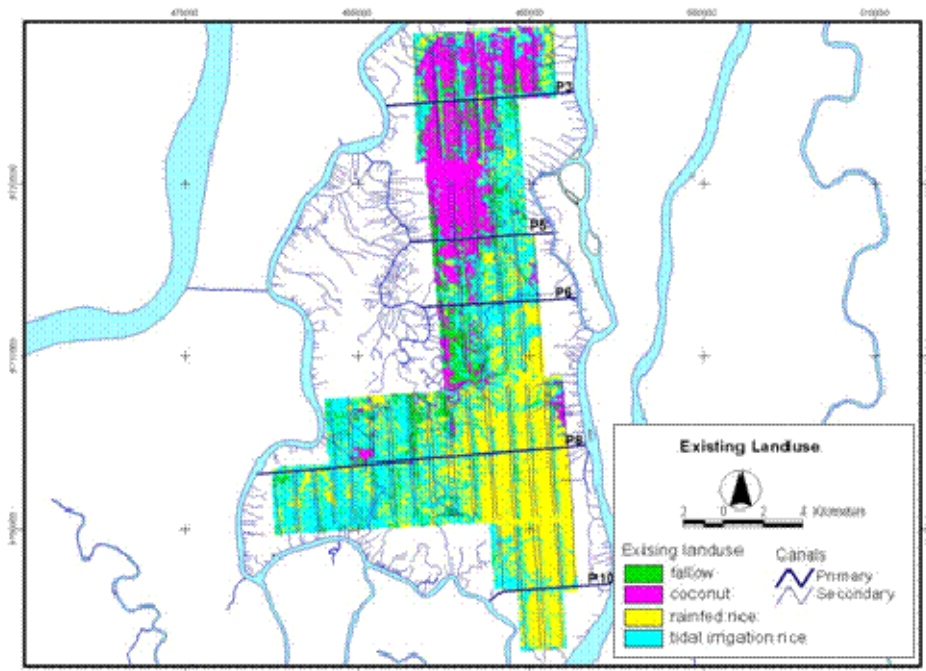


Figure 7. Land use in Telang I (Data interpreted from Landsat image, 2003)

### Development scenarios

Two situations have been studied:

- *present condition*. No effect of sea level rise and land subsidence;
- *future scenarios*. There will be sea level rise and land subsidence, estimated for the next 25 year and 50 year.

## METHODOLOGY

### Data collection

Data collected for the analyses in this study were the following:

- topographic data from the Integrated Irrigation Sector Project (IISP), Telang Saleh project

- of 1993 have been used in this study. These topographic data were used as primary data;
- base map consisting of thematic layers of spatial information together with database attributes: e.g. rivers, roads, administration boundaries, scheme networks, and infrastructure layout;
- satellite images with remote sensing data obtained for the most recent acquisition, based on Landsat ETM for the whole area and SPOT5 resolution 2.5 m for selected areas;
- time series of rainfall and groundwater table of the study area from 1993 - 1997 (IISP, Telang Saleh project), from 2004 - 2008 (LWMTL and Strengthening Tidal Lowland Development (STLD) projects), and from 1985 - 2007 (Badan Meorologi dan Geofisika (BMG), Kenten station, Palembang);
- tidal fluctuation data from 1993 - 1997 (IISP, Telang Saleh project), from 2004 - 2008 (LWMTL and STLD projects) and from 2001 - 2008 (Pelabuhan Cabang Palembang);
- soil characteristics from various researches in the study area carried out by a student of the Soil Department, Faculty of Agriculture, University of Sriwijaya;
- sea level rise in Indonesia from NOAA and IPCC (Intergovernmental Panel on Climate Change (IPCC), 2007).

### Model development

Analyses and modelling have been carried out to analyse the present condition and possible future problems. The methodology that has been developed in this research is based on model simulations with respect to hydraulics and land subsidence and on a Geographic Information System (GIS).

#### *Hydraulic mathematical modelling*

For the open water system DUFLOW has been used to analyze the flow parameters (Q and h) in the delta system, losses and the drainage index for the entire scheme, salinity intrusion and to derive the boundary conditions for the system level. This computation was calibrated with observed water levels at some spots along the river, as well as with loss of head due to sea level rise in the mouth of the river to the delta and system level. Basically, free flow in open canal systems has been simulated, where control structures like weirs, pumps, culverts and siphons can be included. The selected numerical scheme allows for a rather large time step in the computation and for choosing different lengths of the elementary sections. The basic equations, which are the mathematical translation of the laws of conservation of mass and of momentum are as follows:

$$\frac{\partial B}{\partial t} + \frac{\partial Q}{\partial x} = 0 \quad (1)$$

and

$$\frac{\partial Q}{\partial t} + gA \frac{\partial H}{\partial z} + \frac{\partial(\alpha Qv)}{\partial x} + \frac{g|Q|Q}{C^2 AR} = a\gamma w^2 \cos(\Phi - \phi) \quad (2)$$

Where:

- $t$  = time (s)
- $x$  = distance as measured along the canal axis (m)
- $H(x, t)$  = water level with respect to reference level (m)
- $v(x, t)$  = mean velocity (averaged over the cross-sectional area) (m/s)
- $Q(x, t)$  = discharge at location x and at time t (m<sup>3</sup>/s)
- $R(x, H)$  = hydraulic radius of cross-section (m)

$A(x, H)$	= cross-sectional flow area (m <sup>2</sup> )
$B(x, H)$	= cross-sectional storage area (m <sup>2</sup> )
$g$	= acceleration due to gravity (m/s <sup>2</sup> )
$C(x, H)$	= coefficient of De Chézy (m <sup>1/2</sup> /s)
$w(t)$	= wind velocity (m/s)
$\Phi(t)$	= wind direction in degrees (degrees)
$\square(x)$	= direction of canal axis in degrees, measured clockwise from the north (degrees)
$\gamma(x)$	= wind conversion coefficient (-)
$\alpha$	= correction factor for non-uniformity of the velocity distribution in the advection term, defined as:

These basic equations (1) and (2) were discretized in space and time using the four point implicit Preissmann scheme.

### *Land subsidence modelling*

Land subsidence is not constant in time and space. To calculate land subsidence at a given place and time, two different soils would have to be considered, i.e. clay and peat soils (Suryadi, 1996). In this study land subsidence will focus on clay soil only, with an assumption that peat soil in this area generally has already disappeared.

Land subsidence has been modelled by using the SWAP model for the simulation of clay soils (Soil, Water, Atmosphere and Plant Model) (Kroes et al, 2008). The effect has been combined in GIS to develop a drainability map.

Subsidence in vertical direction can be calculated in the following steps:

- the conversion of moisture content change  $\Delta\theta$  into volume changes of the soil matrix  $\Delta V$ . The relation between  $\Delta\theta$  and  $\Delta V$  follows directly from the shrinkage characteristics (Bronswijk, 1991);
- the conversion of volume change of the soil matrix  $\Delta V$  into crack volume and subsidence. The following equations were used:

$$\Delta z = z - z * \left( \frac{V - \Delta V}{V} \right)^{1/rs} \quad (3)$$

$$\Delta V_{cr} = \Delta V - z^2 * \Delta z \quad (4)$$

Where:

$\Delta z$	= change in layer thickness due to shrinkage and swelling (m)
$\Delta V_{cr}$	= change in crack volume (m <sup>3</sup> )
$V$	= volume of cube of soil matrix before shrinkage/swelling (m <sup>3</sup> )
$\Delta V$	= change in volume of soil matrix due to shrinkage/swelling (m <sup>3</sup> )
$Z$	= layer thickness before shrinkage/swelling (m)
$rs$	= geometry factor

### *Model Builder and ARCGIS*

The results of the model simulations were used in the ARCGIS programme to interpolate and analyse spatial distribution by using Model Builder (Rahmadi et al., 2010). ARCGIS consists of some application extensions to perform any GIS task, from simple to advanced, including mapping, data management, geographic analysis, data editing and geoprocessing



(Environmental System Research Institute, 2001). The ARCGIS Spatial Analyst extension was chosen to model distance, elevation, drainability, hydro-topography, soils, etc. and to generate the water management zoning. In this study ARCGIS 9.2 has been used to analyse spatial data in order to generate a map of water management zoning. Overlay and spatial analyses of all related maps to generate water management zoning have been carried out. Model Builder operates in conjunction with ArcGIS Spatial Analyst, and is designed to work primarily with grid data sets. It groups selected ArcGIS Spatial Analyst functions into eleven wizards that guide you step by step through the procedures necessary to create a final map. As you work through the wizards, Model Builder also creates a model diagram, or flow chart, of the session that captures the geographic data, the spatial functions that operate on the data, and the order of those functions. Model Builder can be created by using arc-catalogue in ARCGIS 9.2. The procedure to use Model Builder can be started by opening Arc-catalogue and to navigate to a folder that you can access. Figure 8 shows the block diagram of the Model Builder to create a drainability and hydrotopography map. To generate water management zoning in Model Builder the same procedure needs to be implemented. Layers represent sea level rise as well as soil subsidence to generate predicted hydrotopography and drainability. Existing land use is derived from satellite images and the soil layer is generated by direct digitizing from secondary map. To run water management zoning at least 4 layers consisting of soil type, land use, predicted hydrotopography and drainability were needed. ARCGIS is a system of parts that can be deployed on a single desktop or distributed on a heterogeneous computer network of workstations and servers.

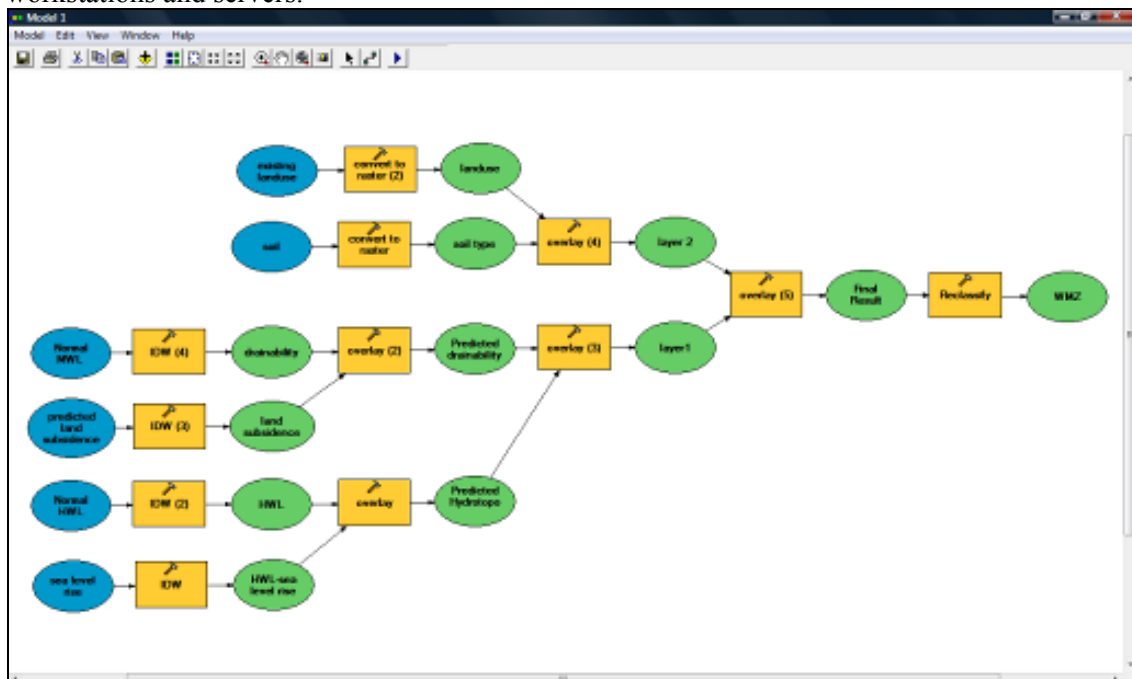


Figure 8. Model Builder to generate a water management zoning map in relation with sea level rise and land subsidence

## RESULTS AND DISCUSSION

### Trend of sea level rise in the study area

Although data collected from PT. Pelabuhan II Cabang Palembang were only recorded from 2001 - 2008 they show a sea level rise trend. Data were recorded based on the average level of Low Water Springtide (LWS), since they were used for navigation purposes. Due to the limited length of the time series, the trend can be used just to see the impact of climate change,

especially sea level rise in the study area (Figure 9). Nevertheless sea level rise was still used from the comprehensive study from related research.

Data were recorded using AWLR (Automatic Water Level Recorder) at Tanjung Buyut station in the mouth of Musi River, Kampung Upang ( $\pm 40$  km from river mouth) and Selat Jaran ( $\pm 45$  km from the river mouth).

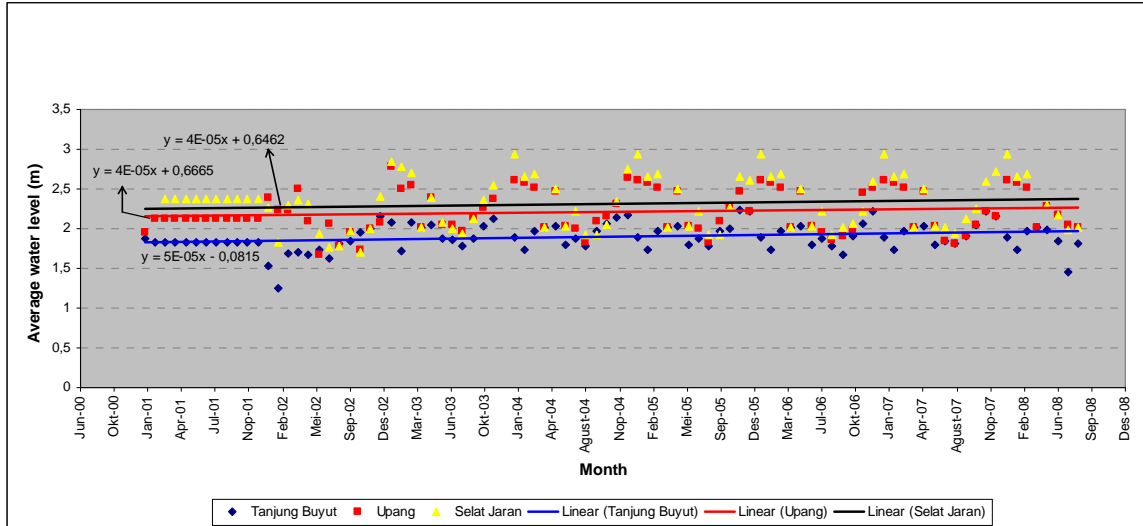


Figure 9. Average water level of Low Water Springtide in Musi River (2001-2008)

### Land subsidence and its facts

In the study area the groundwater is generally kept around the surface, since in most areas wetland paddy is cultivated. There is a relationship between hydro-topographical conditions and groundwater table fluctuations, especially for category A and B areas. An example of the groundwater fluctuation from 2004 - 2008 in the study area (P8-12S) is shown in Figure 10.

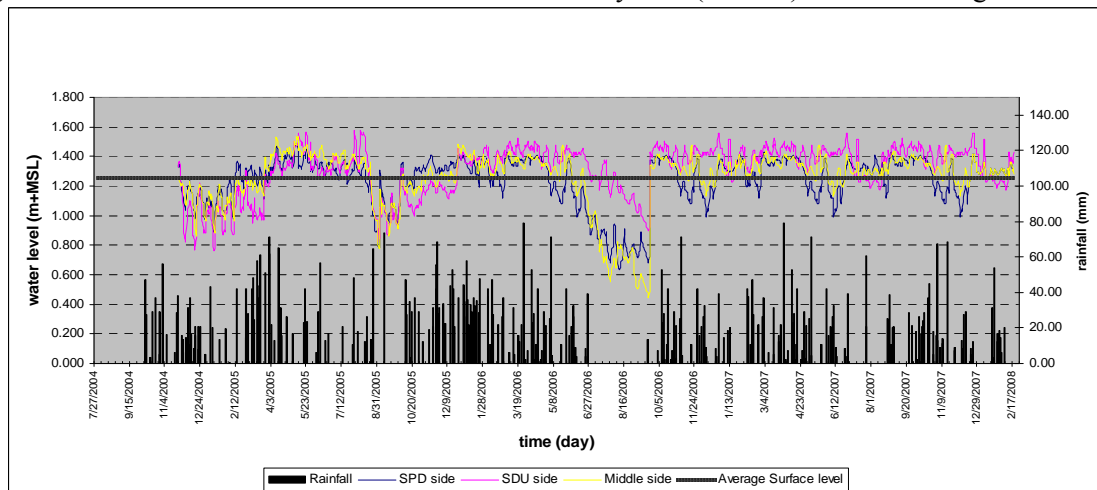


Figure 10. Groundwater level fluctuation at P8-12S Telang I (LWMTL and STLD, 2004-2008)

### SWAP modelling for land subsidence

The SWAP model for land subsidence considers the macropores of the soil. Three main data are used in this model: crop, drainage and weather. Land subsidence in Telang I was simulated in compartments of soil in each layer. The results of the model shows that land subsidence has a relation with groundwater fluctuation, where it varies from 3 - 7 mm/year. In low areas where the groundwater level is near the surface land subsidence is about 3 mm/year, while for higher

areas it is about 7 mm/year. Land subsidence during the beginning of the reclamation period is higher than after a long period. In the present conditions when the soil has already ripened, the land subsidence through swelling, compacting or other processes becomes slower.

In Telang I and its surrounding areas such periods occurred in 1977, 1985, 1993 and 1994. However, as the soil becomes more compact, the effect of a dry period becomes less. Land subsidence in this study was based on data from a few sampling sites only. Due to the limitation of data and information it is assumed that land subsidence in the northern location is from 3 - 7 mm/year. For realistic analyses, a 30% exceedance of land subsidence for GIS analyses has been assumed.

### Water management zoning

In Telang I, there are three main water management zones based on present hydro-topography, drainability, salinity intrusion and soil characteristics. The present land use is used to check and re-delineate water management zones. There are water management zones (WMZ) I, III and VIII, WMZ I for tree crops or dryland crops, rainfed rice dependent on field characteristics and farmers objectives. Areas located in the higher areas with potential drainage of more than 0.60 m. WMZ III concerns tidal irrigated areas, with category A or B for rice and WMZ VIII for rainfed areas or dryland crops, located in areas with a drainage potential of 0.30 – 0.60 m. The northern part of Telang I was planted with coconut due to the peat layer in the past.

#### *Present condition in the wet season*

Topographic data were available as point data based on the survey by PT. Citra Lahan Utama (1993). The grid system for point data is 20 x 20 m. Topographic data presented in the Digital Elevation Model (DEM) were the main data used for this study (Figure 11). The tidal irrigation and drainability map consisted of two of layers that use DEM as their reference data.

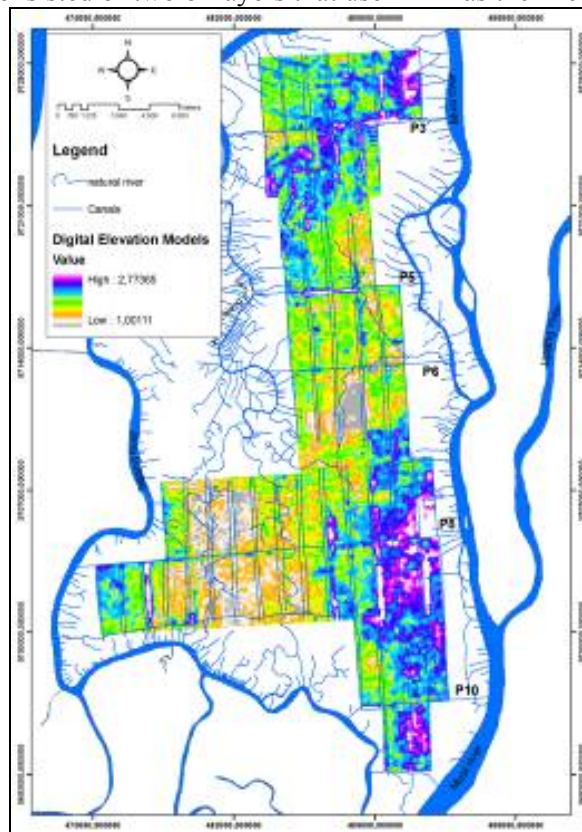


Figure 11 Present digital elevation models (DEM) of the study area (real data type)

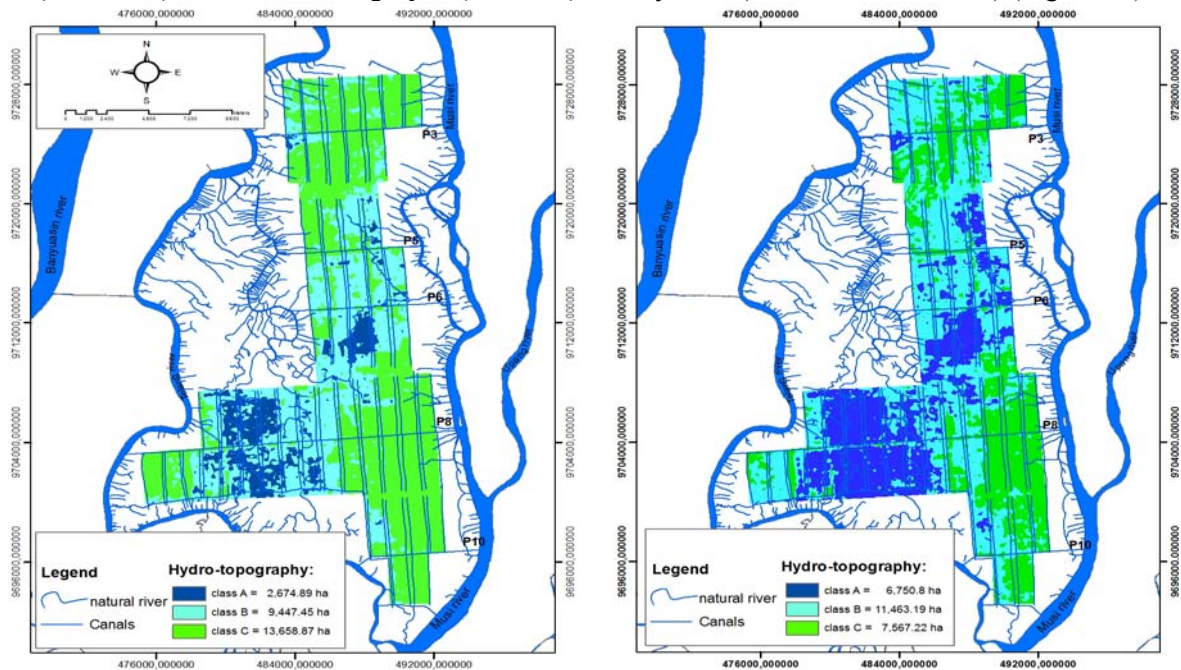


### *Effect of land subsidence and sea level rise in the wet season*

Land subsidence and sea level rise significantly influence future hydro-topography, tidal-irrigated and drainage. Present water management was analysed for 2008 and future water management was analysed for 25 years ahead. The 25 years were chosen based on the uncertain condition in the future, especially for land subsidence.

### *Hydro-topography*

In the present situation, hydro-topography in Telang I is dominated by category C with 13,700 ha or 53% of the area, and followed by category B with 9,430 ha or 37% and category A with 2,680 ha. Because of land subsidence (3 - 7 mm/year) and sea level rise of 2 mm/year, future hydro-topography will significantly change. Based on the GIS modelling it can be stated that in 25 years hydro-topography will become dominated by category A (6,750 ha) or 26%, category B (11,500 ha) or 45% and category C (7,570 ha) or only 29% (Rahmadi et al., 2010) (Figure 12).



*Figure 12. Comparison between present (left) and future hydro-topographical category (right) in Telang*

In the present condition, the largest area in Telang I can be drained sufficiently for rice field and other cultivation purposes. For rice field, most of the drainage base is about 0.30 m or still sufficient for paddy. If land subsidence can not be controlled properly the drainage base will not be sufficient anymore in future. Strengthening of the protection dike will be needed to support better water management in future.

Hydro-topography will influence land quality of the area which directly will influence the delineation of the water management zoning. Water management is derived for each secondary block. Based on the ARCGIS analysis the effect of land subsidence and sea level rise on water management zoning is shown in Figure 13. It can be concluded that the effects of climate change and land subsidence on water management zoning in the future is significant. These significant effects can have positive and negative impacts on the development in the study area particularly and in Indonesia in general. Although land subsidence will be slower in future because of soil compactness and ripeness, it can also be concluded that land subsidence will have a larger effect on water management zoning than sea level rise.

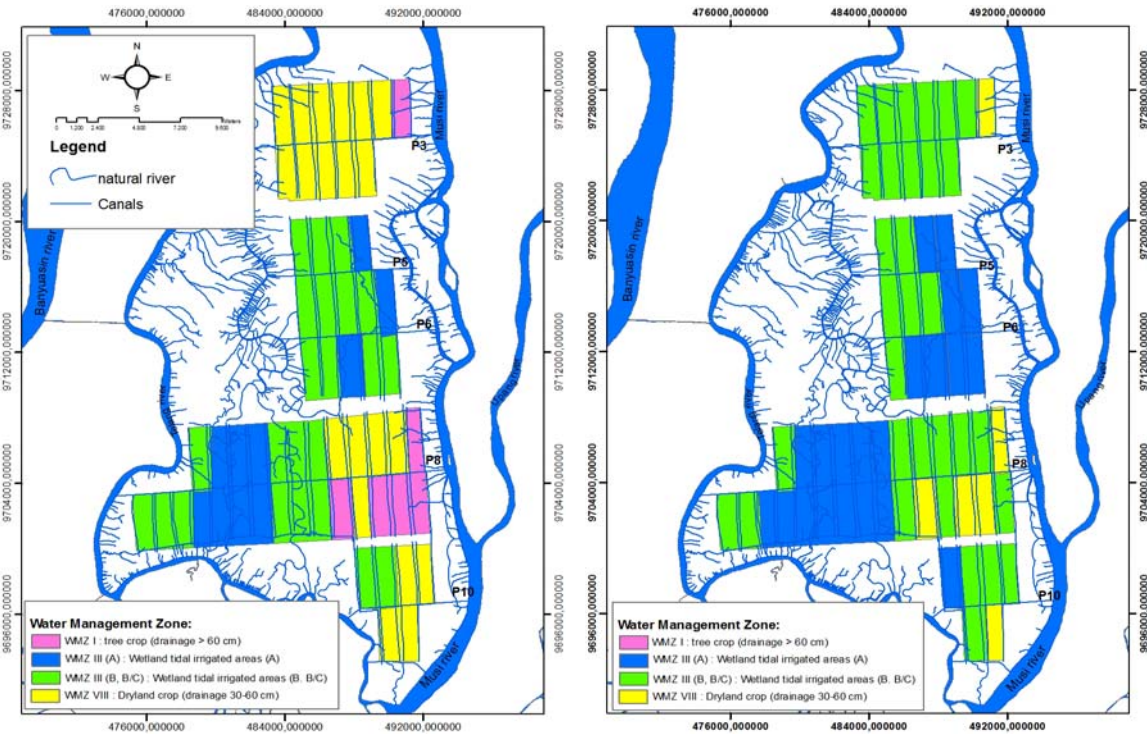


Figure 13. Comparison between present (left) and future (right) water management zoning in the wet season in Telang I

Sea level rise and land subsidence will result in a larger tidal irrigated area with tidal depth 0- 0.25 m or > 0.25 m. Due to this there will be changes in crops from dryland crop in the present condition to wetland rice tidal irrigation and from tree crops to dryland crops. In the dry season the positive effects of sea level rise and land subsidence will result in a larger area with tidal irrigation, meaning that large areas can be cultivated with a double rice crop.

Some measures have to be taken to deal with future conditions, like: proper water management to realise groundwater levels that are optimal for crop growth, improved operation and maintenance (O&M) practises and measures to reduce or even to prevent land subsidence. Institutional strengthening to enhance water users associations (WUA) and O&M agencies will also be required. Structural-measures would also have to be re-considered and can be approached by implementing from design or review design stage where all designs has to take into account the effects of sea level rise and land subsidence.

## FINAL REMARKS

Based on the results of model simulations and discussions, some final remarks can be presented:

- the effects of climate change and land subsidence on water management zoning in future are significant. More area can be irrigated by the tides, but drainage will need more attention. The effect of land subsidence on water management zoning is more important than the effect of sea level rise;
- in future studies use of data on climate change and sea level rise from observation stations in Indonesia is recommended;
- from the analyses and data processing by using ARCGIS, it can be concluded that GIS analyses with the Model Builder technique is very useful in generating land quality and water management zoning. It is recommended to use standard base maps as base layers and BAKOSURTANAL maps with 1 : 50,000 scale as references;
- land subsidence can partly be controlled by applying proper operation of water

- management systems;
- establishment of monitoring stations, like in Telang I (also in other tidal areas) that may represent tidal lowlands development in Indonesia is recommended in order to monitor the impact of sea level rise and land subsidence in present and in future.

## REFERENCES

- Bernstein Lenny, Peter Bosch, Osvaldo Canziani, Zhenlin Chen, Renate Christ, Ogunlade Davidson, William Hare, Saleemul Huq, David Karoly, Vladimir Kattsov, Zbigniew Kundzewicz, Jian Liu, Ulrike Lohmann, Martin Manning, Taroh Matsuno, Bettina Menne, Bert Metz, Monirul Mirza, Neville Nicholls, Leonard Nurse, Rajendra Pachauri, Jean Palutikof, Martin Parry, Dahe Qin, Nijavalli Ravindranath, Andy Reisinger, Jiawen Ren, Keywan Riahi, Cynthia Rosenzweig, Matilde Rusticucci, Stephen Schneider, Youba Sokona, Susan Solomon, Peter Stott, Ronald Stouffer, Taishi Sugiyama, Rob Swart, Dennis Tirpak, Coleen Vogel, Gary Yohe, 2007. *Climate Change 2007: Synthesis Report - Summary for Policymakers.* Pp. 23 in *Intergovernmental Panel on Climate Change Fourth Assessment Report.*
- Bindoff, N.L., J. Willebrand, V. Artale, A. Cazenave, J. Gregory, S. Gulev, K. Hanawa, C. Le Quéré, S. Levitus, Y. Nojiri, C.K. Shum, L.D. Talley and A. Unnikrishnan, 2007: Observations: Oceanic Climate Change and Sea Level. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Bronswijk, J.J.B., 1991. *Magnitude, Modeling and Significance of Swelling and Shrinkage processes in clay soils.* Doctoral Thesis. Wageningen Agricultural University, Wageningen, The Netherlands. (IX) + 455 pp.
- Citra Lahan Utama, 1994. *Laporan Akhir Survei Topografi Telang I.* Direktorat Jenderal Sumberdaya Air. Departemen Pekerjaan Umum, Jakarta, Indonesia.
- Collier, W.L., 1980. *Fifty years of spontaneous and government sponsored migration in the swampy lands of Kalimantan.* Prisma, September 1980. Jakarta, Indonesia.
- Environmental System Research Institute (ESRI), 2001. *Model Builder for ArcView Spatial Analyst 2.* Environmental Systems Research Institute.
- Euroconsult, 1984. *Nationwide study of coastal and near coastal swamp land in Sumatra, Kalimantan and Irian jaya.* Directorate General Water Resources Development. Ministry of Public Works.
- Euroconsult, 1993. Technical Note. *Integrated Irrigation Sector Project.* Directorate General Water Resources Development. Ministry of Public Works.
- Glopper, R.H.J. de, 1973. *Subsidence after drainage of deposits in the former Zuyder Zee and in the brackish and marine forelands in the Netherlands.* Van Zee tot Land no.50, the Netherlands.
- Intergovernmental Panel on Climate Change (IPCC), 2007. *Climate Change 2007: Synthesis report, Intergovernmental Panel on climate Change Fourth Assessment Report* .(Downloaded from [http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4\\_syr\\_introduction.pdf](http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_introduction.pdf) on 10 June 2009)
- Kroes J.G., J.C. Van Dam, P. Groenendijk, R.F.A. Hendriks, C.M.J. Jacobs. 2008. *SWAP version 3.2. Theory description and user manual.* Alterra-report 1649, ISSN 1566-7197. Alterra. Wageningen UR.
- Lotze, H.K., H.S. Lenihan, B.J. Bourque, R.H. Bradbury, R.G. Cooke, M.C. Kay, S.M. Kidwell, M.X. Kirby, C.H. Peterson and J.B.C. Jackson, 2006. *Depletion, degradation and recovery potential of estuaries and coastal seas.* *Science*, 312, 1806-1809.
- Manuwoto, S. 1986. *The time perspective of tidal lowland development.* In: Proceeding of the Lowland Development in Indonesia Symposium, ILRI, Wageningen, the Netherlands.
- Ministry of Public Works, 1984. *Executive Report of Nationwide survey of coastal and near coastal swampland in Indonesia.* Jakarta, Indonesia.
- Naylor, R.L., Battisti, D.S. Vimont, D.J., Falcon, W.P. and Burke, M.B. 2007. Assessing risks of climate variability and climate change for Indonesian rice agriculture. Proceeding of the National Academic of Science 114:7752-7757
- National Oceanic and Atmospheric Administration - Laboratory for Satellite Altimetry (NOAA-LSA), 2007. Regional sea level rise time



- series. [http://ibis.grdl.noaa.gov/SAT/slr/LSA\\_SLR\\_timeseries\\_regional.php](http://ibis.grdl.noaa.gov/SAT/slr/LSA_SLR_timeseries_regional.php)
- Nicholls, R.J., P.P. Wong, V.R. Burkett, J.O. Codignotto, J.E. Hay, R.F. McLean, S. Ragoonaden and C.D. Woodroffe, 2007. Coastal systems and low-lying areas. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 315-356.
- Rahmadi. 2009. *Effects of Climate Change and Land Subsidence on Water Management Zoning in Tidal Lowlands. Case Study Telang I, South Sumatra*. MSc thesis, UNESCO-IHE, Delft, the Netherlands and Sriwijaya University, Palembang, Indonesia.
- Rahmadi, F.X. Suryadi, H.S. Robiyanto, Bart Schultz, 2010. *Effects of Climate Change and Land Subsidence on Hydro-topographical Conditions in Tidal Lowlands Case Study Telang I, South Sumatra*. Paper presented in International Seminar-Workshop on Integrated Lowland Development and Management, Sriwijaya University, Palembang, Indonesia, March 2010.
- Scavia, D., J.C. Field, D.F. Boesch, R. Buddemeier, D.R. Cayan, V. Burkett, M. Fogarty, M. Harwell and Co-authors, 2002. *Climate change impacts on U.S. coastal and marine ecosystems*. *Estuaries*, 25, 149-164.
- Schultz, B., 2006. *Opportunities and threats for lowland development. Concepts for water management, flood protection and multifunctional land-use*. In: Proceedings of the 9<sup>th</sup> Inter-Regional Conference on Environment-Water. EnviroWater 2006. Concepts for Watermanagement and Multifunctional Land-Uses in Lowlands, Delft, the Netherlands, 17 - 19 May, 2006.
- Schultz, B, 2008. *Extreme weather conditions, drainage, flood management and land use*. In: Proceedings of the 10th International Drainage Workshop, Helsinki, Finland and Tallinn, Estonia, 2008, Helsinki University of Technology, Helsinki, Finland.
- Soenarno, 1993. *Irrigation management transfer in Indonesia*. Paper. Directorate General Water Resources Development. Ministry of Public Works.
- Suprpto, 2002. *Land and water resources development in Indonesia*. Website FAO, Rome, Italy
- Suriadikarta, D.A, Sjamsidi G, Mansur D and A. Abdurachman. 2001. *Increasing food crop productivity through intensive agricultural program in Indonesia*. Proceedings Regional Workshop on Integrated Plant Nutrient System (IPNS) Development and Rural Poverty Alleviation, 18-20 September 2001, Bangkok, Thailand.
- Suryadi, F.X. 1996. *Soil and water management strategies for tidal lowlands in Indonesia*. PhD thesis, Delft University of Technology- IHE Delft. Balkema, Rotterdam, The Netherlands.
- United Nations Development Programme Indonesia, 2007. *The other half of climate change. Why Indonesia must adapt to protect its poorest people*. UNDP Indonesia Country Office, Jakarta.