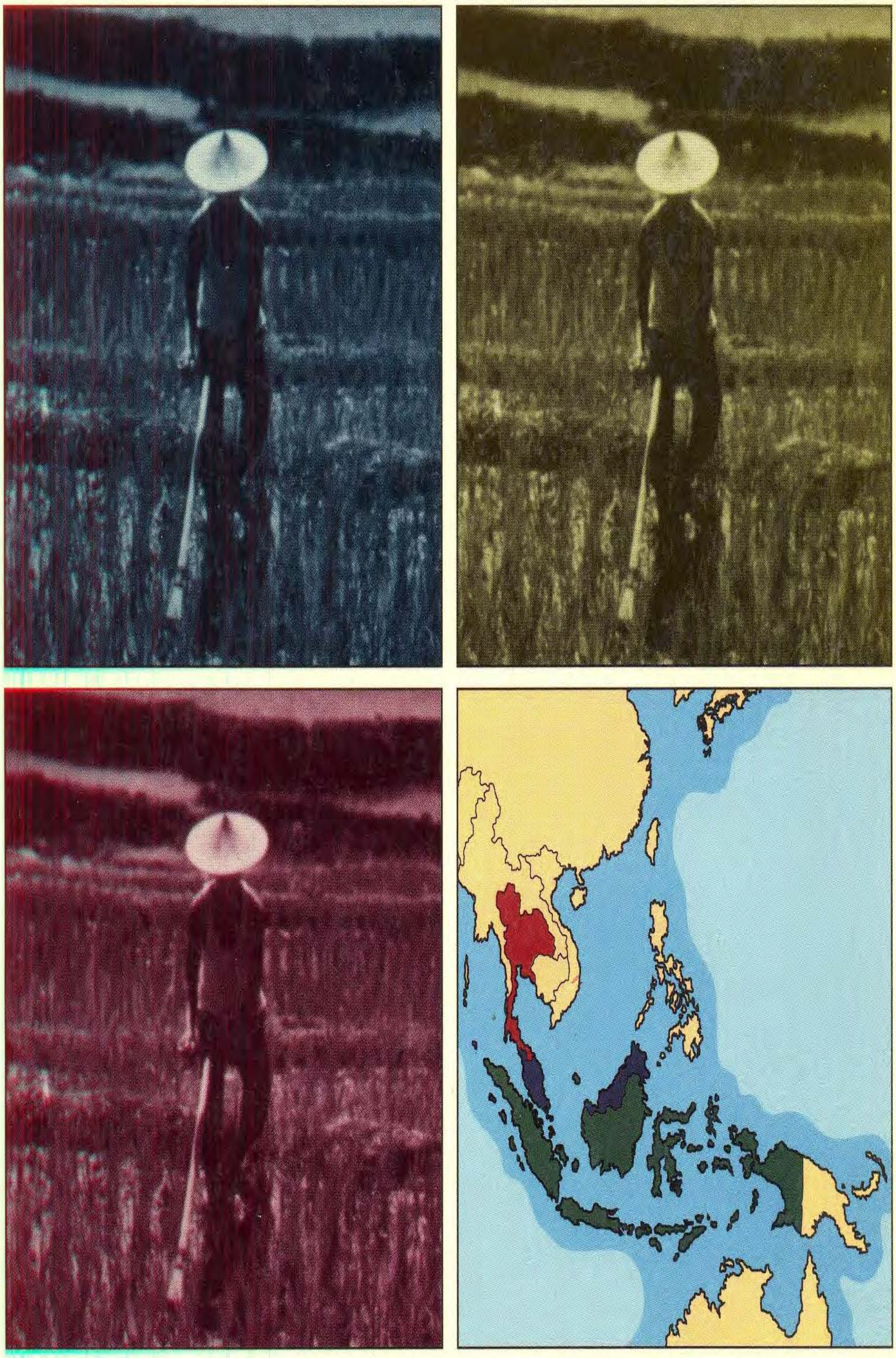

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EARTHWATCH

GLOBAL ENVIRONMENT MONITORING SYSTEM

# *The Potential Socio-Economic Effects of Climate Change in South-East Asia*

*Edited by M. L. Parry, M. Blantran de Rozari, A. L. Chong and S. Panich*
*at the Environmental Change Unit, University of Oxford*

UNITED NATIONS ENVIRONMENT PROGRAMME

UNEP

# THE POTENTIAL SOCIO-ECONOMIC EFFECTS OF CLIMATE CHANGE IN SOUTH-EAST ASIA

# AUTHORS

| | | |
|---|---|---|
| Section I: | *Martin Parry* | (University of Oxford, UK) |
| Section II: | *Amos Eddy* | (A. Eddy Inc.) |
| | *Eric Bird* | (University of Melbourne, Australia) |
| | *Suwanna Panturat* | (Srinakharinwirot University, Thailand) |
| | *Robert Sladewsky* | (A. Eddy Inc.) |
| Section III: | *Amos Eddy* | (A. Eddy Inc.) |
| | *Eric Bird* | (University of Melbourne, Australia) |
| | *Suwanna Panturat* | (Srinakharinwirot University, Thailand) |
| | *Robert Sladewsky* | (A. Eddy Inc.) |
| Section IV: | | |
| Indonesia | | |
| | *M. Blantran de Rozari* | (Bogor Agricultural University) |
| | *Koesoebiono* | (Bogor Agricultural University) |
| | *N. Sinukaban* | (Bogor Agricultural University) |
| | *D. Murdiyarso* | (Bogor Agricultural University) |
| | *K. Makarim* | (Bogor Research Institute for Food Crops) |
| Malaysia | *Chong Ah Look* | (Malaysian Meteorological Service) |
| | *Lee Say Chong* | (Department of Drainage and Irrigation) |
| | *Salim Said* | (Universiti Pertanian Malaysia) |
| | *Peter Ho Yuen Chuen* | (Department of the Environment) |
| | *Ramadasan Krishnan* | (Malaysian Agricultural Research and Development Institute) |
| Thailand | *Ruangdej Srivardharna* | (Kasetsart University) |
| | *Jerapan Jirananda* | (Kasetsart University) |
| | *Vute Wangwacharakul* | (Kasetsart University) |
| | *Sangsant Panich* | (Chulalongkorn University) |
| Section V: | *Eric Bird* | (University of Melbourne, Australia) |
| Section VI: | *Ferenc Toth* | (International Institute for Applied Systems Analysis, Austria) |

# PREFACE

This report describes the results of a project funded by the United Nations Environment Programme (UNEP) over 1988-1991. The project stemmed from the recommendations of a WMO/UNEP/ICSU meeting held in Villach (Austria) in 1985 which emphasized the importance of evaluating the potential socio-economic consequences of greenhouse gas-induced climate change. UNEP funds were made available to National Study Groups (NSGs) in the three case study countries (Indonesia, Malaysia and Thailand). In addition UNEP provided support both for meetings of a project steering committee (PSC) and for advice from expert consultants. Over the four years of the study five meetings of the PSC and NSGs were held in Bangkok (Thailand), Kuala Lumpur (Malaysia) and Anyer (Indonesia). At these meetings the draft reports of the NSGs were presented and revised.

The editor and authors of this report (listed) acknowledge the help of the following in its production: Mr. Peter Usher (UNEP) who was programme leader of the project; Dr. Nay Htun, Regional Director of UNEP's Office for Asia and the Pacific, who was chairman of the PSC (up to 1990); Mr. Goh Kiam Seng, Regional Director (from 1990) of UNEP's Office for Asia and the Pacific who was chairman of the PSC from 1990; Mr. Aca Sughandhy, Assistant to the Minister of Population and Environment, Indonesia; Mr. Kasem Snidvongs, Director General of the Department of Science Service, Ministry of Science, Technology and Energy, Thailand; Dr. Abu Bakar Jaafar, Director General of the Department of Environment, Ministry of Science, Technology and the Environment, Malaysia.

The report was edited by Martin Parry with the assistance of Dr. Blantran de Rozari, Mr. A.L. Chong and Dr. S. Panich. The editorial assistant was Mrs. Cynthia Parry. The text was keyboarded by Mrs. Susan Lane, and the diagrams were drawn by Mr. Kevin Burkhill and Mrs. Jean Dowling.

The members of the National Study Groups were as follows:

**Indonesia**

National Coordinator: Mr. Aca Sugandhy, Assistant to the Minister, State Ministry for Population and Environment
National Technical Coordinator: Dr. M. Blantran de Rozari, Bogor Agricultural University
Secretary: Mrs. Sri Hudayastuti, State Ministry for Population and Environment
Prof. S. Partoatmodjo, Bogor Agricultural University
Ir. Yustita Zainudin, Bogor Agricultural University
Ir. Sutrisno, Meteorology and Geophysical Agency
Mr. Hary S. Meteorology and Geophysical Agency
Dr. A. Bey, Bogor Agricultural University
Ir. Rini Hidayati, Bogor Agricultural University
Dr. Karim Makarim, Centre for Research and Development of Food Crop
Dr. J.S. Baharsjah, Bogor Agricultural University
Mr. Koesoebiono, Bogor Agricultural University
Dr. Otto S.R. Ongkosongo, Oceanology Centre for Research and Development
Dr. N. Sinukaban, Bogor Agricultural University
Dr. H. Suwardjo, Centre for Soil Research and Development
Dr. D. Murdiyarso, Bogor Agricultural University
Ir. Hadi S. Pasaribu, Department of Forestry
Mr. Obin Taryana, Centre for Water Resources Research and Development
Mr. Suladjiono, Jatiluhur Irrigation Authority

**Malaysia**

National Coordinator: Mr. Goh Kiam Seng, Director General of the Department of Environment, Ministry of Science, Technology and the Environment (up to April, 1990); Dr. Abu Bakar Jaafar, Director General of the Department of Environment, Ministry of Science, Technology and the Environment (from April, 1990)
National Technical Coordinator: Mr. Chong Ah Lock, Malaysian Meteorological Service
Dr. Mohd. Zaki Ghazalli, Malaysian Agricultural Research and Development Institute
Ir. Lee Say Chong, Department of Drainage and Irrigation
Ir. Lim Teik Keat, Department of Drainage and Irrigation
Dr. Salim Said, University of Agriculture, Malaysia

Mr. Peter Ho Yueh Chuen, Department of Environment
Ms. Rahmah Mohd. Tahir, Department of Environment
Mr. Ramadasan Krishnan, Malaysian Agricultural Research and Development Institute
Mr. Ahmad Tarmizi Mohd., Palm Oil Research Institute
Mr. Yong Eu Fan, University of Agriculture, Malaysia
Mr. Yeow Pow Kwei, University of Agriculture, Malaysia
Dr. Johari Endan, University of Agriculture, Malaysia
Dr. Yew F.K., Rubber Research Institute of Malaysia
Mr. Johari Hassan, Rubber Research Institute of Malaysia
Ir. Zamali b. Midun, Department of Drainage and Irrigation
Ir. Sea Ching Hoo, Department of Drainage and Irrigation
Ir. Lim Chow Hock, Department of Drainage and Irrigation
Ir. Salmah Mohd. Soom, Department of Drainage and Irrigation
Ir. Muhamad Akhir Othman, Department of Drainage and Irrigation
Mr. Teh Tiong Sa, University of Malaya
Mr. Chan Ah Kee, Malaysian Meteorological Service
Mr. Yong Pok Wing, Malaysian Meteorological Service
Mr. Yeong Nam Heh, Malaysian Meteorological Service

**Thailand**

National Coordinator: Mr. Kasem Snidvongs, Director-General of the Department of Science Service, Ministry of Science, Technology and Energy
National Technical Coordinator: Dr. Pakit Kiravanich, Secretary General of Office of Atomic Energy for Peace, Ministry of Science, Technology and Energy
Dr. Ruangdej Srivardhana (Leader), Faculty of Economics and Business Administration, Kasetsart University
Mrs. Jerapan Jirananda, Faculty of Economics and Business Administration, Kasetsart University
Dr. Vute Wangwacharakul, Faculty of Economics and Business Administration, Kasetsart University
Miss Apinya Diawatanawiwat, Faculty of Sciences, Kasetsart University
Dr. Sangsant Panich, Faculty of Engineering, Chulalongkorn University
Captain Nakorn Tanuwong, Hydrographic Department, Royal Thai Navy
Commander Sayan Popraiwan, Survey Division, Hydrographic Department, Royal Thai Navy

The consultants who contributed to the study included Dr. Eric Bird (University of Melbourne, Australia), Dr. Amos Eddy (Norman, Oklahoma), Dr. Martin Parry (Environmental Change Unit, University of Oxford) and Dr. Ferenc Toth (International Institute for Applied Systems Analysis, Austria).

# EXECUTIVE SUMMARY

Recent attempts to estimate the potential socio-economic effects of greenhouse gas (GHG) induced warming have included a small number of preliminary scenario-based assessments using outputs of General Circulation Models (GCMs). However, these studies have all been based in developed economies, mainly in northern midlatitude countries. The purpose of the present study was a) to generate estimates of potential impacts in a form likely to be of use to policy-makers, and b) to test our capability for assessing impacts in tropical developing economies using available information from General Circulation Models.

Three countries were chosen for study: Indonesia, Malaysia and Thailand. National study teams were selected from scientists in national meteorological offices, environmental agencies, agricultural research institutes and local universities. In order to develop usable impact estimates policy-makers were involved both in the design and implementation of the study.

In this report a description is given of the methods and models used in the study, the possible physical and economic impacts that may stem from continued emissions of greenhouse gases, and the array of policy responses that may be appropriate.

## IMPACTS IN INDONESIA

In Indonesia the projected warming under a "2 x $CO_2$" climate is estimated to lead to an increase in mean annual temperatures of about 3°C and a rise in average sea level of about 0.6 m. Rainfall could decrease in some regions but might generally increase and, according to the Goddard Institute for Space Studies (GISS) "2 x $CO_2$" experiment, could double in some areas such as south-eastern Indonesia. Such changes in rainfall would be likely to have substantial effects on the amount of water available for irrigation (which might increase and therefore be beneficial), and on rates of soil erosion and soil leaching (which would generally be adverse in their effects on agriculture).

Considering effects on water supply, the estimated increases in rainfall would probably more than compensate for increasing evaporation due to higher temperatures and there would be more water to fill the reservoirs. There could, therefore, be a 30 per cent increase in the irrigation area of the Brantas and Citarum Basins in the western part of Java. In the Saddan Basin the area of potential irrigation could increase by 130 per cent. However, higher levels of rainfall are likely to increase the rate of soil erosion. Experiments with the SWRRB model for changes in rainfall and temperature projected under the GISS "2 x $CO_2$" scenario indicate that erosion rates in the Citarum, Brantas and Saddan watersheds could increase by 14, 18 and about 40 per cent respectively. The increase in erosion would result in losses of over 2,000 tons in soybean production in the upper Citarum River Basin, 2,500 tons in the Brantas Basin and 2,700 tons in the Saddan River Basin. Levels of soil fertility would likely be diminished by higher rates of leaching of soluble nutrients, and the study concludes that average fertility levels could decline by 2 to 8 per cent.

Rice yields are expected to decrease largely as a result of higher temperatures and, in some instances, reduced water availability. Largest losses would be in early season rice, but overall annual yield losses could be mitigated by increases in late season rice with the consequent average annual yield loss being about 4 per cent.

Soybean, an important part of the diet for about three quarters of the Indonesian population, could frequently suffer a yield loss of over 10 per cent, largely as a result of lower yields in the early season. If a decrease in insolation occurred, then further reductions in yield could not be avoided, but with appropriate management these potential losses could be compensated by increases in productivity, and overall yields could be expected to increase.

The most severe impacts could be expected on maize, where model experiments with the GISS "2 x $CO_2$" climate scenario indicate reductions in yield of between 25 and 65 per cent. Improved management could mitigate these effects and keep the maximum decline to 50 per cent.

Additional adverse effects on agriculture are estimated to occur as a result of land losses due to sea-level rise. For example, in the districts of Krawang and Subang 95 per cent of the reduction in local rice supply (down 300,000 tons) is estimated to occur as a result of inundation of the coastal zone. In the same districts maize output would be reduced by 10,000 tons, about half of this due to inundation. Sea-level rise would also be likely to affect fish and prawn production. In the Krawang and Subang Districts the loss is estimated at over 7,000 tons and 4,000 tons respectively (valued at over US$0.5m). In the lower Citarum Basin sea level rise could result in the inundation of about 26,000 ha of ponds and 10,000 ha of crop land. This could result in the loss of 15,000 tons of fish, shrimp and prawns and about 940,000 tons of rice.

The overall effect would be to reduce potential average income. The estimated reductions of yield would cost the rice farmer US$10.50 to US$17.30 annually, the soybean farmer US$22.0 to US$72.00 and the maize (corn) farmer US$25.50 to US$130.00 annually. It is estimated that the decrease in yield would cause, in the Subang District alone, about 43,000 farm labourers to loose their jobs. In addition more than 81,000 farmers would have to look for other sources of income due to the inundation of their rice fields or prawn and fish farms due to sea level rise.

## IMPACTS IN MALAYSIA

In Malaysia the projected warming under the GISS "2 x $CO_2$" climate is equivalent to about a 3-4°C increase in mean annual temperature.There is no significant change in the seasonal pattern of rainfall, but increases in rainfall are projected, firstly, for the coastal regions of Sarawak in January and February, and secondly for southwestern Peninsular Malaysia in the intermonsoon period during March, April and May. Absolute levels of air humidity are projected to increase owing to higher rates of evaporation but, since air temperatures are also higher, relative humidity is not expected to alter greatly. No information is available concerning possible changes in the daily, seasonal and annual variability of climate.

Three sectors were chosen for the study of potential impacts from changes in climate, namely agriculture, water resources and coastal. For the agricultural sector, the production of rice, maize, oil palm and rubber were studied.

Potential impacts on rice production were studied in the region of Muda in the coastal plain of Kedah and Perlis, this being the largest rice growing area in Malaysia (126,000 ha producing 700,000 tons annually from two crops a year). The CERES Rice Model was run for current climate for 17 years (1968-84) and for the GISS "2 x $CO_2$" climate for 17 years. Under the altered climate the maturation period for rice is shortened by several days, with consequent reductions in yield from 12 to 22 per cent and with the largest reductions in the main-season crop. Under the higher temperatures the increased demand for irrigation is 15 per cent.

The study concluded that the implied reductions in rice yield would significantly affect levels of farm income. Since farms in the area are already small (averaging 1.4 ha), farmers might be forced to seek alternative income sources with the poorest perhaps relinquishing their land and with average farm size increasing as a result. In general, levels of rural poverty might be expected to increase.

Although it is not easy to generalise at the national level from the Muda study, it does appear that there would occur a nationwide increase in the demand for irrigation for rice, that water would be limited as a consequence and that the practice of growing rice two times a year would need to be limited to a much smaller area than today. The effect on national rice output could be substantial. The study concludes that Malaysia's production, which currently satisfies about 60 per cent of demand, might be reduced to less than 50 per cent.

The potential effects of the projected changes in climate on yields of maize were examined in the Serdang region. The crop is not significantly sensitive to small increases in temperature and rainfall, but is more substantially affected by changes in solar radiation. A 10 per cent decrease in radiation causes a reduction of total biomass production by as much as 20 per cent.

Increases in rainfall in the months of March, April and May could increase oil palm productivity in the alluvial coastal areas of Malaysia provided that solar radiation remains unaltered. But exceptionally high rainfall could limit yields unless soil drainage was improved. Overall, the study concludes that oil palm yields on alluvial soils would not be substantially altered under the projected changes of climate, but these conclusions are not applicable to oil palm plantations in inland regions of sedimentary soils.

Assuming an increase in mean annual temperature by 2°C and in rainfall by 10 per cent, the east coast of Peninsular Malaysia may become too wet for rubber culivation, with rainfall interfering excessively with tapping; and regions which are currently near the dry margins of current rubber production may become too dry. Overall, the study concludes that potential yield levels might, as a national average, be reduced by about 15 per cent, but that improved clones could more than compensate for this by enabling a 25 to 50 per cent yield increase. At present total rubber production is valued at M$3.6 billion. The potential effect due to climate-related yield reductions could amount to a quarter of this. The impacts are likely to be most strongly felt by rubber smallholders. There is already a trend toward smallholders selling out to larger estates, with consequent outmigration to urban areas. Climate change would be likely to aggravate this problem.

The possible effects of climate change on water resources was studied in the Kelantan River Basin in the northeast corner of Peninsular Malaysia. Under the higher levels of rainfall projected under the GISS "2 x $CO_2$" scenario and assuming current patterns of rainfall variability, the frequency of occurrences of peak discharge increases by 9 per cent, implying more flood damage and a 5 per cent increase in the size of the flood-affected population. In contrast, higher rates of evaporation would lead to approximately a one-third increase in water deficit in the dry season, resulting in shortage of water for irrigation, reduction of rice yields and a reduction of the cultivable area for rice.

The effects of sea level rise could also be severe. Much of Malaysia is characterised by low lying coastal plain. In these areas topographical surveys have indicated that a 1 metre rise in mean sea level would, on average, lead to a landward retreat of shoreline of about 2.5km. This implies subtantial losses of agriculturally productive land, of mangrove forests and of the fisheries associated with mangroves.

## IMPACTS IN THAILAND

In Thailand the warming under the GISS "2 x $CO_2$" climate is equivalent to a 3°C to 6°C increase in current mean annual temperature, a projection that is broadly in agreement with other GCMs. There are, however, substantial differences between GCMs concerning changes in precipitation, which vary widely from normal but generally show a reduction under the GISS "2 x $CO_2$" scenario. Northern Thailand may be drier in most of the months except in July which is traditionally a dry period and this would appear to benefit cropping. However, August and September would experience only between 73% and 89% of present rainfall. Other GCMs however do not indicate such a reduction in rainfall and it is important to emphasise this uncertainty. Under the GISS "2 x $CO_2$" scenario winters are also drier but as very little rain is normally expected during that time of year the adverse implications may be less.

Two particular aspects of the Thai economy were studied with respect to potential impacts from these projected changes in climate: effects on rice production in Ayuthaya Province and effects of sea level rise in Suratthani Province.

The CERES model was run for a 25-year set of daily climate variables (1964-1988). Model outputs for the current climate substantially exceeded observed values for transplanted rice and were lower than expected for yields of direct seeded rice. It was not possible, however, to conduct an adequate validation of the model and to re-tune it to observed data for Thailand. As a consequence, the results should be treated with caution.

The results indicate that under a change of climate projected for a doubling of $CO_2$ main crop rice cultivation in Ayuthaya Province would increase in the order of 8%. These benefits would however be, in most cases, quite marginal because they are substantially less than the existing year-to-year variation. The modelled yields were also characterised by marginally greater yield variations. Off season rice, planted from mid-December to early February, exhibits a 5% increase in average yield under the GISS "2 x $CO_2$" climate with concurrent increases in variation of 3-40%. However, little value can, be placed on these results because of lack of model validation. Indeed, the results are not consistent with those for Chiang Mai which were validated against observed data, and which indicate a decrease in rice yield of about 5% under the GISS "2 x $CO_2$" scenario.

Thailand has approximately 2940km of coastline, much of which contains important economic activities such as shrimp farming and rice farming. The study considered the potential impact of a 0.5m and 1m rise of sea levels in the Suratthani Province in southern Thailand. This region is characterised by a sand dune line which may mark an ancient shoreline and has a consistent elevation about 1m above present sea level. It was therefore used as an indicative boundary to the area potentially affected by a 1m sea level rise. The suggestion is that 7,400ha (37%) of the study area would be affected by inundation under a 1m sea-level rise. About 4,200ha of productive agricultural land and large numbers of shrimp ponds would be lost.

## EFFECTS OF SEA-LEVEL RISE

An integrated survey was made of the potential effects of sea-level rise on coastlines of Thailand, Malaysia and Indonesia. In general all three countries have a high proportion of coastal plains both sandy and swampy that would be physically and ecologically sensitive to sea-level rise. The issue may have particular importance because some of the coasts of South-East Asia are at present characterised by land subsidence which may be contributing to a more frequent occurrence of flooding, for example in the Bangkok region and in the coastal suburbs of Jakarta.

Where the coastal zone is characterised by steep and cliffed coasts they will tend to be undercut to form basal cliffs and slumping will become more frequent on the vegetative slopes. Receding cliffs are already a characteristic of the more exposed shores of promontories and islands especially those washed by ocean swell and waves generated by the SW monsoon as on the Andaman sea coast of Thailand and in SW Sumatra.

On sandy beach coasts sea level rise would tend to initiate beach erosion, or accelerate it where it is already taking place. In general, submergence will result initially in the deepening of near shore water so that larger waves break upon the shore, thus increasing erosion. It should be emphasised that it is not possible to predict the location of a sandy coastline in the next century if sea level has risen 1m but it is that most sandy coastlines will have retreated and that they will be eroding. Beach resorts and tourist facilities that have been developed extensively on low lying coasts in South-East Asia will be threatened (e.g. on Bali in Indonesia, at Port Dickson, Penang and Kuala Trengganu in Malaysia and at Pattaya and Rayong in Thailand). Structural work such as concrete sea walls and boulder ramparts will be necessary to protect developed seaside land, but such structures usually result in wave reflection which depletes the beaches that were the original tourist attraction. Artificial beach renourishment is an expensive alternative (about $3m/km) and may only be feasible in intensively urban resort areas such as Pattaya in Thailand, the north coast of Penang in Malaysia and the resort beaches on Bali.

There are large areas of swampy lowland on the coasts of South-East Asia, especially on the shores of the deltas built where large rivers have delivered vast amounts of silt and clay to prograde the coast. These are very extensive on the NE coast of Sumatra and the south coast of Irian Jaya. Sedimentation from rivers is still prograding deltaic areas. Such deposition will accelerate if rainfall and runoff from the river catchments is augmented as a consequence of global warming. However, a rising sea level will tend to curb the growth of deltas and if the rate of submergence is greater than the rate of deposition, their shorelines will be cut back. Examples of this can already be seen on parts of subsiding delta coastlines which are receding because of a diminished fluvial sediment supply to the river mouth. On the north coast of Java some river mouths have changed naturally, during episodes of flooding, to a new outlet for subsequent delta growth. The outcome has been rapid erosion of the abandoned delta lobes.

The natural vegetation associated with the coastal lowlands of South-East Asia is mangrove swamp, backed by marshes and areas of freshwater forest, but in many areas this vegetation has been profoundly modified by human activities, notably drainage and land reclamation. In the three countries studied mangroves occupy a total of about 40,000km$^2$. They grow in the upper part of the inter-tidal area, usually near mean tide line. Mangroves have become extensive on these coasts during the past 6000 years when sea level has remained constant. Prior to this there was a phase of rising sea level beginning about 18,000 years ago. The projected future sea level rise could reverse this sequence, reducing and removing mangroves from the more exposed areas and confining them to inlets and estuaries where continuing muddy sedimentation, keeping pace with the rising sea, might allow them to survive. Under natural conditions mangroves are backed by low lying, estuarine and alluvial land which could be displaced if the rising sea drove the mangrove zone landward. However, over much of South-East Asia the hinterland has been reclaimed for agriculture, usually rice farming or plantations producing rubber, palm oil or coconut; and embankments (bunds) have been built at the inner margin of mangroves. Where there is a bund at the rear of the mangroves delimiting the present high tide limit, attempts would need to be made to maintain it as sea level rises and to enlarge it to prevent wave overtopping and marine flooding. If this happens the retreating mangrove fringe will not be able to colonise the developed hinterland; it will become narrower and in many places will disappear altogether as the inter-tidal zone narrows and steepens. The coastline will thus become more artificial.

Extensive areas of mangroves have also been converted to ponds for the production of fish or prawns. The simplest ponds, (traditional for many centuries on the north coast of Java), are located in banked areas with sluices to prevent the gravitational inflow and outflow of sea water and the entry of fish and prawn fry. In recent decades fish and prawn ponds have become more elaborate, especially in Thailand and Malaysia, with pumping systems to maintain a sea water supply and the use of aerators, breeding techniques and fertilisers to generate high productivity from intensive aquaculture. Where the mangrove area has been converted to aquaculture, the sea level rise will threaten to breach the enclosing banks and submerge the fish and prawn ponds. If these ponds are to be maintained the enclosing walls and the floors will have to be raised to match the levels of the rising sea. Alternatively a protective sea wall may be built and pumping systems introduced to control the inflow and outflow of sea water.

In addition to these direct effects, marine submergence of coastal areas in South-East Asia will raise the water table so that some low lying parts of coastal plains will become permanent swamps or lakes; the salinity of these will depend upon the interaction between sea water incursion and any increase in rainfall and freshwater runoff. It is possible that the rise in groundwater will be accompanied by the upward movement of subterranean salt, resulting in saline damage to rice fields and farmland soils. It may be tempting in such conditions to convert these areas into brackish-water, fish and prawn ponds to replace those threatened or lost in the mangrove areas.

Coral reefs occupy about 150,000km$^2$ within the East Asian seas, and there are fringing reefs around many headlands and high islands. A slowly rising sea level will stimulate the revival of coral growth on reef flats and these may maintain their level relative to the rising sea. Upward growth of existing corals is in the range of 4-7mm/year and thus may be able to keep place with rising sea levels. However, as indicated above, many coral reefs are already under various kinds of ecological stress, and some of the less vigorous may fail to revive, being permanently submerged as sea level rises. Fringing reefs are less likely to survive than outlying reefs because of increasing turbidity in coastal waters as larger waves erode the beaches and the land behind them.

It will be evident that some environmental changes are already in progress on the coasts of South-East Asia, and that substantial modifications, both natural and man-made would have occurred on these coasts during the coming century even if there were no global warming and sea level rise. Coastal erosion is already extensive and likely to continue, and coastal environments will be changed by further urban and industrial development. The combination of such pressures, together with possible future sea level rise due to global warming suggests a number of possible strategies:

i) *Adapt and evacuate* Under this strategy land lost to submergence and erosion would include large areas of currently productive coastal land, especially fish and prawn ponds. It would not be difficult to convert rice fields into fish and prawn ponds as sea level rises, but who would bear the cost of resettlement and land transformation for rice farmers?

ii) *Hold the coastline* It has been estimated that the improvement of coastal defences to counter a sea level rise of 20cms along approximately 250km of coastline would cost US$1 billion; for a 1m sea rise the cost would be US$10 million per kilometre. In these terms the cost of preventing sea incursion on 5000km of low lying coastline in Thailand, Malaysia and Indonesia would total about US$50 billion.

iii) *Counter attack* The cost of building sea walls and putting in drainage and pumping systems to manage the land margin as sea level rises would be great, and it is difficult to envisage South-East Asian countries achieving this on a large scale without substantial international assistance. An alternative solution may be to construct sea walls offshore and reclaim the enclosed shallow areas for productive use. Where this is possible, the economic returns from the land gained could offset at least part of the cost of building sea walls and associated structures. The disadvantage of building sea walls along the coast or offshore is the associated reduction in the extent of mangrove swamps and tidal mudflats, with consequent losses in the productivity of fish and shellfish resources.

In the short term, over the next few decades, the wisest response to the predicted sea level rise is likely to be a reorganisation of coastal land use planning in low lying coastal areas, delimiting these areas in relation to predicted submergence and erosion. For example, it is unwise to develop new resorts within 200m of the present high tide line on beach rich terrain unless plans allow for abandonment or relocation during the coming century. Aquaculture could be restructured towards intensive production from relatively small and concentrated areas which can be protected from submergence and erosion as sea level rises and can be adapted to new tidal levels.

## POLICY IMPLICATIONS

The study included two workshops (in Malaysia and Indonesia) to consider the policy implications of the reported results. The workshops were designed to inform policy makers about the magnitude and characteristics of potential future climate change, to consider the range of possible response strategies to mitigate adverse impacts and to outline the need for future research.

The workshops were conducted as policy exercises, bringing together policymakers and their scientific advisors at the national government level and scientists who had worked on the study to generate the impact assessments. Five major types of policy response were considered at these exercises: economic (changes in existing tax structure, subsidies, pricing systems, etc.), technological (breeding new varieties, constructing dams and coastal protection structures), institutional (enhanced or distorted market mechanisms, formal government regulations, legal instruments), research needs (information required for formulating adequate response strategies), and monitoring (characteristic signs of change, both biological and socio-economic, that could provide the necessary early warning to ensure timely action).

# I. *AIMS AND METHODS*

## 1. BACKGROUND

Occurrences of climatic extremes, particularly droughts, over the past two decades have drawn public attention to the issue of climate variability and possible climate change. Such occurrences are frequently accompanied by loss of both human and animal lives, and by dislocation of socio-economic activities in the affected countries, particularly those with the least developed technologies.

Another factor to which public attention has been focused over the past decade is the effect of man's activities on the environment. Such activities include large-scale deforestation, especially in tropical countries, changes in land use practices, the burning of fossil fuels and the emission of industrial waste gases into the atmosphere. There is now considerable scientific consensus that these activities, in particular the alteration of the composition of the atmosphere, is likely to lead to changes in the global radiation balance and to result in a long-term global warming with serious socio-economic effects (IPCC, 1990).

An international conference organised by UNEP, WMO and ICSU in Villach during 1985 to assess the effect of greenhouse gas emissions on climate noted that many important economic and social decisions are being made today on the assumption that past climate data, without modification, are a reliable guide to the future (WMO, 1986). Such decisions relate, for example to water resource management, agriculture, drought relief, structural design, etc. Estimates of possible future climate change must be refined so that decisions on future important projects take such change into account.

UNEP also concluded that attention should be focused on the possible impact of climate change on various sectors such as agriculture, water resources, forestry, etc., in order to define appropriate responses to mitigate undesirable consequences.

One of the recommendations of the Villach Conference was that support for the analysis of policy and economic options required for a response to climate change should be increased by governments and funding agencies. It was felt that in these assessments, the widest possible range of social responses aimed at preventing or adapting to climate change should be identified, analysed and evaluated. In addition, it was suggested that such studies be undertaken in a regional context, in order to provide a linkage between available knowledge and economic decision making and to characterise regional vulnerability and adaptability to climate change.

## 2. PROJECT OBJECTIVES

In response to the needs described above, UNEP developed a research project on "Socio-economic impacts and policy responses resulting from climate change in South-East Asia". This had the following *long-term* objectives:

(i) To enable the governments of Indonesia, Malaysia and Thailand to adopt appropriate policies and strategies to respond to possible future climate change, in particular policies relating to long-term planning in agriculture and food production, water resources management, energy supply, coastal structures and coastal defence, and human settlements.

(ii) To increase awareness of the possible adverse impacts of global climate change.

In addition, the following *short-term* objectives were pursued:

(i) To understand and characterise regional vulnerability and adaptability to climate change in the context of South-East Asia.

(ii) To evaluate the impact of climate change on a number of economic and social systems in Indonesia, Malaysia and Thailand in order to facilitate the taking of appropriate measures to mitigate those impacts.

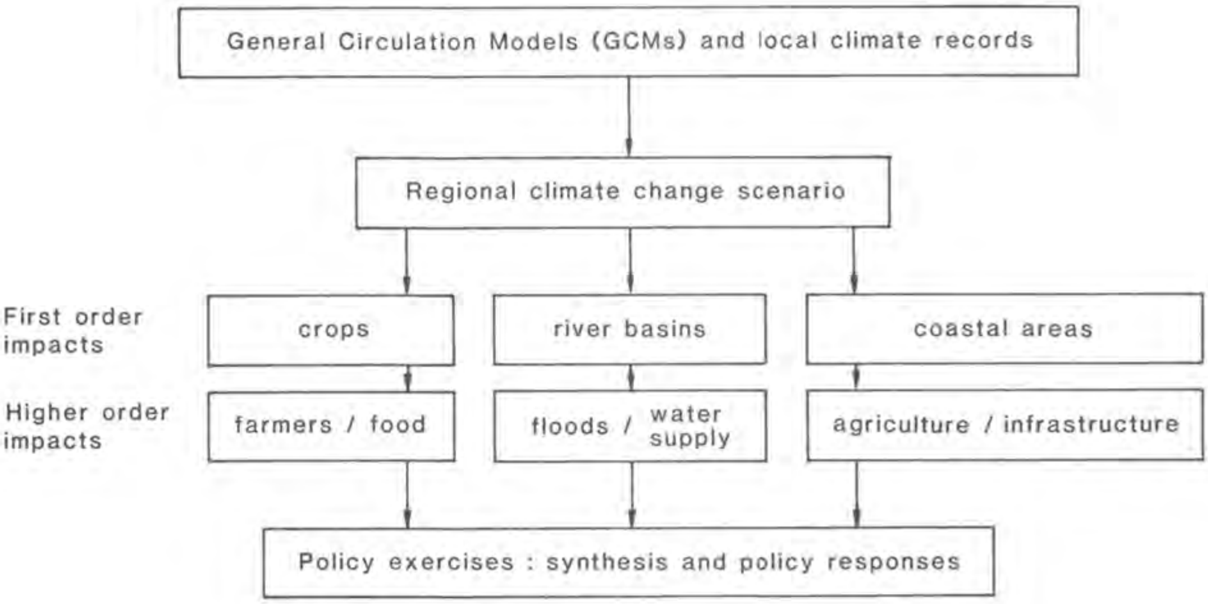


**Figure 1.1** **Overview of the project activities.**

## 3. SCOPE OF THE REPORT

This report contains the results and conclusions of the project's work. It includes a wide range of assessments, including those of:

(i) The impact of possible future global climate change on:

- Agriculture, particularly on rice, maize, oil palm and rubber production.

- Water resources management, water quality and water availability for human and animal consumption, industrial use and irrigation, etc.

(ii) The impact of possible future changes in sea level on:

- Mariculture and prawn production including marine ecosystems, e.g. mangroves, coral reefs and lagoons.

- The tourist industry, especially coastal resorts.

- Salt intrusion in estuaries, deltas and the impact of increased storm frequency.

## 4. METHODS

The study was intended to be a partially integrated assessment of the regional impacts of possible future climate change. A fully integrated assessment would consider impacts at a number of different levels (e.g. the biophysical level, the level of farms and corporations and the national level). But such assessments are not possible until the full complement of systems models are available. The partially integrated approach adopted here has the following characteristics (Figure 1.1):

- Outputs from general circulation models of the atmosphere (GCMs) are used to characterise possible future climates.

- Models of first order relationships are used to estimate effects of climate change at the biophysical level (e.g. on runoff, on crop yields).

- Expert judgement is employed to assess economic effects at the enterprise and regional levels.

- Technical adjustments and policy responses are considered by using policy exercises to explore means of reducing negative impacts and exploiting positive ones.

## 4.1 THE DEVELOPMENT OF CLIMATIC SCENARIOS

The study considered the effect of an equivalent doubling of atmospheric $CO_2$ on the climate of the region (a "2 x $CO_2$" climate scenario). In order to characterise this climate, outputs from experiments with three GCMs were applied to the baseline (current) climate (1951-75). These indicate that, while no major changes are predicted in either the timing or other main features of the monsoon rains in the region, there may be significant changes in the amount of rainfall.

A second important feature is that all three models predict a warming in all months, although the average increase is 3-4°C. Since there may be over-estimation of such temperature increases, these estimates can be used as an upper limit when studying the potential effects on food production and water resources. One important implication of the projected temperature increases is the shortening of the growing period for crops with consequent reductions in potential yield.

A third feature of the "2 x $CO_2$" climatic scenario is that we cannot yet say what changes may occur in the day-to-day or year-to-year variability of climate. At present we must assume that current variability remains unaltered, and simply apply the changes in mean temperature, rainfall and radiation to the existing distribution of, for example, dry years and wet years.

## 4.2 SEA-LEVEL SCENARIOS

For sea levels the most recent prediction, based on analyses for the Intergovernmental Panel on Climate Change (IPCC) and assuming the continuation of current trends in greenhouse gas emissions, is a global sea-level rise of 20cm by 2030 and 60cm by 2090, with considerable regional variation (IPCC, 1990). Even if greenhouse gas (GHG) emissions were halted by the year 2030, global sea level would continue to rise by 40cm by 2100, levelling off a century or so later. Given the uncertainties, and since topographic surveys do not enable the study of effects of sea-level rises of less than one metre, the scenario of a one-metre sea-level rise (highest high tide) is adopted in this report.

## 4.3 IMPACT MODELS

Two types of impact model were used to estimate the consequences of an altered climate in South-East Asia: models of the responses of crop growth, and models of runoff and soil erosion. Models of crop growth were run for three crops: rice, soybean and maize. These were CERES or CERES-type models which require daily weather input for precipitation, maximum temperature, minimum temperature and solar radiation. Descriptions of the models are given in Section II.

The SWRRB Water model was used to estimate changes in runoff and soil erosion that might result from changes in climate. Since levels of runoff can affect the accumulation of water in reservoirs, the SWRRB model enabled an estimation to be made of changes in the amount of stored water available for rice irrigation.

# II. *SCENARIOS OF CLIMATE AND SEA-LEVEL CHANGE*

## 1. CURRENT CLIMATE OF THE REGION

The climate of South-East Asia is predominantly the consequence of its monsoons. Both the agriculture and the water resources of the area depend critically on these natural phenomena. There are two phases of the annual monsoon cycle. The June-September monsoon is usually well established over the entire area by the first of June, although it begins about one month earlier in the southern parts of the region. Two sources of air are associated with this time period: a deep, moist air mass from the Indian Ocean which brings the main rainy season to Thailand and as far south as northern peninsular Malaysia; and a shallower stable air mass from Australia which brings the dry season to Indonesia (particularly to the eastern islands). Oscillations with periods of 4-5 days, 10-20 days, and 40-50 days in this monsoon have been studied, and the latter two scales have been associated with the often drought-producing break-monsoon events which can have disastrous consequences to the agriculture of the area. Quantitative impacts of such precipitation variability on rice yield have been studied by Eddy and Panturat (1990), and Panturat and Eddy (1990). In these studies the variability was related to the ENSO/EL NIÑO phenomenon.

The November-March monsoon is characterized by a slightly higher average surface wind speed (4-6 m/sec) than for the June-September period. Air masses arrive from either the Pacific with the dry and stable trade winds or as cold surges out of southern China. In both cases moisture is absorbed by the air as it crosses the South China Sea and this is then returned to the land as rainfall: i) along the coast of eastern peninsular Malaysia and extending into southern Thailand and ii) along the north coast of Borneo. After passing over the Andaman Sea this air joins the equatorial westerlies in the Indian Ocean and returns to provide rainfall to Western Sumatra, Java, and southwestern Sulawesi. The cold surges associated with this November-March monsoon have been related to the 4-5 day and the 10-20 day oscillations and are often associated with severe flooding in southern Thailand and Malaysia and with rough seas which are dangerous to shipping.

Some of the main features of the precipitation and solar radiation patterns with which this study is concerned can be inferred from Figures 2.1 , 2.2 and 2.3. These patterns of rainfall and solar radiation are critically important for the predominant food crop in the region which is rainfed rice. This crop demands both water and sunshine during the vegetative phenological stage, abhors moisture stress during the reproductive stage, and then depends mainly on solar radiation during the grain filling stage. One of the purposes of this study is to assess the effect of the possible changes in these climate variables on rice production.

In order to relate the climate to agricultural productivity and water resource management, the study used computer simulation models which require time series of daily values of maximum and minimum temperature, precipitation, and solar radiation incident at the earth's surface. Such daily time series which are continuous over several years can be made up of actual daily observations, or daily values generated from monthly statistics, or a combination of the two. The most representative set has been derived from daily time series of TMAX (maximum temperature), TMIN (minimum temperature) and PCP (precipitation): while the daily radiation (RAD) has been produced from monthly long-term radiation statistics using the method described by Panturat (1989). Where data were missing these were generated using a standard statistical technique and employing information on temperature and precipitation from UNDP (1982) and Thornthwaite Associates (1963). These data on current climate are for the period 1951-75 for Thailand, 1968-86 for Malaysia and 1950-70 for Indonesia.

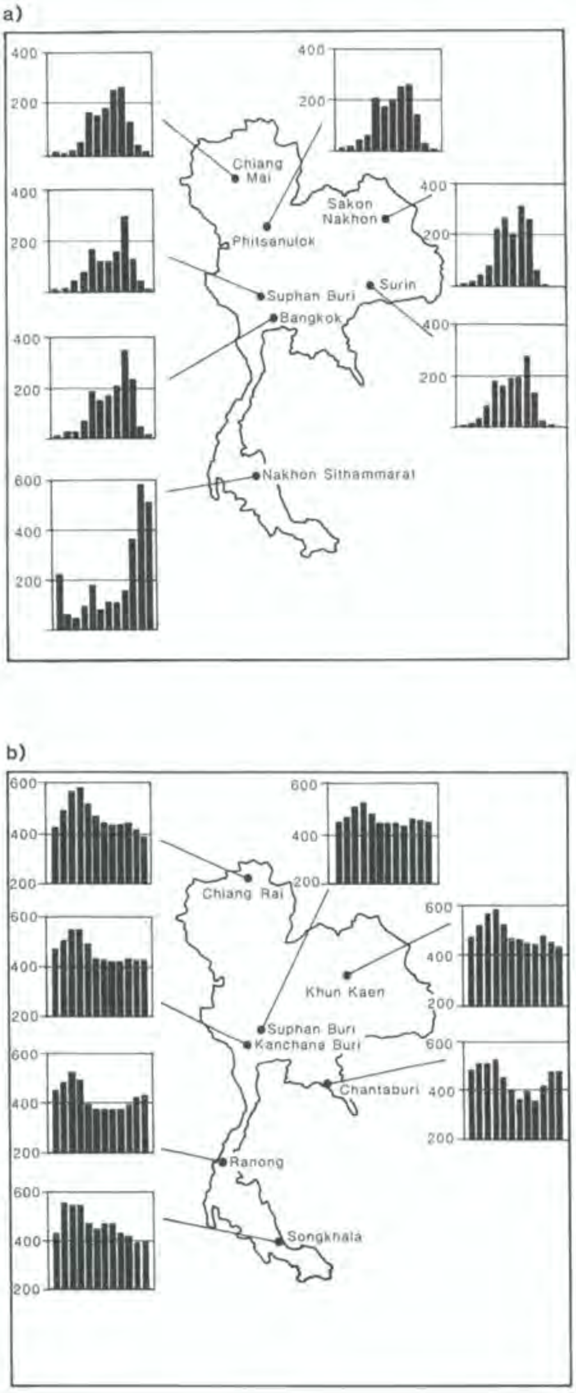


**Figure 2.1** a) Monthly mean rainfall (mm) in Thailand, 1951-75.
b) Monthly mean daily radiation (ly/day) in Thailand, 1951-75.

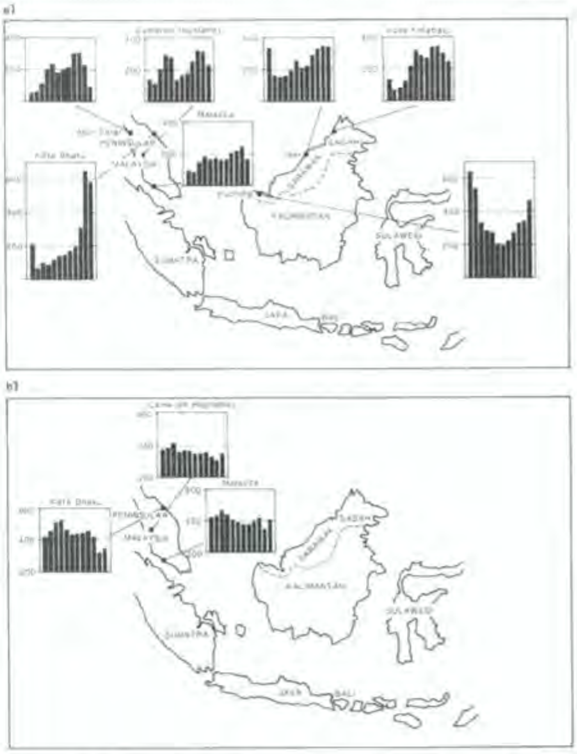


**Figure 2.2** a) Monthly mean rainfall (mm) in Malaysia, 1968-86.
b) Monthly mean daily radiation (ly/day) in Malaysia, 1968-86).

# 2. SCENARIOS OF CLIMATE CHANGE

Scenarios of possible future climate change were based on outputs from General Circulation Models (GCMs). A GCM consists of a complex set of mathematical expressions for thermodynamic and fluid dynamic relationships which are considered to be adequate to describe (at least statistically) the present state of the atmosphere. Output from three GCMs were used in this study. These were GCMs developed at the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamic Laboratory (GFDL), and Oregon State University (OSU).

The GCMs have several features in common:

i) Each model has been run twice: once with initial conditions which represent the current climate (in particular with respect to the atmospheric constituent $CO_2$), and once with the equivalent $CO_2$ component doubled, thus giving rise to the nomenclature "1 x $CO_2$" and "2 x $CO_2$". Although the actual changes in $CO_2$, CFCs and other factors are of considerable interest in

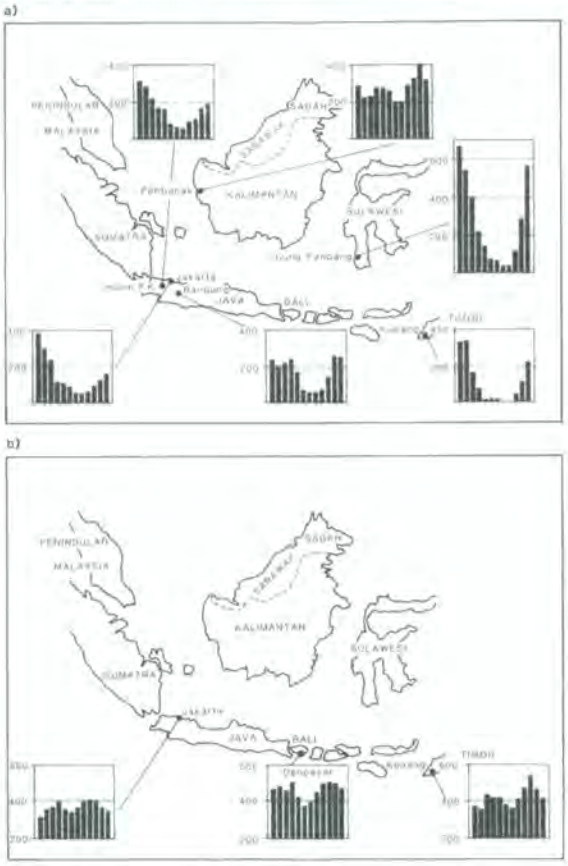


**Figure 2.3** **a) Monthly mean rainfall (mm) in Indonesia, 1950-70.**

**b) Monthly mean daily radiation (ly/day) in Indonesia, 1950-70.**

themselves, our interest here is focused on the consequences of the imposed changes in the models' initial conditions to the surface fields of temperature, precipitation and incident solar radiation.

ii) In any climate model run, for the present climate or double $CO_2$, the atmosphere and ocean must first be "spun up" to their equilibrium states. This spin-up usually requires 5 to 25 simulated years, depending on how it is done. Then the model has to be run for 10 (simulated) years to obtain an adequate sample of weather situations to form a proper climatology (Jenne, 1988).

iii) Ten-year averages for each month of the surface output variables (daily temperature, monthly precipitation totals, and incident solar radiation) were used in the present study for each run ("1 x $CO_2$", "2 x $CO_2$"),

iv) These model output statistics are available at a set of model-specific grid points, with the following spatial resolution:

GISS 7.83 Deg Lat by 10.0 Deg Long
GFDL 4.4 Deg Lat by 7.5 Deg Long
OSU 4.0 Deg Lat by 5.0 Deg Long

An important feature of all current GCMs is their difficulty in simulating the present ("1 x $CO_2$") climate. In the cases of temperature and precipitation grid point differences between the three models' "1 x $CO_2$" output (monthly means over 10 years of simulation) are as large as, indeed sometimes larger than, the grid point differences between the "2 x $CO_2$" and the "1 x $CO_2$" means. In order to lessen this problem, a geographical (grid point) bias was reduced by making use only of ratios ("2 x $CO_2$"/"1 x $CO_2$") of the monthly mean variables to derive the climate change scenarios. In the case of temperature, the variable was transformed into degrees Absolute (deg Kelvin) before the ratios were taken.

In order to produce a GCM scenario of daily values of the required 4-vectors at a point, the monthly GCM grid point output ratios were interpolated to a station location for which data on current climate are available. Next these monthly mean GCM ratios were interpolated to obtain a set of 366 daily values. Lastly the (multi-year) daily values of the four variables in the current climate data set were multiplied by the appropriate GCM-derived daily ratio to obtain the final multi-year GCM scenario.

It should be noted that:

- The spatial interpolation is bilinear and can be done in two ways: 1) the 1 x $CO_2$ and the "2 x $CO_2$" can be interpolated separately to give solutions at the station location, and then the ratios "2 x $CO_2$"/"1 x $CO_2$" can be taken; or, 2) the ratio can be formed first at each of the four surrounding grid points and then these ratios can be interpolated to the station location. It is clear that the resulting ratios at the station location will not be the same for both methods. In this study the latter method is used.

- The time interpolation is done by assigning the (space interpolated) monthly values to mid-month and then filling in daily values between these mid-month values by linear interpolation.

- Precipitation occurs in the GCM scenarios on exactly the same days as in the current climate data set.

The following approximate figures give an idea of the space disaggregation problem:

| GCM Model | Area (at 0 Deg.Lat) Represented by 1 Grid Point Value |
|---|---|
| GISS | 373824 sq. mi. |
| GFDL | 158982 sq. mi. |
| OSU | 95486 sq. mi. |

and for comparison:

| | |
|---|---|
| Total area of Thailand | 198114 sq. mi. |
| Average area of a Thai Province | 2700 sq. mi. |
| Size of a major irrigated rice project in Northern Thailand | 22 sq. mi. |
| Size of the largest irrigated rice project in Malaysia (MADA) | 386 sq. mi. |
| Average farm size in the Central Region of Thailand | ·015sq. mi. |

The GCM "2 x $CO_2$" scenario monthly mean statistics are given in Figures 2.4, 2.5 and 2.6. The first feature of major importance to note is that none of the 3 GCM models predict an important change in either the timing or the main features of the monsoon rains in any of the three countries studied. If this had not have been the case, serious socio-economic disruptions would have been implied.

The second important feature to note is that all three models predict a warming in all months; however, this long-term average increase in monthly means of temperatures is restricted to less than 5°C. The only exception is in the case of the January temperature increase predicted by the GISS model in northern Thailand: this was about 6°C. Because many competent scientists consider such temperature increases to be somewhat exaggerated these estimates can be used as an upper limit for study of the potential impacts of temperature change on the food production and water resource sectors of the economy.

This general increase in temperature would result in an increase in evapotranspiration across the entire area. The increase in evaporation losses from reservoirs, lakes, and streams will be accompanied by increases in irrigation water demand during the dry season.

Such statistics, however, give no information concerning changes from the present day-to-day or year-to-year variability of climate. Although interannual variability changes may be found in derived variables such as crop yield, these variabilities derive from non-linear interactions among the mean values of the climate variables and other model inputs such as soil and cultivar genetics, and not from changes in these two unknown climatological variances themselves. Panturat and Eddy (1990) reported some preliminary findings in this regard. Thus, food security policy changes which might be based on changes in the frequencies of runs of drought years should be viewed with some caution, inasmuch as some of the climatological forcing factors are missing.

Some of the implications of the differences between the variable estimates made by the 3 GCM models can be addressed by using Figures 2.4, 2.5 and 2.6. Differences in the estimates of temperature change will translate into differences in growing season length as estimated by plant process models such as CERES Rice (discussed in the next section of this report). The length of time, in calendar days, which a cultivar such as rice spends in each phenological stage depends on the ambient temperature. Figure 2.4 shows that all three GCM models imply a reduction in the length of the growing season at all 3 locations. The GISS model suggests the greatest reduction and the OSU model the least.

One of the consequences of shortening that portion of the growing season spent in the grain filling phenological stage is the possibility of yield reduction. The yield depends to a significant extent on the solar radiation received during this stage and, for a given daily radiation amount available, any reduction in the number of days during grainfill will reduce the yield. For a given cultivar the length of time spent in each phenological stage is parameterized in terms of degree days: the higher the temperature, the fewer the number of calendar days needed to satisfy each of these genetic criteria.

From this discussion it is clear that the intermodel variations in the impact on yield of such temperature-induced growing season changes will depend on the associated solar radiation estimates made by each model for that time period when the plant is in the grain filling stage.

In light of these combined temperature/radiation effects, one might anticipate the following consequences of the differences between the output from the three GCMs:

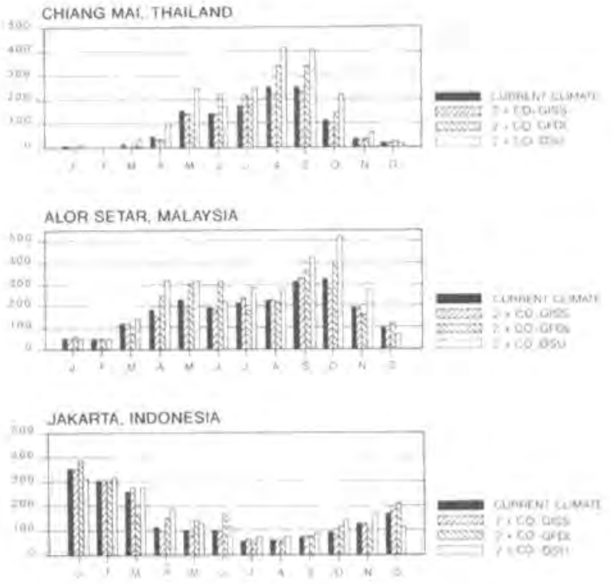


**Figure 2.4** **Changes in mean monthly rainfall (mm) in South-East Asia under "2 x $CO_2$" climate scenarios projected by three General Circulation Models. GISS = Goddard Institute for Space Studies. GFDL = Geophysical Fluid Dynamics Laboratory. OSU = Oregon State University. Current Climate = 1951-75.**

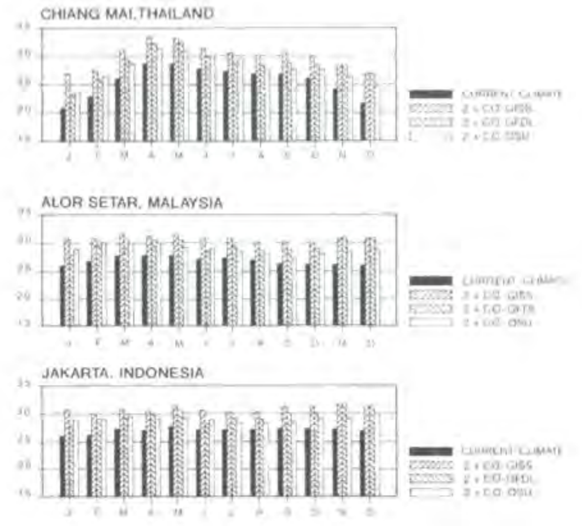


**Figure 2.5** **Changes in mean monthly temperature (°) in South-East Asia under "2 x $CO_2$" climate scenarios projected by three General Circulation Models. GISS = Goddard Institute for Space Studies. GFDL = Geophysical Fluid Dynamics Laboratory. OSU = Oregon State University. Current Climate = 1951-75.**

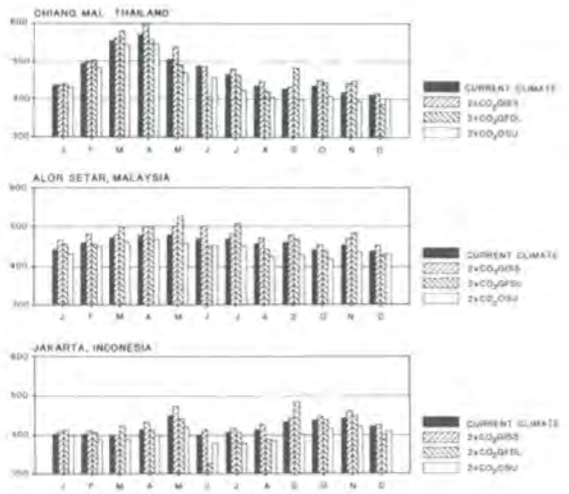


**Figure 2.6** **Changes in monthly mean radiation (ly/day) in South-East Asia under "2 x $CO_2$" climate scenarios projected by three General Circulation Models.GISS = Goddard Institute for Space Studies. GFDL = Geophysical Fluid Dynamics Laboratory. OSU = Oregon State University. Current Climate = 1951-75.**

i) For major rice planted in Chiang Mai (Thailand) which reaches the grain filling stage in late November and early December, the number of calendar days spent gathering the solar radiation is smallest for the GISS and the GFDL models, while the radiation available averages least for the OSU model. This would suggest the highest yields for the GISS "2 x $CO_2$" climate, the second highest for the GFDL "2 x $CO_2$" and the smallest for the OSU "2 x $CO_2$". Yields associated with all three climate scenarios are smaller than that associated with the current climate.

ii) For rice planted in Jakarta (Indonesia) which reaches the grain filling stage in June, the number of calendar days spent gathering the solar radiation is smallest for the GFDL model and second smallest for the OSU model. This suggests that the smallest yields are associated with the GFDL "2 x $CO_2$" climate and the decrease in yields from current climate are somewhat less for the other two GCM "2 x $CO_2$" climate scenarios.

With regard to rainfall, the five driest months at Chiang Mai, Thailand are considered. Figure 2.5 shows that all 3 GCM "2 x $CO_2$" climate scenarios predict considerable warming for this period, with the GISS model showing the most extreme of these evapotranspiration water-demanding temperature regimes. Crops grown during this season will demand much more irrigation water. This extra water would be available during the monsoon seasons under the GFDL and OSU "2 x $CO_2$" scenarios. At the other two study locations (Jakarta and Alor Setar) the GFDL and OSU models also produce estimates of an increase in the annual rainfall, while the GISS model indicates no significant change in this variable. An unchanged rainfall supply must be viewed together with the in evapotranspiration (resulting from temperature increase) when water resource management policies are being examined.

In conclusion, it should be emphasized that, at their current stage of development, GCMs are an imperfect means of simulating either the current or the future climate of South-East Asia. In this study therefore, they are used as tools not for forecasting climate change but for producing one or more scenarios of future climate that would be consistent with continued emission of greenhouse gases.

# 3. SCENARIOS OF SEA-LEVEL CHANGES

Increases in temperature due to greenhouse gas emissions are expected to result in an expansion of the volume of near-surface ocean water (the "steric effect"), and the partial melting of the world's snowfields, ice sheets and glaciers, releasing water into the oceans. The outcome will be a world-wide sea-level rise (Barth and Titus, 1984).

There have been various estimates of the scale of this global sea-level rise. Analyses carried out by the U.S. Environmental Protection Agency in Washington led Hoffman (1984) to predict an accelerating sea-level rise, attaining 0.24 to 1.17 metres by the year 2050, and 0.56 to 3.45 metres by the year 2100. According to these predictions the mean level of the oceans will rise one metre by the year 2045 (high scenario), or by the year 2140 (conservative scenario); the most likely (intermediate) scenario is an accelerating rise attaining one metre over the coming century (Figure 2.7).

This is consistent with the prediction by the Climatic Research Unit, University of East Anglia, that the oceans will stand 12 to 16 centimetres above their present level by the year 2030 (Raper *et al.*, 1988), but more conservative than the prediction from the Villach Conference, held in Austria in October 1985, that global sea level would rise 20 to 140 centimetres by the year 2030, due largely to thermal expansion of the oceans. Somewhat higher scenarios have been presented by those who predict a rapid melting of the Antarctic ice sheet, but this is not likely to occur within the next few centuries. The most recent prediction, based on analyses made for the Intergovernmental Panel on Climate Change (IPCC, 1990) is of a global sea-level rise of 20cm by 2030 and 65cm by 2100, with considerable regional variation. Even if greenhouse gas emissions were halted in the year 2030, global sea level would continue to rise 40cm by 2100, levelling off a century or so later. Acknowledging the uncertainties, the scenario of a sea level highest high tide rise of one metre is adopted in this report.

Some statistical analyses of long-term tide gauge records have indicated that global sea level has already risen 10 to 15 centimetres during the past century, and is now rising about 1.2 mm/year (Gornitz and Lebedeff 1987). However, as Pirazzoli (1986) demonstrated, tide gauge records over recent decades show much variation in mean sea-level trends: on some coasts mean sea level has risen, on others it has fallen, and on others oscillated, with no net change.

Unfortunately the global distribution of reliable long-term tide gauge records is too uneven for the precise assessment of modern trends, and it is not yet certain that the global sea-level rise has started. It is expected that the Global Sea Level Observing System (GLOSS) now being established in UNESCO, with a much more representative network of tidal stations around the world's coastline, will provide more accurate information in the next few decades, but by the time this information is available the Greenhouse Effect is likely to have produced an obvious global sea-level rise.

Meanwhile, a *relative* sea-level rise has been taking place where the land margin is tectonically subsiding, as on the Gulf and Atlantic coasts of the United States, the south and south-east coasts of Britain, the Netherlands and north Germany, north-eastern Italy (particularly in the Venice region, where subsidence of up to 27 centimetres occurred between 1872 and 1985), and several other areas. On these coasts the effects of a sea-level rise can already be seen (Milliman, 1988).

The actual rate of sea-level rise during the coming century will be greater than the global scenario

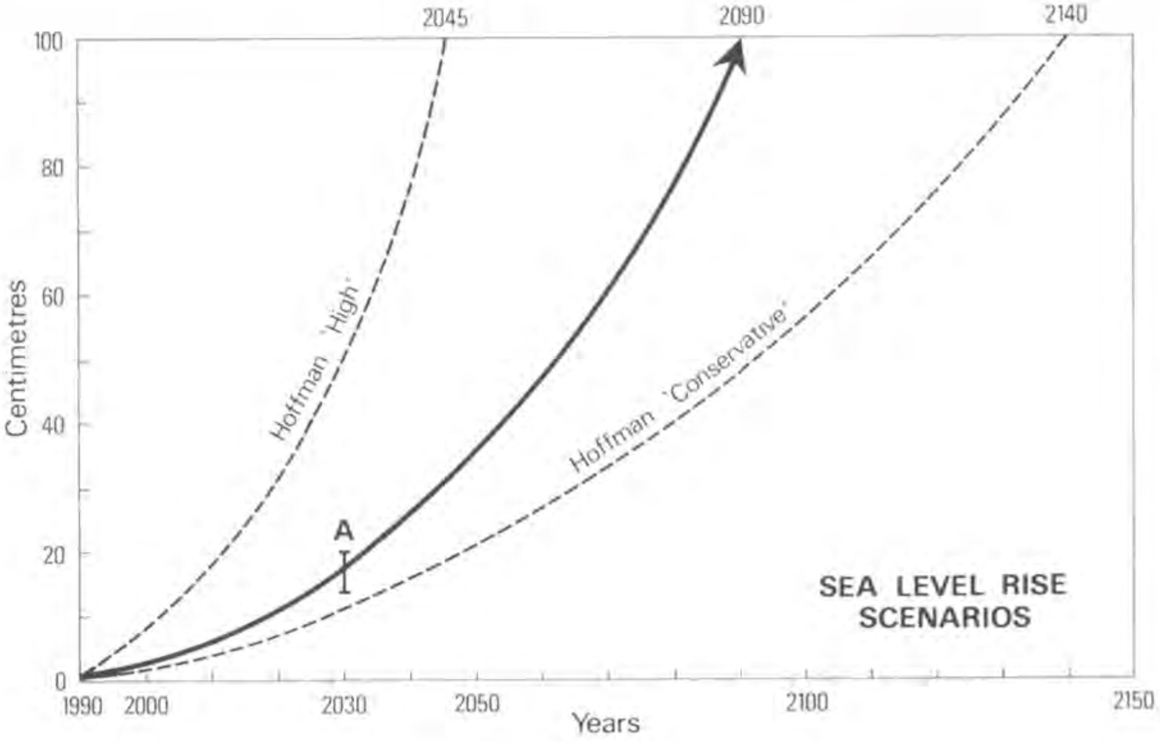


**Figure 2.7** Sea-level rise scenario adopted in this study. See text for details.

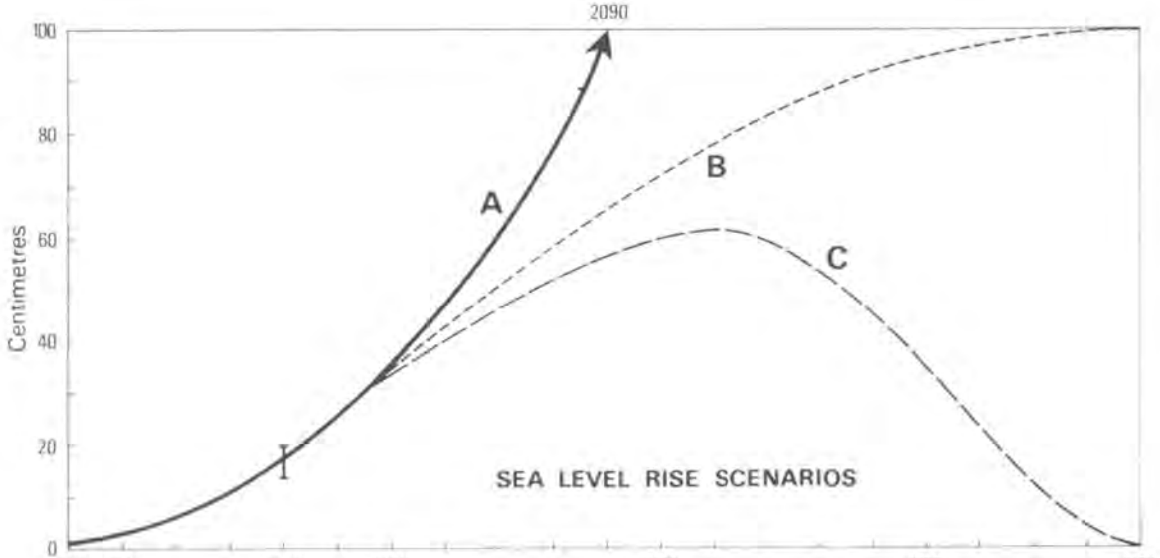


**Figure 2.8** Alternative sea-level scenarios:

A - Scenario adopted in this study (Figure 2.7)
B - Assuming immediate curbing of "greenhouse gas" emissions
C - Assuming management of the atmosphere to restore "greenhouse gases" to mid-20th Century levels.

(Figure 2.7) on coasts that are tectonically subsiding (including parts of the Bight of Bangkok, the north-east coast of Sumatra, and the north coast of Java), and somewhat reduced on coasts that are rising tectonically, as in parts of eastern Indonesia.

It should also be noted that if concerted international action were to be taken to reduce the input of greenhouse gases into the atmosphere the rate of global sea-level rise would be reduced. In Figure 2.8, A is the scenario if the Greenhouse Effect proceeds unmodified; B is the possible attainment of a new equilibrium as the result of immediate curbing of greenhouse gas emissions, with sea level stabilising a metre above its present level, after two centuries; and C is the outcome of global atmospheric management to restore conditions which existed during the mid-20th century, whereby a sea-level rise could be followed by a return to the present level after two centuries.

# III. *MODELS FOR ASSESSING POTENTIAL IMPACTS*

## 1. INTRODUCTION

Several models were used to assess the possible effects of climate change on crop yields and water resources and of sea-level rise on coastal areas. These included simulation models for rice, maize and soybean yields (CERES Rice, CERES Maize and SOYGRO) and a soil water run-off and river basin model (SWRRB). The purpose of this section is to describe these models and illustrate their use in studies of the potential impact of climate change.

## 2. THE CERES RICE MODEL

The CERES Rice model was developed by Godwin and Singh (1989) as part of a general crop modelling project (IBSNAT, 1988), and is increasingly being used in most of the rice growing areas of the world. The algorithm works on a daily time step to simulate the growth and development of a rice plant, subject to input which can be classified as weather, soils, plant genetics and the cultural practice of the farmer.

### 2.1 USES OF WEATHER-RELATED INPUT

The hydrological, botanical, and chemical processes simulated are affected daily by the input weather variables: precipitation (PCP), maximum temperature (TMAX), minimum temperature (TMIN), and incident solar radiation (RAD).

The *hydrology* begins with the rainfall and disposes of the water as a function of antecedent conditions and parameter settings of various types. Firstly, there are 12 irrigation options from which the modeler can choose.

Direct Seeded Choices: Upland

i) Never irrigate, rainfed
ii) Irrigate according to a specifiable field schedule
iii) Irrigate automatically to field capacity, triggered by a given parameter
iv) Assume no water stress

Transplanted Choices: Lowland

v) Assume no water stress
vi) Never irrigate, bunded
vii) Automatic irrigation to constant bund height
viii) Irrigate according to a specifiable field schedule

Direct Seeded Choices: Lowland (Bunded)

ix) Automatic irrigation to constant bund height
x) Never irrigated, rainfed
xi) Irrigate according to a specifiable field schedule
xii) Assume no water stress

Thus, the hydrologic accounting system of the model monitors daily changes in: precipitation, irrigation, paddy flood water evaporation, bare soil evaporation, water uptake by the plant, soil water content, percolation, drainage, and runoff.

The *heat* budget makes use of the temperature input from day to day through various combinations of TMAX and TMIN to calculate, for example: water temperature, soil temperature, growth heat units (in degree days above a given base temperature: 8°C for the present study) accumulated heat units to trigger changes in the phenological stages of the plant, chemical transformation rates, photosynthesis rates, grain number, and translocation (e.g. grain filling).

The *solar radiation* used by the plant each day is mainly incorporated into the calculations of photosynthesis and the subsequent production of carbohydrates. It is particularly influential during the grain filling stages. RAD is also used in combination with TMAX in the evapotranspiration estimations.

The main *chemical processes* simulated "exogenously" to the plant itself are concerned with the aerobic and the anaerobic nitrogen transformations, which can be thought of as mainly upland- and paddy-related respectively. (However, if the paddy dries out, the nitrogen transformation process switches to the aerobic format.) The principal chemical changes surrounding this nitrogen fixation are: nitrification, mineralization of the organic nitrogen, immobilization to organic nitrogen, and denitrification of $NO_3$ to gas. The type of chemical transformations represented here are modelled to be temperature dependent. Hydrolysis is also modelled to be temperature dependent.

Some of the *botanical* processes represented by this algorithm are: germination onset, transplantation shock, growth of leaves, stems, roots, seeds, phenological development, photosynthesis, transpiration, respiration, water and nutrient uptake, and translocation of the photosynthate.

These processes are all functions (often non-linear) of various combinations of the input weather variables: PCP, TMAX, TMIN, and RAD. For example, "extreme" values of TMAX and TMIN are used to modify or stop the growth of the plant. As a proxy variable for the phytochrome ratios which characterize the solar radiation, daylength is used to trigger the beginning of the reproductive stage of the plant. The input RAD values represent only the intensity (in mj/square meter) of the solar radiation incident to the earth's surface (plant canopy).

## 2.2 USES OF SOIL RELATED INPUT

As was the case for the weather input, the hydrological, botanical, and chemical processes simulated are affected daily by the input soil data which can be grouped into three types.

The first group comprises: base soil albedo, stage 1 evaporation limit, whole profile drainage rate, runoff curve number, mineralization factor, and cation exchange coefficient.

The second group represents a multilayered profile for the following characteristics for each layer: layer thickness, lower limit of soil water content, drained upper limit of soil water content, saturated soil water content, root hospitality factor, bulk density, and organic carbon content.

The third group represents the initial conditions (excluding fertilizer) at the beginning of the growing season for the following variables for each layer: height of the perched water table, initial soil water content, extractable ammonium, extractable nitrate, and acidity (pH). It is clear how both the water and chemical contents of the soil are affected daily, as well as through sporadic impulses of water addition via rainfall and irrigation. The ability of the roots to penetrate the soil, and hence provide the plant with water and nutrients, is a function of the root hospitality factor. This can degrade if there is a toxic buildup (e.g. aluminum) in the soil because of poor drainage. Soil salinization problems are of this type; however, at present these must be handled by resetting the hospitality factor exogenously to the model run.

Another soil control on rice production occurs in the between-season ability of the paddy to dry and increase the trafficability for field preparation. In processes such as drainage and percolation, the leaching of nutrients, bare soil evaporation, and runoff from the soil on which upland rice is grown can have a much greater influence on the effect of climate change than does the lowland rice soil. This is particularly true in the case of soils which are too sandy. Indirect soil-related impacts are a function of cultural practices such as puddling, tillage, harvesting, and crop rotation.

## 2.3 USES OF VARIETY INPUT

A subset of the genetic coefficients, which are used in the model to describe the variety of rice planted by the farmer, controls the integration of transformations of the daily temperature in order to determine the length of specified phenological stages of the plant. The coefficients input to the model are: length of vegetative period in degree days above 8°C, length of grain filling period in degree days above 8°C, onset of panicle initiation in hours of daylength, increase in reproductive period in degree days per hour, potential grain number, kernel weight tillering factor and a temperature dependency factor. The impact of climate and climate change on rice yield can be dramatically affected by the specification of these coefficients, as will be seen later in this section.

## 2.4 USES OF CULTURAL PRACTICE INPUT

The management practices used by the farmer in producing his rice crop are specified by the parameters in this input to the model. These decision parameters can be grouped as follows:

i) Planting decisions, viz: will upland or paddy rice be grown, what is the bund height, what variety will be grown, what is the sowing date, will the rice be direct seeded or transplanted, how long after seeding will the transplanting take place, what will be the plant density (in case of transplanting: plants per hill and hills per square meter), and what is the sowing depth?

ii) Irrigation decisions, viz: the irrigation schedule will specify application dates and amounts, if irrigation is to be supplied on demand, instead of scheduled, what criteria are to be used to trigger irrigation, will the paddy be puddled (to increase water holding capacity), and what is the irrigation efficiency?

iii) Fertilizer application decisions viz: application dates, amounts, depths, and chemical type (although there are 12 types listed in the model, not all options have been activated; this study used UREA only), and the method of incorporation.

iv) Harvest practice and land preparation: Provision has been made for the model to accept exogenously prepared estimates of incorporation into the soil of straw and root biomass. The depth of incorporation of the straw as well as the shoot carbon/nitrogen ratio must be specified. This biomass is converted to (non-fertilizer) initial conditions for extractable ammonium and nitrate as noted above in the soil section.

It is important to note that sensitivity tests of the CERES Rice model indicate that many elements of the farmer decision-making outlined above can have more profound effects on yields of rice grain than can be produced by any of the climate change scenarios described in this report.

# 3. THE SWRRB WATER MODEL

A description of this model has been published by Arnold, *et al.*, (1990). The purpose of the model is to estimate water and sediment yields for rural river basins. According to the authors: "The model is; a) physically based, b) capable of computing the effects of management changes on the output, c) capable of simulating a variety of management strategies, d) able to simulate long periods of time, and e) capable of operating on subdivided basins." The processes represented by the model are: surface runoff, percolation, return flow, evapotranspiration, snow melt, transmission losses, pond and reservoir storage, sedimentation, and crop growth. Although SWRRB is run using daily time steps, the sub-daily scale of events is of significance, particularly to the erosion process. For this reason, thunderstorms are modelled using a parameterization scheme to represent timing, intensity, and recurrence interval. The following represents a selection of the input required by the SWRRB model.

## 3.1 WEATHER DATA

The same weather scenarios described for use by the CERES Rice model are used here. The format and the variables (PCP, TMAX, TMIN, RAD) are both the same. SWRRB has its own weather generator for use when real data are unavailable.

## 3.2 BASIN DATA

For each river basin the input data are: total basin area and number of sub-basins

## 3.3 SUB-BASIN DATA

For each sub-basin, the following input data are required:

Geophysical data, viz: fraction of basin in sub-basin, runoff curve number, soil albedo, water content of snow on ground, main channel length, hydraulic conductivity of alluvium, Manning's Channel N value, overland flow N value, return flow travel time, sediment concentration in return flow, USLE erosion control factor, average slope length, average slope steepness, average channel width, and average channel depth.

Ponds data viz: fraction of sub-basin area for ponds, total surface area of ponds, runoff from catchment area to fill ponds when empty, initial pond volumes, normal sediment concentration, initial sediment concentration and hydraulic conductivity.

Reservoirs data viz: fraction of sub-basin that flows into reservoirs, total reservoir surface area at principal spillway, runoff volume required to fill reservoir to principal spillway, total reservoir surface area at emergency spillway, initial reservoir volume, average spillway release rate, initial sediment concentration in reservoir, normal sediment concentration in reservoir, and hydraulic conductivity of reservoir bottom.

Soils data viz: number of soils in the sub-basin, soil profile data as given for CERES Rice model, particle size distribution, percent clay, sieve value (percent silt + clay), and maximum routing depth.

Crop data, viz: planting date, harvest date, vegetation type (annual or perennial), tillage practice, average annual crop management factor, maximum leaf area index, and maximum rooting depth.

**Table 3.1** **20-year statistics for yields (kg/ha) shown in Figure 3.1. The percent changes are with respect to mean yields under current climate except that the observed results for Alor Setar are for 16 years and are not shown in Figure 3.1**

| Station | Scenario | Mean yield | Standard deviation | % Changes from current climate |
|---|---|---|---|---|
| Chiang Mai | Current Climate | 4762 | 606 | 0.0 |
| (Thailand) | GISS "2 x $CO_2$" | 4341 | 328 | -8.84 |
| (Observed) | GFDL "2 x $CO_2$" | 4166 | 244 | -13.57 |
| | OSU "2 x $CO_2$" | 4027 | 283 | -15.43 |
| Alor Setar | Current Climate | 3845 | 234 | 0.00 |
| (Malaysia) | GISS "2 x $CO_2$" | 3617 | 149 | -5.93 |
| (Simulated | GFDL "2 x $CO_2$" | 3552 | 136 | -7.62 |
| | OSU "2 x $CO_2$" | 3739 | 170 | -2.76 |
| Alor Setar | Current Climate | 4215 | 322 | 0.00 |
| (Malaysia) | GISS "2 x $CO_2$" | 3931 | 345 | -6.74 |
| (Observed) | | | | |
| Jakarta | Current Climate | 3592 | 119 | 0.00 |
| (Indonesia) | GISS "2 x $CO_2$" | 3422 | 167 | -4.73 |
| (Simulated) | GFDL "2 x $CO_2$" | 3275 | 103 | -8.83 |
| | OSU "2 x $CO_2$" | 3383 | 134 | -5.82 |

Irrigation data, viz: switch (yes or no), water stress factor to start irrigation, and irrigation runoff ratio.

The principal aspects of climate change likely to affect the water supply estimates made by the model would be related to: changes in evapotranspiration (e.g., changes in water demand by basin vegetation, and open water evaporation), changes in runoff into reservoirs (thereby changing water supply available to users), changes in pond water supply, changes in the variability of reservoir and pond water supply, changes in erosion resulting from changes in precipitation intensity, and changes in the sedimentation of ponds and reservoirs.

## 4. THE MAIZE AND SOYBEAN MODELS

These two models were developed for the USAID IBSNAT project (IBSNAT, 1988). They have many of the same features as the CERES Rice model, except for the paddy specification, the transplanting feature, and the anaerobic nitrogen cycle. CERES Maize is described in Jones and Kiniry (1986) and SOYGRO in Jones, *et al.*, 1988.

## 5. CROP MODEL-WATER MODEL LINKAGES

Linkages between these models are exogenous to the model runs at the present time. They are the result of policy decisions with respect to the reservoir water allocation, and farmers decisions with respect to which crop to grow and what irrigation strategy to apply. An example of such linkages using CERES Rice and SWRRB is provided later in this section of the report.

## 6. USE OF MODELS IN CLIMATE CHANGE IMPACT ASSESSMENTS

This section presents six brief examples of the use of the CERES and SWRRB models in studies of the potential effects of climate change. It serves to illustrate some of the advantages and limitations of

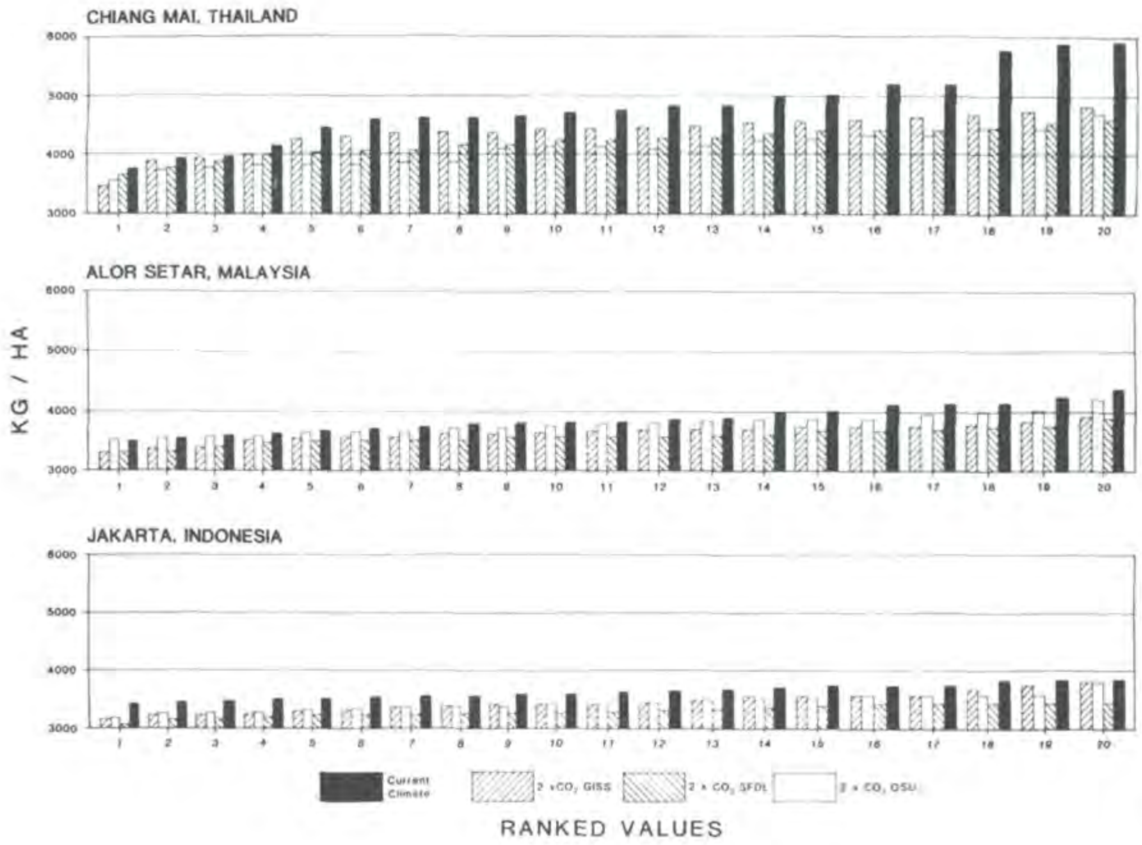


Figure 3.1 **Ranked rice yield (kg/ha) for current climate and for three GCM "2 x $CO_2$" scenarios.**

the models for this purpose.

The examples cover three countries (Thailand, Malaysia, Indonesia) three climate change scenarios,
(GISS "2 x $CO_2$", GFDL "2 x $CO_2$", OSU "2 x $CO_2$"), three upland crops (rice, maize, soybeans), lowland rice in Malaysia and Thailand, the aggregation problem (lowland rice yield variability among multiple sites spread across one country), basin water supply for multi-use reservoirs, erosion and rice production as a function of water allocation policy.

## 6.1 SIMULATED EFFECTS ON UN-IRRIGATED RICE

A graphical representation of some of the results from this study is given in Figure 3.1. Although the presentation is in terms of crop yield, it can more properly be viewed simply as a set of non-linear transformations of the climate scenarios' 4-vector weather variable time series. In order to accomplish this the soil, genetic coefficients, and cultural practice were held constant for all the runs shown. Most importantly all runs were made for "150 day", transplanted, bunded, and rainfed rice model configurations. The sowing date was just after mid-year in Chiang Mai and Alor Setar. The only variation from this was to displace the sowing date by six months in the case of Jakarta with respect to the other two stations. Consequently, the variations in yields shown in Figure 3.1 are purely functions of variations in climatology: among stations, among years, and among climate scenarios.

Some of the statistics associated with the rice yield curves are given in Table 3.1. This also compares yields obtained using weather generator-simulated current climate data for Alor Setar and yields using observed weather data for the same station input to the CERES Rice model. Notice that the yield variability is higher when the observed weather input was used than when the "weather generator" data were used. This is an unfortunate consequence of the algorithms in the particular weather generator used in the present study.

One feature of interest in climate change impact analysis is an assessment of possible changes in risk associated with rice farming. In order to make such assessments information is required on the changes in the variability of the yield. Some insight into the manner in which variance changes in the input weather scenario are transformed by the CERES Rice model into changes in the variance of the output estimates of yield has been considered by Panturat and Eddy (1990). It is important to note that the climate change data obtained from the three GCM models' output used in this study concerns changes in monthly mean values only. No information on changes in the variance of the GCM estimates of precipitation, temperature, and solar radiation was available at the time of this study.

### 6.2 SIMULATED EFFECTS ON IRRIGATED UPLAND CROPS

This set of experiments examined the impact of one of the climate change scenarios (GISS) on upland crop yields at Chiang Mai in northern Thailand. The object was to compare changes in GISS "2 x $CO_2$"/current climate crop yield and irrigation water demand ratios that would result from changing specific input variables as follows:

- Clay soil vs sandy soil.
- Fertilized vs non-fertilized.
- Dry season crop vs wet season crop.
- Cultivar change (rice vs maize vs soybeans).

Most of the results from this set of experiments were obtained from 25-year model runs of dry season, 90-day "Second" rice and wet season, and 150-day "Major" rice. The "Major" rice was planted in June and the "Second" rice in February. Irrigation (when used) was supplied on demand from the crop, and fertilizer (when used) was applied at the rate of 10 kg/ha (urea) at each of three times during the growing season. Table 3.2 summarises the simulated effects of changes in climate, while Tables 3.3, 3.4, and 3.5 describe soil, fertilizer, and irrigation effects respectively.

The highest yielding crop was irrigated and fertilized "Second" rice grown on clay soil under the current climate. The lowest yields were associated with the non-fertilized sandy soil.

Table 3.2 suggests that the smallest adverse climate change impacts could be on "Second" rice, provided that a 30% increase in irrigation water were to be available. "Major" rice would seem to be likely to suffer a decrease in yield of between 5% and 15% depending on the cultural practices of fertilization and/or irrigation employed. Irrigation water demand under the GISS "2 x $CO_2$" climate in the case of the wet season rice crop decreases because of an increase in the July precipitation.

Table 3.3 shows that sandy soil requires more water to grow a smaller rice crop than does clay soil. Table 3.4 illustrates the large increases in yield that fertilizer can produce given enough irrigation water, with the largest increases seen in the sunny "Second" rice season.

Table 3.5 shows that although there is a greater need for water in the dry "Second" rice season, when adequate irrigation is combined with sufficient fertilizer, this gives the greatest upland rice yields.

It was found that soybeans and maize simulated for a June planting in Chiang Mai suffered a 15% to 20% decrease in yield under the GISS "2 x $CO_2$" climate. Both were non-irrigated, and unfertilized crops.

### 6.3 LOWLAND RICE IN MALAYSIA

The MADA project in the north west of the Malay peninsula is the largest area with integrated management of rice production in Malaysia. About 100,000 hectares of irrigated land produces about 700,000 metric tons of rice annually from 2 crops/year. The Alor Setar weather station, which provided the 18-year time series of observations used in this study, is located nearly in the center of the area. Two crops per year are grown under careful irrigation scheduling and fertilizer application. The "off season" crop is planted in four time periods: the first period begins sowing in early March and the last period begins sowing in mid-April. Sowing begins for the "main season" crop near the first of September for group 1 and in mid-October for group 4. Some padis are transplanted and some are direct seeded in each group in both seasons.

**Table 3.2** **Effects of climate changes on 25-year mean model estimates of yield and water demand of Upland rice at Chiang Mai, Thailand**

| | | | | GISS "2 x $CO_2$"/current climate | |
|---|---|---|---|---|---|
| Rice Crop | Soil | Fertilized | Irrigated | Water demand | Grain yield |
| Major | Clay | No | No | | .95 |
| | | | Yes | | .86 |
| | | Yes | No | | .94 |
| | | | Yes | .96 | .92 |
| | Sandy | No | No | | .99 |
| | | | Yes | | .86 |
| | | Yes | No | | .54 |
| | | | Yes | .97 | .93 |
| Second | Clay | No | Yes | 1.35 | 1.01 |
| | | Yes | Yes | 1.33 | .89 |
| | Sandy | No | Yes | 1.31 | .99 |
| | | Yes | Yes | 1.32 | .91 |

**Table 3.3** **Upland, irrigated fertilized, current climate, 25-year mean rice yield ratios under the conditions shown**

| | Sandy soil/clay soil yield ratios | |
|---|---|---|
| Rice crop | Water demand | Rice grain |
| Major | 1.27 | .94 |
| Second | 1.20 | .84 |

**Table 3.4** **Upland, irrigated, clay soil, current climate, 25-year mean rice yield ratios under the conditions shown**

| Rice crop | Fertilized/non-fertilized yield ratios |
|---|---|
| Major | 1.54 |
| Second | 2.55 |

**Table 3.5** **Upland, fertilized, clay soil, current climate, 25-year mean rice yield ratios under the conditions shown**

| Rice crop | Irrigated/non-irrigated yield ratios |
|---|---|
| Major | 1.28 |
| Second | 2.62 |

This study simulated the growth of "off season" padi rice sowed about the first of March, and evaluated the effects of a change from 18 years of current weather data input to 18 years of GISS "2 x $CO_2$" input. Both the automatic irrigation and the rainfed options have been used, and the padis had urea fertilizer applied at a rate of 60 kg/ha each time for 3 applications. Simulations also included the option which prescribes no water nor fertilizer stress for comparison purposes. Table 3.6 shows some of the main results. In general the GISS "2 x $CO_2$" climate appears to reduce the grain yields by 20% to 25% in the case of direct seeding, and by about 15% to 20% in the case of transplanted rice. As was the case for the Chiang Mai upland rice, some 20%-25% more irrigation water is demanded under the GISS "2 x $CO_2$" climate regime than under current climate. The irrigated, transplanted rice seems to operate under no stress conditions in both climatic conditions, while stress experienced by the crop under direct seeded, rainfed conditions resulted in about a quarter of the yield being lost in both current and GISS "2 x $CO_2$" climatic regimes.

## 6.4 THE AGGREGATION PROBLEM

One of the most serious problems associated with establishing an objective framework within which to study policy responses to climate change impacts on crop production and water supply is the generalization from point yield estimates to aggregated area production estimates. The following material is provided to show both the necessity and the feasibility of accomplishing this task. The simple example illustrated in Table 3.7 establishes the necessity to have *more than one* time series of point estimates of lowland (paddy) rainfed, "major" rice yields if one wishes realistically to quantify national level climate change impacts on national rice production.

A rice variety and a sowing date was chosen for each of seven sites in Thailand which is "typical" for the surrounding area. The same soil and the same fertilizer application strategy was used for all sites to eliminate this source of variability. The model output yields were calibrated to make the mean and variance of the yields for current climate match the mean and variance of the observed yields. The GISS "2 x $CO_2$" yields were calibrated to be compatible with this procedure, while leaving the ratios between the GISS "2 x $CO_2$" and current climate mean yields and variances unchanged. From Table 3.7 it is clear that no one site can be used to represent climate change impacts on rice production across the entire country.

The following discussion is offered to support the concept that it is feasible to represent a significant fraction of the total national "Major" rice productivity with a sufficiently small number of sample sites so that climate change impacts on this commodity at the national level can be assessed realistically.

In order to assess the representativeness of the 7 sites reference should be made to Table 3.8. Note that this table is produced using "observed" provincial level yield data only. This table is to be interpreted as follows. In the Northeastern region the provinces of Sakon Nakhon and Surin are representative of 13 provinces out of the 17 in that region. This was established by correlating the observed "Major" rice yield data (16 years) for those two provinces with the same time series for all provinces in the region and then selecting those whose correlation coefficients were statistically significant. These 13 provinces produced (in 1987) 28.6 percent of the national level "Major" rice while the entire northeastern region produced 36.2 percent. Thus, if the 16 years of observed yields from the provinces of Sakon Nakhon and Surin are used in linear multiple regression to estimate the 16 years of regional level mean yields, they explain 76 percent of the (adjusted) variance of the latter. It was found that 3 provinces selected from this region could explain 91 percent of the (region level) variance. Other multiple regression runs of this type have led to the conclusion that over 90% of the variance in "Major" rice production in Thailand could be explained through the use of about 12 carefully selected provinces as indicators.

The next step is to discover the extent to which a CERES Rice model simulation of rice yield can simulate a time series of its observed (production/harvested area) counterpart. Data sets required to tune (calibrate) the CERES Rice model (using its available cultural practice options, as described above) are available for Thailand, comprising:

- Representative rice soils.
- Representative varieties.
- Irrigated areas.
- Fertilization.
- Planting and harvest dates.
- Daily weather stations.

It is a matter of standard (although non-trivial) procedure to use non-linear programming

**Table 3.6** **Effects of climate changes on Lowland rice yields at Alor Setar (Malaysia), (18-year average model estimates). Irrigation implies to bund height. No stress (NS) implies adequate water and fertilizer at all times**

| Cultural practice | | Yield ratios | | | |
|---|---|---|---|---|---|
| Planting | Irrigation | Current clim. Yld/NS yld. | GISS "2 x $CO_2$" climate Yld/NS yld. | Grain yield GISS "2 x $CO_2$" /current clim. | Irrig. demand GISS "2 x $CO_2$" /current clim. |
| Transp. | No Stress | 1.00 | 1.00 | .86 | NA |
| Transp. | Rainfed | .83 | .86 | .84 | NA |
| Dir. Seed | Rainfed | .77 | .74 | .79 | NA |
| Transp. | Irrig. | .99 | .99 | .81 | 1.20 |
| Dir. Seed | Irrig. | .92 | .85 | .75 | 1.23 |

**Table 3.7** **Model output yield ratios for GISS "2 x $CO_2$"/current climate for seven locations in Thailand. (Bangkok station is represented by Don Muang weather and Pathum Thani yields)**

| Station | Region | GISS "2 x $CO_2$"/current climate yield ratios |
|---|---|---|
| CMI:Chiang Mai | Northern | .94 |
| PIT:Phitsanulok | Northern | .86 |
| SAK:Sakon Nakhon | Northeastern | .71 |
| SUR:Surin | Northeastern | .64 |
| SUP:Suphan Buri | Central | .89 |
| BKK:Bangkok | Central | .92 |
| SRI:Nakhon Sri Thammarat | Southern | .97 |

**Table 3.8** **Percent 1987 Major rice production represented by stations shown in regions. NCOR: Number provinces within region showing statistically significant correlation with one of sites shown in same region**

| Sites | % Var | Region | NCOR | % Natnl. prod. | Total | Region % natnl. |
|---|---|---|---|---|---|---|
| CMI,PIT | 70 | Northern | 10 | 22.5 | 17 | 28.5 |
| SAK,SUR | 76 | Northeastern | 13 | 28.6 | 17 | 36.2 |
| PAT,SUP | 80 | Central | 13 | 15.6 | 25 | 28.8 |
| SRI | 64 | Southern | 1 | 1.8 | 14 | 6.5 |
| Total | | | 37 | 68.5 | 73 | 100.0 |

Total: Total number of provinces in region.

% Var: Percent variance of regional productivity explained by sites chosen using linear multiple regression.

Note: Pathum Thani observed yields were used in place of Bangkok metro area data as being more representative of the central region rice farming.

algorithms to minimize the variance of the (appropriately weighted) model yield estimates about the (provincial level) observed yields, given a set of decision variables (e.g. the genetic coefficients) subject to appropriate constraints. This has been beyond the scope of this project. Once this last step has been accomplished it is clear that climate change impacts on rice production at the national level can be successfully estimated as a function of climate scenario and cultural practice.

## 6.5 IMPLICATIONS OF CLIMATE CHANGE FOR FUTURE WATER ALLOCATION POLICY

Combined use of water and crop yield models can help in assessing possible changes in water available for irrigation due to changes in climate, and thus suggest potentially appropriate policies of water allocation. The present study considered effects of climate change on water supplied by the Mae Nam Ngat basin in northern Thailand.

The methodology developed for this purpose is as follows:

i) 300 monthly values (1951-1975) of water volume delivered by the basin to the reservoir were obtained via the SWRRB model for current climate and for the GISS "2 x $CO_2$" scenario. 25-year monthly mean values of this inflow into the reservoir are shown in Figure 3.2 for both these climate regimes. The main impact of the GISS "2 x $CO_2$" weather input appears to be a decrease of harvested water in September and October and an increase in July (Figure 3.3). This can be understood to a certain extent from an examination of Figure 3.4, provided that one keeps in mind that the basin response time (particularly of the sub-surface flow) will delay the appearance in the reservoir of rain falling on the catchment basin.

ii) 25 values of grain yield and irrigation water demand were obtained for each irrigated "Second" and "Major" rice crop grown during the same time period.

iii) Downstream water use was assumed to be constant over the time period for a given policy, with the reference policy (12.87) defined to be that which consumed a constant 12.87 cubic meters per second (CMS) of reservoir water. An alternative policy (9.65) was defined in the same way. Once a policy was selected, the appropriate water consumption was subtracted month by month from the reservoir contents.

iv) Irrigation water available to grow "Second" rice was removed from the reservoir each year as follows: A scan of the reservoir volume was made each year (after accounting for the downstream water use) and the month with the minimum water contents, and that associated minimum water volume, was ascertained. This minimum volume was then provided by the reservoir for irrigation of the "Second" rice crop during February, March, April, and May of that year.

It will be noticed that in reality this would require a forecast of the irrigation water supply at the beginning of the crop season. Such a forecast is in fact made by the MADA project personnel for our Alor Setar study area on a regular basis. This permits an efficient cropping strategy to be formulated at the beginning of each season and has been reported to be cost effective.

v) Irrigation water available from the Mae Nam Ngat reservoir to grow the "Major" rice crop each year was calculated by summing the amount of inflow each month which was in excess of the amount required to fill the reservoir after the supply required for both downstream use and (the earlier) "Second" rice irrigation had been removed.

vi) 25-year monthly mean values of water contents (after water withdrawal for usages as specified above) under the two downstream water use policies given are shown in Figure 3.2. Figure 3.4 shows that the most serious adverse climate change impact on this reservoir water usage is in May, as one would expect. A year by year examination of the reservoir response to policy 12.87 under the GISS "2 x $CO_2$" climate scenario revealed that in about 20% of the years the water volume available for the irrigation of the "Second" rice crop was unacceptably small. Policy 9.65 did not produce this problem.

vii) The next step was to make use of the water demand imposed by the crop each season, together with the water supply calculated above, to calculate the number of hectares which could be irrigated under the assumed irrigation strategy.

viii) The irrigated area was multiplied by the model-estimated irrigated grain yield for each of the 25 years, and for each of the 2 crops per year, in order to obtain the irrigated crop production.

ix) Finally, the above procedure was accomplished for nine policies and illustrative results are presented in Figure 3.5.

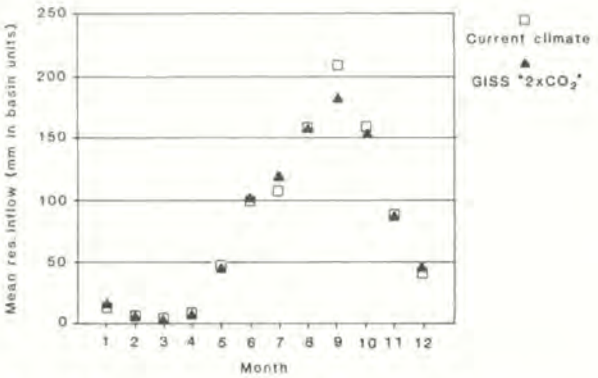


**Figure 3.2 25-year mean monthly water inflow into the Mae Nam Ngat Reservoir, Thailand.**

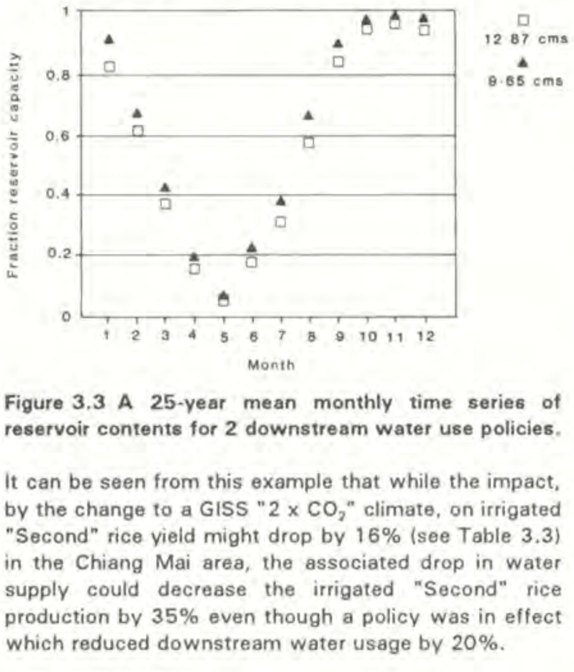


**Figure 3.3 A 25-year mean monthly time series of reservoir contents for 2 downstream water use policies.**

It can be seen from this example that while the impact, by the change to a GISS "2 x $CO_2$" climate, on irrigated "Second" rice yield might drop by 16% (see Table 3.3) in the Chiang Mai area, the associated drop in water supply could decrease the irrigated "Second" rice production by 35% even though a policy was in effect which reduced downstream water usage by 20%.

## 6.6 EROSION

The erosion of soil from arable land, and its deposition into ponds and reservoirs, represents a double disbenefit which results from poor cultural practice of the human component of the biosphere. Models such as the SWRRB used in this study can provide quantitative estimates of the potential impacts of climate change associated with such practice.

**Table 3.9 25-year mean annual climate change impacts (GISS "2 x $CO_2$"/current climate) for the Mae Nam Ngat Basin**

| Process | Ratio:GISS "2 x $CO_2$"/ current climate |
|---|---|
| Deep percolation | .97 |
| Basin sediment yield | .81 |
| Precipitation | .97 |
| Basin water yield | .96 |

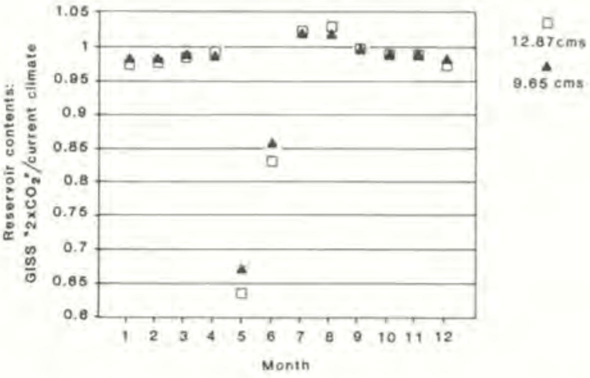


**Figure 3.4 25-year mean monthly climate change impacts on reservoir contents for 2 downstream water use policies: current climate and GISS "2 x $CO_2$" climate.**

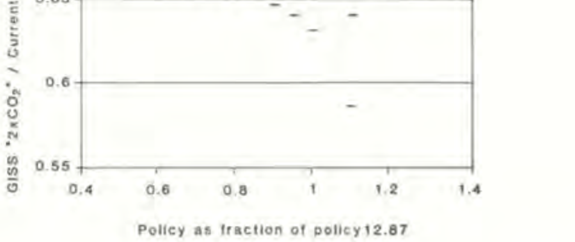


**Figure 3.5 25-year mean impacts on irrigated rice as a function of policy. S. AREA - Second rice area ratios. S. PROD = Second rice production ratios. T. PROD = Total rice production ratios.**

Table 3.9 shows some 25-year mean annual climate change impacts on sediment yield associated with the SWRRB runs discussed above. The 25-year mean monthly impacts are shown in Figure 3.6. When viewed at this level of time aggregation, these impacts seem innocuous. However, the sedimentation problem lies rather with the few high-yield events than with the many smaller values which occur more often over an extended time period. Figure 3.7 shows that, in fact, the effect of the GISS "2 x $CO_2$" scenario of climate change (on erosion from this basin) is to reduce both the frequency of occurrence and intensity of these extreme events.

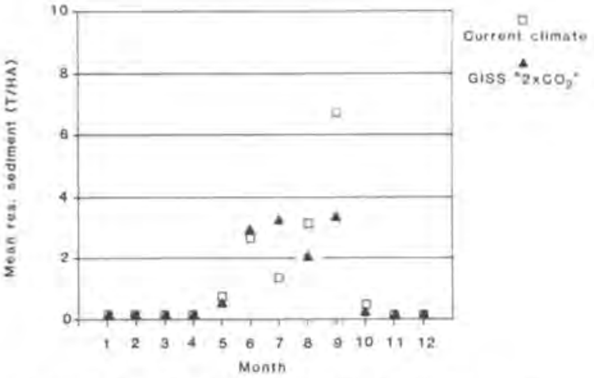


**Figure 3.6 25-year mean monthly sediment yield from Mae Nam Ngat Catchment Basin, Thailand.**

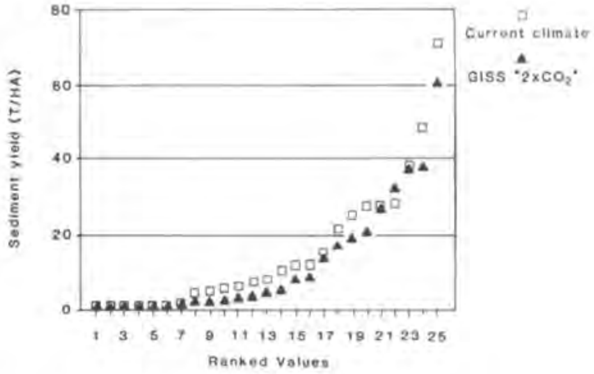


**Figure 3.7 Ogives of 25-years of (uncalibrated) sediment yield in Mae Nam Ngat Basin for current climate and GISS "2 x $CO_2$" climate.**

# 7. METHODS OF ASSESSMENT OF IMPACTS OF SEA-LEVEL RISE

The extent of submergence resulting from a sea-level rise can be estimated by surveying from the existing highest high tide shoreline to the appropriate contour, e.g. 1 meter above this level.

In addition there will be changes due to erosion and deposition as sea level rises. These can be assessed in terms of geomorphological theory, e.g. a 1 metre sea-level rise is likely to deepen nearshore waters and augment wave heights, and hence accelerate erosion. This may be at least partly offset by deposition, which can be assessed from rates of cliff recession and fluvial sediment yields. However, existing models (such as the Bruun Rule) have proved inadequate because specific conditions required are not generally fulfilled on the coasts of South-East Asia. Refinements of such models are being developed but are not yet available.

Alternatively the effects of sea-level rise can be studied and measured on coasts which have been subsiding in recent decades. Such studies have shown that erosion accelerates as submergence proceeds on cliffs, beaches, deltas, and coastal wetlands. Unfortunately, there are other complicating factors, such as impacts of human activities and structures, including those which are responses to the rise of sea level relative to the land as these coasts subside. Nevertheless, measurements of coastline recession on subsiding sectors of the Gulf and Atlantic coasts of the United States can be extrapolated to give the scale of erosion as sea level rises globally.

In contrast with climatic predictions, there are no generally applicable models of coastline changes resulting from a sea-level rise. Coastlines are varied in form and structure, and it is necessary to deal separately with each type of coast, classified on the basis of geomorphological research. This research is in progress in South-East Asia, and will be used as the basis of national assessments in due course.

# IV.1 ASSESSMENT OF SOCIO-ECONOMIC IMPACTS OF CLIMATE CHANGE IN INDONESIA

## 1.1 INTRODUCTION

This study focuses on the potential effects of climate change on agricultural potential and water resources. It takes as a case study three river basins: the Citarum River Basin in northwest Java (Figure 1.1), the Brantas River Basin in East Java and the Saddan River Basin in South Sulawesi.

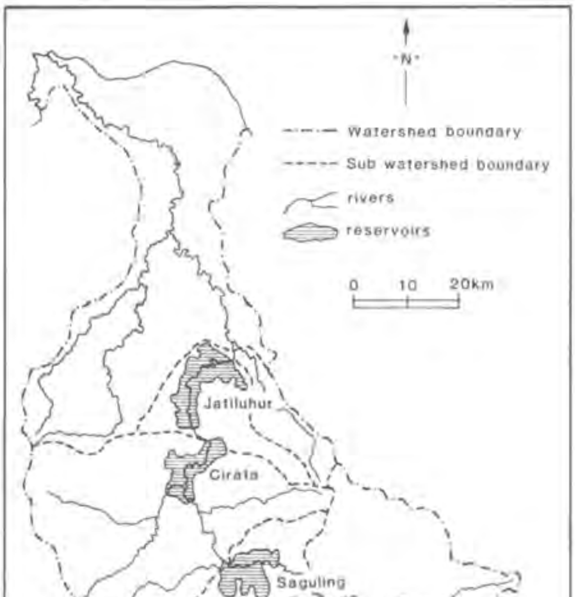


**Figure 1.1** **Citarum River Basin, Indonesia**

## 1.2 CLIMATE SCENARIOS

Scenarios of possible future climate change were based on outputs from the Goddard Institute for Space Studies (GISS) general circulation model (GCM) for a "2 x $CO_2$" equilibrium climate (see Section II).

Ratios of the GISS "2 x $CO_2$" values to current climate for seven variables (air temperature, precipitation, surface runoff, surface air humidity, incident surface solar radiation, total cloud cover and average surface wind speed) were applied to observed mean climate date (1950-70) for 50 meteorological stations. Tables 1.1 and 1.2 show the change in air temperature and precipitation.

The change in temperature ranges from 1.0 to of 1.4 percent. This means that with a mean daily air temperature of 26.8°C, there would be an increase of between 3.0 to 4.2°C. The largest changes are estimated to occur in Bengkulu (3.87°E, 102.99°E) where for seven consecutive months from October to April, the temperature increases by 1.4 percent. Conversely, Sorong (0.93°S, 131.1°E) experiences a smaller change, in the order of 1.1°C for eight months. There is no difference in the temperature change between elevations. Wamena (4.07°S, 138.95°E) at about 1500m experiences about the same magnitude of change as Kokenau (4.62°S, 136°E) at 3m.

More substantial changes in precipitation are estimated ranging from about -32% to 234%. Both occur in the same location, i.e. Merauke (8.47°S, 140.38°E), where in April rainfall decreases to 68.3% while in November it increases to 333.9% of current mean values. In general annual rainfall in Indonesia is estimated to increase under the GISS "2 x $CO_2$" climate.

However, there are locations which may receive less rain in some months. These are mostly in the equatorial zone between 3.60°N and 1.20°S. Figure 1.2 shows the estimated rainfall under the GISS "2 x $CO_2$" climate in Pontianak (0.00°N, 109.40°E) as compared with the year 1972 (an ENSO year) and with 1974 (a wetter than normal year). There is little overall difference.

**Table 1.1 Temperature: ratio of GISS "2 x $CO_2$" climate to current climate (1950-70)**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pekan Baru | 1.013 | 1.013 | 1.014 | 1.014 | 1.012 | 1.011 | 1.011 | 1.012 | 1.013 | 1.013 | 1.013 | 1.013 |
| Gorontalo | 1.012 | 1.012 | 1.012 | 1.012 | 1.011 | 1.011 | 1.012 | 1.012 | 1.012 | 1.012 | 1.012 | 1.012 |
| Tg.Pinang | 1.013 | 1.012 | 1.013 | 1.013 | 1.012 | 1.011 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 |
| Mapanget | 1.011 | 1.011 | 1.011 | 1.012 | 1.011 | 1.011 | 1.012 | 1.011 | 1.012 | 1.012 | 1.012 | 1.012 |
| Sibolga | 1.013 | 1.013 | 1.014 | 1.014 | 1.012 | 1.011 | 1.01 | 1.012 | 1.013 | 1.013 | 1.013 | 1.013 |
| Tarempa | 1.012 | 1.012 | 1.011 | 1.012 | 1.011 | 1.010 | 1.011 | 1.012 | 1.01 | 2.013 | 1.014 | 1.014 |
| Tarakan | 1.011 | 1.011 | 1.011 | 1.013 | 1.011 | 1.012 | 1.013 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 |
| Polonia | 1.013 | 1.013 | 1.014 | 1.014 | 1.012 | 1.011 | 1.011 | 1.013 | 1.013 | 1.013 | 1.013 | 1.012 |
| Ranai | 1.012 | 1.011 | 1.010 | 1.012 | 1.011 | 1.010 | 1.012 | 1.012 | 1.012 | 1.013 | 1.014 | 1.014 |
| Pontianak | 1.013 | 1.012 | 1.011 | 1.012 | 1.012 | 1.011 | 1.012 | 1.012 | 1.012 | 1.013 | 1.014 | 1.014 |
| Tabing | 1.013 | 1.014 | 1.014 | 1.014 | 1.012 | 1.011 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 | 1.013 |
| Sorong | 1.012 | 1.011 | 1.011 | 1.012 | 1.011 | 1.010 | 1.011 | 1.011 | 1.011 | 1.012 | 1.011 | 1.011 |
| Manukwari | 1.012 | 1.012 | 1.012 | 1.012 | 1.011 | 1.010 | 1.011 | 1.011 | 1.012 | 1.012 | 1.012 | 1.012 |
| Biak | 1.013 | 1.012 | 1.012 | 1.012 | 1.011 | 1.010 | 1.011 | 1.011 | 1.012 | 1.012 | 1.012 | 1.012 |
| Balikpapan | 1.013 | 1.012 | 1.012 | 1.012 | 1.011 | 1.011 | 1.013 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 |
| Jambi | 1.013 | 1.013 | 1.013 | 1.014 | 1.012 | 1.011 | 1.012 | 1.012 | 1.013 | 1.014 | 1.014 | 1.013 |
| Serui | 1.013 | 1.012 | 1.012 | 1.012 | 1.011 | 1.010 | 1.011 | 1.011 | 1.012 | 1.013 | 1.012 | 1.012 |
| Pangkal P. | 1.013 | 1.013 | 1.013 | 1.014 | 1.012 | 1.011 | 1.012 | 1.012 | 1.013 | 1.014 | 1.014 | 1.014 |
| Tlg.betutu | 1.013 | 1.013 | 1.014 | 1.014 | 1.012 | 1.011 | 1.012 | 1.012 | 1.013 | 1.014 | 1.014 | 1.014 |
| Banjarmasin | 1.013 | 1.013 | 1.013 | 1.012 | 1.011 | 1.011 | 1.013 | 1.012 | 1.013 | 1.013 | 1.013 | 1.013 |
| Ambon | 1.013 | 1.012 | 1.012 | 1.012 | 1.011 | 1.011 | 1.012 | 1.011 | 1.011 | 1.012 | 1.011 | 1.011 |
| Kaimana | 1.013 | 1.012 | 1.012 | 1.012 | 1.011 | 1.011 | 1.011 | 1.011 | 1.012 | 1.013 | 1.012 | 1.012 |
| Bengkulu | 1.014 | 1.014 | 1.014 | 1.014 | 1.013 | 1.011 | 1.012 | 1.012 | 1.013 | 1.014 | 1.014 | 1.014 |
| Kendari | 1.013 | 1.013 | 1.012 | 1.011 | 1.010 | 1.011 | 1.013 | 1.012 | 1.012 | 1.012 | 1.012 | 1.012 |
| Wamena | 1.013 | 1.013 | 1.013 | 1.013 | 1.012 | 1.011 | 1.012 | 1.011 | 1.012 | 1.013 | 1.013 | 1.013 |
| Astraksetra | 1.013 | 1.013 | 1.014 | 1.014 | 1.013 | 1.012 | 1.012 | 1.012 | 1.013 | 1.014 | 1.013 | 1.013 |
| Kokenau | 1.013 | 1.013 | 1.013 | 1.013 | 1.012 | 1.011 | 1.012 | 1.011 | 1.012 | 1.013 | 1.013 | 1.013 |
| Mandai | 1.013 | 1.013 | 1.012 | 1.011 | 1.010 | 1.011 | 1.013 | 1.012 | 1.012 | 1.011 | 1.012 | 1.012 |
| Teluk Betung | 1.013 | 1.013 | 1.014 | 1.014 | 1.013 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 | 1.013 |
| Tual | 1.013 | 1.013 | 1.012 | 1.013 | 1.012 | 1.011 | 1.012 | 1.011 | 1.012 | 1.012 | 1.012 | 1.012 |
| Bawean | 1.013 | 1.013 | 1.013 | 1.013 | 1.012 | 1.012 | 1.013 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 |
| Serang | 1.013 | 1.013 | 1.014 | 1.013 | 1.012 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 | 1.013 |
| Tanah Merah | 1.012 | 1.012 | 1.013 | 1.013 | 1.012 | 1.011 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 | 1.013 |
| Halim P.K. | 1.013 | 1.013 | 1.013 | 1.013 | 1.012 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 | 1.013 |
| Bandung | 1.013 | 1.013 | 1.013 | 1.013 | 1.012 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 | 1.013 |
| Tegal | 1.013 | 1.013 | 1.013 | 1.013 | 1.012 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 | 1.013 |
| Semarang | 1.013 | 1.013 | 1.013 | 1.013 | 1.012 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 | 1.013 |
| Surabaya | 1.013 | 1.013 | 1.013 | 1.013 | 1.012 | 1.012 | 1.013 | 1.012 | 1.012 | 1.012 | 1.012 | 1.012 |
| Madiun | 1.013 | 1.013 | 1.013 | 1.013 | 1.012 | 1.012 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 | 1.012 |
| Cilacap | 1.013 | 1.013 | 1.013 | 1.013 | 1.012 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 | 1.012 |
| Saumlaki | 1.014 | 1.014 | 1.012 | 1.012 | 1.012 | 1.012 | 1.012 | 1.011 | 1.013 | 1.012 | 1.013 | 1.012 |
| Merauke | 1.012 | 1.011 | 1.012 | 1.014 | 1.013 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 | 1.012 | 1.013 |
| Rembiga | 1.013 | 1.012 | 1.012 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 | 1.011 | 1.011 | 1.012 | 1.012 |
| Waingapu | 1.012 | 1.012 | 1.012 | 1.012 | 1.012 | 1.013 | 1.014 | 1.013 | 1.011 | 1.010 | 1.011 | 1.012 |
| Kupang | 1.013 | 1.013 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 | 1.012 | 1.012 | 1.011 | 1.012 | 1.012 |

In some locations such as Saumlaki (7.98°S, 131.30°E), where there is already ample rainfall during the west monsoon, increases in rainfall may cause problems in soil conservation. On the other hand at locations such as Kupang (10.17°S, 123.67°E), where sufficient rainfall is currently restricted to three to four months, the increase might be beneficial (Fig. 1.3). There might still, however, be problems with erosion. For Kupang in particular, there are substantial increases of rainfall in April and May. However, there is also a lengthening of the period with sufficient water for crop growth and thus a beneficial lengthening of the growing season.

**Table 1.2 Rainfall: ratio of GISS "2 x $CO_2$" climate to current climate (1950-70)**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pekan Baru | 1.165 | 1.210 | 1.381 | 1.330 | 1.234 | 1.083 | 1.012 | 1.193 | 1.115 | 1.086 | 1.134 | 1.023 |
| Gorontalo | 1.257 | 1.372 | 1.332 | 1.364 | 1.107 | 0.878 | 0.872 | 1.106 | 1.061 | 1.245 | 1.369 | 1.320 |
| Tg. Pinang | 1.233 | 1.391 | 1.574 | 1.257 | 1.150 | 1.091 | 0.974 | 1.226 | 1.049 | 1.037 | 1.063 | 0.973 |
| Mapanget | 1.398 | 1.505 | 1.277 | 1.333 | 0.978 | 0.762 | 0.752 | 1.101 | 1.034 | 1.179 | 1.318 | 1.363 |
| Sibolga | 1.142 | 1.117 | 1.317 | 1.322 | 1.218 | 1.031 | 0.975 | 1.197 | 1.148 | 1.092 | 1.120 | 1.011 |
| Tarempa | 1.278 | 1.637 | 1.909 | 1.245 | 1.093 | 1.151 | 0.899 | 1.373 | 0.992 | 0.965 | 0.908 | 0.842 |
| Tarakan | 1.156 | 1.477 | 1.255 | 1.133 | 0.953 | 0.891 | 0.807 | 1.235 | 1.062 | 1.104 | 1.014 | 1.124 |
| Polonia | 1.149 | 1.082 | 1.329 | 1.301 | 1.168 | 0.993 | 0.907 | 1.272 | 1.156 | 1.080 | 1.067 | 0.939 |
| Pontianak | 1.337 | 1.578 | 1.717 | 1.122 | 1.027 | 1.065 | 0.959 | 1.178 | 0.961 | 0.993 | 1.039 | 0.976 |
| Tabing | 1.146 | 1.170 | 1.306 | 1.360 | 1.280 | 1.088 | 1.056 | 1.126 | 1.143 | 1.119 | 1.192 | 1.084 |
| Sorong | 1.468 | 1.512 | 1.428 | 1.433 | 1.115 | 0.890 | 0.910 | 1.099 | 1.007 | 1.230 | 1.816 | 1.386 |
| Manokwari | 1.387 | 1.442 | 1.353 | 1.347 | 1.102 | 0.925 | 0.949 | 1.103 | 1.053 | 1.235 | 1.610 | 1.332 |
| Biak | 1.315 | 1.375 | 1.302 | 1.287 | 1.111 | 0.968 | 0.996 | 1.105 | 1.089 | 1.247 | 1.483 | 1.293 |
| Balikpapan | 1.175 | 1.283 | 1.531 | 1.350 | 1.221 | 1.029 | 1.014 | 1.084 | 1.052 | 1.250 | 1.287 | 1.208 |
| Jambi | 1.213 | 1.263 | 1.361 | 1.263 | 1.195 | 1.058 | 1.048 | 1.083 | 1.086 | 1.094 | 1.189 | 1.094 |
| Pangkal P. | 1.261 | 1.293 | 1.356 | 1.182 | 1.127 | 1.021 | 1.043 | 1.042 | 1.046 | 1.079 | 1.201 | 1.110 |
| Tlg.betutu | 1.232 | 1.234 | 1.281 | 1.221 | 1.174 | 1.026 | 1.073 | 1.007 | 1.078 | 1.107 | 1.243 | 1.148 |
| Banjarmasin | 1.222 | 1.182 | 1.487 | 1.319 | 1.242 | 1.031 | 1.091 | 0.982 | 1.035 | 1.249 | 1.378 | 1.235 |
| Ambon | 1.230 | 1.273 | 1.585 | 1.550 | 1.424 | 1.155 | 1.195 | 1.118 | 1.032 | 1.375 | 2.231 | 1.324 |
| Kendari | 1.137 | 1.176 | 1.804 | 1.647 | 1.508 | 1.207 | 1.200 | 1.081 | 1.067 | 1.461 | 1.733 | 1.314 |
| Wamena | 1.149 | 1.210 | 1.275 | 1.172 | 1.253 | 1.189 | 1.205 | 1.063 | 1.157 | 1.344 | 1.411 | 1.252 |
| Kokenau | 1.215 | 1.397 | 1.529 | 1.327 | 1.348 | 1.309 | 1.258 | 1.122 | 1.123 | 1.411 | 1.840 | 1.277 |
| Mandai | 1.129 | 1.198 | 1.814 | 1.589 | 1.455 | 1.265 | 1.278 | 1.179 | 1.079 | 1.564 | 1.504 | 1.319 |
| Tual | 1.162 | 1.357 | 2.081 | 1.821 | 1.616 | 1.666 | 1.433 | 1.264 | 1.116 | 1.605 | 2.050 | 1.298 |
| Bawean | 1.200 | 1.164 | 1.376 | 1.183 | 1.118 | 1.074 | 1.166 | 1.099 | 1.052 | 1.373 | 1.326 | 1.193 |
| Serang | 1.165 | 1.128 | 1.236 | 1.150 | 1.120 | 1.079 | 1.102 | 1.098 | 1.084 | 1.257 | 1.238 | 1.129 |
| Tanah Merah | 1.447 | 2.079 | 1.506 | 0.916 | 1.189 | 1.300 | 1.198 | 1.086 | 1.122 | 1.385 | 2.241 | 1.278 |
| Halim P. K. | 1.167 | 1.124 | 1.240 | 1.129 | 1.096 | 1.069 | 1.102 | 1.100 | 1.079 | 1.277 | 1.237 | 1.124 |
| Bandung | 1.147 | 1.111 | 1.260 | 1.112 | 1.071 | 1.079 | 1.107 | 1.134 | 1.080 | 1.330 | 1.224 | 1.106 |
| Tegal | 1.164 | 1.115 | 1.263 | 1.074 | 1.024 | 1.039 | 1.108 | 1.108 | 1.068 | 1.353 | 1.232 | 1.109 |
| Semarang | 1.166 | 1.122 | 1.291 | 1.073 | 1.012 | 1.038 | 1.125 | 1.116 | 1.065 | 1.392 | 1.244 | 1.116 |
| Surabaya | 1.153 | 1.168 | 1.422 | 1.180 | 1.099 | 1.150 | 1.225 | 1.219 | 1.075 | 1.509 | 1.302 | 1.170 |
| Madiun | 1.137 | 1.140 | 1.375 | 1.127 | 1.048 | 1.117 | 1.188 | 1.206 | 1.079 | 1.499 | 1.261 | 1.129 |
| Cilacap | 1.121 | 1.097 | 1.299 | 1.084 | 1.022 | 1.077 | 1.119 | 1.169 | 1.084 | 1.425 | 1.211 | 1.082 |
| Saumlaki | 0.973 | 1.212 | 3.135 | 2.661 | 2.091 | 2.484 | 1.809 | 1.525 | 1.201 | 2.026 | 1.737 | 1.290 |
| Merauke | 1.802 | 3.094 | 1.824 | 0.683 | 1.145 | 1.441 | 1.202 | 1.138 | 1.067 | 1.439 | 3.339 | 1.320 |
| Waingapu | 1.168 | 1.441 | 1.822 | 1.453 | 1.299 | 1.730 | 1.807 | 1.826 | 1.107 | 2.071 | 1.476 | 1.395 |
| Kupang | 0.992 | 1.226 | 2.678 | 2.222 | 1.758 | 2.351 | 2.000 | 1.871 | 1.184 | 2.261 | 1.316 | 1.356 |

## 1.3 DESCRIPTION OF THE STUDY AREAS AND METHODOLOGY

The Citarum River (250 km) is the longest river in West Java. There are three large reservoirs along the river : Saguling, Cirata and Jatiluhur (Figure 1.1). All of them are multipurpose, used to regulate floods, to generate electric power, to irrigate rice fields, to supply domestic and industrial water, to regulate inland water fisheries and to provide recreation resources.

The upper Citarum River Basin was chosen as a study area for assessment of the biophysical impacts of climate change on erosion and water resources. Studies of the impact of sea-level rise on coastal agricultural land and food production were carried out in the downstream section of the river basin (the Districts of Bekasi, Krawang and Subang).

Upper Brantas River Basin has five reservoirs (Sengguruh, Walahar, Wlingi, Karangkates and

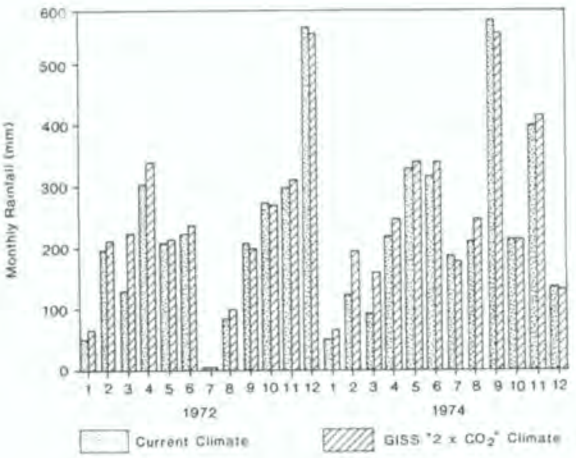


**Figure 1.2** **Rainfall at Pontianak, Indonesia, under current climate and under the GISS "2 x $CO_2$" scenario.**

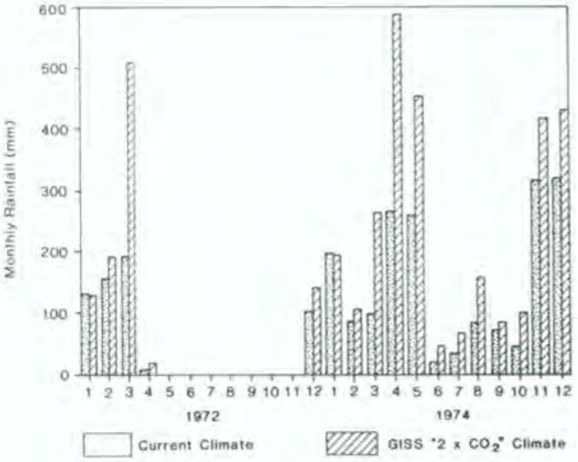


**Figure 1.3** **Rainfall at Kupang, Indonesia, under current climate and under the GISS "2 x $CO_2$" scenario.**

Selorejo). It covers an area of 205,000 ha and is characterised by brown regosol soils which are highly susceptible to erosion and are generally poorly managed. Most of the land therefore requires more attention to conservation. The forested area is still extensive, especially in the Sumber Grantas sub-watershed. Forest land covers 28 percent of the total area.

The Saddan River Basin is much larger than the previous two. Covering an area of 630,700 ha the main catchment is located in the Toraja highland. The Benteng Dam which has been exploited since colonial time is located near Enrekang. Red-yellow podzolic soil dominates the area with parent material of acid vulcan tuff and sandstone.

## 1.4 RESEARCH METHODS

### 1.4.1 Soil erosion

The effects of climate change on erosion were estimated using the Universal Soil Loss Equation, USLE (Sinukaban 1989), which takes the form:

$$A = RKLSCP$$

where : A = the predicted average annual soil loss in tons per hectare.

R = the rainfall and runoff factor is the number of rainfall erosion index units.

K = the soil erodibility factor is the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, which is defined as a 22 m length of uniform 9 percent slope continuously in clean-tilled fallow.

L = the slope length factor is the ratio of soil loss from the field slope length to that from a 22 m length under identical conditions.

S = slope steepness factor is the ratio of soil loss from the field slope gradient to that from a 9 percent slope under identical conditions.

C = the cover and management factor is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled-continuosly fallow.

P = the conservation practice factor is the ratio of soil loss using a conservation practice (i.e. contouring, strip cropping, or terracing) to that with straight-row up and down slope cultivation.

The data needed for the study were collected from the Departments of Agriculture and Forestry, the Agency for Meteorology and Geophysics, Bogor Agricultural University, and some from direct observations.

### 1.4.2 Water resources

The evaluation of the effects of climate change on water resources was based on estimated changes in the water balance of the study areas on a monthly basis using the method of Thornthwaite and Mather (1957).

The data required for these analyses were:

- Meteorological data, to calculate evapotranspiration as output of water from the study areas.
- Rainfall data, to estimate input of water to the study areas. Data from several stations were needed to estimate the area rainfall.
- Soil physical properties, to estimate maximum water holding capacity in the soil.
- Vegetation cover, to estimate the rooting depth from which soil water is extracted.

Soil water regime was calculated using parameters such as soil moisture storage and its changes, soil water deficit, and surplus. The water yield was estimated from the amount of river discharge compared with water surplus or the amount of possible surface runoff.

### 1.4.3 Coastal zone encroachment

It should be noted that only the impacts resulting from a static rise in sea level were considered in this study. Estimations of impact are based on a mean sea-level rise of 1 metre. No consideration was taken of impacts caused by tides, salt intrusion and impeded backwater flooding.

In the area of the lower Citarum River Basin there is a coastal belt of brackish water fish ponds, 2.5 to 4km wide, while the area behind this is primarily under wet rice fields, some dry field agriculture, and cultivated home gardens. The study considered the possible losses in the area and production of fish ponds and agricultural land, and the number of households (NHH) directly involved in aquaculture and agriculture which might be affected by these losses.

The practice in the area is to construct fish or prawn ponds 0.5m above the level of lowest tide. Therefore at normal tides the bottom of the ponds will be below the water level. This means that with a 0.6 metre sea-level rise, all the ponds will be inundated at normal tides, and in addition some of the paddies or dry field agriculture above this level may be flooded.

The data for this study were taken from the Agricultural Offices of the Districts of Krawang, Bekasi and Subang for the years 1988 - 1989.

### 1.4.4 Food production

The data on food production were collected from the Agricultural Research Station in Sukamandi for the years 1981-1986 and from the Agricultural Offices of the Districts of Krawang and Subang for the years 1981 - 1989.

#### Rice

Two models were used to study the impact of climate change on rice yield. One is an empirical-statistical model (Irawati, 1988) and the other a simulation model (de Vries *et al.*, 1988). Irawati used Thompson's model for soybean and corn in the U.S. Mid West (1969, 1970), adjusting it to the prevailing conditions of the northern coastal plain of West Java. This model was found to predict fairly well the yield of 20 planting seasons. Irawati's model was applied for ten years (Blantran de Rozari and Baharsjah, 1989), with 2 planting seasons per year, January - June and July-December, in three of the four districts in the downstream section of the Citarum River.

#### Soybean

Response of soybean (Glycine max (L)) yield to a changed climate was simulated with the SOYGRO V5.41 model developed by Jones *et al.* (1988). It is a process-oriented crop growth model and differs from earlier models in that it uses a modified phenology model and more genetic coefficients for a range of cultivars while maintaining flower, pod and seed formation through reproductive growth. The model was tested against field experiment data for three seasons from Mojosari using the variety Wilis. With the exception of one season, the difference between the simulated and actual yield was within an acceptable range. The model was then applied to the down-stream area of the Citarum River Basin. As is typical practice throughout most of the country, the soybean crop is not irrigated but is planted in paddy fields between rice crops. The soybean yield was simulated for two seasons per year, one beginning on 10th April and the other on the 1st October.

To reflect the increase in cloud cover with higher rainfall and a more humid atmosphere, additional model runs were made assuming a 25% decrease of solar radiation, both for rainfed and irrigated soybean crops.

Simulations were also run under the GISS "2 x $CO_2$" climate, taking advantage of the increased water supply of the basin. These runs assumed no stress conditions throughout the growing period.

Maize

The effect of a change in climate on maize yield was simulated by using the Crop-Environment Resource Synthesis Maize which was developed by the USDA Agricultural Research Service at Temple, Texas (Ritchie, 1986). The model was tested at 16 locations in the United States and in France. It consists of two versions, a Standard one and a Nitrogen Version, and is more simple than the Soygro Model with only two input files (a parameter file and a weather file). The Standard Version has three output files, while the Nitrogen Version has six. The model was applied to corn growth and development in the Sukamandi Research Station using the same soil and weather data as for the soybean yield analyses. The variety used was Abimayu which has a growing season of about 80-90 days.

## 1.5 IMPACTS ASSESSMENT

### 1.5.1 Impacts on soil erosion

The pressure for land has already pushed agriculture on to slopes which are very susceptible to erosion even under the normal precipitation pattern. With the present rainfall, the erosion rate in the upper part of the selected watersheds is already high. It ranges from 44 to 480 ton/ha/yr in the Citarum watershed, 200 to 439 ton/ha/yr in the Brantas watershed, and 300 to 600 ton/ha/yr in the Saddan watershed. With the climate change suggested by the GISS "2 x $CO_2$" experiment the erosion rate would increase by 14.5 percent in the Citarum watershed, 18 percent in the Brantas watershed, and 38-43 percent in the Saddan watershed (Table 1.3). These high erosion rates will severely deteriorate farm productivity. This is primarily because erosion washes out the most fertile top soil, decreases soil fertility, and deteriorates soil physical properties. The total reduction of agricultural productivity in the upland agricultural system resulting from the increased erosion rate will depend on the soil type, agricultural management and crop type.

In a study of soybean productivity based on the model of Shah (1982) and Sudirman *et.al.*, (1985) the rate of decline of soil productivity due to erosion was shown to range from 3.4 - 17.4 percent in the Citarum, 8.6 -16.4 percent in the Brantas, and 9.5 - 27.0 percent in the Saddan watershed. The reduction of soil productivity from climate change alone ranged from 2.0 - 3.8 percent in the Citarum, 2.3 - 3.9 percent in the Brantas, and 3.9 - 8.8 percent in the Saddan watershed. The national average for soybean production is about 1 metric ton/ha; climate change alone would decrease the soybean production by about 35 kg/ha/yr in the Citarum and Brantas and 65 kg/ha/yr in the Saddan watershed. The productivity of other food crops would decline by similar amounts as a result of climate change.

The total area of upland agriculture that would be affected in the study area by climate change is as follows: 57,800 ha in the Citarum, 72,200 ha in the Brantas, and 41,300 ha in the Saddan watershed. The predicted number of farmers that would be affected by the erosion problem is about 89,000 in the Citarum, 124,000 in the Brantas, and 114,000 in the Saddan watershed (Dept. Kehutanan, Dirjen RRL 1987). Increased erosion resulting from climate change will not only affect farm productivity, but will also increase sedimentation in streams and reservoirs. The total amount of sedimentation increase in reservoirs was not calculated in this study. As a result of increasing sedimentation in reservoirs, particularly in Saguling and Jatiluhur in the Citarum watershed, the life span of the dams will be shortened and serious damage to the power plant may result. Damage to the power plant would affect the electricity and irrigation water supply for most of West Java.

A decrease in upland agriculture productivity would have further socio-economic effects on the community. If the area of upland agriculture were planted to soybean, the total loss of soybean production due to climate change would be 2023 mt in the Citarum, 2527 mt in the Brantas and 2684 mt in the Saddan watershed. Assuming a price for soybeans of US $ 324.00/ton, the total loss would be US $ 655,450 in the Citarum, US $818,740 in the Brantas, and US $ 869,610 in the Saddan watershed. The total area of soybean harvested in Indonesia in 1989 was 1,254,000 ha. Assuming that the area of soybean remains the same, the total loss of production through erosion due to climate change alone is 43,890 mt; this would result in a loss of US $ 14,220,300 every year.

Reduced productivity of upland agriculture and increased pressure on land could result in the exploitation of the remaining forest area for household fuel and basic family requirements. Farmers' incomes would decline and this in turn would affect the regional economic condition. The decline in power and irrigation water supply could adversely affect both industrial activity and rice

**Table 1.3 The impact of climate change on rainfall erosivity and erosion in the selected watersheds**

| Watersheds | Rainfall erosivity(R) | | Predicted erosion/yr | | | |
|---|---|---|---|---|---|---|
| | With normal rainfall data | With climate change | With normal rainfall data | | With climate change | |
| | | | (ton/ha) | (mm) | (ton/ha) | (mm) |
| I. Citarum Watershed | | | | | | |
| Sub-Watershed Cisokan | | | | | | |
| 1. Ciherang | 2000 | 2290 | 44.2 | 4.4 | 50.6 | 5.1 |
| 2. Ciputri | 2000 | 2290 | 124.8 | 10.4 | 142.9 | 11.9 |
| 3. Galudra | 2000 | 2290 | 214.7 | 17.9 | 245.8 | 20.5 |
| 4. Cibeureum | 1900 | 2176 | 483.5 | 40.3 | 553.6 | 46.1 |
| 5. Sukamulya | 2000 | 2290 | 214.7 | 17.9 | 245.8 | 20.5 |
| 6. Cijedil | 1900 | 2176 | 483.5 | 40.3 | 553.6 | 46.1 |
| 7. Wangunjaya | 1900 | 21 | 161.2 | 13.5 | 184.6 | 15.8 |
| 8. Sukaratu | 2000 | 90 | 229.1 | 19.1 | 262.2 | 21.8 |
| 9. Cisarandi | 1900 | 2176 | 62.4 | 6.2 | 71.4 | 7.1 |
| 10.Cibeber | 1900 | 2176 | 483.5 | 40.3 | 553.6 | 46.1 |
| 11.Sukajaya | 1700 | 1945 | 423.0 | 35.2 | 494.2 | 41.2 |
| Sub Watershed Citarik | | | | | | |
| 1. Tanjungsari | 1900 | 2176 | 44.6 | 4.5 | 51.1 | 5.1 |
| 2. Cileunca | 1500 | 1716 | 123.3 | 10.3 | 141.1 | 11.8 |
| 3. Anjarsari | 1970 | 2256 | 331.2 | 27.6 | 479.3 | 31.6 |
| 4. Cicaleunka | 1300 | 1487 | 201.9 | 16.8 | 230.8 | 19.2 |
| Sub Watershed Cikapundung | | | | | | |
| 1. Pakardago | 1375 | 1573 | 114.3 | 9.5 | 130.6 | 10.9 |
| 2. Cimahi | 1375 | 1573 | 190.9 | 15.9 | 218.2 | 18.2 |
| II. Brantas Watershed | | | | | | |
| Sub Watershed Kwayangan | *) | | *) | | | |
| 1. | 1268 | 1509 | 200 | 16.7 | 238 | 19.8 |
| Sub Watershed Konto | | | | | | |
| 1. | 1548 | 1823 | 293 | 24.4 | 316 | 26.3 |
| 2. | 1548 | 1823 | 439 | 36.6 | 517 | 43.1 |
| 3. | 1548 | 1823 | 268 | 22.3 | 316 | 26.3 |
| III. Saddan Watershed | **) | | **) | | | |
| Sub Watershed Mamasa | | | | | | |
| 2. II | 1687 | 2445 | 661 | 55.1 | 920 | 76.6 |
| 2. IX | 1550 | 2170 | 192 | 16.0 | 270 | 22.5 |
| 26. I | 1875 | 2606 | 302 | 25.2 | 420 | 35.0 |

*) Based on rainfall data 1970-1979.

**) Based on rainfall data 1974-1986.

production in the lowland areas of West Java (Bekasi and Karawang), with implications for the national economy.

### 1.5.2 Impacts on water resources

#### 1.5.2.1 Upper Citarum River Basin

Calculations of water balance of the Upper Citarum River Basin were based on rainfall data collected from 8 stations in the area. Data from these stations were averaged arithmetically to calculate the rainfall. In order to estimate monthly potential evapotranspiration, temperature data from Bandung (Husein Sastranegara Airport) was used. Based on the predominant soil texture, which is clay loam, the maximum Water Holding Capacity (WHC) was estimated to be 250 mm. As the predominant vegetation is shallow-rooted annual crops (25 - 40 cm) it was assumed that the root depth would be about 30 cm. Hence, the effective WHC is 75 mm. Changes in soil moisture due to fluctuations in input and output of water are shown in Table 1.4. Calculation of water deficit (D) and surplus (S) was carried out using the following equations :

$D = PE - AE$ and $S = (P - PE) - ST$
where PE is potential evapotranspiration, AE is actual evapotranspiration, P is precipitation, and ST is change in soil moisture storage.

The streamflow or river discharge was measured at Nanjung before entering the reservoir. It was found that the fluctuation of streamflow matched the soil moisture surplus. The water balance was then simulated using changes of rainfall and air temperature assumed under the GISS "2 x $CO_2$" climate (Table 1.5). Results of the simulation using single and simultaneous impacts of soil moisture deficit and surplus are derived from Table 1.4 and shown in Table 1.6.

It is shown that the increase of rainfall would result in a higher water surplus and a shortened period of water deficit (from 4 months to 3 months). A temperature increase, which causes higher rates of evapotranspiration, would result in a reduction in total water surplus. However, the combined impact of increased rainfall and temperature demonstrates an increase of 132 percent in annual soil water surplus and a reduction of 62 percent in annual soil water deficit.

### 1.5.2.2 Upper Brantas River Basin

Sixteen rainfall stations were used to estimate the rainfall covering an area of 205,000 ha. The monthly temperature data was taken from Brawijaya University meteorological station in Malang. Since the predominant soil is more sandy than in the previous study area, with a small portion of loam, the maximum WHC is considered to be 150 mm. A more permanent vegetation cover (forest and plantation) is found in the upper Brantas Basin and is assumed to have a root depth of about 70 cm. Therefore, the effective WHC is 105 mm. Rainfall and air temperature data were taken from Maduin (Iswahyudi Airport) to simulate the monthly water balance (Table 1.7).

The simulated changes in soil moisture deficit and surplus under the GISS "2 x $CO_2$" climate assuming changes either in rainfall or temperature, and for both rainfall and temperature are shown in Table 1.8.

The results were similar to those for the Upper Citarum Basin, i.e. that the increase in rainfall affects soil moisture more significantly than the temperature increase in terms of both duration and total water deficit or surplus. Moreover, for sandy soils such as those found in the Upper Brantas River Basin, there is a greater likelihood of a longer period of water deficit, although the total annual rainfall does not differ substantially from the Upper Citarum total rainfall. Distribution of vegetation types (root depth) might also have caused the difference in soil moisture regimes.

### 1.5.2.3 Upper Saddan River Basin

The water balance calculation for the Upper Saddan River Basin used rainfall data taken from 10 stations and temperature data taken from Ujung Pandang (Mandai Airport) (Table 1.9). Although clay loam soil is dominant in the area as in the Upper Citarum River Basin, the vegetation cover is primarily trees and plantation crops with deeper root zones (75 cm). Therefore, the maximum WHC of 250 mm is effectively as much as 158 mm. The effects of rainfall and air temperature changes on soil water deficit and surplus under the GISS "2 x $CO_2$" climate are shown in Table 1.10. Under current climate the area experiences almost no deficit, and the impact of a temperature increase on soil water deficit would be minimal despite increased evapotranspiration. Changes in water surplus in all cases are relatively small, although the total rainfall is almost the same as in the Upper Citarum River Basin. This indicates that the vegetation upstream is functioning well. The exploitation of Benteng Reservoir is therefore very much dependent on the upstream management of the watershed. For this basin particularly the simultaneous impact of increased rainfall and temperature on soil water surplus could be 230 percent.

Table 1.4 Monthly water balance of Upper Citarum River Basin

| Parameters | Unit | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainfall | mm | 278 | 226 | 281 | 248 | 150 | 79 | 69 | 66 | 96 | 171 | 265 | 288 | 2217 |
| Air Temperature | °C | 24.6 | 24.7 | 25.0 | 25.0 | 25.0 | 24.1 | 23.6 | 23.8 | 25.1 | 25.0 | 25.1 | 24.7 | 24.6 |
| Heat Index |  | 11.16 | 11.23 | 11.44 | 11.44 | 11.44 | 10.82 | 10.48 | 10.61 | 11.50 | 11.44 | 11.50 | 11.23 | 134.28 |
| Potential Evapotranspiration | mm | 107 | 109 | 113 | 113 | 113 | 101 | 94 | 97 | 114 | 113 | 114 | 109 | 1296 |
| Sun's Declination | rad | -0.37 | -0.24 | -0.04 | 0.16 | 0.32 | 0.40 | 0.37 | 0.25 | 0.06 | -0.14 | -0.32 | -0.40 |  |
| Day length | hr | 12.37 | 12.23 | 12.04 | 11.84 | 11.68 | 11.59 | 11.63 | 11.76 | 11.94 | 12.14 | 12.31 | 12.46 | 11.99 |
| Correction factor |  | 1.031 | 1.019 | 1.003 | 0.987 | 0.973 | 0.966 | 0.969 | 0.980 | 0.995 | 1.011 | 1.026 | 1.034 | 1.000 |
| Adjusted Evapotranspiration | mm | 111 | 111 | 113 | 111 | 110 | 96 | 91 | 95 | 114 | 114 | 117 | 112 | 1296 |
| Rainfall Adjusted Evapotranspiration | mm | 167 | 115 | 168 | 137 | 40 | -18 | -22 | -29 | -18 | 57 | 148 | 176 | 921 |
| Accumulated Potential Water Loss | mm | - | - | - | - | - | -18 | -22 | -29 | -18 | 57 | 148 | 176 | 921 |
| Soil Moisture | mm | 75 | 75 | 75 | 75 | 75 | 58 | 43 | 29 | 22 | 75 | 75 | 75 |  |
| Change in Soil Moisture | mm | 0 | 0 | 0 | 0 | 0 | 0 | -17 | -16 | -14 | -6 | 53 | 0 |  |
| Actual Evapotranspiration | mm | 111 | 111 | 113 | 111 | 110 | 96 | 85 | 80 | 102 | 114 | 117 | 112 | 1262 |
| Deficit | mm | 0 | 0 | 0 | 0 | 0 | 1 | 7 | 15 | 11 | 0 | 0 | 0 | 34 |
| Surplus | mm | 167 | 115 | 168 | 137 | 40 | 0 | 0 | 0 | 0 | 4 | 148 | 176 | 955 |
| Streamflow | mm | 3595 | 3733 | 4190 | 3834 | 2671 | 1403 | 998 | 668 | 481 | 740 | 1611 | 2880 | 26805 |

Maximum Water Holding Capacity = 250.0 mm/m
Effective Water Holding Capacity = 75.0 mm/m
Effective Root's Zone = 30.0 cm

Accumulated Heat Index (I) = 134.3
A factor (as function of I) = 3.143
Latitude = -7.13 degrees = -0.12 radians

**Table 1.5** Ratios of rainfall (P) and air temperature (T) of the GISS "2 x $CO_2$" climate to current climate (1950-70) in Bandung

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | 1.15 | 1.11 | 1.26 | 1.11 | 1.07 | 1.08 | 1.11 | 1.13 | 1.08 | 1.33 | 1.22 | 1.11 |
| T | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 |

**Table 1.6** Impact of increasing rainfall and/or temperature on soil water deficit (D) and surplus (S) (mm) in Upper Citarum River Basin

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Current Climate | | | | | | | | | | | | | |
| D | 0 | 0 | 0 | 0 | 0 | 1 | 7 | 15 | 11 | 0 | 0 | 0 | 34 |
| S | 167 | 115 | 168 | 137 | 40 | 0 | 0 | 0 | 0 | 4 | 148 | 176 | 955 |
| GISS "2 X $CO_2$" - (Rainfall) | | | | | | | | | | | | | |
| D | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 5 | 0 | 0 | 0 | 16 |
| S | 209 | 140 | 241 | 164 | 54 | 0 | 3 | 0 | 0 | 72 | 206 | 207 | 1290 |
| GISS "2 X $CO_2$" - (Temperature) | | | | | | | | | | | | | |
| D | 0 | 0 | 0 | 0 | 0 | 2 | 8 | 17 | 14 | 0 | 0 | 0 | 41 |
| S | 165 | 112 | 165 | 134 | 37 | 0 | 0 | 0 | 0 | 0 | 143 | 173 | 928 |
| GISS "2 X $CO_2$" - (Temperature and Rainfall) | | | | | | | | | | | | | |
| D | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 9 | 7 | 0 | 0 | 0 | 21 |
| S | 206 | 137 | 238 | 161 | 48 | 0 | 0 | 0 | 0 | 65 | 203 | 204 | 1262 |

**Table 1.7** **Ratios of rainfall (P) and air temperature (T) of the GISS "2 x $CO_2$" climate to current climate (1950-70) in Madiun**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | 1.14 | 1.14 | 1.38 | 1.13 | 1.05 | 1.12 | 1.19 | 1.21 | 1.08 | 1.50 | 1.26 | 1.13 |
| T | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 |

**Table 1.8** **Impacts of increasing rainfall and/or temperature on soil water deficit (D) and surplus (S) (mm) in Upper Brantas River Basin**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Current climate | | | | | | | | | | | | | |
| D | 0 | 0 | 0 | 0 | 0 | 6 | 21 | 62 | 82 | 22 | 0 | 0 | 193 |
| S | 190 | 154 | 168 | 50 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 152 | 735 |
| GISS "2 X $CO_2$" - (Rainfall) | | | | | | | | | | | | | |
| D | 0 | 0 | 0 | 0 | 0 | 4 | 13 | 52 | 77 | 0 | 0 | 0 | 145 |
| S | 237 | 195 | 283 | 74 | 28 | 0 | 0 | 0 | 0 | 0 | 39 | 183 | 1038 |
| GISS "2 X $CO_2$" - (Temperature) | | | | | | | | | | | | | |
| D | 0 | 0 | 0 | 0 | 0 | 7 | 24 | 66 | 87 | 27 | 0 | 0 | 211 |
| S | 185 | 150 | 163 | 45 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 140 | 701 |
| GISS "2 X $CO_2$" - (Temperature and Rainfall) | | | | | | | | | | | | | |
| D | 0 | 0 | 0 | 0 | 0 | 5 | 16 | 56 | 82 | 0 | 0 | 0 | 158 |
| S | 232 | 190 | 278 | 69 | 24 | 0 | 0 | 0 | 0 | 0 | 27 | 178 | 998 |

**Table 1.9** Ratios of rainfall (P) and air temperature (T) of the GISS "2 X $CO_2$" climate to current climate (1950-70) at Ujung Pandang

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | 1.13 | 1.20 | 1.51 | 1.59 | 1.46 | 1.27 | 1.28 | 1.18 | 1.08 | 1.56 | 1.50 | 1.32 |
| T | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 |

**Table 1.10** Impact of increasing rainfall and/or temperature on soil water deficit (D) and surplus (S) (mm) in Upper Saddan River Basin

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Current Climate | | | | | | | | | | | | | |
| D | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| S | 53 | 75 | 118 | 169 | 54 | 62 | 14 | 0 | 0 | 8 | 23 | 123 | 698 |
| GISS "2 X $CO_2$" - (Rainfall) | | | | | | | | | | | | | |
| D | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S | 80 | 119 | 340 | 363 | 151 | 116 | 54 | 0 | 25 | 120 | 117 | 208 | 1649 |
| GISS "2 X $CO_2$" - (Temperature) | | | | | | | | | | | | | |
| D | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 |
| S | 47 | 69 | 112 | 163 | 48 | 57 | 10 | 0 | 0 | 0 | 0 | 0 | 512 |
| GISS "2 X $CO_2$" - (Temperature and Rainfall) | | | | | | | | | | | | | |
| D | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S | 74 | 113 | 334 | 357 | 144 | 111 | 50 | 0 | 15 | 113 | 110 | 203 | 1624 |

### 1.5.3 Impacts on the coastal agricultural lands

#### 1.5.3.1 The Bekasi District

The Bekasi District has three coastal sub-districts: Tarumajaya, Muaragembong and Babelan.
Table 1.11 shows that with a sea-level rise of 1m, 7,227 ha of brackish water ponds will be inundated.

**Table 1.11 Potential inundation due to 1m sea-level rise: Area and production of coastal fish ponds, and the number of households (NHH) of fish farmers involved in aquaculture of coastal fish ponds in the Bekasi District. (1985 data)**

| Sub-district | Area (ha) | Production (ton) | NHH |
|---|---|---|---|
| Tarumajaya | 475 | 160 | 78 |
| Muaragembong | 6,610 | 3,837 | 1,387 |
| Babelan | 342 | 199 | 61 |
| Total | 7,227 | 4,197 | 1,526 |

This means a loss of production of 4,197 tons of fish and shrimp, which could result in the loss of livelihood for 1,526 households which depend on fish and shrimp culture. With an average household size of five persons, this would affect about 7,630 people. The agricultural land of the three coastal sub-districts of Bekasi District consists of 9,980 ha wet rice fields, 400 ha dry fields, and 1,735 ha cultivated home gardens (based on 1985 figures). There are 1,736 households which depend on agriculture. A 1m rise in sea level would result in the inundation of agricultural land held by these households and thus lead to the loss of their livelihood (Table 1.12). Assuming an average household size of five persons, about 8,680 people would be affected. The annual loss of production due to inundation is estimated to be 62,275 tons of rice, 210 tons of corn, 1,280 tons of cassava, 525 tons of sweet potatoes, 125 tons of soy bean, and 25 tons of mung bean (Table 1.13).

**Table 1.12 Potential inundation due to 1m sea-level rise: Area of agricultural fields and number of households (NHH) directly involved in agriculture in the coastal sub-districts of the Bekasi District**

| Sub district | Wet rice field (ha) | Dry field (ha) | Home garden (ha) | NHH |
|---|---|---|---|---|
| Tarumajaya | 4,040 | 80 | 330 | 573 |
| Muarangembong | 1,625 | 300 | 935 | 935 |
| Babelan | 4,315 | 20 | 470 | 1,194 |
| Total | 9,980 | 400 | 1,735 | 1,736 |

**Table 1.13 Potential inundation due to 1m sea-level rise: Agricultural production in the coastal sub-districts of the Bekasi District**

| Coastal sub-district | Rice (ton) | Corn (ton) | Cassava (ton) | Sweet potatoes (ton) | Soy bean (ton) | Mung bean (ton) |
|---|---|---|---|---|---|---|
| Tarumajaya | 23,100 | 10 | 50 | – | 20 | - |
| Muaragembong | 3,290 | 90 | 260 | 290 | – | 10 |
| Babelan | 35,885 | 110 | 970 | 235 | 105 | 15 |
| Total | 62,275 | 210 | 1,280 | 525 | 125 | 25 |

### 1.5.3.2 Krawang District

There are four coastal sub-districts in the Krawang District: Batujaya, Pedes, Tempuran, and Cilamaya. Refering to conditions in 1985, a one meter rise in sea level would inundate a total of 10,939 ha of brackish water ponds, with an annual production of 7,327 tons of fish and shrimp. This loss of fish ponds due to inundation would mean a loss of livelihood for 1,957 households (or approximately 9,785 people) which directly depend on aquaculture (Table 1.14).

The number of households directly dependent on agriculture as a source of income is shown in Table 1.15 Inundation would lead to a loss of 43,265 ha of wet rice fields, 1,645 of dry fields, and 6,380 ha of cultivated home gardens. The number of households losing their livelihood would be 76,771 or about 383,855 people. The annual loss of production due to inundation of the agricultural land of the four coastal sub-districts would amount to 531,480 tons of rice, 113 tons of corn, 1526 tons of cassava, 145 tons of sweet potatoes, and 54 tons of mung beans (Table 1.16 - based on 1985 production figures).

**Table 1.14 Potential area and production of coastal fish ponds, and the number of households (NHH) of fish farmers involved in aquaculture in the coastal sub-districts of the Krawang District**

| Coastal sub-district | Area (ha) | Production (ton) | NHH |
|---|---|---|---|
| Batujaya | 5,143 | 3,791 | 683 |
| Pedes | 4,346 | 3,362 | 682 |
| Tempuran | 666 | 68 | 129 |
| Cilamaya | 784 | 116 | 463 |
| Total | 10,939 | 7,327 | 1,957 |

### 1.5.3.3 Subang District

In the three coastal sub-districts of the Subang District (Pamanukan, Pusakanagara, and Ciemas) inundation due to a rise in sea level (based on 1986 figures) would lead to a loss of 7,393 ha of coastal fish ponds with an annual production of 4,354 ton of fish and shrimp. In turn this means a loss of livelihood for 14,658 households directly involved in aquaculture in coastal fish ponds (Table 1.17).

**Table 1.15 Potential area of agricultural fields and number of households (NHH) directly involved in agriculture in the coastal sub-districts of the Krawang District**

| Coastal Sub-district | Wet rice field (ha) | Dry field (ha) | Home garden (ha) | NHH |
|---|---|---|---|---|
| Batujaya | 12,990 | 1,110 | 2,210 | 24,512 |
| Pedes | 12,080 | 120 | 1,275 | 17,780 |
| Tempuran | 8,420 | 380 | 1,450 | 11,992 |
| Cilamaya | 9,770 | 35 | 1,450 | 22,487 |
| Total | 43,265 | 1,645 | 6,380 | 76,771 |

**Table 1.16** **Potential agricultural production (tons) in the coastal sub-districts of Krawang District**

| Coastal sub-district | Rice (ton) | Sweet Corn (ton) | Potato (ton) | Cassava (ton) | Mung bean (ton) |
|---|---|---|---|---|---|
| Batujaya | 143,990 | 68 | 145 | 111 | 54 |
| Pedes | 152,980 | 18 | - | 602 | - |
| Tempuran | 111,150 | - | - | 707 | - |
| Cilamaya | 123,360 | 27 | - | 97 | - |
| Total | 531,480 | 113 | 145 | 1,526 | 54 |

**Table 1.17** **Potential area and production of coastal fish ponds, and the number of households (NHH) of fish farmers involved in aquaculture of coastal fish ponds in the coastal sub-districts of the Subang District**

| Coastal sub-district | Area (ha) | Production (ton) | NHH |
|---|---|---|---|
| Pamanukan | 3,735 | 2,619 | 7,705 |
| Pusakanagara | 805 | 263 | 1,594 |
| Ciasem | 2,853 | 1,472 | 5,359 |
| Total | 7,393 | 4,354 | 14,658 |

In the case of agriculture, the result of inundation would be a loss of 29,395 ha of wet rice fields, 145 ha of dry fields, and 6,080 ha of home gardens. The number of households affected would be 66,741 or approximately 333,705 people (Table 1.18). The loss of agricultural production due to inundation amounts to 347,905 tons of rice, 1,220 tons of corn, 4,745 tons of cassava, 2,795 tons of sweet potatoes, 590 tons of soybean, and 120 tons of mung beans (Table 1.19).

#### 1.5.3.4 Coincidency of high tide and flood

Indonesia was recently provided with an opportunity to observe the scale of possible inundation due to a 1m sea-level rise. Late in November 1988, sea levels in most parts of the country began to rise. In early December newspapers reported a peak rise of 1.95m in the Tanjung Priok Harbour of Jakarta. Throughout the northern part of Central and West Java, the peak was estimated to be about 1m. On the 9th December, an incessant rain began which continued in some areas until the 19th of December. Flooding was extensive and far inland. Krawang, which lies about 20 km from the coast, was flooded to a depth of 0.75 m.Thousands of hectares of crops were damaged and had to be replanted. Millions of fish and prawns disappeared from their ponds and had to be replaced. Capital loss due to this single incident was in billions of rupiahs (1985 rupiah = US $1.00).

The estimated 1m rise in sea level under a "2 x $CO_2$" climate would not cause such large scale flooding as in December 1988. It would probably cover only 40 percent of the area inundated at that time. But with a rise in sea level, extreme incidents of a similar kind would be more frequent as a 40 cm rise is sufficient to hold back the flood flow out to sea. The increase in surplus water in the Citarum and Brantas River Basins (30%) and the Saddan River Basin (130%) would add greatly to this occurrence.

### 1.5.4 Impact on food crops production

A rise in temperature due to increased atmospheric $CO_2$ will affect the physiological processes of most crops. The increase in temperature projected for Indonesia under a "2 x $CO_2$" climate will affect the efficiency of solar radiation utilization in photosynthesis. $C_3$ crops, such as rice and soybean, are believed to be more susceptible to increased photorespiration under higher ambient levels of atmospheric $CO_2$ than are $C_4$ crops such as maize (de Wit, *et.al.*, 1978).

This study considered three of the crops which are important in the Indonesian diet: rice, which is the staple food for most Indonesians; soybean, which is an important source of protein; and corn, a staple food for about 10 percent of the population.

**Table 1.18** **Potential area of agricultural fields and number of households (NHH) directly involved in agriculture in the coastal sub-districts of the Subang District**

| Coastal sub-district | Wet rice field (ha) | Dry field (ha) | Home garden (ha) | NHH |
|---|---|---|---|---|
| Pamanukan | 9,540 | 25 | 1,655 | 21,358 |
| Pusakanegara | 11,740 | 70 | 2,220 | 26,696 |
| Ciasem | 8,115 | 50 | 2,205 | 18,687 |
| Total | 29,395 | 145 | 6,080 | 66,741 |

**Table 1.19** **Potential agricultural production in the coastal sub-districts of the Subang District**

| Coastal sub-district | Rice (ton) | Corn (ton) | Cassava (ton) | Sweet Potato (ton) | Soy bean (ton) | Mung bean (ton) |
|---|---|---|---|---|---|---|
| Pamanukan | 87,230 | 290 | 945 | 135 | 20 | 20 |
| Pusakanegara | 126,465 | 570 | 2,075 | 1,130 | 560 | 90 |
| Ciasem | 134,210 | 360 | 1,725 | 1,530 | 10 | 10 |
| Total | 347,905 | 1,220 | 4,745 | 2,795 | 590 | 120 |

Simulation models were used to determine the yield of rice (Oryza sativa L.), soybean (Glycine max L.) and maize (Zea mays L.) under the GISS "2 x $CO_2$" climate. Models for all three crops were tested in the Sukamandi Agricultural Research Station and all simulations were run using the weather and soil data from the Sukamandi Agricultural Research Station.

### 1.5.4.1 Rice

Figures 1.4 and 1.5 indicate yield responses under the GISS "2 x $CO_2$" climate based on experiments with the empirical-statistical yield model (Irawati, 1988). Yields for the January-June season decreased by about 2.5 percent on average. The largest decrease of about 13.5 percent occurred in 1980 when sunshine duration increased fairly sharply in the second part of the season. Yield increases of up to 4.4 percent occurred several times in each of the districts (Fig. 1.4). The July-December planting results showed average increases of about 5.4 percent (Fig 1.5). The highest increase was obtained in 1982 in the District of Subang, when rice yield under the GISS "2 x $CO_2$" climate exceeded that under the present climate by 12.9 percent. In the District of Krawang and Bekasi the difference was over 18 percent. It should be pointed out that 1982 was an ENSO year and was one of Indonesia's driest.

The validity of these results were questioned because it was thought that yields of $C_3$ species, such as rice, would decrease under higher temperatures. Rice yields were therefore simulated a second time using the PUDOC-IRRI model LID (de Vries *et al.* 1988). Assuming optimum farming practices, a simulation was run for a February, June and September planting. Weather data for the year 1983 were used, with temperatures under the GISS "2 x $CO_2$" climate multiplied by a factor of 1.013, 1.012 and 1.013 for the February, June and September plantings respectively.

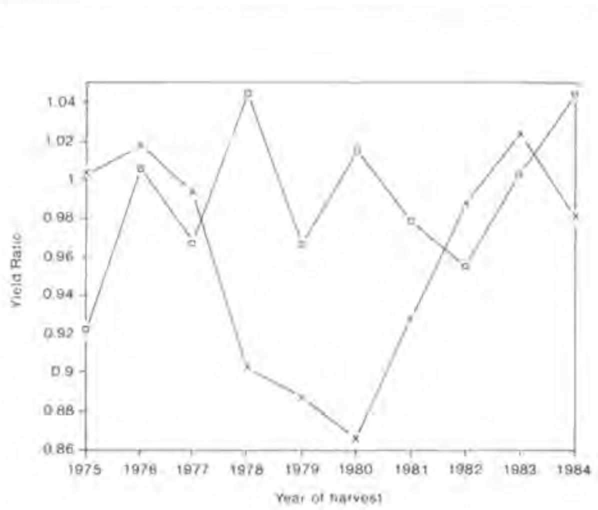


**Figure 1.4 Ratio of rice yield under the GISS "2 x $CO_2$" scenario to rice yield under current climate (1950-70) for the January-June planting.**

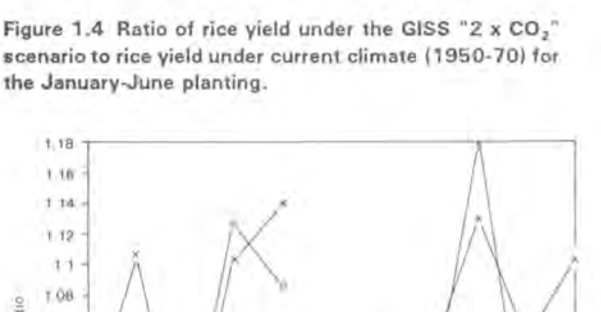


**Figure 1.5 Ratio of rice yield under the GISS "2 x $CO_2$" scenario to rice yield under current climate (1950-70) for the July-December planting.**

Table 1.20 shows the productivity of rice under the current and the GISS "2 x $CO_2$" climate. The table shows clearly that the yield differences are more pronounced between the planting seasons than between the climates. In terms of grain yield, changes occur during the September planting, when the maximum rate of photosynthesis falls from 32.2 kg $CO_2$/ha/hour under the current climate to 28.0 kg under the GISS "2 x $CO_2$" climate. Maintenance respiration for the same season shows a smaller decrease of 4.4 percent. The grain yield, however, increases by about 2.3 percent.

The simulation results confirm the results of the empirical model discussed above. Higher temperatures under the enhanced Greenhouse Effect climate do not always result in a decrease in rice yield as hypothesized. Thus the results of the empirical model, which covers a period of 20 planting seasons, can be accepted. A study of the impact of climate change on rice production in Japan leads to the same conclusion (Yoshino *et al.*, 1988).

Therefore we may expect rice yield to decrease by 10 percent or more in at least six out of ten January-June plantings. For the July-December planting, rice yields increase more often than decrease; decreases were only 3.5 percent.

In terms of food supply for the farmers, a decrease of about 10 percent does not create a problem. Although the average rice yield is below that obtained in experimental plots, production from an area of about 0.4 hectares is sufficient for the food requirements of the average farmer. However, in terms of annual income, the lower yields would mean a loss of income of about 3% in four out of ten years in the Districts of Krawang and Bekasi. With about 0.4 hectares per farm under rice production and a yield of 3.5 tons per hectare, this would mean an annual loss of 3.0 percent of the farmer's yearly income from the rice crop of US $325.00.

In the Krawang District, for example a farmer with an acreage of 0.4 hectares will lose about US $ 17.00 from the January-June planting. However, he will gain an extra US $ 6.50 from the July - December planting. Therefore, the farmer's loss of income would be about $ 10.50 yearly. For farmers with 0.7 hectares of land, the annual loss would be over US $ 17.30. At the district level, the January - June planting would incur a total loss over 1.2 million tons of rice. From the July - December planting the district would gain over 0.4 million tons. Therefore, in a normal year the rice stock for the district would be 0.8 million tons less than at present.

### 1.5.4.2 Soybean

The ratios of change for temperature and rainfall between the current and GISS "2 x $CO_2$" climate in the Citarum River Basin are 0.012 and 0.1944 respectively. In the second planting season they are 0.013 and 0.364 each.

The higher temperatures under a GISS "2 x $CO_2$" climate would almost certainly harm most crops,

**Table 1.20 Effect of climate change on the production of grain and rice straw in three planting seasons of 1983 (as simulated by the model of de Vries *et al.*,1988)**

| Crop Parameter | "1 x $CO_2$ climate" | | | "2 x $CO_2$ climate" | | |
|---|---|---|---|---|---|---|
| | Feb | Jun | Sep | Feb | Jun | Sep |
| Grain yield (kg/ha) | 9485 | 8844 | 9168 | 9492 | 8800 | 9378 |
| Straw production (kg/ha) | 5639 | 6194 | 6442 | 5569 | 6133 | 6408 |
| (kg $CO_2$/ha/hr) | 41.2 | 34.5 | 32.2 | 41.1 | 39.5 | 28.0 |
| PLEA (kg $CO_2$/ha/hr/ W $m^{-2}$) | 0.45 | 0.45 | 0.47 | 0.45 | 0.46 | 0.48 |
| TPEM (-) | 0.845 | 0.742 | 0.707 | 0.843 | 0.794 | 0.676 |

especially through the processes which are thermally regulated. This applies to species which have their origin in cooler climatic regions but would affect native species as well. Soybean (Glycine max) is one of those species which originated in the mid-latitudes, but has adapted to the tropical climate.

Under the GISS "2 x $CO_2$" climate, it is estimated that the soybean yield would decrease on average by 2.3 percent. This figure is misleading, as in seven out of the twelve seasons simulated, the yield decreases by over 10 percent (Figure 1.6), but when averaged against the very high increase during the first season of 1984 this much lower figure was reached. The 1984 season was marked by low maximum and minimum temperature, which were usually above 31° and 22° Centigrade.

The decreased average yield under the GISS "2 x $CO_2$" climate was largely due to less generative growth which is reflected in the number of seed produced per unit area. There was also a decrease of biomass production. On the other hand seed weight, and therefore seed growth, increased by nearly two percent. This indicates that the translocation of the photosynthetic products may be somewhat better under the GISS "2 x $CO_2$" climate.

When insolation was reduced, soybean yield was more seriously affected. An exception was the second planting of 1981 when the yield increased by a surprising 21 percent, compared to that under the current climate (Figure 1.7).

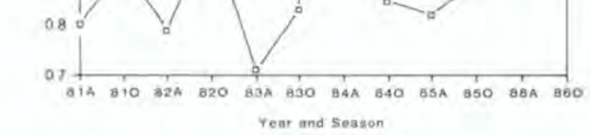


**Figure 1.6** **Ratio of soybean yield under the GISS "2 x $CO_2$" scenario to soybean yield under current climate (1950-70) April planting (A). October planting (O).**

Figure 1.7 shows that for four consecutive seasons, October 1981 to April 1983, soybean yield was equal to or better than the yield under the changed climate with no reduction in radiation. This might indicate that during these four seasons, and again during the April 1985 planting, solar radiation was beyond the optimum amount, while in the other seasons it was less so.

The most prominent cause for the decrease in yield under the GISS "2 x $CO_2$" climate with reduced solar radiation is the slow formation of pods. This agrees with the findings of Baharsjah (1980).

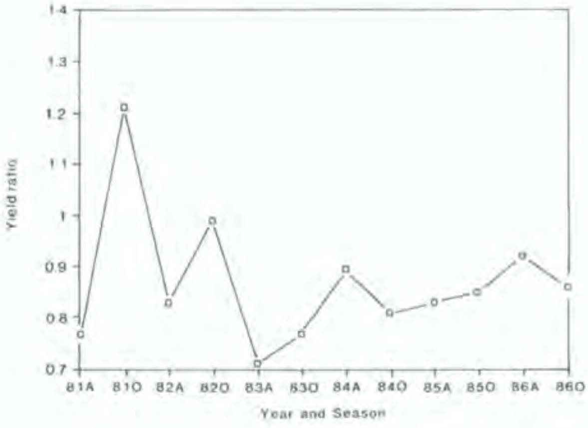


**Figure 1.7 Ratio of soybean yield under the GISS " 2 x $CO_2$" scenario with reduced radiation to soybean yield under current climate (1950-70). April planting (A), October planting (O).**

The average soybean yield in the area is 600 - 700 kg per hectare. A yield loss of between 60 - 70 kg seed in one season, would be significant for a farm of less than one hectare in size. About 50 percent of farmers in the District of Subang operate farms under 0.5 hectares, and about 80 percent under one hectare. These farms will lose a big part of their income. The farmers with under 0.5 ha of land would lose between US \$ 22.00 to \$ 41.00 of their income. With an average size of 0.7 hectares, an income decrease of \$ 39.00 to \$ 72.00 would result.

According to 1986 figures, there are 2250 hectares planted to soybean in the Subang District. The decrease in the soybean yield would mean a cut in the soybean stock of the district by an average of over 380 tons. In certain years, however, the soybean stock might be reduced by more than 700 tons.

During one of the SOYGRO model runs it was found that the soybean crop often got seriously stressed, particularly during the first seven planting seasons. Therefore a further simulation under irrigation (i.e. with no moisture stress) was carried out for each season. The results of these calculations (Figure 1.8) indicated that even under the GISS "2 x $CO_2$" climate soybean yields exceeded that under the current climate. Soybean production is mainly rainfed in most of the country.

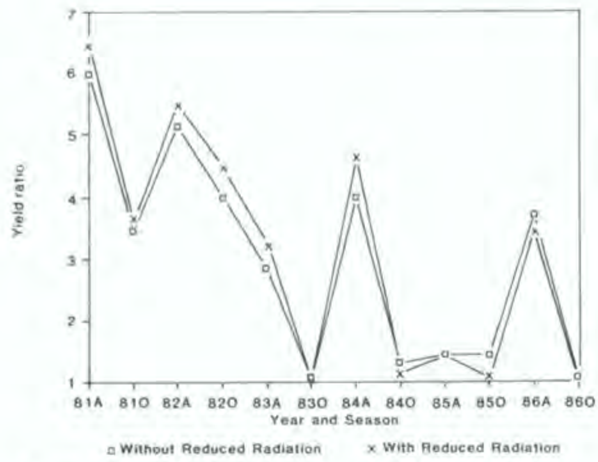


**Figure 1.8 Ratio of soybean yield under the GISS "2 x $CO_2$" scenario with no water stress (with and without reduced radiation) to soybean yield under current climate. April planting (A), October planting (O).**

The use of irrigation meant that yields were comparable whether under reduced incident radiation or under no reduction of solar radiation. Even with reduced light, yields of the well-irrigated crops showed an increase (Figure 1.8). The option to irrigate should be considered seriously. This would require only an input of technology and a small capital investment and would quite easily be brought into effect since farmers throughout Indonesia are already organized into groups.

### 1.5.4.3 Corn

Corn (*Zea mays L.*) was planted only in April each year between 1980 and 1986. The crop was fertilized with 150 kg of urea on the day of sowing. Thirty days later the treatment was repeated using the same fertilizer which contained 22.5 kg of nitrogen.

Figure 1.9 shows the ratio of the grain produced under the GISS "2 x $CO_2$" climate to that under current climate. Under the "2 x $CO_2$" climate, the corn crop suffers greater yield reductions than does the soybean. Decreased biomass production was very often the cause. In the first two years low grain filling occurred, while in the last two years the formation of grain was not satisfactory.

The total corn production from the 5357 ha under maize in the districts of Bekasi, Krawang and Subang is about 1543 metric tons. With an average yield decrease of 40 percent, the area would lose about 617 tons yearly. This constitutes an income loss of US \$ 66,500 for the district. For the average farmer with 0.4 hectares of land the income loss would be

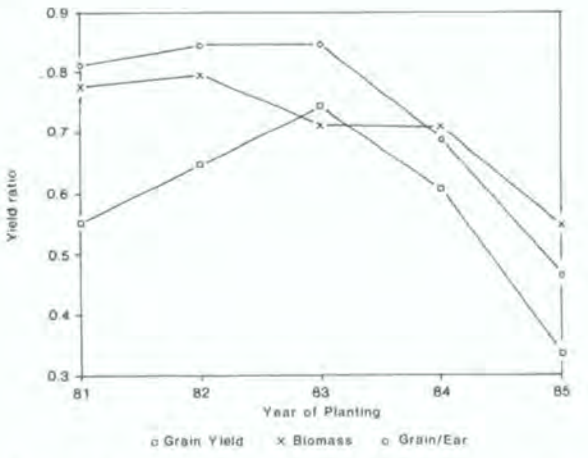


**Figure 1.9** **Ratio of maize yield and its components under the GISS "2 x $CO_2$" scenario to maize yield under current climate (1950-70).**

considerable (US $ 52) Farmers could switch to soybeans which is a less risky crop than maize. However, the cost of soybean seeds is higher in addition to paying for the bacteria innoculate.

Efforts should be made to ameliorate the impact of climate change on these farmers. As with the soybean crop, the application of irrigation on maize was considered (using a schedule of one application every 2 to 6 days rather than as demanded by the crop). Figure 1.10 shows the ratio of maize yield under the GISS "2 x $CO_2$" climate with irrigation compared to that under current climate. The results show that irrigation could lessen the loss in income in at least four out of the five years simulated. In the 1982 and 1984 type weather years, irrigation could increase yields of maize by about 25 percent over that of present climate conditions. There is however, a yield loss of more than 20 percent on average. Increasing the use of nitrogen fertilizer does not appear to reduce the yield loss. Both under current climate as well as under the GISS "2 x $CO_2$" climate nitrogen demand was met quite well, except during the first week when there was a very light nitrogen stress.

Corn yields in the district of Subang are between 1500 and 1900 kg/ha. Taking an average yield loss of 20 percent and a maximum of about 58 percent, farmers with 0.4 ha of land would face a reduction in average income of US $25. However, in any one year this loss could be as high as US $75. For farmers with 0.7 ha of land the income loss would be US $45 and once or twice in ten years the loss could reach US $130.

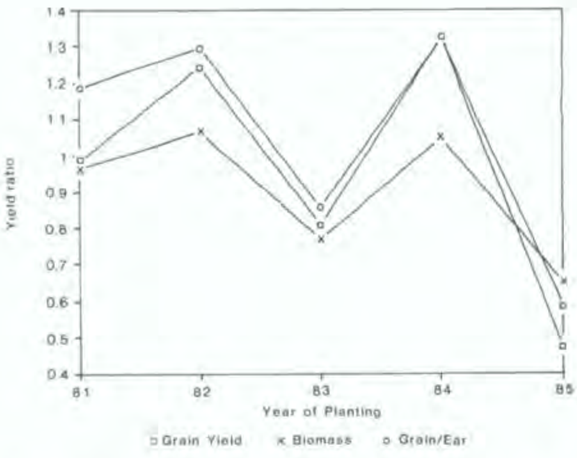


Figure 1.10 **Ratio of maize yield and its components under the GISS "2 x $CO_2$" scenario with scheduled irrigation to maize yield under current climate (1950-70).**

Farming in the uplands will suffer most under the changed climate. The lowland farmers, planting two rice crops per year could be helped by the application of irrigation. For farmers with 0.4 hectares of land, the total loss from two rice plantings and one corn planting per year, would be about nine percent of annual income, while the farmers with 0.7 hectares would lose about 10 percent. For the 35.9 percent of the labour force who do not own or operate farms but whose incomes derive from working for farmers, decreases in crop yield could mean the loss of their jobs because farmers with less than 1 ha of land (30% of all farmers) could not afford to hire these labourers.

Assuming that half of the hired labour work the farms and the farmers with less than 1 ha of land hire one and two workers respectively, there would be more than 15,000 labourers or about 15 percent of the Subang District's labour force out of work. In addition, the district will face a cut in income from the tax levied from its food crop products which has decreased under the double $CO_2$ climate.

## 1.6 POLICY IMPLICATIONS

This study shows that there are three biophysical aspects which are vulnerable to climate change. These are the loss of arable lands due to sea-level rise, decreased soil fertility incurred by the increased soil erodibility and decreased crop productivity. The decreased crop yield implies that the farmers would have a reduced income. The small tenant farmer is particularly vulnerable.

Society as a whole will bear the consequences of decreased yields in two ways. First there is the loss of food supply, which amounts to about 4 percent of rice, 14 percent of soybean and more than 20 percent of maize. Second, there is loss of jobs. If farmers at present spend 20 percent of their yearly income for farm labour, they may not be able to do so in future. For instance, a farmer who plants rice twice yearly and soybean once a year, would lose about 4 percent of his rice yield and about 14 percent of his soybean yield. This means he would be unable to hire 20 percent of the labour for his rice crop and about 70 percent of the labour for his soybean crop.

A conservative estimate of the resulting unemployment would be 40 percent. In the district of Subang for instance, this means there would be a need to create more than 43,000 new jobs based on the present population. Assuming that population growth in the future could be lowered to about 1.5 percent, new job opportunities would need to be in excess of 250,000. The conclusion is that improved management and the introduction of new agricultural technology would be necessary to prevent yield decreases and thus to avoid reduced income and employment.

Increased soil erodibility may impoverish the soil of the upper watershed areas with subsequent reduction of farmers' incomes. Continuous impoverishment, however, may lead to abandonment of farms and this would constitute another major socio-economic impact.

Therefore the three biophysical impacts could result in five socio-economic consequences: a decrease in income, a decrease in food supply, a loss of job opportunities, a loss of income and a reduction in the farming population.

The cost of preserving the present coastal lands from inundation with a rise in sea level would be prohibitive and present day technology is insufficient for the large scale protection and reclamation of the long coastline that would be threatened. Therefore, abandonment of extensive coastal areas would need to be considered with preparatory action taken as early as possible to resettle the population.

The experience of the December 1988 flooding shows that inundation was not restricted to the agricultural area. Roads, railroads and an airport were flooded causing transportation to cease for a time. With a rise of sea level, coastal as well as flat island tourist resorts would become unusable.

Food production could be affected by climate change in two ways: first, by a decrease in crop yields and second through the loss of farm land. In the upper watershed areas the loss of arable land would mean a decrease in food production and in some agricultural export commodities. In the threatened coastal area it would mean a loss in food production as well as in agricultural export commodities. This could reduce income for farmers with consequent reduction in job opportunities for the farm labourers and a reduced food supply.

Integration of proper soil and water conservation measures would be essential in the upper watershed areas. However, in areas where the slopes are too steep for arable agriculture, agroforestry might be the best choice. In the upstream areas which are suitable for arable farming conservation programmes should be established. The experiences gained from the Brantas River Basin Programme may not be suitable in other regions and under an increased rainfall regime. Therefore, it is necessary to establish working groups to study the conservation requirements of each major river basin throughout the country.

As shown by this study, erosion may increase by 3-27 percent. This would raise the siltation rates of reservoirs and render them less effective in producing electricity and in conserving water or controlling floods. Therefore sound conservation programmes should be implemented in the upper watershed areas.

In the upper river basins the GISS "2 x $CO_2$" climate implies increased water yield in terms of soil moisture surplus and river discharge. However, increased soil erosion due to increased rainfall depth and intensity might cause a reduction in the storage capacity and life span of reservoirs. This means that measures would need to be taken concerning soil and water conservation in these areas. Such measures should include (a) upland conservation farming to promote sustainable agriculture, (b) reforestation of steep slopes with permanent vegetation cover of suitable species (both economically and environmentally) and (c) construction of check dams to prolong reservoir life spans.

The reduction of farm incomes and the loss of jobs could endanger the available resources or disrupt the society. Therefore, efforts should be made to ameliorate the impact of climate change on yield. This could be done by reducing the cost of production through improved management and the introduction of new varieties of crops. At present, crop breeding programmes are directed only to pest or disease resistance. Although under the GISS "2 x $CO_2$" climate various new pathogens and insects might appear thus making such research important, it is also necessary to carry out breeding programmes leading to the creation of crop varieties adapted to higher temperatures or lower rates of respiration. Resistance to moisture stress should be made a priority in these programmes.

Although improved yields from new crop varieties could solve the problems of loss of farm income and unemployment of farm labourers, food supplies would still be reduced due to the loss of arable lands in the coastal zone and in the upstream areas of the river basins. New agricultural land would have to be found and developed to compensate for these losses and provide new homesteads for those lost through inundation or reforestation programmes. This would require the removal of the population from areas that are most vulnerable to inundation and their resettlement in more favourable areas.

Current agricultural programmes have not made optimum use of current climatic resources. If the availability of arable land is diminished, and there is increased population pressure, the optimal use of the new agricultural land should be a priority. For this, consideration of climatic potentials is of utmost importance. For the coastal fish and shrimp farmers, there may be no choice other than to switch to farming. Since most of them only began fish and shrimp farming quite recently it should not be difficult for them to divert these interests.

## 1.6 CONCLUSIONS AND RECOMMENDATIONS

### 1.6.1 Conclusions

In Indonesia the global warming projected under a "2 x $CO_2$" climate is estimated to produce an increase of 1.0 to 1.4 percent in surface air temperature and a sea-level rise of 1m. Precipitation could decrease at some locations in certain months, but would mostly increase. Estimates for the precipitation increases in the south eastern part of Indonesia are as high as 200%. These changes in climate could have significant biophysical impacts. In the Citarum, Brantas and Saddan watersheds the erosion rate could increase by 14.5, 18.0 and 38-43 percent respectively. Subsequently soil fertility would be degraded which would lower its productivity by 2 to 3.8 percent, 2.3 to 3.9 percent and 3.9 to 8.8 percent in the Citarum, Brantas and Saddan River Basins respectively.

In spite of increasing evapotranspiration, there would be more water to fill the reservoirs. Therefore, there could be about a 30 percent increase in the irrigation area in the lower regions of the Brantas and Citarum Basins. In the Saddan Basin, the surplus water could increase the present irrigated area by more than 130 percent.

The rise in sea level could result in the inundation of about 26,000 ha of ponds and roughly 100,000ha of crop land in the lower Citarum Basin. This could result in the loss of some 15,000 tons of fish, shrimp and prawns and about 940,000 tons of rice.

The change in climate could also lead to a decrease in yields. Rice, the staple food of most Indonesians, would be affected seriously, especially early season rice. However, late season rice could mitigate this loss, so that there would be an average annual yield loss of about 4.0 percent.

Soybean, an important part of the diet of about 70 percent of Indonesians, could frequently suffer a yield loss of over 10 percent. This is mainly due to the lower yields of the early season. If a decrease in insolation occurred, then further reductions in soybean yield could not be avoided. But with proper management these losses could be abated and yields could surpass the present levels of productivity.

The impact of climate change on maize yields would be more severe than on rice and soybean yields. Yield loss for this crop is at least 25 percent and could be as high as 67 percent. The introduction of new management practices could help to mitigate the impacts and keep the decline to a maximum of 50 percent.

The increase in erosion would result in soil losses of over 2,000 tons in the upper Citarum River Basin, 2,500 tons in the Brantas and 2,700 tons in the Saddan River Basin. Thus, in addition to the decline in food supply, many farmers could also lose their source of income in the upper river basins.

In the downstream areas, the loss in soybean production would be about 1,050 tons, of which over 200 tons would be the result of yield decreases in the Districts of Krawang and Subang. Rice stock supply would have a shortage of around 300,000 tons in the District of Krawang and around 221,000 tons in the Subang District. Ninety-five percent of these production losses would be the result of inundation of the coastal zone. Maize production in both districts would decline by more than 10,000 tons, 46 percent of which would be the result of the decrease in yield.

In addition, inundation of the low lying coastal zone would affect fish and prawn production. In the Krawang and Subang Districts the loss would be over 7,000 and 4,000 tons respectively with a total value of US $ 511,892.

Yield decrease could cost the rice farmer US $10 - US $17, the soybean farmer US $22 - $72, and the maize growers US $25 - US $130 annually.

The overall effect of the projected climate change for the study area would be loss of income or income source, loss of job opportunities and loss of homesteads. In addition food supply would be disrupted and the overall revenue of the area would be reduced.

Further research is needed to establish the following:

- Which low lying coastal zones should be protected and which will have to be abandoned?
- Which upstream area of each river basin should remain arable and which reforested?
- What number of farm labourers would lose their employment and what jobs could be created as alternatives?

In addition to the existing transmigration program there should be an effort to resettle the population living in the coastal zones and upstream areas of river basins where agriculture would no longer be feasible. Climatic conditions should be taken into consideration in the future use and management of existing and newly acquired agricultural lands. Crop breeding programmes should give priority to developing crop varieties that are resistant to higher thermal stress as well as to water stress. Site specific studies may need to be conducted to determine proper conservation measures and to integrate these measures into the farming systems of each river basin. In this way it is hoped that not only will the agricultural productivity in upstream areas be secured, but also the hydrological infrastructures be protected.

### 1.6.2 Recommendations

Policies should be developed to anticipate the possible adverse impacts of climate change on the economy and society of vulnerable areas in Indonesia. One of the most important policy responses would be to integrate soil and water conservation practice in the farming systems aiming at a sustainable agricultural system throughout each watershed area. This would not be an easy task because of the following factors:

- Most of the farmers are small holders or tenants.
- Most of the farmers are poor.
- Most of the farmers are poorly educated.
- Most of the agriculture is on marginal land.

Therefore, in order to established sustainable agricultural systems in the watersheds, such policies would need to be formulated as part of a national policy of economic strategy. They should include:

- Proper regulation of land ownership and the tenure system.
- Provision of more extension workers of sufficient expertise.
- An adequate system of financial assistance or cooperative societies.
- An interdisciplinary programme for increasing land productivity and land rehabilitation.
- An effective agency to coordinate the integrated reform programme.

A more detailed study of possible changes in run-off due to increased soil moisture surplus is required. The recommendations of such a study for watershed management should be implemented by local government which would appoint watershed managers.

To mitigate against the loss of low lying coastal agricultural land, working groups should be established to determine which coastal zones could and should be protected from inundation.

Crop breeding programmes and acquisition of new agricultural lands must give first priority to climatic considerations in order to meet the requirements of the possible changes in climate.

To maintain the present arable land in upstream portions of river basins, conservation measures should be enforced under proper regulations.

The following research is recommended:

- Site specific studies to establish proper conservation measures for major river basins.
- Economic modelling of erosion to obtain insights into the economic aspects of erosion.
- The establishment of a system to monitor the sedimentation in streams and reservoirs and the stream flow of major river basins.
- Studies of the effects of increased rainfall, increased siltation and reduced water capacity on the life span of reservoirs and on power generation and irrigation.
- Site specific studies to determine the biophysical characteristics of coastal zones of socio-economic importance as a basis for decisions on the preservation or abandonment of coastal areas.
- Research on adaptability to thermal stress of aquaculture in order to select species most capable of adaptation to the new environment.
- Research on selecting varieties of the major upland crops which are resistant to thermal and moisture stress.

# IV.2 ASSESSMENT OF SOCIO-ECONOMIC IMPACTS OF CLIMATE CHANGE IN MALAYSIA

## 2.1 INTRODUCTION

The assessment of potential impacts of climate change in Malaysia focused on three sectors - agriculture, water resources and impacts of sea-level rise on coastal. In the agriculture sector the following studies were conducted:

- Rice production in the Muda area.
- Maize growth and yield in MARDI, Serdang, Selangor.
- Oil palm yield in coastal region.
- Rubber in Peninsular Malaysia.

In the water resources sector a case study was made of the Kelantan River Basin.

To assess the impacts of sea-level rise on coastal resources a case study was conducted in the area of the West Johor Agricultural Development Project Phase I.

## 2.2 CLIMATE SCENARIOS

Scenarios of possible future climate change were based on outputs from the Goddard Institute for Space Studies (GISS) General Circulation Model. These changes were expressed as ratios to values of current climate (using data from the ASEAN Climatic Atlas and the Compendium of Climatic Statistics, 1951-1975). Average monthly ratios of change for temperature, rainfall, and humidity were generated for a network of Malaysian stations.

### 2.2.1 Temperature

Table 2.1 shows the ratios of temperature, humidity, and rainfall. There is a consistent and quite uniform increase in the temperature values. The increase of 1% to 1.4% on the Kelvin Scale is equivalent to about 3 to 4°C. Thus the GISS model predicts that the Malaysian region will be 3 to 4°C warmer assuming that atmospheric concentrations of equivalent $CO_2$ are doubled.

### 2.2.2 Rainfall

Figure 2.1 shows estimated changes in rainfall for selected stations in Malaysia. There is no significant change in temporal rainfall pattern. In general, the 'wet' and 'dry' periods at each location occur during the same time of the year.

However, two distinct differences are notable. Firstly, the rainfall at Kuching and Miri during the months of January and February increases significantly. There is also a significant increase in the intermonsoon rainfall in southwest Peninsular Malaysia during the months of March, April and May. The histograms for the Cameron Highlands and Malacca show this change quite clearly.

### 2.2.3 Humidity

A consistent and quite uniform increase in humidity is evident, the warmer environment leading to higher rates of evaporation. However, since air temperature also rises the relative humidity of the air does not change significantly.

### 2.2.4 Limitations of data generated by the GISS GCM

The data generated by the GISS GCM which were used for the impact assessment, are long period mean values for each month and location. The time series of each weather variable were not available. Hence, variances of the weather data were not known. The values of the ratios indicated only the changes in the mean values of the weather data. For complete assessment of the impact of the greenhouse warming on agricultural, water and coastal resources, it is important to know the variabilities of the weather data. It is the "spread" of weather variables that gives information on the probabilities of occurrence of extreme events which have far greater impacts on the environment than the usual or normal events. However, since the variances of weather data were not available, this limitation has to be taken into consideration during the assessment of the potential impact of greenhouse gas-induced warming.

**Table 2.1** **Ratios of GISS "2 x $CO_2$" climate: current climate (1951-1975)**

COMPOSITE SURFACE AIR TEMPERATURE

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KUCHING | 1.012 | 1.011 | 1.010 | 1.102 | 1.011 | 1.010 | 1.012 | 1.012 | 1.012 | 1.013 | 1.014 | 1.014 |
| MALACCA | 1.013 | 1.013 | 1.013 | 1.014 | 1.012 | 1.011 | 1.011 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 |
| SIBU | 1.012 | 1.011 | 1.010 | 1.012 | 1.011 | 1.010 | 1.012 | 1.012 | 1.012 | 1.013 | 1.014 | 1.014 |
| MERSING | 1.013 | 1.012 | 1.012 | 1.013 | 1.012 | 1.010 | 1.011 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 |
| KUALA LUMPUR | 1.013 | 1.013 | 1.013 | 1.014 | 1.012 | 1.011 | 1.011 | 1.013 | 1.012 | 1.013 | 1.013 | 1.013 |
| BINTULU | 1.012 | 1.011 | 1.010 | 1.012 | 1.011 | 1.010 | 1.012 | 1.012 | 1.011 | 1.013 | 1.014 | 1.014 |
| KUANTAN | 1.012 | 1.012 | 1.012 | 1.013 | 1.011 | 1.010 | 1.011 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 |
| SITIAWAN | 1.013 | 1.013 | 1.013 | 1.014 | 1.012 | 1.011 | 1.011 | 1.013 | 1.012 | 1.013 | 1.013 | 1.012 |
| MIRI | 1.012 | 1.011 | 1.010 | 1.012 | 1.011 | 1.011 | 1.012 | 1.012 | 1.011 | 1.013 | 1.014 | 1.014 |
| CAMERON HIGHLANDS | 1.013 | 1.012 | 1.013 | 1.013 | 1.012 | 1.011 | 1.011 | 1.013 | 1.012 | 1.013 | 1.013 | 1.013 |
| IPOH | 1.013 | 1.012 | 1.013 | 1.013 | 1.012 | 1.011 | 1.011 | 1.013 | 1.012 | 1.013 | 1.013 | 1.012 |
| BAYAN LEPAS | 1.013 | 1.012 | 1.013 | 1.011 | 1.011 | 1.011 | 1.011 | 1.013 | 1.012 | 1.013 | 1.013 | 1.012 |
| KUALA TERENGGANU | 1.012 | 1.012 | 1.012 | 1.013 | 1.011 | 1.011 | 1.011 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 |
| KOTA KINABALU | 1.011 | 1.011 | 1.011 | 1.012 | 1.011 | 1.011 | 1.012 | 1.02 | 1.012 | 1.013 | 1.013 | 1.013 |
| SANDAKAN | 1.011 | 1.011 | 1.011 | 1.013 | 1.011 | 1.011 | 1.012 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 |
| ALOR SETAR | 1.013 | 1.012 | 1.013 | 1.013 | 1.011 | 1.011 | 1.011 | 1.013 | 1.012 | 1.013 | 1.013 | 1.013 |
| KOTA BHARU | 1.013 | 1.012 | 1.012 | 1.012 | 1.011 | 1.011 | 1.011 | 1.012 | 1.012 | 1.013 | 1.014 | 1.013 |

COMPOSITE SURFACE AIR HUMIDITY

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KUCHING | 1.286 | 1.257 | 1.244 | 1.232 | 1.270 | 1.151 | 1.207 | 1.239 | 1.229 | 1.291 | 1.359 | 1.356 |
| MALACCA | 1.273 | 1.280 | 1.292 | 1.301 | 1.261 | 1.222 | 1.222 | 1.263 | 1.254 | 1.276 | 1.298 | 1.303 |
| SIBU | 1.288 | 1.260 | 1.245 | 1.237 | 1.267 | 1.158 | 1.207 | 1.241 | 1.230 | 1.289 | 1.355 | 1.347 |
| MERSING | 1.277 | 1.276 | 1.280 | 1.284 | 1.264 | 1.203 | 1.217 | 1.260 | 1.249 | 1.281 | 1.314 | 1.317 |
| KUALA LUMPUR | 1.271 | 1.284 | 1.299 | 1.312 | 1.259 | 1.231 | 1.222 | 1.270 | 1.258 | 1.276 | 1.293 | 1.297 |
| BINTULU | 1.289 | 1.264 | 1.246 | 1.241 | 1.264 | 1.164 | 1.208 | 1.243 | 1.230 | 1.289 | 1.352 | 1.340 |
| KUANTAN | 1.277 | 1.279 | 1.283 | 1.291 | 1.264 | 1.206 | 1.214 | 1.267 | 1.252 | 1.283 | 1.315 | 1.316 |
| SITIAWAN | 1.269 | 1.287 | 1.304 | 1.321 | 1.252 | 1.239 | 1.218 | 1.274 | 1.260 | 1.273 | 1.286 | 1.290 |
| MIRI | 1.289 | 1.266 | 1.249 | 1.248 | 1.258 | 1.171 | 1.207 | 1.244 | 1.230 | 1.288 | 1.343 | 1.330 |
| CAMERON HIGHLANDS | 1.271 | 1.283 | 1.294 | 1.307 | 1.250 | 1.227 | 1.213 | 1.269 | 1.256 | 1.274 | 1.294 | 1.297 |
| IPOH | 1.270 | 1.283 | 1.296 | 1.309 | 1.248 | 1.230 | 1.213 | 1.270 | 1.257 | 1.272 | 1.291 | 1.294 |
| BAYAN LEPAS | 1.267 | 1.283 | 1.295 | 1.307 | 1.236 | 1.233 | 1.206 | 1.267 | 1.257 | 1.266 | 1.285 | 1.288 |
| KUALA TERENGGANU | 1.274 | 1.273 | 1.275 | 1.2778 | 1.244 | 1.202 | 1.202 | 1.258 | 1.244 | 1.276 | 1.311 | 1.312 |
| KOTA KINABALU | 1.281 | 1.269 | 1.269 | 1.274 | 1.234 | 1.189 | 1.204 | 1.240 | 1.238 | 1.277 | 1.307 | 1.295 |
| SANDAKAN | 1.279 | 1.276 | 1.282 | 1.295 | 1.226 | 1.205 | 1.208 | 1.241 | 1.248 | 1.270 | 1.287 | 1.273 |
| ALOR SETAR | 1.267 | 1.277 | 1.285 | 1.291 | 1.224 | 1.223 | 1.196 | 1.259 | 1.253 | 1.263 | 1.288 | 1.290 |
| KOTA BHARU | 1.271 | 1.271 | 1.274 | 1.275 | 1.230 | 1.206 | 1.195 | 1.254 | 1.243 | 1.269 | 1.303 | 1.304 |

PRECIPITATION

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KUCHING | 1.339 | 1.398 | 1.306 | 1.103 | 1.013 | 1.054 | 0.948 | 1.219 | 0.933 | 0.954 | 0.967 | 0.964 |
| MALACCA | 1.151 | 1.137 | 1.327 | 1.331 | 1.213 | 1.077 | 0.972 | 1.263 | 1.096 | 1.058 | 1.079 | 0.963 |
| SIBU | 1.293 | 1.437 | 1.242 | 1.134 | 1.006 | 1.027 | 0.905 | 1.265 | 0.949 | 0.986 | 0.941 | 0.959 |
| MERSING | 1.170 | 1.163 | 1.341 | 1.310 | 1.186 | 1.082 | 0.959 | 1.280 | 1.065 | 1.036 | 1.050 | 0.947 |
| KUALA LUMPUR | 1.138 | 1.112 | 1.336 | 1.343 | 1.218 | 1.075 | 0.954 | 1.307 | 1.107 | 1.056 | 1.065 | 0.936 |
| BINTULU | 1.254 | 1.482 | 1.136 | 1.137 | 0.977 | 0.987 | 0.850 | 1.312 | 0.964 | 0.975 | 0.909 | 0.950 |
| KUANTAN | 1.154 | 1.137 | 1.371 | 1.331 | 1.190 | 1.089 | 0.923 | 1.364 | 1.069 | 1.023 | 1.012 | 0.894 |
| SITIAWAN | 1.126 | 1.090 | 1.329 | 1.323 | 1.185 | 1.057 | 0.937 | 1.340 | 1.119 | 1.047 | 1.054 | 0.934 |
| MIRI | 1.209 | 1.439 | 1.036 | 1.121 | 0.920 | 0.906 | 0.808 | 1.310 | 0.979 | 0.989 | 0.925 | 1.017 |
| CAMERON HIGHLANDS | 1.131 | 1.103 | 1.325 | 1.292 | 1.143 | 1.047 | 0.937 | 1.334 | 1.106 | 1.033 | 1.045 | 0.955 |
| IPOH | 1.128 | 1.100 | 1.319 | 1.285 | 1.136 | 1.042 | 0.938 | 1.329 | 1.111 | 1.033 | 1.049 | 0.963 |
| BAYAN LEPAS | 1.119 | 1.098 | 1.292 | 1.230 | 1.076 | 1.016 | 0.943 | 1.303 | 1.127 | 1.022 | 1.056 | 1.012 |
| KUALA TERENGGANU | 1.144 | 1.134 | 1.308 | 1.215 | 1.039 | 1.013 | 0.945 | 1.310 | 1.074 | 1.003 | 1.035 | 1.018 |
| KOTA KINABALU | 1.130 | 1.245 | 1.000 | 1.130 | 0.861 | 0.756 | 0.777 | 1.143 | 1.008 | 1.056 | 1.058 | 1.239 |
| SANDAKAN | 1.092 | 1.228 | 0.954 | 1.136 | 0.871 | 0.717 | 0.725 | 1.099 | 1.042 | 1.097 | 1.082 | 1.274 |
| ALOR SETAR | 1.116 | 1.109 | 1.266 | 1.157 | 0.999 | 0.988 | 0.947 | 1.276 | 1.125 | 0.998 | 1.054 | 1.065 |
| KHOTA BARU | 1.132 | 1.126 | 1.271 | 1.151 | 0.976 | 0.979 | 0.955 | 1.273 | 1.092 | 0.992 | 1.049 | 1.077 |

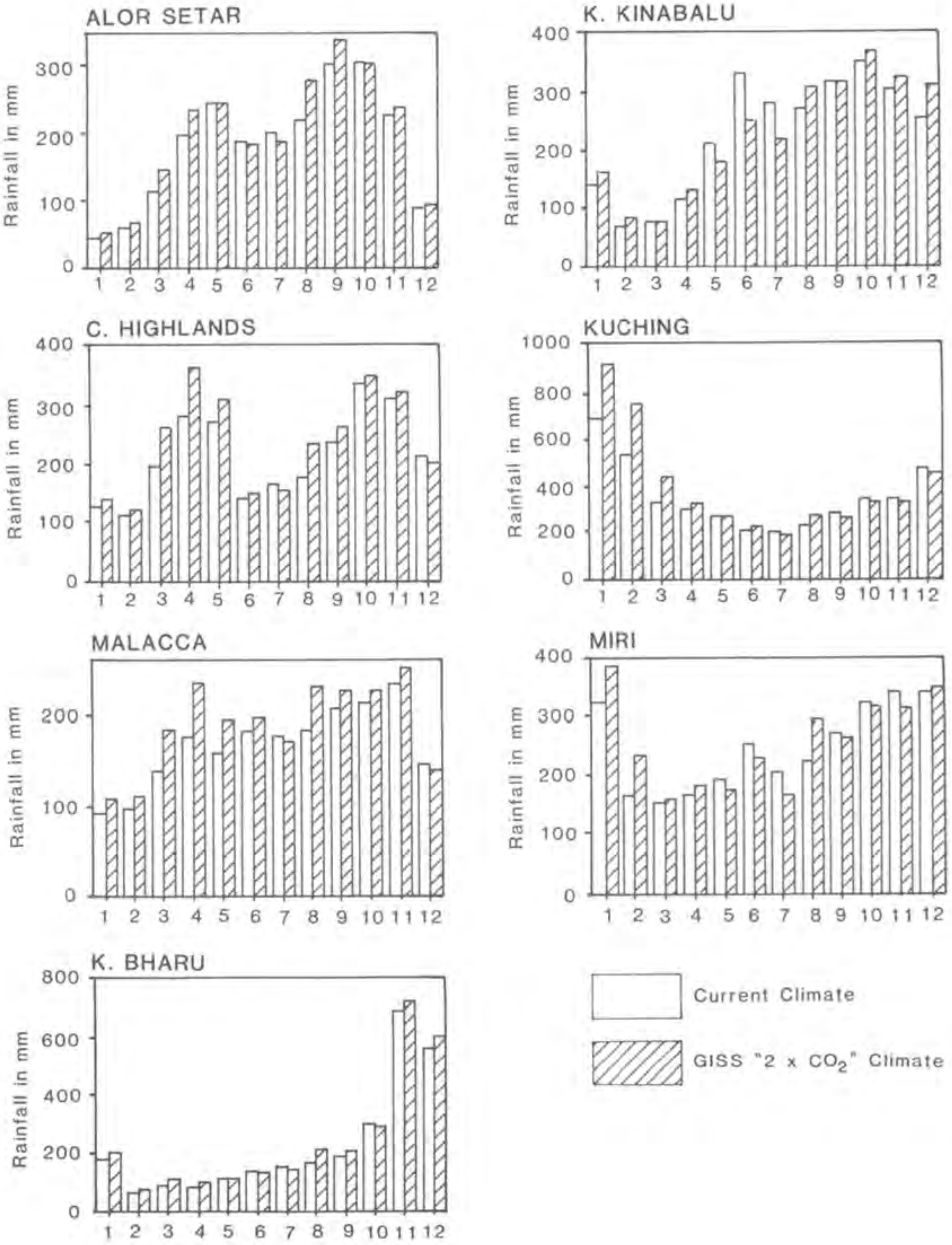


**Figure 2.1** Mean monthly rainfall for 7 stations in Malaysia, 1951-75.

## 2.3 AGRICULTURE

### 2.3.1 Rice

The Muda project site in the coastal plain of Kedah and Perlis was chosen for intensive study for the following reasons:

i) Analysis of climate change impacts on rice production and water resources is a problem of national concern.

ii) The climate change scenarios used imply significant changes in water supply and demand as well as changes in rice production.

iii) A selection of management and policy alternatives would be available to mitigate adverse effects and enhance beneficial effects.

iv) Data required to accomplish these intensive studies were readily available.

v) The region is the largest rice growing area in Malaysia.

The main food crop in Malaysia is rice. The Muda irrigation project was started in 1965 to provide irrigation, drainage and other facilities for the double cropping of rice in the coastal plain of Kedah and Perlis. The total area covers approximately 126,000 ha of which the net padi area is about 96,000 ha. Today this area produces about 700,000 metric tons of rice annually from two crops a year. The principal components of the Muda irrigation scheme include two large reservoirs, a system of main conveyance and local distribution canals, and a coast embankment to prevent ingress of tidal water.

The soil series chosen as representative of the area are Telok, Tualang and Kundor which cover more than 50% of the Muda area. Tualang, Telok and Kundor are classified as belonging to the family of fine, mixed acid isohyperthermic-Tropic Fluvaquent (Typic Sulfaquent) or Thionic Fluvisols according to the FAO- UNESCO Soil Taxonomy system. The results showed that the impacts of climate change on rice yields are quite similar for all three soil types.

There have been more than 10 varieties of rice planted in the Muda area. However in recent years the two main varieties have been IR42 and MR84. The rice variety chosen for this study was IR42 which is considered as a non-photosensitive variety. Irrigation supply is computer-controlled at MADA (Muda Agricultural Development Authority) headquarters based on needs and approval. The planting method is either by direct seeding or by transplanting. Direct seeding and fertilizing is done by broadcasting. Transplanting density is 16 hills/m$^2$ with 3-7 plants/hill. The direct seeding density is 300 plants/m$^2$.

The CERES-Rice Model (version 2.00, see description in Section II) was run for 17 years of current climate (1968-84) and for the GISS "2 x $CO_2$" climate of Alor Setar. The "2 x $CO_2$" climate/current climate grain yield ratios are summarized in Table 2.2. All the runs show a reduction in grain yield under the "2 x $CO_2$" scenario. The yield under the "2 x $CO_2$" climate is estimated to be 12 to 22% lower on average than it is under the current climate for both transplanted and direct seeded rice crops for various soil types and cultural practices. The yearly reduction in grain yields ranges from 5% to 32%. The results also indicate that the impact of climate change on grain yields is more pronounced for the main-season crop.

The application of fertilizers results in significant changes in grain yields. The mean yields with fertilizer vary from 6687 to 7183 kg/ha whereas if no fertilizer is applied the yields drop to 1812 to 2208 kg/ha. It is important to note that losses in yield may be somewhat offset by the direct "fertilization" effect of increased ambient $CO_2$. Studies by J.D. Cure (1985) indicate that the yield of rice may increase by 15% as a result of a doubling of the ambient $CO_2$. Eddy, *et al.*, (1989) reported an increase in yield of about 10% for fertilized and irrigated rice due to a doubling of $CO_2$.

Under the "2 x $CO_2$"climate scenario, the average maturation periods of both transplanted and direct-seeded rice are shortened (Table 2.3). The maturation period is shortened by 4 to 5 days for off-season rice and up to 10 days for the main-season crop. The predicted length of growing period was slightly longer than the quoted value of the 136 day rice variety.

The current climate showed that the irrigation water demand is higher for transplanted rice than for direct-seeded rice for both main and off-season crops. This is probably due to the fact that transplanted rice requires longer maturation periods and the off-season crop receives less rainfall compared to the main-season crop. Under the "2 x $CO_2$" climate scenario, the irrigation demand for direct-seeded rice is higher for both off and main-season crops than under current climate. The increase in irrigation demand varies from 1%

**Table 2.2** **Effect on rice grain yield and irrigation demand**

| Soil | Season | Planting method | "2 x $CO_2$" climate/current climate ratio | |
|---|---|---|---|---|
| | | | Grain yield | Irrigation demand |
| Tualang | Off | Transplant | 0.80 | 0.98 |
| | Off | D/Seeded | 0.86 | 1.16 |
| | Main | Transplant | 0.78 | 1.06 |
| | Main | D/Seeded | 0.88 | 1.15 |
| Telok | Off | Transplant | 0.81 | - |
| | Off | D/Seeded | 0.80 | - |
| | Main | Transplant | 0.79 | - |
| | Main | D/Seeded | 0.81 | - |
| Kundor | Off | Transplant | 0.81 | - |
| | Off | D/Seeded | 0.79 | - |
| | Main | Transplant | 0.78 | - |
| | Main | D/Seeded | 0.80 | - |

**Table 2.3** **Effect on maturation period of rice**

| Climate | Season | Planting methods | Mean maturation period (days) |
|---|---|---|---|
| Current | Main | Transplant | 151 |
| Current | Main | D/seeded | 145 |
| Current | Off | Transplant | 146 |
| Current | Off | D/seeded | 140 |
| GISS "2 x $CO_2$" | Main | Transplant | 141 |
| GISS "2 x $CO_2$" | Main | D/seeded | 135 |
| GISS "2 x $CO_2$" | Off | Transplant | 141 |
| GISS "2 x $CO_2$" | Off | D/seeded | 136 |

to 33% for direct-seeded rice with an average of about 15%. There appears to be greater variability in the effect of climate change on irrigation demand for the off-season direct-seeded crop. For the transplanted rice the results show little consistency and conclusions cannot be made at this stage.

It should be noted that the Muda region experiences a distinct annual dry season. Both its rainfall pattern as well as the extreme temperature values are unique and thus it may not be appropriate, without due care, to extend the results of this project to other regions in Malaysia.

The reductions in padi yield estimated for an altered climate are likely to affect the net income of farmers in the Muda region. With less padi to sell, they would receive less cash subsidy than is currently given to them at the time of sale of padi after the harvest. This would force smaller farmers to rely more heavily on other sources of income, which in turn might lead them to abandon their padi land. If that were to happen, the abandonment of the smaller farms would lead to an increase in the average farm size.

Reduced yields may increase the number of farmers with incomes below the national poverty line, defined in 1981 as M$290 per month. With a declining income the poorest farmers, those who are tenants, might switch activities to other forms of agriculture or leave altogether, thus altering the pattern of land tenure in the region.

Since the irrigation demand is expected to increase under the "2 x $CO_2$" climate the practice of growing rice two times a year may cease or be limited to a smaller area. This would affect the total rice production of the country.

The overall effect of the changes described above might be to reduce Malaysia's potential for rice production. At present, the target is to produce domestically about 60% of national rice consumption. This figure would be reduced to about 49% under the "2 x $CO_2$" climate, assuming a 19% reduction in national rice production.

### 2.3.2 Maize

Changes in temperature and precipitation were used in experiments with the CERES Maize model developed by the USDA. Since data were not available for solar radiation, the model was used with current solar radiation and with 0.9 and 1.1 times current levels.

The growth parameters evaluated were total biomass, yield, straw dry weight, maturation and silking periods, leaf area index, grain numbers and nitrogen uptake. Three population densities were considered: 50,000, 66,700 and 100,000 plants per hectare. Under the "2 x $CO_2$" climate, maximum and minimum temperatures during the growing period of the maize crop increase about 30% and total rainfall increases about 12%. However, while changes in temperature and total rainfall do not affect the production of maize significantly, the crop is particularly sensitive to changes in solar radiation. A 10% drop in solar radiation causes reduction in total biomass production by as much as 20%, while an increase of solar radiation by 10% raises biomass production by 11%. This implies that if the greenhouse effect induces greater cloud cover, the productivity of crops with a high solar radiation requirement such as maize may be severely affected.

### 2.3.3 Oil palm

Three major soil series planted with oil palm in the coastal alluvial soil of Peninsular Malaysia were selected for the study. Yield response equations and yield potential equations were used to partition the effects of rainfall and soil drainage conditions for the coastal alluvial soils in Peninsular Malaysia. The regression equations have been used by varying the annual rainfall and drainage status at average level of other site characteristics.

In other areas studies have shown that a dry season and several months of reduced sunshine hours have an adverse effect on the oil palm bunch yields.

With regard to the oil palm planted in the coastal alluvial soils of Peninsular Malaysia, where the water deficit is very minimal, it was found that the soil moisture is not the limiting factor. Rather, the most limiting factor in the areas is the soil drainage status. Poor soil drainage seems to limit yield performance with or without fertilizer. This condition could be improved by proper drainage of soils.

Rainfall has been shown to have a significant influence on oil palm yield without fertilizer. A timely application of sufficient fertilizers is important in order to achieve optimum yield and care should be taken to avoid wet months, when losses due to leaching and run-off may be high.

An increase in rainfall in the months of March, April and May could be beneficial to oil palm productivity in the coastal alluvial areas provided that solar radiation remains unaltered. However, an exceptionally high rainfall exceeding 2600 mm per year would eventually limit the yield response to fertilizers. Assuming that solar radiation and the rainfall distribution pattern are unaltered, the suggestion is that oil palm yields would remain unaffected.

On coastal soils, the limiting factor is soil drainage. Higher rainfall would have an adverse effect on drainage and improved drainage systems would be required. However, excessive drainage may result in the lowering of the water table, especially during the low rainfall season. Therefore, good drainage and water management techniques which keep the water table at the desired level would be required to maintain current levels of oil palm production in the coastal region.

These results are only applicable within the limits of the study areas of the coastal alluvial soils. Future studies are necessary for inland regions of sedimentary soils planted with oil palm.

### 2.3.4 Rubber

The following climate scenario was adopted in the study of the impacts on rubber: temperature increases of 3-4°C, rainfall increases of 10%, relative humidity unaltered, a sea-level rise of 1 metre.

According to a theoretical climatic classification model for rubber, the effect on rubber cultivation of a mean daily air temperature increase of 2°C (i.e. mean temperature of 28° to 29°C) may be negligible (Yew and Sys, 1990). However, if the mean temperature increases by 4°C (i.e. an air temperature of 31°C) then the effect on rubber cultivation is expected to be moderate. No in-depth study has been made of the impact of temperature change alone on rubber growth and productivity, but where temperature is combined with other climatic parameters, higher temperatures of between 30-31°C may result in more months with moisture stress or even more dry months. Based on observations of the effects of the recent drought in 1990 on rubber productivity, a 3% to 15% crop decrease due to increased drought conditions can be expected. (Yew, *et al.*, 1990).

A rainfall increase of 10% can cause a 13% decrease in yield (Yew, *et al.*, 1985). Depending on when the rainfall occurs, rainfall interference with tapping can also cause a loss of yield between 13% (Yew, 1982) and 30% (Dahlan and Yahava, 1979), giving a mean loss of about 21%. Increased rainfall may exacerbate the problem of rainfall interference with tapping, thus in the coastal parts of Kelantan, Trengganu and Johor which suffer from this problem, rubber cultivation may become marginal or no longer viable.

Without more coastal defences, a sea-level rise of 1 metre could flood coastal areas, affecting an estimated 80,000 ha of land under rubber. Rubber cultivation in these areas may have to be abandoned.

Based on the above climate change scenario, parts of Kedah, a part of Perak lying between Grik and Kuala Kangsar, and parts of Kelantan and Trengganu may become too dry for rubber production. Currently this region has 3 to 5 dry months and 1 to 4 months of frequent moisture stress days. The east coast of Peninsular Malaysia may become too wet for rubber cultivation, suffering from intense rainfall interference with tapping. In the worst possible situation, a total area of not more than 3,826,289 ha (29% of the land area of Malaysia) may become marginal or unsuitable for rubber cultivation, with another 80,000 ha being flooded.

A more realistic view is that rubber could still be cultivated in most parts of the country. Newer clones may increase yields by 24% to 50% but these gains could be negated by a decrease in yield of 15% due to climate change.

The total production of natural rubber in Malaysia in 1989 stood at 1,360,000 tons, providing a national revenue of about M$3.6 billion in 1989. Based on an average estimated increase of 37% in yield per hectare of newer clones, national production in the future is expected to rise to about 1,860,000 tons providing a national revenue of M$4.93 billion, based on current prices. Under the climate change scenario described above, with the expected loss of land due to flooding and a decrease in yield of about 15%, the technological improvement would be negated and the total national production is expected to drop to 1,506,000 tons earning a national revenue of about M$4 billion. In absolute terms, although there is a net increase of national revenue of about M$0.4 billion, the loss due to climate change is M$0.93 billion per annum.

The adverse effects of climate change may be felt most by rubber smallholders. At present, the average size of smallholding size is about 2 ha with a yield per hectare of about 1000 kg per year, and earnings of about M$300 per month. With higher yielding clones (37% increase), the income of smallholders is expected to increase by about M$110 to about M$410 per month. However, climate change could negate this increase in yield from 370 to only 165 kg/ha/year. The increase in smallholders income is thus reduced to about M$40 per month.

To diversify risks, commercial estates plant crops such as oil palm, rubber, and cocoa in approximately the following ratios 60:30:10. Additionally, the total land area allocated to agriculture is also gradually being reduced as more and more estates industrialize. Climate change may be a factor influencing the existing crop mix, but there are other more important factors such as returns to investment (which are dependent on prevailing market prices, immaturity period and costs of production) and labour requirements.

The negating effects of climate change on yield increases in the future may tend to make the present size of smallholding uneconomic. The phasing out of uneconomic smallholding will continue with the consolidation of the Mini Estate Type of smallholdings. A future scenario may emerge where ownership is separated from management, with the smallholders becoming share holders and paid workers on their estates. It must be emphasized that this process will occur as the country progresses and industrializes regardless of any climate change. However, climate change may serve to hasten this process.

Out-migration from the agricultural sector, such as rubber, to the industrial sectors has been a major problem in Malaysia. Adverse climate change would make the agricultural sector less attractive and increase migration to industrial sectors.

With increasing competition from synthetic rubber and also other rubber-producing countries, Malaysia cannot afford to be complacent with regard to research and development in rubber. Irrespective of climate change, it needs to develop means of increasing yields and reducing production costs in order to remain competitive.

## 2.4 WATER RESOURCES

The methodology adopted in this part of the study was to identify a representative river basin, select suitable mathematical models, carry out baseline runs to determine the present situation, amend the input data to account for climate change, and carry out simulation runs based on the new data. The results of the simulation analysis provided a quantitative estimate of the possible effects of climate change on floods and water deficit and allowed an assessment of the magnitude of the problem.

The time available for the study did not permit a country wide coverage, thus the scope of work was confined to a detailed coverage of one representative river basin which would best highlight the impacts of climate change in critical problem areas. The major problem areas are in flooding and water availability particularly in the dry season.

A number of river basins in the country were surveyed and the Kelantan River Basin was selected as the representative basin for the following reasons:

i) Flooding is a major problem in the basin. In a major flood experienced in 1967, 300,000 hectares (or some 20% of the total state area) were inundated, 540,000 residents were affected (of which 125,000 had to be evacuated), 30 lives were lost and flood damage to public property was estimated to be over M$30 million. The flood problem has also been a limiting factor in the establishment of industries and commerce in the state.

ii) There is a distinct wet and dry season in the basin. While the annual rainfall is high, 50% falls in the three monsoon months of October to December. This has resulted in severe floods in the wet season, and shortage of water in the dry season. The impact of climate change, if any, is less likely to be masked by the variability of rainfall pattern in the region.

iii) The basin has a reasonable network of meteorological and hydrological gauging stations and long term records are available.

Kelantan lies in the north-eastern corner of Peninsular Malaysia with a land area of 14,943 sq.km. The State has a population of 1.09 million (1988) which is 6.4% of the national population. It is estimated that the population will be 1.88 million by the year 2010. There are four main crops cultivated, namely, padi, tobacco, rubber and oil palm. Kelantan accounts for about 13% of national padi production.

In the Kelantan River Basin, two aspects of water resources are of particular concern, namely, flood peaks and durations during the wet season, and the monthly distribution of water resources over the whole year, with particular emphasis on the dry season. Modelling of the first aspect is essentially based on a rainfall-runoff characterisation of the catchment while the second aspect required an investigation of the water balance of the basin.

A number of mathematical models were considered and the Storage Function Model was adopted because it satisfactorily described the hydrological characteristics of the catchment without imposing too high a demand on input data. In using the model, the river catchment was divided into sub-basins and the storage functions applied. The runoff data for each sub-basin were then combined to obtain the total runoff for the river basin.

To determine the water balance of the river basin the model adopted was the Thornthwaite and Mather Water Balance Model which mathematically simulates the complex process interlinking rainfall, evapotranspiration and moisture content of the soil profile, (Teh and Alias, 1982).

### 2.4.1. Flood flows

In the use of the Storage Function Model, the Kelantan River Basin was first divided into sub-catchments and river channel blocks (JICA,1989). A series of runs was made to obtain the baseline values for the years 1983, 1984 and 1986. The rainfall input was then adjusted for the values under the "2 x $CO_2$" scenario and another series of runs was carried out. The flood hydrographs obtained were then analyzed and compared (Figures 2.2 to 2.4).

In all three years, there was an increase in both flood peaks and duration, and while the flood duration increase was not significant, the peak discharge registered a significant increase in all three cases of approximately 9%. A nine percent increase in flood peaks would result in a larger overbank spill and hence more widespread flooding of the Kelantan River Basin. In terms of flood recurrence, it would mean that a 30-year return period flood in the future would have almost the same effect as a 50-year return period flood at present. The higher flood peaks would affect more people, inundate more land, cause more flood damage and disrupt more severely the economy of the river basin. In terms of flood protection, this would require the construction of larger engineering works at higher costs.

For the socio-economic impacts, the assets expected to be affected in the probable inundation area for the years 1988 and 2010 are shown in Table 2.4, for two cases of flood magnitudes, given in terms of their return periods. The estimates are projected for the year 2030 for both current and "2 x $CO_2$" climates, assuming for the latter a 9% increase in flood discharge. With a 9% increase in flood peak, the population affected by flooding in 2030 would increase by 5.37% for the 13-year flood and by 6.06% for the 50-year flood. Other assets, with the exception of oil palm, also show increases of between 5% and 8%. In terms of flood damage, the total losses would amount to M$583,349,000 and M$883,079,000 for the 13-year and 50-year return periods respectively in the year 2030 (current climate). With a 9% increase in flood peak ("2 x $CO_2$" climate) the losses would increase to M$652,391,000 and M$979,084,000 for the 13-year and 50-year flood respectively. These represent increases of between 10% and 12% in total flood damage (Table 2.5).

### 2.4.2. Water balance

Using the Thornthwaite and Mather Water Balance Model, a series of runs was made for the period 1979 to 1986. The rainfall input was then increased to correspond to rainfall amounts assumed under the GISS "2 x $CO_2$" climate and another series of runs was carried out (Table 2.6). Figures 2.5 to 2.7 depict graphically the mean monthly values of runoff, evapotranspiration and water deficit for current and "2 x $CO_2$" climates.

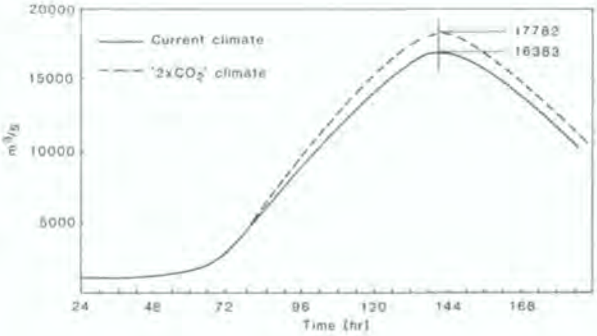


**Figure 2.2** Simulated flood hydrograph in the Kelantan River (1983) (at Guillemard Bridge).

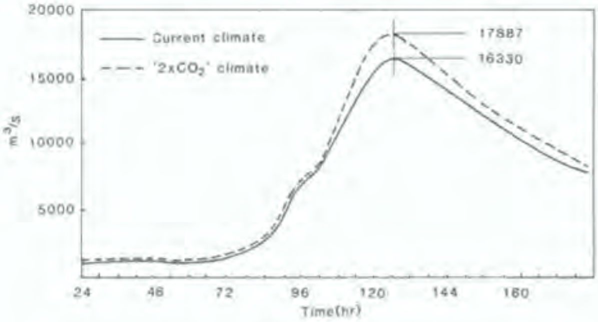


**Figure 2.3** Simulated flood hydrograph in the Kelantan River (1984) (at Guillemard Bridge).

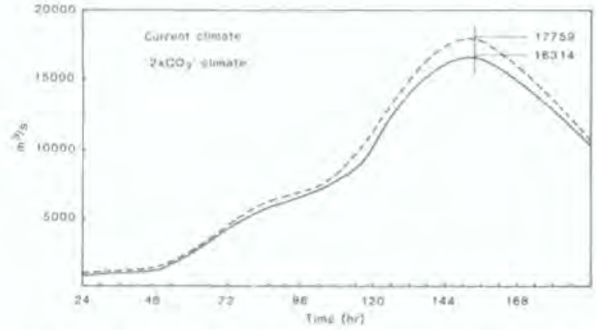


**Figure 2.4** Simulated flood hydrograph in the Kelantan River (1986) (at Guillemard Bridge).

From Figures 2.5 and 2.6 it can be seen that the change to mean monthly runoff and evapotranspiration under the "2 x $CO_2$" climate is not significant. However, the resulting mean monthly water deficits obtained from the water balance model show some interesting differences. From May to December, there is no significant change, but from January to April there are appreciable differences (35, 31, 31 and 12 percent respectively).

**Table 2.4 Assets affected in the probable inundation area**

| Year | Affected population (person) | | Paddy (ha) | | Tobacco (ha) | | Rubber (ha) | | Oil palm (ha) | | Residential house (ha) | | Public building (ha) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 13-yr | 50-yr | 13-yr | 50-yr | 13-yr | 50-yr | 13-yr | 50-yr | 13-yr | 50-yr | 13-yr | 50-yr | 13-yr | 50-yr |
| 1988 | 200,880 | 247,710 | 18,789 | 23,362 | 2,756 | 3,567 | 13,305 | 17,595 | 787 | 812 | 40,176 | 49,542 | 1,151 | 1,957 |
| 2010 | 334,264 | 412,189 | 21,683 | 26,959 | 2,756 | 3,567 | 15,590 | 20,612 | 11,918 | 1,979 | 66,853 | 82,438 | 2,521 | 3,256 |
| 2030 | 455,522 | 561,715 | 24,334 | 30,229 | 2,756 | 3,567 | 17,664 | 23,355 | 2,940 | 3,040 | 91,105 | 112,34 | 3,435 | 4,437 |
| 2030* | 479,983 | 595,729 | 25,629 | 32,117 | 2,943 | 3,827 | 18,975 | 25,178 | 2,968 | 3,070 | 95,997 | 119,14 | 3,666 | 4,755 |
| Percent Increase ** | 5.37 | 6.06 | 5.58 | 6.24 | 6.79 | 7.29 | 7.42 | 7.81 | 0.75 | 0.99 | 5.37 | 6.06 | 6.72 | 7.23 |

* Indicate assets affected for the case of 9% increase in flood peak under the GISS "2 x $CO_2$" scenario in the year 2030

** Under current climate and GISS "2 x $CO_2$" climate in the year 2030

**Table 2.5 Probable Flood Damage (Unit: Thousand M$)**

| Year | Direct damage | | | | | | Indirect damage (C) | | Total (A) + (B) + (C) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Agriculture (A) | | Non-Agriculture (B) | | | | | | | |
| | | | House/building | | Infrastructure | | | | | |
| | 13-yr | 50-yr | 13-yr | 50-yr | 13-yr | 50-yr | 13-yr | 50-yr | 13-yr | 50-yr |
| 1988 | 53,114 | 84,730 | 53,806 | 78,557 | 16,142 | 23,567 | 36,919 | 56,056 | 159,981 | 242,910 |
| 2010 | 80,329 | 128,808 | 164,093 | 243,069 | 49,228 | 72,921 | 88,095 | 133,439 | 381,745 | 578,238 |
| 2030 | 105,070 | 168,879 | 264,354 | 392,625 | 79,306 | 117,788 | 134,619 | 203,787 | 583,349 | 883,079 |
| 2030* | 119,768 | 189,317 | 293,901 | 433,711 | 88,170 | 130,114 | 150,552 | 225,942 | 652,391 | 979,084 |
| Percent Increase ** | 13.99 | 12.10 | 11.18 | 10.46 | 12.46 | 10.46 | 11.83 | 10.87 | 11.83 | 10.87 |

*Indicates Probable Flood Damage for the case of 9% increase in flood peak due to GISS "2 x $CO_2$" climate in the year 2030

** Under current climate and GISS "2 x $CO_2$" climate in the year 2030

The 30% to 35% increase in water deficits in the dry season would exacerbate the present position where shortage of water, especially for irrigation, is already critical. For rice cultivation, this could result in a reduction in the cultivable area, possible reduction in yields and a higher energy cost for supplying water (in Kelantan most of the irrigation supply is pumped and pumping costs would increase as water availability and hence river water level drops). For oil palm, there would be a double impact - the higher rainfall in the wet season would impair the drainage, while in the dry season the plant would experience water deficits. Both of these effects would contribute to a decline of yields. There would also be a need for larger storage dams in the upper catchment which would mean higher construction costs and more severe environmental damage.

Overall, the change in the water resources as a result of climate change could have considerable impacts on the social and economic activities of the Kelantan River Basin. Higher flood peaks would affect more people, inundate more land, cause more flood damage and disrupt more severely the economy of the river basin. Higher water deficits would affect directly farmers' ability to produce more efficiently. They would increase the cost of water supply for irrigation, domestic consumption and industrial use.

Water from the Kelantan River is at present used for domestic, industrial, river maintenance flow and irrigation. Regardless of climate change, total water demand from the river is estimated to increase from the present use of 105.5 cumec (1985) to 161.1 cumec in 2010 and 163.8 cumec in 2030. By 2030 the domestic and industrial demand would account for 9.2 cumec, river maintenance flow would remain the same at 70 cumec and irrigation demand would account for the balance of 84.6 cumec. Due to its cropping pattern, irrigation demand for padi is at a peak in April, while other water demands require constant flow throughout the year. With increases in water deficit occurring as a result of climate change, water supply in the basin would be affected. While the deficit may not affect the domestic, industrial and river maintenance demand, it would affect irrigation demand significantly, especially for padi cultivation during the off-season period between March and July. It has been estimated that the total irrigable area for padi in the year 2030 would be 50,000 ha, requiring an annual peak demand of 84.6 cumec of water. The deficit would therefore result in the abandonment of 65 to 70 percent of the off-season crop. The consequent loss of padi land of between 32,500 ha and 35,000 ha would affect the livelihood of tens of thousands of farmers and the loss of millions of ringgit (M$).

## 2.5 IMPACT OF SEA-LEVEL RISE ON COASTAL RESOURCES

Malaysia has a long coastline of about 4,800 km. The coastal zone not only sustains but also contributes significantly to the economic development of the country. Major towns, ports and large agricultural and fisheries projects are located within the coastal zone. Thus any significant sea-level rise could have serious and profound effects on the livelihood of a large proportion of the population.

To date, little attention has been given to the phenomenon of sea-level rise in Malaysia. There are no long term data on the tide and sea levels and their temporal fluctuations. Hence, there is no historical information on measured sea-level rise along any part of the Malaysian coastline.

Generally, the coastline of Malaysia has a varied character. The primary physiographic features and coastal ecosystems include steep/cliffed coastline, permatang coast/beaches, delta/coastal plain, coastal wetlands, inlets, estuaries/lagoons, volcanic coast, and corals. While the west coast of Peninsular Malaysia is sheltered by the island of Sumatra and thus supports extensive wetland development, the east coast of Peninsular Malaysia and the coasts of Sabah and Sarawak face more intense wave activity emanating from the South China Sea.

For the present report the effects of a projected one metre sea-level rise on the Malaysian coastal resources were assessed with special emphasis on four specific areas of impact:

- Coastal erosion.
- Increased flooding.
- Loss of coastal wetlands.
- Saline intrusion.

The reasons for choosing the one metre sea-level rise scenario are given in Section II of this report.

The National Coastal Erosion Study completed in 1985 indicated that about 27% of the Malaysian coastline is eroding at varying degrees of severity. Tidal inundation of low-lying coastal plain was also common before these areas were reclaimed for agriculture through polder development. The almost continuous line of coastal bunding along

**Table 2.6** **Monthly Runoff (in mm). 1st row: under current climate (1951-75), 2nd row: under GISS "2 x $CO_2$" climate**

| Year | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1979/80 | 36 | 20 | 56 | 28 | 392 | 285 | 12 | 0 | 0 | 0 | 0 | 0 |
| | 12 | 29 | 64 | 20 | 401 | 298 | 12 | 0 | 0 | 0 | 0 | 0 |
| 1980/81 | 0 | 153 | 131 | 166 | 156 | 227 | 39 | 1 | 0 | 0 | 16 | 8 |
| | 0 | 200 | 145 | 156 | 156 | 237 | 40 | 2 | 0 | 0 | 15 | 8 |
| 1981/82 | 0 | 0 | 24 | 77 | 161 | 221 | 14 | 1 | 0 | 0 | 0 | 56 |
| | 0 | 0 | 24 | 62 | 160 | 232 | 14 | 1 | 0 | 0 | 0 | 59 |
| 1982/83 | 56 | 75 | 116 | 131 | 107 | 376 | 79 | 3 | 0 | 0 | 0 | 0 |
| | 42 | 105 | 132 | 121 | 105 | 398 | 84 | 3 | 0 | 0 | 0 | 0 |
| 1983/84 | 21 | 88 | 133 | 68 | 84 | 820 | 88 | 180 | 79 | 28 | 94 | 90 |
| | 7 | 107 | 148 | 56 | 80 | 877 | 95 | 197 | 99 | 41 | 96 | 86 |
| 1984/85 | 59 | 46 | 65 | 142 | 58 | 298 | 135 | 5 | 207 | 28 | 87 | 37 |
| | 41 | 46 | 72 | 135 | 53 | 315 | 144 | 5 | 265 | 36 | 86 | 35 |
| 1985/86 | 2 | 35 | 191 | 274 | 144 | 201 | 57 | 3 | 0 | 0 | 0 | 0 |
| | 2 | 47 | 210 | 268 | 142 | 210 | 61 | 3 | 0 | 0 | 0 | 0 |
| Mean | 25 | 60 | 102 | 126 | 157 | 347 | 61 | 28 | 41 | 8 | 28 | 27 |
| | 15 | 76 | 114 | 117 | 157 | 367 | 64 | 30 | 52 | 11 | 28 | 27 |
| % change | -40 | 27 | 12 | -7 | 0 | 6 | 5 | 7 | 27 | 37 | 0 | 0 |
| Standard deviation | 26 | 51 | 57 | 81 | 110 | 217 | 44 | 67 | 79 | 14 | 43 | 35 |
| | 19 | 67 | 63 | 835 | 115 | 234 | 47 | 741 | 101 | 19 | 44 | 34 |

the west coast of Peninsular Malaysia and certain stretches of the coastline of Sarawak prevents inundation and makes possible the agricultural development of the reclaimed coastal belt.

Extensive coastal wetlands such as the mangrove belt are found along sheltered coasts and around river mouths. Presently, these wetlands are under intensive pressure for conversion to other economic uses such as agriculture and aquaculture. Saline intrusion is not perceived as a problem at present as unsuitable sites contaminated by saltwater are identified during the planning stage of locating water intakes/abstraction points.

The West Johor Agricultural Development Project Phase I was selected for this study because a substantial amount of relevant physical and socio-economic data for the study area had already been collected by the Project as well as by two more recent studies (the National Coastal Erosion Study (Economic Planning Unit,1985) and the ASEAN-USAID funded South Johor Coastal Resources Management Project (Kadri, *et al.*, 1987)).

The West Johor Agricultural Development Project Phase I area covers some 148,517 ha on the west coast of the State of Johor. The area is located at the extreme southern point of Peninsular Malaysia, west of Singapore Island. Flooding, water logging, and saline intrusion in the coastal area and the valley plains were common occurrences prior to the implementation of the project. To alleviate these problems and to increase the economic potential of the area, the Government implemented an integrated agricultural development project in

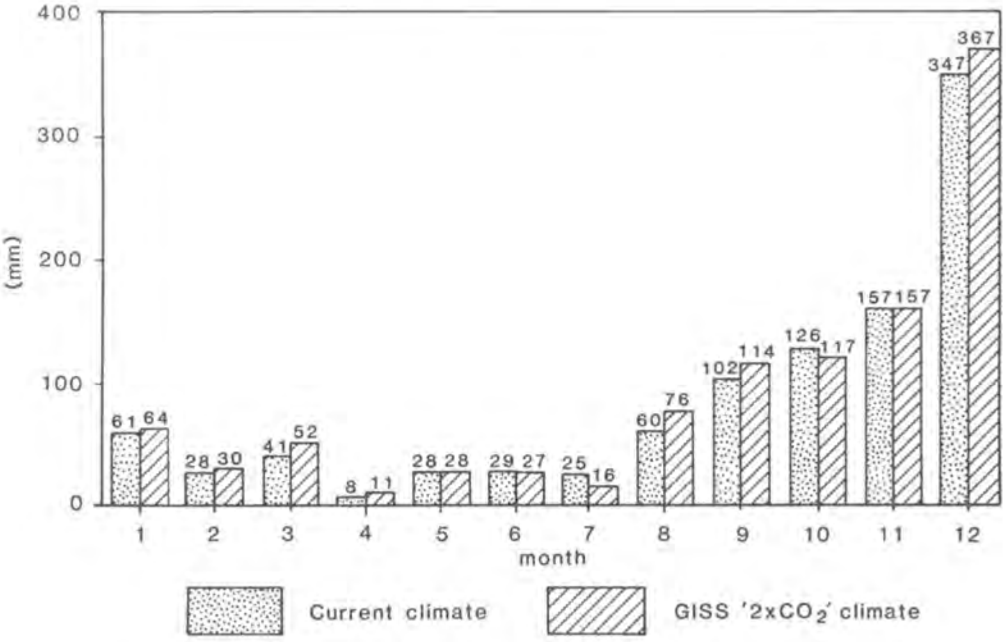


**Figure 2.5** Mean monthly runoff (mm) for Kelantan River Basin for current climate (1951-75) and GISS "2 x $CO_2$ climate.

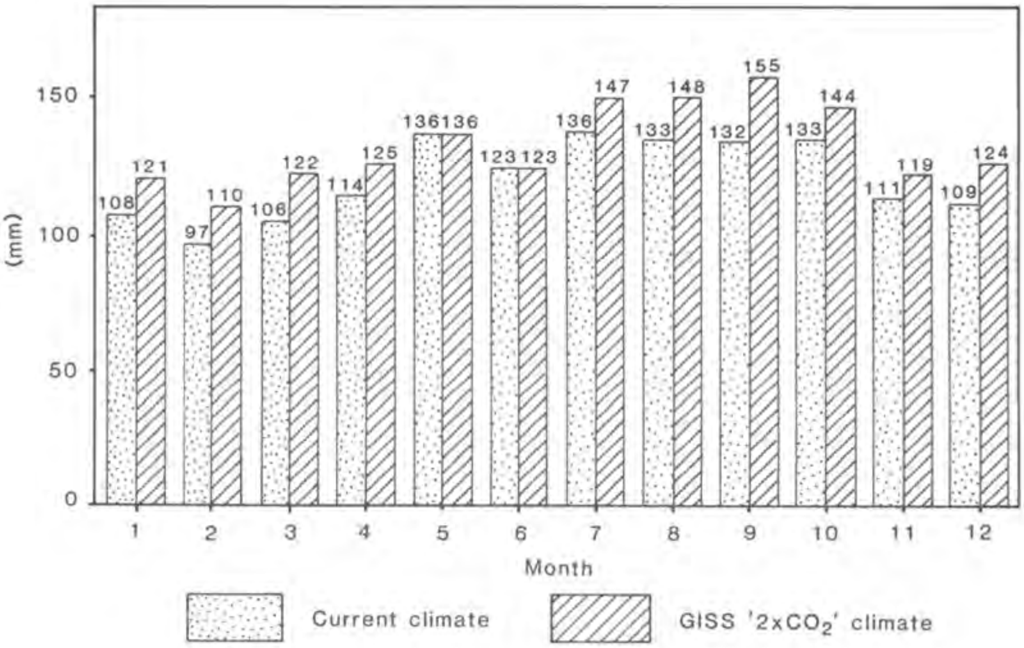


**Figure 2.6** Mean monthly evapotranspiration (mm) for Kelantan River Basin for current climate (1951-75) and GISS "2 x $CO_2$" climate

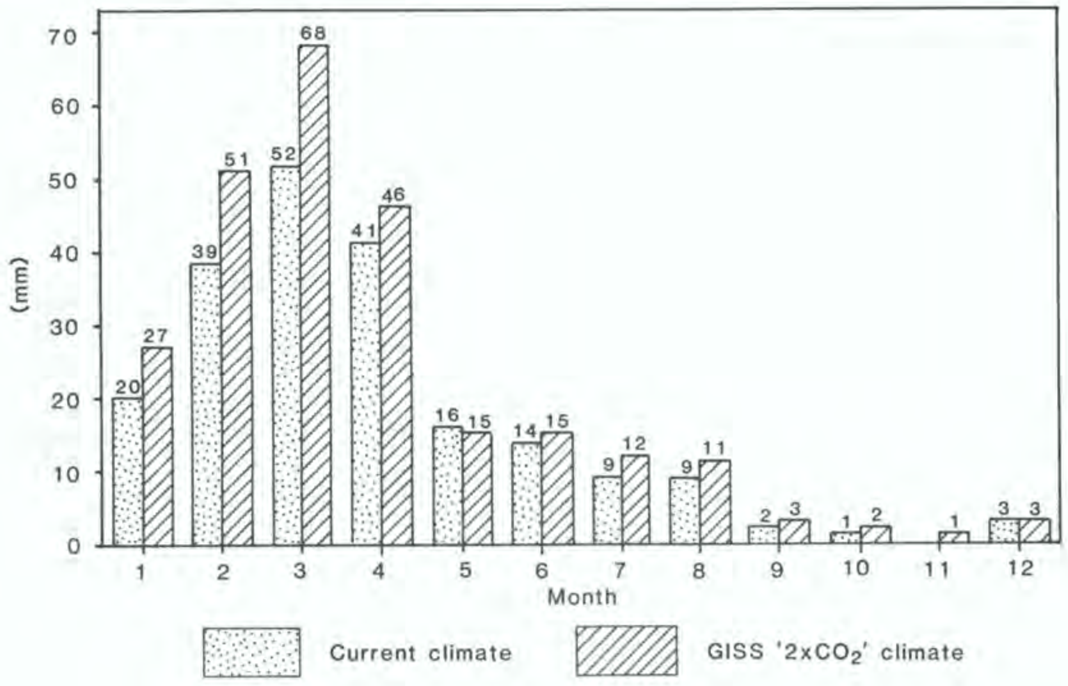


**Figure 2.7** Mean monthly water deficit (mm) for Kelantan River Basin for current climate (1951-75) and GISS "2 x $CO_2$" climate.

1974. The project primarily involved the construction of coastal embankments, canalization and diversion of the rivers, construction of the necessary control structures such as dams, barrages and tidal control gates, road communications, bridges and crossings, etc., and provided the necessary agricultural extension services.

The rate of shore retreat caused by sea-level rise was computed using the Bruun Rule (Bruun 1962, 1983). While acknowledging the limitations of Bruun's Rule, which is strictly applicable to coasts that are in equilibrium and which omits other potentially significant factors such as the cross shore and long shore movements of sediments, it was chosen because it is the only practical way of yielding a rapid, semi-quantitative assessment of sandy shore responses to a rise in the sea level. Field observations of contemporary coastal processes and information on the shoreline response to Holocene change in sea level were supplementary tools used in the assessment.

It is accepted that the Bruun's Rule is not applicable to assessing the shoreline response of mud coasts (which constitute about half of the coastline of Malaysia) to a rise in sea level. It is recognized that there is a basic difference between the dominant processes involved in wave-sandy coast and wave-mud coast interactions. This fundamental difference precludes the direct application of basic concepts on coastal processes operating on sandy coastlines to those comprising cohesive sediments. A more appropriate approach is to conduct comparative field studies. Specifically, a transposition technique similar to that employed in hydrological studies is utilized to assess the likely responses of a mud coast to a projected higher sea level. Although this approach has its technical merits, it has not yet been tested in the field. Hence, the resulting assessment for mud coasts is necessarily more qualitative and speculative than that for sandy shorelines.

The spatial extent of land submergence under a static water elevation was obtained from topographic maps prepared from project surveys, which are of finer resolution than available published topographical sheets. Unfortunately, these project-based surveys were only carried out for discrete blocks of coastal development and assumptions had to be made regarding similarity in ground profile for the intervening areas in order to arrive at a national aggregate. The assessment of the impacts of a rising sea level on saline intrusion is more complex. As there is a dearth of relevant information, this assessment is necessarily qualitative.

### 2.5.1 Impacts of a projected sea-level rise

The first direct consequence of a rise in sea level is the inundation of the low lying coastal plain. The available published topographical maps in Malaysia do not have contours closer than 15m (50ft) intervals, and hence the potential areas subject to tidal flooding in the event of a sea-level rise cannot be determined from these. However, project-based topographical survey plans for development projects, which are usually of finer resolution, are available for particular areas. Based on these contours prepared for the project, it was estimated that with a one metre rise the sea would advance shoreward a distance of about 2.5 km. By assuming that this average width of submerged coastal strip holds for the entire project shoreline of 82 km, it was further estimated that the total project area likely to be inundated would be 20,000 ha.

Coastal erosion is likely to accompany a rise in sea level. For sandy shores and based on sediment budget consideration in a cross-shore direction, a horizontal recession rate of one metre per one centimetre vertical rise in mean sea level has been reported in the literature. While no similar rate has been postulated for mud coasts, it is generally acknowledged that the recession rate could be higher. Hence, an additional width of at least 100 m of coastal land abutting the newly established land-sea interface would be expected to be eroded. This addition is likely to be over and above the shoreline retreat based on the current rate of erosion. While the horizontal extent of the projected shoreline retreat is dwarfed by the width of the coastal belt that may be inundated, the erosive and episodic nature of the wave-induced forces would put shoreline facilities into jeopardy, thereby inflicting damage on shorefront properties and infrastructure.

The current rate of conversion of mangrove lands for agriculture has reduced the mangrove area to a linear belt outside the coastal bund, where mangroves have not already been decimated by coastal erosion. Under normal circumstances, the mangrove forest would be able to migrate landward as sea levels rise, provided the vertical rate of natural mangrove migration is not less than the rate of sea-level rise. Given the typical concave upward profile of the coastal plain, there is still a likelihood that a net reduction in mangrove area may result. The above conclusion is based on the assumption that there is available space for such a landward migration to take place. However, the presence of the coastal bund invariably means that such a natural adjustment would not be realized.

In the case of mangrove migration the rate of sea-level rise assumes importance. If the present rate of conversion of mangrove areas to other uses remains unabated, it is likely that the mangrove forest along the Project shoreline would have vanished before the projected sea-level rise finally takes its toll. On the other hand, the current awakening of environmental consciousness about the need to maintain and protect the ecological functions of mangrove areas, (which serve as a coastal habitat for wildlife, a nursery and feeding ground for fisheries, a source of nutrient supply and a protective vegetation belt against coastal erosion) does indicate the increasing acceptance of the concept of sustainable development. Hence, it may be reasonable to assume that the development of the remaining mangrove area would be regulated. It then follows that any future loss of mangrove forests in the Project area would be the direct impact of a sea-level rise.

While saline intrusion is anticipated, it is not generally considered to be a problem because of the shift in water sourcing strategy towards reservoir systems. However, the impacts on existing water abstraction facilities at certain vulnerable locations could be serious. The projected increases in water deficits, despite an increase in precipitation, might lead to increases in water abstraction, thereby resulting in lower river maintenance flow. Hence, increases in saline intrusion, caused by a rise in sea level, are further reinforced and may lead to contamination of hitherto freshwater sources.

### 2.5.2 Socio-economic impacts

The economic losses associated with the bio-physical impacts identified above fall into five broad categories:

- Loss of agricultural production from inundated land.
- Loss of mangroves.
- Loss of fisheries resources.
- Loss of infrastructure/properties.
- Loss of recreation/tourism benefits.

The completion of the West Johor Agricultural Development Project Phase I has enabled the reclamation of about 7,000 ha of previously tidally submerged land. With the general improvement in the drainage regime, the completed infrastructural work has also led to an appreciation of the value of agricultural land to the current level of about M$20,000 per ha.

The 20,000 ha of coastal land projected to be submerged as a result of a one-metre rise in sea level would also include mangrove forests covering 9,000 ha, the balance of 11,000 ha being agricultural land. The direct loss in terms of land value is estimated to be about M$220 million.

On the basis of the capitalized value of mangrove forestry products previously estimated for the Sg. Pulai Mangrove Forest area, the value of mangrove land in the study area is estimated to be about M$6,000/ha for forestry alone. This brings the direct value of mangrove loss to M$54 million.

Mangroves play an important role in the maintenance of nearshore fisheries. Along the west coast of Peninsular Malaysia an estimated 41% of the fish landings may be associated with mangroves. Based on this figure, the annual value of mangrove-associated fish landings along the Project shoreline amounts to about M$6.1 million. Capitalized over a 20-year cycle the amortized value stands at about M$80 million.

The loss of infrastructure/properties in the area is less easily computed. It is noted that part of the loss is already implicitly included in the loss computed for agricultural production (on the basis of total land submerged). Due to the coastal proximity of the road alignment, it is possible that a part of the present coastal road link will be subject to damage, thereby requiring rerouting. The alignment of the new North-South Expressway is more inland, hence, only local and intra-district transportation links are likely to be affected. Currently, it is difficult to quantify this projected interruption to transportation due to a lack of relevant data such as traffic counts and rerouting corridors.

Available information on tourism development in Johor indicates that the main thrust of current and future efforts will be directed at developing the east and southeast coasts, the most ambitious one being the Desaru Resort Development Project. The present influx of tourists to the Project coastline is primarily associated with seafood restaurants. In the foreseeable future, mangrove nature parks may generate some increase. It is not possible at present to put a monetary value to these recreation-based and tourism-related benefits, hence economic effects of a sea-level rise cannot be calculated.

In terms of population affected by a one-metre rise in sea level, a rough estimate (based on a linear distribution of settlement pattern in a shore-normal direction) is in the region of 40,000. This would include most fishermen/farmers who are dependent on coastal resources for their livelihood and generally reside within 3 km of the coastline. Social tension resulting from relocation, dislocation and the need for alternative employment, especially for the fishing communities, is likely to be significant.

### 2.5.3 Discussion

Leaving aside policies for limiting global warming (which require global effort and co-operation), responses to sea-level rise may include the following strategies:

i) Retreat from the shoreline.
ii) Defence of the coast line.
iii) Nourishment of the beach area.

The abandonment option as embodied in strategy i) is unrealistic for developed coasts such as urban centres and port facilities. For less developed coasts such as the Project Area, the planning decisions are less clear-cut, but would largely depend on site-specific socio-economic factors.

As estimated earlier, the economic loss due to a one-metre sea-level rise is estimated at about M$354 million plus other as yet non-quantifiable losses associated with infrastructure and tourism. About 40,000 coastal inhabitants are expected to be dislocated, both in terms of settlement and employment. These losses are unlikely to be acceptable.

Option ii) is an on-going effort under the National Coastal Erosion Control Plan, which encompasses a two-pronged strategy, namely, a focus on construction for critically eroding areas and a focus on management for other erosion areas. Invariably, the mitigation measure adopted is the direct strengthening of the coastal bund with quarrystones. Along the Project shoreline, up to 5 km of the coastal bund has been strengthened in this manner. The average cost of this work is about M$1 million/km.

With the projected sea-level rise, the wave climate incident on the Project coastline is unlikely to change due to the limited wind fetch even though the water depth would have increased. Hence, the same rock size for reinforcement can continue to be used. It will be necessary to raise the bund height to contain the higher sea level. Depending on the rate of the sea-level rise, the increase in bund height may further stress the marine clay foundation, which may lead to geotechnical instability. At present, the capacity of the marine clay as a foundation material has already been exceeded in some locations elsewhere. Hence, if the rate of loading is commensurate with the long-term rate of increase in the strength of the subsoil due to the process of consolidation, raising the height of the coastal bund to contain a rising sea is an economic and feasible proposition. Otherwise, more elaborate soil improvement and much gentler structure slope may be required to contain the sea advance.

The shore reinforcement strategy ensures the integrity of landward development, but on the seaward side, the loss of mangroves will continue. Similarly, there will be an added cost of pumped drainage as the drainage network would suffer a drop in efficiency due to the higher sea level.

The third strategy of beach nourishment is already a prevalent practice along sandy shores. However, its feasibility for mud coasts remains untested. A similar concept is that of profile adjustment where the entire active profile of sediment movement is nourished. However, to provide a more stable substrate for mangrove colonization, substantially more investment in the form of offshore structures that reduce incoming wave energy and promote sedimentation may be necessary. In addition, alternative forms of freshwater input (the continuous bund would have reduced this supply to precipitation only) would be required to provide a brackish environment essential for healthy mangrove growth.

Despite the current effort, it is felt that much more needs to be done. In this respect, the following areas have been identified to form the foci for future work:

i) The response of a shoreline to a rising sea is site specific, which renders aggregation of the likely impacts at the national level difficult. Further refinement of the study results is needed, particularly on other representative coastal areas, such as corals, recreation beaches and urban centres.

ii) Current knowledge of mud coast processes is very inadequate. Even though research efforts on cohesive sediment dynamics, especially in developed countries, have increased in response to the need for wetland protection and expansion into marginal areas, an improved understanding of the mechanics of mud coast erosion is unlikely to occur in the near future. This is especially true in developing countries such as Malaysia.

iii) Further gaps in knowledge identified in this study relate to the inadequate understanding of physiological responses of agricultural crops to prolonged flooding, water logging and elevated water table, and to the relationship between mangroves and fishery production.

## 2.6 POLICY RESPONSES

The probable impacts described above provided the basis for an assessment of the policy responses that would be necessary to adapt to or mitigate the impacts of climate change. A test policy exercise was carried out from 16th to 17th July 1990 at Genting Highlands (near Kuala Lumpur), with the objective of identifying appropriate policy responses. The policy responses identified were based on discussions between various experts representing a wide spectrum of government, research and university institutions. Due to time constraints these policy responses were not subjected to thorough assessment of their sensitivity, nor was quantitative analysis of them undertaken. The policy responses that were identified, and which are summarised here, represent only the results of a preliminary assessment.

### 2.6.1 Agriculture sector

Policy responses for the agricultural sector were based on specific case studies, (eg. on rice growing in the Muda region) and on an assessment of changes in rubber yield to past variations in weather. Impacts on other agricultural crops were not available for analysis. In addition, impacts caused by changes in sea level, resulting in loss of agricultural land, were not considered in the policy exercise.

The policy options identified were as follows:

i) Breeding new crop varieties or clones that are adaptive to climate change. The maintenance of a broad genetic base for crops is also essential.

ii) Management of water resources to ensure more efficient water control and use.

iii) Policies to encourage changes in crop types, including establishment of a rice import policy taking into account potential production and future demand.

iv) Review of policy on income support subsidy, possibly increasing subsidies for crops whose yields are projected to decline (e.g. rice).

v) Review of the role of farmers' organizations (and co-operatives), encouraging more efficient use of land through land consolidation and sharing of materials, machinery and labour.

vi) Policies to reduce farm fragmentation and encourage more intensive agricultural practices.

vii) Environmental impact assessments for new land development schemes, taking into account possible future changes of climate.

viii) Diversification of employment opportunities to farmers in the agricultural and non-agricultural sectors, including training of farmers to acquire new skills.

ix) Awareness programmes for planners, project managers and farmers with respect to climate change.

x) Establishment of a (government) interagency planning group on climate change.

### 2.6.2 Water resources

As with agriculture, the evaluation of impacts on water resources due to climate change was based on a specific case study: the Kelantan River Basin. In order to enable extrapolation of results across the country, the water resource model would need to be run with hydrological inputs representing a range of local climates. The effects due to sea-level rise were not considered, though these would certainly alter hydraulic conditions particularly at the lower reaches of rivers. Low-lying areas could become permanently flooded, and saline intrusion could extend further upstream.

Policy options identified included the following:

i) Adoption of measures to prevent floods and alleviate water deficit through structural measures, for example, the development of dams and bunds and river channel improvement. This approach is likely to require heavy capital investment and cause other environmental and social impacts as a result of inundation of land, relocation of population and loss of forests and other natural resources.

ii) Adoption of non-structural responses that are likely to complement structural measures, such as the establishment of flood warning and evacuation plans and the regulation of land use. Mechanisms for monitoring hydrological, meteorological and land-use changes are essential components of the response. Policy guidelines in relation to the above should be established.

iii) Establishment of a water resource use and management policy which establishes priorities in water use, water pricing, water regulation and distribution. This policy should be used to guide the National Agricultural Policy and other policies dependent on water resources.

iv) Adoption of improved water management practices in hydropower generation, irrigation and water supply.

### 2.6.3 Coastal resources

Sea-level rise would cause inundation of coastal structures, increase the rate of coastal erosion as well as increase saline intrusion. The study examined policies based on these direct impacts due to sea-level rise. However, it was felt that the identification of policy responses required a more thorough investigation of socio-economic aspects such as employment, income levels and migration patterns which could not be easily assessed in the present study.

Policy options available for adapting to or mitigating sea-level rise include the following:

i) Review of existing structural measures to protect coastal areas and their enhancement, where necessary, to counter predicted sea-level rise; and/or the development of new structural measures at safe distances from the sea, including barriers to prevent sea-water intrusion along streams.

ii) Relocation of population and important infrastructure facilities from areas likely to suffer inundation.

iii) Development of a coastal resources management policy and plan for all coastal zones outlining, for example, types of land use, buffer zones and structural defense requirements.

iv) Monitoring of changes to coastal regions including erosion patterns, coastal currents, tides and land use.

### 2.6.4 Discussion

The policy responses outlined above represent the result of a preliminary assessment. Socio-economic variables such as employment, social status, income levels and distribution and migration patterns, are factors that should also be considered in formulating policies. These have, however, not been considered in this report. In addition, the responses identified thus far will need to be quantitatively analyzed to provide an indication of their practicality for implementation.

## 2.7 CONCLUSIONS

Under the scenario of climate change adopted for this study (the GISS "$2 \times CO_2$" climate):

i) The Malaysian Region would be 3° to 4° C warmer.

ii) Significant increases in the rainfall over Sarawak during January and February could be expected.

iii) Significant increases could occur in the intermonsoon rainfall of southwest Peninsular Malaysia during March, April and May.

These and other possible changes of climate were used as input data for impact studies on agriculture and water resources. For the study of coastal resources, a scenario of a 1m rise in sea level by the year 2090 was adopted.

There are many uncertainties with regard to the timing, magnitude and regional patterns of climate change. The IPCC has predicted a global mean temperature rise of about 0.3°C per decade (with an uncertainty of 0.2 to 0.5°C per decade), leading to a likely increase in the global mean temperature of about 1° C above the present temperature by the year 2025, and 3°C before the end of the next century, under Business-as-Usual Scenario (Houghton, *et al.*, 1990).

While there is some agreement among the various GCMs concerning possible future changes in temperature at the global level, there is less agreement regarding the predictions at regional scales, particularly for rainfall. The GISS model, like the other GCMs, is also unable to indicate what changes may occur in the pattern of extreme weather events.

Faced with all these uncertainties, it must be emphasized that the results of this report must be used with great caution. Nevertheless, they do give valuable insights of the potential impacts of climate change. The results are intended as a basis for exploring the options available to policy makers, particularly those which relate to decisions on long-term projects (i.e. those with lifetimes of 30 years or more) when climate change may become effective.

The main impacts discussed in this report are summarised below.

The maturation period for rice will be shortened on average by 4 to 5 days for the off-season crop and about 10 days for the main season crop. The impacts on the main-season crop will be more pronounced than on the off-season crop. The yield under the "$2 \times CO_2$" climate is estimated to be 12 to 22% lower than under current climate. Average irrigation demand is about 15% higher for direct-seeded rice. For transplanted rice the irrigation demand shows no consistent change and it is difficult to draw any firm conclusions on this.

The usual planting density for maize under normal cultural practices in Malaysia is about 53,000 plants/ha with a planting distance of 75cm by 25cm. In many instances, at this planting density, the changes brought about by climate change are minimal. Changes in yield or yield component can occur only if there is a drastic change in the amount of radiation received by the crop canopy. The small increase in temperature and precipitation shown by this simulation is still within the crop tolerance limit. However, physiological processes are affected to a certain degree by these small changes. The magnitude of the effects are greater with increases in the planting density. The effects of over crowding could lead to greater modification to changes in microclimatic parameters, particularly temperature and radiation interception. As maize is not a major cash crop in Malaysia, its socio-economic impact was not evaluated.

The study of oil palm production shows that on coastal soils the limiting factor is apparently the soil drainage condition. Therefore good drainage and water management techniques to keep the water at the desired level are very important in oil palm production for overcoming the impacts of climate change.

In the rubber industry, there are on-going development strategies especially in the area of plant breeding to boost yields and reduce production costs. Hence, despite potential adverse impacts from climate change, a net increase in total natural rubber production can be expected as a result of higher yields from new clones. Irrespective of climate change, there is already a slow outmigration of labour from rubber and other agricultural sectors to the urban industrial sectors. The move towards larger holdings is an expected evolution in management practice, and adverse climate change may hasten this process.

Because the studies on rice, maize and oil palm were site specific, it may not be appropriate to draw general conclusions from the results of these studies. It will be necessary to study other major crops as well as taking into consideration other factors (such as the impact of climate change on crop pests), in order to assess the full extent of the impacts of climate change on agriculture. At the same time, it is also important to note that on-going efforts to improve yields may offset the adverse effects of climate change on plant production. Results from these studies can be used to derive maximum benefits from the favourable responses of crops to climate change and to ameliorate the adverse effects.

Under the GISS "2 x $CO_2$" climate there would occur a significant increase in flood peaks in the Kelantan River (by about 9%), and in mean monthly water deficits during the drier months of January to April (by 30 to 35%). With changes in the water resources regime as a result of climate change there would be significant socio-economic impacts on the Kelantan River Basin. Policy responses in the form of appropriate development plans which take account of these impacts would therefore be required in order to minimize negative effects and derive maximum benefits in view of limited financial resources available. Although the results may be extended to give an indication of the effects of climate change on water resources in other parts of the country, similar studies for other major river basins, especially in Sarawak where significant changes in the rainfall pattern are expected, are necessary to provide detailed projections required for meaningful policy decisions.

The potential impacts of a one-metre sea-level rise were examined using the West Johor Agricultural Development Project Phase I. This study concluded that the consequences of sea-level rise might include further aggravation of the existing coastal erosion, increased tidal flooding which could result in loss of low-lying coastal farm lands, depletion of mangrove swamps due to drowning and increased danger of freshwater contamination due to saline intrusion. The implications for agricultural production, tourism, urban systems and industrial complexes, loss in infrastructure and cost implications of bund improvement have been considered in a general manner and need more detailed study. There is also a need for further research to improve the understanding of mud coast processes and the physiological responses of plants to the various physical impacts engendered by sea-level rise.

A climate change of the magnitude projected would, without doubt, affect almost every aspect of life in Malaysia. However, while the present study has been able to assess the bio-physical impacts of climate change, the socio-economic aspects have not been considered in detail.

# IV. 3 *ASSESSMENT OF SOCIO-ECONOMIC IMPACTS OF CLIMATE CHANGE IN THAILAND*

## 3.1 INTRODUCTION

About 60 per cent of Thailand's population gains its livelihood from agriculture. In addition, much of its urban population, particularly in the Bangkok area, lives within 1 metre above current mean sea level. The potential effect of global warming on agricultural output and on low-lying settlement thus provides the focus for this study.

## 3.2 CLIMATE SCENARIOS

Scenarios of possible future climate change were based on outputs from the Goddard Institute for Space Studies (GISS) General Circulation Model (GCM) experiments for a "2 x $CO_2$" equilibrium climate (see Section II). Under this scenario Thailand experiences an increase in average temperature of about 3 to 4°C. Probably more important are estimated changes in rainfall, which are given for three GCMs for Bangkok and Chiang Mai (Table 3.1). Under the GISS "2 x $CO_2$" climate Chiang Mai is drier in most months, except in July which is traditionally a dry spell during the northern rainy season. The change thus appears to imply a benefit for agriculture. However, August and September are estimated to receive only 73 and 89 percent of present rainfall and this would probably affect yield adversely. It is important, however, to note that other GCMs do not show such reductions in rainfall. The assessments of potential impacts are likely, therefore, to depend greatly on the type of scenario of climate change that is adopted.

## 3.3 EFFECTS OF CLIMATE CHANGE ON RICE PRODUCTION IN AYUTHAYA PROVINCE

### 3.3.1 Introduction

A case study was conducted of possible effects of climate change on rice yields in Ayuthaya Province in central lowland Thailand. The basic model used to estimate rice yield was the CERES rice simulation model (see Section III for full description). There are four main classes of input to the model: climate, soils, plant genetics and cultural practice. The climate inputs were radiation, temperature (maximum and minimum) and rainfall. The climate change scenario was generated by the General Circulation Model (GCM) of the Goddard Institute for Space Studies (GISS). Ratios of the difference between the GISS "2 x $CO_2$" and current climate runs (Table 3.2) were applied to the 25-year daily climate variables (radiation, maximum and minimum

**Table 3.1** **Precipitation (mm/day) at Bangkok (BKK) and Chiang Mai (CM) (30 yr avg) and ratio to GISS "2 x $CO_2$" climate**

| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BKK | 0.30 | 1.00 | 0.94 | 2.21 | 6.13 | 5.20 | 5.12 | 6.60 | 11.3 | 7.72 | 1.61 | 0.31 |
| Ratio: | | | | | | | | | | | | |
| GISS | 1.10 | 1.16 | 1.15 | 0.80 | 0.86 | 1.23 | 0.96 | 1.12 | 1.13 | 0.85 | 1.04 | 1.27 |
| GFDL | 1.41 | 0.92 | 0.69 | 1.76 | 1.00 | 1.19 | 1.38 | 0.96 | 1.02 | 1.26 | 1.00 | 1.23 |
| OSU | 1.13 | 0.93 | 1.06 | 0.73 | 1.23 | 1.28 | 1.53 | 1.15 | 0.98 | 0.94 | 1.03 | 0.97 |
| CM | 0.32 | 0.12 | 0.43 | 1.57 | 5.15 | 4.47 | 5.54 | 7.76 | 8.00 | 3.68 | 1.38 | 0.65 |
| Ratio: | | | | | | | | | | | | |
| GISS | 0.65 | 0.56 | 0.69 | 0.84 | 0.72 | 1.12 | 1.38 | 0.73 | 0.89 | 0.90 | 0.86 | 0.91 |
| GFDL | 1.03 | 1.59 | 1.34 | 1.04 | 0.78 | 1.57 | 1.11 | 0.95 | 1.39 | 0.86 | 1.78 | 1.33 |
| OSU | 0.89 | 0.99 | 1.08 | 1.03 | 0.98 | 1.00 | 1.08 | 1.03 | 0.93 | 1.07 | 0.97 | 1.12 |

**Table 3.2** **Ratio of GISS "2 x $CO_2$" climate to current climate (Ayuthaya, 1964-88) for radiation, temperature and precipitation.**

| Month | Radiation | Temperature | Precipitation |
|---|---|---|---|
| 1 | 0.941 | 1.011 | 1.221 |
| 2 | 0.973 | 1.009 | 1.341 |
| 3 | 0.992 | 1.008 | 1.289 |
| 4 | 1.069 | 1.008 | 0.783 |
| 5 | 1.100 | 1.009 | 0.667 |
| 6 | 1.023 | 1.013 | 1.220 |
| 7 | 1.031 | 1.012 | 0.818 |
| 8 | 1.021 | 1.009 | 1.288 |
| 9 | 1.027 | 1.009 | 1.237 |
| 10 | 1.040 | 1.014 | 0.820 |
| 11 | 1.096 | 1.012 | 1.085 |
| 12 | 0.973 | 1.014 | 1.355 |

temperature and precipitation for 1964-1988). Two sets of experiments (for current climate and for the GISS "2 x $CO_2$" climate) were thus conducted with the rice model.

The experiments used the weather data available from the Bangkok meteorological station. No other stations provide data on daily radiation. Data on soils, plant genetics and cultural practice were obtained from the study area, Ayuthaya province. These are described below.

### 3.3.2 The study area and general characteristics of households

The area chosen for the Thailand case study was Pranakhorn Sriaythya province (Ayuthaya) in the central region of the country. It is a province about 75 kilometres north of Bangkok with a total area of 2,547.6 sq.km.

Of the total 114,606 households in 1986, 69,119 (60%) were in agriculture. Results of a 1984 village survey showed that nearly 70% of agricultural households earned their income from a single activity (Table 3.3). Rice and hired labour were the major sources of earnings for the households engaged in a single activity. Among the households in which rice was cultivated about 47% of them earned income from rice only.

**Table 3.3** **Composition of households with single and multi-activities, Ayuthaya province, 1984**

| | |
|---|---|
| Single activity | 49,640 |
| rice | 18,057 |
| field crops | 436 |
| hired labour | 23,654 |
| other | 7,493 |
| Multi-activities | 22,151 |
| rice and field crops | 1,498 |
| rice and others | 16,958 |
| field crops and others | 374 |
| rice, field crops and others | 2,192 |
| Total | 71,791 |

Source: Ministry of Agriculture and Co-operative, *Agricultural and cooperative development approach for Changwat Pranakhorn Sriayuthaya*, no date (in Thai).

#### 3.3.2.1 Land use

Of the total land in the province, 85% is in agriculture (rice cultivation accounts for 96% of this and the remainder is in field crops and fruit trees). Thirty-seven per cent of households in the province own land, another 30% are landless. The remaining households both own and rent land.

### 3.3.2.2 Irrigation

There are large, medium and small scale irrigation schemes in the province. About 1.23 million rai (196,800ha) of land are under 15 large and medium scale schemes. There are 191 deepwell irrigation projects and other small irrigation schemes in the province. All of the province is partially irrigated and about one-half of the land is fully irrigated.

### 3.3.2.3 Agriculture

Average rice yield of the first crop of the 3 years 1987-1989 was 2,075 kg/ha, compared to the 2,162 kg/ha average for the central plain. Similarly, average rice yield of the second crop was 3,637 kg/ha, lower than the 3,850 kg/ha average of the central plain. In contrast, the average yield of the first glutinous rice crops of the province was 2,437 kg/ha, higher than the regional average (2,025 kg/ha).

Seventy-six per cent of agricultural income of farmers in the province is from rice, 17% from livestock and the remaining from other crops and fisheries (Table 3.4).

**Table 3.4 Average agricultural income by sources (bath/ha).**

| Source | Income | % of total |
|---|---|---|
| Rice | 97,087 | 75.9 |
| Field crops | 11,662 | 0.9 |
| Vegetables | 1,456 | 1.1 |
| Fruit trees | 550 | 0.4 |
| Fisheries | 5,831 | 4.6 |
| Livestock | 21,800 | 17.0 |
| Total | 138,386 | 100.0 |

Source: Ministry of Agriculture and Co-operatives, *Agricultural and co-operative development approach for Changwat Pranakhorn Sriayuthaya*, no date (in Thai).

### 3.3.2.4 Rice Culture in the area

There are about 190,000 hectares of planted rice land in the province. More than half of the total rice area (about 60%) is planted with deep-water rice. The rest is irrigated and mainly planted with local new varieties. Two rice crops per year are planted in irrigated low land and only a single crop per year in the deep-water area. Chemical fertilizer is applied twice, about 20 days and 50 days after planting. The amount varies between each application and crop (Table 3.5). Transplanting is mainly used for the main crop and direct seeding for the second crop.

### 3.3.2.4.1 Genetic variables

Five varieties of rice are currently grown in the area. Their genetic characteristics are important inputs in the CERES rice model (for example, differences in the length of the grain filling period affects yield substantially). Six main genetic characteristics are included in the model as genetic variables. Unfortunately, several of genetic coefficients required were not available and estimates were made by a rice genetic expert (Table 3.6). The Pinkaew variety is planted in the deep-water area and is photo sensitive, the remaining varieties are planted in low-land areas and are non-photosensitive.

### 3.3.2.4.2 Soil characteristics

There are four major soil types in the region - Ayuthaya, Sena, Rachburi and Singburi series. As with the genetic coefficients, the soil profiles required by the CERES model, were not readily available and the coefficients had to be estimated on the basis of the most similar soil types available and the judgement of soil experts. Due to the lack of available data and the nature of the soil profiles, only two soil types were used for the simulation - Ayuthaya (soil type 1) and Rachburi (soil type 2).

### 3.3.3 The estimated effects of climate change

Using the model and the parameters described above, several effects on yield of different combinations of climate, soil types, genetics and cultural practices were analyzed. Simulations were completed for both main and off season crops. The results of these are summarised below.

### 3.3.3.1 The main crop

The absolute values of yield estimated for the current climate and GISS "2 x $CO_2$" climate are not consistent with actual observation. The modelled yields of transplanted rice are much higher than the national average of about 2,000 kg/ha. On the other hand, yields of direct-seeded rice are lower than expected, particularly without the addition of fertilizer (Table 3.7). Such a high

**Table 3.5** **Timing, quantity (kg/ha) and type of fertilizer used.**

| Crop | Application | Days after planting | Quantity | Type |
|---|---|---|---|---|
| First | 1 | 20 | 20-25 | 16-20-0 |
| | 2 | 50 | 20-25 | 16-20-0 |
| Second | 1 | 25 | 30-35 | 16-20-0 |
| | 2 | 50 | 25 | 21-0-0 |

**Table 3.6** **Genetic coefficients for rice varieties**

| Genetic Variable | Pinkaew | GK7 | GK11 | GK21 | GK23 |
|---|---|---|---|---|---|
| Length of vegetative period | 937.5 | 525 | 1,075 | 325 | 525 |
| Increase in length of reproductive period | 257.3 | 257.3 | 257.3 | 257.3 | 257.3 |
| Length of grain filling period | 750.0 | 750.0 | 750.0 | 750.0 | 750.2 |
| Optimum photo period (hours) | 10 | 10 | 10 | 10 | 10 |
| Potential grain number | 75 | 75 | 75 | 75 | 75 |
| Kernel weight (gm/kernel) | .0306 | .0282 | .0334 | .0274 | .0271 |

**Notes: Length vegetative period is in degree days (above 8°C) from emergence to end of juvenile stage.**
**Increase in length of reproductive period is in degree days.**
**Length of grain filling period is in degree days (> 8°C).**

fluctuation and inconsistency is most likely due to the model itself. Normally, any model to be used in a particular area should be validated by field data and observation; this had not been done for the Thai case.

In addition to the lack of validation, the simulation of rice yield is found to be quite sensitive to some genetic coefficients such as the grain filling period. Because of the limitation of both the model and the data, the analysis of climate change on rice yield is confined here to relative changes. If data on absolute change in rice yield are required, the model would need to be validated carefully to reflect the local environment and local data.

The conditions set for the analysis were as follows:

. Two soil series: Ayuthaya (soil type 1) and Rachuri (soil type 2).

. Five rice varieties: Pinkaew (photo-sensitive), GK7, GK11, GK21 and GK23 (all non-photo sensitive).

. Cultural practices: transplanting and direct seeding, with (two applications) and without fertilizer.

. No water stress for main season, fully-irrigated for off season.

**Table 3.7** 25 year average rice yield, current climate and GISS "2 x $CO_2$", main season, Ayuthaya province, Thailand

| Soil | Var. | Planting | Fertilizer | Current climate | Yield (kgs/ha) GISS "2 x $CO_2$" | % Change |
|---|---|---|---|---|---|---|
| 1 | PINKAEW | TRANS | YES | 10,027 | 10,313 | 2.85 |
| | | | NO | 9,834 | 10,313 | 4.87 |
| | | DIRECT | YES | 1,760 | 1,906 | 8.28 |
| | | | NO | 501 | 508 | 1.46 |
| | GK7 | TRANS | YES | 9,467 | 9,645 | 1.88 |
| | | | NO | 9,467 | 9,645 | 1.88 |
| | | DIRECT | YES | 2,497 | 2,586 | 3.65 |
| | | | NO | 452 | 456 | 0.79 |
| | GK11 | TRANS | YES | 10,243 | 10,617 | 3.66 |
| | | | NO | 10,243 | 10,617 | 3.66 |
| | | DIRECT | YES | 1,937 | 1,975 | 1.98 |
| | | | NO | 464 | 482 | 3.97 |
| | GK21 | TRANS | YES | 9,113 | 9,183 | 0.77 |
| | | | NO | 9,113 | 9,183 | 0.77 |
| | | DIRECT | YES | 1,226 | 1,920 | 56.61 |
| | | | NO | 455 | 342 | -0.13 |
| | GK23 | TRANS | YES | 9,463 | 9,637 | 1.84 |
| | | | NO | 9,463 | 9,637 | 1.84 |
| | | DIRECT | YES | 1,661 | 2,593 | 56.12 |
| | | | NO | 455 | 342 | -23.08 |
| 2 | PINKAEW | TRANS | YES | 10,027 | 10,313 | 2.85 |
| | | | NO | 9,834 | 10,313 | 4.87 |
| | | DIRECT | YES | 1,521 | 1,615 | 6.17 |
| | | | NO | 403 | 409 | 1.39 |
| | GK7 | TRANS | YES | 9,467 | 9,645 | 1.88 |
| | | | NO | 9,467 | 9,645 | 1.88 |
| | | DIRECT | YES | 1,654 | 1,707 | 3.18 |
| | | | NO | 354 | 355 | 0.16 |
| | GK11 | TRANS | YES | 10,243 | 10,617 | 3.66 |
| | | | NO | 10,243 | 10,617 | 3.66 |
| | | DIRECT | YES | 1,453 | 1,523 | 4.82 |
| | | | NO | 340 | 413 | 21.47 |
| | GK21 | TRANS | YES | 9,113 | 9,183 | 0.77 |
| | | | NO | 9,113 | 9,183 | 0.77 |
| | | DIRECT | YES | 1,777 | 1,837 | 3.39 |
| | | | NO | 342 | 341 | -0.30 |
| | GK23 | TRANS | YES | 9,463 | 9,637 | 1.84 |
| | | | NO | 9,463 | 9,637 | 1.84 |
| | | DIRECT | YES | 1,661 | 2,593 | 56.12 |
| | | | NO | 342 | 342 | -23.08 |

- Plant population 100 plants/m$^2$ for direct seeding and 16 hills/m$^2$ for transplanting.

#### 3.3.3.2 Change in yield

The results (Table 3.7) show that under the "2 x $CO_2$" climate change projected, rice yields in Ayuthaya province would generally increase (with some exceptions, i.e. GK21 and GK23 varieties). Yields would increase up to 8%. In most cases, however, the benefits would be marginal and have a negligible effect on farmers' income.

For transplanted rice with no water stress, the soil type has no effect on rice yield. The same is true for fertilizer application. The results from the with/without fertilizer simulation are unexpected, probably being due to the model itself, and should thus be reinvestigated.

In contrast, under the direct-seeding condition, rice yields on soil type 1 are slightly higher than on soil type 2. Farmers with soil type 1 gain from climate change slightly more than those with soil type 2. Again, taking into account the time span of 30-40 years, such a difference is negligible.

Effects on yield were observed for different rice varieties. The results, however, throw some doubt on the model's validity for the Thai case. For example, yields for Pinkaew variety, (a deep-water rice), are similar to yields of all low land high-yielding varieties while, in practice, yields of the latter are much higher.

#### 3.3.3.2.1 Yield variation

In addition to changes in average rice yields, another aspect of change which is important to small and semi-subsistence farmers is the change in yield variation. Climate change can affect yield variation and hence become a risk to farmers.

Most farmers in Ayuthaya are commercial farmers and the risk aspect might not be so important as it is in other regions. Nevertheless, increasing risk can also affect competitiveness of substitute crops and hence agricultural diversification.

The effect of climate change on yield variation was analyzed from changes in standard deviation of yield between the model runs for current and "2 x $CO_2$" climate. For the main season crop the analysis was done only for soil type 1.

In general, there is no conclusive change in the pattern of yield and its variation. For transplanted rice with no water stress there is a trade-off between higher yield and greater yield variability, particularly for Pinkaew, GK11 and GK21 varieties. For GK7 and GK23, the yields are higher and the variation is less (Table 3.8 and Figures 3.1 a to f). The extent of the trade-off varies from variety to variety. For instance, an increase in yield of 4% of the GK11 variety is accompanied by an increase in yield fluctuation of 3%, while an increase in yield of less than 1% for the GK21 variety corresponds with an increase in yield variation of more than 7%.

Similar to the case for transplanted rice, mixed results are obtained for yield and risk in both fertilized and non-fertilized direct seeded rice in Ayuthaya. For certain varieties, there is an additional gain of higher yields with less variation but for some varieties there is a trade-off between the two (Table 3.8).

#### 3.3.3.3 The off-season crop

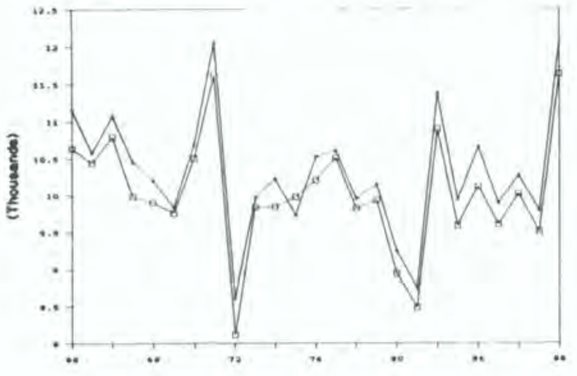
Off-season rice is grown only in low-land irrigated areas. Planting, mainly by direct seeding, takes place from the middle of December to early February. Chemical fertilizer is applied twice (30 kg/ha and 25 kg/ha) about 25 days and 50 days after planting. Full irrigation is assumed. A simulation was done for both soil types. The results are shown in Table 3.9.

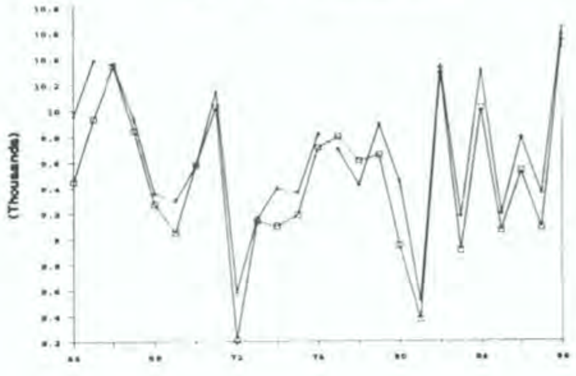
Yield increases are observed for all varieties and soil types except for the GK11 in soil type 1. Yields of most varieties increase by about 5% under the "2 x $CO_2$" climate. A more positive effect is observed on soil type 2 than on soil type 1.

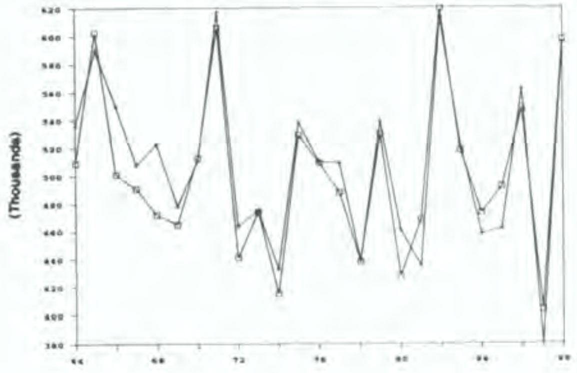
Climate change also causes greater variability of rice yield. Except for the GK11 variety in soil type 1, all off-season rice crops exhibit higher production uncertainty under the "2 x $CO_2$" climate (ranging from 3% to more than 40%). The percentage increase in yield variation is more than the percentage increase in yield for all cases (Table 3.9). The benefit from higher yields of the off-season crop, as with the main crop, is thus off-set by higher yield variation.

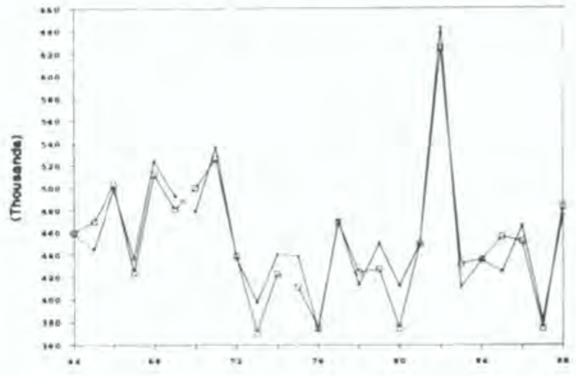
### 3.3.4 Limitations

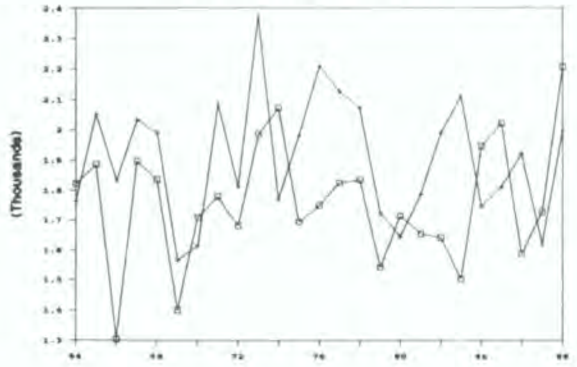
It should be emphasised that the analysis of the potential effects of climate change on rice production were limited by difficulties with the CERES model and its applicability. The model was not validated against observed data. Impact experiments were run for only one site (Ayuthaya


(a) Pinkaew, Transplant, Fertilized, Main


(b) GK7, Transplant, Fertilized, Main


(c) Pinkaew, Direct, Non-Fertilized, Main


(d) GK7, Direct, Non-Fertilized, Main


(e) Pinkaew, Direct, Fertilized, Main

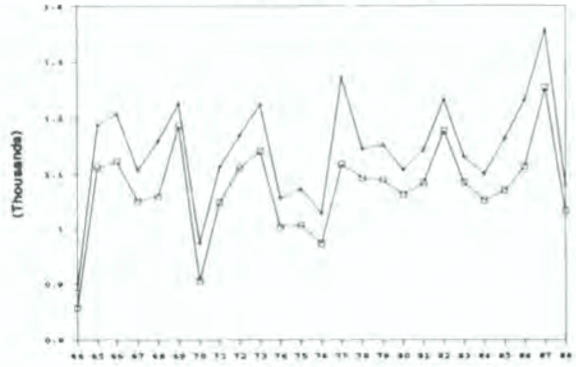

(f) GK7, Direct, Fertilised, Off, Soil 1

**Figure 3.1** Simulated rice yields under current climate (1951-75) and under GISS "2 x $CO_2$" climate. □ = current climate, + = GISS "2 x $CO_2$" climate.

**Table 3.8** **Effects of climate change on quantity and variation of rice yield, main season, Ayuthaya province, Thailand**

| Soil Variety | Planting practice | Fertilize | Yield (kg/ha) | |
|---|---|---|---|---|
| | | | Quantity | Variation |
| 1 PINKAEW | TRANS | YES | 2.85 | 4.3 |
| | DIRECT | YES | 8.28 | -0.92 |
| | | NO | 1.46 | 2.39 |
| GK7 | TRANS | YES | 1.88 | -6.58 |
| | DIRECT | YES | 3.65 | -12.72 |
| | | NO | 0.79 | -0.66 |
| GK11 | TRANS | YES | 3.66 | 2.62 |
| | DIRECT | YES | 1.98 | 3.60 |
| | | NO | 3.97 | -4.56 |
| GK21 | TRANS | YES | 0.77 | 7.58 |
| | DIRECT | YES | 56.61 | -1.46 |
| | | NO | -0.13 | -5.16 |
| GK23 | TRANS | YES | 1.84 | -6.20 |
| | DIRECT | YES | 56.12 | 3.67 |
| | | NO | -23.08 | 0.72 |

Province). The direct "fertilizing" effect of increased atmospheric $CO_2$ was not considered.

## 3.4 EFFECTS OF SEA-LEVEL RISE IN KANCHANADIT DISTRICT, SURAT THANI PROVINCE

### 3.4.1 Introduction

For the purpose of the case study in Thailand, two figures for sea-level rise were used - 0.5m and 1.0m over the next 100 years. A case study was made in the district of Southern Surat Thani province (Amphur Kanchanadit).

Kanchanadit is an Amphur (a district) of Surat Thani Province in Southern Thailand. It is approximately 650 kilometres from Bangkok. The district covers an area of 1,113 km$^2$ or 695,625 rais (111,300ha) and is composed of 12 Tambols (sub-districts). It is one of seven districts of Surat Thani Province which are situated on the Ban Don Bay. Its shoreline extends eastward for 22 kilometres. Along the coastline is a mangrove forest which has been mostly converted into shrimp farms. The central part of Kanchanadit District is flat land which is suitable for rice cultivation. The land rises gradually from the coast to a hilly area which is suitable for para-rubber, oil palm and fruit orchards. Many types of minerals are also found in this inner zone. The area has a typical Thai shoreline, with shrimp farming and rice farming as important economic activities.

Although a rise in sea level could affect many aspects of the coastline (e.g. saline intrusion, coastal erosion, etc.) the present study deals only with the effects of land inundation.

**Table 3.9** **Effects of climate change on rice yield, direct seeded, fertilizer applied, off-season, Ayuthaya, Thailand**

| Soil | Variety | Yield (kg/ha) Current climate | GISS "2 x $CO_2$" | % Change | Yield variation % Change |
|---|---|---|---|---|---|
| 1 | GK7 | 1,073 | 1,141 | 5.96 | 16.43 |
| | GK11 | 1,074 | 895 | -20.00 | -5.72 |
| | GK21 | 1,226 | 1,291 | 5.03 | 8.93 |
| | GK23 | 1,084 | 1,145 | 5.33 | 10.54 |
| 2 | GK7 | 1,047 | 1,113 | 5.93 | 14.59 |
| | GK11 | 848 | 846 | 1.51 | 3.31 |
| | GK21 | 1,059 | 1,266 | 16.35 | 41.22 |
| | GK23 | 1,059 | 1,125 | 5.87 | 17.75 |

### 3.4.2 Method and results of study

From field investigation a sand dune line was found approximately 3-4 kilometres from the present shore line and at about 1 metre above the present sea level. This line was used to define the area likely to be inundated by a 1 metre rise in mean sea level.

With the help of the Royal Thai Navy's Department of Hydrography the potential areas of flooding due to sea-level rises of 0.5 to 1.0 metre were mapped (Figures 3.2 and 3.3). The map showing areas of inundation were then superimposed on present land use maps to give an indication of the potential first order impacts. The results are shown in Table 3.10.

### 3.4.3 Policy implications of a sea-level rise.

As inundation occurs the present paddy lands and other agricultural areas would probably be converted to shrimp ponds. Resettlement of the local population would be necessary and the government would need to provide the necessary infrastructure for the new area of resettlement.

Within the flood prone region there are areas which will remain dry due to the rolling topography. On these areas the present activities may continue but perhaps with increased production costs. Some of the lands subject to inundation could be protected from flooding and continue their production if sufficient investment is made. This requires the government's attention and assistance, possibly in the form of credits, and the development of appropriate technologies and necessary infrastructures.

## 3.5 POLICY IMPLICATIONS

The case studies considered in this report were confined to small areas which are insignificant when compared with Thailand's overall rice and shrimp production. Hence the results can be extrapolated to the national policy level only with the greatest degree of caution.

The rice model which links the climate model with the crop production model is not sufficient for suggesting a meaningful national policy. The model itself, with calibrations to match the local environment, was able to give good predictions of rice yields. However, it does not include other crops. In the dynamic world people adjust themselves to changing economic conditions; in order to evaluate the possible selection of other crops as an adjustment to a changing climate it is necessary to use relevant crop prediction models (for example models for maize, cassava and other annual crops which could possibly replace rice). Without these models it is not possible to consider policy measures for coping with the climate change impacts on different crops.

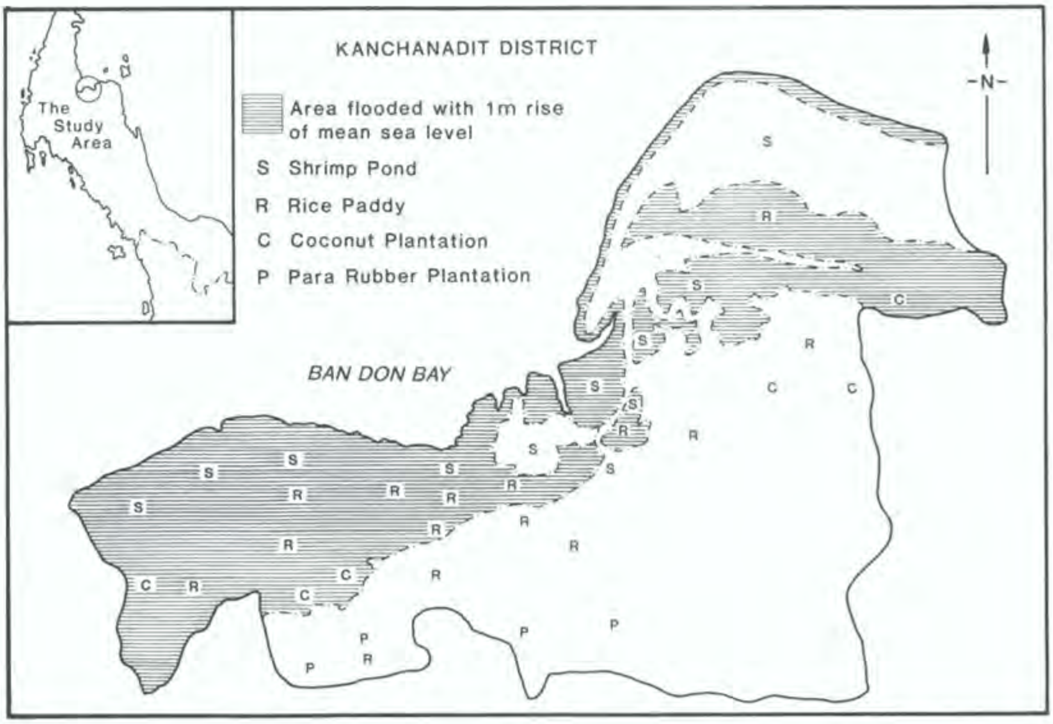


**Figure 3.2** Flooded area at 1.0 metre sea-level rise, Kanchanadit District, Thailand.

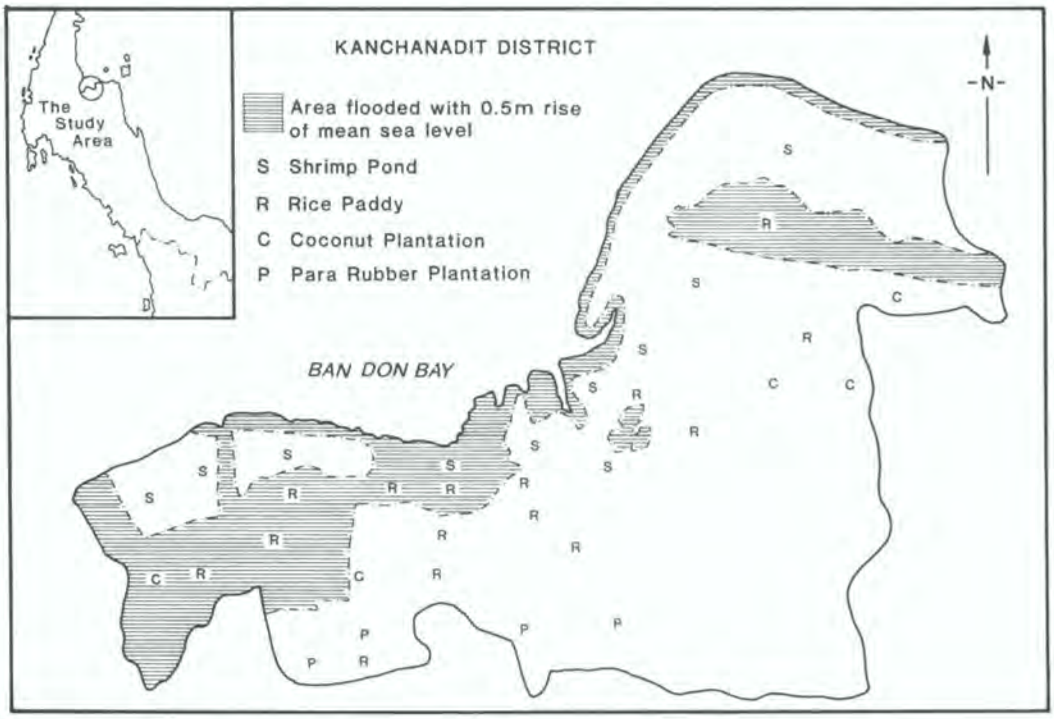


**Figure 3.3** Flooded area at 0.5 metre sea-level rise, Kanchanadit District, Thailand.

**Table 3.10** **First Order Impacts of sea-level rises of 0.5-1.0 metre, Kanchanadit District, Surathani Province, Thailand**

| | $Km^2$ | Rai |
|---|---|---|
| 1. Total area of Kanchanadit District (12 sub-districts) | 1,113.0 | 695,625.0 |
| 2. Area of 5 sub-districts under the survey | 203.2 | 127,027.5 |
| Present land use classification | | |
| - Shrimp pond | 63.5 | 39,664.5 |
| - Rice paddy | 64.5 | 40,300.0 |
| - Coconut plantation | 14.4 | 9,025.0 |
| - Para-rubber plantation | 20.1 | 12,587.5 |
| - Community land | 40.7 | 25,450.6 |
| 3. Inundated area: <u>0.5 metre sea-level rise</u><br>Total inundated area | 46.8 | 29,261.9 |
| Land use classification | | |
| - Shrimp pond | 8.8 | 5,524.4 |
| - Rice paddy | 26.9 | 16,832.5 |
| - Coconut plantation | 3.1 | 1,912.5 |
| - Para-rubber plantation | - | - |
| - Community land | 7.9 | 4,992.5 |
| Plus 5.68 kilometres of road being submerged under sea water. | | |
| 4. Inundated area: <u>1.0 metre sea-level rise</u><br>Total inundated area | 74.4 | 46,490.6 |
| Land use classification | | |
| - Shrimp pond | 23.3 | 14,490.6 |
| - Rice paddy | 32.5 | 20,297.5 |
| - Coconut plantation | 8.3 | 5,162.5 |
| - Para-rubber plantation | 1.2 | 765.0 |
| - Community land | 9.1 | 5,680.0 |
| Plus 21.2 kilometres of road being submerged under sea water. | | |

The present study of sea-level rise impacts has another shortfall. Since it does not include a study of beach erosion and shore morphology within the study area, the results are incomplete. The actual land area subject to inundation by a 0.5 or 1.0m rise over 100 years would be affected by the processes of erosion and salinization and policy decisions must consider these effects.

As in the case of rice farming, shrimp farmers will adjust themselves to economic forces which change over time. A one-metre sea-level rise over 100 years indicates a gradual change of the physical condition within the study area and this allows for the farmers' adjustment to the changing environment. The kinds of adjustment likely to occur are difficult to assess as they will depend on many factors such as technology and market many factors such as technology and market prospects for shrimp and related commodities. Other economic activities such as marine fishing may also influence the farmer's decision.

Although the limited case studies in the two areas of Ayuthaya and Surat Thani Provinces are not a sufficient basis for discussion of national policies in response to impacts of climate changes, the project has been able to draw to the attention of policy makers the potential impacts of climate change.

A partial analysis of sea-level rise in Surat Thani Province provides information relevant to policy decisions. Even with a rising sea level it is assumed that shrimp production will continue to be the dominant economic activity of the area. Without significant changes in the Thai economy, shrimp will continue to be an important commodity for both export and local consumption. Thus the choice of protecting or abandoning the shrimp ponds in the Kanchanadit District will depend on the price of shrimp and the cost of preserving the present shrimp producing area.

Where it is not economical to make use of the flooded land, it is anticipated that all economic activities will be moved inland of a new shoreline. As the shrimp farm industry is now moving rapidly into capital intensive production, large shrimp producing companies will tend to occupy the shoreline and hence cause the resettlement of existing villages and households. The following are some issues which should be considered in formulating policies for the transformation of Kanchanadit District as a result of a rise in sea level:

i) Concentration of large shrimp producing companies tends to threaten the environment (e.g. water pollution) and adversely affect the local population.

ii) With the encroachment of big companies into the area, the livelihood of the local shrimp farmers is threatened by the increased pollution from the discharge of the larger shrimp industries.

iii) The rise in sea level will cause the inundation of some public facilities such as schools, public health centres, government offices, etc. The government must be prepared to provide these public services to the new settlements.

iv) Employment opportunities must be created for the people dispersed from the coastal area by the encroachment of large shrimp producing companies. These companies could provide employment as could other enterprises, such as marine culture. Employment in the service sector of the community is also possible and the government can play an important role in this.

v) In Kanchanadit District, the inner zone is mountainous and is covered with natural forests. It is the national policy to preserve as much natural forest as possible. With the loss of coastal land there would be pressure on this forest land which is under government supervision. This conflict of uses would need to be resolved by policies to accommodate both the displaced people and the need for preservation of the forest.

### 3.6 CONCLUSIONS AND RECOMMENDATIONS

It is beneficial, not only to Thailand but to the South-East Asia Region as a whole, that this project was initiated by UNEP and supported by the governments of Indonesia, Malaysia and Thailand. Although the Thai studies cannot be regarded as complete, they give a foundation for further research and a relevant framework for policy analysis which will become very important in the future. The study of rice yields in Ayunthaya Province is too limited in its scope, both in terms of area and crop alternatives, to be applicable to the country as a whole but it forms a basis for further work on the impacts of climate change on agriculture in Thailand.

The case study on sea-level rise did not include the problems of beach erosion and shore morphology in its analysis. Hence, it is not possible at present to do a dynamic and longterm study of the impacts of sea-level rise nor to formulate appropriate policy responses. However, it has been possible to identify some tentative primary impacts and some relevant policy issues.

In order to develop policies at the local and national level in response to the effects of a climate change resulting from a doubling of $CO_2$, the following recommendations are made:

i) The climate-crop production model needs expansion to incorporate other relevant crops into its system, i.e. maize, cassava, etc.

ii) This model, after being expanded, must then be validated for reliable results. It is necessary that the predicted absolute values be used in the analysis.

iii) The case studies carried out thus far are very limited in area and do not represent the Thai rice and shrimp economies. Therefore, more data and information must be drawn from studies of other regions and areas in order to formulate valid national policies.

iv) In order to understand the impacts of sea-level rise more thoroughly studies of shore morphology and erosion must be undertaken.

v) For the formulation of sensible policies, we need to know more about human responses to changing circumstances. This indicates the necessity of dynamic analysis which was not used in the present Thai study. Although dynamic analysis is complicated, requires a large amount of data and is difficult to develop, sensible and effective policy recommendations cannot be obtained without such analysis.

# V. *EFFECTS OF SEA-LEVEL RISE*

## 1. INTRODUCTION

The coastlines of Thailand (3,200 km), Malaysia (4,800 km) and Indonesia (80,000 km) total 88,000 km, and the population of the three countries (over 250 million) includes dense concentrations in coastal regions, notably to the north of the Bight of Bangkok and in northern Java. The coastlines are varied, with a high proportion of coastal plains, some sandy, others swampy or deltaic (Table 5.1), which have been built up by deposition of sediment during the past 6,000 years, while the sea has stood at, or close to, its present level. There are also sectors of steep and cliffed coast.

**Table 5.1 Proportions of coastal zones in Thailand, Malaysia and Indonesia**

| | Steep & cliffed coast | Sandy beach coast | Swampy/deltaic coast |
|---|---|---|---|
| Thailand | 10% | 56% | 34% |
| Malaysia | 6% | 51% | 43% |
| Indonesia | 16% | 32% | 52% |

Note - There are sectors where steep or sandy coastal zones have a narrow fringe of mangrove swamp, and where swampy or deltaic coastal zones are fringed by a narrow sandy beach. Reclamation and sea wall construction has produced artificial coastlines along some cliffed and beach-fringed coasts and the seaward margins of swampy and deltaic coasts, but the proportion of artificial coastline is still quite small (1 to 2%) in each of these countries.

## 2. PHYSICAL AND ECOLOGICAL EFFECTS

If global sea level rises in the manner predicted by the scenarios (see Section II), attaining a metre during the coming century, there will be extensive marine submergence of low-lying coastal areas (Titus, 1986, Bird, 1986). By the time global sea level has risen one metre, the highest tides will reach at least a metre above their present limits, for there will generally be a slight increase in coastal tide ranges as the oceans deepen. The low tide line will also move landward, so that at least part of the existing intertidal area will become permanently submerged. In detail there will be variations related to coastal configuration and nearshore sea floor morphology.

On hard rock coasts the high tide line a century hence can be estimated by surveying a contour one metre above the present high tide limit, but on most other coasts the extent of submergence will be increased by erosion as the nearshore waters deepen, so that larger and more destructive waves break upon the shore. Other factors that will modify the extent to which the coastline will retreat as the result of a one-metre sea-level rise include tectonic uplift or depression of the land margin, subsidence due to the extraction of groundwater, oil or minerals from the underlying strata, and subsidence resulting from the weight of the encroaching sea, especially where there are compressible soft sediments, such as peat, beneath the submerging area. There is also a possibility that climatic changes will result in an increased supply of sediment from rivers, augmented by heavier catchment runoff or depleted vegetation, or material from more rapidly eroding cliffs; this will in some places maintain or prograde the coastline, at least partly offsetting the land losses that would otherwise occur.

A sea-level rise will initiate erosion on many coasts that are at present stable or accreting, and accelerate it where there is already recession in progress. Coastline erosion will also increase where climatic changes lead to more frequent and severe storms and surges. The extent of erosion will depend largely on how the nearshore sea floor is modified by the rising sea as the coastline moves landward. Again there will generally be a deepening of nearshore waters and a consequent increase in wave energy and coastline retreat, but in areas where climatic change increases the sediment supply derived from fluvial or alongshore sources the transverse profile may be maintained, or even shallowed, in nearshore waters as the sea rises. In such cases wave energy will not be augmented, and there may be little, if any, coastline erosion.

The geomorphological and ecological changes that accompany a sea-level rise can already be seen and studied on coasts where land subsidence is in progress (Bird, 1988), but the predicted rate of global sea-level rise of one metre over the next century is faster than that recorded in any of the gradually subsiding coastal areas over the past century. The Venice region, for example, has subsided by up to 30 centimetres since 1890, largely because of groundwater extraction. Higher rates of subsidence have occurred as the result of sudden earthquakes - up to 2 metres on the Alaskan coast during the 1964 earthquake, and up to 1.6 metres on the Colombian coast during the 1979 earthquake - but the changes that resulted from such sudden events are not a reliable indication of what will happen during the gradually accelerating sea-level rise which has been forecast.

On the coasts of South-East Asia land subsidence (and hence a relative sea-level rise) has been taking place along the coast at the head of the Gulf of Thailand, especially in the Bangkok region where groundwater extraction has lowered the land surface by up to 1.6 metres during recent decades (Figure 5.1). There are also sectors of the west Malaysian coast, parts of the north coasts of Sumatra and Java, and some areas on the south coast of Irian Jaya, where it is thought that land subsidence is taking place. It is possible that land subsidence is contributing to the recurrence of flooding in the coastal suburbs of Jakarta.

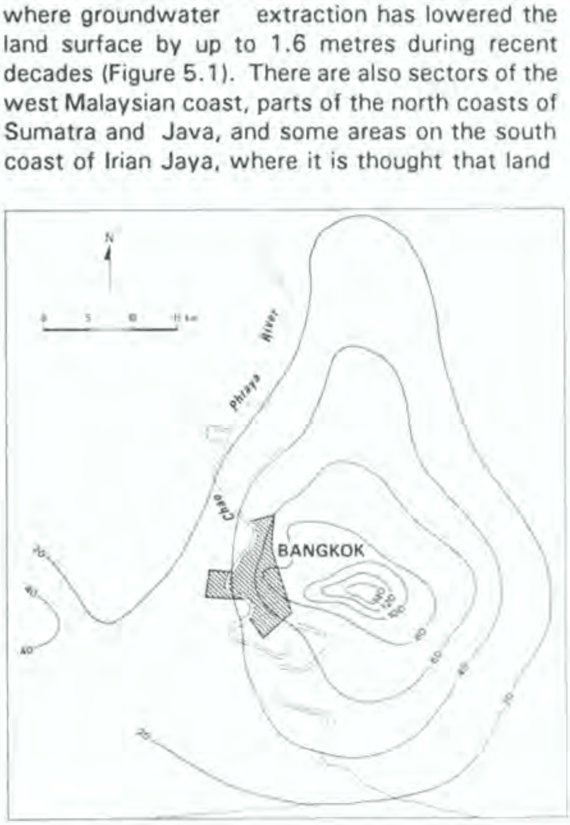


**Figure 5.1** **Contours showing the extent of land subsidence (in centimertes) in the Bangkok region between 1934 and 1978, due largely to groundwater extraction and the compression of depleted subsurface aquifers.**

In assessing the nature and extent of such changes, it is useful to recognise three broad categories of coastal zone: steep and cliffed coasts, sandy beach-fringed coasts, and swampy or deltaic coasts, most of which have (or had) extensive mangrove areas. Substantial parts of the swampy or deltaic coasts of South-East Asia have been converted for aquaculture or reclaimed for rice cultivation, plantation agriculture or urban development. In addition, river mouth environments, tidal mudflats, coral reefs and seagrass ecosystems will be treated as separate categories.

## 2.1 STEEP AND CLIFFED COASTS

Steep coasts in South-East Asia are generally slopes mantled with weathered material, held in place by a scrub and forest cover, rather than actively-receding cliffs. They are extensive around the Indonesian archipelago, and on headlands such as Cape Rachado in Malaysia and Cape Liant near Sattahip in Thailand. Occasionally there is slumping of the weathered mantle, especially after the slope foot has been undercut by storm waves. A rising sea level will generally deepen nearshore waters and submerge at least part of the existing intertidal zone, thereby intensifying wave attack at the base of these bluffs and accelerating erosion (Figure 5.2). They will be undercut to form basal cliffs, and slumping will become more frequent on the vegetated slopes.

There are already receding cliffs on the more exposed shores of promontories and islands, especially those washed by ocean swell and waves generated by the southwest monsoon, as on the Andaman Sea coast of Thailand and in south-western Sumatra. Where the cliffs are retreating very slowly because they are cut into resistant rock, as on the limestones of the Phangna region in Thailand, a rising sea level will simply enlarge basal notches upwards, but on softer formations such as volcanic ash in southern Java and the lateritic clay and sandstone headlands of Peninsular Malasyia, cliffs will be cut back more rapidly as the sea rises, and areas of land will be lost.

Where there are buildings, roads, and other structures close to the crests of cliffs and steep coastal slopes increased undercutting and slumping of the weathered mantle is likely to result in damage and destruction. For example, where

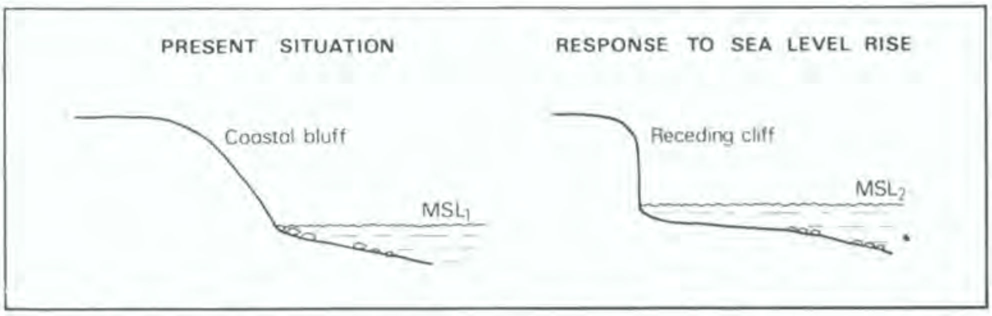


**Figure 5.2** **As sea level rises, coastal bluffs will become receding cliffs, and recession of existing cliffs will accelerate.**

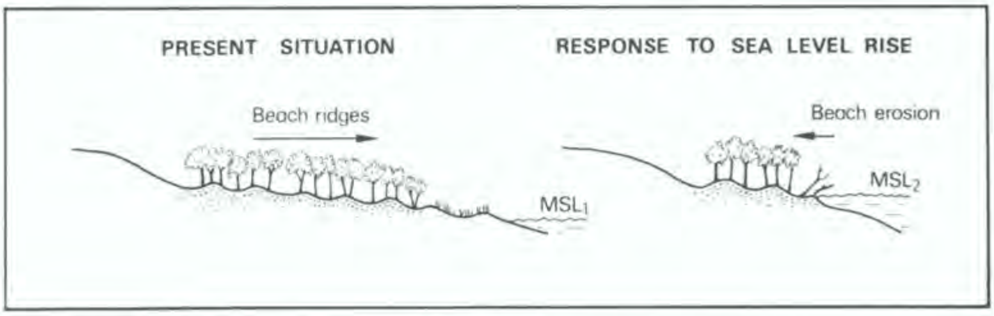


**Figure 5.3** **Where parallel beach ridges have formed, a rising sea level will result in the cutting back of their seaward margin.**

hotels have been built on top of headlands bordered by steep coastal bluffs in the Pattaya region, Thailand, accelerating erosion by a rising sea level will lead to demands for expensive engineering works to protect these sites.

## 2.2 SANDY BEACH COASTS

Sandy beaches occur extensively in South-East Asia. Some consist of sand washed in from the sea floor, which has locally been cemented to form beach rock; others have been supplied by rivers, especially those that drain steep and high catchments; and others are derived from the erosion of nearby cliffs. Many beaches are backed by low parallel sandy beach ridges, usually planted with coconut palms. This terrain, known as permatang in Malaysia, results from intermittent progradation of sandy beaches by accretion of sand washed up by wave action (Figure 5.3). Near Butterworth, for example, the beach ridge plain is 6 kilometres wide, and similar broad ridged sandy lowlands are found around the shores of the Gulf of Thailand (e.g. to the west of Rayong), and locally in Indonesia, especially along the south coast of Java west of Jogjakarta. Sometimes the beach ridges are surmounted by coastal dunes, as at Parangtritis in southern Java, and in places they are backed by, or intrespersed with, lagoons and swamps.

Sandy beaches are subject to short-term alternations, known as 'cut and fill', whereby they are cut back and lowered by erosion during stormy periods and rebuilt during calmer weather. This is well known along the east coast of Peninsular Malaysia, where beach erosion is severe each year in the northeast monsoon, and the beaches are at least partly restored during the calmer dry season. Beaches that are in equilibrium with the cyclic processes generated by wave action in nearshore waters show no net change over a period of a year or so. However, surveys of historical changes on sandy beaches around the world have shown that in recent decades erosion has been prevalent on many of them. More than 70% of the world's sandy coastlines have receded during the past century, less than 10% having prograded, while the rest have either remained stable or oscillated, with no net change (Bird 1985). The beaches of the South-East Asian region are no exception: erosion has prevailed on many of them over the past few decades. In Malaysia the National Coastal Erosion Study (1985) found that 27% of the coastline was retreating, and beach erosion has been widely reported from Thailand and Indonesia, especially along the coasts of southern Sumatra and West Java.

There are several reasons for the onset of beach erosion. On some sandy coasts the supply of sand from rivers has diminished as a result of dam construction and sediment interception upstream by reservoirs. On others there has been a reduction in sand supply from alongshore (especially where intercepting breakwaters have been built), or from the sea floor. There are places where wave attack has increased because of the deepening of nearshore water, especially where the land margin and nearshore zone have been subsiding. Some beaches have eroded as a consequence of sand extraction for road making and constructional purposes, or to obtain minerals such as tin or gold. In Thailand detrital tin deposits have been mined on the coast at Takua Pa and elsewhere, and silica sand has been extracted near Songkhla and Chumpon Rayong. Silica sand mining has also lowered beach ridges in East Johor, Malaysia, making them more vulnerable to erosion.

The predicted sea-level rise will initiate beach erosion, or accelerate it where it is already taking place. In general, submergence will result initially in the deepening of nearshore water, so that larger waves break upon the shore, increasing erosion (Figure 5.3). Bruun (1962) showed that a sea-level rise will result in erosion of the beach and removal of sand to the nearshore zone in such a way as to restore the previous transverse profile (Figure 5.4). This restoration will be completed when the sea has become stable at a higher level (cf. Scenario B in Figure 2.8, Section II). If the beach was initially in equilibrium with the processes at work on it, coastline recession will come to an end as a new equilibrium is achieved at the higher sea level, and it is possible to calculate how much retreat will occur, assuming no gains or losses from the hinterland or alongshore. However, this theoretical sequence is difficult to apply where the beaches are already in disequilibrium; and, as we have seen, beach erosion is already widespread. As sea level rises, there will certainly be a tendency for sand to be withdrawn from the beach to the sea floor, but the transverse profile will not be restored until the sea-level rise has come to an end. As long as the sea is rising, sandy coastlines will continue to recede as erosion accompanies submergence. Halting of coastline recession can only be predicted in terms of the more optimistic scenarios of global sea-level rise (Scenarios B and C in Figure 2.8), which will require international agreement and action to manage the Earth's atmosphere, and so control the Greenhouse Effect.

In practice, as sea level rises, sandy beaches will disappear from sectors where they are already narrow, and backed by high ground or mangrove swamps, but they will persist where they can retreat through wide beach ridge plains. As an approximation, a sea-level rise of one metre followed by a stillstand at that level will cut back most sandy beaches by 100 to 200 metres beyond the limits of submergence (Bird, 1985). Beaches that are already in retreat will be cut back further, but there may be some areas where the sand supply is maintained, either from cliff erosion, discharging rivers, or the sea floor, at a sufficient level to compensate for the effects of submergence. The indications are that these will be very localised in South-East Asia. If sea level continues to rise, beach erosion will proceed and extend far beyond these limits.

It should be emphasised that it is not possible to predict the location of a sandy coastline a century hence if sea level has risen one metre and is continuing to rise: all that can be said with this scenario is that in a hundred years' time most sandy coastlines will have retreated substantially, and that they will be eroding. If the sea rises at an increasing rate (Figure 2.8, A), beach erosion will correspondingly accelerate.

Beach resorts and tourist facilities have been developed extensively on low-lying sandy coasts in South-East Asia: especially on Bali in Indonesia, at Port Dickson, Penang and Kuala Trengganu in Malaysia, and at Pattaya and Rayong in Thailand. In many places, hotels have been built on beach ridges, and these will be threatened as the coastline is cut back by a rising sea. It is already obvious that structural works such as concrete sea walls and boulder ramparts will be built to protect developed seaside land, but such structures usually result in wave reflection, which deplete the beaches which were the original tourist attraction.

Artificial beach renourishment is an alternative, but it is expensive (in the order of $US 3 million/kilometre), and may only be feasible in a few intensively-developed urban resort areas such as Pattaya in Thailand, the north coast of Penang in Malaysia, and the resort beaches on Bali. Beaches have been renourished on a small scale at Port Dickson and, less successfully, at Morib in Malaysia. The cost of coast protection and beach renourishment will be too large to preserve long sectors of the coastline with a narrow seaside fringe of "ribbon development" of hotels and chalets, and these are likely to be abandoned. It will be easier to nourish and maintain artificial beaches in coves and embayments, as at Kata Beach on the west coast of Phuket in Thailand, than on long straight or gently-curving sandy

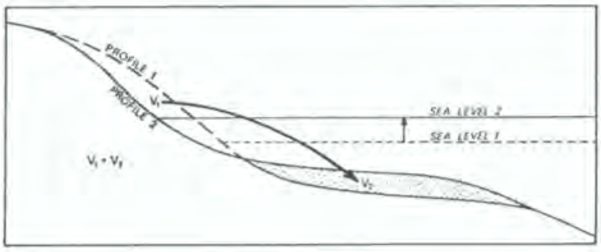


**Figure 5.4** **The Bruun Rule states that a sea-level rise will lead to erosion of a beach and deposition nearshore in such a way as to restore the initial transverse profile after the sea-level rise comes to an end. It applies to beaches that are in equilibrium with the processes at work on them, and neither gaining nor losing sand offshore, onshore or alongshore, when a sea-level rise begins. It cannot be used to predict the extent of coastline retreat where these conditions are not fulfilled, and where a continuing sea-level rise is in prospect.**

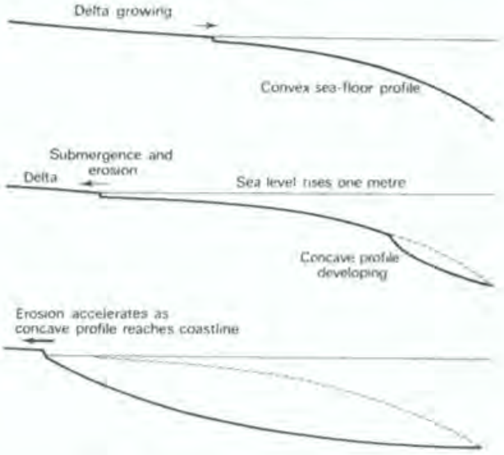


**Figure 5.5** **Effects of a sea-level rise on a delta. As sea level rises the delta margin is submerged, and erosion is initiated. Re-shaping of the nearshore sea floor from a convext to a concave profile results in accelerated erosion as the conc ave profile intersects the coastline. These effects will be reduced or cancelled, where the supply of fluvial sediment is sufficient to maintain a growing delta and a nearshore convex profile deposition.**

beaches of the kind found on the east coast of Peninsular Malaysia, which will require massive breakwaters to retain sand within nourished compartments.

## 2.3 SWAMPY AND DELTAIC COASTS

There are large areas of swampy lowland on the coasts of South-East Asia, especially along the shores of the deltas built where large rivers have delivered vast amounts of silt and clay to prograde the coast. They are very extensive on the northeast coast of Sumatra and the south coast of Irian Jaya. Swampy lowlands also fringe estuaries such as the Perak and Johor Rivers in Malaysia and the Sarawak River, and coastal lagoons such as Songkhla Lake in Thailand and the Segara Anakan in southern Java.

Sedimentation from rivers is still prograding deltaic areas. On the north coast of Java fluvial deposition around river mouths during episodes of flooding has been advancing the coastline locally by up to 200 metres/year, partly as the result of increasing sedimentation following deforestation and the introduction of agriculture in the steep hinterland. Such deposition will accelerate if rainfall and runoff from the river catchments is augmented as a consequence of global warming. However, a rising sea will tend to curb the growth of deltas, and if the rate of submergence is greater than the rate of deposition, their shorelines will be cut back (Figure 5.5).

Examples of this can already be seen on parts of subsiding delta coastlines which are receding because of a diminished fluvial sediment supply to the river mouths. On the north coast of Java some river mouths have changed naturally, during episodes of flooding, to a new outlet for subsequent delta growth, as on the Cimanuk, while others have been diverted by cutting canals to a new outlet, as on the Solo delta. The outcome has been rapid erosion of the abandoned delta lobes. On the Citarum delta, the onset of more general coastline erosion followed the completion of the Jatiluhur Dam upstream in 1970, after which the sediment supply to the coast diminished sharply. With a sea-level rise, such erosion will become still more widespread. A delay in the onset of severe erosion has been noted on formerly prograding deltas pending the change from a convex nearshore profile of progradation to a concave profile of erosion, and the effects of a rising sea, deepening nearshore waters, will be similar (Figure 5.4).

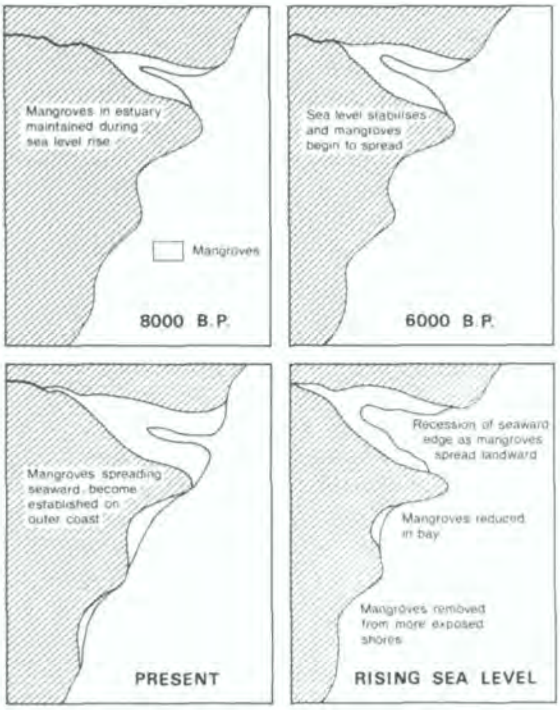


**Figure 5.6** **Changes in the extent of mangroves on a coastline in Holocene times. 8,000 years ago, when sea level was rising, mangroves were generally confined to estuaries where mud accretion kept pace with the rising sea. As the marine transgression ended about 6,000 years ago the mangroves began to spread, and now occupy embayments on the outer coastline. If sea level rises, mangroves will be reduced on the outer coastline, but may persist in muddy estuaries where accretion maintains their substrate.**

## 2.4 MANGROVES

The natural vegetation associated with the coastal lowlands of South-East Asia is mangrove swamp, backed by marshes and areas of fresh-water forest, but in many areas this vegetation has been profoundly modified by human activities, notably drainage and land reclamation. In the three countries mangroves occupy a total area of about 40,000 square kilometres. They grow in the upper part of the intertidal area, usually above the mean tide line. Where the sea is shallow and the coast sheltered, mangroves are spreading directly on to accreting tidal mudflats, but often the seaward fringe consists of a narrow sandy beach of sand which has been sorted by wave action. This is the case along the shores of the swampy lowlands on the west coast of Peninsular Malaysia, and in Sarawak and Sabah.

**Figure 5.7** **The present (1990) extent of mangroves on the coast of the Ranong district, south-west Thailand. A sea-level rise is expected to remove the mangroves on the outer coastline facing the Andaman Sea and greatly reduce them in the lee of the offshore islands.**

Mangroves have become extensive on these coasts during the sea-level still stand of the past 6,000 years. Before that, there was a phase of rising sea level in the Late Quaternary, beginning about 18,000 years ago (accompanying natural global warming and the consequent reduction of the Earth's glaciers and ice sheets), during which mangroves were confined to sheltered inlets and estuarine sites where they could migrate landwards, or persist on accreting muddy substrates as submergence proceeded. Stratigraphic studies in northern Australia have shown that mangroves were growing in such sites 8,000 years ago, and that when the Holocene marine transgression came to an end they spread out to other embayments and more exposed sites of muddy accretion along the outer coast (Figure 5.6). It is likely that a similar evolution took place in South-East Asia, notably in the Ranong area of western Thailand (Figure 5.7), along the shores of

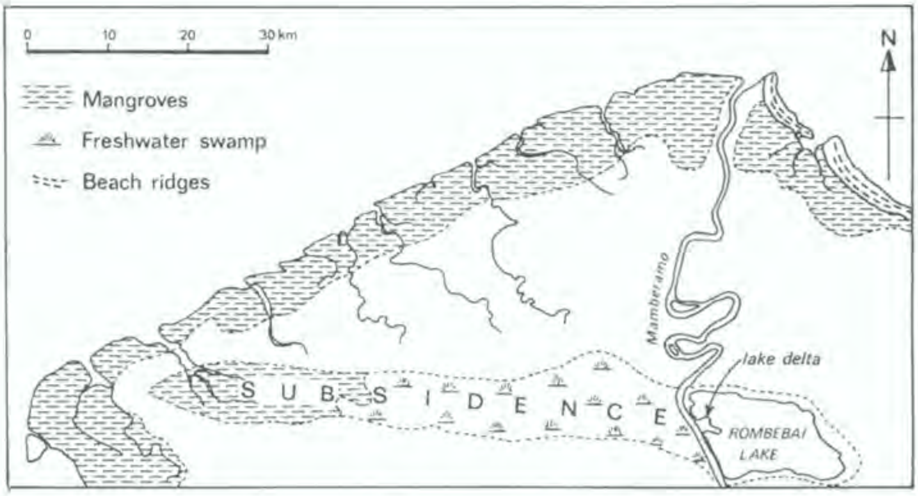


**Figure 5.8** The capacity of mangroves to retreat as sea level rises is indicated on sectors where subsidence of the land has occurred. On the Mamberamo delta, Irian Jaya, Indonesia, mangroves have spread back into the western part of a subsiding corridor across the southern part of the delta.

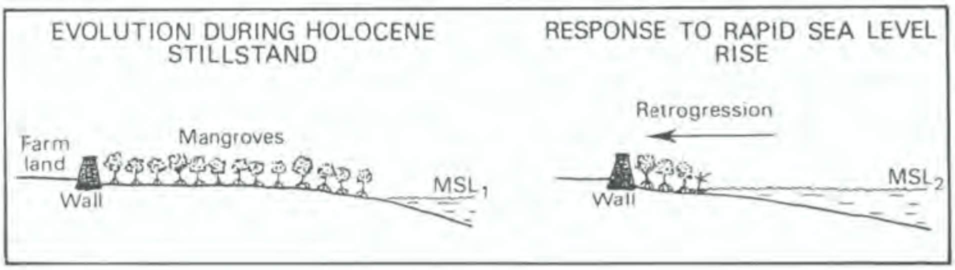


**Figure 5.9** As sea level rises the mangrove zone will tent to migrate landwards, displacing other vegetation, as the outer shore is cut back by erosion. In many areas, however, the mangroves are backed by a wall (or bund) built to protect farmland from marine flooding. The rising sea will erode the mangrove fringe, which will become narrower, and eventually disappear, leaving the wall exposed to wave attack at high tides.

the Strait of Malacca, and around the Indonesian archipelago. The forecast sea-level rise - essentially a rapid resumption of the Holocene marine transgression - could reverse this sequence, reducing and removing mangroves from the more exposed areas and confining them to inlets and estuaries where continuing muddy sedimentation, keeping pace with the rising sea, allows them to survive.

A sea-level rise will thus modify the distribution and composition of remaining mangrove areas in South-East Asia. They will be maintained, or will continue to prograde, only where the rate of substrate accretion equals or exceeds the rate of sea-level rise, particularly in the vicinity of river mouths receiving sediment. There is also a possibility that as sea level rises, some sediment stirred from bordering mudflats by wave action will be washed onshore into the mangrove fringe, building up the substrate. Such a process could maintain, or even widen, the mangrove fringe as its inner margin transgresses landwards, but the extent to which this will occur is a topic for further research. On the West Johore coast in Malaysia much of the mangrove fringe is already being cut back by erosion, the remaining mangroves growing on a terrace with a sharp cliff along the seaward side. In most places submergence is expected to cause die-back and erosion of the seaward margins of the mangroves, and there will be a tendency for them to migrate landwards as the sea rises if hinterland sites are available.

Under natural conditions mangroves are backed by low-lying estuarine and alluvial land, with freshwater swamp or forest, which could be displaced if a rising sea drove the mangrove zone landward. Subsidence of part of the Mamberamo Delta, in Irian Jaya, was followed by the spread of fringing mangroves back into the subsiding area (Figure 5.8). Over much of South-East Asia the hinterland has been reclaimed for agriculture, usually rice farming or palm plantations producing rubber, oil or coconuts, and embankments (bunds) have been built at the inner margin of the mangroves. The modelling of physical, ecological responses to sea-level rise on mangrove coasts backed by natural swamp land is now relevant to only a small proportion of South-East Asian coastal wetlands. Where there is a bund at the rear of the mangroves, delimiting the present high tide limit, attempts will be made to maintain it as sea level rises, and enlarge it to prevent wave overtopping and marine flooding. If this happens, the retreating mangrove fringe will not be able to colonise the developed hinterland; it will become narrower, and in many places will disappear altogether as the intertidal zone narrows and steepens (Figure 5.9). The coastline will thus become more and more artificial.

Where they have not been felled or cleared, mangroves still grow luxuriantly on the low-lying coasts of South-East Asia. There are more than 30 species, often zoned in distinct ecological communities, forming forests up to 40 metres high intersected by branching tidal channels. These can still be seen in some localities, such as the Ranong area of southwestern Thailand (Figure 5.7), parts of the north coast of Sarawak, and southern Irian Jaya, but the impact of human activities on mangrove areas has been very extensive, especially during the last few decades.

In Thailand about 98,000 people live in or near the mangroves, mostly at the landward edge, but there are also fishing villages within the mangrove area and on outlying mangrove islands (Kunstadter, *et al.*, 1986). There are also mangrove villages in western Malaysia. Around the Segara Anakan, an estuarine lagoon in southern Java, about 8,000 people live in the mangrove area, moving their villages seaward as the mangroves spread on to accreting tidal mudflats. Mangroves have sometimes been seen as waste areas awaiting reclamation for productive use, but they are ecologically very rich. They are important as a breeding area for fish and prawn; they sustain important fisheries; they protect the shore from erosion and promote accretion by trapping drifting sediment; and they are used for the production of charcoal, firewood, poles, timber and fishing gear, as well as incidental food (crabs and edible fruit) and some medicinal aids. Even where people do not actually live in mangrove areas neighbouring communities make use of them by frequently visiting them in search of these various products (Kunstadter, *et al.*, 1986).

Some areas of mangrove have been exploited for timber production and fuel wood others have been cleared in order to dredge out placer deposits, such as tin, which occur beneath the mangrove mud, but the most extensive clearance has been made for the establishment of aquaculture (fish and prawn ponds), and salt pans. In the vicinity of urban centres, mangroves have been reclaimed for urban expansion and industrial and port development: the former mangrove swamps around the mouth of the Chao Phraya River have disappeared in the course of the growth of the port of Bangkok, and there has been similar large-scale reclamation of mangrove areas for land development around such places as Penang and Melaka in Malaysia and Jakarta and Surabaya in

Indonesia. Mangrove losses have therefore already been extensive, even before any sea-level rise occurs. In Thailand human activities have reduced the mangrove area to less than 40% of its original extent (Aksornkoae, 1988), and similar reductions have occurred in Malaysia and Indonesia.

Extensive areas of mangroves have been converted to ponds for the production of fish or prawns. The simplest of these, traditional for many centuries on the north coast of Java, are extensive embanked areas with sluices to permit the gravitational inflow and outflow of sea water and the entry of fish and prawn fry; they are drained for harvesting. Similar ponds, mainly for prawn production, have displaced large areas of mangroves in Thailand, and to a lesser extent in Malaysia. In recent decades fish and prawn ponds have become more elaborate, especially in Thailand and Malaysia, with pumping systems to maintain a sea water supply and the use of aerators, breeding techniques and fertilisers to generate high productivity from intensive aquaculture.

Where the mangrove area has been converted to aquaculture, a sea-level rise will threaten to breach the enclosing banks and submerge the fish or prawn ponds. If these ponds are to be maintained the enclosing walls and the floors will have to be raised to match the levels of the rising sea. Alternatively a protective sea wall may be built, and pumping systems introduced to control the inflow and outflow of sea water. Where modification of existing ponds to adjust to the effects of sea-level rise proves uneconomic, they will be abandoned, and recolonised by mangroves. It seems likely that the more elaborate fishponds, managed by marine irrigation, will survive as economic units that can be maintained as sea level rises, whereas the low-technology intertidal ponds will disappear.

In addition to these direct effects, marine submergence of coastal areas in South-East Asia will raise the near-coast water table so that some low-lying parts of coastal plains will become permanent swamps or lakes, the salinity of which will depend on the interaction between rising marine incursion and the offsetting effects of any increase in rainfall and freshwater runoff. It is possible that the rising ground water will be accompanied by the upward movement of subterranean salt, resulting in saline damage to rice fields and farmland soils. It will be tempting, in such conditions, to convert these areas into brackish-water fish and prawn ponds to replace those threatened or lost in the way that has just been described.

## 2.5 COASTAL LAGOONS

Coastal lagoons have formed where sand spits and barriers have grown to enclose inlets and embayments. In most cases they are linked to the open sea by way of a tidal entrance. They have generally been reduced in depth and area by sedimentation from inflowing rivers and by swamp encroachment. A sea-level rise will enlarge and deepen them (Figure 5.10), with submergence and erosion of fringing swamp areas, and widening of tidal entrances. Breaching and erosion of enclosing barriers may lead eventually to the reopening of the original coastal inlets and embayments as marine areas.

Songkhla Lagoon in South-East Thailand, is an example of a coastal lagoon that will be greatly enlarged by a one-metre sea-level rise. The accompanying increase in salinity with greater marine incursion will lead to ecological changes, freshwater plant and animal communities being replaced by brackish ecosystems, unless sluices are built to keep out the rising sea. The same is true of the long, narrow estuarine lagoons at Merang and Setiu on the northeast coast of Peninsular Malaysia. In southern Java the Segara Anakan is a coastal lagoon bordered by mangrove swamps that are spreading forward rapidly on to tidal mudflats which are accreting as the result of sediment inflow from the Citanduy River (Figure 5.11). In recent decades the sediment inflow has been augmented by soil erosion, due to deforestation of the steep headwater regions. A sea-level rise here will help perpetuate the lagoon, diminishing the rate of mangrove encroachment.

## 2.6 RIVER MOUTHS

The large rivers in South-East Asia carry vast quantities of water to the sea, and only their lower reaches are estuarine (i.e. brackish as the result of marine tidal incursions). A rising sea level will submerge and widen the mouths of these rivers, and modify the present pattern of shoal deposition. There will be increasing penetration by salt water, which may also invade underground aquifers in coastal regions. Greater abstraction of water for irrigation and urban or industrial development will increase the risk of salt intrusion and contamination of fresh water recources as sea level rises. In some places it may be feasible to insert tidal sluices to prevent sea water inflow.

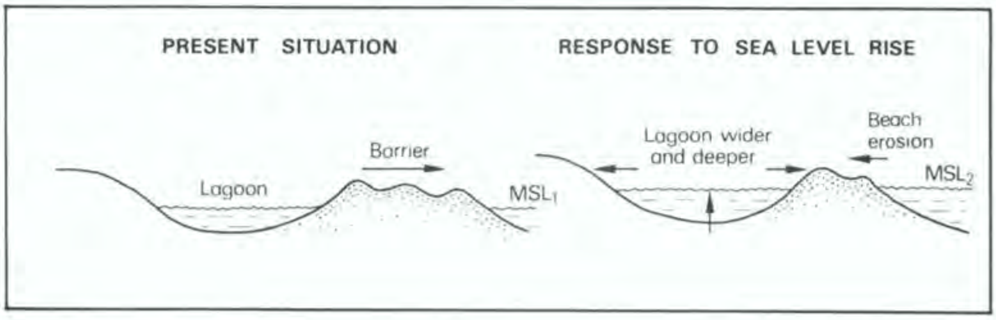


**Figure 5.10** A rising sea level will enlarge and deepen coastal lagoons (such as Songhkla Lake in south east Thailand), and also erode the barriers that enclose them.

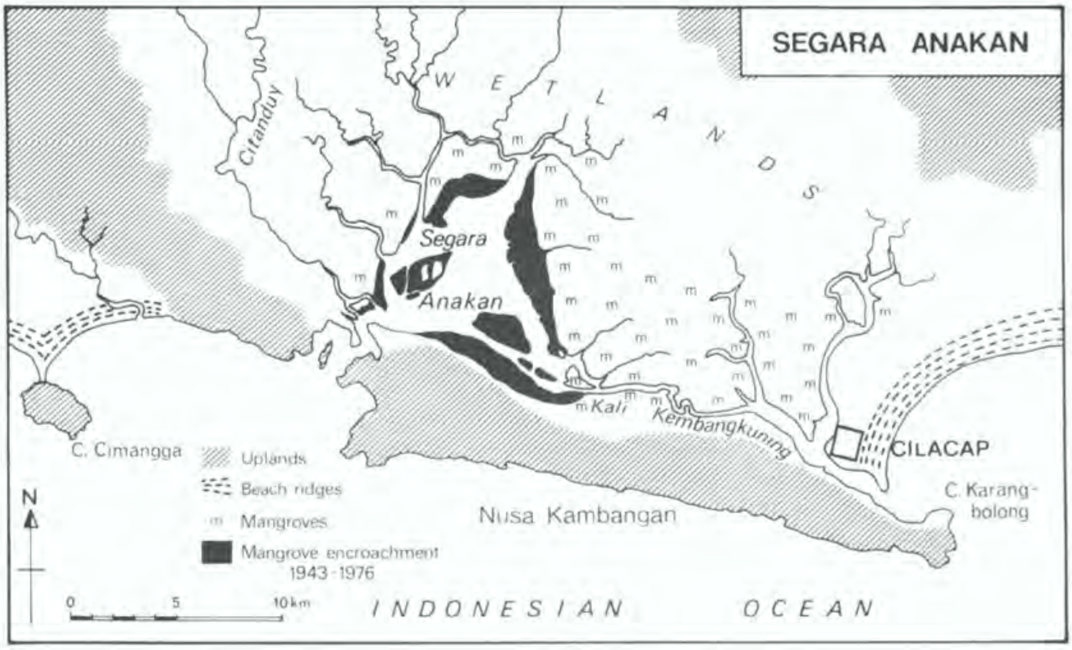


**Figure 5.11** The Segara Anakan, an estuarine lagoon in southern Java, has been shallowing rapidly as the result of inwashing of sediment from rivers, notably the Citanduy. In recent decades there has been rapid mangrove encroachment. A rising sea level will here slow down mangrove encroachment and delay the infilling of the lagoon by fluvial sedimentation.

The problem is already evident in the Bangkok region (Figure 5.1), where sea level rise will form a landward protrusion east of the city if sea walls are not built to prevent it (Figure 5.12).

**Figure 5.12** **Prediction of the extent of marine submergence of the coast north of the Gulf of Thailand by a one-metre sea-level rise if no walls are built to prevent it. Note the landward protrusion east of Bangkok where submergence will extend into an area of recent land subsidence (see Fig. 5.1).**

The discharge of river floodwaters will be impeded as sea level rises. The Indonesian National Report mentions extensive river flooding when heavy rains accompanied exceptionally high tides in Java in 1988. Riverside towns such as Telok Intan on the Perak River in western Malaysia, which already suffers frequent flooding and high tide inundation, will have to be protected by enclosing levees or raised by deposition of earth materials and the reconstruction of roads and buildings at a higher level. Alternatively, they may be abandoned as the population moves to a new site on higher ground.

Sea-level rise will increase tidal flushing of bays and estuaries, which may help to disperse pollution in such areas as Jakarta Bay in Indonesia. Navigation to coastal ports may be facilitated, but it will be necessary to rebuild existing quays and docks to higher sea levels.

## 2.7 TIDAL MUDFLATS

Tidal mudflats occur extensively in the Strait of Malacca, the Bight of Bangkok, and off the north coast of Java, and generally lie seaward of mangroves. Local people collect such products as seaweed, cockles, mussels, oysters and sea cucumbers from these mudflats, and there are possibilities of farming these organisms. As sea level rises, the outer part of the tidal mudflat zone will become permanently submerged, but erosion of mangrove swamps and coastal lowlands will extend them landward. Where sea walls are built, however, it is likely that the tidal mudflats, like the mangrove zone, will be reduced and eventually obliterated by the rising sea. Even without a sea-level rise, substantial areas of tidal mudflats have been lost as the result of land reclamation, notably around Penang Island in Malaysia, and there are plans to reclaim many remaining mudflat areas.

## 2.8 CORAL REEFS

Coral reefs occupy about 150,000 square kilometres within the East Asian seas and there are fringing reefs on many headlands and high islands. Reefs are exposed at low tide within the Indonesian archipelago, east and west of Peninsular Malaysia, on the Andaman Sea coasts of Thailand and northern Malaysia, and in the Gulf of Thailand. As coral growth is impeded by turbidity and sedimentation, reefs are poorly developed, or absent, in the vicinity of river mouths and along deltaic shorelines.

Most coral reefs have been built up to just above low-tide level, and the reef flats exposed at low tide are mainly dead coral with various algae, bordered by living and growing coral ecosystems in the intertidal and subtidal zones. Some reef flats are surmounted by small islands (cays) of coralline sand and gravel eroded from the surrounding reef and washed up by wave action: the Thousand Islands, north of Jakarta, and Sipandan Island, off Sabah, are good examples. They rise just above present high tide level, and carry land vegetation, usually modified by human activity.

Some coral reefs have been damaged by the use of explosives to harvest fish, and by fishermen beating the shallows to drive fish into nets. The use of chemicals and gases to capture fish has also had adverse ecological consequences. Others have been quarried for sand, gravel and building stone, or damaged by the cutting of boat access channels, or by boat anchors. Many have been affected by pollution, including the in-washing of muddy sediment generated by nearby tin dredging, as in the Phuket region, or drilling for oil. In recent decades, deforestation of hinterlands has increased turbidity in coastal waters, killing many fringing and nearshore coral reefs by blanketing them with sediment. Excessive nutrients from eroding soils,

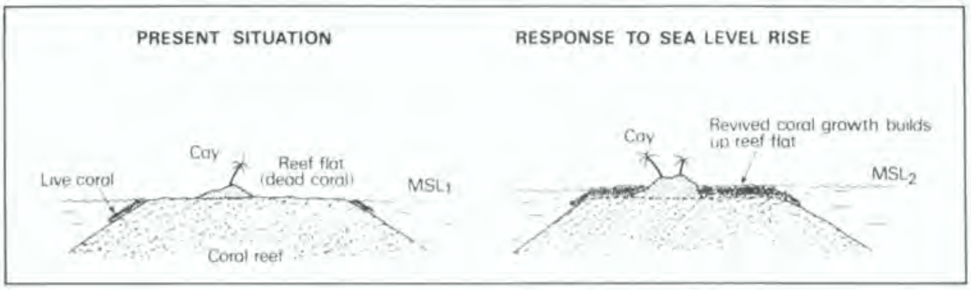


**Figure 5.13** Coral reefs will grow upwards where sea-level rise is sufficiently slow (less than 5mm/year) to permit coral growth to maintain the reef surface. Sandy islands (cays) on coral reefs may be preserved by such upward growth of surrounding reefs, but where this does not occur they are likely to be washed away by the rising sea.

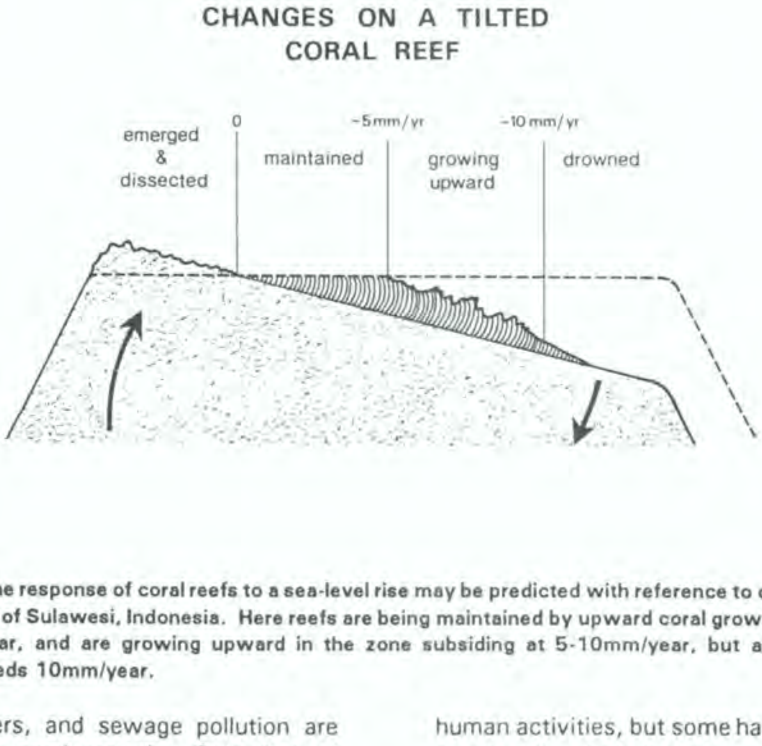


**Figure 5.14** The response of coral reefs to a sea-level rise may be predicted with reference to changes on tilting reefs, as off the south coast of Sulawesi, Indonesia. Here reefs are being maintained by upward coral growth in the zone subsiding at less than 5mm/year, and are growing upward in the zone subsiding at 5-10mm/year, but are drowned where the subsidence rate exceeds 10mm/year.

agricultural fertilisers, and sewage pollution are also detrimental to coral growth. Collecting of shells and precious corals has impoverished many reefs, and several Marine National Parks have been set up to protect coral ecosystems from these impacts, but the products are widely on sale, and controls are not yet effective. Outbreaks of destructive crown-of-thorns starfish on coral reefs, as at Patong in Malaysia, may be a response to human activities, but some have interpreted this as a natural phenomenon. Recent reports of widespread coral bleaching may be an indication of higher temperatures in tropical seas, an early response to global warming.

A slowly rising sea level will stimulate the revival of coral growth on reef flats (Figure 5.13); some scientists consider that they will maintain their level relative to the rising sea (Neumann and MacIntyre, 1988). Upward growth of existing corals is in the range 0.4 to 7 mm/year (Hopley and Kinsey, 1988), and studies of tilting coral reefs south of Sulawesi have shown zones of slow submergence (< 5 mm/year) where upward growth is being maintained passing laterally to zones of more rapid submergence (5-10 mm/year) where the corals are failing to "catch up", and to zones (> 10 mm/year) where the reefs are drowned and inert (Figure 5.14). However, as has been indicated, many coral reefs are already under various kinds of ecological stress, and some of the less vigorous may fail to revive, becoming permanently submerged as sea level rises. Fringing reefs are less likely to survive than outlying reefs because of increasing turbidity in coastal waters as larger waves erode the beaches and the land behind them.

Low islands on reef flats will be eroded, and may disappear, overwashed by storm surges, as sea level rises, but they could survive where submergence is slow enough for the corals to grow upward and maintain a surrounding protective reef. They may even be enlarged by accretion of coralline material derived from this growing reef. However, the freshwater lenses within low islands, upon which natural vegetation and crops depend, and which are important as water resources for local people, will shrink as they are forced upwards, and become more saline as the sea rises. The ensuing ecological changes will be adverse for human occupance and agriculture.

### 2.9 SEAGRASSES

Seagrasses, of which more than 20 species exist in the South-East Asian region, typically occupy parts of the shore and nearshore zones out to a depth of about 10 metres. Their growth is related to light penetration, turbulence, substrate conditions and tide range. Unlike corals, their growth is improved by accessions of fine-grained sediment and the increase in nutrients which results from non-toxic pollutants, but if the nutrients become excessive (eutrophication) seagrass beds can be blanketed and destroyed by proliferating algae.

Seagrasses are valuable in providing breeding and feeding grounds and cover for many fish and shellfish species, and in promoting organic accretion, which can augment the nutrient bank beneath the nearshore sea floor. They can diminish wave action, and help to stabilise the adjacent coast. Where seagrass beds have been destroyed the release of substrate sediment renders the water turbid, and less favourable for corals and other marine organisms; wave action is less impeded, and may attack the coastline.

As sea level rises the zone occupied by seagrasses will tend to migrate landwards, the inner margin spreading on to submerging sandy and muddy substrates as beaches are submerged and mangrove swamps overwashed, the outer margin dying away as the water becomes too deep. It is possible that the seagrass zone will actually become wider and richer on coasts where broad plains, rich in soil nutrients, are being submerged by the rising sea.

### 2.10 SOME PROBLEMS

So far the environmental consequences of a sea-level rise have been discussed in general terms, with illustrative examples from South-East Asia. In practice, local conditions must be taken into account in determining what will actually happen as a result of natural processes and human activity. Further research is necessary on each kind of coastal environment, both natural and as modified by human impacts, to determine more accurately the extent of the changes that will result from sea-level rise.

## 3. SOCIO-ECONOMIC EFFECTS AND POLICY RESPONSES

It will be evident that some environmental changes are already in progress on the coasts of South-East Asia, and that substantial modifications, both natural and man-induced, would have occurred on these coasts during the coming century even if there were no global warming and sea-level rise. Coastline erosion is already extensive, and likely to continue, and coastal environments will be changed by further urban and industrial development. There may be innovations, such as the breeding of salt-tolerant crops cultivable in sea water or saline soils, new products from mangrove agroforestry, and the generation of organic materials from algal cultures in marine enclosures. There will also be adaptations to changing local, regional and global economic circumstances, some of which seem readily predictable (such as continuing growth of the human population), but many quite unforeseeable. The question of socio-economic effects and policy implications of sea-level rise is therefore one of incremental responses to environmental changes other than those that would have occurred anyway. It is an academic abstraction in the sense that what will actually occur will be a response to overall circumstances, of which climatic change and sea-level rise will be components. Nevertheless, there are some distinctive issues that will have to be addressed if sea-level rise occurs. Some require a physical response, such as the building of structures; others a socio-economic response, such as the movement of people, products, and money; and all will require the framing and application of policy by decision-makers.

Socio-economic changes are difficult to predict as they generally take place more rapidly than environmental changes such as a sea-level rise by one metre over the course of a century. Most structures existing at present in coastal areas threatened by submergence and erosion in South-East Asia are not designed to last for more than a few years or decades, and their abandonment in the face of the rising sea could prove much less expensive than the building of large sea walls, pumping and drainage systems. The most general response to sea-level rise is likely to be gradual evacuation and abandonment, with accompanying social adaptation and land use changes. However, there is already intense population pressure in some low-lying coastal regions, and this, together with an unwillingness to surrender large areas of coastal lowland to an encroaching sea, may prompt engineering solutions such as the construction of sea walls along selected parts of the coast, or even offshore.

### 3.1 SCENARIO 1: ADAPT AND EVACUATE

Sectors of the coastline of South-East Asia that have been retreating as the result of erosion in recent decades include beach-fringed plains on the shores of the Gulf of Thailand, on the east coast of Peninsular Malaysia, parts of the north shores of Sabah and Sarawak, and the southwest coast of Sumatra. Apart from a few beach resort areas, where the retreating shore has been locally armoured with ramparts of boulders (rock from quarries or coral reefs), there has been little attempt to prevent coastline recession.

There are several deltaic areas where erosion has been rapid following the natural or artificial diversion of river mouths, particularly along the north coast of Java. Locally the coastline has retreated by as much as 500 metres in the past three decades. The land lost was partly mangrove swamp, but also included substantial areas that had been developed as brackish-water fish and prawn ponds (tambak): where the sea has breached the enclosing walls of fish and prawn ponds they now lie derelict. To landward, ricefields have been damaged by salt water intrusion. People who occupied the lost coastal terrain have either retreated inland to higher ground or moved to other areas.

Similar, but more extensive, changes will accompany coastal submergence as sea level rises, and may necessitate evacuation of numerous people who now live in low-lying areas. Preliminary calculations suggest that a one-metre sea-level rise will submerge and erode some 5,000 square kilometres of land in Thailand, a similar area in Malaysia, and at least twice this area in Indonesia. Over the three countries several million people will be affected, posing problems of large-scale resettlement comparable with those that have arisen in the course of the Indonesian transmigration programmes.

The land lost to submergence and erosion will include large areas of currently productive coastal land, especially fish and prawn ponds. It is possible that coastal people and their land and sea use systems could move landward as the coastline retreats, but this would usually mean displacing other people and existing land uses (such as rice farming by aquaculture) from the immediate hinterland. It would not be difficult to convert rice fields into fish or prawn ponds as sea level rises, but there are questions of land tenure and social equity. In practice it could be the rice farmers in the immediate hinterland who were most disadvantaged, if pond-operators move back to take over the ricefields for aquaculture. Who will bear the costs of resettlement and land transformation? The implication is that the area farmed for rice could be reduced, and rice production from the coastal regions fall, in order that fish and prawn production may be maintained.

The National Reports present case studies of the socio-economic implications of such changes in sample areas in Thailand, Malaysia and Indonesia.

### 3.2 SCENARIO 2: HOLD THE COASTLINE

Alternatively, a sea-level rise may generate a more positive reaction. A possible response to general submergence of the low-lying coasts of South-East Asia could be to try to hold the present coastlines by constructing sea walls (the "Dutch solution"), and either reclaim the areas that would otherwise pass below sea level, or perpetuate their wetland ecosystems (including aquaculture) by building pumping and draining systems to maintain present water levels. In the Netherlands (more than half of which are below present high tide level) it has been estimated that the raising and elaboration of coastal defences to counter a sea-level rise of 20 centimetres along about 250 kilometres of coastline would cost about $US 1 billion: for a one metre rise the cost would be about $US 10 million per kilometre (Goemans, 1986). In these terms the cost of preventing sea incursion on 5,000 kilometres of low lying coast in Thailand, Malaysia and Indonesia would total about $US 50 billion.

In the Netherlands the strategy has been to reduce the length of the protected coastline by building dams to reclaim inlets and embayments from the sea - the Dutch Delta programme has shortened the coastline by 688 kilometres at a cost of $US 20 billion - and there may be a case for this on the more indented sections of coastline in South-East Asia.

In West Johore, on the southwest coast of Peninsular Malaysia, extensive areas of low-lying coastal plain are protected by bunds built of earth and stone, initially along the landward boundary of the mangrove fringe, to protect land developed for plantation agriculture, notably coconut and oil palm. In many such places the mangroves have subsequently been cut back, and where they have disappeared the bunds are exposed to wave attack from the Strait of Malacca. Some bunds have been breached, and plantation areas that lay behind them submerged and destroyed by erosion: the relics of coconut trees may be seen on the muddy foreshore at low tide at Lurus, for example. Elsewhere, the bunds have been enlarged and armoured, and are now substantial sea walls. It seems likely that efforts will be made to hold the coastline here if sea level rises.

## 3.3 SCENARIO 3: COUNTER-ATTACK

The cost of building sea walls and putting in drainage and pumping systems to manage the land margin as sea level rises would be great, and it is difficult to envisage South-East Asian countries achieving this on a large scale without substantial international assistance. An alternative solution may be to counter-attack by constructing sea walls offshore, and reclaiming the enclosed shallow areas for productive use. Where this is possible, the economic returns from the land gained could offset at least part of the cost of building sea walls and associated structures. In 1989 the Malaysian Prime Minister Mahathir Mohamad suggested that a series of sea walls about 3.2 kilometres offshore should be constructed along the Strait of Malacca coast of Peninsular Malaysia over the next 30 years as a prelude to large scale reclamation of the shallow nearshore area there. A similar approach could be applied to the coastline of the Bight of Bangkok, where an offshore sea wall would permit large scale land reclamation in association with a new drainage and irrigation system adjusted to the rise of sea level (Figure 5.15). Other areas where a counter-attack strategy may prove attractive include Jakarta Bay in Indonesia.

The disadvantage of building sea walls along the coast or offshore is that there will be reductions in the extent of mangroves and tidal mudflats, with consequent losses in the productivity of fish and shellfish resources. Once built, it is likely that sea walls will be elaborated in a sequence familiar from the history of the Netherlands coast, where coastal defences have become successively higher and wider to counter a continuing relative sea-level rise (Figure 5.16).

It is possible that sea walls could be built on some sectors of the coast, leaving intervening natural areas where beaches, mangroves and tidal mudflats can persist, allowed to migrate landwards.

## 3.4 ECONOMIC ISSUES

As Broadus (1988) observed, substantial costs will be imposed on low-lying coastal areas by a rising sea level. The size of these costs will depend to a large extent on how well the problems are anticipated, and the kinds of incremental human responses that take place to gradually evolving changes. In economic terms there is the cost of allowing the sea to rise and submerge low-lying areas, with accompanying erosion, and the alternative cost of preventing this happening.

Even without a sea-level rise there are problems arising from such questions as the replacement of mangrove ecosystems, which contribute to the sustenance of existing marine and estuarine fisheries, by fish or prawn ponds, and the loss of areas already developed as fish or prawn ponds on eroding deltaic land, together with the people who operate and benefit from them. There is the question of whether low-lying coastal land now developed as primitive, labour-intensive fish or prawn ponds using tidal irrigation, which contribute directly to the food supply, as well as to the income, of local people should be reallocated to more complex, highly mechanised mariculture systems developed and operated by companies employing relatively few people and generating an expensive product for sale elsewhere. There are areas where the development of facilities for

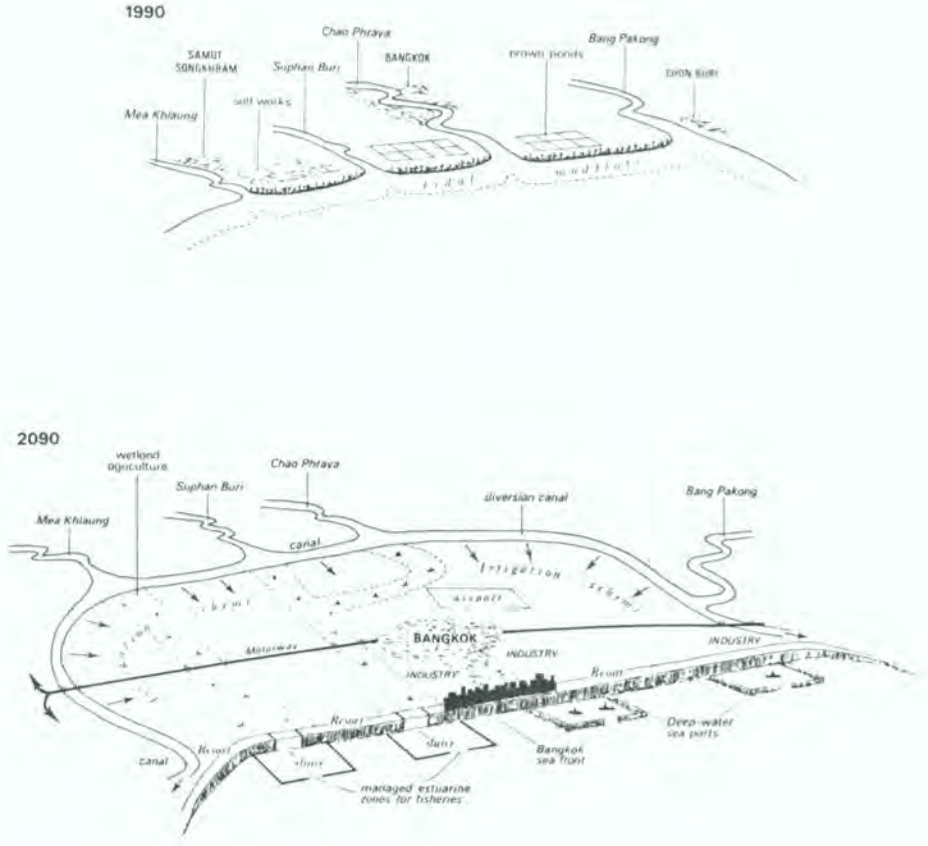


**Figure 5.15** **The coastal region at the head of the Gulf of Thailand as it is now (1990), and as it would be a century hence if the response to sea-level rise is to "counter-attack" by building a sea wall offshore and reclaiming the tidal mudflats behind it.**

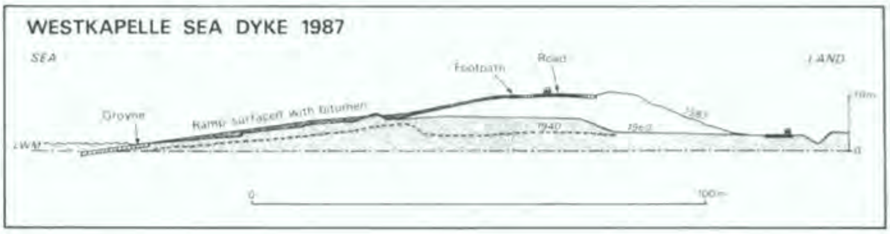


**Figure 5.16** **Stages in the enlargement of a Dutch sea wall. In 1940 it was 2.5 metres high and 30 metres wide, and by 1987 it was more than 10 metres high and over 130 metres wide, its seaward slope faced with bitumen.**

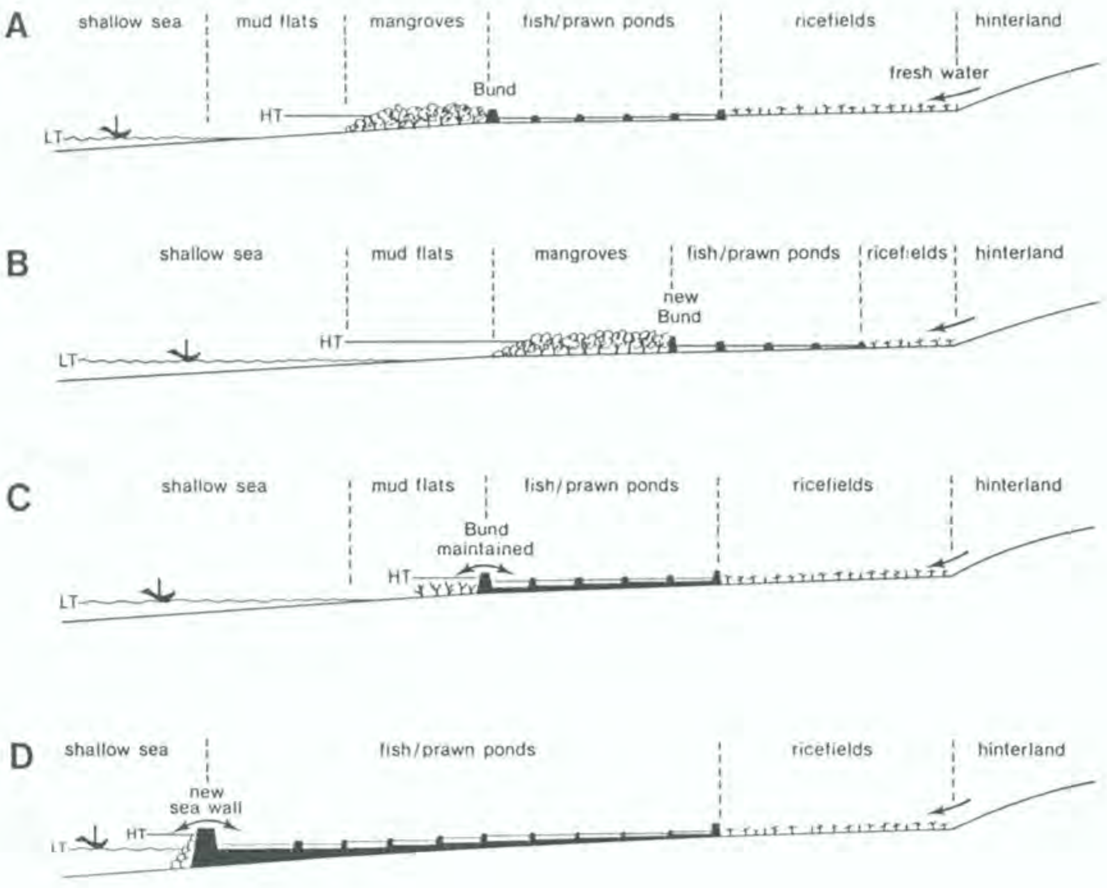


**Figure 5.17** **Scenarios for sea-level rise responses on the coast of South-East Asia. A - Typical land-use zonation. B - Changes if the seaward margin is abandoned as sea level rises. C - Situation of a sea wall is maintained to hold the present coastline as sea level rises. D - Situation if a sea wall is built offshore to prevent submergence by the rising sea, and the former mangrove and mudflat zones are reclaimed.**

tourists can disadvantage or displace coastal farmers and fishermen. The effects of a sea-level rise will be to intensify some existing problems and generate new ones.

The basis for economic assessments can be illustrated with reference to the situation most characteristic of South-East Asia, where mangrove-fringe coastal lowlands have been developed into a zonation of nearshore shallow sea, intertidal mudflats, residual mangrove fringe, earthen bund delimiting high tides, then brackish-water fish or prawn ponds in the zone permitting gravity drainage and irrigation by sea water, ricefields irrigated by fresh water at slightly higher levels, and a rising hinterland with forest or plantations or dryland farming (Figure 5.17, A). Such a zonation recurs, with minor variations, along many sectors of the Thai and Indonesian coast, and to a lesser extent in Malaysia, where the fish and prawn ponds are still relatively localised. It is examined in the Thai National

Report with reference to Ban Phot, an area bordering Ban Don Bay, and in the Indonesian National Report with reference to the districts of Bekasi, Krawang and Subang in West Java.

The issues arising when such a zonation is modified by a sea-level rise to one metre are now considered. An unimpeded sea-level rise (i.e. if the bund is breached and abandoned) will set each of these zones back landward (Figure 5.17, B). As the sea encroaches, the intertidal mudflats will be submerged, but the mangrove fringe will be driven back, exposing new intertidal mudflats up to a slightly higher level. The submerging fish and shrimp ponds will disappear beneath colonising mangroves, but the maintenance of this ecosystem will ensure continued productivity of its resources, notably nearshore fisheries. The critical fish or prawn pond zone, dependent upon tidal irrigation and drainage, can be moved landward behind a new bund, to displace at least part of the ricefield zone, which will be reduced, and perhaps extinguished. Indeed, in this scenario, the losses consequent upon sea-level rise will be confined to the ricefield zone (together with its farmers and their dependents), although some costs will be incurred in transforming ricefields into fish or prawn ponds.

The second scenario is based on holding the coastline by maintaining the bund, which is enlarged and raised to prevent the rising sea invading the coastal lowland (Figure 5.17, C). As the sea encroaches, the existing intertidal mudflat is submerged, and the mangrove fringe reduced or destroyed: some intertidal mudflats may persist at a slightly higher level. Loss of the mangrove fringe will expose the bund to wave action at high tide and necessitate its armouring against increasing marine erosion. On the landward side the zone of fish or prawn ponds can persist, either with the aid of pumping systems to provide and remove sea water as required, or by dumping material to raise their floors and enclosing walls to match the higher sea level. Either of these changes will affect the ricefield zone to landward, which now risks salt water inundation. A second bund can be constructed to prevent this, and the freshwater irrigation of the ricefields maintained, but pumping will be necessary to remove water when the fields are to be drained. The losses in this scenario are the mangrove fringe (and the resources, including nearshore fisheries, associated with it) and perhaps part of the intertidal mudflat; the costs are in the elaboration of the existing bund, the building of a second one to keep salt water out of the ricefield zone, the institution of pumping systems for drainage and irrigation, and perhaps the raising of levels in the zone of fish or prawn ponds. It is estimated that these building costs would be of the order of $US 5 million per coastline kilometre, not including the lateral bunds (running inland from the coast) that would be required at the boundaries of each region thus treated.

The third scenario envisages a counter-attack by building an offshore sea wall, at or below the existing low tide line, and the reclamation of the intertidal mudflats and the mangrove fringe for productive purposes, usually additional fish or prawn ponds (Figure 5.17 D). As in the previous scenario, these would have either to be serviced with marine irrigation and drainage pumping systems, or artificially raised to a level appropriate for gravitational inflow at high tide and outflow at low tide. There would be the loss of the intertidal zone and the mangroves, together with the resources they at present generate, but the increased production from the reclaimed area could in due course at least partly offset these losses and the costs of building the sea wall and reclaiming the intertidal area. The initial outlay in building costs would be of the order of $US7 million per coastline kilometre (plus the cost of a lateral boundary wall), but this could be treated as an income-generating investment rather than a simple capital outlay.

This analysis is only a preliminary assessment. A more refined treatment would take account of such factors as potential market forces (local, national and global), population changes (including migration), conservation issues (such as the need to maintain some mangrove ecosystems), local subsistence, and the geographical context (e.g. which sectors are to respond and in which way). Nevertheless, the three scenarios offer the most likely choices for future policy-makers on sectors of the South-East Asian coast where the described zonation exists, and similar scenarios could be developed for the other coastal land use associations that occur in the three countries considered. It is anticipated that the next phase of this project will concentrate on the effects of sea-level rise, and address this problem on the basis of national assessments of the nature, problems and extent of each of the land use associations to be found on the coasts of South-East Asia.

## 3.5 POLICY IMPLICATIONS

In the short term, over the next few decades, the wisest response to the predicted sea-level rise is likely to be reorganisation of coastal land use planning in low-lying coastal areas by drawing set-back lines determined in relation to predicted submergence and erosion. For example, it is unwise to develop new resorts within 200 metres of the present high tide coastline on beach ridge terrain unless they are designed to be abandoned or relocated during the coming century as submergence and erosion proceed. Large and expensive hotels designed to attract luxury tourism should be built on high ground, rather than on low-lying beach ridge terrain. Aquaculture should be restructured towards intensive production from relatively small and concentrated areas that can be protected from submergence and erosion as sea level rises, and adapated to new tidal levels.

The development of extensive sea walls is likely, at least on some parts of the coast, as a response to sea-level rise. The coastlines of Thailand, Malaysia and Indonesia will thus become increasingly artificial, and planning is required to conserve areas of mangrove and tidal mudflat, and to maintain beaches. Protection of existing developed resort areas by sea walls will lead to wave reflection, and loss of the beaches that were the original attraction for tourists - a concrete wall is not as great an attraction as a sandy beach lined with coconut palms. It would be wise to halt resort development on low-lying sandy beach ridge areas, so that beaches can persist as recreational attractions as the low-lying sandy terrain is cut back by the rising sea.

Uncertainties remain. Further research is needed on the changes that will occur on each type of coastline found in South-East Asia as sea level rises, and of the socio-economic responses to these changes. But it is already clear that careful planning and management of coastal areas can minimise the adverse impacts of the predicted sea-level rise.

# VI. *POLICY IMPLICATIONS*

## 1. OVERVIEW OF THE POLICY COMPONENT OF THE STUDY

Earlier sections of this report have presented detailed accounts of achievements by the National Study Groups (NSGs). These activities included preparation of regional scenarios of climate change, assessments of first order impacts on selected crops and resource systems, evaluation of higher order economic and social implications of the first order impacts, and, finally, analyses of possible policy respones to mitigate those impacts. The purpose of this section is to address this last issue in more detail.

The project consisted of two major components. The objectives of the scientific component included identification of the most important impact areas, and thorough assessments of the potential impacts of climate change on those environmental, natural resource, economic, and social components which Indonesia, Malaysia, and Thailand regarded as important with respect to their well-being and long-term development. The policy component was aimed at formulating and analyzing strategic policy responses that these countries might consider to mitigate the impacts in order to protect their environmental and natural resource base, their economic vitality and properity.

### 1.1 POLICY EXERCISES

The primary objective of the project was to generate local policy responses to global climate change. This implied that the involvement was required of policymakers responsible for strategic planning in various government agencies whose jurisdictions might be severely affected by impacts of climate change. The policy exercise approach was proposed to provide a structured interaction between the NSGs and senior representatives of the policymaking community. The design of and previous experiences with the policy exercise approach suggested that it might serve to synthesize the key findings of the impact assessments and help to communicate them to the participating policymakers in an appropriate form.

A policy exercise (PE) is a flexible structured process designed as an interface between analysts and policymakers. Its function is to synthesize and assess knowledge accumulated in several relevant fields of science for policy purposes. It is carried out in one or more periods of joint work involving scientists, policymakers, and support staff. A period consists of three phases (preparation, workshop, and evaluation) and can be repeated several times. The most important procedures of the exercise include scenario writing in the form of "future histories" and scenario analysis via the interactive formulation and testing of alternative policies that respond to challenges presented in the scenarios. These scenario-based activities take place in an institutional setting reflecting the institutional features of the problem at hand. They are enhanced by a series of complementary activities.

There are two basic types of participants in the PEs: policymakers as members of one or more policy team(s), and experts serving on the control team. Their activities at the workshop are coordinated and moderated by a facilitator. If there are more policy teams their relationship can be cooperative or competitive depending on the problem they are dealing with.

A PE is carried out in three phases. The preparations phase usually takes 3 to 10 months, depending on the nature of the problem and the staff and resources available. It includes one or more meetings of the PE core group, drafting scenarios, collecting models and data, preparing the required analyses, conducting pre-interviews with the policy participants, and packaging all the information in an exercise manual.

The workshop phase of a PE is an intensive and focused 2-3 day period of work. Following a short introduction and briefing, the participants interactively work through a number of scenarios each of which is describing a plausible path of future development patterns. Members of the policy team, in a role reasonably close to their real life responsibilities, develop policy responses to events and trends in the scenario. These policies are then evaluated by experts on the control team with help from policy analysts and computer models. An updated scenario is presented to the policy team(s) and a new cycle is started.

The evaluation phase of the exercise involves further analyses of the workshop material, preparation of reports and various forms of documentation from the exercise, and an overall evaluation.

Products of a PE include a summary of the problem, analysis, and major results, a detailed policy assessment especially relevant to technological initiatives required to ease the constraints that might threaten future development, a statement on the institutional changes required to cope with the problems identified by the analysis and recommendations concerning the research and monitoring necessary to acquire improved knowledge and more policies of response.

### 1.2 CONCERNS ABOUT THE POLICY COMPONENT IN THE SOUTH-EAST ASIA PROJECT

The NSGs expressed a mixed response to the proposed policy analysis component. At the beginning of the preparations phase, experts involved in the impact assessment work were concerned as to whether it was appropriate to involve senior policymakers in the study. They felt that present knowledge about the possible regional and local impacts of climate change and the uncertainties characterizing the rate and magnitude of global change did not justify the involvement of the policy community at this point. "Aren't we going too fast when we want to present highly uncertain results to senior policymakers?" asked a senior member of one NSG at the first preparatory meeting. One possible way to manage climate impact related uncertainties that was proposed was to use multiple scenarios of climate change, biophysical impacts, and socio-economic adaptive capabilities. As it will be demostrated later, this was not the case at either the Malaysian or the Indonesian exercise.

Another related concern was that the kind of informal interactions offered by the policy exercise approach are not part of the usual science-policy interactions in countries in South-East Asia. It was felt that lack of experience by policymakers and scientists working together in such an informal setting might lead to loss of interest of policymakers in issues related to climate change. Other NSG members argued, however, that PEs would provide the opportunity for policymakers to become involved in activities related to climate change and thus obtain first-hand information relevant to their current work on, for example, the 6th Malaysia Plan and the Second Outline Perspective Plan in Malaysia and similar activities in the other two countries.

Two of the three NSGs, Malaysia and Indonesia decided to organize national policy exercises in the context of this project. Due to the above concerns and other constraints of the project, the PE protocol was only loosely followed. For example, formal PE scenarios were not developed due to lack of time. In addition, the pre-interviews conducted in the preparatory phase of the PE included only a subset of the policy participants. The result was that some participants were not familiar with the objectives, procedures, and input material of the workshops and, as they pointed out, could not adequately prepare themselves for effective participation.

Despite all these shortcomings and limitations, the PE workshops were successful both in Malaysian and Indonesia. They provided for information exchange between researchers and policymakers on the potential local impacts of climate change for the first time in these countries. Scientists had a valuable chance to present the results of their initial analyses. They enhanced the awareness of the policymaking community for potential local implications of climate change. They also received from the policymakers useful comments and guidance for future work.

### 1.3 PROCEDURES

PE workshops were conducted in Malaysia and Indonesia. The workshops were organized around the same procedural design but they were kept flexible in order to respond to the special interests of the participating groups and to the dynamics that evolved in the course of the sessions.

Five major objectives were defined for the PE workshops:

i) To inform policymakers about the magnitude and characteristics of possible climate change, about the potential impacts on the selected biophysical systems, and about the economic and social implications of the first order impacts.

ii) To synthesize the results of the single-sector or single-resource studies and to put them into a broader context of long-term objectives for socio-economic development.

iii) To generate a set of possible response strategies that might be considered at the local, regional, or national level to mitigate adverse impacts of climate change and to evaluate these strategies with the help of analysts who prepared the impact assessments.

iv) To identify major gaps in our knowledge about the nature of regional climate change, in our assessment techniques, and in the assessment results that reduce their usefulness for policymakers.

v) to outline the needs for future research efforts and to define guidelines for impact assessments in order to make them more relevant and useful for strategic policy formulation.

The procedures followed at the workshops were designed to fulfill these objectives. The workshops started with a plenary session of detailed presentations of the impact assessment reports by working groups of the NSGs. This was followed by sub-sessions concerned with formulating sector-specific responses to the impacts. The responses were reported and discussed at a subsequent plenary session. The next step was to identify cross-sectoral linkages among the various impact areas and to revise earlier responses in the light of the cumulative impacts and to consider new responses that are more appropriate to handle the problems of cross-sectoral linkages. This was again a small-group activity. Following a plenary discussion of the revised policy responses, participants were regrouped to explore linkages from different perspectives. In the final plenary session, participants were asked to explore the possibilities of how the impact assessments and policy responses based on relatively small regions might be aggregated at the national scale and to what extent the results might be used for policy formulation at the national level. The last phase of the workshop was a debriefing and evaluation session aimed at assessing the quality of the input material as well as the usefulness of the PE procedures.

This procedural design provided a solution to another limitation of the PE workshop. The NSGs developed only one scenario of possible future climate change (one based on outputs from the GISS GCM, see Section II for details). As a result, workshop participants had the chance to work with only one scenario of potential future biophysical impacts and socio-economic implications. By making several iterations with the same scenario, participants had the opportunity to investigate the impact mechanisms from various angles and to explore a diversity of cross-sectoral linkages.

## 1.4 CONTEXTS FOR THE POLICY RESPONSES

There are several problems in capturing policymakers' attention and collaboration on issues involving time scales far beyond those of their own personal careers and the planning horizons of their institution. Climate change is one such issue and the situation is made even worse by the fact that it is difficult to present "evidence" about past trends of GHG emissions and changing climate. If, in addition, these issues are characterized by significant scientific uncertainties, it is very difficult to persuade policymakers to seriously consider what they might do to mitigate the projected deleterious impacts. This attitude had been confirmed by the pre-interviews conducted with many policy participants several months before the workshops. But the pre-interviews also proved that there is a strategy that might work in capturing the policymakers' attention and in generating their interest to participate in the workshop.

The essence of this strategy was to link the local impacts of climate change identified and analyzed by the NSG working groups to four major sets of issues, three of which represent important concerns for the policy community today. The strategy was to:

i) Link impacts of climate change to current problems and strategies to solve them. The NSGs and the policy participants were asked to identify persistent social and economic problems in the economic sectors or geographical regions covered by the climate impact assessments. The objective was to evaluate whether the currently perceived solutions and strategies remain valid over the longer term if the natural resource base or the economic activities were to be affected by future climate change.

ii) Link impacts of climate change to ongoing or planned long-term government programmes. The goal here was to re-evaluate these long-term development programs in the light of the possible climate impacts identified by the study groups and to clarify whether the objectives and implementation strategies remained valid under changing climatic conditions.

iii) Link impacts of climate change to the perceived long-term objectives for overall socio-economic development. The relevant question is which components of the long-term futures of these nations might be threatened or enhanced by climate change.

iv) Identify potential new economic and social problems and opportunities emerging over the coming decades as a result of climate change.

## 1.5 GENERATING POLICY RESPONSES

Because of a lack of succinct scenarios of climate impacts at the PE workshop, participants had to work with the materials presented by the working groups (oral presentations and photocopies of the transparencies) and with rather long written reports. In order to structure the debate, they were provided with response forms specifying what should be the main characteristics of their policy responses.

The first four items of the response form describe the problem participants considered as important implications of climate change. In the case of rice production, for example, the biophysical impacts include temperature and precipitation changes and the resulting decline in yields. The economic impacts of these changes would be the decreasing income due to declining sales and reduced cash subsidy, and the increasing number of farmers giving up economically unfeasible paddy farming. The social implications of these changes might include increasing social tensions due to higher rates of unemployment, increasing rural poverty, and mass migration to urban or other rural areas.

The second part of the response form was intended to provide guidelines for specifying the main characteristics of the response strategy. Five major types of policy responses were considered at the exercises: economic (changes in existing or the introduction of new taxes or subsidies, the modification of price systems, etc.), technological (breeding new varieties, constructing dams or coastal protection schemes), institutional (enhanced or distorted market mechanisms, formal government regulations, legal instruments), research needs (what is the most important missing information that scientists should provide for use in formulating more adequate response strategies?) and monitoring (what are the most charateristic signs of change, both biophysical and socio-economic, that could provide the necessary early warning to ensure timely actions?).

For each proposed strategy, participants first specified to which of the above groups it belonged. This was followed by a short description of the given response strategy (what to do) and a specification of the key government agencies and other institutions that are supposed to participate in the preparation and implementation (who does it). The next item was an outline of the means and techniques of implementation (how to do it) and the sources of funding to carry out the proposed strategy (resources for doing it). The final step involved an analysis of the expected secondary implications of the proposed response strategy (side-effects).

An example of the possible economic responses to mitigate impacts of declining rice yields and incomes of paddy farmers in Malaysia would be to increase the amount of cash subsidy provided to them (what to do). Details of this strategy would be developed by the Department of Agriculture within the Ministry of Agriculture together with the Economic Planning Unit of the Prime Minister's Department (who does it). The amount of subsidy might follow a degressive amount of money per unit of rice sold according to the land area cultivated by the farmers (how to do it). The funds to pay the subsidies should come from the Federal Government budget (resources for doing it). The negative implications of these policies include the possibility of a permanently increased drain on the central government budget, distorted food prices and the associated efficiency problems (side-effects).

There was a general tendency in the PEs to consider, first, the array of "technical fixes" to solve the problems that might be created by a changing climate. As a result of repeated encouragement from the PE facilitator, the analyses were extended to consider the economic measures that could be implemented to mitigate the most adverse effects. The most difficult task was to conceive far-reaching institutional changes that might make government structures, legal systems, property rights, and other institutions more appropriate to manage the challenges resulting from climate change.

Probably the most specific and possibly the most valuable outcomes of the PE workshops were related to research and monitoring. Policymakers provided the analysts involved in the impact assessment work with guidance and recommendations regarding future research in order to provide the kind of information they will need to formulate more specific and better founded responses. The workshops also outlined monitoring needs to identify the most vulnerable regions, economic sectors, and social groups and proposed a series of biophysical indicators as early-warning signs to detect local implications of climate change.

## 2. POLICY RESPONSES IN MALAYSIA

Participants at the Malaysian PE were organized into three groups according to the three major impact areas investigated by the Malaysian NSG: agriculture, water management, and coastal areas.

### 2.1 AGRICULTURE

The group concerned with impacts on agriculture evaluated first the socio-economic implications of climate change in the Muda region in the coastal plain of Kedah and Perlis. Almost the entire farming population of the region would fall under the present poverty line if present yields declined by 20 percent. This would imply smaller amounts available for the farmers' own consumption and also drastically reduced cash subsidies from selling the produce to authorized government organizations.

The first obvious response considered was to increase the amount of cash subsidy paid to the farmers per unit of paddy sold. This would compensate farmers for their loss in income due to lower yields and would keep the poorest farmer groups (small owners and small tenants) above the poverty line. The increased cash subsidy in itself would make an additional incentive to mobilize hidden reserves in the present forms of farm management and cultural practices. By adjusting the cash subsidy to the land area owned or rented by different farmer groups, the government is, in fact, controlling the rate of land abandonment and migration by managing the economic viability of their farming activities.

Increased cash subsidy to farmers, nonetheless, entails a series of negative side effects. The first and most apparent side-effect is the permanent and increasing drain on the federal government budget. A survey carried out in the Muda region in 1980-81 (Soon, 1983) revealed that contribution from cash subsidy to the total net income was about 25 percent for owners, and over 40 per cent for tenants and owner-tenants. This currently represents a significant proportion of government spending at the national level and is bound to increase if the income losses due to impacts of climate change were compensated only by increased cash subsidy.

Differentiating the amount of subsidy according to land size and tenant group has been raising equity problems already, and adjusting the schemes to the slowly changing biophysical conditions seems to be even more difficult. Subsidizing paddy farming also raises the question as to how appropriate the "cheap food" policy would be for Malaysia over the long-term, as the country is pursuing more efficient use of its natural resources and encouraging only profitable economic activities. Cheap food often leads to unnecessary wastes in storage and use, thus part of the money provided to help a social group adversely affected by changes in their external biophysical conditions is wasted as a result of underpricing their final product.

Increasing the amount of fertilizers provided free to farmers under the Government's Fertilizer Subsidy Scheme in order to off-set their yield losses by higher rates of fertilizer application would also have a mixed outcome. Economically, increasing the amount of a free production factor has the same negative effects as the increase of cash subsidy paid after the finished product (drain on government budget, equity problems, efficiency issues and waste of at least part of the resources). But in addition, the environmental impacts of increased fertilizer use make this arrangement even less attrractive. Increasing application of chemicals over the past decades has gradually deprived poor farmers of important sources of non-farm income and food procurement (fishing in the streams and canals). Besides aggravating this problem, soil degradation, groundwater contamination and eutrophication of the irrigation canals are likely to increase.

Probably the most negative long-term implication of the policies described above is that they would inevitably intercept the slow changes in farm size and land ownership patterns that are primarily driven by market forces. For many decades, the paddy sector in Malaysia was characterized by gradually increasing joint ownership, subdivision, and fragmentation of peasant landholdings due to the practice of Islamic and "adat" inheritance schemes (Sundaram, 1988). As farms had become smaller and smaller, their economically feasible operation became increasingly difficult and farmers had to look for additional, non-farm sources of income. At some point when their farm-related income became only a small portion of their total income, they decided to give up paddy altogether and abandoned their lands.

Parallel to this process emerged a relatively small, well-to-do group of land owners accumulating large areas as their own property. Concentration of land ownership and the spread of landlessness began gradually to transfer the landlord-tenant relationship into a capitalist type of agriculture characterized by landowner-wage laborer relationships. Government intervention by increasing the cash subsidy and other forms of support to small farmers might slow down this process, make the transition longer and more painful, and might considerably delay the transformation of the Malaysian agriculture into a more efficient system.

Cash subsidies, free fertilizers, and other similar types of support are becoming less defendable politically for the future. One important reason for Malaysia's successful economic development recently has been the careful balance between striving for higher efficiency and pursuing improvements in social equity. With the successful completion of the First Outline Perspective Plan in 1990, this balance is expected to shift towards emphasizing efficiency and performance while direct support is likely to be limited to the most impoverished social strata. Official documents about the main principles of the Second Outline Perspective Plan are not yet available but publications by non-government organizations (see for example Kok, *et al.*, 1990) and the pre-interviews conducted with government officials in preparation for the PE workshop indicate the need for and the likely willingness to make this gradual shift towards a more liberal economic system.

The second obvious strategy proposed by the agricultural group to cope with the possibility of decreasing yields under an altered climate was to increase efforts to breed new rice varieties. Two major objectives were set for the breeding efforts. First, improved versions of the currently cultivated varieties should enable yield increases, thus compensating for the projected yield losses due to increasing climatic stresses. Second, the new cultivars should be better adapted to the altered climate, so that losses due to the sensitivity of the present varieties to the future climate stresses can be off-set.

There is one common problem making both of these tasks less trivial than they first appear to be. This problem is our lack of knowledge about the changes in pest-crop relationships under changing climatic conditions. The complex interactions between plant development and pest attacks are difficult to model and they were not considered in the plant process model used by the Malaysian NSG. The projected decline in yields might be even more dramatic if the generally hotter and wetter climate proved to be favorable to pests. Therefore, breeding efforts should not only improve the crop suitability under altered climatic conditions but also seek to improve their pest resistance under the same conditions. Research to provide this information for the breeders has not yet begun, but is urgent in order to give more time for developing the appropriate cultivars by the time they are needed.

If yields were to decrease as a result of climate change, while average farm size was shrinking due to inheritance practices, and the national rice self-sufficiency targets could not be met then one possible strategy to cope with these problems would be to reclaim once-developed but recently abandoned land, or to open up new, untapped areas for rice production in other regions of the country. Malaysia has large reserves of land suitable for agriculture, and land pressure is not expected to be a problem.

The agricultural group also considered the scenario in which decreasing yields accelerated the process of land abandonment, increasing farm size, and the shift towards the capitalist agricultural management based on the landowner-laborer relationship. The task of the government in this case is to help displaced farmers through this transition process by providing them with new sources of income and employment opportunities, by organizing training and continuing education programmes for them to qualify for new openings in the industry and services sectors, and by providing assistance in solving their housing and other problems emerging in the resettlement phase.

A combined economic and institutional response to impacts of climate change would be to consider yield decreases (under present farm size and cultural practice conditions) and economic infeasibility of small farms as an opportunity to speed up the transition to larger farm sizes and more efficient management and ownership patterns based on affordable, more efficient technologies. This strategy involves legal constructions that satisfy Islamic property rights and inheritance practices and provide a satisfactory consolidation of land ownership. Economic assistance is likely to be needed by the new owners to transform the plots currently under predominantly manual cultivation into fields suitable for mechanical cultivation. Technology evaluation and technological impact assessments are required to prepare this transition and financial mechanisms will be needed to implement it. Economic assistance will certainly be needed for the displaced farmers and their families.

Preliminary estimates of the economically desirable and socially affordable speed of this transition process would also be needed by plant breeders. Many physiological and physiognomical properties of the new plant species, including those strongly affecting their yields, depend heavily on the technology and cultural practices under which they will be grown. If breeders start developing new cultivars appropriate for a future altered climate under currently predominant manual technologies and practices employed by small farmers, the resulting cultivars might give optimum yields under the new climate but are likely to be highly inappropriate for the then prevailing large-scale, heavily mechanized farming technologies.

The agricultural group felt that the problems revealed by the impact assessments and discussed at the workshop were important enough to propose some formal procedures to manage the impacts of climate change. The group proposed to set up an Interagency Planning Group to supervise and coordinate research and monitoring efforts necessary to systematically collect information about the expected patterns and possible impacts of climate change. Based on this gradually improving knowledge, the Interagency Planning Group could develop and propose appropriate policy measures to mitigate the adverse impacts. These would include assessments about the necessary timing of different measures given the long lead times in both biophysical systems and socio-economic adaptation. The collection of possible response strategies and their most appropriate timing would need to be regularly re-evaluated on the basis of continuing research and monitoring. A number of Technical Working Groups would coordinate the Interagency Planning Group, one of which could address the problems of agriculture.

## 2.2 WATER RESOURCES

The assessment of impacts of climate change on water resources in the Kelantan River Basin revealed two major problems: increased risk of floods in the rainy season and increased water deficit in the dry season. Both impacts may lead to severe disruptions amongst agricultural, industrial and other economic activities in the region and cause damage to infrastructure and property.

The water resource group considered two types of responses to mitigate the impacts of increasing flood risk: structural and non-structural measures. The technical-structural measures involved dam construction, river network analyses, and associated civil engineering works. Non-structural measures included flood warning and evacuation systems, and land-use regulation and zoning schemes. All these options assume a considerable research effort to improve modelling techniques and enhanced monitoring efforts to collect data on changing rainfall-runoff patterns to feed into the new models. The group distinguished between short-term, in some cases, urgent tasks to mitigate risks of flooding and also long-term flood mitigation strategies. In the short term detailed analyses are required to identify the critical areas with high risks of flooding within the Kelantan River. This should be followed by designing the necessary engineering works, and implementation of flood protection schemes. Among the long-term solutions, the group discussed the possibility of removing population from areas which are difficult or prohibitively expensive to protect and simultaneously develop new urban centres away from flood-prone areas.

Such measures, however, may have significant negative side-effects. Damming the river entails loss of land and other resources due to inundation. Population and economic activities need to be removed from these areas. Besides the direct financial costs of relocation, the secondary socio-economic costs are also significant (loss of old property, neighbourhood, lifestyle, in some cases the source of income or profession, and other stress factors). New land use regulations derived from the reassessed flood mitigation strategies and flood frequency - flood prevention relationships inevitably can affect land prices and insurance premiums and thus significantly alter potential land use.

All the above responses require inter-agency coordination. Key institutions in planning and implementing structural measures in Malaysia are the Department of Irrigation and Drainage, the National Electricity Board, the Public Works Department, and the Economic Planning Unit. Among the non-structural measures, evacuation plans already exist for all the major river basins in Malaysia. Their compilation is coordinated by the National Security Council. These plans will need to be modified as the information about the changes in frequencies and flood peaks and durations due to changes of climate becomes available.

Strategies proposed to mitigate the impacts of increasing water deficit during the dry season partly overlap with flood mitigation strategies. Once again, the most obvious structural measure would be to store water in large dams. Background calculations used in the impact assessments show that the most favourable financial conditions of dam construction can be obtained for multi-purpose dams (flood mitigation, irrigation, and hydropower generation). Therefore, existing plans to utilize the water resources and the planned structural measures may need to be revised for a range of potential new precipitation regimes.

Even with the most economically justifiable water management strategies, water stress is likely to be unavoidable at least in parts of the river basin. Therefore, water user priorities and appropriate distribution schemes will need to be established for such situations. The present order of user priorities is the following: 1. domestic; 2. industrial; 3. river maintenance flow; 4. irrigation. It is apparent from the list that irrigation and thus agriculture will be the most heavily affected, but establishing new industrial facilities with high water demand should also be prevented in regions where the probability of water deficit is expected to increase. As farmers may suffer unacceptable yield losses or may need to abandon their crop altogether in some years due to water deficit, some institutional arrangements will be required to assist them.

Water pricing policy is another institutional measure that might contribute to mitigating water deficit, especially in the critical stress periods. Present water pricing schemes should be revised and in some cases completely restructured in order to ensure better, more efficient use of water. In addition to price incentives, technologies and management practices should be promoted to save water. Besides the users, water authorites should also upgrade their infrastructure to prevent leakages and losses in the conveying systems.

Over the short-term, efficiency improvements in water use, improved management practices, and other water conservation measures driven by price incentives and techological changes are the cheapest ways of mitigating the water deficit problem. Long-term solutions include the construction of multi-purpose dams and formal control of land use. Short-term measures can be used to "buy time" for acquiring more information about possible future changes in climate that would be required for development of appropriate long-term adaptations.

Unfavourable side effects of structural measures have been discussed above. Major changes in the present pricing system would also involve losers, mainly in the agricultural sector. Some farmer groups might not afford to pay for the more expensive irrigation water. They would need to change the crops they grow or abandon their land altogether. Repercussions of the direct impacts of climate change on food production at the national scale thus will be further deteriorated by the indirect impacts on food production through water availability and irrigation costs.

## 2.3 COASTAL AREAS

The group of experts and policymakers concerned with developing and analyzing strategic responses to changes in the coastal areas as a result of sea-level rise had to deal with complex interactions involving various ecosystems and socio-economic processes. Implications of sea-level rise in West Johor present a special problem because most of the area was claimed from the sea over the past 30 years as a result of large investments in coastal structures and drainage facilities.

The first and immediate concern of the group was related to the question of how these areas (and the investments) could be protected from impacts of the rising sea level. Raising and broadening the coastal bunds seems to be an obvious solution to protect the area from inundation. This could be carried out in several smaller steps to adapt the structures to the gradually increasing mean sea level or in fewer larger steps. The question is whether the value of the land and economic activities behind the bunds justify the investment costs.

If the area is going to be protected from inundation by higher bunds the next problem will be related to drainage. The concern here is to what extent the current drainage systems will be appropriate for future requirements. Due to the increasing backwater effect, the efficiency of the existing drainage system should be improved considerably in order to prevent and regulate saline intrusion. The tidal control structures need to be reviewed in detail in order to assess their hydraulic capacity. Whether the level of tidal control gates should be raised and their number increased would depend on such an evaluation. As the water table is expected to be higher in the fields, farmroads would need to be raised. Existing electricity and water systems will also need to be adapted to the higher water levels.

Stronger defence of the coastline was deemed to be necessary to prevent, or at least control, coastal erosion. Beach nourishment will be required to compensate beach erosion especially in the popular tourist areas. Tourism-related employment and income may still decline in the affected areas.

The group decided, perhaps surprisingly, not to do anything about the loss of mangroves due to drowning. The mangroves have been under increasing pressure over the past two decades and have been disappearing at alarming rates due to near-shore development and land conversion. Most of the mangrove areas are likely to disappear altogether by the time the threat of drowning due to higher mean sea level and decreasing dilution becomes really serious. Severe implications of mangrove losses were nonetheless discussed by the group, especially the expected reductions in sea shells, cockles, and shrimp production.

It is most likely that it will not be feasible to protect most of the 4800 km long coastline of Malaysia by structural measures. For these areas, new land zoning schemes must be prepared to ensure timely relocation of the various economic activities at the least possible costs. Rezoning of agricultural land seems to be the most sensitive issue with respect to timing because plantation crops have a 20 to 30-year productive lifetime and only slight changes in the drainage conditions might lead to significant yield losses or death of the plants (for example, oil palms). The new land development plans should also contain regulations about limiting the new constructions to areas at least 4 meters above the current mean sea level.

Local and regional government agencies should also prepare to manage the social stress and to compensate for the economic losses resulting from relocation of population. There are several reasons why population relocation might be necessary. Small coastal settlements may need to be abandoned because the value of land and other economic assets there do not justify the costs of their structural protection. Economic activities might need to be discontinued because of their collapsing natural resource base: coastal fisheries, brackish water aquaculture, and tourism are among the most severely affected sectors.

Even though sea-level rise seems to be a slowly emerging phenomenon compared to other changes induced by climate change, the extent of the areas affected, the long lifetime and high economic value of the coastal structures and other types of infrastructure (roads, railways, ports, telecommunication facilities, etc.), and the number of people involved require early planning and timely action. The coastal resources group felt that there was a need to strengthen the manpower capacity at relevant government agencies to cope with the problems, establish the appropriate monitoring networks and continuously evaluate the data collected from them, design new coastal protection structures that are appropriate to the changing conditions, and prepare guidelines for making land inventories and for formulating new land zoning systems based on feasible coastal protection measures. A series of biophysical and socio-economic indicators needs to be monitored to provide the necessary information for all these activities: tidal levels, shore line responses, drainage efficiency, income levels, settlements patterns, infrastructures, etc.

# 3. POLICY RESPONSES IN INDONESIA

Participants in the Indonesian Policy Exercise were all members of the National Committee for Monitoring and Evaluation of Impacts of Climate Change and the Environment. National agencies represented at the exercise included the Departments of Forestry, Agriculture, Public Works and Health. In addition, institutions involved in environmental and climate-related monitoring programs, such as the Meteorological Office, National Space and Aeronautical Institute, and Hydro-oceanographic Institute were also represented. Participants were divided into two groups on water management and agriculture, and on coastal zones.

## 3.1 WATER MANAGEMENT AND AGRICULTURE

The group concerned with water management and agriculture first reviewed the direct impacts of changing temperatures and precipitation regimes on crop production and water availability. It concluded, however, that indirect impacts could be more significant. For example, the crop studies did not reveal dramatic changes in yields as a result of possible changes in climate but most upland crops and yields in upland agriculture are likely to suffer major losses because increases in precipitation would accelerate soil erosion. In addition, while water management systems might have difficulty in handling the increased amounts of run-off under an altered climate, the problem is likely to be made more difficult by the effects of increasing soil erosion (silting reservoirs, etc.).

The group identified three major issues of cross-sectoral impacts between agriculture and water management. First, the reduction of crop yields due to greater (and probably more intense) rainfall causing increased soil erosion; second, the reduction of water storage capacities due to increasing siltation in the reservoirs, irrigation and drainage networks; third, changes in the quantity of water available for hydroelectric power generation systems.

These problems were then summarized in a diagram in order to make the linkages clear as well as to identify the possible points of intervention for the various government agencies represented by participants in the group (see Figure 6.1). The response strategies proposed by the participants mainly focused on technical and technological options. These were complemented in some cases by defining the associated research and development needs and monitoring requirements.

Based on the proposed strategies to prevent erosion, the Department of Forestry has a number of options to tackle the problem at its source. These include increasing reforestation, establishing and spreading agroforestry systems, planting fuelwood stocks, and carrying out selected logging. The group failed to provide any description of the appropriate economic incentives and legal measures and their enforcement that are necessary for implementation. They did point out, however, that the present and future rates and patterns of deforestation, shifting cultivation and grazing should be monitored in order to implement the appropriate control strategies.

The Department of Public Works might contribute to solving the problem of erosion by constructing checkdams, and by participating in the land use law enforcement. Their research and development task is to develop more efficient civil works structures. A series of monitoring activities would also be required to design appropriate erosion control and water management structures. The most important data required include river discharge, suspended and bed-load, and water quality.

The Department of Agriculture also has an important role to play in erosion control efforts by encouraging agricultural conservation practices, especially in upland regions, where agriculture is increasingly spreading on steeper slopes. This would require on-farm research and development of agronomical and technological options better suited to the upland conditions in Indonesia. Here again, no economic incentives, legal measures, or enforcement possibilities were specified.

## 3.2 COASTAL RESOURCES

Most of the discussions in the coastal resources group revolved around credibility issues: how sound is our knowledge about climate change, how reliable are the GCMs, why should we talk about impacts of sea-level rise when the opposite can be observed at several locations in Indonesia, and the like. It is not surprising that their recommendations have little relevance to the possible problems identified in the NSG's impact assessment; rather they stress the importance of further research efforts, site specific studies, and other data collection to get "evidence" about climate change and sea-level rise.

The coastal zones group stressed the need for much more data to support the impact assessment work in all areas of climate impacts. Key institutions in building up the data sets for use in studies on sea-level rise include the National Coordination for Survey and Mapping Board (BAKOSURTANAL), the Research and Development Center for Oceanography, the Institute for Hydro Oceanography, the Indonesian Navy (DISHIDROS), and the Directorate General of Sea Transportation. It was proposed that monitoring and detecting changes in climate and the modelling of local patterns of climate change be delegated to the Meteorological and Geophysical Agency (BMG), the National Institute for Aeronautic and Space (LAPAN), and the University of Indonesia.

The group emphasized the need to encourage further studies on climate change, its general implications and specific local impacts. Working groups should be set up to carry out detailed studies of the most sensitive coastal areas so that they can forewarn government agencies about the possible implications of sea-level rise. The national planning board and the regional planning agencies should be informed about the results of the present NSG study and of any future studies on sea-level rise and climate impacts. In addition, the National Planning Board was requested by the State Ministry for Population and Environment to give priority to studies about climate change and its impacts.

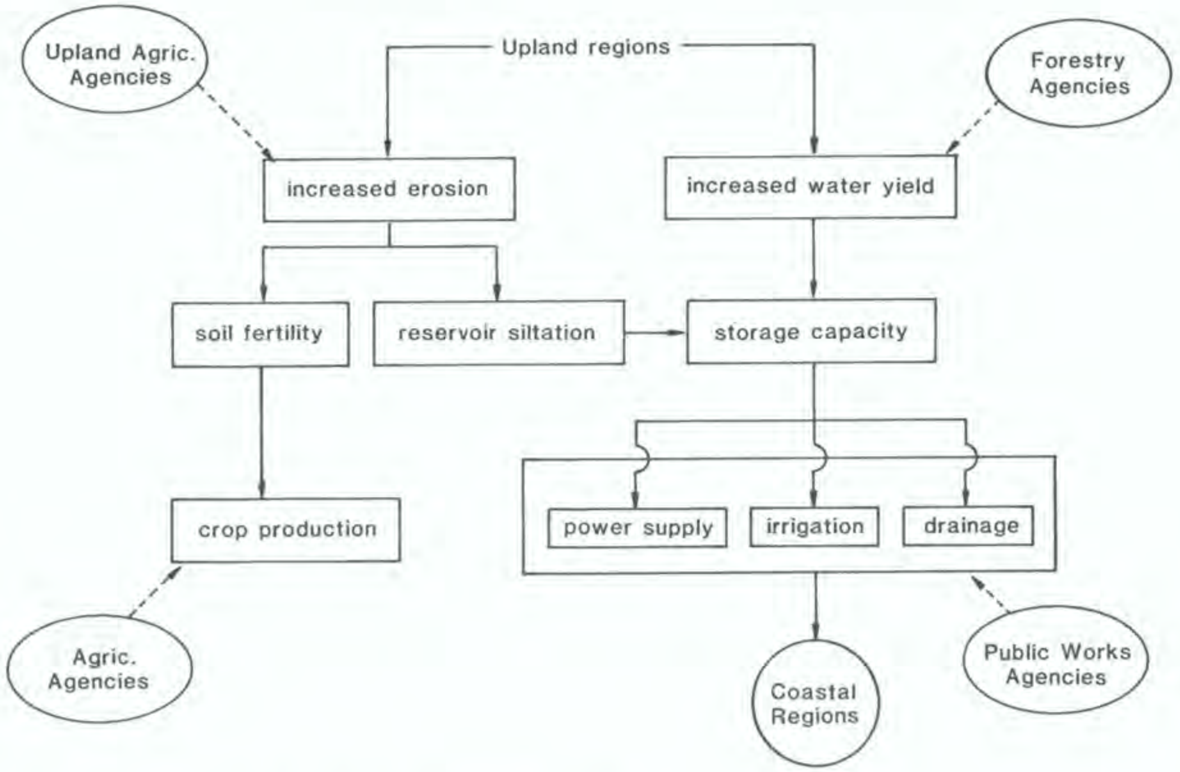


Figure 6.1 Water-agriculture linkages in the Indonesian PE.

## 4. EVALUATION OF POLICY IMPLICATIONS IN THAILAND

The agricultural part of the Thai impact assessment was limited to the analysis of potential impacts of climate change on rice production in Central Thailand. The overall conclusion is that, under the scenario adopted in the study, potential rice yields in the Ayuthaya province would increase. The study was subject to a number of severe limitations (see Section IV.3) and the results were not appropriate as an input to policy analysis. In particular the model yield was not properly calibrated according to the characteristics of the region.

The sea-level rise component of the Thai NSG work assessed the land area lost under 0.5 and 1 meter sea-level rise scenarios. The analysis does not include other possible first order impacts such as saline intrusion, coastline erosion, etc.

The NSG report noted that it is very difficult to describe the potential damage that might occur a century from now when the sea level is expected to rise by 0.5 or 1m (see Section IV.3). It therefore draws no conclusions concerning policy implications. There are, however, two approaches that might usefully have been followed.

The first is to consider current risk. Some of the shorelines in Thailand are already subject to severe erosion. This process is likely to worsen as sea level rises just a few centimeters, something that may be expected in a few decades rather than in a hundred years. Mangroves are already disappearing at an alarming rate along the shores of Thailand. This process would also be accelerated by a slow and gradual increase in sea level. Although we do not clearly understand all the important functions of these mangrove areas, what we know is sufficient to call for at least partial protection of them.

Transient processes could also usefully be considered. The shoreline retreat will be a gradual process occasionally intercepted by drastic events such as floods and extended high tides. Saline intrusion will also take place gradually. Parts of Bangkok are already flooded for several weeks during the wet season. Coastal infrastructure (roads, railroads, power lines, port facilities, residential and commercial buildings) are supposed to last several decades but they might be rendered useless if constructed with the present shoreline in mind. These considerations bring the issues into the time horizon of long-term planning.

Based on the (partial) results presented for the Kanchanadit District, the question remains as to what extent the results can be generalized for other coastal areas in Thailand. What are the methods appropriate for identifying the most sensitive areas where the impacts are likely to develop earlier, and therefore where monitoring the processes and designing actions will be required earlier. It is true that 50 to 100 years is a long time, but Thailand has almost 3000 km of coastline and this means that developing and implementing the adaptive measures will also take decades. An initial step is to avoid investments that will be rendered useless relatively soon by the early phases of possible sea-level rise. These would have been some of the questions to be addressed by a PE in Thailand. However, as with the rice study, the impact assessment results were not sufficient to serve as an input to any serious attempt at developing and analyzing response strategies.

## 5. SUMMARY AND EVALUATION

Two of the three NSGs, Malaysia and Indonesia, organized national policy exercises (PEs) as part of this study. Due to long time horizons and high levels of scientific uncertainties characterizing the subject matter, the concerns about involving policymakers in an unusual style of interaction, and a series of other constraints of the project, the PE protocol was only loosely followed. For example, formal PE scenarios were not developed for use at the workshops.

Another constraint was that the pre-interviews conducted in the preparatuions phase of the PE covered only a subset of the policy participants in Malaysia and none in Indonesia. Those who went through the pre-interviews and were regularly briefed by the NSG in the preparations phase were familiar with the subject matter, the terminology, the objectives and the limitations of the whole exercise and had a much better understanding of what they were expected to do. Those who came to the workshops with no initial contact to the project were not familiar with the objectives, procedures and input material of the workshops and, as they pointed out, could not adequately prepare themselves for effective participation. The lesson learned is that sufficient time and money should be devoted to the pre-interviews and pre-workshop briefings to get the participants interested and committed, because this would greatly improve the efficiency of the PE.

Despite all these shortcomings and limitations, the PE workshops were successful both in Malaysia and Indonesia. They provided for information exchange between researchers and policymakers on the local impacts of climate change for the first time in these countries. Scientists had a valuable opportunity to present the results of their initial analyses. They enhanced the awareness of the policymaking community for potential local implications of climate change. They also received useful comments from policymakers and guidance for their future work.

The strategy of linking the detected impacts of the long-term and uncertain phenomena of climate change to the current and persistent problems faced by policymakers, and to the ongoing long-term development programs they are pursuing, was a highly successful way in which to capture the attention of the policymaking community. This approach was also helpful in overcoming the "discounting barrier", which leads to the view that very few future impacts of climate change would justify significant amounts of investments today based on the usual cost-benefit calculation.

But if the impacts are addressed in the above context, the emphasis is shifted to issues which are difficult to describe in monetary terms, but represent important policy concerns. The economic value of national food self-sufficiency or the economic costs of social stresses resulting from relocating the inundated population in large numbers are virtually meaningless. These issues are addressed in terms of social values or political choices and the financial implications at best provide useful background information.

This strategy, however, needs to be further enhanced in future studies on regional responses to climate change. Underlying the relevant policy context are the long-term changes characterizing the natural resource base (as in the case of soils, for example, erosion, contamination, salinization, etc.) and the long-term changes in the socio-economic system utilizing those resources (e.g. land fragmentation, ownership transformation). They will inevitably imply changes in technologies, management practices, and many other components which might make the system more or less vulnerable to impacts of climate change. Therefore, these long-term underlying changes should also be identified and analyzed in the preparation of regional or national response strategies.

The dominant point of view adopted in the PEs was that of the national government. Little effort was devoted to analyzing the response options at the local, regional or provincial levels. As a result, the range of response strategies was not the widest that could have been considered. There are, for example, economically more efficient and socially less destructive ways to mitigate the potential impacts of a changing climate on paddy farmers than, for example, adopting a national response strategy such as increasing cash subsidies to farmers.

Some general tendencies could be observed at both PEs. Participants first looked at the most apparent "technical fixes" to solve the problems created by a changing climate. As a result of repeated encouragement from the facilitator, they extended their analyses to the economic measures they could implement to mitigate the most severe implications. The most difficult task was to conceive of far-reaching institutional changes that might make the government structures, legal systems, property rights, and other institutions more appropriate to manage the challenges resulting from climate change.

The most specific and probably the most valuable outcomes of the PE workshops were related to research and monitoring. Policymakers provided the impact analysts with recommendations regarding future research needed to provide the kind of information necessary to formulate more specific and better founded responses, especially if they involve major financial commitments. The workshops also outlined monitoring needs to identify the most vulnerable regions, economic sectors, and social groups and proposed a series of biophysical indicators as early-warning signs to detect the local implications of climate change.

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