ISSN:1683-1489

Mekong River Commission

# An assessment of water quality in the Lower Mekong Basin

MRC Technical Paper
No. 19

November 2008

Meeting the Needs, Keeping the Balance

Mekong River Commission

# An assessment of water quality in the Lower Mekong Basin

MRC Technical Paper

No. 19

November 2008

Published in Vientiane, Lao PDR in November 2008 by the Mekong River Commission

Cite this document as:

MRC (2008) An assessment of water quality in the Lower Mekong Basin. MRC Technical Paper No.19. Mekong River Commission, Vientiane. 70 pp.

ISSN: 1683-1489

Editors: E. Ongley and T.J. Burnhill
Graphic design: T.J. Burnhill
Cover photograph: Khoi Tran Minh

184 Fa Ngoum Road, Unit 18, Ban Sithane Neua, Sikhottabong District,
Vientiane 01000, Lao PDR
Telephone: (856-21) 263 263 Facsimile: (856-21) 263 264
E-mail: mrcs@mrcmekong.org
Website: www.mrcmekong.org

# Table of Contents

# Table of figures

# Table of tables

# Acknowledgements

This paper is based on the work of Anders Wilander, who was contracted to undertake the review by the Environment Programme of the MRC. The paper was technically edited by Edwin Ongley, who also provided some of the technical basis for the assessment including recommendations on water-quality indexes, threshold values for MRC-monitored parameters, and some assessment methodology. The paper has also been edited to conform to the style of the MRC Technical Paper series.

# Abbreviations and acronyms

| | |
|---|---|
| BOD | Biological Oxygen Demand |
| CCME | Canadian Council of Ministers of the Environment |
| CERN | China Educational and Research Network |
| CIIS | China Information Services |
| COD | Chemical Oxygen Demand |
| DO | Dissolved Oxygen |
| EU | European Union |
| EEA | European Environment Agency |
| FAO | Food and Agriculture Organization of the United Nations |
| GEF | Global Environment Facility |
| LMB | Lower Mekong Basin |
| MRC | Mekong River Commission |
| NPSs | Non-point sources |
| PCDD/Fs | Dibenzo-p-dioxins/dibenzo furans |
| RTAG | Regional Technical Advisory Group |
| STATID | Station identification |
| TN | Total Nitrogen |
| TP | Total Phosphorus |
| $WQI_{al}$ | Water Quality Index for aquatic life |
| $WQI_{hi}$ | Water Quality Index for human impact |
| $WQI_{ag}$ | Water Quality Index for agricultural uses |
| WQMN | Water Quality Monitoring Network |

# Summary

Water quality is one of the key factors affecting the environmental health of the Mekong river system. As the livelihoods of most of the 60 million people who live in the Lower Mekong Basin (LMB) wholly or partly depend on aquatic resources, the environmental health of the river is a major concern to the governments of the countries in the basin. In 1985, the Mekong River Commission (MRC) established the Water Quality Monitoring Network (WQMN) to provide an ongoing record of the water quality of the river, its major tributaries, and the Mekong Delta. The number of stations sampled has varied over the years since the inception of the network. Ninety stations were sampled during 2005. Of these, 55 are designated 'Primary Stations' as they have basin wide, or transboundary, significance. The remaining 35 are designated 'Secondary Stations'. Twenty-three of the Primary Stations are located on the mainstream, (17 on the Mekong, and 6 on the Bassac), 23 on tributaries, and 9 on the Delta.

This report documents an assessment of data recorded from 1985 to 2005 or, in some cases, the sub-set of data recorded from 2000 to 2005. Three main categories of water-quality indexes (WQI) are used: (i) for the protection of aquatic life ($WQI_{al}$), (ii) for human impact ($WQI_{hi}$), and (iii) for agricultural use ($QWI_{ag}$). Each WQI category is subdivided into classes according to the number of chemical parameters (DO, pH, etc.) that meet guideline thresholds. The classes are: (i) $WQI_{al}$: High Quality, Good Quality, Moderate Quality, Poor Quality; (ii) $WQI_{hi}$: Not Impacted, Slightly Impacted, Impacted, Severely Impacted, and (iii) $WQI_{ag}$: No Restrictions, Some Restrictions, Severe Restrictions.

In the mainstream and tributaries, the $WQI_{al}$ is mostly High Quality. However, in the Delta only one station is classed as High Quality and two others are Good Quality. Of the remainder, four are Moderate Quality, and one is Poor Quality. Signs of significant human impact on water quality ($WQI_{hi}$) are observed at stations in the uppermost part of the LMB and downstream of Phnom Penh. The lower index values at the downstream stations reflect higher population densities, particularly in the highly populated and intensively farmed Delta. At all but one of Delta stations the $WQI_{hi}$ is classed as Severely Impacted. In the mainstream and tributaries, the $WQI_{al}$ is consistently at the level of No Restrictions. However, at some stations on the Cau Mau peninsular of the Delta, the $WQI_{al}$ is classed as Severe Restrictions.

Three major sources of pollution are evaluated:

1. Urban Areas. The total discharge from urban areas is 150,000-170,000 tonnes year of BOD, 24,000-27,000 tonnes/year of total-N, and 7200-8100 tonnes/year of total-P. Sewage water from part of Vientiane is collected and discharged to oxidation ponds and then into the That Luang Marsh. The marsh acts as a 'natural treatment facility', which reduces both BOD and nutrients. Part of the sewage from Phnom Penh is also discharged into a wetland downstream. Discharge from rural areas increases the sewage load to the Mekong and tributaries.

2. Industrial wastewater. Industrial development has the potential to increase substantially the pressure on aquatic resources in the future. At present no information is available on industrial discharges.

3. Agriculture. Estimates based on available data suggests a loss of about 225,000 tonnes of nitrogen and 37,000 tonnes of phosphorus per year. However, these losses are unevenly distributed; more than 40% of each is likely to be lost from agriculture in northeastern Thailand and the Delta.

There is no strong evidence for transboundary pollution within the LMB (i.e. between the Lao PDR and Thailand, the Lao PDR and Cambodia, and Cambodia and Viet Nam). However, there is some evidence for transboundary transmission of pollutants from the Upper Mekong Basin into the LMB.

There is no sign of any significant basin-wide trends for any parameter. With the continuing development of both agriculture (increased use of fertilisers) and urbanisation there is reason to expect changes in water quality in some tributaries. It is possible that reforestation of areas in the Khorat Plateau will lead to water-quality improvement.

There are three principal water quality issues in the Lower Mekong Basin:

1. Salinity. High salinities caused by saltwater intrusion are nearly ubiquitous in the Delta (but not on the mainstreams of the Mekong and Bassac Rivers). Fifty-four of the stations analysed have a maximum conductivity greater than the threshold of Some Restrictions in the $WQI_{agI}$ (for general agricultural use). For nine of these (all of which are located on the Ca Mau peninsula of the Delta) the $WQI_{agI}$ is at the level of Severe Restrictions. However, most stations have a short period of No Restrictions for general irrigation (5th percentile i.e. statistically less frequent than one month per year). There is a clear difference between the dry and rainy seasons at most stations. In some of the Thai tributaries (Nam Kam, Nam Chi, and Nam Mun) improvements in salinity reflect regulation of the flow of water, which allows higher flow during the most severe part of the dry season.

2. Acidification. When exposed to air (oxygen) sulphate soils in the Delta produce sulphuric acid, which leaches to the canal system. The most severely affected area is the Plain of Reeds, but similar effects are recorded in some areas in Cambodia. The situation in the Plain of Reeds seems to improve in the western parts of the canal system that are close to the Mekong. Further east, there are still times of the year when extremely low pH-values are measured.

3. Eutrophication. There is a significant increase in the total-P concentrations at the mainstream stations, while no such difference is found for the tributaries. At the Delta stations, there is also a significant increase in total-P concentrations in samples collected during 2005. Although the concentrations of nitrogen and phosphorus generally are lower than the threshold values for $WQI_{al}$ there most likely is an effect on algae, periphyton

(attached algae on substrata such as stones), and floating aquatic vegetation. It is evident that the tributaries usually have a surplus of nitrogen, while there is a ‘balance’ in the mainstream. Some Delta stations also seem to have surplus nitrogen.

KEY WORDS: Mekong, Lower Mekong Basin, Mekong Delta, water quality, Water Quality Index, pollution, transboundary issues.

# 1. Introduction

## 1.1 Background

The livelihoods of most of the 60 million people who live in the Lower Mekong Basin (LMB) depend to some extent on the water resources of the Mekong River. These livelihoods rely on the environmental health of the Mekong River and its tributaries remaining in good condition. Water quality is a key factor in determining environmental health. Under the guidance of the Mekong River Commission, the four lower riparian countries (the Lao PDR, Thailand, Cambodia and Viet Nam) have monitored the water quality of the LMB since 1985 (monitoring of the Cambodian component began in 1993).

The Mekong River is the longest river in South East Asia, the twelth longest in the world, and the tenth largest by discharge (Dai and Trenberth, 2002). It rises on the Tibetan Plateau and flows southward through China, Myanmar, the Lao PDR, Thailand, Cambodia and Viet Nam, where it discharges into the South China Sea (Figure 1.1). The catchment of the river, which has an area of 795,000 km$^2$, is functionally divided into two: the Upper Mekong Basin (that flows southwards through China, where it is called the Lancang River), and the Lower Mekong Basin, which includes parts of the Lao PDR, Thailand, Cambodia and Viet Nam (Figure 1.1). The river forms the border between the Lao PDR and Myanmar in the transition zone between the upper and lower basins. The Mekong River Basin Diagnostic Study (MRC, 1997) and the State of the Basin Report (MRC, 2003) provide further information on the basin, its water-related resources, and its inhabitants.

The hydrology of the Mekong system is dominated by the annual monsoon cycle, such that the discharge during the wet season (from June to November) may be up to twenty times greater than during the dry season (December to May). Geography also plays an important role in the annual variation of discharge, as the contribution to the flow coming from the Upper Mekong Basin varies according to the season. For example, at Kratie (in Cambodia) the so-called 'Yunnan Component' compromises 40% of the dry season flow, but only 15% of the wet season flow (MRC, 2005). In contrast, 50% of the sediment discharged into the South China Sea from the Mekong comes from China (MRC, 2004).

An additional hydrological complication occurs downstream near Phnom Penh, where the Tonle Sap – Great Lake system enters the Mekong. During the rainy season excess water from the Mekong flows 'upstream' in the Tonle Sap and into the Great Lake, causing expansion of the water body by up to 70% and creating extensive wetlands around the entire lake. During the dry season, water drains out of the Great Lake back into the Mekong system and then into the Delta, thereby adding to low flow discharges in the region downstream of Phnom Penh.

South of Phnom Penh the Mekong divides into the complex distributary system that forms the Mekong Delta. Here, salinities of up to 1 g/L can extend 70 km upstream of the river mouth, and tidal influences can be measured as far upriver as Phnom Penh. In the Delta reverse flows occur daily during the tidal cycle.

The Mekong's complex hydrology makes water-quality monitoring and interpretation difficult, especially in mainstream stations below Kratie.

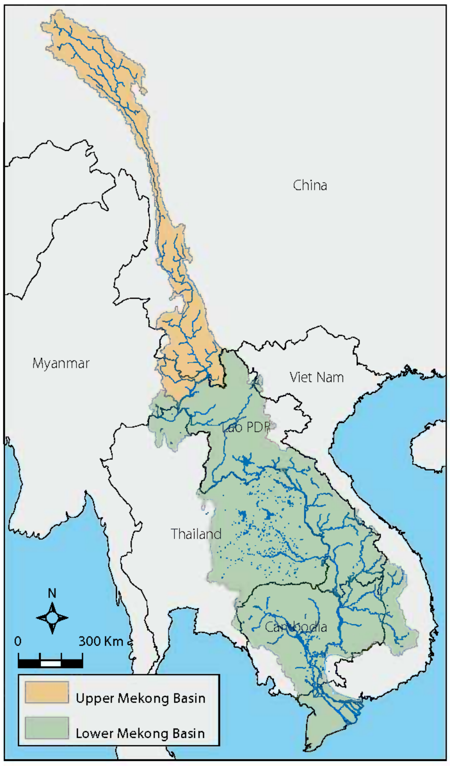


Figure 1.1 The Mekong River Basin.

The Mekong's catchment is geographically diverse. The basin is mountainous in China, in the north of the Lao PDR, and along the frontier between Viet Nam and the Lao PDR and Cambodia. The Khorat Plateau, mainly in Thailand, is a vast agricultural area situated on salt deposits that can affect water quality locally. The tropical Great Lake of Cambodia and the Tonle Sap river form a unique lacustrine and wetland complex. The water quality of this complex has been monitored by the MRC since 1993 and as part of a special study on nutrient and sediment budgets undertaken by the MRC's Water Utilisation Programme[1]. However, there has been no systematic or substantial scientific study of the nutrient dynamics of the Great Lake and it is not known with certainty if the lake is N or P limited. It is known that there is extensive anoxia in the wetlands surrounding the lake, probably due to oxygen consumption by intensive

---

[1] Some of the material in this chapter is taken from MRC (2007a) and from Ongley (2008). The MRC report focuses on toxic chemicals and is a companion volume to this present paper.

bacterial decay of organic matter in this zone. It is not known if nutrient loadings from the surrounding land are transported through the wetlands into this shallow lake, or if these loads are consumed within the wetlands. Despite anoxic conditions, the wetlands are enormously productive and fish species are adapted to these conditions. The area downstream of Phnom Penh and the Delta is dominated by agriculture and is densely populated. Caged fish culture, although prevalent throughout the basin, is particularly intense in the Delta region.

The MRC's Water Quality Monitoring Network (WQMN) has been evaluated several times, most recently by Lyngby *et al.* (1997). Ongley (2008) provided an analysis of certain aspects of water quality in the LMB. However, this current paper is the first attempt to provide a comprehensive analysis of the entire database covering the period 1985–2005. It focuses on the main parameters included in the database—major ions, nutrients, and certain physicochemical attributes, such as pH and salinity. The programme does not include toxic chemicals (metals, pesticides, industrial chemicals, etc.). These were investigated in a special diagnostic study and have been reported elsewhere (MRC, 2007a).

## 1.2 Sources of pollution

### Upper Mekong Basin

The provincial government of the Yunnan Province in the People's Republic of China, located immediately upstream of the Chinese/Lao border, is reported to have inspected 1042 industrial enterprises in the basin in 2000, and shut down four of these (CIIS, 2002). Since 1986, the Simao Paper Plant and the Lanping Lead-Zinc Mine have been built on the banks of the Lancang (Mekong) River. In addition to these industrial enterprises, a number of hydropower stations, including those at Manwan, Dachaoshan, and Jinhong, have been built (or are almost complete) on the Lancang. Four more hydropower stations are under construction or are planned for the next 20 years (including Xiaowan, located 550 km upstream of the Chinese/ Lao border[1], and Nuozhadu). Chinese data for water quality of the Lancang are not accessible and not shared with the MRC. However, Chinese news sources (e.g. CIIS, 2002) frequently report that the water of the Lancang meets international standards for drinking water (for those parameters for which Chinese agencies routinely monitor). MRC (2007a) notes that ecotoxicological assessment carried out for the MRC on the Lao side of the Chinese border suggests that at this site there is some toxicity that requires further investigation.

### Lower Mekong Basin

In the LMB, there are few sources of pollution that contribute directly to the Mekong. Thailand's contribution to pollution in the basin is mainly limited to salt leaching from the subsurface of the Khorat Plateau. There are no data that suggest that areas of irrigated

---

[1] The largest hydroelectric dam in China after the Three Gorges Dam on the Yangtze River, CERN (2002).

agriculture or the limited industrial development in Thailand within the Mekong Basin are significant contributors of pollution to the mainstream of the Mekong.

### *Municipal wastewater*

The two largest urban areas (Vientiane in the Lao PDR, and Phnom Penh in Cambodia) are of concern as they lie on the banks of the Mekong. Currently, Vientiane, a city of less than 500,000 inhabitants, discharges its municipal sewage into the That Luang Marsh — a wetland that discharges into the Mekong River some distance downstream of Vientiane. This discharge is small at this time and is not thought to pose any immediate risk to the mainstream of the Mekong. However, development of Vientiane city (including substantial land reclamation in the That Luang Marsh for urban and industrial purposes) is a concern, and may pose greater threats to the mainstream in the future.

Phnom Penh, a city of approximately 1.7 million inhabitants, also discharges much of its urban sewage into a series of wetlands that drain into the Bassac — a distributary of the Mekong. Additionally, certain industrial and municipal discharges as well as storm-water runoff, discharge directly into the Tonle Sap — a tributary of the Mekong. The MRC (2007), reports local pollution of an industrial nature in the Tonle Sap at Phnom Penh. However, it is not certain whether or not this poses any significant risk either locally or downstream. There is a substantial riparian population in Phnom Penh that occupies housing located on piles along the margin of the river. There are also a number of floating villages on the Great Lake of Cambodia. These populations discharge domestic sewage directly into the water column. However, the loading and significance of these discharges are not known.

Using population statistics and data on urban sanitation coverage[1] for year 2000 for the LMB (MRC, 2003), and person equivalent loads of BOD, total-N and total-P, total municipal waste load is estimated at 150,000 – 170,000 tonnes/year of BOD, 24,000 – 27,000 tonnes/year of total-N, and 7200 – 8100 tonnes/year of total-P.[2] However, much of this load is not transported directly to rivers insofar as ‘black water’ (human excreta) in many urban areas (e.g., most of Vientiane) is disposed through domestic septic/leaching systems or collected by truck from household holding tanks and deposited into municipal lagoons, and leaching pits (for grey water). Therefore, the actual municipal waste load discharged to rivers should be less than the estimated amounts.

*Person equivalent loads.*

| Substance | g/person/day |
|---|---|
| BOD | 30 |
| Total-P | 2.4 |
| Total-N | 8 |

---

[1] ‘Coverage’ includes septic systems, pour/flush latrines, pit toilets as well as piped waste discharge (MRC, 2003).

[2] The range of values is a result of varying estimates of urban sanitation coverage.

In the Mekong Delta, the Vietnamese cities of Tan Chau and Chau Doc, on the Mekong and the Bassac Rivers respectively, are major urban centres and are subject to tidal influences. River pollution identified at these locations is probably attributable to local sources, but there has been no definitive work on transboundary transport of pollutants from upstream. Analysis of transboundary risk concluded that the current data could neither support nor deny the presence of transboundary pollution between Cambodia and Viet Nam (Hart *et al.*, 2001).

### *Industrial development*

The scale of industrial development in the LMB is relatively low. There are no data or specific information on the role of industry in water pollution of the mainstreams of the Mekong or Bassac rivers. The MRC (2007a) reports that in 2003 and 2004 the full suite of industrial contaminants was below detection level in water samples. Analysis of these same contaminants in bottom sediment found that a small number of sites in the downstream component showed minor effects of industrial contamination.

### *Agriculture and non-point source pollution*

#### Fertiliser

Agriculture has developed substantially in the LMB since the start of water quality monitoring, with an increase in paddy fields of nearly 40% overall, and a doubling og paddy-field area in Viet Nam (MRC, 1988, 2003). Both the increase in yield and area cropped has led to large increases in production of paddy rice. In the past decade alone, rice production has increased tremendously—by 81% in Cambodia, 38% in the Lao PDR, 33% in northeast Thailand, and (over four years) by 27% in Viet Nam (MRC 2003). Some of this increase is due to cultivation of larger areas, but there has also been a major increase in use of fertilizers (Table 1.1). Agriculture, therefore, is a potential contributor of nutrients to rivers in the LMB. In addition to the expansion and intensification of paddy rice production, there is also significant production of other crops such as maize, cassava and sugar cane.

Little is known about losses of nutrients from agriculture in tropical climates and none about such losses in the LMB. A literature search (Table 1.1) for comparable types of agriculture provides a basis for estimating nutrient loss for the LMB. The composition of fertilizers used in the LMB also is not known, but it is likely in the order of 30% N and 10% P. In Viet Nam there are fertilizers with a N content of 10–18% and a P content of 5–16%. A large portion of applied fertilizer is probably urea with a N content of 46%.

Table 1.1 *Use of fertilizers in the LMB, (MRC 2003).*

| Country | Total t/year | Total t/year | Use in kg/ha/year | Use in kg/ha/year |
|---|---|---|---|---|
| | 1989 | 1999 | 1989 | 1999 |
| Cambodia | 3000 | 7900 | 0.1 | 2.1 |
| Lao PDR | 3000 | 8100 | 0.4 | 8.5 |
| Thailand | 818,800 | 1,801,700 | 39.8 | 100.1 |
| Viet Nam | 563,000 | 1,934,600 | 88.2 | 263.2 |
| Total | 1,387,800 | 3,752,300 | | |

Table 1.2 *Losses from paddy rice fields. Application as kg/ha/year. (Data from literature search.)*

| Country | Application N | Application P | Loss N % | Loss P % |
|---|---|---|---|---|
| Korea | 155–210 | 30–52 | 57–65 | 8.8–9.4 |
| China | | | 64 | 42 |
| Korea | | | 20 | 10 |

Losses of nutrients are correlated with fertilizer application. Using conservative values for losses of 20% and 10% for N and P respectively, and a fertilizer composition of 30% N and 10% P, the estimated loss of N and P is shown in Table 1.3. These losses are unevenly distributed, with more than 40% of each likely to be lost in northeast Thailand and in the Delta.

Table 1.3 *Estimate of losses of nutrients from agriculture within the LMB.*

| Country | Loss N t/year | Loss P t/year |
|---|---|---|
| Cambodia | 474 | 79 |
| Lao PDR | 486 | 81 |
| Thailand | 108,102 | 18,017 |
| Viet Nam | 116,076 | 19,346 |
| Total | 225,138 | 37,523 |

### Non-point sources

There have been no studies of the effects of non-point source pollution on the water quality of the Mekong River. There is anecdotal evidence of the use of mercury in artisanal placer gold extraction upstream of the Great Lake of Cambodia and in the mainstream in the Lao PDR and possibly in some tributaries of the Mekong. Large-scale caged fish culture that lines the banks of the Mekong and Bassac rivers downstream of the Cambodian/Viet Nam border are likely sources of non-point source pollutants. In-stream caged fish culture occurs elsewhere throughout much of the LMB, but it is not on such a large scale. Discharge of human waste from all river vessels plying the Mekong, especially tour boats in the reach extending upstream from Luang Prabang (Lao PDR) to the China border, and accidental spills from river barge traffic, are water quality threats. Recent hydraulic works to enhance barge traffic on the Mekong in the section between China and northern Lao PDR may increase the potential to potential for marine spills. Other types of pollution from non-point sources, such as residual dioxins/furans from use of Agent Orange during the American War, were detectable in bottom sediments at low levels at some downstream sites (MRC, 2007a).

### Mining

Mining activities are likely to increase in the LMB. At present, mining is intensive in parts of the Lao PDR and in areas of Cambodia near the Thai border. There is currently no information on water quality issues arising from the extraction and processing of ores. Large-scale gold extraction uses cyanide, although well-constructed retention dams control leaching of cyanide and other heavy metals. In the LMB, the main potential problems with mining are likely to be associated with catastrophic failure of retention dams (tailings dams), poorly constructed or managed retention dams, and spill of chemicals such as cyanide during transport on the Mekong river. The MRC (2007a) reports that the diagnostic study could not find cyanide in water or bottom sediments above the detection limit. Artisanal placer (gold) mining using mercury could be an issue in the LMB, but mercury associated with sediments has been found above the 'Threshold Effects Level' at only three downstream sites (MRC, 2007a). This mercury may be from industrial sources.

Exploration for oil and gas in Cambodia, the Lao PDR, and Thailand could lead to water-quality problems if commercial quantities of hydrocarbons are found.

### Toxic organic contaminants and pesticides

Until recently there has been very limited research or other data on organic contaminants in the Mekong River Basin. Evidence presented at the 2nd Asia Pacific International Conference on Pollutants Analysis and Control indicates that there is little evidence of persistent organic pesticides even in parts of the basin where it is known there has been high levels of use (e.g. agricultural pesticides used intensively in parts of Thailand). In a recent major study of contaminants, the MRC (2007a) reported on organic contaminants in water and on bottom sediments, including polychlorinated dibenzo-*p*-dioxins/dibenzo furans (PCDD/Fs). Generally, the level of organic contaminant pollution is very low with most contaminants being less than levels of detection. Pesticides in water were not detectable, however analysis of pesticides on sediments is inconclusive due to the detection limits being well above thresholds of biological concern. Limited bioassay analysis indicates low levels of toxicity at a few sites (MRC, 2007a).

### Salinity and Acidification

Salinity has been frequently identified as a potential pollution issue. Two areas are notable for their high salinities. The first is the Khorat Plateau in Thailand, where the natural leaching of rock salt drains via the Nam Mun into the Mekong at Khong Chiam. The second is in the Delta, where saline intrusion is common. Although the MRC (2007a) found abundant evidence of salinity in tributary areas on the Khorat Plateau (Figure 1.2), there is no evidence of impact at the confluence of the Mun and Mekong.

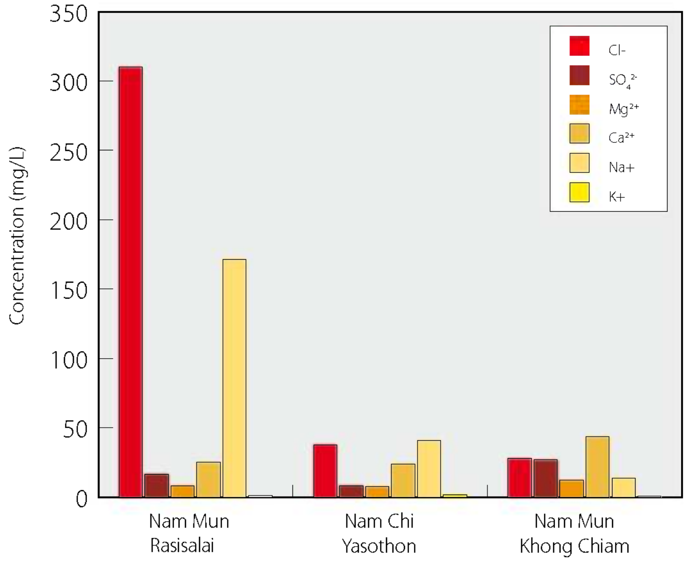


Figure 1.2 Major ion profiles from tributaries on the Khorat Plateau in 2003.
Nam Mum at Rasisalai and Khong Chiam, and the Nam Chi at Yasothon (from MRC, 2007).

Salinity in the Delta is a site-specific water-quality problem and is discussed in Chapter 5.1. Acidification, which is also a site-specific problem related to geology and sub-soils (especially in the Delta), is discussed in Chapter 5.2.

# 2. Methodology

## 2.1 Station network

The Water Quality Monitoring Network programme (WQMN) commenced in the first half of 1985 with 30 stations (Figure 2.1). Since then, the number of sampled stations each year has varied. The peak sampling years were 1995 and 2004. In 2005, 90 stations were sampled.

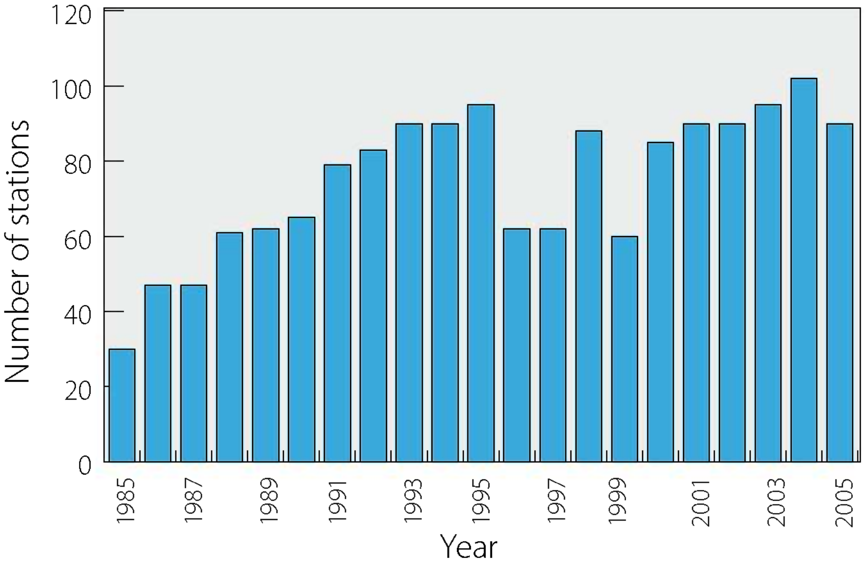


Figure 2.1 Development of the station network.

Since 2004, the network has been divided into a Primary Network consisting of 55 stations having basin-wide and/or transboundary interest, and a Secondary Network comprising the remaining stations having mainly local or national interest. The stations are monitored and analyses performed by national laboratories under the overall technical guidance of the MRC, which maintains a quality assurance programme. Stations are sampled 12 times per year, usually on the 15th of each month, at a depth of 0.5 m in the middle of the cross-sectional profile (thalweg), or at the point of maximum flow if the midpoint is not representative. The parameters measured are shown in Table 2.1. The Primary Network that is mainly used in this assessment is shown in Figure 2.2.

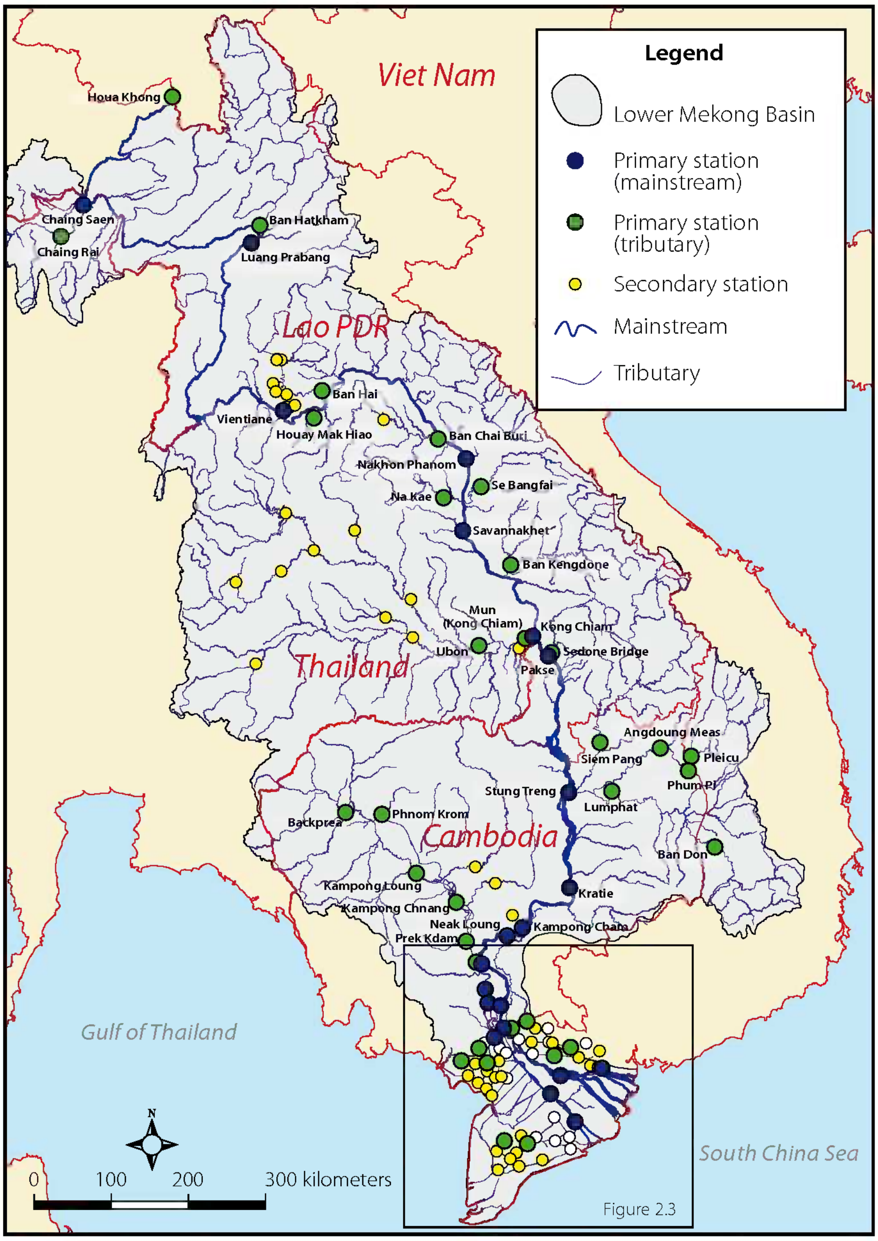


Figure 2.2 WQMN in the Lower Mekong Basin, indicating stations sampled in 2005.

Table 2.1 *Parameters of the MRC WQMN.*

| | | | | |
|---|---|---|---|---|
| Temperature | Sodium | Nitrite + Nitrate | Phosphate ($PO_{4\text{-}3}$) | $COD_{Mn}$ |
| Conductivity (mS/m) | Potassium | Total Ammonia | Total-P | Aluminium |
| TSS (mg/L) | Calcium | Total Nitrogen[1] | | Iron |
| pH | Magnesium | | | Silica |
| DO (mg/L) | Chloride | | | Chlorophyll-a[2] |
| | Sulphate | | | Faecal coliforms[2] |
| | Alkalinity | | | |

1 Two of the countries do not measure this. 2 Added in 2007.

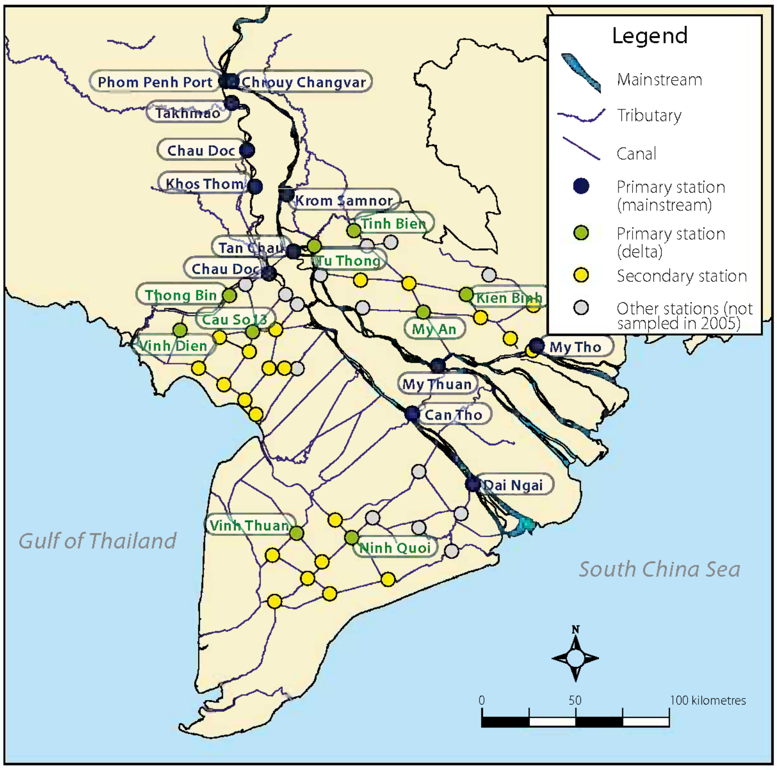


Figure 2.3 WQMN in the Delta area, indicating stations sampled in 2005.

The number of stations sampled depends on the logistical arrangement provided by each country, but most are sampled regularly every year. A few stations in Cambodia and the Lao PDR are not easily accessible, especially in the rainy season, making sample quality control quite challenging. The MRC regularly evaluates the database and has developed a spreadsheet application that applies five tests (e.g. ion balance). These are integrated into a reliability score that is recorded as part of the database. Internal and external quality assurance programmes, together with external comparisons made by expert contractors, indicate that the data are generally reliable (MRC, 2007a).

The assessment reported in this technical report uses data covering the 20-year period, 1985–2005, or in some cases the subset of data collected from 2000–2005.

## 2.2 Benchmark station selection

Benchmark stations are those that have the following characteristics:

- Representative of the characteristics of a larger area or adjacent stations;
- They should preferably have a long time-series;
- Represent an anomalous or ‘hot spot’ situation that merits long-term monitoring;

- Whenever possible they should represent different countries.

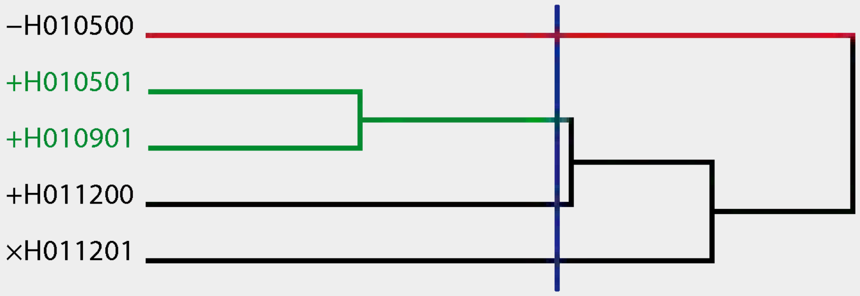
Where two stations are on either side of an international border, both are selected to reflect transboundary issues. The assessment uses the entire database for all stations, while the benchmark stations are used to identify trends.

The initial selection of stations was made subjectively, then verified and amended as required, using a clustering algorithm (see the box below on Ward's cluster method, details of which were published by Basak *et al.*, 1988). These, or some selection of these, are under consideration as permanent 'benchmark' stations for future reporting. Some important stations, such as Houa Khong (see Figure 2.2) at the China border, were not considered in this assessment as the record length is too short to be meaningful. In other cases, stations are in transition from older sites to newer and better located sites (Table 2.2).

### *Ward's Cluster Method*

*In order to find similarities between different stations, Ward's cluster (multivariate) method joins similar stations into clusters, forming a dendrogram. Parameters for the cluster analysis are selected. The two stations that are most similar with respect to the selected parameters join early in the dendrogram. The degree of similarity is illustrated by the length of the horizontal line that joins the pair. After joining, the mean value for the pair is again compared with the other data and the next closest one joins the pair.*

*In this example with five stations, the two marked in green are the most similar and the one marked in red differs the most from the others. There are four possible clusters – the two stations indicated in green, a cluster consisting of the three stations marked with +, a cluster consisting of the green and black stations, and finally a cluster consisting of all five stations. Selection of clusters is up to the user who can decide how many clusters are required or how closely the stations in each cluster should resemble each other. In this example, the user has placed a vertical blue line to indicate his threshold for cluster identification. Moving the blue line to the left or right creates more or fewer clusters.*



## Mainstream stations

Clustering of the mainstream stations was done for (i) all parameters used in the three water quality indices (see below), (ii) for a subset of parameters reflecting only nutrients, and (iii) using only $COD_{Mn}$ and DO. On the basis of these results, Table 2.2 gives the final choice of benchmark stations on the mainstream. This includes mainstream stations in the Delta area.

Table 2.2 *Mainstream benchmark stations.*

*Ordered from upstream to downstream. Transboundary stations are shaded grey.*

| Code | Name | Country | River | Comment |
|---|---|---|---|---|
| 010501 | Chiang Saen | Thailand | Mekong | |
| 011201 | Luang Prabang | Lao PDR | Mekong | |
| 011901 | Vientiane | Lao PDR | Mekong | |
| 013101 | Nakhon Phanom | Thailand | Mekong | |
| 013901 | Pakse | Lao PDR | Mekong | Transboundary station. Moved upstream in 2005. |
| 014501 | Stung Treng | Cambodia | Mekong | New in 2005. Use as transboundary station in 2010 |
| 014901 | Kratie | Cambodia | Mekong | Transboundary station. See above for Stung Treng |
| 019801 | Chrouy Changvar | Cambodia | Mekong | Formerly Phnom Penh |
| 019806 | Neak Loeung | Cambodia | Mekong | Transboundary station. Move to Krom Samnor in 2010 |
| 019803 | Tan Chau | Viet Nam | Mekong | Transboundary station |
| 019804 | My Thuan | Viet Nam | Mekong | Most downstream station above distributaries |
| 019805 | My Tho | Viet Nam | Mekong | Only part of flow due to distributaries |
| 033402 | Koh Khel | Cambodia | Bassac | Transboundary station. Move to Khos Thom in 2010 |
| 033403 | Khos Thom | Cambodia | Bassac | Transboundary station. New in 2005 |
| 039801 | Chau Doc | Viet Nam | Bassac | Transboundary station |
| 039803 | Can Tho | Viet Nam | Bassac | Most downstream, long-term station |
| 029812 | Dai Ngai | Viet Nam | Bassac | Added in 2005 |

## Tributary stations

Table 2.3 *Tributary benchmark stations.*

*Ordered from upstream to downstream.*

| Code | Name | Country | River | Comment |
|---|---|---|---|---|
| 100101 | Ban Hatkham | Lao PDR | Nam Ou | |
| 230103 | Ban Hai | Lao PDR | Nam Ngum | At bridge over Highway 13 (from 2005) |
| 290103 | Ban Chai Buri | Thailand | Nam Songkhram | |
| 350101 | Ban Kengdone | Lao PDR | Se Bang Hieng | |
| 380128 | Mun (Kong Chiam) | Thailand | Nam Mun | |
| 390105 | Sedone Bridge | Lao PDR | Se Done | Near Pakse (from 2005) |
| 440103 | Angdoung Meas | Cambodia | Se San | |
| 450101 | Lumphat | Cambodia | Sre Pok | |
| 020106 | Kampong Luong | Cambodia | Great Lake | |
| 020101 | Phnom Penh Port | Cambodia | Tonle Sap | |
| 370104 | Yasathon* | Thailand | Nam Chi | |
| 381699 | Lam Dom Noi* | Thailand | Nam Mun | |

* Secondary Stations that are selected due to their location on the Khorat Plateau with evaporite geological substrata and saline ground water.

### Delta stations

Because the conditions in the Delta are different to those elsewhere in the basin, different criteria were used to select Delta stations that are not on the mainstream. There are 31 stations (in 2005) located on the canals and distributaries of the Delta in Viet Nam, of which nine stations are designated by the Vietnamese as Primary Stations. These exclude the six stations located on the mainstreams of the Mekong and Bassac (Table 2.2). The aquatic environmental conditions in the Delta are very complex with local problems of acidification from acid sulphate soils, sea water intrusion, and localised pollution from high population densities. Attempts to cluster stations using various groupings of parameters mainly failed to produce any consistent stations that could be used for general assessment purposes. As a consequence, clustering was carried out according to specific water-quality conditions that are known to occur in the Delta. This resulted in the following representative stations (Table 2.4):

Table 2.4 *Delta benchmark stations.*

| Code | Name | Status | Comments |
|---|---|---|---|
| H988311 | Vinh Dieu | Primary | More permanently acid status |
| H988209 | Vinh Thuan | Primary | Seasonal variation between acid and neutral conditions |
| H988211 | Ninh Quoi | Primary | Seasonally variable salinity |
| H988203 | Nhu Gia | Secondary | High trophic state |
| H988205 | Ho Phong | Secondary | Permanent salinity |
| H988207 | Chu Chi | Secondary | High organic pollution |
| H988208 | Thoi Binh | Secondary | Average organic pollution |
| H988306 | Cau So 5 | Secondary | Normal trophic state |

## 2.3 Data partitioning according to discharge

It is well known that water-quality data can be greatly influenced by river discharge. In the LMB discharge is dominated by the monsoon period. The long-term mean annual and monthly discharge at selected stations are given in Table 2.5. The onset of the wet season at any station is defined when the flow first exceeds the mean annual discharge (MRC, 2007b). Likewise, the end of the wet season is defined when the flow first falls below the mean annual discharge. These definitions are illustrated in Figure 2.4, which uses the station at Kratie as an example. The timing of onset and end of the flood according to these definitions are the most consistent features of the annual hydrograph (MRC, 2007b). For the purposes of this study, the months from June through to November are included in the wet season (Table 2.5). June and November are included as the onset and end of the wet season occurs during these months, even though the mean monthly discharge of each month is less than the mean annual discharge.

The validity of this partition can be further investigated by examining conductivity values that are highly flow dependent. As seen in Figure 2.5, few data points violate the data partition over the entire period of record.

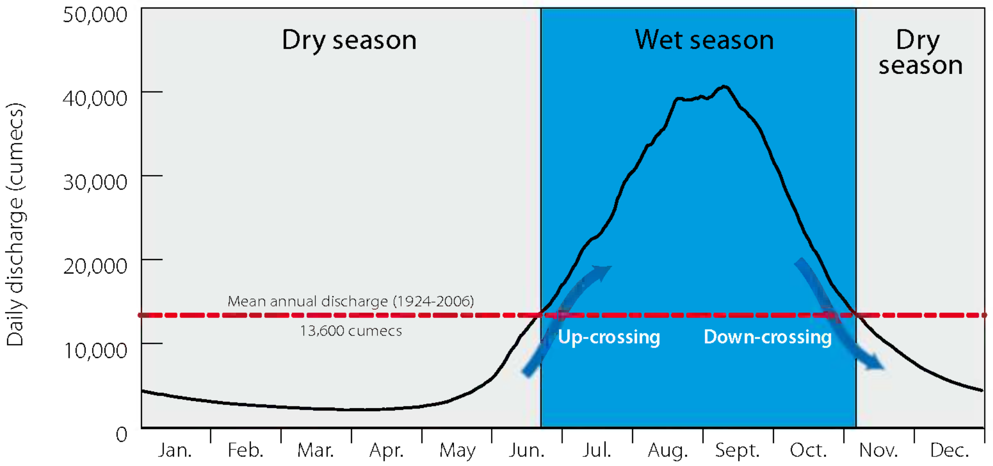


Figure 2.4 Definition of the wet and dry seasons, using the hydrograph at Kratie as an example (MRC, 2007b).

Table 2.5 *Schematic table indicating wet season months (in blue) for selected stations.*

| Discharge | Chiang Sean | Luang Prabang | Vientiane | Nakhon Phanom | Paskse | Kratie |
|---|---|---|---|---|---|---|
| Mean annual discharge | 2,700 | 3,900 | 4,400 | 7,100 | 9,700 | 13,600 |
| Jan | 1,150 | 1,690 | 1,760 | 2,380 | 2,800 | 3,620 |
| Feb | 930 | 1,280 | 1,370 | 1,860 | 2,170 | 2,730 |
| Mar | 830 | 1,060 | 1,170 | 1,560 | 1,840 | 2,290 |
| Apr | 910 | 1,110 | 1,190 | 1,530 | 1,800 | 2,220 |
| May | 1,300 | 1,570 | 1,720 | 2,410 | 2,920 | 3,640 |
| Jun | 2,460 | 3,110 | 3,410 | 6,610 | 8,810 | 11,200 |
| Jul | 4,720 | 6,400 | 6,920 | 12,800 | 16,600 | 22,200 |
| Aug | 6,480 | 9,920 | 11,000 | 19,100 | 26,200 | 35,500 |
| Sep | 5,510 | 8,990 | 10,800 | 18,500 | 26,300 | 36,700 |
| Oct | 3,840 | 5,750 | 6,800 | 10,200 | 15,400 | 22,000 |
| Nov | 2,510 | 3,790 | 4,230 | 5,410 | 7,780 | 10,900 |
| Dec | 1,590 | 2,400 | 2,560 | 3,340 | 4,190 | 5,710 |

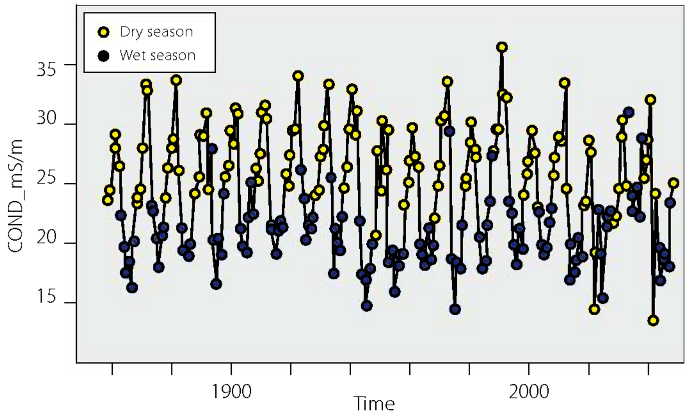


Figure 2.5 Seasonal variation in conductivity at Chiang Saen.

## 2.4 Trend analysis

Commonly a time-series is composed of three components: (i) trend, (ii) cyclic variation, and (iii) random variation.

The preferred way of evaluating time-series is to assume that it is monotonous (the water-quality data for most of the time-series conform with this) and to use a non-parametric method for the evaluation. Such a method minimises the importance of both extremes and missing values. Most commonly used is Theil's (Sen's) slope and the seasonal Mann-Kendall test for the calculation of the significance of a trend (slope). Both perform the calculations by season (by month here) in order to reduce the effects of seasonal variation.

## 2.5 Water-quality indices and guideline values

This assessment follows the recommendations of Ongley (2006a) in his review of water-quality index methodology and water-quality guideline (trigger/threshold) values for key parameters. Special consideration is given in the assessment (Chapter 3) to the situation in the Delta, as some parameter values such as $COD_{Mn}$ are affected, analytically, by salinity.

### Guideline values

Table 2.6 contains the consensus values used in this assessment together with statistical information on parameter distributions within the database. These values are subject to adjustment in the future as the MRC gains more experience with the technical criteria.

Table 2.6 *Comparison of guideline values relative to the MRC database.*

*Statistical data are Database to 2000, for all stations;* $NH_3$*-N is calculated for this assessment, using pH and temperature data for each station.*

| Parameter | Guideline value | Units | WQMN database | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Mean | Median | Standard Dev. | Skewness | Max. | Min. |
| Aquatic Life | | | | | | | | |
| DO | > 5.0 | mg/L | 6.37 | 6.7 | 1.86 | -0.83 | 10.00 | 0.05 |
| pH | 6.5 – 8.5 | | 7.06 | 7.2 | 0.94 | -2.13 | 9.77 | 2.66 |
| $NH_3$-N | < 0.1 | mg/L | (not reported by MRC) | | | | | |
| Conductivity | < 70 | mS/m | 281 | 20 | 812 | 3.59 | 5260 | 1.1 |
| $NO_{2\text{-}3}$-N | < 0.7 | mg/L | 0.289 | 0.216 | 0.285 | 2.42 | 3.32 | 0.001 |
| Total-P | 0.13 | mg/L | 0.081 | 0.052 | 0.097 | 4.38 | 2.11 | 0.001 |
| Human Impact | | | | | | | | |
| $NH_4$-N | <0.05 | mg/L | 0.061 | 0.031 | 0.155 | 9.47 | 2.69 | 0.0 |
| $COD_{Mn}$ | < 4 | mg/L | 3.26 | 2.55 | 2.77 | 2.07 | 29.50 | 0.011 |

## Aquatic life

The Water Quality Index for aquatic life ($WQI_{al}$) is comprised of:

| | | |
|---|---|---|
| DO, pH, $NH_3$, Conductivity | Meets guideline | =2 |
| | Does not meet guideline | =0 |
| $NO_{3-2}$, total-P | Meets guidelines | =1 |
| | Does not meet guideline | =0 |

The values of 0, 1 and 2 are weightings used in the algorithm to reflect the relative importance, or confidence, in the parameter. In this assessment $NH_4$ (total ammonia) is used in place of $NH_3$, as the latter is not available for some sites due to the absence of temperature and/ or pH values that are used to calculate the amount of $NH_3$. In the Mekong system, it is probable that very little of total ammonia is the un-ionized and toxic $NH_3$.

The $WQI_{al}$ is calculated for each station as follows:

$$WQI_{al=} \frac{\sum (p1 + p2 \ldots\ldots p_n)}{M} \times 10$$

where: ‘p’ is the number of points per sample day
‘n’ is the number of sample dates in the year
‘M’ is the maximum possible number of points for measured parameters in the year

This procedure provides for bias in cases where some measurements were not taken. Multiplying by ten provides for a scale between 10 (highest quality) and 0 (lowest quality). The following scale is used in this assessment but may require future adjustment.

| Grade scale | Class | Comments |
|---|---|---|
| 10 – 9.5 | High Quality | (Requires that all four primary parameters must be compliant, with few exceptions) |
| <9.5 – 9 | Good Quality | (Requires that the four primary parameters must be compliant most of the time) |
| <9 – 7 | Moderate Quality | (One or more of the four primary parameters will not be compliant much of the time) |
| <7 | Poor Quality | (Many of the primary parameters will not be compliant most of the time) |

## Human impact

Human impact differs from water quality for aquatic life. For aquatic life, water quality must meet a technical requirement for the maintenance of aquatic life. In contrast, the Water Quality Index for ‘human impact’ ($WQI_{hi}$) indicates only the influence of human pressure on water-quality relative the average over the period of record. In this way, it is possible to assess, over time, if human pressure on water quality is increasing or decreasing through time. This does not imply that the water is polluted, only that there is evidence of human pressure on water quality. In some classification systems of human impact $NH_3$-N is the preferred nitrogen species due to its toxicity. However, as this is very low in the Mekong, the MRC has elected to use total ammonia ($NH_4$-N). In the Hong Kong index system BOD is used. However, the MRC uses only $COD_{Mn}$, which is substituted here as an indicator of human impact. The following parameters are used to assess human impact:

DO, $COD_{Mn}$, $NH_4$

The assessment protocol is similar to the equation used for aquatic life, except that each parameter has equal weight insofar as all parameters are directly implicated in human impact and the technical values are reliable.

The proposed grade scale for $WQI_{hi}$:

| Grade scale | Class |
|---|---|
| 10 – 9.5 | Not Impacted |
| <9.5 – 8.5 | Slightly Impacted |
| <8.5 – 7 | Impacted |
| <7 | Severely Impacted |

## Agricultural Uses

Because agriculture, especially irrigated rice, is of such importance in the LMB, the assessment includes an index for agricultural uses. The specific crop requirements differ substantially from crop to crop and between different agricultural uses. An index for the three subcategories of agricultural uses, based on FAO (1985) salinity guidelines in agriculture, is given in Table 2.7. For reporting here, the annual mean station value is reported and coloured according to the colour scale noted in Table 2.7.

Table 2.7 *Salinity guidelines for agricultural use of water. Adapted from FAO, 1985.*

| Agricultural Use | Units | Degree of Restriction | | |
|---|---|---|---|---|
| | | None[1] | Some[1] | Severe[1] |
| | | Salinity (conductivity) | | |
| General Irrigation | mS/m | < 70 | 70 – 300 | >300 |
| Paddy Rice Irrigation | mS/m | <200 | 200 – 480 | >480 |
| Livestock & Poultry[2] | mS/m | <500 | 500 – 800 | >800 |
| Weight factor | | 2 | 1 | 1 |

1. None = 100% of yield. Some = 50 – 90% of yield. Severe = <50% of yield. 2. There are differences between livestock and poultry. Poultry are less tolerant than livestock to salinity.

The methodology for calculating the $WQI_{ag}$ follows that used for aquatic life. The conductivity data are evaluated for each station, for each type of agricultural use. Weight factors are applied to account for situations where one or two months of less than No Restrictions use would unduly bias the results downward. The result for each type of agricultural use is based on a scale of 1 – 10, where 1 is the worst and 10 is the best water quality.

The proposed grade scale for $WQI_{ag}$ is:

| Grade scale | Class |
|---|---|
| 10 – 8 | No Restrictions |
| <8 – 7 | Some Restrictions |
| <7 | Severe Restrictions |

## Calculation of dissolved substance transport

The calculation of a dissolved substance transport (load) requires data for both flow and concentration. The data are available in various frequencies, usually daily for flow but only monthly for concentrations. The general form of the equation for calculating loads is:

$$T = Q * C$$

where 'T' is transported load in tonnes, 'Q' is flow (Q) and 'C' is concentration of the chemical parameter.

There are several methods of loading calculation, depending on the available data:

1. Simple multiplication of flow and concentration
   where:
   Qt = Monthly mean flow over time t
   Ct = concentration at time t
   t = time (here month)
   F = conversion factor to produce tonnes per month

2. Interpolation of the monthly concentration values to obtain daily values to be multiplied with daily flow values.

3. Correlation between instantaneous flow and concentration to be used in the calculation of daily transport.

The first method is used here. It facilitates the calculation and most probably keeps systematic errors low. The second and third methods are not advised as the interpolations and correlations are usually poor.

For the transport calculation, single missing concentration values were interpolated from adjacent values. When two or more consecutive values were missing, they were not interpolated and the station-year(s) was omitted from the calculation. The effect of an erroneous interpolation is difficult to evaluate. However, since the maximum monthly flow can represent as much as 60% of the annual flow, and the median flow represents only up to 25% of the annual flow, it is likely that the interpolated concentration value is within ± 20% of the 'true' value. Thus the error contributed by an interpolated value, to the annual transport of a substance, is likely to be approximately +/- 5%. Monthly transport values are summed to give annual transport values of the substance.

# 3. Water quality assessment

## 3.1 Effects of river discharge on water quality

There are two principal effects of river discharge on concentrations of water-borne substances. The first is the effect of flow on pollutants coming from point sources that are independent of flow, such as that from municipal waste water and industrial discharges. In this case, increasing flow causes dilution of the pollutant concentration, yet the total transported load remains constant. The second effect is the so-called ‘runoff effect’, in which substances from non-point sources (NPSs) are mobilised by runoff. This is the case for pollutants from agriculture, erosion of land surfaces, street runoff from urban areas, etc.. In this case, increased losses from NPSs occur during rainfall and one commonly sees an increase in the concentration in the river and an increase in total transported load. The relationship between rainfall, runoff, and pollutant concentration/load is complex however, and depends to a considerable extent on the size of the river system—the larger the river, the more difficult it is to establish precise relationships for this phenomenon.

In the Mekong, the annual cycle of high/low flow dominates flow-concentration relationships and individual rain events, even very large ones, are not very visible in the main river. Using flow data normalised against the mean annual flow for each station reveals the cyclic pattern over the period 1985–2005 (Figure 3.1).

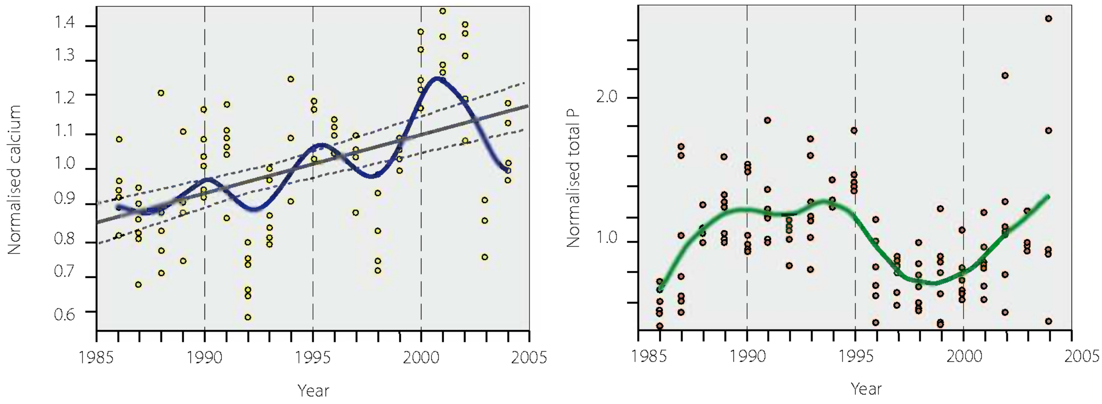


Figure 3.1 Normalised flow and concentrations of Calcium and total-P for mainstream stations in the LMB.

While a simple linear regression over the time of observation indicates an increase of about one percent per year for these stations, analysis of the period 1960–2004 from Vientiane and Kratie indicates that there has been no significant change in the average magnitude of flow over this longer period (MRC, 2005).

One can assume that the leaching of calcium would be constant annually. If so, then a higher flow would lower concentrations by dilution. Peak flows in 1990, 1995, and 2001 coincide with low calcium concentrations and the low flow years 1992 and 1998 have high concentrations, illustrating the dilution phenomenon.

A large part of the total-P is bound to solids in water. Transport of P from land, especially agricultural surfaces, is enhanced by periods of high rainfall. The cyclic behaviour, seen in Figure 3.1, is loosely related to flow in that high flow years (e.g. 1990 and 1995) tend to have higher total-P concentrations and low concentrations occur during relatively low-flow years (2000–2002).

Despite the evidence above, it is concluded that flow normalisation procedures are not especially useful for chemical trend analysis in the LMB.

## 3.2 Water quality indices

### Basin-wide patterns

The median annual values for the Water Quality Index (WQI) for aquatic life, human impact, and agricultural uses, for mainstream and tributary stations are shown in Figure 3.2 for the period 2000–2005. These were calculated using the entire database of Primary Stations. Figure 3.3 gives details of these in the Delta area. Tables 3.1 to 3.3 contain the index value and the quality class for the Primary Stations over the same period of record.

### *Mainstream (Table 3.1)*

Aquatic Life ($WQI_{al}$): All bar one of the stations on the mainstream are classed as High Quality.

Human Impact ($WQI_{hi}$): Throughout the mainstream, the values for this index are significantly lower than the indices for $WQI_{al}$. Only Kratie is classed as Not Impacted. The other stations are classed as either Slightly Impacted or Impacted, with one station (Can Tho on the Bassac) classed as Severely Impacted. By and large, the stations downstream of Phnom Penh are classed as Impacted, which may be attributed to higher population densities along this stretch of the river. However, Houa Khong and Chiang Saen, the two most upstream stations, are also classed as Impacted.

Agricultural Use ($WQI_{ag}$): All stations are classed as No Restrictions.

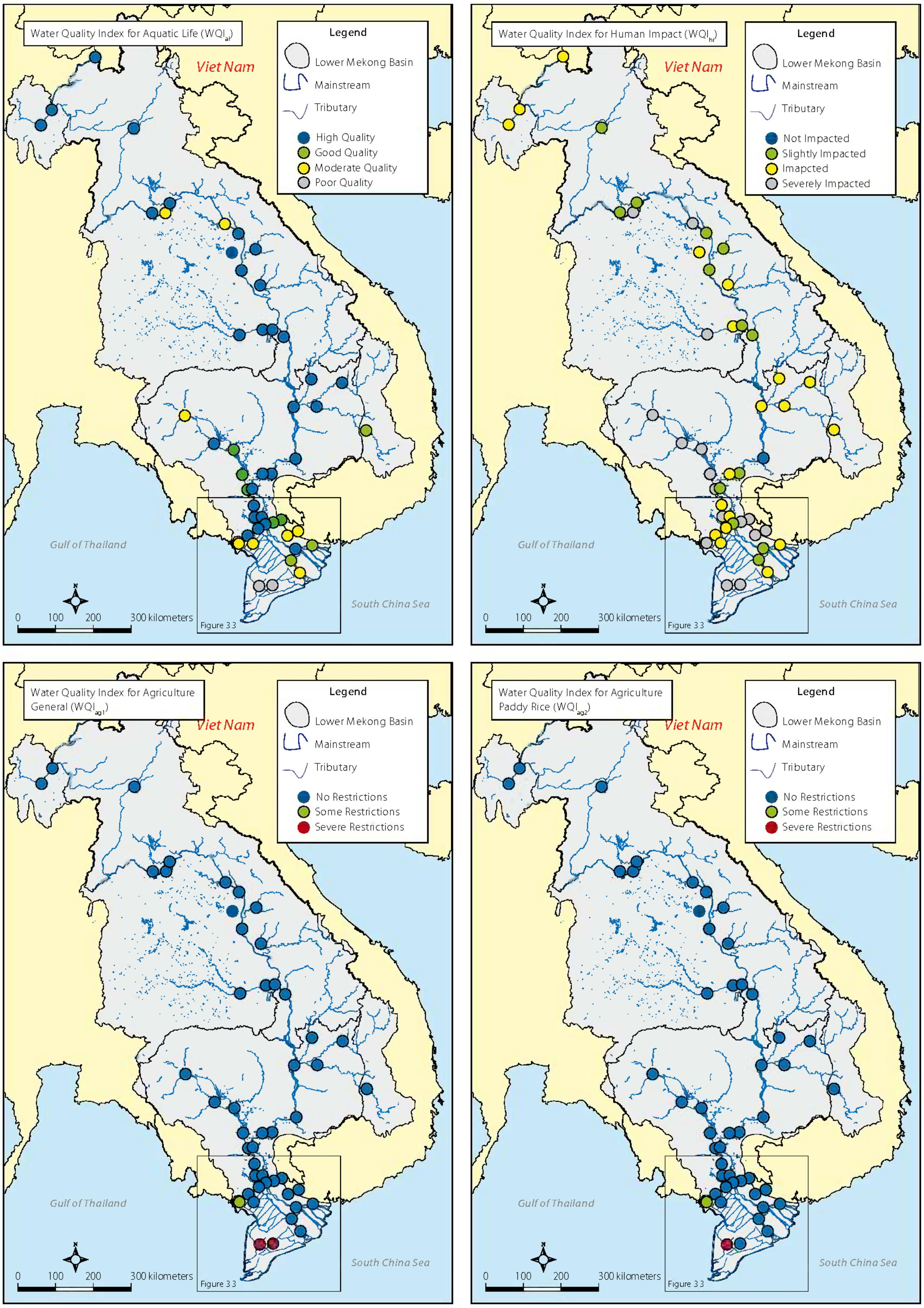


Figure 3.2 Median values for WQ classes for mainstream and tributary stations for the period 2000-2005.

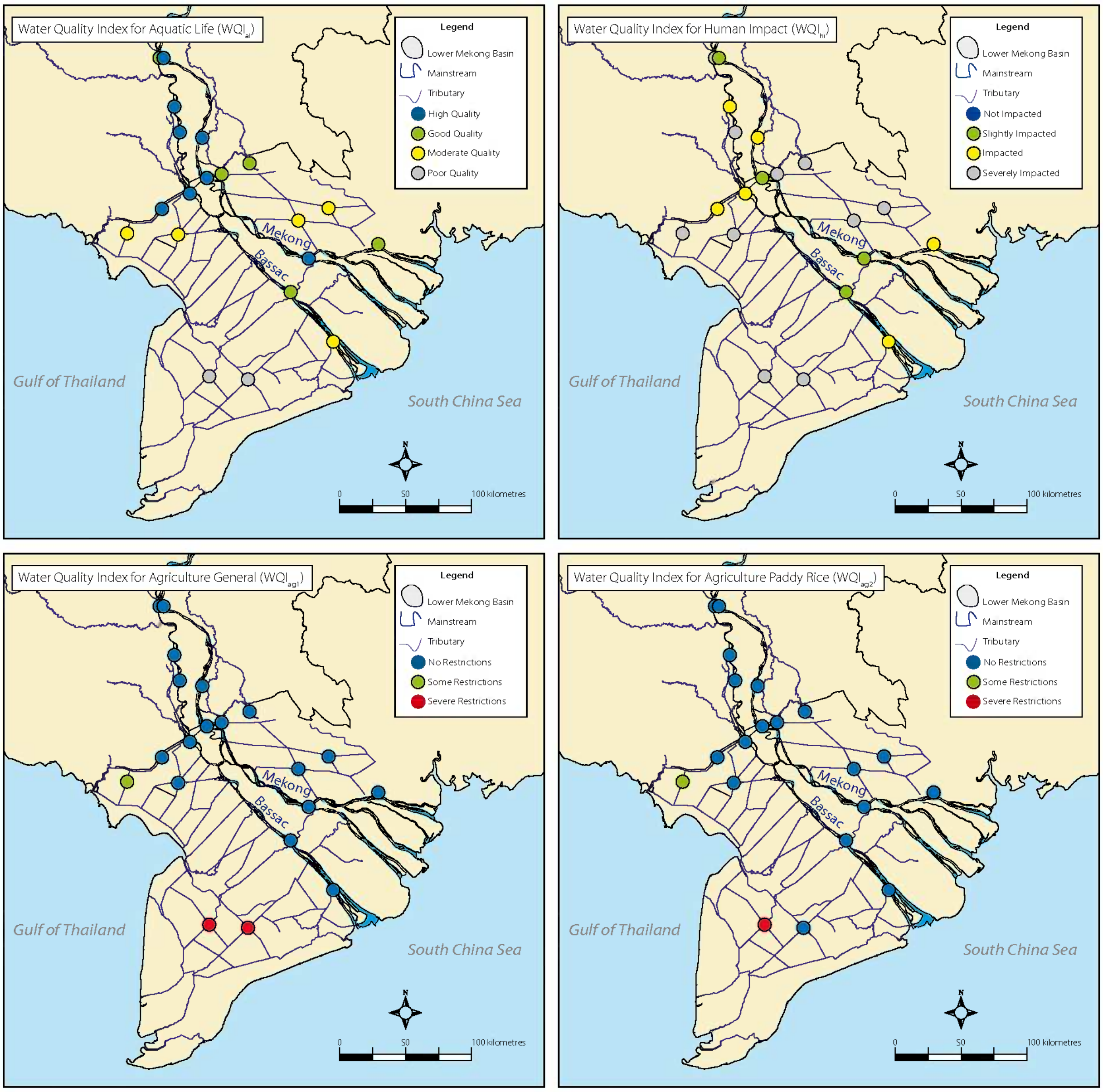


Figure 3.3 Median values for WQ classes the Delta stations for the period 2000-2005.

Table 3.1 *Water quality indices for Primary Stations on the mainstream.*

| Station Code | Name | River | $WQI_{al}$ | $WQI_{hi}$ | $WQI_{ag1}$ General | $WQI_{ag2}$ Paddy rice | $WQI_{ag3}$ Livestock |
|---|---|---|---|---|---|---|---|
| H010500 | Houa Khong | Mekong | 9.9 | 7.8 | 10.0 | 10.0 | 10.0 |
| H010501 | Chiang Saen | Mekong | 9.7 | 8.4 | 10.0 | 10.0 | 10.0 |
| H011201 | Luang Prabang | Mekong | 9.8 | 8.5 | 10.0 | 10.0 | 10.0 |
| H011901 | Vientiane | Mekong | 9.7 | 8.5 | 10.0 | 10.0 | 10.0 |
| H013101 | Nakhon Phanom | Mekong | 9.8 | 8.6 | 10.0 | 10.0 | 10.0 |
| H013401 | Savannakhet | Mekong | 9.9 | 8.9 | 10.0 | 10.0 | 10.0 |
| H013801 | Khong Chiam | Mekong | 9.8 | 8.6 | 10.0 | 10.0 | 10.0 |
| H013901 | Pakse | Mekong | 9.9 | 8.9 | 10.0 | 10.0 | 10.0 |
| H014501 | Stung Treng | Mekong | 9.8 | 7.6 | 10.0 | 10.0 | 10.0 |
| H014901 | Kratie | Mekong | 10.0 | 9.5 | 10.0 | 10.0 | 10.0 |
| H019806 | Neak Loeung | Mekong | 9.8 | 8.2 | 10.0 | 10.0 | 10.0 |
| H019802 | Kampong Cham | Mekong | 9.8 | 8.8 | 10.0 | 10.0 | 10.0 |
| H019801 | Chroy Changvar | Mekong | 9.8 | 9.0 | 10.0 | 10.0 | 10.0 |
| H019807 | Krom Samnor | Mekong | 10.0 | 7.9 | 10.0 | 10.0 | 10.0 |
| H019803 | Tan Chau | Mekong | 9.5 | 8.5 | 10.0 | 10.0 | 10.0 |
| H019804 | My Thuan | Mekong | 9.5 | 8.6 | 10.0 | 10.0 | 10.0 |
| H019805 | My Tho | Mekong | 9.1 | 8.3 | 9.2 | 10.0 | 10.0 |
| H033402 | Koh Khel | Bassac | 9.6 | 7.0 | 10.0 | 10.0 | 10.0 |
| H033403 | Khos Thom | Bassac | 10.0 | 6.4 | 10.0 | 10.0 | 10.0 |
| H039801 | Chau Doc | Bassac | 9.6 | 8.3 | 10.0 | 10.0 | 10.0 |
| H039803 | Can Tho | Bassac | 9.4 | 8.6 | 10.0 | 10.0 | 10.0 |
| H029812 | Dai Ngai | Bassac | 8.8 | 7.2 | 8.8 | 9.2 | 9.6 |

*Note:* Median values for 2000–2005. * = transboundary station. The colour of the values follow the respective WQ classes noted below.

$WQI_{al}$

| | |
|---|---|
| 10–9.5 | High Quality |
| <9.5–9 | Good Quality |
| <9–7 | Moderate Quality |
| <7 | Poor Quality |

$WQI_{hi}$

| | |
|---|---|
| 10–9.5 | Not Impacted |
| <9.5–8.5 | Slightly Impacted |
| <8.5–7 | Impacted |
| <7 | Severely Impacted |

$WQI_{ag}$

| | |
|---|---|
| 10–8 | No Restrictions |
| <8–7 | Some Restrictions |
| <7 | Severe Restrictions |

Table 3.2 *Water quality indices for Primary Stations on tributaries.*

| Station Code | Name | River | Years | $WQI_{al}$ | $WQI_{hi}$ | $WQI_{ag1}$ General | $WQI_{ag2}$ Paddy rice | $WQI_{ag3}$ Livestock |
|---|---|---|---|---|---|---|---|---|
| H020101 | Phnom Penh Port | Tonle Sap | 6 | 9.4 | 6.2 | 10.0 | 10.0 | 10.0 |
| H020102 | Prek Kdam | Tonle Sap | 6 | 9.0 | 6.3 | 10.0 | 10.0 | 10.0 |
| H020103 | Kampong Chhnang | Tonle Sap | 6 | 9.2 | 6.4 | 10.0 | 10.0 | 10.0 |
| H020106 | Kampong Luong | Great Lake | 6 | 9.8 | 6.7 | 10.0 | 10.0 | 10.0 |
| H020107 | Sangkeo River* | Great Lake | 1 | 8.0 | 2.2 | 10.0 | 10.0 | 10.0 |
| H020108 | Phnom Krom | Great Lake | 1 | 8.1 | 4 | 10.0 | 10.0 | 10.0 |
| H050104 | Chiang Rai | Nam Mae Kok | 6 | 9.5 | 8.1 | 10.0 | 10.0 | 10.0 |
| H230103 | Ban Hai | Nam Ngum | 1 | 9.5 | 9.2 | 10.0 | 10.0 | 10.0 |
| H290103 | Ban Chai Buri | Nam Songkhram | 1 | 8.7 | 5.8 | 10.0 | 10.0 | 10.0 |
| H310102 | Na Kae | Nam Kam | 6 | 9.7 | 7.2 | 10.0 | 10.0 | 10.0 |
| H320101 | Se Bang Fai | Se Bang Fai | 6 | 9.8 | 9.2 | 10.0 | 10.0 | 10.0 |
| H350101 | Ban Kengdone | Se Bang Hieng | 6 | 9.8 | 8.3 | 10.0 | 10.0 | 10.0 |
| H380104 | Ubon | Nam Mun | 1 | 9.7 | 5.8 | 10.0 | 10.0 | 10.0 |
| H380128 | Mun (Kong Chiam) | Nam Mun | 1 | 9.5 | 7.5 | 10.0 | 10.0 | 10.0 |
| H430102 | Siem Pang | Se Kong | 1 | 9.8 | 7.2 | 10.0 | 10.0 | 10.0 |
| H440103 | Angdoung Meas | Se San | 1 | 9.7 | 7.4 | 10.0 | 10.0 | 10.0 |
| H450101 | Lumphat | Sre Pok | 1 | 9.7 | 7.4 | 10.0 | 10.0 | 10.0 |
| H451303 | Ban Don | Sre Pok | 1 | 9.4 | 9.2 | 10.0 | 10.0 | 10.0 |
| H910108 | Houay Mak Hiao | Houay Mak Hiao | 1 | 7.6 | 1.4 | 10.0 | 10.0 | 10.0 |

*Note:* Median values for 2000–2005. * = Secondary Station. The colours of the values follow the respective WQ classes shown beneath Table 3.1.

Table 3.3 *Water quality indices for Primary Stations on the Delta.*

| STATID | Name | River | Years | $WQI_{al}$ | $WQI_{hi}$ | $WQI_{ag1}$ General | $WQI_{ag2}$ Paddy rice | $WQI_{ag3}$ Livestock |
|---|---|---|---|---|---|---|---|---|
| H988115 | Thong Binh | Thong Binh | 2 | 9.5 | 8.1 | 10.0 | 10.0 | 10.0 |
| H988316 | Tinh Bien | Vinh Te | 1 | 9.2 | 6.4 | 10.0 | 10.0 | 10.0 |
| H988311 | Vinh Dieu | T3 | 5 | 7.1 | 5.8 | 7.5 | 8.8 | 9.6 |
| H988305 | Cau So 13 | Tri Ton | 5 | 8.8 | 5.3 | 10.0 | 10.0 | 10.0 |
| H988110 | My An | No 28 | 2 | 8.8 | 5.4 | 10.0 | 10.0 | 10.0 |
| H988107 | Kien Binh | Duong van Duong | 2 | 7.8 | 4.2 | 9.2 | 10.0 | 10.0 |
| H988114* | Tu Thuong | Tu Thuong | 1 | 9.2 | 5.3 | 10.0 | 10.0 | 10.0 |
| H988209 | Vinh Thuan | Chac Bang | 6 | 4.8 | 3.9 | 1.0 | 2.5 | 5.0 |
| H988211 | Ninh Quoi | Quan Lo–Phung Hiep | 6 | 6.2 | 3.7 | 6.7 | 8.8 | 9.2 |

*Note:* Median values for 2000–2005. The colours of the values follow the respective WQ classes shown beneath Table 3.1.

### *Tributaries (Table 3.2)*

The water quality of stations on the tributaries differs significantly from those on the mainstream.

Aquatic Life ($WQI_{al}$): While the water quality at most stations is classed as High Quality, stations on the Tonle Sap are classed as Good Quality, and those on the Great Lake (with the exception of Kampong Luong) are classed as only Moderate Quality.

Human Impact ($WQI_{hi}$): Most of the stations, including those on the Great Lake and the Tonle Sap, are classed as Severely Impacted. The stations on the Se Kong, Se San and Sre Pok are classed as either Impacted or Slightly Impacted. None of the tributary stations are classed as Not Impacted.

Agricultural Use ($WQI_{ag}$): All stations are classed as No Restrictions.

### *Delta (Table 3.3)*

Aquatic Life ($WQI_{al}$): Of the selected stations only Thong Binh is classified as High Quality; two others are classed as Poor Quality.

Human Impact ($WQI_{hi}$): All the stations bar one (Thong Binh) are classed as Severely Impacted. This is understandable because the Delta is by far the most densely populated area in the entire LMB, and has intense agricultural activity. The impacts caused by these factors are exacerbated by the relatively low flow of water through the canals from the Mekong and Bassac.

Agricultural Use ($WQI_{ag}$): Water quality for agriculture use is classed as either No Restrictions or Some Restrictions at most of the selected stations. Vinh Thuan, located in the middle of Ca Mau peninsula, is the only station where all the $WQI_{ag}$ sub-categories are classed as Severe Restrictions. At another station, Ninh Quoi, the subcategory $WQI_{ag1}$ is classed as Severe Restrictions, however the other subcategories ($WQI_{ag1,}$ and $WQI_{ag2}$) are both classed as No restrictions.

## Trends through time

### *Mainstream*

Temporal trends in water quality indices for selected mainstream stations for the period of record are shown in Figure 3.4. The $WQI_{al}$ index is based on guidelines values, which in turn are based on technical criteria that are largely independent of the water quality of the Mekong river. The trends indicate that this WQI is always of high quality, although more downstream stations illustrate a declining quality in recent years; this is also the case for tributary stations (Figure 3.5).

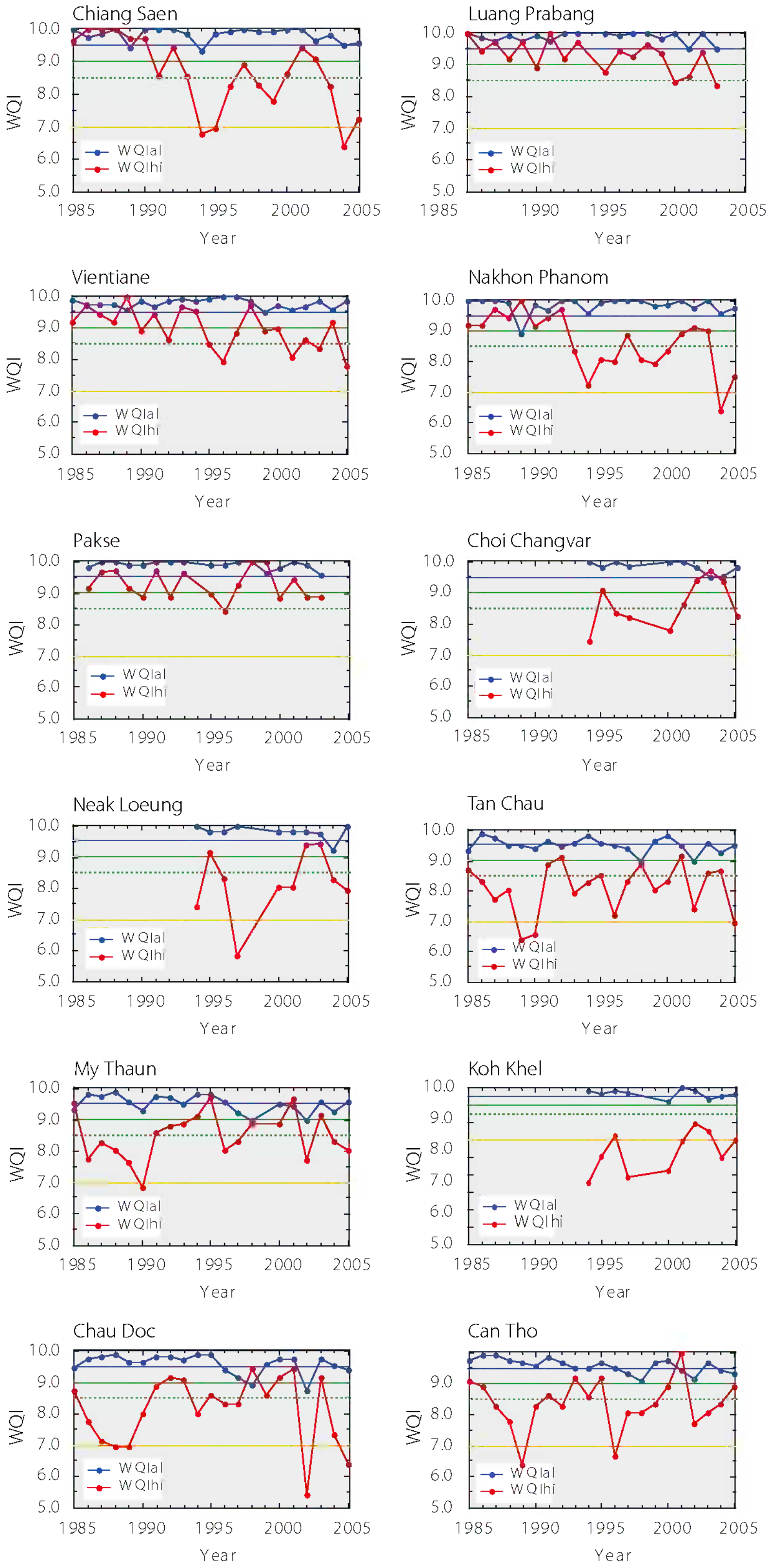


Figure 3.4 WQI trends for a selected number of mainstream stations. The stations are listed from upstream to downstream.

The blue horizontal line is the threshold for High Quality ($WQI_{al}$) and Not Impacted ($WQI_{hi}$). The solid green line the threshold for Good Quality ($WQI_{al}$). The dotted green line shows the threshold for Slightly Impacted ($WQI_{hi}$). The yellow-brown line is the threshold for Impacted ($WQI_{hi}$) and Moderate Quality ($WQI_{al}$).

It might be expected that the sparsely populated upstream areas should be less affected by human activity than the much more heavily populated areas downstream. However, this is not the case. As can be seen in Figure 3.4, the upstream stations of Chiang Saen and Vientiane are as badly impacted as some downstream stations. Also, the general decline in water quality from human impact in the four upper stations is not matched in the lower stations, except at Chau Doc. This decline over time in the upstream stations merits attention: it should be establish if this is caused by local conditions, or is from the Upper Mekong Basin.

### *Tributaries*

Trends are presented for eight tributary stations (Figure 3.5). In general the $WQI_{hi}$ index values are stable but show some declining trends in recent years. As for mainstream stations, the $WQI_{al}$ in tributaries is good, but there is a general decline in 2005, as Figure 3.6 illustrates.

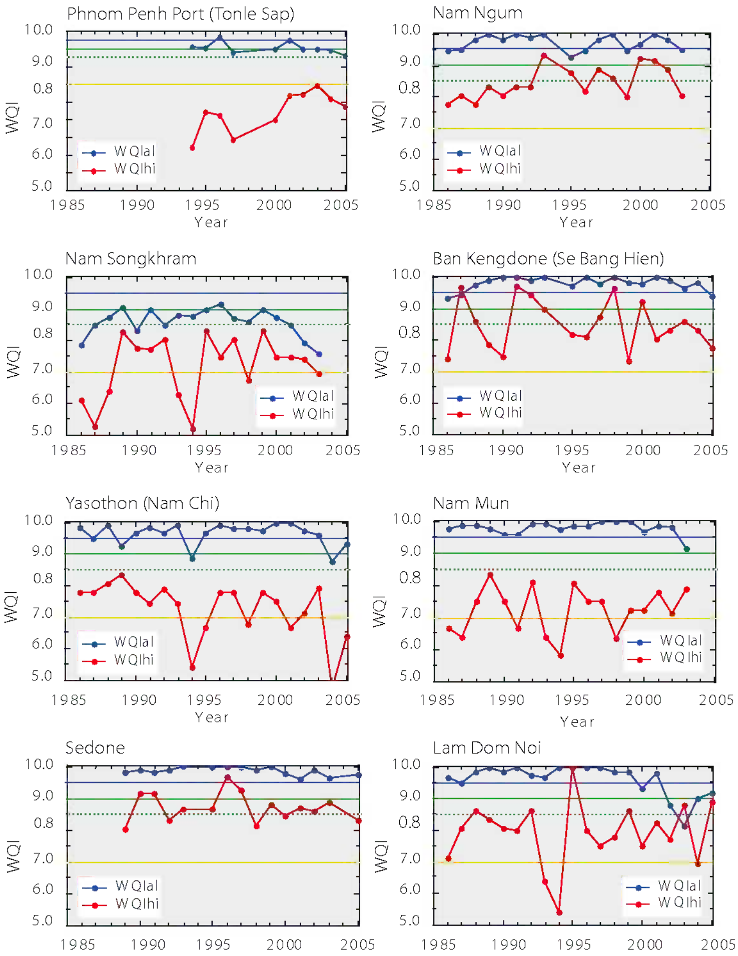


Figure 3.5 WQI trends for a selected number of tributary stations.
The blue horizontal line is the threshold for High Quality ($WQI_{al}$) and Not Impacted ($WQI_{hi}$). The solid green line is the threshold for Good Quality ($WQI_{al}$). The dotted green line shows the threshold for Slightly Impacted ($WQI_{hi}$). The yellow-brown line is the threshold for Impacted ($WQI_{hi}$) and Moderate Quality ($WQI_{al}$).

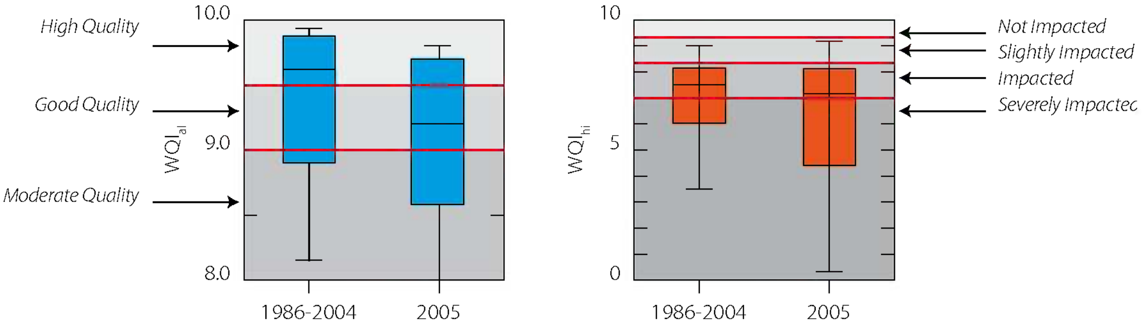


Figure 3.6 WQI for tributary stations: Comparison between 1986-2004 and 2005.
In Blue: $WQI_{al}$ and in Red: $WQI_{hi}$.

## Delta

Time-series data for stations not on the mainstream are long enough only for a limited number of stations. Here four stations, two each from Ca Mau and Long Xuyen areas are presented (Figure 3.7). No trends are evident for these stations except that human impact appears to be increasing in 2005, as indicated in Figure 3.6.

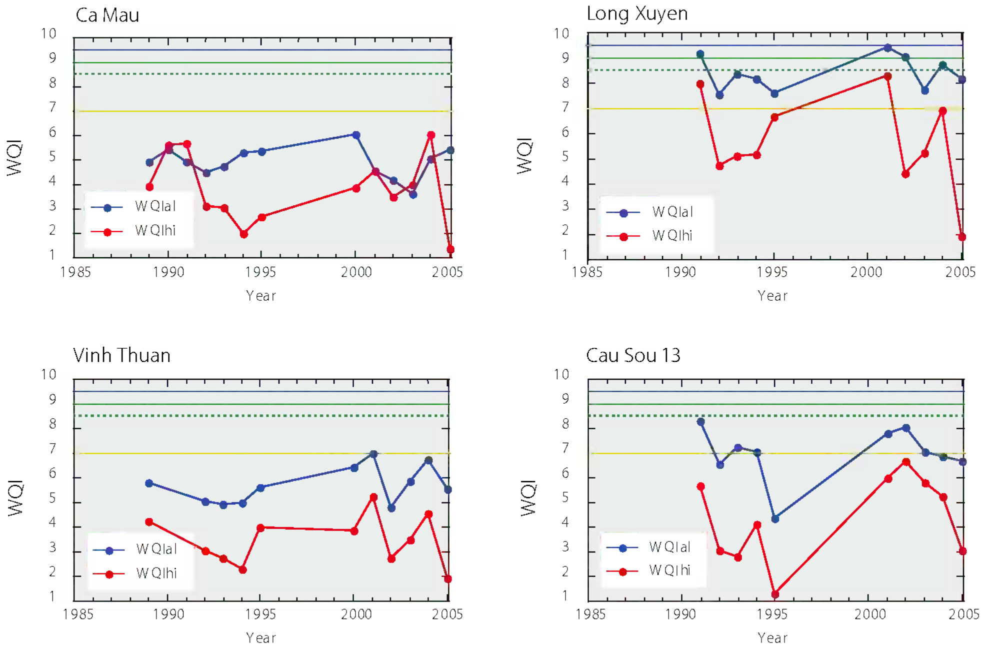


Figure 3.7 WQI for tributary stations: Comparison between 1986 – 2004 and 2005.
The blue horizontal line is the threshold for High Quality ($WQI_{al}$) and Not Impacted ($WQI_{hi}$). The solid green line is the threshold for Good Quality ($WQI_{al}$). The dotted green line shows the threshold for Slightly Impacted ($WQI_{hi}$). The yellow-brown line is the threshold for Impacted ($WQI_{hi}$) and Moderate Quality ($WQI_{al}$).

## 3.3 Trends of individual parameters

Determining trends is a difficult procedure and depends mainly on the approach adopted. Commonly, trends are depicted using linear regression, or a linear trend using Theil's slope procedure. Neither of these recognise curvilinear trends, such as are found with cyclical trends, in which case a smoothing procedure is used to reveal cyclical variation as well as indicating a trend. Smoothing may be made using moving average, a spline function or best, a LOWESS weighting procedure. One example is presented here (Figure 3.8), in which nitrate+nitrite concentration rises in the 1995 – 2000 period after a relatively steady increase during the previous decade. This is followed by an apparent decrease in nitrate+nitrite concentrations. The example also provides the line (in black) and equation for a linear trend and Theil's slope (in red).

Trend data using linear regression are presented in the State of the Basin Report (MRC, 2003) for, amongst other parameters, total phosphorus and total nitrogen. A distinct pattern with increasing concentrations was found in the Delta, while statistical trends were not common in the remaining area of the basin. In this assessment, Theil's (Sen's) slope was calculated for parameters included in the WQI. While some slope values are significant, there is no evidence of any general significant trend. However, the rise in nutrient levels in the last few years at many stations in the Delta is something that merits closer attention.

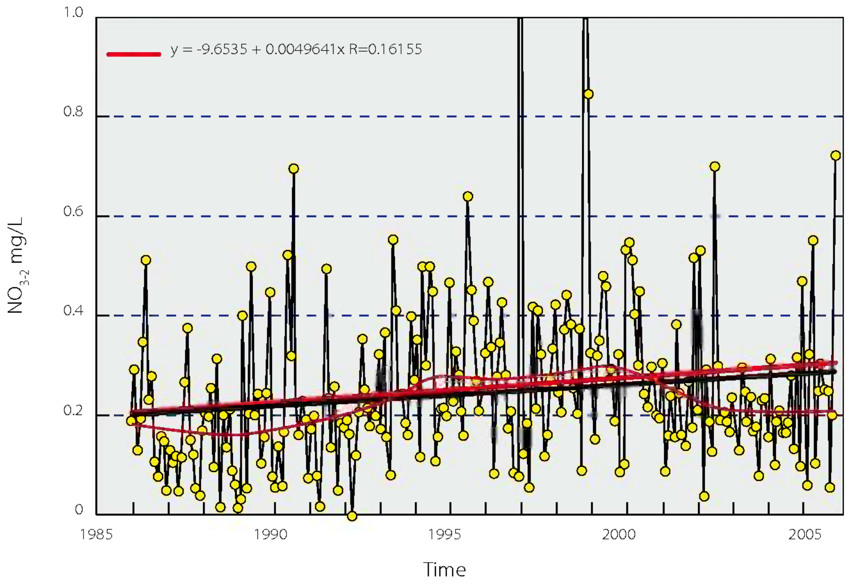


Figure 3.8 Example of a time series: Change of nitrate+ nitrite concentrations with time at Chau Doc.

The straight red line gives the result for a linear regression and the black line the linear trend using Theil's slope. The red curve is a weighted model (LOWESS) to fit the data, which shows cyclic variation.

## Conservative elements

Traditionally, most monitoring programmes determine concentrations of major ions. These ions are: calcium, magnesium, sodium and potassium (positive ions or cations) and alkalinity (hydrogen carbonate), sulphate and chloride (negative ions or anions). Major ions are good measures of chemical weathering, which releases dissolved matter from the soil and bedrock. Changes in major ion concentrations gave the first indicators of acidification in Europe and North America. Changes may also indicate the effects of intensified forestry well before there are signs of soil deterioration. Furthermore, the nature of some major ions affects the chemical behaviour and biological availability (or toxicity) of trace metals. As mentioned in Chapter 1, the LMB has an extensive drainage system with numerous tributary inflows and complex hydrology. As a result it can be difficult to determine whether changes in concentrations of pollutants, such as nutrients and organic matter, are due to dilution or to self-purification processes. In cases where flow data are lacking, major ions can assist in resolving which of these factors is the cause.

Two major ions, alkalinity and sodium, show decreasing concentrations along the length of the river (Figure 3.9), which is not usually observed in other rivers. However in the Mekong, runoff from high rainfall in southern Lao PDR and Cambodia dilutes the salts. The sudden drop in alkalinity at Ta Khmau and Koh Khel stations (both are located on the Bassac) is likely to be caused by drainage of sulphuric acid from soils, which lowers alkalinity. Sodium concentrations behave in a similar way, but not so abruptly.

## Nutrients

Concentrations of total-P are low at most mainstream stations, with the exception of the four stations in the Mekong Delta: Tan Chau and My Thuan on the Mekong, and Chau Doc and Can Tho on the Bassac (Figure 3.9). These higher concentrations are the result of high population density and intensive agriculture.

Nitrate concentrations are also somewhat elevated at these four mainstream stations, but are lower than some upstream stations such as Chiang Saen, Nakhon Phanom and Khong Chiam (Figure 3.9). These three upstream stations are all close to tributaries coming in from Thailand.

## Organic matter

The concentration of organic matter ($COD_{Mn}$) mirrors dissolved oxygen (DO), where a high concentration of $COD_{Mn}$ is accompanied by low DO (Figure 3.9). Organic matter is oxidised by bacteria while consuming oxygen. Trends in both parameters are indicative of higher impacts downstream of Pakse. The worst conditions are found at Ta Khmau and Koh Khel, stations which are both on the Cambodian side of Bassac River, and downstream from Phnom Penh. It is worth noting that almost all the data are less than (better than) the guideline for $COD_{Mn}$.

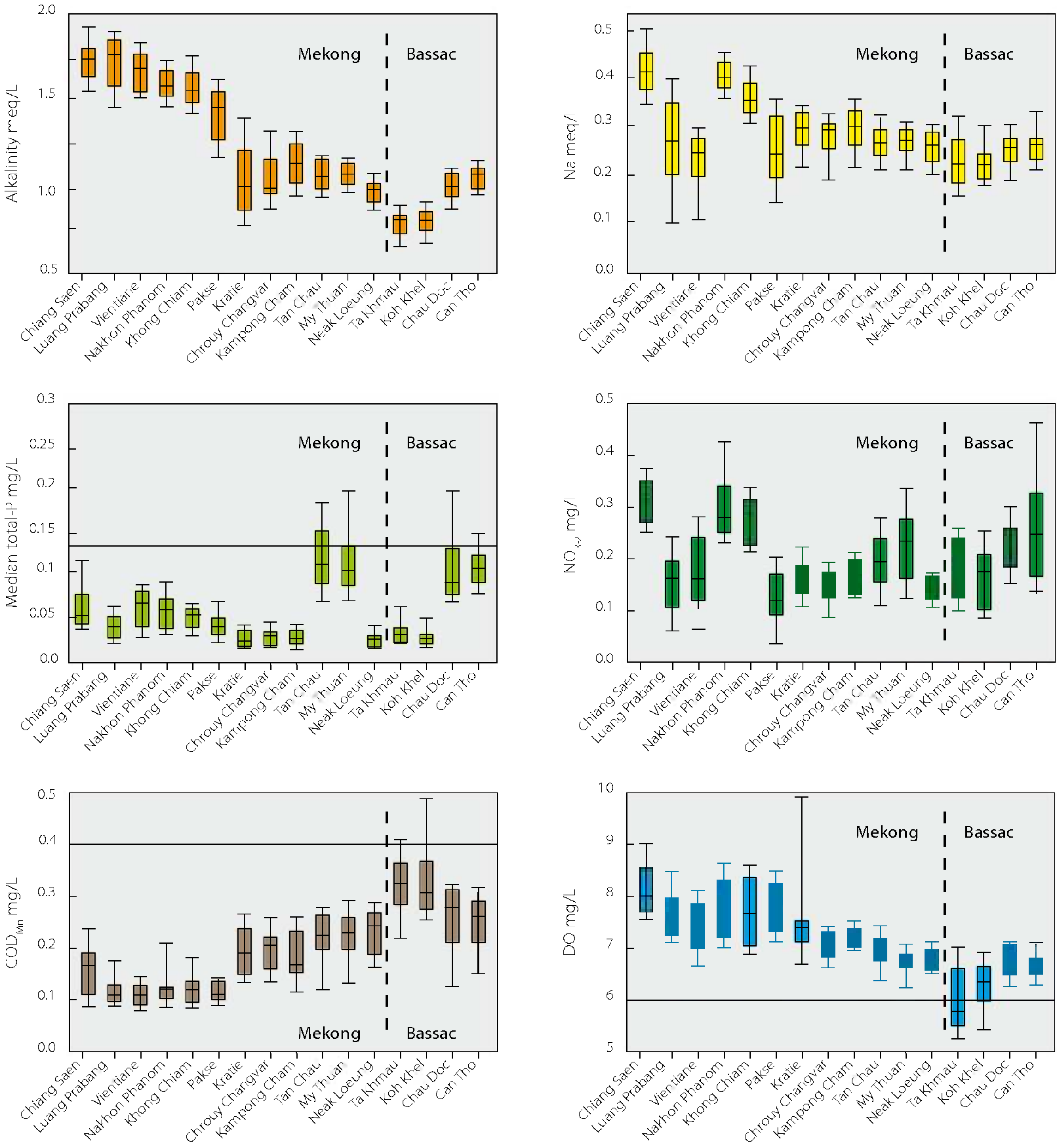


Figure 3.9 **Selected parameters at mainstream stations (upstream to downstream).**

Box plot presenting 25, 50 (median) and 75 percentiles. The whiskers indicate 10 and 90 percentiles. Data are for the period 1985 – 2005. Vertical line separates Mekong stations from Bassac stations. Horizontal lines are threshold values (Table 2.6). Threshold value for $NO_{2\text{-}3}$ is 0.7mg/L.

## 3.4 Transported loads

The study of the transport of dissolved substances provides information on both losses from drainage areas and the impact of the 'self purification' processes on the amounts transported in the mainstream.

Data for 27 stations and a total of 297 station-years are available for the assessment. Four stations have a full 18 years of data, for which transported load can be calculated; 13 stations have at least ten years of data (Table 3.4).

Table 3.4 *Stations for which transported load can be calculated.*

| Station Code | River | Station | Country | Number of years |
|---|---|---|---|---|
| H010501 | Mekong | Chiang Saen | Thailand | 18 |
| H011201 | Mekong | Luang Prabang | Lao PDR | 17 |
| H011901 | Mekong | Vientiane | Lao PDR | 18 |
| H013101 | Mekong | Nakhon Phanom | Thailand | 18 |
| H013401 | Mekong | Savanakhet | Lao PDR | 7 |
| H013801 | Mekong | Khong Chiam | Thailand | 18 |
| H013901 | Mekong | Pakse | Lao PDR | 16 |
| H019803 | Mekong | Tan Chau | Viet Nam | 2 |
| H019804 | Mekong | My Thuan | Viet Nam | 2 |
| H039801 | Bassac | Chau Doc | Viet Nam | 2 |
| H039803 | Bassac | Can Tho | Viet Nam | 2 |
| H050104 | Nam Mae Kok | Chiang Rai | Thailand | 8 |
| H230102 | Nam Ngum | Tha Ngon | Lao PDR | 2 |
| H290102 | Nam Songkhram | Ban Tha Kok Daeng | Thailand | 17 |
| H310102 | Nam Kam | Na Kae | Thailand | 14 |
| H320101 | Se Bang Fai | Se Bang Fai | Lao PDR | 10 |
| H350101 | Se Bang Hien | Ban Keng Done | Lao PDR | 13 |
| H370104 | Nam Chi | Yasothon | Thailand | 17 |
| H370122 | Nam Chi | Ban Chot | Thailand | 17 |
| H371203 | Huai Pa Thao | Ban Tad Ton | Thailand | 13 |
| H380103 | Nam Mun | Ubon | Thailand | 17 |
| H380127 | Nam Mun | Kaeng Saphu Tai | Thailand | 17 |
| H380134 | Nam Mun | Rasi Salai | Thailand | 15 |
| H390104 | Se Done | Bansouvanakhili | Lao PDR | 11 |
| H440201 | Se San | Kon Tum | Viet Nam | 2 |
| H440601 | Se San | Trung Nghia | Viet Nam | 1 |
| H450701 | Sre Pok | Duc Xuyen | Viet Nam | 3 |

## Conservative substances

The transport patterns of the conservative substances should be similar all along the mainstream, at least as far as Pakse (Figure 3.10). Calcium and silica show similar transport patterns. The load of each is reduced downstream of Savannakhet. In the case of silica, there is a more pronounced drop in transport load from Savannakhet to Khong Chiam.

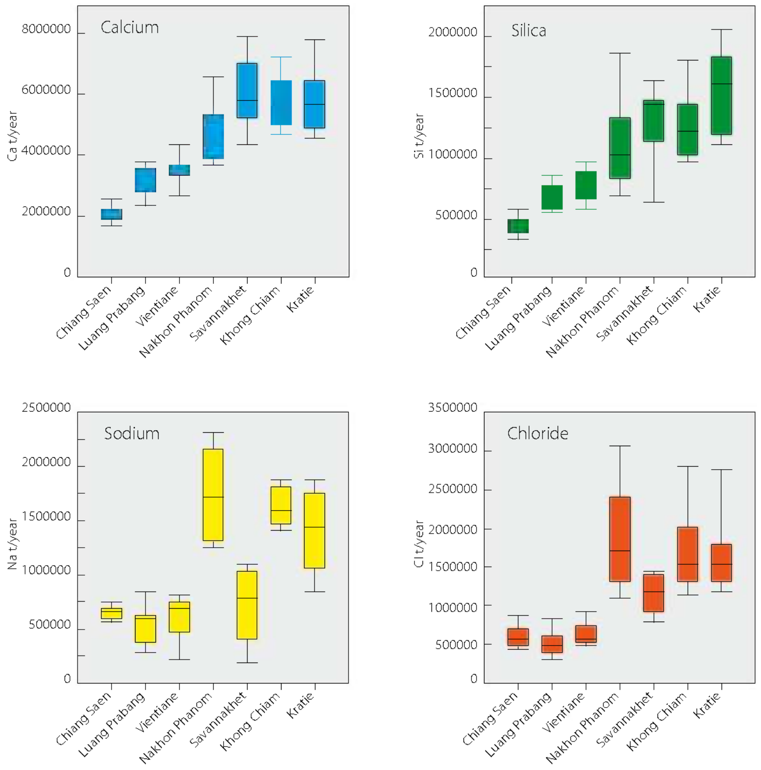


Figure 3.10 Distribution of annual transported loads of calcium, silica, sodium, and chloride at mainstream stations.
All available data were used. Box plot representing 25, 50 (median) and 75 percentiles. The whiskers indicate 10th and 90th percentiles.

However, other conservative substances, such as sodium and chloride, appear to behave very differently, with a major increase at Nakhon Phanom and a very large reduction in load immediately downstream at Savannakhet. One explanation is that the data at either Savannakhet or Nakhon Phanom are not representative of the river cross section (i.e. sampled at an inappropriate location). Yet the fact that calcium and silica do not behave this way is perplexing.

Sodium and chloride contributions from the Khorat Plateau may be the cause of the elevated loadings at Nakhon Phanom, as this station is downstream of the confluence of the Nam Songkhram. Raw data for the Nam Songkhram indicate that the minimum, median and maximum value of Na concentration are each at least an order of magnitude higher than in the mainstream at Vientiane (median values shown in Table 3.5). Also, Figure 3.10 shows that the annual transported load of sodium is much higher at Nakhon Phanom than it is upstream at Vientiane, or downstream at Savannakhet.

The approximate similarity between sodium loadings at Khong Chiam, which is upstream of the confluence with the Nam Mun, and at Pakse (the next station downstream), suggests that the Nam Mun is not a significant contributor of salinity from the Khorat Plateau. However, this does not account for the much lower loading of Na and Cl at Savannakhet. There are two possible explanations: (i) the sampling site at Savannakhet is more representative of mainstream Mekong flow and is not representative of mixed flows of the Mekong and the Nam Songkhram (which joins the Mekong further upstream), and (ii) that the sampling location at Nakhon Phanom is biased towards flow of the Nam Songkhram. The data at Nakhon Phanom and stations further downstream (i.e. Khong Chiam and Pakse) have similar loadings and concentrations of sodium, suggesting that the Nam Songkhram has a significant influence on the Mekong, at least for concentrations of these ions, and that the data at Savannakhet are not representative.

If one eliminates Savannakhet as unrepresentative, the data at these stations show some consistency. There is no significant difference between the three uppermost stations, Chiang Saen, Luang Prabang, and Vientiane. However, there is a significant increase in transported load at Nakhon Phanom, which lies downstream of the confluence of the Mekong with the Nam Songkhram. For the period covered, the mean transported load at Nakhon Phanom is not significantly higher than at the two downstream stations. Transport data for chloride (Fig. 3.10) show a similar pattern, while data for calcium are continuously increasing downstream, due perhaps to left bank tributary inputs of calcium.

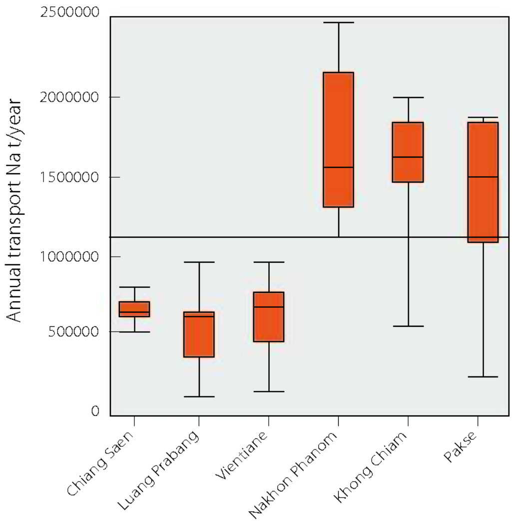


Figure 3.11 Annual transport of sodium at six mainstream stations.

The period of record covers 15 years. Stations are from upstream to downstream.

It seems reasonable to conclude that the Nam Songkhram is the source of the higher concentrations values of sodium and chloride in the mainstream at Nakhon Phanom (Table 3.5).

Table 3.5 *Comparison of median values of selected parameters at mainstream stations of Vientiane and Nakhon Phanom, with the Nam Songkhram.*

| | Vientiane | Nam Songkhram | Nakhon Phanom |
|---|---|---|---|
| Na (meq/L) | 0.245 | 2.820 | 0.410 |
| Cl (meq/L) | 0.170 | 2.820 | 0.266 |
| Conductivity (mS/m) | 22.700 | 44.500 | 21.535 |
| $NO_{3-2}$-N (mg/L) | 0.189 | 0.268 | 0.286 |
| Total-P (mg/L) | 0.052 | 0.032 | 0.056 |
| $COD_{Mn}$ (mg/L) | 1.100 | 2.200 | 1.205 |

## *Nutrients*

There is marked difference between the transport patterns for inorganic nitrogen and total phosphorus (Figure 3.12). While there is a substantial increase in nitrogen load between Vientiane and Nakhon Phanom (possibly due to contributions from the larger concentrations in the Nam Songkhram), the step wise increase in total-P seems to take place further upstream between Luang Prabang and Vientiane. The pattern observed for nitrogen may be caused by higher loads coming from agricultural activities on the Khorat Plateau via the Nam Songkhram. The increase in total-P transport could be an effect of the higher river-side population upstream of Vientiane.

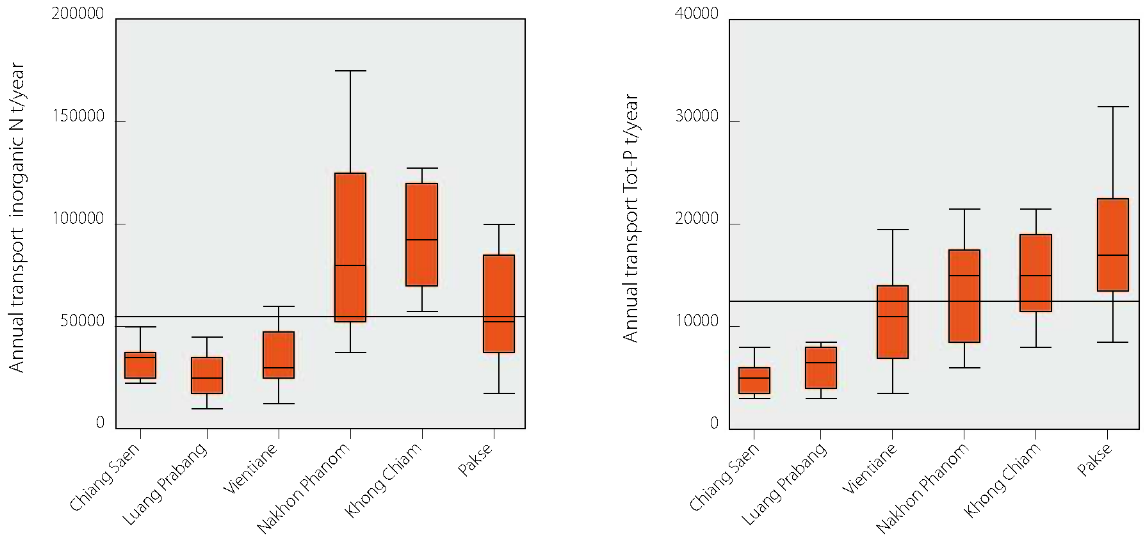


Figure 3.12 Annual transport of inorganic nitrogen and total phosphorus at mainstream stations (upstream to downstream) for 15-year period.

Savannakhet is omitted as there are only six years of transport data.

Organic matter such as $COD_{Mn}$ increases in two steps, first at Nakon Phanom and then at Khong Chiam (Figure 3.13).

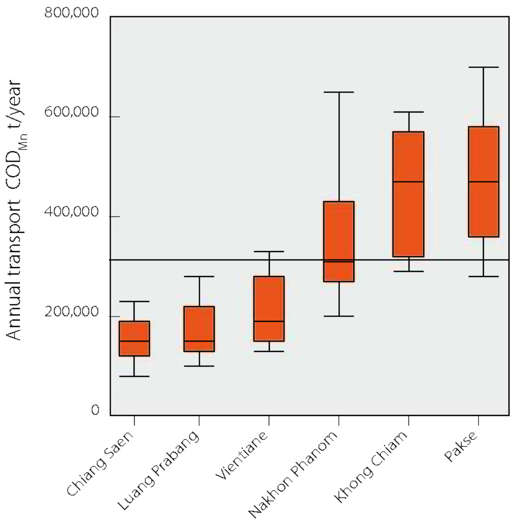


Figure 3.13 Annual transport of $COD_{Mn}$ at mainstream stations for 15-year period.

The increase at Nakon Phanom may reflect higher concentrations of COD coming from the Nam Songkhram (Table 3.5). Increases further downstream probably reflect tributary inputs, but this has not been specifically investigated here.

In comparison with the major ions of the conservative elements, the concentrations of nutrients and organic matter (non-conservative elements) are affected by physical, chemical and/or biological processes. Along the mainstream, the data do not indicate that there is substantial 'self-purification' that would result in reduction in measured concentrations and, therefore, reduction in chemical load. Biophysical processes include sedimentation, which could diminish total-P, oxidative bacterial processes to reduce organic matter; or denitrification, which can reduce inorganic nitrogen. However, tributaries or increasing population further downstream, may contribute to these elements so that concentration levels do not diminish.

# 4. Transboundary water quality

## 4.1 Transboundary areas

The Mekong Basin is an international river basin covering six countries. Transboundary water quality is, therefore, a key concern of the Mekong River Commission and of the four lower riparian countries that are Member Sates of the Commission.

There are five main transboundary areas:

- *People's Republic of China/Lao PDR.* In 2004 a boundary station at Houa Khong (Lao PDR) was established to monitor the boundary between the Upper and Lower Mekong Basin. Until recently, this location has been difficult to access on a frequent basis. As noted in the introductory chapter, water pollution in China has been an area of concern over the years, with failures in enforcement now acknowledged by the Chinese government. How this might affect the Mekong will not be known until data from the Houa Khong station has been collected for a number of years.

- *Lao PDR/Myanmar.* This short section of the Mekong is in remote, sparsely populated regions of both countries. At this time there is no reason to expect any significant problems in this section. It is, however, a reach of increasing barge traffic between China and northern Thailand.

- *Thailand/Lao PDR (at the Mekong River).* Thailand and the Lao PDR have similar concerns over sediment erosion and transport into the Mekong, nutrient pollution from riparian cities, towns and villages along the mainstream, the potential for contaminants from developing industrial areas (especially on the Thai side), agricultural chemicals, and salinity from the Khorat Plateau of Thailand.

- *Lao PDR/Cambodia.* No particular issues have been raised over water quality at this border, other than concerns by Cambodia over possible dioxins/furans from the Lao PDR/ Viet Nam border area sprayed with Agent Orange during the American War.

- *Cambodia/Viet Nam.* This frontier area is heavily populated, especially on the Vietnamese side. There is concern over the possibility that industrial contaminants from the city of Phnom Penh will be transported downstream. The Phnom Penh area mainly affects water quality of the Bassac due to the nature of the flow at the divergence of the Mekong and Bassac rivers.

## 4.2 Transboundary pollution within the LMB

Transboundary water quality issues in the LMB were first evaluated by Hart *et al.* (2001). Potential transboundary effects were identified in two areas:

(i) downstream of Phnom Penh through the Mekong and Bassac rivers into Viet Nam, and;

(ii) downstream of Vientiane into Thai the part of the mainstream.

Downstream of Phnom Penh, the transboundary risk was assessed as low to moderate with respect to eutrophication, and as low for organic matter expressed as dissolved oxygen (DO). The assessment also showed a low risk of transboundary impacts downstream of Vientiane relating to both eutrophication and organic matter (COD).

This paper examines potential transboundary water-quality issues at the following localities using MRC data on nitrates, total-P, and $COD_{Mn}$:

(i) between Lao PDR (Vientiane) and Thailand (Nakhon Phanom);

(ii) between Lao PDR (Pakse) and Cambodia (Kratie);

(iii) between Cambodia (Koh Khel) and Viet Nam (Chau Doc).

Higher concentrations of nitrate were recorded at Nakhon Phanom than at Vientiane (Figure 4.1). These may be sourced from the wastewater discharge from That Luang Marsh, some distance downstream of Vientiane. However, this discharge is not active during the dry season, as there is a small check-dam at the mouth of the marsh where it outflows into the river. As shown in Table 3.5, nitrate levels entering the mainstream from the Nam Songkhram are also higher, and these could influence measurements at Nakhon Phanom. However, as concentrations of total-P and $COD_{Mn}$ show similar distributions at Vientiane and Nakhon Phanom, it seems unlikely that transboundary transfers occur between these two stations.

Concentrations of nitrate and total-P are lower at Kratie than upstream at Pakse (Figure 4.1). These conditions are probably the result of dilution due to the inflow of tributary waters with lower concentrations of these ions. However, $COD_{Mn}$ concentrations are higher at Kratie, indicating an upstream source. The source of these high concentrations cannot be determined from the current database. It could be the mainstream in the Lao PDR, the Se Kong (which rises in the Lao PDR and flows through Cambodia), or either the Se San or the Sre Pok (which rise in Viet Nam and flow through Cambodia).

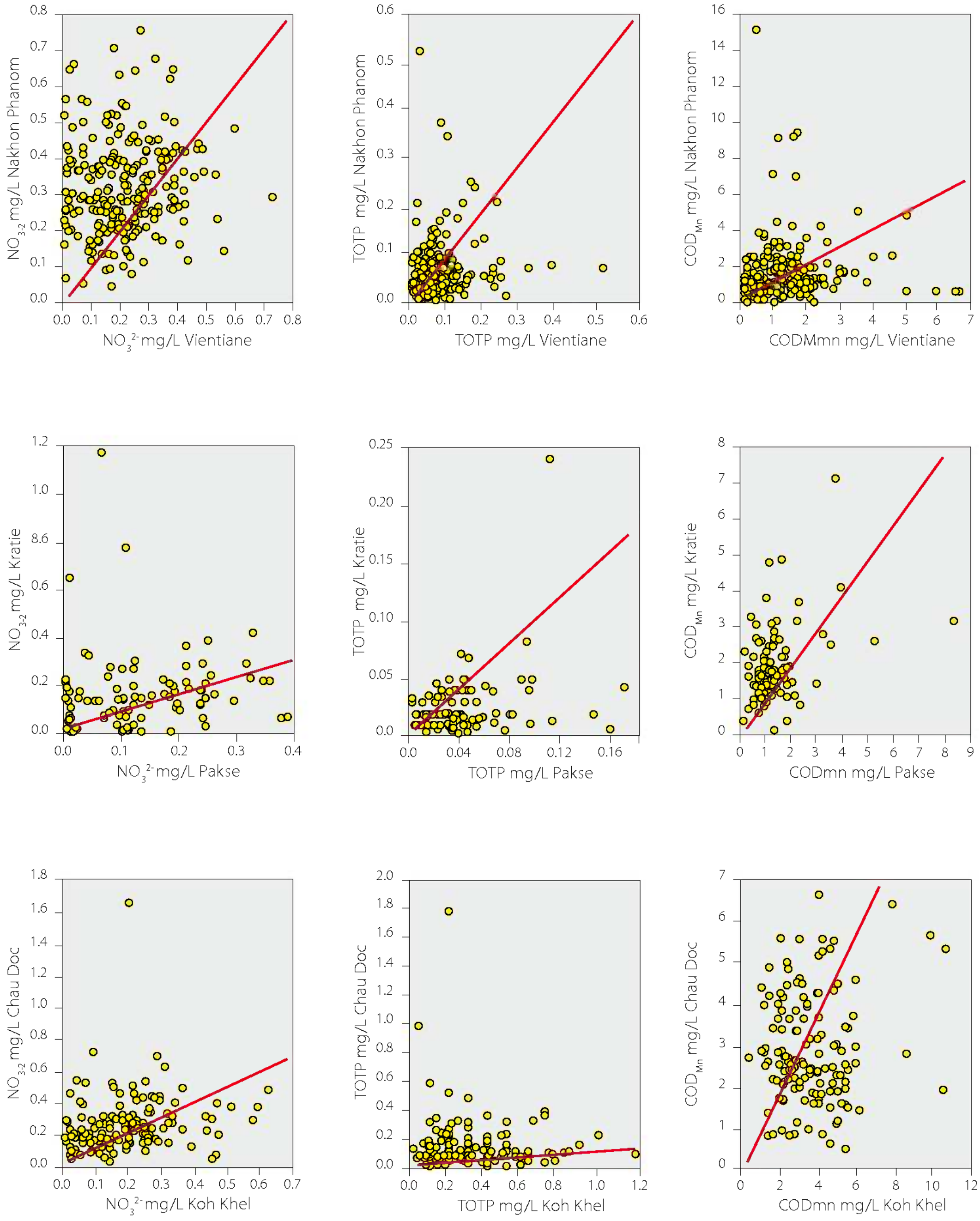


Figure 4.1 Assessment of transboundary transport of nitrate-N, total-P and COD$_{Mn}$ between selected transboundary locations: Vientiane and Nakhon Phanom, Pakse and Kratie, and Koh Khel and Chau Doc.
The red lines represent a 1:1 relationship in which both stations would have the same concentrations.

In general, the concentrations of nitrate and total-P are higher at Chau Doc in Viet Nam than at Koh Khel in Cambodia (Figure 4.1). This suggests that these nutrients are mainly produced within Viet Nam and not derived primarily from Cambodia. Data on total-P indicates that the range and median concentrations upstream of the city of Phnom Penh are very similar to those at the Cambodian boundary station of Koh Khel on the Bassac (Figure 3.9). Although the mean values are approximately the same, the range for $NO_{3-2}$ is somewhat larger at the Cambodian (Bassac) border relative to Cambodian stations immediately upstream of Phnom Penh, (Figure 3.9), again suggesting that Phnom Penh is not a major contributor to transboundary transport of nitrogen.

This assessment draws the same conclusion as that of Hart *et al.* (2001), that there seems to be only minor indications of transboundary pollution. A more definitive assessment would require evaluation of several supporting parameters and a calculation of transported loads.

## 4.3 Transboundary pollution from China

The situation at the Chinese/Lao border is a special case insofar as monitoring at the border station at Houa Khong only began in August of 2004 and, for this assessment, has only 17 months of data. It can be seen in Table 3.1 that this station is affected ($WQI_{hi} = 7.8$). The next most upstream station, at Chiang Saen, is less affected compared with Houa Khong. The entire reach from China to Chiang Saen is quite remote, providing a preliminary indication by the results from Houa Khong that there is transboundary impact from China. Other evidence for transboundary pollution from China is the toxicity recorded at the China/Lao PDR border during the two years of the special diagnostic study of contaminants (MRC, 2007a).

# 5. Issues concerning water quality in the Lower Mekong Basin

This chapter explores three priority water quality concerns in the LMB—salinity, acidity and eutrophication. Salinity and acidity are particular problems in the Delta region of the basin and are further complicated by the effects of tidal cycles. Salinity in the Khorat Plateau is caused by geological deposits of rock salt.

## 5.1 Salinity

High conductivity values are found in two different areas in the LMB; in the Khorat Plateau, where the origin is rock salt in the subsurface, and in the Delta where high salinity is due to seawater intrusion. Salinity, as it relates to water for agricultural uses, is also discussed in Chapter 3. Throughout the entire monitoring period, as many as 36 of the stations have maximum conductivity values that are below the lowest threshold value for agricultural use. Fifty-four stations have a maximum conductivity greater than 70 mS/m, which is the lowest threshold of Some Restriction class of the $WQI_{agl}$ (water-quality for general agricultural irrigation use).

### Mekong Delta

Nine of the 54 stations where salinity is above the threshold of Some Restrictions (Table 5.1) are severely affected. All are located on the Ca Mau peninsula of the Delta (Figure 2.2). With the exception of one station, the water quality for paddy rice falls within the Severe Restriction for more than half the time (median values), with an estimated reduction of yield of more than 50% (FAO, as cited in Ongley, 2006a).

Table 5.1 *Conductivity data (mS/m) for the worst affected Delta stations.*
*Red cells indicate poor quality for irrigation for paddy rice (conductivity >480 mS/m).*

| | Station Code | Minimum | 5th percentile | 10th percentile | 25th percentile | Median |
|---|---|---|---|---|---|---|
| My Thanh | H988202 | 18 | 66 | 102 | 294 | 1158 |
| Nhu Gia | H988203 | 19 | 24 | 37 | 116 | 452 |
| Cau Sap | H988204 | 38 | 112 | 209 | 502 | 1232 |
| Ho Phong | H988205 | 85 | 381 | 546 | 1162 | 2565 |
| Ca Mau | H988206 | 32 | 102 | 159 | 439 | 1968 |
| Chu Chi | H988207 | 55 | 200 | 269 | 688 | 1970 |
| Vong The | H988208 | 46 | 79 | 106 | 218 | 1555 |
| Cau Tri Ton | H988209 | 34 | 70 | 96 | 206 | 879 |
| Phouc Sinh | H988214 | 30 | 75 | 117 | 339 | 1184 |

## *Changes in conductivity through time*

In the Delta, variation in conductivity occurs both seasonally and between years. Human interventions have also caused step changes in conductivity at some stations.

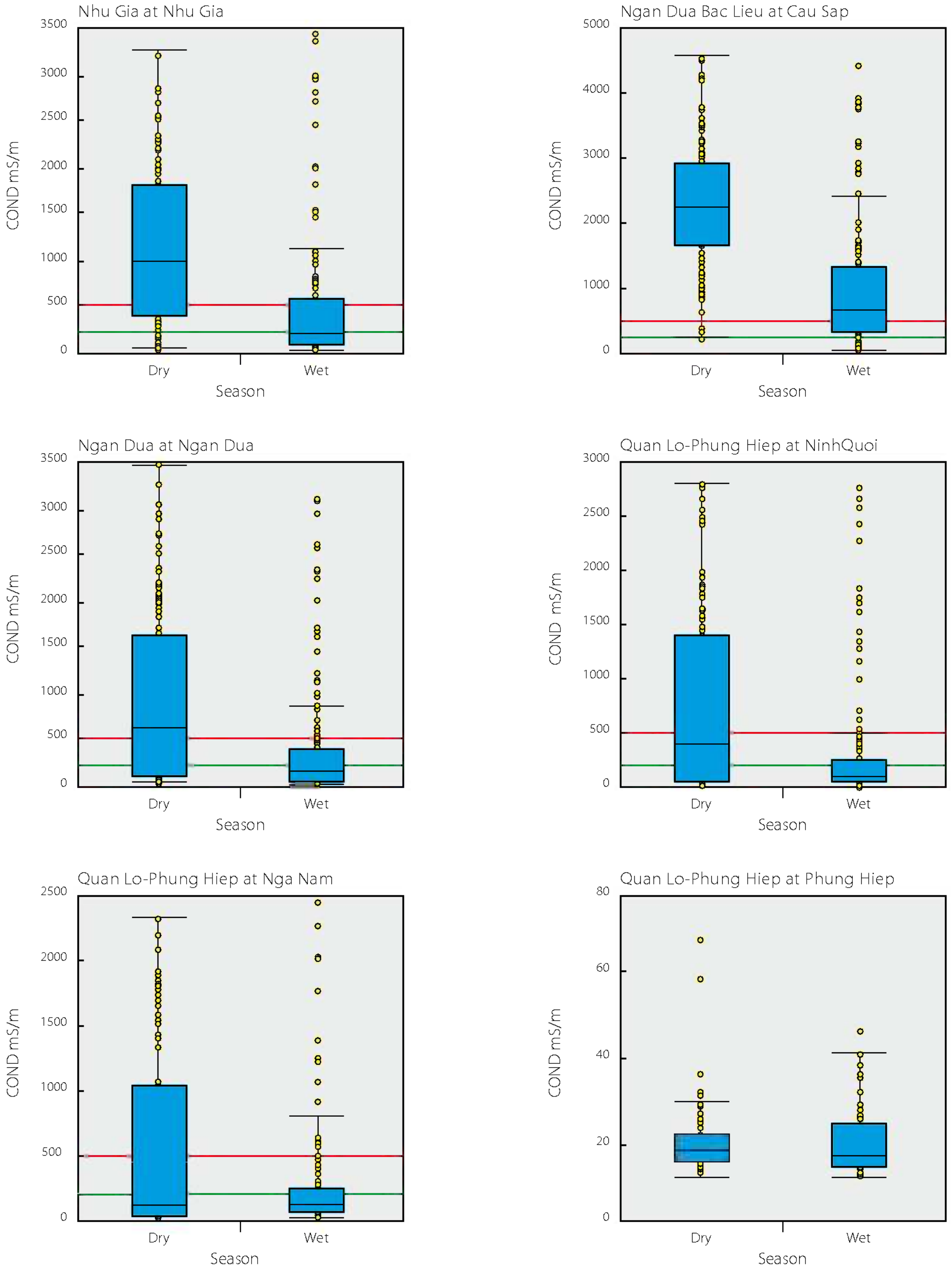


Figure 5.1 Variation between dry and rainy season in conductivity (salinity) for selected stations in the Ca Mau peninsula.

The green line indicates the threshold for Some Restriction quality water (conductivity >200 mS/m) and the red line indicates the threshold for Severe Restriction (conductivity >480 mS/m) for paddy rice irrigation. Data are for 1990 – 2005.

## *Seasonal variations*

At most stations, there is a clear difference in conductivity between the wet and dry seasons. In the Ca Mau peninsula, these differences are so large that the quality changes from Severe Restrictions in the dry season to Some Restrictions in the wet season (Figure 5.1). Figure 5.1 show the situation over a period of 15 years. Over this period, there have been changes in the conditions in a large part of the Ca Mau area, and as a result the water-quality status has improved at many of the stations (see 'Changes due to human interventions' section, below). At most Delta stations located off the mainstream, conductivity seems to mainly vary according to season/flow. The data at Vinh Thuan station is a typical example of this (Figure 5.2).

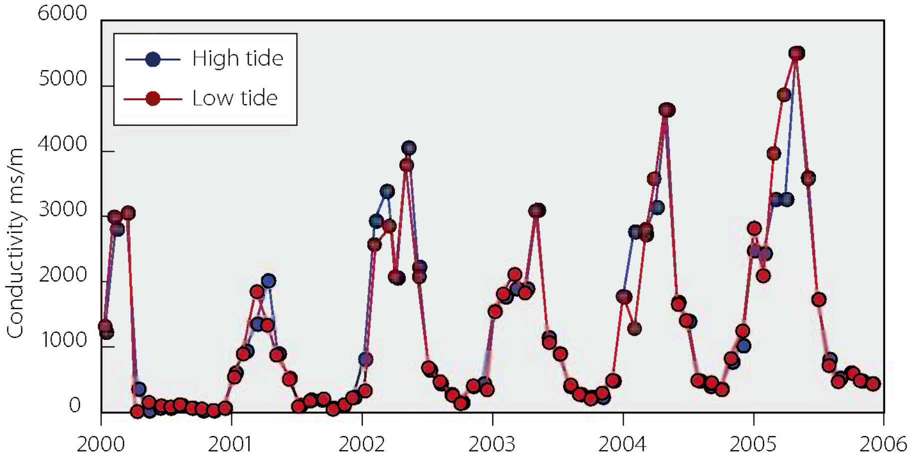


Figure 5.2 Variation in conductivity at Vinh Thuan.

Values for high tide in blue and for low tide in red.

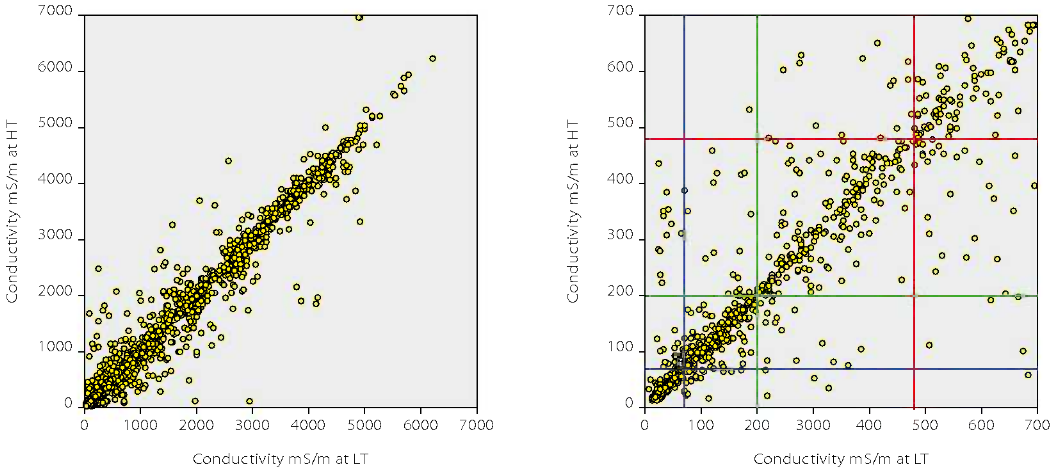
## *Changes between years*

It is reasonable to assume that high-flow years are associated with a relatively low conductivity in the Delta and vice versa. This assumption was tested using the available flow data from the Pakse station as there are no flow data for Delta stations. While the flow contributions from the southern part of the Annamite mountains, which form the boundary between the Lao PDR and Viet Nam, and the outflow from the Great Lake are missing, the data from Pakse are a reasonable surrogate for the actual flow. Since the effect of flow on salinity is likely to be felt during low-flow periods, the test was made using the annual 25th percentile for flow and comparing this with the annual median conductivity at Ca Mau station. Only weak relationships are found and it is concluded that any long-term relationship between conductivity and flow for the Delta stations is not readily evident.

*Effects of the tide*

In general there is no difference in conductivity between high tide and low tide at mainstream stations. A typical example is Dai Ngai station, the most downstream Delta station on the Bassac River, which was monitored from 2004 to 2005 and showed conductivity through that time.

However, there are tidal influences at some stations within the Delta. During April and May there seems to be a larger variation between the two tidal conditions than there is from September to November. April and May are months when the flow starts to increase after the dry season and there is a large variation in flow of water from the Mekong and Bassac, resulting in differences in water levels and thus the inflow of seawater. In September the flow is generally highest and it continues to be high until November, thus reducing seawater intrusion.



All data

Data range restricted to 'usable' data

Figure 5.3 Conductivity values for stations at high and low tide during the same sampling day. To the right, a subset of the data is restricted to 0–700 mS/m, which reflects the usable range of salinity in irrigation water. Blue lines delineate the threshold Some Restrictions water quality for general irrigation (70 mS/m), the green lines delineate threshold for Some Restrictions water quality for paddy rice (200 mS/m), and the red lines delimit the threshold for Severe Restriction in water quality for paddy rice (480 mS/m). Data are for 40 Delta stations. HT= High Tide; LT=Low Tide.

Understanding tidal effects on conductivity is only of practical value if variations in water quality restricts water usage for periods during the tidal cycle. Figure 5.3, plots the threshold (480 mS/m) for Severe Restrictions quality (for paddy rice irrigation). Samples in the uppermost right quadrant (bounded by the red lines) have Severe Restrictions in water quality during both low and high tides. The lower left quadrant (bounded by the red lines) contains those samples that have No Restrictions or Some Restrictions in water quality all the time. This shows that (at least for paddy rice irrigation) examination of data from the supply point can be used to help decide whether irrigation should be permitted, or otherwise. A similar observation can be made for general irrigation, which is more restrictive in terms of water quality requirements.

## *Changes due to human intervention*

Salinity at most of the stations seems only to vary seasonally, with little long-term change over periods of years. However, there is a set of stations that shows substantial step changes over time. The construction of sluice gates has generally reduced the inflow of seawater to the canals (Figure 5.4, left side). However, no such beneficial effects were observed at other stations (right side of Figure 5.4).

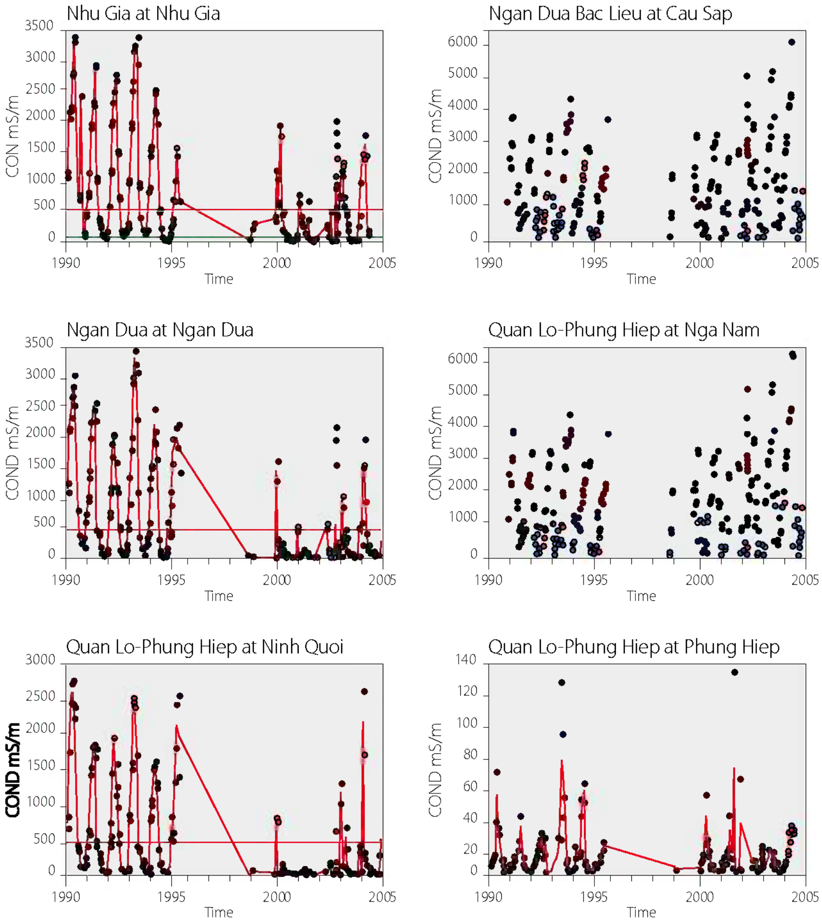


Figure 5.4 Changes over time for conductivity (salinity) at a selected number of stations.
Left-hand stations show step changes reflecting human intervention. Right-hand stations show no evidence of human intervention. Red markers indicate the dry season (December–April) and blue markers the rainy season (May–November). The green line indicates the upper limit for No Restrictions status for general irrigation and the red line indicates the upper limit for paddy rice (Severe Restrictions—conductivity >480 mS/m). Stations in the Delta (Ca Mau peninsula).

## *Khorat Plateau*

Evaporates (as sodium chloride—halite, potassium chloride—sylvanite, and potassium magnesium chloride—carnallite) are present in the subsurface strata of the Khorat Plateau in northeastern Thailand (Poonsook, 1988) and also parts of the Vientiane Plain. At the outset of the water-quality monitoring programme, leaching from these areas was noted as a possible source of salt that could affect the water quality of the Mekong. Earlier in the programme, high conductivities were frequently observed during the dry season at some stations. However, during recent years (2000–2005), these occurrences have been rare. Only in the headwaters of the Nam Mun is the threshold for Some Restriction $WQI_{agl}$ exceeded (about 20% of the time).

Human intervention seems to have resulted in dramatic changes to salinity in the dry season, as seen in Figure 5.5. These improvements in the Thai tributaries have probably been achieved through flow regulation, which has resulted in a higher river flow during the worst part of the dry season.

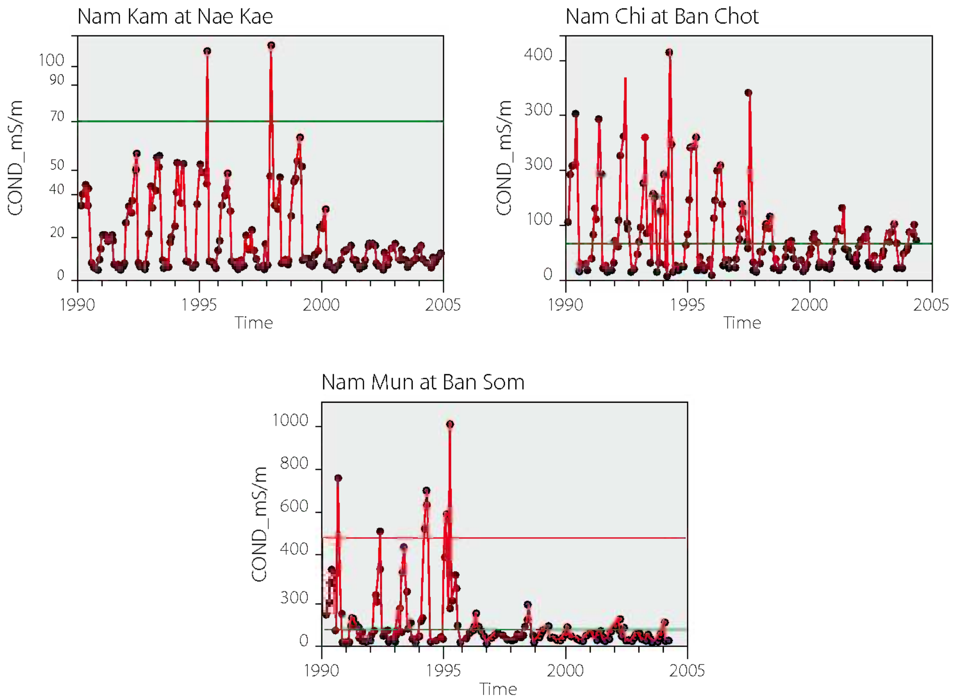


Figure 5.5 Changes over time for conductivity (salinity) for a selected number of tributary stations from the Khorat Plateau.

Red markers indicate the dry season (December–April) and blue markers the rainy season (May–November). The green line indicates the threshold for No Restrictions water quality for general irrigation and the red line indicates the threshold for Some Restrictions in water quality for paddy rice. Nam Chi and Nam Mun stations are Secondary Stations and are not located in Figure 2.2, Chapter 2.

## 5.2 Acidification

Some areas in the lower parts of the LMB have so-called actual or potential acid sulphate soils. This is especially the case in the Plain of Reeds (area along the Cambodian/Viet Nam border). Such soils contain pyrite, which is oxidized to sulphuric acid upon contact with air, and the drainage water will have a low pH and initially high concentrations of iron. During leaching, the acid water dissolves minerals containing aluminium, and this could lead to high and potentially toxic concentrations in the water.

The assessment of acidification in this chapter is initially focused on the WQI for aquatic life, which sets a lower threshold pH value of 6.5 for the basin as a whole. The measured values of 107 sample stations are below that limit at least once, and at 54 sample stations this limit was violated ten percent of the time (10th percentile), corresponding to about once per year. Outside of the Delta, six stations have a 25th percentile (i.e. exceeding the threshold a quarter of the time) value below 6.5. Three of these are located in Cambodia, two in Thailand and one in the Lao PDR. The comparative distribution of pH and conductivity for stations within and outside the Delta is shown in Figure 5.6.

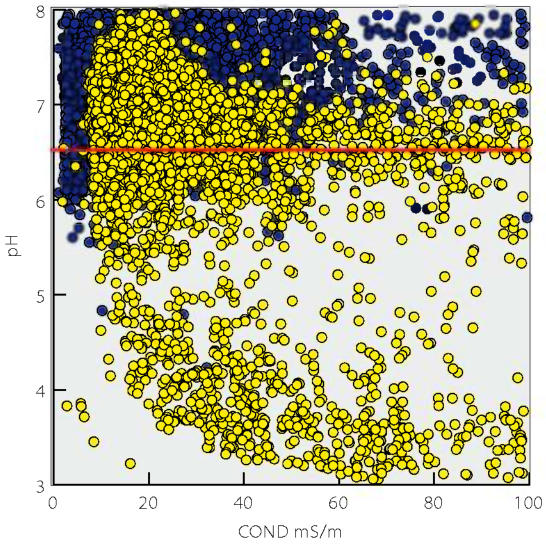


Figure 5.6 **The relationship between pH and conductivity.**
Yellow markers are used for the Delta stations and blue for the other stations. The data are limited to pH <8 and conductivity <100 mS/m. The blue line is the RTAG lower threshold value of pH=6.5 for aquatic life.

## Aluminium and pH

Although pH is generally considered the major factor affecting biota in acidic waters, consideration should be given to toxic effects from aluminium. Aluminium is toxic at concentrations of cationic Al between 0.02 mg/L for sensitive organisms and 0.1 mg/L for more robust animals. Very high concentrations are common in the acidified waters of the Delta (Figure 5.7) and is mostly in the bio-available cationic form at low pH. The extent of the effects on the biota in the area is not known.

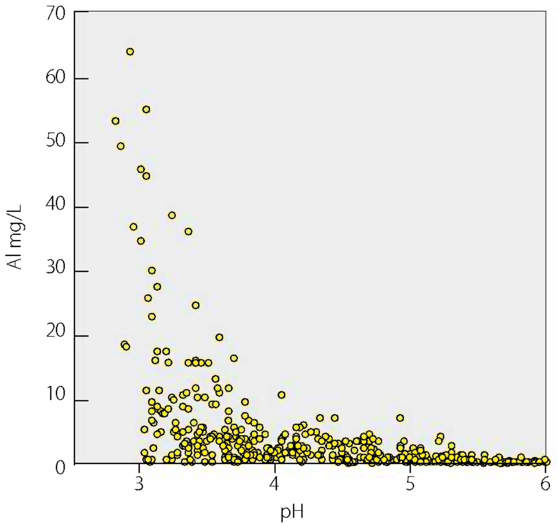


Figure 5.7 The relationship between aluminium concentrations and pH-values for Delta stations. The 0.100 mg/L threshold value of aluminium for robust biota is virtually on the X axis.

## Effect of low pH-values and salinity on nutrients and organic matter in the Delta

Many biotic processes are limited by low pH-values and this may be the case in the Delta. To evaluate this hypothesis, monthly data (totalling 4011 samples) from Delta stations for the 2000–2005 period were examined. It is expected that if a low pH-value is solely responsible for high concentration of another constituent (or low in the case of DO), there should be some correlation between the pH-value and the concentration of the constituent in question. There is, however, no indication that ammonia is related to pH. Nitrate concentrations seem somewhat positively related with pH and could indicate a lower nitrification rate at low values of pH. However, when evaluated as sum of inorganic nitrogen there is no pattern observable. Neither organic matter nor DO appear to be related to pH. Possibly a clearer picture may have been obtained if the data had been evaluated by station or by season. However, on aggregate, there is little evidence to support the hypothesis.

The analytical method description used by the MRC states that Cl may interfere positively at concentrations above 100 mg/L (3 meq/l). This is supported by Figure 5.8, in which $COD_{Mn}$ is consistently above the mean $COD_{Mn}$ concentration for values of Cl above 50 meq/L. The mean

$COD_{Mn}$ value for the 91 samples with a Cl concentration >100 meq/L is 8.2, as compared to the mean of 4.8 for all samples. Based on Figure 5.8, it is recommended that for samples with a Cl concentration above 50 meq/L of Cl, the analytical value for $COD_{Mn}$ should be lowered to, perhaps below 6 mg/L in order to avoid incorrect determination of WQI values for human impacts ($WQI_{hi}$).

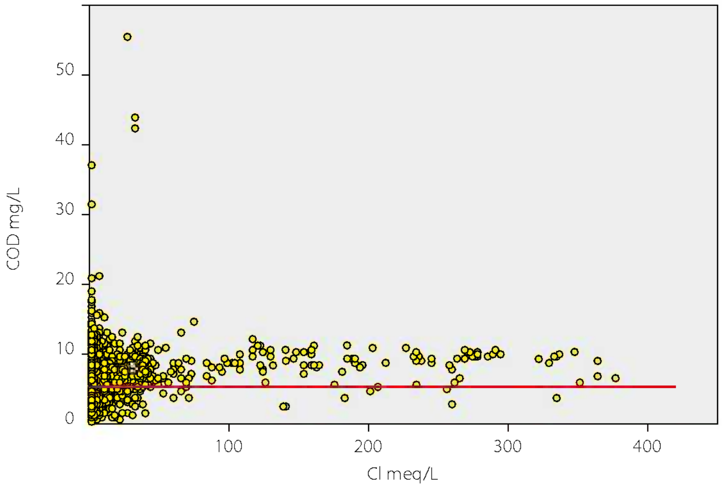


Figure 5.8 The relation between chloride concentration and $COD_{Mn}$ for Delta stations. The horizontal red line shows the mean $COD_{Mn}$ concentration. The x-axis is limited to data <450 meq/L.

## 5.3 Eutrophication

Some authors define eutrophy as an excess concentration of nutrients, while others prefer to use a definition based on biological response (productivity). For rivers, the first definition is easier to apply. The European Environment Agency (EEA, 1999) has defined excess nutrient as "a state which can result in:

- direct effects which can be immediate or predictable (due to nutrient accumulation) and which can be observed directly in the ecosystem or in the river/water use;
- an increased production of biomass which exceeds the recycling (aerobic materialization) capacity of the ecosystem."

### Problems of analysis

Laboratories in Cambodia and the Lao PDR are unable to determine total-N. In the case of total-P, sub-sampling for the digestion step may give rise to variation due to the large concentrations of sediments encountered in many samples. Difficulties also arise in obtaining representative sub-samples. This is illustrated by comparing the ratio of phosphate-P ($PO_4$) to total-P concentrations (Figure 5.9). An unexpected number of samples show very high total-P in comparison with phosphate-P. This may be due to a sub-sampling error during analysis, where one sub-sample has an unrepresentatively higher concentration of suspended solids relative to other sub-samples. Figure 5.10 provides evidence that the very high values of N and P are probably analytical errors.

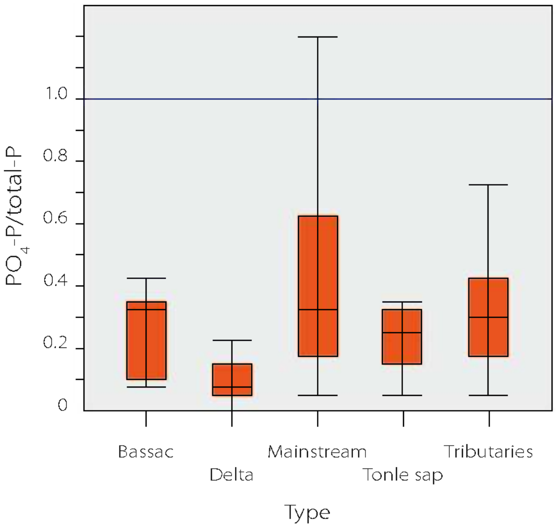


Figure 5.9 The ratio $PO_4$-P/total-P for different types of water in the LMB.
Box plots representing 25, 50 (median) and 75 percentiles. The whiskers indicate 10 and 90 percentiles. Annual mean values for 2000–2005. The blue line shows the 1:1 relationship, where all total-P is in the form of phosphate ($PO_4$). The extension of the whisker for mainstream stations above the blue line is an indication of error in the data as $PO_4$ cannot exceed total-P.

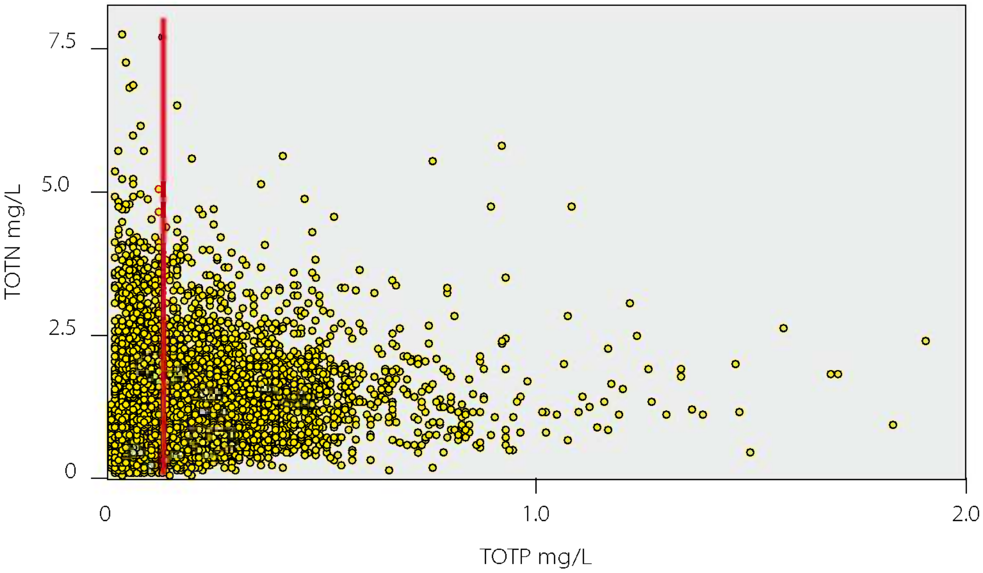


Figure 5.10 The relationship between total-N and total-P.
The red line indicates the RTAG total P threshold for $WQI_{al}$. (Refer to Table 2.6).
Data are for the period 2000-2005.

## Nutrient availability

The importance of total-P for algae, periphyton and floating vegetation is difficult to evaluate. Part of the total-P may be locked into the living biota or bound to suspended particles and is unavailable for use by plants under aerobic conditions. The only significant form of inorganic phosphorus that is readily available and assimilated by the biota is orthophosphate ($H_2PO_{4-}$ , $HPO_4^{2-}$, and $PO_4^{3-}$). Particulate-bound P can also be released into the water under some circumstances (anoxia) and then becomes available to algae and aquatic plants.

The ratio of phosphate to total-P gives an indication of the percentage of P that is readily available to algae and aquatic plants. There are large differences in the $PO_4$:total-P ratios in the various sections of the LMB (Figure 5.9). The highest ratios are found in the mainstream with a median of 0.33 (33%) and the lowest in the Delta, with a median value of only 0.07 (7%). European rivers have a ratio of about 60% of the total-P as phosphate-P (EEA 1999). However, European rivers have low concentrations of suspended solids. Because of the affinity of P for suspended solids, the ratio is expected to be much lower in the Mekong, as indicated in Figure 5.9.

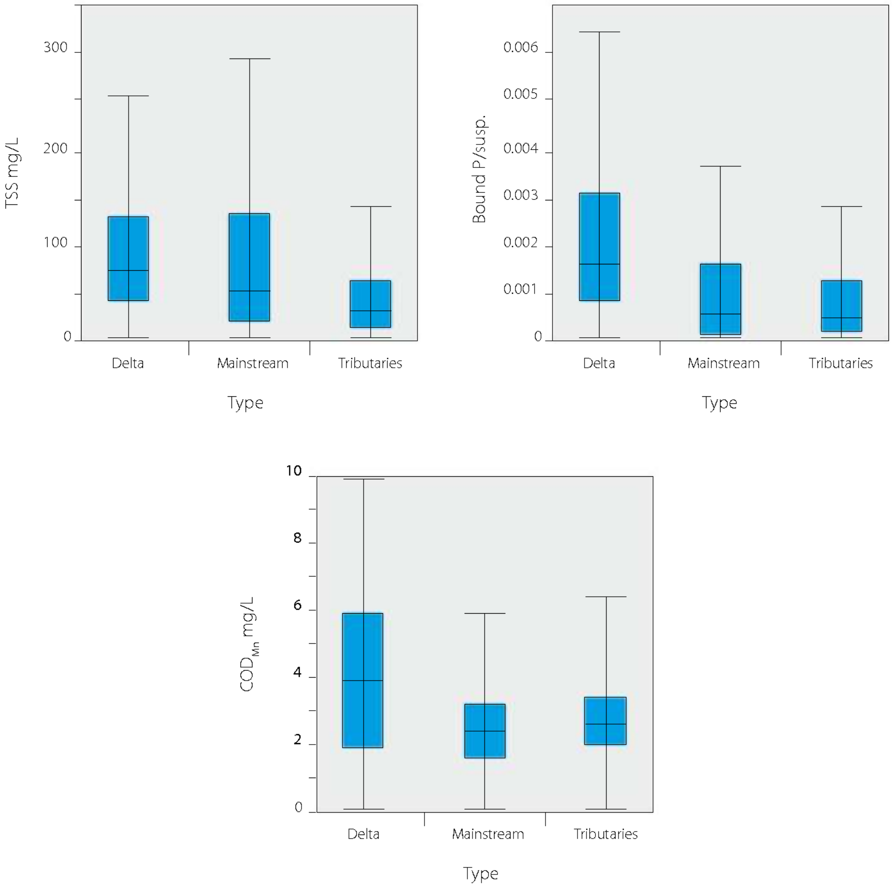


Figure 5.11 Concentrations of TSS, total P-$PO_{4-}$P) and $COD_{Mn}$ in the LMB.
Box plots representing 25th, 50th (median) and 75th percentiles. The whiskers indicate 10th and 90th percentiles. Values are for 2000 – 2005.

This small proportion of phosphate-P in the Delta may be caused by higher concentrations of suspended solids (particulates) or it may be that the slow flow in the many Delta canals allows for greater growth of algae, which assimilate this soluble form of phosphorus. The Delta stations have about equally high concentrations of suspended matter as the mainstream stations but more than in the tributaries (Figure 5.10).

However, the ratio of bound P (total-P minus $PO_{4}$-P) to total suspended solids (TSS) is higher at the Delta stations than at the mainstream and tributary stations. This deviation is likely to be due either to erosion of soils with a higher concentration of phosphorus, or to a higher amount of organic matter in canal water, which binds phosphorus. The latter hypothesis is supported by Figure 5.10 in which (i) Delta stations have a median COD of about 4 mg/L, while both mainstream and tributaries have median values of around 2.2 mg/L, and (ii) the ratio of bound-P:TSS is higher at Delta stations than elsewhere in the LMB. This indicates that at least some of the particular-bound P is attached to organic matter. Phosphorus bound into organic matter is more easily hydrolysed to soluble orthophosphate, which is available for algae growth.

## Nutrients and eutrophication

The relationship between N and P is a core issue for understanding problems of eutrophication. Most of the knowledge on this subject comes from northern temperate lakes in North America and Europe. The fact that the Mekong is tropical and relatively turbid, makes the transfer of this knowledge to the Mekong situation difficult. There has been little research into N:P ratios and phytoplankton abundance and species in the LMB. Research in tropical lakes of Africa shows that this is an extremely complex issue that is not wholly dependent on the N:P ratio. An additional factor that mitigates against algal growth is the large TSS in the Mekong, many tributaries, and in Delta stations. Excess P will be quickly bound up by suspended particles and made unavailable for algal growth. Another mitigating factor prevalent in Africa is light limitation of algal growth due to high levels of turbidity (TSS) which is also common in the Mekong system. (Guildford *et al.*, 2003; Lehman and Branstrator, 1993; Moss, 1969; Mugidde *et al.*, 2003).

The RTAG $WQI_{al}$ threshold values for total-P for the protection of aquatic life are 0.13 mg/L, and 0.7 mg/L for the sum nitrite and nitrate-N (Table 2.6). The threshold value for total-P is the same as maximum values for cyprinid waters given by the EU Directive for freshwater fish (EEA 1999). The status of total-P conditions in 2005 and that of previous years (1986 to 2004) for mainstream, tributary and Delta stations are shown in Figure 5.12.

As shown in Figure 5.12, tributary stations are well below the threshold value, as are most mainstream stations. However, Delta stations frequently violate this threshold. In 2005, there was a substantial increase in the total-P concentrations for the mainstream stations, while the condition did not change in the tributaries. The Delta stations also deteriorated in 2005.

The status for the other nutrient, nitrogen (nitrate), included in the water quality index for the protection of aquatic life ($WQI_{al}$), is presented in Figure 5.13. Threshold values are sometimes exceeded in the Delta stations. Like P, there is also a significant increase in Nitrate-N concentrations in 2005.

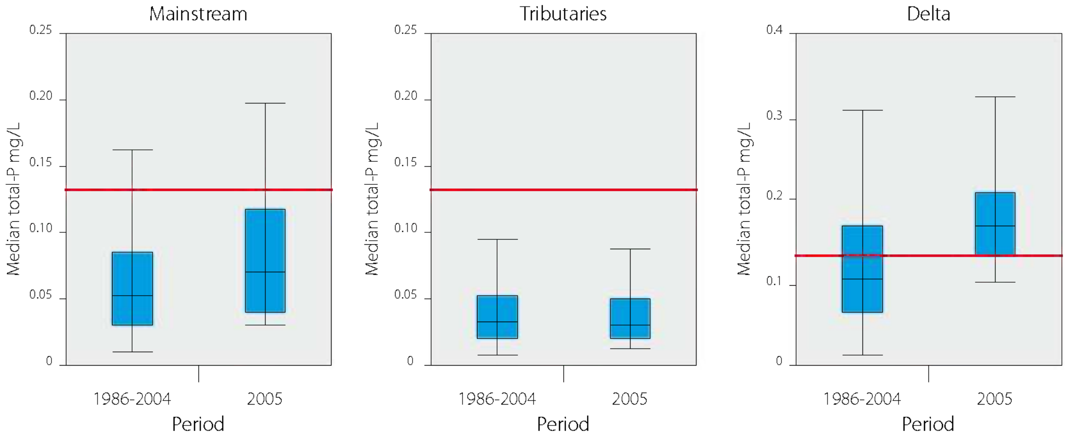


Figure 5.12 Comparison of (median) total-P concentrations for the three types of stations for 1986 – 2004 and 2005.
Box plots representing 25th, 50th (median) and 75th percentiles. The whiskers indicate 10th and 90th percentiles. The red line shows the RTAG threshold for the protection of aquatic life (Refer to Table 2.6).

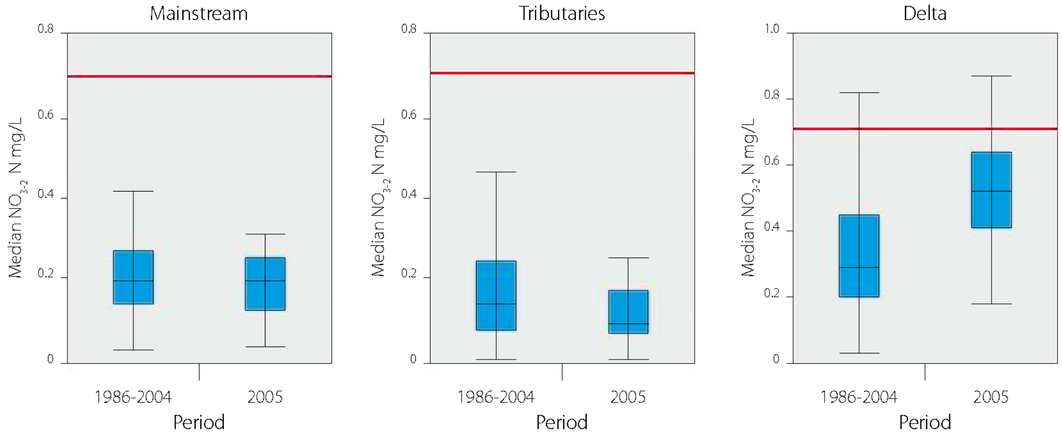


Figure 5.13 Annual median nitrate-N concentrations for the three types of stations. Comparison between long-term conditions (1986 – 2004) and 2005.
Box plots representing 25th, 50th (median) and 75th percentiles. The whiskers indicate 10th and 90th percentiles. The horizontal red line shows the RTAG threshold for the protection of aquatic life (refer to Table 2.6).

For plant growth requirements, the N:P ratio values between 7 and 10 are usually considered to be optimal. A higher ratio may indicate a surplus of nitrogen compounds, and a lower one a surplus of phosphorus relative to plant demand. Few ratio values are available for tropical areas. Ratios for total-N/total-P for the three types of stations of the Mekong are presented in Figure 5.14. The median N:P ratio for mainstream and Delta stations falls within the generally accepted range for N to P balance. The ratio for tributaries seems high and could indicate susceptibility to eutrophication if additional P is added.

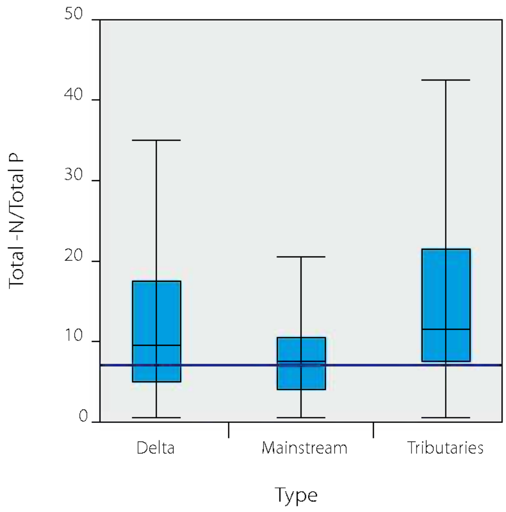


Figure 5.14 Total-N/total-P ratio for the three types of stations in the LMB.
The blue line indicates the optimal requirements (7:1) for algae. Box plots representing 25th, 50th (median) and 75th percentiles. The whiskers indicate 10th and 90th percentiles.

# 6. Conclusions

The assessment of 1985–2005 water-quality data based on records at the MRC Water Quality Monitoring Programme started during the first half of 1985. This assessment, which uses data over the period 1985–2005 or, in some cases, the sub-set of data from 2000–2005, provides a useful picture of the quality of the river water and the major sources of pollution. Three indexes (WQI) were developed, each of which relates to a specific issue related to water quality:

- $WQI_{al}$ for the protection of aquatic life;
- $WQI_{hi}$ for human impact on water quality, and;
- $WQI_{ag}$ for agriculture use, which in turn contains three subcategories: $WQ_{ag1}$ (general irrigation), $WQ_{ag2}$ (paddy rice), and $WQ_{ag3}$ (livestock and poultry).

Each WQI category is subdivided into classes according to the number of chemical parameters (DO, pH, etc.) that meet guideline thresholds. The classes are:

- $WQI_{al}$: High Quality, Good quality, Moderate Quality, Poor Quality;
- $WQI_{hi}$: Not Impacted, Slightly Impacted, Impacted, Severely Impacted;
- $WQ_{ag}$: No Restrictions, Some Restrictions, Severe Restrictions.

Fifty of the Primary Stations (including one Secondary Station used as a proxy) sampled over the period 2000–2005 have data that are sufficiently complete to allow a reliable calculation of each index value.

The $WQI_{al}$ is mostly High Quality in the mainstream and tributaries. However, in the Delta only one station is High Quality and two others are Good Quality; delete four are Moderate Quality, and one is Poor Quality.

With regard to $WQI_{hi}$, human impact on water quality is recorded at stations in the uppermost part of the LMB and downstream of Phnom Penh, where lower index values reflect higher population densities. In the remote upper reaches, causes of the impacts on water quality may originate in the Upper Mekong Basin (largely from China). The $WQI_{hi}$ at all Delta stations bar one is Severely Impacted. Because this is the most densely populated and intensively farmed area in the entire LMB, and, because there is a relatively low flow of water through the canals from the Mekong and Bassac rivers, the level of human impact is high.

There is little evidence that $WQI_{al}$ has changed systematically through time. However, significant temporal trends can be observed in the $WQI_{hi}$, and many of the mainstream stations recorded lower index values in the last year, or last few years.

*Number of Primary Stations in each WQI category and class*

| $WQI_{al}$ | Class | | | |
|---|---|---|---|---|
| | High Quality | Good Quality | Moderate Quality | Poor Quality |
| Mainstream | 19 | 2 | 1 | 0 |
| Tributaries | 11 | 4 | 4 | 0 |
| Delta | 1 | 2 | 4 | 2 |

| $WQI_{hi}$ | Class | | | |
|---|---|---|---|---|
| | Not Impacted | Slightly Impacted | Impacted | Severely Impacted |
| Mainstream | 1 | 11 | 9 | 1 |
| Tributaries | 0 | 3 | 7 | 9 |
| Delta | 0 | 0 | 1 | 8 |

| $WQI_{ag1}$ | Class | | |
|---|---|---|---|
| | No Restrictions | Some Restrictions | Severe Restrictions |
| Mainstream | 22 | 0 | 0 |
| Tributaries | 19 | 0 | 0 |
| Delta | 6 | 1 | 2 |

| $WQI_{ag2}$ | Class | | |
|---|---|---|---|
| | No Restrictions | Some Restrictions | Severe Restrictions |
| Mainstream | 22 | 0 | 0 |
| Tributaries | 19 | 0 | 0 |
| Delta | 8 | 0 | 1 |

| $WQI_{ag3}$ | Class | | |
|---|---|---|---|
| | No Restrictions | Some Restrictions | Severe Restrictions |
| Mainstream | 22 | 0 | 0 |
| Tributaries | 19 | 0 | 0 |
| Delta | 8 | 0 | 1 |

## Sources of pollution

Three major sources of pollution are evaluated:

### *Municipal sewage discharge*

The municipal discharge of pollutants is calculated using urban population and data on improved sanitation for 2000–2003. The total discharge from urban areas is 170,000-150,000 tonnes/year of BOD, 27,000-24,000 tonnes/year of total-N, and 8,100-7,200 tonnes/year of total-P.

Sewage water from part of Vientiane is collected and discharged to oxidation ponds and then moves to the That Luang Marsh. The marsh acts as a treatment facility and reduces both BOD and nutrients. Part of Phnom Penh has a similar situation with discharge into a downstream wetland.

Discharge from rural areas also increases the load to the Mekong and tributaries. However, leaching from latrines is likely to be relatively small. It has not been possible to estimate these amounts.

### *Industrial wastewater*

Industrial development has the potential to increase substantially pressure on aquatic resources substantially in the future. At present no information is available on industrial discharges.

### *Agriculture*

Agriculture accounts for about 80% of land use in Thailand and in the Delta. Losses of nutrients from agriculture are difficult to assess. An attempt based on available data suggests a loss of about 225,000 tonnes of nitrogen and 37,000 tonnes of phosphorus per year. However, these losses are unevenly distributed; more than 40% of each is likely to be lost to agriculture in northeast Thailand and the Delta.

## Transboundary pollution

There is no strong evidence for transboundary pollution in the LMB (Lao PDR to Thailand, Lao PDR to Cambodia, and Cambodia to Viet Nam). This conclusion is the same as that of other investigations (Hart *et al.* 2001). There is stronger evidence that there is transboundary transmission of pollutants from the Upper Basin (China) into the Lower Mekong Basin.

## Changes through time

Time series are now available for a period of about 20 years. However, the evaluation of time series is difficult. In most cases there is some cyclic variation in the water chemistry. Sometimes this variation is caused by variation in water flow. However, testing for this failed to find more than a few cases where this is significant. Some parameters and stations have significant slopes. However, there is no sign of any basin-wide significant trend for any parameter. With the continuing development of both agriculture (increased use of fertilizers) and urbanisation there is reason to expect changes in water quality in some tributaries. Possibly, reforestation of areas in the Khorat Plateau will lead to water quality improvement.

## Selected water quality issues

### *Salinity*

High salinities are nearly exclusively found in the Delta (but not on the mainstreams of the Mekong and Bassac) due to saltwater intrusion. However, deposits of rock salt in the subsurface of the Khorat Plateau can lead to high concentrations during the dry season. A total of 55 stations have a maximum conductivity higher than 70 mS/m, which is the threshold of Some Restrictions for water quality for general agricultural use. Only nine of these are severely affected by high salinity and all are located in the Ca Mau peninsula of the Delta. With the exception of one station, these are Severely Restricted for paddy rice during more than half the time (median values). However, most stations have a short period when $WQI_{agl}$ is classed as No Restrictions ($5^{th}$ percentile; statistically less frequent than one month per year).

There is a clear difference between the dry and rainy seasons at most stations. In the Ca Mau peninsula these differences are so large that the quality varies between 'Severe Restrictions' in the dry and Some Restrictions during the rainy season.

The construction of sluice gates in the Ca Mau area after 1995 has improved the conditions at several stations such as at Nhu Gia, Ngan Dua, Ninh Quoi, and Phung Hiep.

In the Thai tributaries (Nam Kam, Nam Chi, and Nam Mun) improvements in salinity reflect the regulation of the flow of water, which allows higher flow during the worst part of the dry season.

### *Acidification*

The most severely affected area is the Plain of Reeds on the Delta, but some areas in Cambodia have similar characteristics. The situation, in the Plain of Reeds seems to improve in the western parts of the canal system close to the Mekong. Further east there are still instances of extremely low pH. Construction of a dense network of canals in the Delta allows passage of Mekong water, which neutralises acidity leached from adjacent soils. Effects of airborne acidification are not observed since pH-values are reasonably high and sulphate concentrations relatively low.

### *Eutrophication*

All values of N are less than the threshold values. In 2005 there was a significant increase in the total-P concentrations for the mainstream stations while no such difference was found for the tributaries. At the Delta stations there was also a significant increase in total-P concentrations during 2005. Although the concentrations of nitrogen and phosphorus are generally lower than the threshold values for $WQI_{al}$ there is most likely an effect on algae, periphyton (attached algae on e.g. stones) and floating aquatic vegetation.

# 7. References

Basak S.C., Magnuson V.R., Niemi C.J., and R.R. Regal. (1988) Determining Structural Similarity of Chemicals Using Graph Theoretic Indices. *Discr. Appl. Math.* **19**, 17–44.

CCME (2005) *Canadian Water Quality Guidelines.* Canadian Council of Ministers of the Environment, Publication No. 1299; ISBN 1–896997–34–1, Ottawa, Canada.

CERN (China Educational and Research Network) (2002) Work Starts on Lancang River Power Station. http://www.edu.cn/20020125/3018726.htm

CIIS (China Information Services) (2002) No Pollution to Mekong River. http://us.tom.com/english/543.htm

China Daily (2003) For China, Xiaowan Dam a Reservoir for Progress. http://www.ipsnews.net/mekong/stories/xiaowan.html

Dai A and K.E. Trenberth (2002) Estimates of Freshwater Discharge from Continents: Latitudinal and Seasonal Variations. *Journal of Hydrometeorology.* **3** (6), 660–687.

EEA (1999) *Nutrients in European ecosystems.* Environmental Assessment Report No 4.

FAO (1985) Water Quality for Agriculture. Food and Agriculture Organization of the United Nations. FAO Irrigation & Drainage Paper No.29 (Rev. 1).

Hart, B.T., Jones, M.J. and G. Pistone (2001) Transboundary Water Quality Issues in the Mekong River Basin. Final Report (unpublished), Mekong River Commission.

Guildford, S.J., Hecky, R.E., Taylor, W.D., Mugidde, R. and H.A. Bootsma (2003) Nutrient Enrichment Experiments in Tropical Great Lakes Malawi/Nyasa and Victoria. *J. Great Lakes Res.* **29** (Supplement 2), 89–106.

Kallf. J. (2002) *Limnology.* Prentice Hall

Lehman, J.T. and D. K. Branstrator (1993) Effects of nutrients and grazing on the phytoplankton of Lake Victoria. *Verh. Internat. Verein. Limnol.* **25**, 850–855.

Lyngby, J.E., Ongley, E.D. and A. Wilander (1997) Water Quality Monitoring Network Project Review and Modernization. Final Report to the Mekong River Commission, Bangkok, Thailand, Dec. 1997.

Moss, B. (1969) Limitation of algal growth in some central African waters. *Limnol. Oceanogr.* **14**, 161–601.

MRC (1988) Perspectives for Mekong development. Revised Indicative Plan (1987). Interim Committee for Coordination of Investigations of the Lower Mekong Basin Committee report, April 1988.

MRC (1992) Fisheries in the Lower Mekong Basin. Review of the Fishery Sector in the Lower Mekong Basin. Main report and Annexes. Interim Committee for Coordination of Investigations of the Lower Mekong Basin. May 1992.

MRC (1997) Mekong River Basin Diagnostic Study. Mekong River Commission and United Nations Environment Programme, Bangkok, Thailand.

MRC (2003) State of the Basin Report. Mekong River Commission, Phnom Penh. ISSN 1728:3248.

MRC (2004) Overview of the Hydrology of the Mekong Basin. Draft Report, Water Utilization Start-Up Project. Mekong River Commission, December, 2004.

MRC (2005) *Overview of the Hydrology of the Mekong Basin*. Mekong River Commission, Vientiane, 73pp.

MRC (2007a) Diagnostic Study of the Lower Mekong Basin. MRC Technical Paper No.15, Mekong River Commission, Vientiane, 57pp.

MRC (2007b) Annual Mekong Flood Report 2006. Mekong River Commission, Vientiane, 76pp

Mugidde, R., Hecky, R.E., Hendzel, L.L. and W.D. Taylor (2003) Pelagic Nitrogen Fixation in Lake Victoria (East Africa). *J. Great Lakes Res.* **29** (Supplement 2),76–88.

Ongley, E.D. (2006a) Water Quality Guidelines and Index: Recommendations for Mekong Water Quality Assessment. Unpublished Consultant's Report for the Mekong River Commission, Vientiane, Lao PDR.

Ongley, E. (2006b) Basin and national annual reporting framework recommendations. Ver. 1-22/05/06. Unpublished report for MRC-RTAG, 2006.

Ongley, E.D. (2008) Water Quality of the Lower Mekong River. In Campbell, I. (Editor), *The Mekong: Biophysical Environment of an International River Basin*. Elsevier Inc. (in press).

Ongley, E.D and X. Wang (2004) Transjurisdictional Water Pollution Management in China: The Legal and Institutional Framework. *Water International* **29** (30), 270-281,

Phillips, M.J. (2002) Freshwater aquaculture in the Lower Mekong Basin. MRC Technical Paper No. 7. Mekong River Commission.

Poonsook Vimuktayon (1988) Surface water quality in the lower Mekong basin in Thailand. In: *Proceedings of Final Workshop on Water Quality Monitoring Network in the Lower Mekong Basin*. Ho Chi Minh City, September 1988. Mekong Secretariat.

Sverdrup-Jensen, S. (2002) Fisheries in the lower Mekong Basin: Status and Perspectives. MRC Technical Paper No 6. ISSN 1683–1489.

Xinhua New Agency (2005) Water Pollution Worsening: SEPA. http://www.china.org.cn

# Appendix 1. Primary Stations

| Station Code | Station Name | River | Country | Status | Benchmark | Transboundary |
|---|---|---|---|---|---|---|
| H010500 | Houa Khong | Mekong | Lao PDR | M-Me | Y | Y |
| H010501 | Chaing Saen | Mekong | Thailand | M-Me | Y | |
| H011200 | Luang Prabang | Mekong | Lao PDR | M-Me | Y | |
| H011901 | Vientiane | Mekong | Lao PDR | M-Me | Y | |
| H013101 | Nakhon Phanom | Mekong | Thailand | M-Me | Y | |
| H013401 | Savannakhet | Mekong | Lao PDR | M-Me | | |
| H013801 | Khong Chiam | Mekong | Thailand | M-Me | | |
| H013900 | Pakse | Mekong | Lao PDR | M-Me | Y | Y |
| H014501 | Stung Treng | Mekong | Cambodia | M-Me | Y | Y |
| H014901 | Kratie | Mekong | Lao PDR | M-Me | Y | Y |
| H019806 | Neak Loung | Mekong | Cambodia | M-Me | Y | Y |
| H019802 | Kampong Cham | Mekong | Cambodia | M-Me | | |
| H019801 | Chrouy Changvar | Mekong | Cambodia | M-Me | Y | |
| H019807 | Krom Samnor | Mekong | Cambodia | M-Me | | |
| H019803 | Tan Chau | Mekong | Viet Nam | M-Me | Y | Y |
| H019804 | My Thuan | Mekong | Viet Nam | M-Me | Y | |
| H019805 | My Tho | Mekong | Viet Nam | M-Me | Y | |
| H033401 | Tak Khmau | Bassac | Cambodia | M-Ba | | |
| H033402 | Koh Khel | Bassac | Cambodia | M-Ba | Y | Y |
| H033403 | Khos Thom | Bassac | Cambodia | M-Ba | Y | Y |
| H039801 | Chau Doc | Bassac | Viet Nam | M-Ba | Y | Y |
| H029812 | Dai Ngai | Bassac | Viet Nam | M-Ba | Y | |
| H039803 | Can Tho | Bassac | Viet Nam | M-Ba | Y | |
| H050104 | Chaing Rai | Nam Mae Kok | Thailand | T | | |
| H100101 | Ban Hatkham | Nam Ou | Lao PDR | T | Y | |
| H910108 | Houay Mak Hiao | Houay Mak Hiao | Lao PDR | T | | |
| H230103 | Ban Hai | Nam Ngum | Lao PDR | T | Y | |
| H290103 | Ban Chai Buri | Nam Songkhram | Thailand | T | Y | |
| H320101 | Se Bangfai | Se Bang Fai | Lao PDR | T | | |
| H310102 | Na Kae | Nam Kam | Thailand | T | | |
| H350101 | Ban Kengdone | Se Bang Hieng | Lao PDR | T | Y | |
| H380104 | Ubon | Nam Mun | Thailand | T | | |
| H380128 | Mun (Kong Chiam) | Nam Mun | Thailand | T | Y | |
| H390105 | Sedone Bridge | Se Done | Lao PDR | T | Y | |
| H430102 | Siem Pang | Se Kong | Cambodia | T | | |
| H440103 | Angdoung Meas | Se San | Cambodia | T | Y | |
| H440402 | Pleicu | Se San | Viet Nam | T | | |
| H440102 | Phum Pi | Se San | Cambodia | T | | |
| H450101 | Lumphat | Sre Pok | Cambodia | T | Y | |
| H451303 | Ban Don | Sre Pok | Viet Nam | T | | |

| Station Code | Station Name | River | Country | Status | Benchmark | Transboundary |
|---|---|---|---|---|---|---|
| H020107 | Backprea | Great Lake | Cambodia | T | | |
| H020108 | Phnom Krom | Great Lake | Cambodia | T | | |
| H020106 | Kampong Luong | Great Lake | Cambodia | T | Y | |
| H020103 | Kampong Chhnang | Tonle Sap | Cambodia | T | | |
| H020102 | Prek Kdam | Tonle Sap | Cambodia | T | | |
| H020101 | Phnom Penh Port | Tonle Sap | Cambodia | T | Y | |
| H988316 | Tinh Bien | Vinh Te | Viet Nam | TD | | |
| H988114 | Tu Thuong | Tu Thuong | Viet Nam | TD | | |
| H988115 | Thong Binh | Thong Binh | Viet Nam | TD | | |
| H988311 | Vinh Dieu | T3 | Viet Nam | TD | Y | |
| H988305 | Cau So 13 | Tri Ton | Viet Nam | TD | | |
| H988110 | My An | No 28 | Viet Nam | TD | | |
| H988107 | Kien Binh | Duong Van Duong | Viet Nam | TD | | |
| H988209 | Vinh Thuan | Chac Bang | Viet Nam | TD | Y | |
| H988211 | Ninh Quoi | Quan Lo – Phung Hiep | Viet Nam | TD | Y | |

| | Total | Benchmark | Transboundary |
|---|---|---|---|
| Mekong | 17 | 12 | 5 |
| Bassac | 6 | 5 | 3 |
| Tributary | 23 | 12 | 0 |
| Delta | 9 | 3 | 0 |
| Total | 55 | 29 | 8 |

# Appendix 2. Secondary Stations

| Station Code | Station Name | River | Country |
|---|---|---|---|
| H230206 | Thalath (Keokou) | Nam Lik | Lao PDR |
| H230199 | Nam Ngum at Dam site | Nam Ngum | Lao PDR |
| H231801 | Nam Souang | Nam Souang | Lao PDR |
| H231901 | Nam Houm | Nam Houm Canal | Lao PDR |
| H910106 | Ban Sok | That Luang Marsh | Lao PDR |
| H910107 | Donedang | Nam Pasack (That Luang Marsh) | Lao PDR |
| H910103 | Hoa Khoa | That Luang Marsh | Lao PDR |
| H370104 | Yasothon | Nam Chi | Thailand |
| H380134 | Rasi Salai | Nam Mun | Thailand |
| H381699 | Lam Dom Noi | Lam Dom Noi | Thailand |
| H390104 | Souvannakhilli | Se Done | Lao PDR |
| H610101 | Kampong Thom | Tonle Sap Lake | Cambodia |
| H620101 | Kompong Thmar | Tonle Sap Lake | Cambodia |
| H988102 | Tan Thanh | Hong Ngu | Viet Nam |
| H988105 | Tram Chim | Dong Tien | Viet Nam |
| H988106 | Hung Thanh | Phuoc Xuyen | Viet Nam |
| H988111 | My Phuoc Tay | Nguyen Tan Thanh | Viet Nam |
| H988113 | Long Dinh | Nguyen Tan Thanh 1 | Viet Nam |
| H988112 | Rach Chanh | Rach Chanh | Viet Nam |
| H988310 | Lo Gach | Tam Ngan | Viet Nam |
| H988306 | Cau So 5 | Ba The | Viet Nam |
| H988312 | Tam Ngan | Tam Ngan | Viet Nam |
| H988309 | Cau Tri Ton | Tri Ton | Viet Nam |
| H988313 | Tri Dien | Tri Ton | Viet Nam |
| H988308 | Vong The | Ba The | Viet Nam |
| H988307 | Vong Dong | Rach Gia – Long Xuyen | Viet Nam |
| H988314 | Soc Xoai |  | Viet Nam |
| H988315 | My Lam |  | Viet Nam |
| H988210 | Ngan Dua | Ngan Dua | Viet Nam |
| H988208 | Thoi Binh | Chac Bang | Viet Nam |
| H988214 | Phuoc Sinh | Quan Lo – Phung Hiep | Viet Nam |
| H988207 | Chu Chi | Cho Hoi | Viet Nam |
| H988206 | Ca Mau | Quan Lo – Phung Hiep | Viet Nam |
| H988205 | Ho Phong | Canh Den – Ho Phong | Viet Nam |
| H988204 | Cau Sap | Ngan Dua – Bac Lieu | Viet Nam |

# Appendix 3. Delta Stations

| Station Code | Station Name | Status |
|---|---|---|
| H988316 | Tinh Bien | Primary |
| H988114 | Tu Thong | Primary |
| H988115 | Thong Bin | Primary |
| H988311 | Vinh Dien | Primary |
| H988305 | Cau So13 | Primary |
| H988110 | My An | Primary |
| H988107 | Kien Binh | Primary |
| H988209 | Vinh Thuan | Primary |
| H988211 | Ninh Quoi | Primary |
| H988102 | Tan Thanh | Secondary |
| H988104 | An Long | Secondary |
| H988105 | Tram Chim | Secondary |
| H988106 | Hung Thanh | Secondary |
| H988111 | My Phuoc Tay | Secondary |
| H988112 | Rach Chanh | Secondary |
| H988113 | Long Dinh | Secondary |
| H988203 | Nhu Gia | Secondary |
| H988204 | Cau Sap | Secondary |
| H988205 | Ho Phong | Secondary |
| H988206 | Ca Mau | Secondary |
| H988207 | Chu Chi | Secondary |
| H988208 | Thoi Binh | Secondary |
| H988210 | Ngan Dua | Secondary |
| H988214 | Phuoc Sinh | Secondary |
| H988307 | Vong Dong | Secondary |
| H988308 | Vong The | Secondary |
| H988309 | Cau Tri Ton | Secondary |
| H988310 | Lo Gach | Secondary |
| H988312 | Tam Ngan | Secondary |
| H988313 | Tri Dien | Secondary |
| H988306 | Cau So 5 | Secondary |
| H988101 | Hong Ngu | |
| H988103 | Cai Mon | |
| H988108 | Tuyen Nhon | |
| H988109 | Phong My | |
| H988201 | My Xuyen | |
| H988202 | My Thanh | |
| H988212 | Nga Nam | |
| H988213 | Phung Hiep | |
| H988301 | Nui Sap | |
| H988302 | Bathe | |
| H988303 | Tri Ton | |
| H988304 | Nha Bang | |
| H988314 | Soc Xoai | |
| H988315 | My Lam | |

Recent papers in the MRC Technical Paper series:

MRC Technical Paper No. 11 Hydro-acoustic survey of deep pools in the Mekong River of southern Lao PDR and northern Cambodia.

MRC Technical Paper No. 12 Tagging Fish - a case study from the Tonle Sap, Cambodia.

MRC Technical Paper No. 13 Biomonitoring of the lower Mekong River and selected tributaries.

MRC Technical Paper No. 14 Fish Migration Triggers in the Mekong River and other freshwater tropical systems.

MRC Technical Paper No. 15 Diagnostic study of water quality in the Lower Mekong Basin.

MRC Technical Paper No. 16 Fish Consumption and the Yield of Fish and Other Aquatic Animals from the Lower Mekong River Basin.

MRC Technical Paper No. 17 Socio-economics of the fisheries of the lower Songkhram River Basin, northeast Thailand.

MRC Technical Paper No. 19 Yield and value of the wild fishery of rice fields in Battambang Province, near Tonle Sap, Cambodia

Mekong River Commission
P.O.Box 6101,Vientiane 01000,
Lao PDR.Telephone: (856) 21 263 263 Facsimile: (856) 21 263 264
E-mail: mrcs@mrcmekong.org
Website: www.mrcmekong.org