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Mekong River Commission

Diagnostic study of water quality in the Lower Mekong Basin

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Meeting the Needs, Keeping the Balance

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[1] Agriculture & Environmental Research Institute (a French public research centre).

Abbreviations and Acronyms

AFNOR: Association Française de Normalisation
BOD5: Biological Oxygen Demand (5 days)
BTEX: Benzene, Toluene, Ethylbenzene and Xylene
CN: Cyanide
COD: Chemical Oxygen Demand
DAIpo: Diatom Assemblage Index to organic water pollution
VOCs: Volatile Organic Compounds
DO: Dissolved Oxygen
GEF: Global Environment Facility
IBD: Indice Biologique Diatomées = Biotic Diatom Index
IPS: Indice de Polluosensitivité spécifique = Specific polluo-sensitivity index
ISQG: Interim Sediment Quality Guideline
I-TEQ: International Toxicity Equivalents
LMB: Lower Mekong Basin
MRC: Mekong River Commission
NMCs: National Mekong Committees
OCDD: Octadichlorodibenzodioxin
OCDF: Octadichlorodibenzofuran
PAHs: Polycyclic Aromatic Hydrocarbons
PCBs: Polychlorinated Biphenyls
PCD: Pollution Control Department
PCDDs: Polychlorinateddibenzodioxins
PCDFs: Polychlorinated dibenzofurans
PEC: Probable Effect Concentration
PEL: Probable Effect Level
QA/QC: Quality Assessment / Quality Control
TEC: Threshold Effect Concentration
TEF: Toxicity Equivalent Factor
TEL: Threshold Effect Level
TSS: Total Suspended Solids
USEPA: United States Environmental Protection Agency
WQDS: Water Quality Diagnostic Study
WQMN: Water Quality Monitoring Network
WUP: Water Utilisation Programme

Summary

Water-quality monitoring in the Lower Mekong Basin has been carried out at approximately 100 stations (in Lao PDR, Thailand and Viet Nam since 1985, and since 1993 in Cambodia) by national laboratories coordinated by the Mekong River Commission (MRC). This programme uses conventional physico-chemical measurements typical of such programmes world-wide. Because there is little data on environmental contaminants in the Mekong River and its tributaries, the GEF/MRC Water Utilization Programme (WUP) commissioned a major diagnostic study of water quality in the Lower Mekong Basin.

The study was carried out in two phases, with field campaigns in 2003 and 2004. Twenty-two sites were sampled in 2003, and, on the basis of results from that year's survey, 16 sites were selected for sampling in 2004. The field campaigns were undertaken during the dry season in both years. Samples of river water and river-bed sediments were analysed for a wide range of conventional parameters, and for toxic micro-pollutants, including persistent and bio-accumulating organic pollutants such as pesticides, PAHs, PCBs, dioxins and furans. Sediment was included as many of the persistent toxic compounds are known to accumulate in this substrate. Because concentrations of particular chemicals are not explicitly linked to ecological health, a bioassay test was conducted at selected sites in both years to assess presence/absence of toxicity. The data from 2003 demonstrated that the conventional water-quality data collected through the MRC water-quality programme is of satisfactory reliability, therefore these conventional parameters were not analysed in 2004.

The study establishes current baseline conditions for environmental contaminants in the lower Mekong River and its major tributaries. Concentrations of metals in water and sediment are mainly below any level of concern. Industrial contaminants and pesticides in water are all less than the detection limit and less than published criteria (where available) for biological effects. The environmental effect of pesticides on sediments cannot be determined as the detection limits available in this study were too high for most pesticides. On analysis, samples from several sites gave a positive toxic response to the bioassay test organism, however measured chemistry was almost always lower than published threshold effects levels. A few sites had levels of some compounds that are higher than other sites (but lower than threshold effects levels) and deserve additional attention, both in terms of defining more precisely the nature and extent of contamination, and to determine if these pose any downstream and/or trans-boundary risk. The stretch of the Mekong River where it leaves China and enters Lao PDR is problematic insofar as toxicity was recorded in both years, however this is not correlated with measured chemistry.

KEY WORDS: Mekong; water-quality; toxicity; environmental contaminants; trans-boundary issues.

Figure 1. The Mekong River Basin

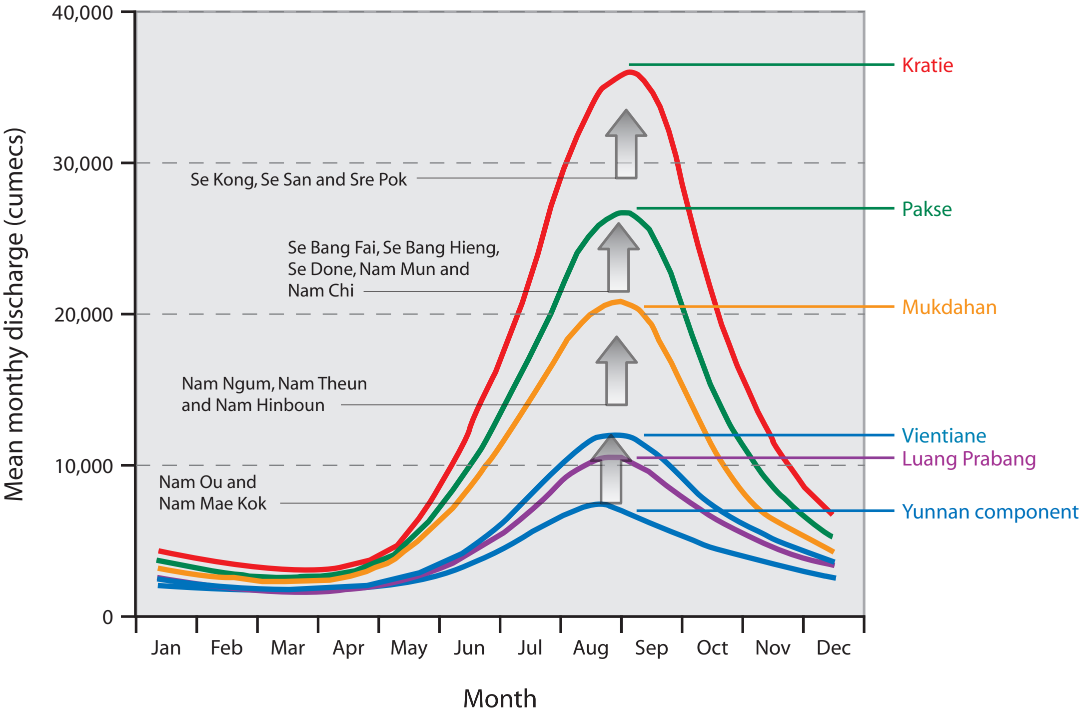

Figure 2. Mean monthly discharge at selected locations showing the main tributaries in each reach. Arrows indicate from upstream to downstream. The period of record is 1960-2000 (MRC, 2004)

1. Introduction

The water resources of the Mekong River provide livelihoods for most of the 60 million people who live in the Lower Mekong Basin. These livelihoods to a large extent depend on the environmental health of the Mekong River and its tributaries remaining in good condition. Water quality is a key determinant of environmental health. The Mekong River Commission has monitored the water quality of most of the river since the mid 1980s (monitoring of the Cambodian stretch of the Mekong only began in 1993). The parameters the MRC monitors are the conventional physico-chemical measures that are employed by similar programmes world-wide. Because there are little data on environmental contaminants in the Mekong River and its tributaries, the MRC Water Utilization Programme (WUP) commissioned a major diagnostic study of water quality in the Lower Mekong Basin. This report documents the results of the study, which included additional data from field sampling campaigns undertaken during 2003 and 2004.

The Mekong River Basin

The Mekong River is the longest river in southeast Asia, the 12th longest in the world, and the 10th largest by discharge (Dai and Trenberth, 2002). It rises in the Tibetan Plateau and flows southward through China, Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam where it discharges into the South China Sea (Figure 1). The river's basin, which has an area of 795,000 km^2, is functionally divided into the Upper Basin—which flows southwards through China (where it is called the Lancang River), and the Lower Basin—which includes Lao PDR, Thailand, Cambodia and Viet Nam (Figure 1). The river forms the boundary between 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.

Since 1957, Lao PDR, Thailand, Cambodia and Viet Nam (the 'riparian countries') have cooperated in management of the Lower Mekong Basin through the 'Committee for the Coordination of Investigations of the Lower Mekong Basin' or the Mekong Committee (a forerunner of the Mekong River Commission) under a statute endorsed by the United Nations. In April 1995, these four countries signed the 'Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin' (the Mekong Agreement) which empowers the Mekong River Commission (MRC) and its secretariat (MRCS). Under this agreement water-quality is specific to Article 3 (Environmental Protection), Article 7 (Prevention and Cessation of Harmful Effects), and to Article 10 (Emergency Situations). The programmes of MRC, including the water-quality programme, apply only to the four riparian countries. Neither China nor Myanmar are signatory to the Mekong Agreement, although both have observer status. The MRC operates its programmes through the National Mekong Committee (NMC) of each member country.

The annual monsoon cycle is the predominant factor controlling the hydrology of the Mekong River and its tributaries. The cycle has a wet season from June to November and a dry season from December to May (see Figure 2 for the mean annual hydrograph). China contributes only 16% of the mean annual discharge, whereas Lao PDR contributes some 35% and up to 60% of the flow during the wet season (MRC, 2005). In contrast, China is the provenance of 50% of the sediments that the Mekong discharges into the South China Sea (MRC, 2005).

Concerns about the construction of dams in the basin led the World Bank/MRC Water Utilisation Project to model the effects of dam development scenarios on the hydrology of the basin (World Bank, 2004). This study concluded that ‘the overall character of the hydrograph is maintained’, that ‘high-flows are marginally reduced, but within the historically observed range’, and that ‘low-flows are significantly increased and are higher than the historically observed range’.

Downstream of Kratie (Cambodia), the hydrology of the Lower Mekong Basin is particularly complex because of the extremely low gradients. During the dry season, the Mekong flows into the South China Sea through the Mekong and Bassac distributary channels and the Mekong Delta. Salinities of up to 1 g/l can extend 70 km upstream from the river mouth and tidal influences are noticed as far upstream Phnom Penh. During the rainy season, a sizeable portion of the Mekong’s water flows ‘upstream’ in the Tonle Sap river and into the Great Lake of Cambodia, causing the area of the lake to expand up to six-fold and creating extensive wetlands around the entire water body. The water drains out of the Great Lake back through the Tonle Sap and into the Mekong system during the dry season, thereby adding to low-flow discharges in the region downstream of Phnom Penh. This hydrological pattern makes hydrological and water-quality monitoring and interpretation difficult, especially in mainstream stations below Kratie. Reverse flows occur daily during the tidal cycle at delta stations in Viet Nam and during wet season reverse-flow in the Tonle Sap river.

The Great Lake–Tonle Sap system of Cambodia is a unique lacustrine/wetland complex. The MRC has monitored the water quality of lake since 1993 and the WUP has undertaken a special study on nutrient and sediment fluxes. However, there has been no systematic or substantial scientific study of the nutrient dynamics of the system. As a result, it is not known with certainty if the lake is N or P limited and whether nutrient loadings from the surrounding land are transported through the wetlands into this shallow lake, or if these loads are consumed within the wetlands. It is known, however, that there is extensive anoxia in the wetlands surrounding the lake and that this probably results from bacteria consuming oxygen during the decay of organic matter. Despite this anoxia, the wetlands are enormously productive and fish species have adapted to these conditions.

Potential sources of pollution

Upper Mekong Basin

Hydropower stations

Two hydropower stations have been built on the on the mainstream (Manwan and Dachaoshan) and six more hydropower stations are planned for development in the next 20 years, including the Xiaowan site that is under construction. The Xiaowan dam, located 550 km upstream of the

China/Lao PDR border, will be the highest hydroelectric dam in China after the Three Gorges Dam on the Yangtze River (CERN, 2002). A Thai-Chinese consortium will build two additional dams on the Lancang in Yunnan province (construction of the Jinhong station was scheduled to begin in 2005 and the Nuozhadu in 2006).

While Chinese sources claim that these dams will have no impact on water quality in the Lower Mekong Basin, there is the danger of release of anoxic bottom waters from reservoirs, which happens at many dams worldwide. Also, according to the China Daily (2002), a 2.7°C reduction in temperature in water is anticipated at the Xiaowan dam site, although this will be mitigated downstream.

Industrial pollution

In 2000, the provincial government of Yunnan Province in China (located immediately upstream of the China/Lao PDR border) inspected 1042 industrial enterprises. This resulted in the forced closures of four plants (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.

Nevertheless, the rapid development of the Lancang basin in China and increasing pollution in Chinese rivers (Ongley & Wang, 2004; Xinhua News Agency, 2005) raise concerns about a deterioration quality of the water arriving in the Lower Mekong basin from China in the future. However, Chinese news sources (e.g. CIIS, 2002) frequently claim that the water of the Lancang meets international drinking water standards (for those parameters for which Chinese agencies routinely monitor). Nevertheless, ecotoxicological assessment of a site on the Lao side of the border with China, which is discussed later in this report, suggests that there is some toxicity in this stretch that needs further investigation.

Lower Mekong Basin

There are only a few sources that could potentially pollute the mainstream in the Lower Mekong Basin. In Thailand, salt leaching from halite deposits underlying the Khorat Plateau—part of the Nam Mun catchment—is a problem, but this is an entirely natural phenomenon. However, even this is diluted to the point where there is no visible change in water-quality in the mainstream downstream of the confluence between the Nam Mun and the Mekong River. There are no data that suggest that irrigated agriculture or the limited industrial areas in Thailand within the Lower Mekong Basin are significant contributors of pollution to the mainstream of the river.

The two largest urban areas (Vientiane in Lao PDR, and Phnom Penh in Cambodia) are of concern as they lie on the banks of the Mekong. Currently, Vientiane, a city of around 500,000 inhabitants, discharges its municipal sewage into the That Luang wetland—a wetland that discharges into the Mekong River downstream of the city This discharge is small and poses little immediate risk to the Mekong mainstream. However, development of Vientiane with substantial land reclamation in the That Luang wetland for urban purposes is a concern, and may pose greater threats to the Mekong mainstream in the future if it is not managed properly.

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 River—a distributary of the Mekong.

In addition, some industrial and municipal waste products, as well as storm-water runoff, discharge directly into the Tonle Sap river—a tributary of the Mekong. While here there is some localised industrial-pollution, it is unclear whether this poses any significant risk either locally or further downstream. Likewise, we do not know the scale of the risk of pollution caused by the sewage coming from many stilt-houses built along the banks of the river and from the floating villages on the Great Lake.

Tidal factors influence the large cities on the Mekong Delta, such as Tan Chau and Chau Doc —located by the Mekong River and the Bassac respectively. The river-pollution recorded at these locations is probably attributable to local sources; however, there is no definitive work on trans-boundary transport of pollutants to rule out upstream sources (Hart *et al*., 2001). However, the extensive large-scale caged aquaculture farming that lines the banks of the Mekong River and the Bassac river downstream of the Cambodia/Viet Nam border is also a possible source of these pollutants. The in-stream caged fish culture, which occurs throughout much of the lower basin, is not on such a large scale and is unlikely to contribute significant pollutants.

There is very limited research or other data on organic contaminants or on non-point sources of pollutants in the Mekong River basin. Information presented at the 2nd Asia Pacific International Conference on Pollutants Analysis and Control, indicates that there is little evidence in the basin of persistent organic-pollutants, even in locations where there is known to have been high levels of use, for example the extensive deployment Agent Orange during the American War, and the intensive application of agricultural pesticides in parts of Thailand.

Recent work by Agusa *et al*. (2005) in Cambodia—a country where fish is the main source of dietary protein—indicates that mercury in some species of freshwater and marine fish is above dietary guidelines. However, their work does not imply large-scale mercury contamination in the freshwater system, although there is anecdotal evidence of mercury usage in the extraction of deposits of placer-gold upstream of the Great Lake and in the mainstream in Lao PDR, and possibly in some of the Mekong’s tributaries such as the Se Kong and Sre Pok rivers.

Other non-point sources include rapid expansion of caged-fish culture throughout the Mekong and its tributaries, discharge of human wastes from vessels plying the Mekong, especially tour boats in the middle reaches upstream from Luang Prabang (Lao PDR), and accidental spills from river boat traffic. The recent hydraulic works (to enhance barge traffic) on the stretch of the Mekong between China and Lao PDR may increase the chance of spillage.

In summary, existing data suggest the quality of the water in mainstream is good, even though the concentrations of suspended sediment are high—especially during the wet season. While there are valid concerns over specific threats arising from current and future land use in the basin, these are based largely on anecdotal evidence. There is little well-documented evidence about specific threats to water quality coming from outside or within the basin. An exception is the Delta region; here good-quality data raises concerns over problems arising from acidification, salinity and organic pollution. However, the extent to which trans-boundary flux of chemicals, caused by local pollution, exacerbates these problems is not clear. Hydraulic conditions, specifically low-flow, may be responsible.

This lack of detailed trans-boundary information, even for issues such as salinity, is a feature of virtually all documents about water quality in the LMB. Also, there has never been any attempt to define baseline conditions for more complex issues, such as sediment quality or persistent bio-accumulation of toxic substances, as a means of establishing criteria against which to measure future change.

MRC water-quality monitoring programme

Until the early 1980s there was little systematic ambient water-quality monitoring in any of the countries, with the exception of Thailand. In 1985, the MRC, in response to riparian concerns over potential water pollution and its trans-boundary implications, began a water-quality monitoring programme in Lao PDR, Viet Nam and Thailand, with assistance from the Swedish government. Cambodia joined the programme in 1993.

The programme monitors approximately 100 permanent stations on the mainstream and important tributaries of the Mekong River (Figure 3). The monitoring involves sampling the mid-stream, or the thalweg at locations where the river is very wide, on a monthly basis. The sampling programme tests only river water, not sediment or other substrates.

Table 1. *List of parameters measured in the MRC water-quality monitoring programme*

Temperature	Na	Sulphate	PO_4^{-3}	Fe
Conductivity	K	Alkalinity	Total P	
TSS (mg/l)	Ca	NO_{2-3}	Si	
pH	Mg	NH_4^+	COD_{Mn}	
DO	Cl	Total N	Al	

Note: NH_4 is the sum of $NH_3 + NH_4^+$, however at neutral pH values most of the ammonia in river water is in the form on NH_4^+.

Stations in some countries collected other parameters, such as total coliform, metals and some pesticides. The MRC acts as a facilitating agency it does not have its own laboratories but rather provides technical guidance to the four member countries.

The MRC's water-quality monitoring programme provides good information on the status and the trends of selected parameters. While it can generate diagnostic and prescriptive information on certain kinds of threats, it cannot deal comprehensively with the impacts (real or anticipated) of present and proposed issues of land use. This type of traditional monitoring focuses mainly on water chemistry and says nothing of ecological effects that are now the primary determinant of 'environment effects' in modern water-quality programmes. In addition, it is now known that it is better to measure many anthropogenic toxicants on solids rather than in the aqueous medium, however, measuring toxicants in sediments is a challenge even for developed countries.

This study provides an interpretation of the large set of data compiled during the years of monitoring. There has been no previous attempt to define downstream loads of common chemicals, or to determine input loadings from China and output loadings into the delta region and to the South China Sea. Furthermore, there has been no attempt to define 'natural'

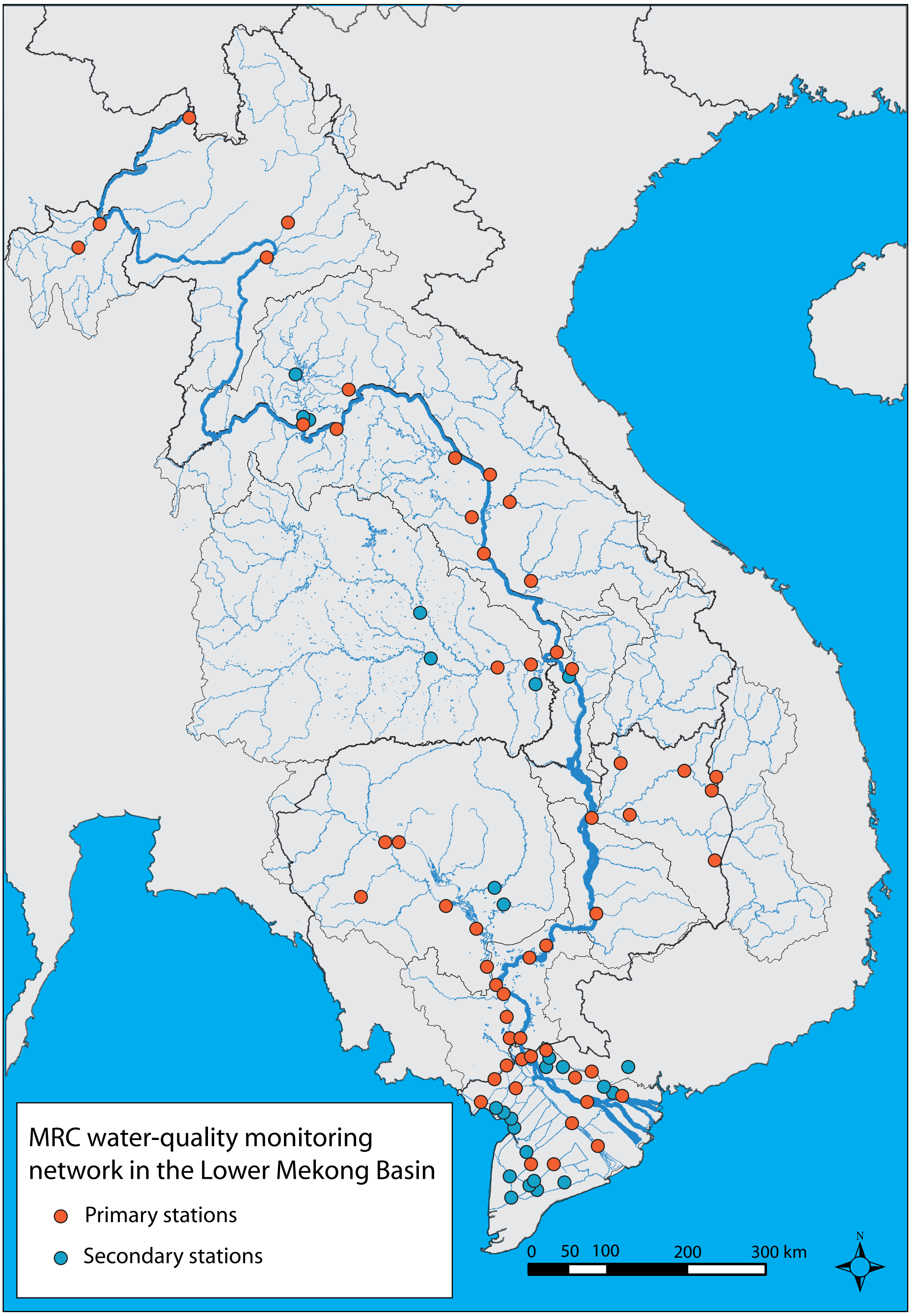

Figure 3. MRC water-quality monitoring network. The map shows the sampling stations in 2004. While this is broadly the same as the network of stations monitored from 1985 to 2003, there are some differences, mainly in the tributary stations. Also from 2004 onwards, the network was divided into primary stations (basin-wide or trans-boundary significance) and secondary stations (national or local significance).

background levels (which are probably not useful) or current ‘baseline’ levels (which are very useful) as yardsticks against which to assess future changes in water quality. This diagnostic study addresses these concerns.

The MRC is very aware that the conventional data collected under its water-quality monitoring programme, while useful for conventional issues such as organic pollution, eutrophication and salinity, does not allow the identification of ‘hot-spots’ where inorganic or organic contaminants may be present or the level of risk that may be associated with contaminants. Nor does it help to identify benchmark sites that future studies can use as a baseline from which to evaluate any changes in water and/or sediment-quality. The lack of reliable information on the status of contaminants in the Mekong system has been of considerable concern to riparian countries.

Water-quality and MRC’s Water Utilisation Programme

The Water Utilization Programme (WUP) is a GEF-funded project for the Lower Mekong River Basin, implemented by the World Bank and executed by the MRC. The WUP addresses the main objective of the MRC, namely helping trans-boundary basin management of water resources, according to the 1995 Mekong Agreement. Accordingly, one of WUP’s chief activities is to develop a set of management ‘proceedures’ concerning water-quality. While doing this the WUP identified the poor state of knowledge of water-quality concerning specific contaminants such as pesticides and industrial pollutants within the basin. Further, WUP specified that the knowledge of water-quality status, trends, and related natural and anthropogenic causes and impacts, present and future, needed clarification before developing water-quality modelling tools.

This diagnostic study aims to provide the WUP and other MRC programmes, with primary information on the status and the trends of important pollutants as a basis for subsequent modelling and development, and to identify potential trans-boundary water-quality issues. The study also fills an important gap in a parallel activity the MRC is undertaking, that is, a major revision of its water-quality monitoring programme. The revision includes all aspects of the programme; however, this study will allow MRC to (i) develop a rational and more cost-effective sampling of contaminants and (ii) to include hot-spots and/or benchmark sites as part of the revised monitoring programme.

Diagnostic study framework

Main activities

The study involved four main activities:

- *Activity 1:* define priority topics, and potential areas within the basin, as a basis for planning and executing the diagnostic study.

- *Activity 2:* provide a comprehensive assessment of water-quality according to the data held in the MRC water-quality database, and to determine the extent to which the MRC database can be used.

- *Activity 3:* design an innovative, advanced, programme of field and laboratory investigations that will complement the MRC water-quality monitoring network activities, by providing benchmark information at key sites, and lead to information that demonstrates the importance, or lack thereof, of real or perceived trans-boundary and basin-wide issues.

- *Activity 4:* implement a field and laboratory programme to obtain contrasting seasonal data as a basis for determining the status of water-quality relative to basin-wide and trans-boundary issues.

Study concept and limitations

The diagnostic study was designed to progress in a series of discrete steps, each of which was dependent on the outcome the previous step or steps. For example, the field programme (Activity 3) could not be designed until the outcome of Activities 1 and 2 was known.

The study used a ‘broad brush’ approach that allowed sampling of the full range of possible water-quality issues (i.e. the full range of contaminants) across the whole basin. This data is particularly relevant to so-called trans-boundary issues. However, achieving a broad geographical coverage meant sacrificing multiple analyses in the river cross-section and through time, with a consequential reduction of statistical confidence.

2. Definition of Priority Topics and Areas

The principal objective of the diagnostic study was to identify indicators of water-quality, and, if possible, trends in these indicators, that signify basin-wide or trans-boundary threats to the ecological health of the river.

There have been numerous efforts over the years, both under WUP and through MRC's water-quality monitoring programme, to identify significant basin-wide and trans-boundary issues. However, while the MRC member countries have consistently identified important issues of water-quality, these tend to be lists of generic concerns (e.g. 'pesticides') based on anecdotal evidence and with imprecise geographical locations. This is not surprising given the lack of hard data on the changes in water-quality conditions caused by development and other anthropogenic activities. Therefore, an essential first step in the study was to examine the historical database to identify patterns and trends in the water quality of the basin as a basis for establishing the sampling programme to be carried out later in the study.

Methodology

The first step in the diagnostic study was an extensive review of published literature and secondary material, such as the TEAM study, to delineate and prioritise basin-wide and trans-boundary issues and their priority.[1] This information helped establish the priorities of the subsequent field-sampling and analytical programme.

According to criteria used MRC's Watershed Classification Project, there are 103 sub-basins in the Lower Mekong Basin. The MRC's Basin Development Programme (BDP) groups these sub-basins into ten hydro-ecological regions, or sub-areas, based on hydrology, land use and land cover, river slope, etc (Figure 4). These subdivisions provided the geographic framework for the literature-based analysis.

Some of the sub-basins are trans-jurisdictional, that is the catchment spreads across international borders before the tributary rivers reach the Mekong (Figure 4).

- Rivers in Nam Mae Kok and Nam Mae Kham sub-basins (Sub-area 1 - Chaing Rai) that rise in Myanmar and pass through Thailand before entering the Mekong.

- Rivers in the Strung Mongkol Borey sub-basin (Sub-area 9 - Tonle Sap) that rise in northeast Thailand and flow south-eastwards into the Great Lake.

- The Se San and Sre Pok rivers (Sub-area 7 - Se San/Sre Pok/Se Kong), which rise in central Highlands of Viet Nam and flow westwards through Cambodia.

- The Se Kong river (Sub-area 7 - Se San/Sre Pok/Se Kong), which rises in Viet Nam and flows through Lao PDR before entering Cambodia.

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[1] TEAM investigated current and emerging issues of water quality in the Mekong portion of Thailand (TEAM 2001).

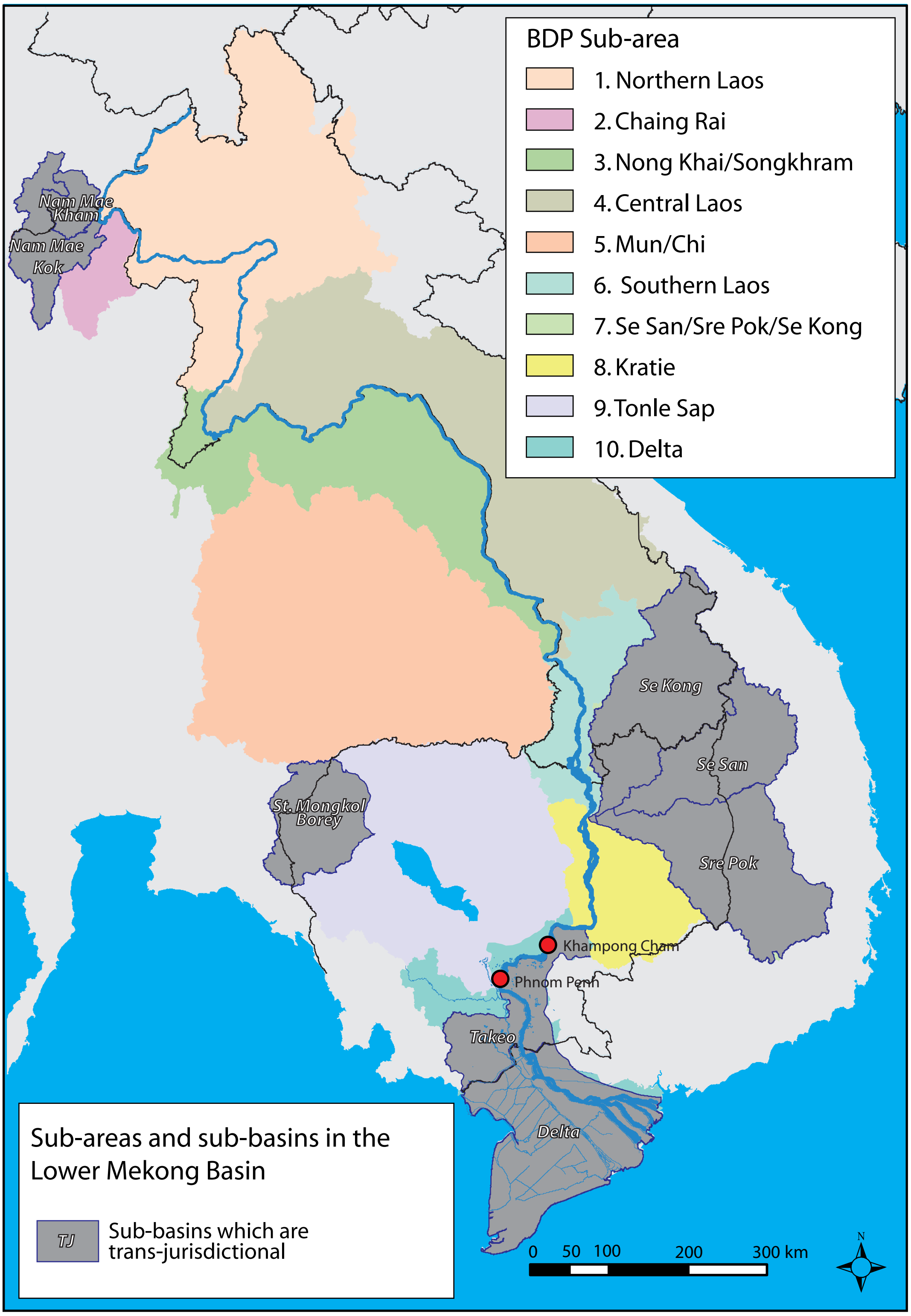

Figure 4. Hydrographic subdivision of the Lower Mekong Basin. Sub-basins that extend across international borders and therefore are trans-jurisdictional are named. (Note also the parts of the Nam Mae Kok and Nam Mae Kham —Sub-area 2 - Chaing Rai—that lie within Myanmar are not included in the Lower Mekong Basin despite the fact that rivers in these catchments flow in the Mekong within the limits of the basin.) The red 'dots' are locations referred to in the text.

In addition to these major tributaries, the Bassac river, the Mekong's major distributary, splits from the mainstream just south of Phonm Penh, Cambodia, before entering the Mekong Delta (Sub-area 10 - Delta). The same is true of a number of the Mekong's other distributaries, including the Tonle Touch river system, which splits from the Mekong even further upstream near Khampong Cham (Figure 4).

Environmental stresses related to land-use, development activities and historical events (such as the use of Agent Orange during the American War) that may have implications for water-quality were noted (see Figure 5 for a detailed list of these stressors). The possible impact of each stressor in each sub-basin was then assessed. In those instances where hard data were not available, which was the majority of cases, subjective estimates of the potential impact were made.

The probable severity of the impact of each stressor was ranked on a scale where H = high impact, M = medium impact, L = low impact, O = not relevant in the sub-basin and ? = lack of information. Figure 5 shows examples of this analysis from two sub-basins.

Cpa: 06/09/02	78					name of river	PREK THNOT
Aau						*or name of lake*	
CAMBODIA						name of main tributary	
						n° of main watershed	
						disharge contribution :	to main tributary
							to Mekong river RIGHT
H=high	**?**	**H**	**M**	**L**	**O**	**Development issue or land use activities**	
M=medium							
L=low							
0=out of prupose					X	hydro-electric powerplant	
?=unknown					X	dams which may affect water quality	
					X	weirs and dikes	
				X		Forest	
		X				Agriculture	
			X			irrigation water supply	
		X				rice field	
		X				arable land	
				X		irrigation project	
		X				fish pond culture	
		X				fishery production	
			X			population density	
		X				settlement area	
				X		agro-industrial plants	
			X			food processing factories	
		X				economic (industrial) development	
		X				economic development project	
			X			industrial waste accidently discharged in reservoir or river	
		X				aquatic life	
				X		recreation	
			X			navigation	
			X			flood- free land devlpmnt	
					X	drinking water supply	
					X	water diversion from Mekong river (Kong-Chi-Mun project	

Cpa: 06/09/02	33					name of river	SE KONG
Aau						*or name of lake*	
LAOS						name of main tributary	
VIETNAM						n° of main watershed	
						disharge contribution (m3/s) :	to main tributary
						max: 3290 min: 33.6 mean: 218	to Mekong river LEFT
						station #: 430105	
H=high	**?**	**H**	**M**	**L**	**O**	**Development issue or land use activities**	
M=medium							
L=low							
0=out of prupose				X		hydro-electric powerplant	
?=unknown				X		dams which may affect water quality	
					X	weirs and dikes	
			X			Forest	
			X			Agriculture	
				X		irrigation water supply	
				X		rice field	
				X		arable land	
			X		X	irrigation project	
			X			fish pond culture	
			X			fishery production	
				X		population density	
					X	settlement area	
			X			agro-industrial plants	
						food processing factories	
			X			economic (industrial) development	
		X				economic development project	
				X		industrial waste accidently discharged in reservoir or river	
			X			aquatic life	
					X	recreation	
					X	navigation	
					X	flood- free land devlpmnt	
			X			drinking water supply	
					X	water diversion from Mekong river (Kong-Chi-Mun project	

Figure 5. Examples of the analysis of stressor levels in two sub-basins (No. 78 - Prek Thnot ,Cambodia and No. 33 - Se Kong, Lao PDR/Viet Nam)

Figure 6. Sub-basins with medium or high levels of one or more stressor

Results

Thirteen of the 103 sub-basins have medium or high levels of one or more stressor (Figure 6 and Table 2). These were chosen as the priority locations for sampling and analysis under Activities 3 and 4 of the study (see Chapter 4).

Table 2. *Sub-basins with medium or high levels of one or more stressor*

Sub-area	Sub-basin	Country	Agriculture	Fishery	Population pressure	Economic development	Industrial waste	Development projects
Chaing Rai	Nam Mae Kok	Thailand/ Myanmar	X	X		X	X	X
	Nam Mae Ing	Thailand	X	X		X		
Central Laos	Nam Ngum	Lao PDR	X	X	X	X		
	Se Bang Hieng	Lao PDR	X					X
Se San/Sre Pok/Se Kong	Se Kong	Viet Nam/ Lao PDR/ Cambodia				X	X	
	Sre Pok	Viet Nam/ Cambodia	X		X			X
Mun/Chi	Nam Chi	Thailand	X	X		X	X	X
	Nam Mun	Thailand	X	X	X	X	X	X
Tonle Sap	Stung Mongkol Borey	Thailand/ Cambodia	X				X	X
	Stung Baribo	Cambodia	X	X	X			
	Prek Thnet	Cambodia	X	X	X	X		X
Delta	Takeo	Cambodia	X	X	X	X		
	Delta	Viet Nam	X	X	X	X	X	X

3. Assessment of MRC Water-quality Database

At the inception of the diagnostic study there had been no comprehensive analysis of the water-quality data held by MRC from its routine Water Quality Monitoring Network (WQMN). In part this was because, until 2001, a consolidated and verified database was not in place. As part of a programme of modernisation of the entire water-quality activity, the data held by MRC since 1985 were reviewed, 'nonsense' values removed, outliers flagged, and the data evaluated against a variety of reliability criteria such as ion balance, etc. The MRC made the resulting 'verified' database available to the study as a basis to determine:

- the status and trends in time and space of important parameters, including nutrients and chloride;
- transported loadings of these parameters;
- weaknesses in the data-sets;
- priority areas of pollution to use as potential benchmark locations for sampling in Activity 3.

Methodology

Transported loadings

To assess transported loadings, data was chosen from only those stations where MRC had recorded at least five continuous years of discharge data (within the period 1985-2000[1]). Of the 98 stations in the network, only 20 meet this criterion. Six of the 20 selected stations are located on the Mekong, four on main tributaries (Nam Chi and Nam Mun rivers), and the remaining 10 on tributaries with smaller drainage areas. Five stations are in Lao PDR and 15 in Thailand, none were in Cambodia or Viet Nam.

Chloride, nitrate ($NO_{3,2}$–N) and phosphate (PO_4–P) loadings were calculated for each of these stations.

The chemical load, L (in kg/d or in t/d), is the product of the daily mean flow, q (m^3/s), and the concentration value at the day of the sampling, C (in mg/l), multiplied by the time dimension factor:

$$L\ (kg/d) = q\ (m^3/s) \times C\ (mg/l) \times 86.4$$

Where: L = Load, q = discharge and C = Concentration

The mean monthly load per year in kg/d or in t/d is then calculated from the 12 monthly loads obtained per year.

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[1] Discharge data are from the MRC hydrometric station database.

It is assumed that sampling once a month is representative for the month and that the discharge measurements are accurate. The assumption of accuracy[2] of the measured data is an important consideration insofar as loads are the product of concentration multiplied by discharge and, therefore, even small errors in measured values can have a major impact on the calculated load. Because it is well known in science that there is variance, sometimes substantial variance, in the measured water-quality and water-quantity data, load values are prone to substantial and inevitable uncertainty.

Water-quality assessment

Water-quality assessment was undertaken on samples from 11 of the 20 stations (Table 3) mentioned above. Of these, six were located on the Mekong mainstream and five on major tributaries. All were situated in sub-basins classed as 'priority' following the literature review described in Chapter 2.

Table 3. *Stations selected for Mekong River water-quality assessment*

Station Code	Station Name	Country	Water Body
H010501	Chiang Saen	Thailand	Mekong
H011201	Luang Prabang	Lao PDR	Mekong
H011901	Vientiane	Lao PDR	Mekong
H013101	Nakhon Phanom	Thailand	Mekong
H013801	Khong Chiam	Thailand	Mekong
H013901	Pakse	Lao PDR	Mekong
H050104	Chiang Rai	Thailand	Nam Mae Kok
H350101	Ban Keng Done	Lao PDR	Se Bang Hieng
H380103	Ubon	Thailand	Nam Mun
H380134	Rasisalai	Thailand	Nam Mun
H370104	Yasothon	Thailand	Nam Chi

There are no water-quality standards, objectives or guidelines that are specific to the Lower Mekong Basin. Therefore, this analysis uses a methodology developed by the French water-basin agencies for the classification of water bodies (SEQ-Eau, 1999, see Table 4). SEQ-Eau define five classes of water-quality based on impairments to ecological health, to drinking water and to recreational activities. The standards, parameters and thresholds defined by these agencies were used in this study. Parameters of similar nature or having similar effects on water bodies are combined into eight groups: (i) organic and other matter that can be oxidised, (ii) nitrogenous matter, (iii) nitrates, (iv) phosphorous matter, (v) suspended matter, (vi) temperature, (vii) mineralisation and (viii) acidification.

However, the French methodology was developed for European rivers and, as a result, some of the threshold values it uses are not appropriate for the Mekong River system. Two problems concern the use of temperature (T) and total suspended solids (TSS) parameters. The rivers in the Lower Mekong Basin (because of its climate, physiography, geology, and land-use) have much higher natural water temperatures and TSS concentrations than any European river.

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[2] There is a substantial body of literature on the subject of load estimates, load algorithms, and uncertainty in these calculations.

Table 4. *Parameters and thresholds used to classify the quality of water in the Mekong River system (after SEQ-Eau, 1999)*

Class of water quality[1]	Very good	Good	Fair	Bad	Very bad
Organic matter and other matter that can be oxidised					
DO (mg/l)	≥8	≥6	≥4	≥3	<3
COD (mg/l O_2)	≤5	≤7	≤10	≤12	>12
NH_4^+ (mg/l NH_4)	≤0.5	≤1.5	≤2.8	≤4	>4
Nitrogenous matter					
NH_4^+ (mg/l NH_4)	≤0.1	≤0.5	≤2	≤5	>5
Nitrates					
NO_3 (mg/l NO_3)	≤2	≤10	≤25	≤50	>50
Phosphorous matter					
TP (mg/l)	≤0.05	≤0.2	≤0.5	≤1	>1
PO_4^{3-} (mg/l PO_4)	≤0.1	≤0.5	≤1	≤2	>2
Suspended matter					
TSS (mg/l)	≤5	≤25	≤38	≤50	>50
Temperature					
T (°C)	≤21.5	≤23.5	≤25	≤28	>28
Mineralization					
Conductivity (µS/cm)	≤2500	≤3000	≤3500	≤4000	>4000
Acidification					
pH Min	6.5	6.0	5.5	4.5	
pH Max	8.2	8.5	9.0	10	

For this reason, temperature and suspended TSS concentrations are not given in the tabulation of results included in the following section (Table 5). Another problem is that this assessment methodology does not include other important parameters such as endemic tropical pathogens and parasites.[3] However, despite these concerns, the other standard parameters used in this methodology provide a synopsis of the overall water-quality of the Mekong River system.

A colour-coded classification of each parameter was designed using these SEQ-Eau (Table 4). The classification is based on the principle of the 'disqualifying parameter' as follows:

1. Measurements of each parameter were assigned a colour according to the criteria in Table 4. This was done for each sampling date at each station.
2. Where several parameters are grouped together, such as organic matter (see Table 4), the group was assigned the colour rating of the worst parameter. For example, if DO and COD were rated green (good) and NH_4^+ was rated orange (bad) the organic matter group was given a overall orange rating.
3. For the period of record, each parameter group was assigned the worst colour recorded, provided that colour was present in 10% of the data set for that year.

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[3] These are not included in the MRC monitoring programme.

Results and discussion

The major points arising from the review of the data from the MRC's water-quality monitoring network are summarised below.

Chemical loads

Chloride

Mekong stations:

- The average daily load of 1000–2000 t/d at upstream stations increases to about 5000 t/d at Pakse.
- Pakse is the only mainstream station where the chloride load shows an increase over the past years.
- The minimum and maximum chloride loadings in the Mekong River vary significantly from year to year. However, this may be an artefact of the methodology and/or the assumption that a single monthly sample is indicative of the monthly concentration.

Tributary stations:

- Chloride load from the Nam Mun river is 1000–2000 t/d and contributes 20–40% of the loading at Pakse.

Nitrate

Mekong stations:

- Average daily loads of nitrate, calculated on yearly basis at each station, are stable over the 1985–2000 period.
- At upstream stations (Chiang Saen, Luang Prabang and Vientiane) average loads are under 100 t/d.
- At the next downstream stations (Nakhon Phanom and Kong Chiam), average loads can reach 150–400 t/d—maximum values of more than 1000 t/d are observed in several years.
- At Pakse, the average loads decrease to 100–150 t/d.

Tributary stations:

- The contribution from the Nam Mun river is estimated at 10–30 t/d.

Phosphate

Mekong stations:

- Average daily loads of phosphate are also stable over the period 1985–2000, however, concentrations of the ion increase significantly from upstream stations to those further downstream.
- At Chiang Saen, the average daily load fluctuates in the range 3000 to 6000 kg/d.
- At the next four stations (Luang Prabang, Vientiane, Nakhon Phanom and Kong Chiam), the concentration increases to 5000–20,000 kg/d.
- At Pakse, the calculated loads fluctuates in the range 10,000 to 50,000 kg/d.

Tributary stations:

- In most of the data-sets, the records for the wet season are incomplete. However, the available data shows the Nam Mun river makes only a small contribution (in the range 500 to 1000 kg/d) to phosphate concentrations in the mainstream.

Water-quality assessment

Table 5 gives the results of the water-quality assessment for six of the groups of parameters (excluding Temperature and Total Suspended Solids) over the 1985–2000 period.

Table 5. *Water quality at 11 localities on the Mekong and its major tributaries (1985-2000)*

Parameters (grouped)	Organic matter	Nitrogenous matter	Nitrates	Phosphorous matter	Mineralisation	Acidification
Chiang Saen (Mekong)	🟩	🟩	🟩	🟩	🟨	🟦
Luang Prabang (Mekong)	🟩	🟦	🟩	🟩	🟩	🟩
Vientiane (Mekong)	🟨	🟩	🟩	🟩	🟨	🟨
N. Phanom (Mekong)	🟨	🟩	🟩	🟩	🟩	🟨
K. Chiam (Mekong)	🟨	🟩	🟩	🟩	🟩	🟨
Pakse (Mekong)	🟩	🟩	🟦	🟩	🟩	🟨
Chiang Rae (Nam Mae Kok)	🟩	🟩	🟩	🟩	🟦	🟩
Ban K. Done (Se Bang Hieng)	🟨	🟩	🟦	🟩	🟩	🟨
Rasisalai (Nam Mun)	🟨	🟩	🟩	🟩	🟥	🟩
Yasothon (Nam Chi)	🟨	🟩	🟩	🟩	🟥	🟨
Ubon (Nam Mun)	🟨	🟩	🟩	🟩	🟥	🟩

Note; Red – bad, yellow – fair, green – good, blue – very good—according to the French water-quality classification system.

Mekong river:

In general, as can be observed from Table 5, water quality at the mainstream stations during the period 1985 to 2000 was generally ‘good’ or ‘very good’. Other interesting observations arising from the analysis of the data set are:

- There is no degradation of the water quality between upstream and downstream stations with the exception of Vientiane where, mainly during the rainy season, low concentrations of DO, higher conductivity and lower pH have been observed.
- Mineralisation in the river decreases from Chiang Saen to Pakse. The fall in conductivity from 2402 to 1873 µS/cm is caused by dilution.
- Temperature increases from upstream to downstream stations, with average values of 23.4°C at Chiang Saen to 26.9°C at Pakse.
- High and increasing TSS concentrations are observed between upstream stations and Vientiane (where they reach an average of 400 mg/l). Downstream of Vientiane the average concentration of TSS drops to 200 mg/l.
- TSS concentration decreases over time, with a notable drop in 1992 (Figure 7) corresponding to the construction of a new dam in the upper-part of the basin.

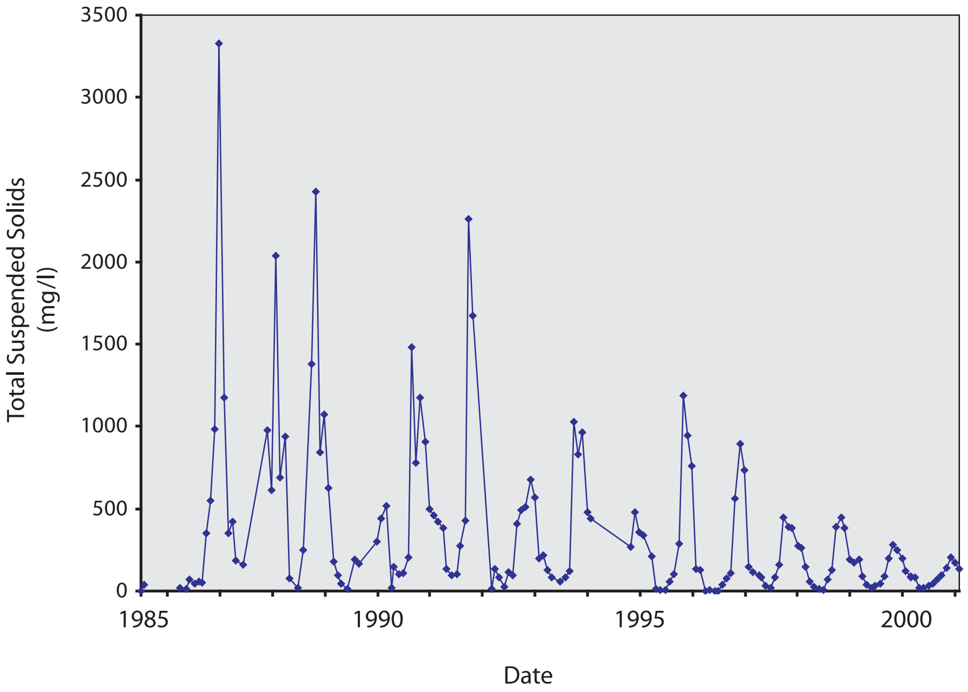

Figure 7. TSS concentrations over time at the Luang Prabang station

Main tributaries:

- In general, water quality (notably the levels of nitrogenous matter, nitrates, phosphorous matter and acidification) at main tributary stations are generally ‘good’ or ‘very good’ (Table 5).
- The high levels of mineralisation in the Nam Chi and Nam Mun tributaries, where average conductivity values range between 2220 and 5200 µS/cm, is a concern. The high levels of salt in these tributaries come from natural (i.e., deposits of rock salt—halite) and anthropogenic (i.e., irrigated agriculture) sources in the Khorat Plateau. However, by Pakse the concentration of salt ions is diluted, and here conductivity is no longer a significant issue.
- In the Se Bang Hieng, Nam Mun and Nam Chi, the concentration of dissolved oxygen is relatively low and as a result the measure of ‘organic matter’ ranks as only ‘fair’. The higher levels of organic matter in the Se Bang Hieng come from agricultural, forestry and industrial activities in the river’s catchment. The high levels of organic matter in the Nam Mun and Nam Chi rivers are the result of intensive agriculture on the Khorat Plateau.
- Average concentrations of TSS in the tributaries are lower, or much lower, than in the mainstream stations downstream of Vientiane.

MRC water-quality database limitations

- *Sampling and site location*: The MRC set up water-quality sampling stations at existing gauging stations. These are not necessarily the best sites for assessing water quality and pollution threats because, sampling frequency is monthly and there is no distinction (e.g., sampling protocol) between the dry and wet season. Stations located on tributaries near their confluence with the Mekong suffer backwater and reverse flow effects during high-water periods, which makes determining causes and effects difficult.
- *Parameters and the media sampled*: The MRC’s database contains mainly the basic physico-chemical parameters of the river water. In addition, sediments are analysed for only TSS; biological parameters are not measured, there is little data on pesticide or industrial pollutants and no toxicity measurements.
- *Data quality and gaps*: The records from many locations are incomplete. However, the data that exists is reliable.

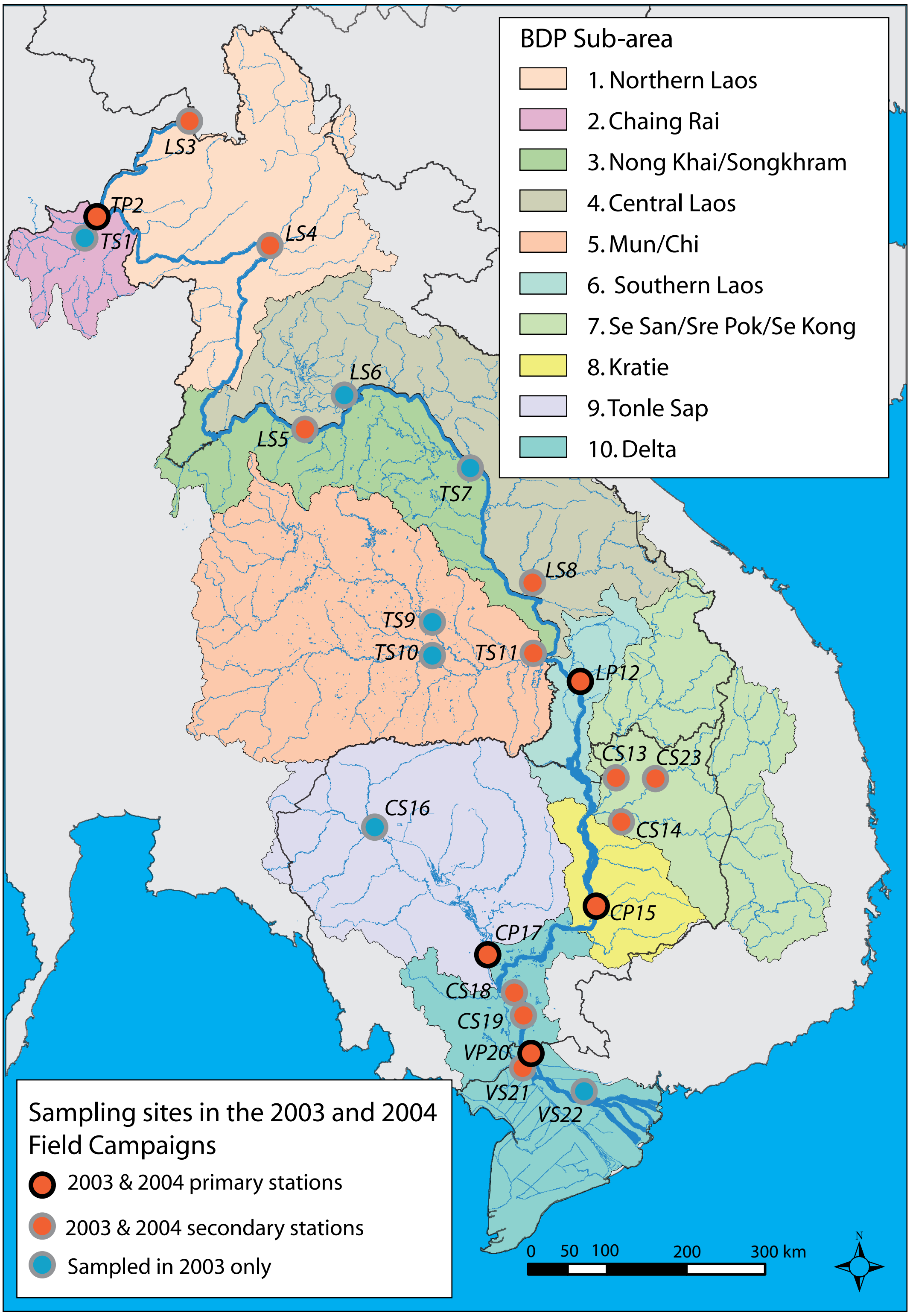

Figure 8. Sampling stations in the 2003 and 2004 field campaigns

4. 2003 and 2004 Field Campaigns

The programme involved two campaigns—during 2003 and 2004. Samples were taken towards the end of dry season (i.e., March or April) to maximise the ability to observe point sources and to minimise the effect of dilution and runoff in the wet season. Sampling during the dry season also eliminates the effects of non-point sources of pollution. The main objectives of the 2003 campaign were to obtain an overview of water-quality throughout the Lower Mekong Basin (in the Mekong and its tributaries) and to identify priority sites for further investigation. The second (2004) campaign concentrated on the stations on the Mekong mainstream and the priority sites that had been identified during the first campaign.

The programme for the 2003 campaign involved selecting the parameters to analyse, the sampling sites, sampling times and frequencies and those laboratories that would undertake the analytical work. In order to get the broadest picture of the level of pollution in the Mekong and its tributaries, the maximum number of parameters were analysed in the first campaign. The information gained during the 2003 campaign was then used to modify the design of the 2004 campaign.

Sampling sites

The 2003 campaign involved 22 sampling stations. The selection of stations was based on the results of the review of literature and other material (Chapter 2) and the analysis of the MRC water-quality data (Chapter 3). These stations are recognised as potential benchmark sites—that is, sites that are representative of a larger geographical area and that provide a reference against which future changes in water quality can be measured.

All the sites were located within the 13 ‘priority sub-basins’ identified during ‘Activity 1’ of the study. Nine of the sites were on the mainstream of the Mekong and 14 were on major tributaries (Figure 8).

Seven of the 22 sites were dropped from the 2004 campaign because no evidence of pollution was found at them during the 2003 campaign. A new site, station CS23 (Se San) was added to the 2004 campaign.

For the following reasons the stations below were designated as ‘main sites’:

- TP2 (Chiang Saen): the most upstream station between Thailand and Lao PDR;
- LP12 (Pakse): trans-boundary contamination from the Khorat Plateau in Thailand;
- CP15 (Kratie): downstream from three trans-boundary catchments (Se Kong: Lao PDR/ Cambodia and Sre Pok and Se San: Viet Nam/Cambodia);
- CP17 (on the Tonle Sap river): representative of the ‘transition’ hydro-ecoregion, an area well-known for the phenomena of ‘reverse flow’ and susceptible to trans-boundary

pollution from the catchments close to the Great Lake and from the upper part of the Lower Mekong Basin during the wet season;

- VP20 (Tan Chau): a few kilometres from the Cambodia/Viet Nam border.

The other stations are considered as secondary. They were selected mostly to address local issues that had been identified by the riparian participants. The distribution of these sampling sites among the four riparian countries is shown in Table 6; most of these stations, with the exception of six new sites, are part of the MRC Water Quality Monitoring Network.

Table 6. *Sampling stations in the 2003 and 2004 campaigns*

Country	Watershed	Station name	Code	Station Number	Field campaign
Cambodia	Mainstream	Kratie	CP15	H014901	2003, 2004
	St Baribo	Prek Kdam (Tonle Sap river)	CP17	H020102	2003, 2004
	Se Kong	Se Kong	CS13	NEW 2003	2003, 2004
	Takeo	Koh Khel (Bassac)	CS18	H033402	2003, 2004
	Sre Pok	Sre Pok	CS14	NEW 2003	2003, 2004
	Upstream Great Lake	Bak Prea	CS16	NEW 2003	2003, 2004
	Mainstream	Neak Leang	CS19	H019806	2003
	Se San	Se San	CS23	NEW 2004	2004
Lao PDR	Mainstream	Pakse	LP12	H013901	2003, 2004
	Mainstream	Lao/China Border	LS3	NEW 2003	2003, 2004
	Nam Ngum	Thangone	LS6	H23102	2003
	Mainstream	Luang Prabang	LS4	H011201	2003, 2004
	Mainstream	Vientiane	LS5	H011901	2003, 2004
	Se Bang Hieng	Ban Keng Done	LS8	H350101	2003, 2004
Thailand	Mainstream	Chiang Saen	TP2	H010501	2003, 2004
	Nam Mae Kok	Chiang Rae	TS1	H050104	2003
	Mainstream	Nakhon Phanom	TS7	H013101	2003
	Nam Chi	Yasothon	TS9	H370104	2003
	Nam Mun	Rasisalai	TS10	H380134	2003
	Nam Mun	Khong Chiam	TS11	H013801	2003, 2004
Viet Nam	Mainstream	Tan Chau	VP20	H019803	2003, 2004
	Plain of Reeds	My An	VS22	NEW 2003	2003
	Bassac	Chau Doc	VS21	H039801	2003, 2004

Sampling programme

Selection of matrices, analyses and sample collection

The assessment of water quality and pollution in the Mekong River system requires multi-media sampling—water, sediment and biota.

Water. Water analyses gives basic information on pollution in terms of dissolved and non-dissolved pollutants (e.g., organic matter, major ions, nutrients, pesticides, PAHs and PCBs). Microbiological measures of pollution (e.g., coliforms and streptococcus) were not recorded because these factors vary through time and single values (as would have been recorded during the 2003 campaign) are not very useful, and can be misleading.

Organochlorine pesticides, a wide range of industrial contaminants (e.g. PCBs, PAHs, dioxins and furans), and most metals in neutral pH environments, have low solubility and are mainly associated in the environment with sediments and biological tissues. These contaminants enter the food chain partly through the ingestion of fine particles by filter feeders and become more concentrated upwards through the food chain. They can reach high enough concentrations in fish and other organisms to cause a variety of problems such as toxicity and/or endocrine disruption.

Sediments. Bottom sediments represent accumulation over long periods of time (weeks to months) and are relatively easy to sample. However, it is recognised that they tend to produce conservative values for sediment-associated chemistry because biological processing of these compounds by micro-organisms can cause rapid decontamination of the sediments.

The concentration of contaminants in bottom sediments (and their toxicity) are influenced by several *in situ* variables such as deposition rates, grain size, organic content and the geochemistry of the adsorbent coatings on fine particles. Bulk samples of bottom sediment, uncorrected for grain size, can be used for quick assessments of the levels of contaminants in bottom sediments at a given site. However, inter-site comparison of uncorrected samples is unreliable because of variations in grain size, organic content, etc. Whether or not one does bulk analysis or analysis on a sample that is corrected for factors such as grain size effects, depends very much on the nature of the questions being asked. In this study the ≤250 µm fraction[1] of freeze-dried and sieved samples was analysed. This fraction contains almost all the contaminant chemistry. Comparisons between sites, in terms of their toxicity, can be improved using bioassays of the sediment samples.

Biota. In terms of biota, the original focus was on fish with analyses of bio-markers, pesticides, antibiotics, PCBs, dioxins and furans. Sampling fish, however, proved difficult, partly because sedentary species representative of the river fauna (rather than that of wetland habitats) are not ubiquitous and partly because of the time constraints imposed by the schedule of the 2003 field campaign. Therefore, it was decided not to sample fish during the 2003 campaign and to focus instead mainly on water and sediment chemistry, while adding an invertebrate bioassay (*Hyalella azteca)*.

Analyses conducted on the different matrices are presented in Table 7.

2003 field campaign

The sampling programme and analyses was carried out at each of the 22 sampling stations noted in Figure 8 and Table 6. Only one sample of each substrate at each site was collected and analysed (Table 8).

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[1] There are a variety of methods for standardization of sediment samples for contaminant analysis in the literature however there is no universally accepted method.

2004 field campaign

Seven of the 22 stations sampled in the 2003 campaign (Figure 6) were dropped from the 2004 campaign because there was no evidence of pollution at these sites. At the request of Cambodia, station CS23 was added in the 2004 field campaign, as it is downstream of the area extensively sprayed with Agent Orange during the American War.

Water analyses at most sites were not repeated as i) major concentrations of ions were similar to those analysed routinely by MRC over the years; ii) nutrients analyses revealed significant quality control problems by the laboratory contractor; and iii) the results of some other parameters were below the level of detection. In general, as the routine water chemistry was very similar to the data already held by MRC, the focus of the analyses was changed to contaminants, with an emphasis on sediments.

Two new parameters were added: (i) Total Organic Carbon (TOC) and (ii) cyanide in water and sediment. The latter was added to determine if the toxin played some role in the high mortality rate of test organisms used in bioassays of sediments from the station at the Lao/China border (LS3) and to address mining activities in the catchments at the Luang Prabang (LS4) and Ban Keng Done (LS8) stations.

A total of 16 stations were sampled. At five stations, where higher levels of contaminants were found during the 2003 campaign, two samples were taken (about 500 m apart) at each site and analysed separately. At the other sampling stations, only one sample was collected (Table 8).

The complete sampling and analytical scheme is presented in Tables 7 and 8.

Table 7. *Analyses conducted on samples collected during the 2003 and 2004 campaigns*

	Water	Sediments
Routine Parameters	W1 TSS, pH, Conductivity, Ca, Mg, Na, K, Fe, Cu, Zn, Mn, Al, CO_3, HCO_3, Cl, SO4, NO_3, NO_2, PO_4, COD	BS2 Bioassays with *Hyalella azteca*
Parameters linked to industry	W2 BTEX, COHV, PAHs, Total Hydrocarbons, Heavy Metals	P2 BTEX, COHV, PAHs, Total Hydrocarbons, Heavy Metals
Parameters linked to agriculture	W4 Pesticides: Organochloride, organophosphorous and triazines	P1 Pesticides: Organochloride, organophosphorous and triazines P3 PCBs P4 Dioxins and furans
Parameters possibly linked to *Hyalella* toxicity and mining activities	CNw Cyanide in water	CNs Cyanide in sediments

Table 8: *Sampling programme undertaken during the 2003 and 2004 campaigns—number of samples collected and analysed by station*

COUNTRY	STATION NAME	CODE	1st FIELD CAMPAIGN (April 2003)								2nd FIELD CAMPAIGN (March 2004)									
			Water			Sediments					Water		Sediments					New Analyses		
			W1	W2	W4	P1	P2	P3	P4	BS2	W2	W4	P1	P2	P3	P4	BS2	TOC	CNw	CNs
CAMBODIA	Kratie	CP15	1	1	1	1	1	1	1	1	0	0	2	2	2	2	(1)	2	0	0
	Prek Kdam (Tonle Sap)	CP17	1	1	1	1	1	1	1	0	0	0	2	2	2	2	1	2	0	0
	Se Kong	CS13	1	0	1	1	0	0	0	0	0	0	0	1	1	1	0	1	0	0
	Koh Khel (Bassac)	CS18	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	0	0
	Sre Pok	CS14	1	0	1	1	1	0	1	0	0	0	0	1	1	1	0	1	0	0
	Bak Prea	CS16	1	0	1	1	0	0	0	0	Station not sampled in 2004									
	Neak Leang	CS19	0	0	1	1	1	1	0	(1)	0	0	1	1	1	1	1	1	0	0
	Se San	CS23	Station not sampled in 2003								0	0	0	1	1	(1)	0	1	0	0
LAO PDR	Pakse	LP12	1	1	1	1	1	1	0	1	0	0	1	1	1	1	1	1	0	0
	Lao/China border	LS3	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2
	Thangone	LS6	0	0	1	1	0	0	0	0	Station not sampled in 2004									
	Luang Prabang	LS4	1	0	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1
	Vientiane	LS5	1	0	1	1	0	0	0	0	0	0	1	1	1	1	0	1	0	0
	Ban Keng Done	LS8	1	1	1	1	1	0	0	0	1	0	0	1	0	0	0	0	1	1
THAILAND	Chiang Saen	TP2	1	1	1	1	1	1	0	1	0	0	1	1	1	1	1	1	0	0
	Chiang Rae	TS1	1	0	1	1	0	0	0	0	Station not sampled in 2004									
	Nakhon Phanom	TS7	1	0	1	1	0	0	0	0	Station not sampled in 2004									
	Yasothon	TS9	1	0	1	1	0	1	0	0	Station not sampled in 2004									
	Rasisalai	TS10	1	0	1	1	0	1	0	0	Station not sampled in 2004									
	Khong Chiam	TS11	1	1	1	1	1	1	0	1	0	0	1	1	1	1	1	1	0	0
VIET NAM	Tan Chau	VP20	1	1	1	1	1	1	0	1	0	0	2	2	2	2	1	2	0	0
	My An	VS22	0	0	1	1	0	0	0	0	Station not sampled in 2004									
	Chau Doc	VS21	1	1	1	1	1	1	0	1	0	0	2	2	2	2	1	2	0	0

Note: W1: Routine parameters; W2: BTEX, COHV, PAHs, total hydrocarbons, heavy metals; W4: Pesticide (organophosphate, organochloride and triazines); P1: Pesticide (organophosphate, organochloride and triazines); P2: BTEX, COHV, PAHs, total hydrocarbons, heavy metals; P3: PCBs; P4: Dioxins and furans; BS2: *Hyalella azteca* bioassays on sediments; TOC: Total organic carbon; CNw: Cyanide in water; CNs: Cyanide in sediments; (1): Sample taken but not analysed

Analytical methodology

Laboratories

Four laboratories carried out the analytical work:

- The Pollution Control Department Laboratory (Thailand) carried the analytical work for the routine parameters in water (W1 samples); most of these parameters are unstable and needed to be analysed as quickly as possible.
- CEMAGREF (France)—bioassays.
- CARSO, (France)—pesticides in water and sediments.
- LEM COFRAC, (Savenne, France)—all other parameters in water or sediments.

Sample transportation

Water and sediment samples were packed in cool boxes (covered with ice wherever available) and shipped by Federal Express to the destination laboratories. Sample conservation and transportation conditions were not always optimal due to the lack of ice in some areas, transportation delays relating to customs procedures, and other factors.

Sampling and analytical methodologies

The sampling and analytical methodologies are briefly summarised in the next three sub-sections.

Water sampling and analysis

Water samples were taken from the middle section of the river, at a depth of between 20 to 30 cm below the surface.

Sediment sampling and analysis

At each site, a sediment grab was used to take samples. Samples were recovered at three different places forming a triangle in order to integrate the spatial variability of the area (Figure 9). The sediment samples from these three areas were then mixed together and stored in jars.

For volatile parameters (BTEX, COHV, etc.), analyses were performed on bulk sediments. For all other parameters, a physico-chemical processing was undertaken (lyophilization, screening to 250 µm, acid mineralization, etc.) before analysis in order to have homogeneous samples that are representative of the original sample.

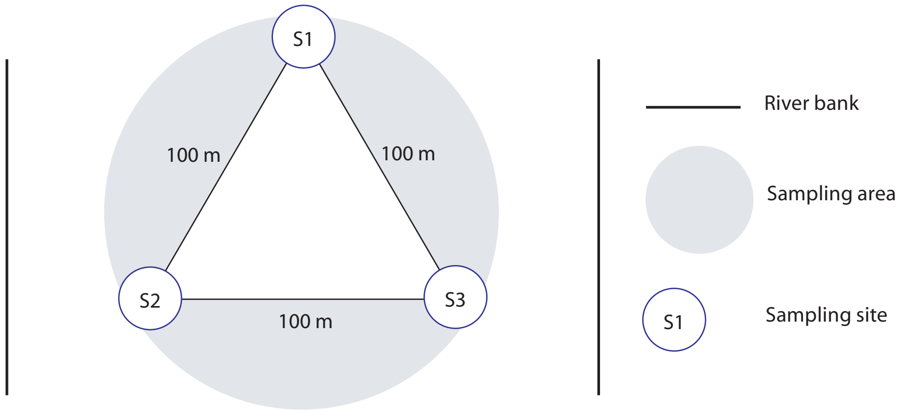

Figure 9. Sediment sampling protocol

Bioassays

In addition to chemical analyses, sediment bioassays were conducted on sediments sampled from selected stations (Table 8) to provide information on the toxicity of the sediments. The bioassays were performed using a crustacean amphipod, *Hyalella azteca*. The measured end points were survival, for acute toxicity, and length, for growth inhibition.

Bioassays from 2003 campaign were conducted according to the draft standards proposed by the Association Française de Normalisation (AFNOR). For the 2004 campaign, the standards used were according to AFNOR Standard T 90.338.1 (AFNOR, 2002). The main difference between the draft and final standard is a small difference in age of the organism at the start of the test (2–9 days for the draft standard, and 4–12 days for the final standard). These two tests produced comparable results, and it was assumed that small difference in the initial age would not induce differences in sensitivity. There was no independent test of this assumption; however, according to ASTM, 'the sensitivity of *H. azteca* appears to be relatively similar up to at least 24–26 day old organisms (Collyard *et al*., 1994)'.

The environmental conditions in the AFNOR standard are similar to those in the ASTM standard (ASTM, 2000) except for the test duration[2] and the age of *Hyalella* at the beginning of the test[3]. It is also similar to the USEPA standard (USEPA, 2000), except that the composition of the control sediments[4] are different.

The following set of conditions were used, in accordance with the draft or published AFNOR standards:

- From their arrival and until the bioassays were performed, the sediment samples were stored at 7°C.

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[2] Test duration of 10 (ASTM) and 14 (AFNOR) days.

[3] Age of 7 to 14 days (ASTM) and 4 to 12 days (AFNOR) at start of the test.

[4] In the US EPA standard, the sediment control is not precisely specified, but it has to allow for the survival, the growth, and the reproduction of a variety of benthic invertebrates; in the AFNOR standard, the composition of the sediment control is specified (mixture of sand and organic matter).

- In the instance of the 2004 field campaign, sediments arrived at the CEMAGREF laboratory in two batches with a ten-day interval in between; bioassays were carried out in three series over three different time-periods: once on the first batches of sediments (samples from Thailand and Lao PDR) and twice on samples from the second batch (from Cambodia and Viet Nam). The first series of bioassays on the second batch was rejected since the validity criteria were not respected and a new series was assayed.

- Two control tests were undertaken 10 days before the start of the assays using silica sand (Fontainebleau sand, 150–210 µm diameter) enriched with organic matter (fish food Tetramin®: 4 g for 2 l of sand).

- Five replicates were done with each sediment sample; 10 organisms were used in each replicate.

- *Hyalella* were raised in the laboratory. Their age at the beginning of the assay ranged from 2 to 9 days for samples from the 2003 campaign, and 5 to 10 days for the 2004 campaign.

- The tests were carried out with continuous water renewal, using four times the volume of the water column per day.

- The test temperature was 23° ± 1°C.

- Physico-chemical parameters (pH, conductivity, temperature, nitrites and ammonia) were measured at least four times during each series of bioassays; no abnormalities in the measurements occurred during the two valid test series as the ammonia concentration remained below 9.7 mg/l[5], which is considered as acceptable (Whiteman *et al*., 1996).

- Minimum survival rate in the control is 70%.

- The survival and length measurements were recorded only at the end of the test (day 14): The organisms were counted, frozen and measured after thawing. The distance between the base of the first antenna and the extremity of the abdomen (top of the third uropod) was measured to ± 0.1 mm using a stereo-microscope at x10 magnification.

Data treatment and processing

Heavy metal toxicants

- *Total metal concentrations:* The total concentration at each station was calculated by summing all the heavy metal concentrations (values the under detection limit were considered as zero) at that station.

- *Threshold effect concentration (TEC) and probable effect concentration (PEC):* The TEC and PEC guidelines established by MacDonald *et al.* (2000) were used to assess the exposure of benthic organism to metal toxicants in sediment and to provide an estimation of the toxicity of the sediments (Table 9). The guidelines provide a ‘threshold

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[5] LC_{50} 96h : 9.7mg/l total nitrogen compound (NH_4+NH_3).

effect concentration' (TEC), below which toxic effects are unlikely, and a 'probable effect concentration' (PEC) above which toxic effects are highly likely to occur. These guidelines, although developed in a context rather different than that prevailing in the Lower Mekong Basin, seem appropriate as relative indicators for assessing potentially toxic sediments.

Table 9. *Threshold level effect concentration (TEC) and probable effect concentrations (PEC) guideline values for heavy metals established by MacDonald et al., (2000)*

Parameters	TEC (mg/kg)	PEC (mg/kg)
Arsenic	9.79	33.00
Cadmium	0.99	4.98
Chromium	43.40	111.00
Copper	31.60	149.00
Nickel	22.70	48.60
Lead	35.80	128.00
Zinc	121.00	459.00
Mercury	0.18	1.06

Note: concentrations are expressed in terms of total concentrations of each metal

- *Threshold Effect Level (TEL) and Probable Effect Level (PEL):* TEL and PEL are interim guidelines of sediment-quality developed by the Canadian Council of Ministers of the Environment (CCME, 1999-2002) for assessing the potential toxicity of sediment-related PCBs and PAHs. They are different from the TEC and PEC values given by MacDonald *et al.* (2000) as they are calculated differently, but they have similar significance.

- *Metal contamination assessment:* The evaluation of overall contamination of metals and their potential toxicity to benthic organisms was assessed and interpreted using the 'mean quotient' method.

  This a parametric method that accounts to a certain extent for additive effects. To obtain the mean quotient at each station for each year, the concentration of individual metals is divided by its PEC; all individual quotients at each site/year are then summed, and the resulting number is divided by the number of measured parameters. A significant increase in the toxicity incidence occurs at mean quotient values above 0.1. Where the mean quotient is above 0.5, about 80% of the samples are considered toxic according to MacDonald *et al.* (2000).

  The mean quotient method was used to interpret the data in the Sediment Results section because it allowed identification of those metals that contributed most to the score and the simplified scoring approach, which is much less discriminatory, for the multi-criteria analysis.

Dioxins and furans in sediment

Toxicity Equivalent Index (I-TEQ): Of the 210 dioxins and furans, only 17 are recognised as toxic. These 17 dioxins and furans have a toxicity ranging from 1 to 0.0001. The estimation of the toxicity of a sediment sample is derived from the quantitative measurement of these 17 toxic congeners to which is applied the respective toxicity equivalent factor (I-TEF). The concentrations of the compounds multiplied by their respective TEF are then summed to obtain a Toxicity Equivalent Index (I-TEQ). Determining I-TEQs for sediment samples will only indicate a potential problem; the actual exposure and toxicity of any species cannot be inferred from the I-TEQs. The I-TEFs initially proposed by Safe and Phil (1990) were used to calculate I-TEQs of the sampled sediments. Based on an interim sediment-quality guideline (ISQG) of 0.85 pg/g proposed in the Canadian Environmental Quality Guidelines (CCME, 1999-2002) a I-TEQ value of 0.1 pg/g was used as background value for the Mekong River Basin sediments[6]. This is far below the 21.5 pg/g Probable Effect Level (PEL) level proposed by CCME.

Polycyclic Aromatic Hydrocarbons (PAHs) in sediments

TEL and PEL values are provided for most of the individual toxic PAHs in the Interim Sediment Quality Guidelines (CCME, 1999–2002). TEC and PEC values of 1,610 µg/g and 22,800 µg/g respectively, for PAHs in sediments are from MacDonald *et al*. (2000) and are used in this study as PAHs were detected at only three stations, and at low values.

Bioassays

Statistical Tests: In results from the 2003 field campaign, significant differences from the control ($p<0.05$) were found by hypothesis tests. Dunnett's test was used—following verification using the Shapiro-Wilk's tests for normality, and the Hartley's test for homogeneity of variance. Calculations were performed using TOXSTAT 3.0 software (Gulley *et al*., 1989). Significant differences in the results of the 2004 field campaign were tested using the Bonferroni t-test ($p<0.05$) [7].

Multi-criteria analysis

Data from the 2003 and 2004 field campaigns and results from the bioassays were used to perform a multi-criteria analysis. This provides a more synthetic and comprehensive picture of the water-quality of the Mekong system. Parameters for which quantifiable results had been obtained were selected for this multi-criteria analysis. These included heavy metals and arsenic, PAHs, dioxins and furans and *H. azteca* bioassays. For each parameter a scoring method similar to that used for heavy metals was used to enable an overall comparison of the stations:

- *Scoring method for heavy metals and arsenic:* (for details see the section on heavy metals presented earlier in this chapter).

- *Scoring method for Total PAHs:* For each station, if the total PAHs concentration is below the TEC value, the score is 0; if it ranges between the TEC and PEC values, the score is 1,

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[6] The interpretation of the results would change somewhat had a value of 0.85 pg/g been chosen rather than 0.1 pg/g. This has an impact on the subsequent interpretation of the results, as noted below.

[7] These values are applied to the total PAHs in this study.

and if it is equal or above PEC value, the score is 2. The higher the score the more likely the toxicity to benthic organisms.

- *Scoring method for Dioxin/Furans (PCDD/PCDFs):* A score of 1 is given when the threshold of 0.1 pg/g used by BURGÉAP (2005) is exceeded, and a score of 2 when the CCME (1999-2002) Interim Sediment Quality Guidelines of 0.85 pg/g is exceeded.
- *Scoring method for* H. azteca*:* According to the hazard ranking system elaborated for the French Ministry of Transport (Babut *et al*., 2004), a score 0 is attributed when both survival and growth are similar to that found in the control (≤10%), a score of 2 is given when either the survival or growth deviated from the control by more than 50%, and otherwise a score of '1' is assigned. This approach to scoring toxicity test results therefore accounts for two end-points, encompassing a wider range of toxic stress causes.

Table 10. *Threshold values used in the multi-criteria analysis*

Parameters	Scores and Thresholds		
	0	1	2
Heavy metals and arsenic	Concentration < TEC	TEC < Concentration < PEC	Concentration > PEC
Total PAHs	Concentration < TEC	TEC < Concentration < PEC	Concentration > PEC
Dioxins and Furans	I-TEQ < 0.1 pg/g	0.1 pg/g < I-TEQ < 0.85 pg/g	I-TEQ > 0.85 pg/g
H. azteca	Mortality or growth ≤10% of control	10%< mortality or growth ≤50% of control	Mortality or growth >50% of control

For each station, the sum of all the scores (for each parameter) is divided by the number of parameters used in order to standardise the stations scores, as not all the stations have values for all the parameters.

5. Results and Discussion

Water

The results outlined below are mostly from the 2003 campaign. As noted above, in 2004, water samples were collected and analysed at only two stations (Lao/China border—LS3, and Ban Keng Done—LS8) for industrial pollutants and pesticides.

Major ions

The results from the 2003 campaign show that the Mekong River system has lower concentrations of mineral ions than some other major rivers of the world (Figure 10).

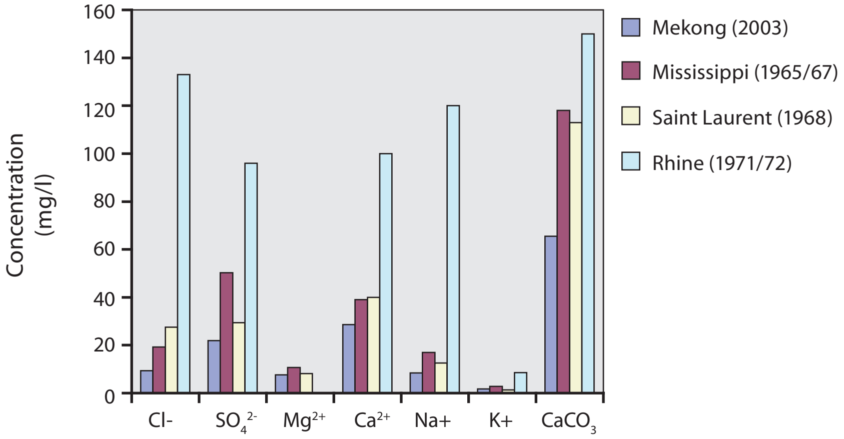

Figure 10. Comparison of the chemical profile of the Mekong with other rivers

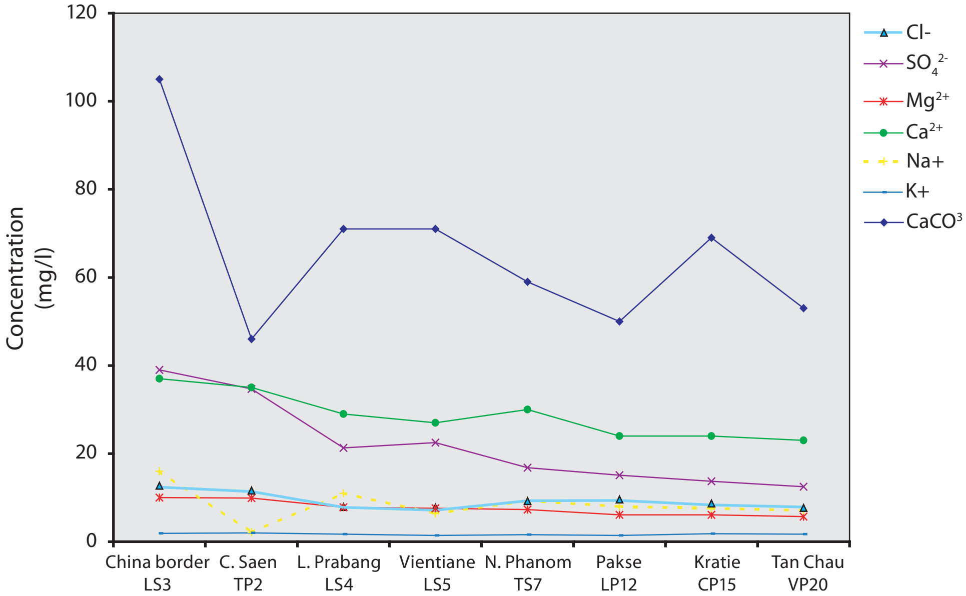

Figure 11. The major ion profiles in the Mekong from upstream (left) to downstream (right)

The concentrations of some major ions (e.g., $CaCO_3$, Ca^{2+}, and SO_4^{2-}) show a tendency to decrease from upstream to downstream stations along the Mekong River (Figure 11). These results have to be taken cautiously, as only one sample was analysed at each station.

Salt contamination from the Khorat Plateau

On the Nam Mun river, high concentrations of chloride and sodium ions (302 and 177 mg/l respectively) were recorded at the upstream station of Rasisalai (TS10). The concentrations downstream at Khong Chiam (TS11) are significantly lower ($Cl^- = 22.3$ mg/l and $Na^+ =$ 12 mg/ l). This reduction results from dilution caused by the discharge of the Nam Chi river at Yasothon station (TS9) (Figure 12). These results were observed during the dry season; it is probable that a similar picture would emerge during wet season flow.

At Pakse (LP12), downstream of the confluence of the Nam Mun and the Mekong River, chloride and sodium concentrations are back to normal with levels (around 9.6 and 8 mg/l respectively). This demonstrates that, as Hart *et al*. (2001) have already noted, salt contamination from the Khorat Plateau carried by the Nam Mun has very little impact on the salinity of the Mekong river.

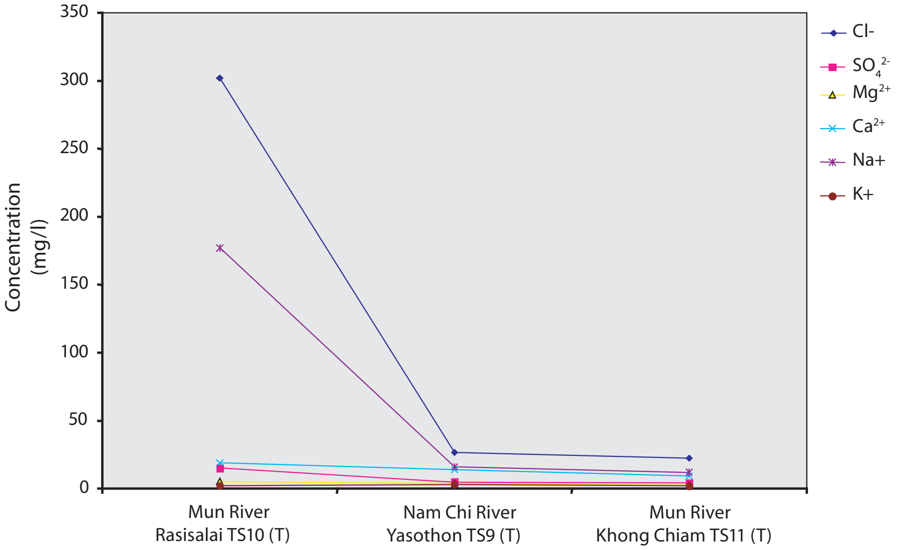

Figure 12. Major ion profiles of tributaries on the Khorat Plateau

Nutrients

Concentrations of nutrients were low despite some evidence of eutrophication (at Koh Khel—CS18) and anthropogenic pollution (at Bak Prea—CS16 and Prek Kdam—CP17) recorded during the 2003 field campaign. These higher levels were generally found at sites located in areas with high population density and/or poor sewage facilities. However, due to poor quality control in the contracted laboratory these data are not reliable.

Industrial contaminants and pesticides

The water samples analysed from both campaigns were below the detection limits for industrial contaminants and pesticides.

Sediments

Total heavy metals concentrations in sediments

2003 campaign

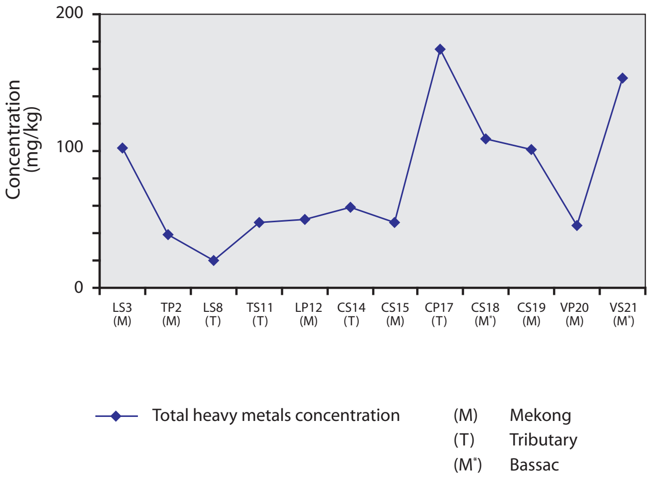

Figure 13. Total heavy metals concentrations recorded during the 2003 campaign

The concentrations of heavy metals recorded during the 2003 campaign are shown in Figure 13. The results indicate that, in the Mekong river, the sites at the Lao/China border (LS3) and Neak Leang (CS19) have elevated levels of heavy metals. The station at Neak Laeng may be affected by the Tonle Sap river, as the Prek Kdam (CP17) station, which is also on the Tonle Sap, shows the highest level of total heavy metals. The second highest concentration of total heavy metals is observed at Chau Doc (VS21), on the Bassac River. Koh Khel (CS18), also on the Bassac, has higher levels of heavy metals. Both sites are downstream of Phnom Penh.

2004 campaign

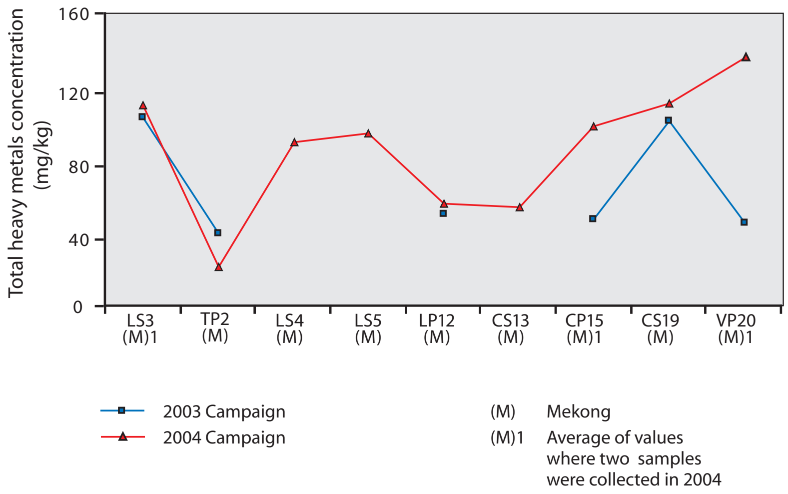

Figure 14. Total heavy metals concentrations recorded during the 2003 and 2004 campaigns

The total heavy metal concentrations found at Kratie (CP15) and Tan Chau (VP20) were higher in 2004 than in 2003 (Figure 14). The other four stations that were sampled during both years have similar concentrations.

In summary, based on total heavy metals concentration results, within-site and between-site variations cannot be explained on the basis of the one or two samples collected at each site once a year during each campaign. However, at present, it can be reasonably inferred that the stations with higher total heavy metal concentrations are located in areas with significant boat traffic and/or with high population densities:

- Lao/China border (LS3): Commercial shipping highway between China and Lao PDR;
- Luang Prabang (LS4): Large volume of tourist-boat traffic;
- Vientiane (LS5): High population density;
- Kratie (CP15): Large volume of boat traffic for tourism and transportation;
- Prek Kdam - Tonle Sap river (CP17): Boat traffic and some industrial activities;
- Koh Khel, Bassac (CS18) and Neak Leang, Mekong (CS19): Downstream of Phnom Penh;
- Tan Chau, Mekong (VP20): High population density in the Mekong Delta;
- Chau Doc, Bassac (VS21): High population density in the Mekong Delta.

Heavy metal concentrations in sediments and their eco-toxicity potential

In order to assess the potential toxicity of the sediments collected during both campaigns, total heavy metal concentrations were compared against threshold values for TEC and PEC; these follow MacDonald *et al*. (2000).

Arsenic

In 2003, only the sediment from the Lao/China border (LS3) showed a concentration above the TEC threshold (9.79 mg/kg). In 2004, six stations registered levels above this threshold —Lao /China border (LS3), Luang Prabang (LS4), Vientiane (LS5), Prek Kdam (CP17), Tan Chau (VP20) and Chau Doc (VS21). However, concentrations at three of these sites only slightly exceeded the TEC threshold. Higher arsenic concentrations were observed at the three others: Lao/China border, Vientiane and Prek Kdam stations (Figure 15). However, at none of the sites did the levels of arsenic approach the PEC threshold.

It is important to note that the observed differences in arsenic concentrations between 2003 and 2004 exceed the analytical uncertainty for arsenic (which is around 22%). These differences could be attributed to a number of factors including sampling variation, heterogeneity at the sites, or a real increase in concentrations of arsenic. Unfortunately, the limited data set does not allow resolution of which of these factors is the cause.

It should also be noted that, as in other countries in S.E. Asia, arsenic is a naturally occurring mineral in the countries of the Lower Mekong Basin.

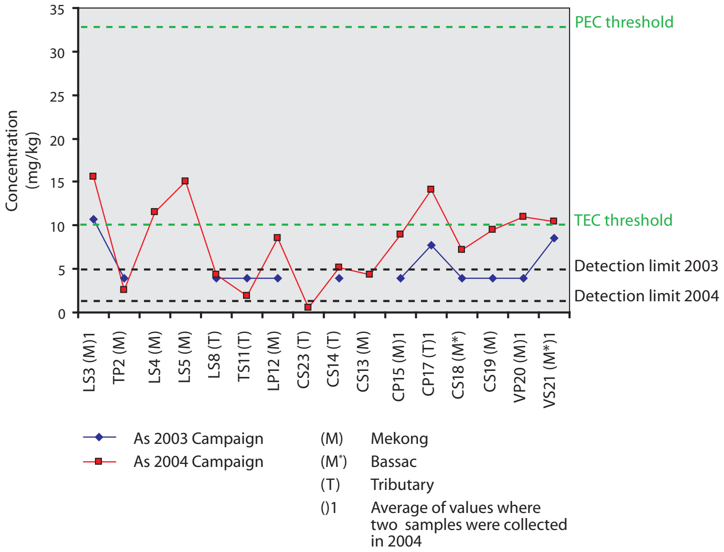

Figure 15. Concentrations of arsenic recorded during the 2003 and 2004 campaigns

Cadmium

No analyses in either campaign detected cadmium. The analytical detection limit of cadmium is 1 mg/kg, which is very close to the TEC threshold of 0.99 mg/kg. It is assumed that all the sediment samples at all sites are unlikely to contain toxic levels of this metal.

Chromium

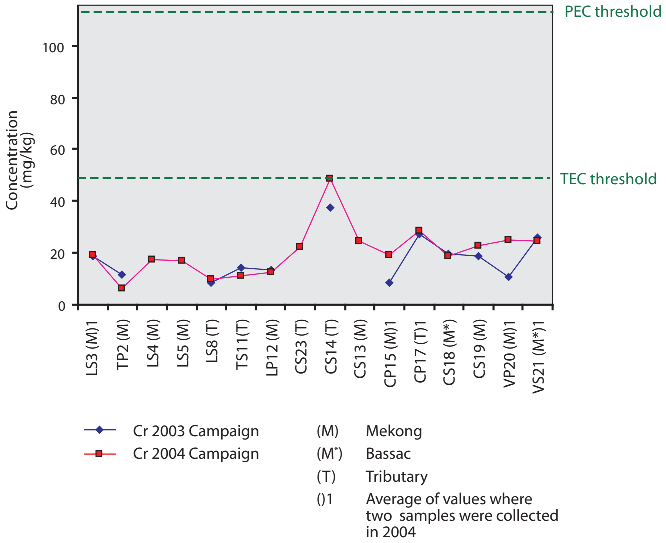

Figure 16. Concentrations of chromium recorded during the 2003 and 2004 campaigns

Chromium concentrations were slightly above the TEC threshold at only one site, (Sre Pok—CS14) and during one year (2004) (Figure 16). At this site in 2003, the concentration was slightly below the same threshold. The 23% difference in concentration observed between the two campaigns is higher than the analytical uncertainty for chromium, which is usually around 13%. This difference is attributed to sample variation and not to analytical variability.

Copper

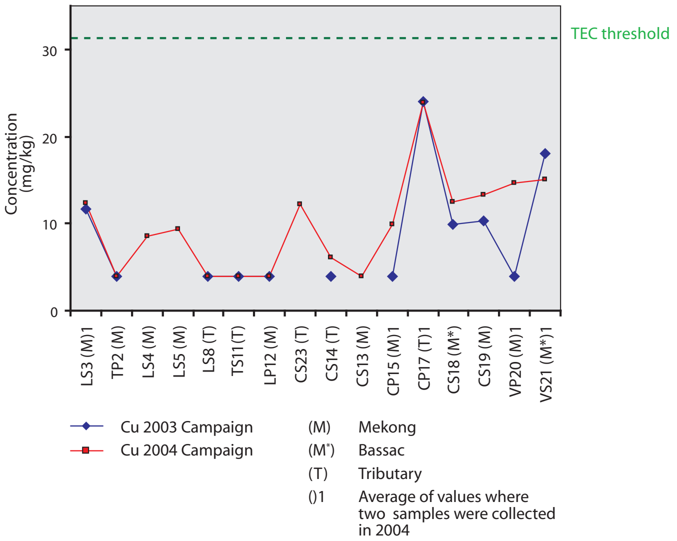

Figure 17. Concentrations of copper recorded during the 2003 and 2004 campaigns

The concentrations of copper measured in the sediments samples in both campaigns were all below the TEC threshold (Figure 17). Benthic organisms are unlikely to suffer from toxicity caused by the concentrations of this metal recorded in these sediments.

Nickel

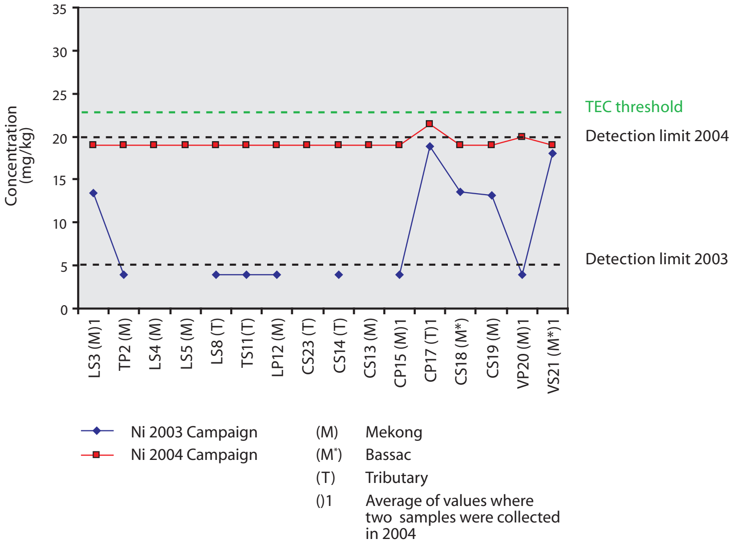

Figure 18. Concentrations of nickel recorded during the 2003 and 2004 campaigns

During both campaigns, the concentration of nickel was well below the TEC threshold (Figure 18). In 2004, the concentrations of nickel at most of the sites was below the detection limit used that year. Due to modifications in the analytical protocol, the detection limit used in 2004 was higher than that used in 2003. However, as both detection limits were below the TEC threshold, it is unlikely that nickel in the sediments could have toxic effects on benthic organisms.

Lead

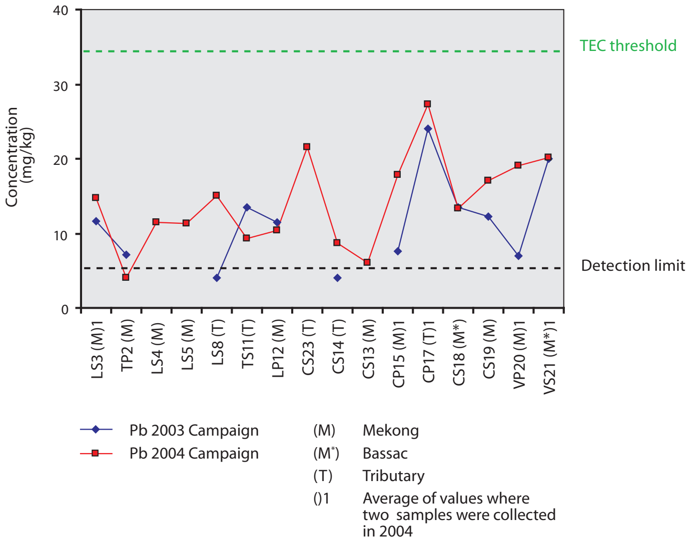

Figure 19. Concentrations of lead recorded during the 2003 and 2004 campaigns

All of the lead concentrations were below the TEC threshold value (Figure 19). Sediments from stations CS23 (Se San) and CP17 (Prek Kdam) have higher concentrations than do the other sites. The analytical uncertainty of lead analysis is low (approximately 14%), therefore these higher values are not the result of analytical variability, but because of some other natural phenomenon.

Zinc

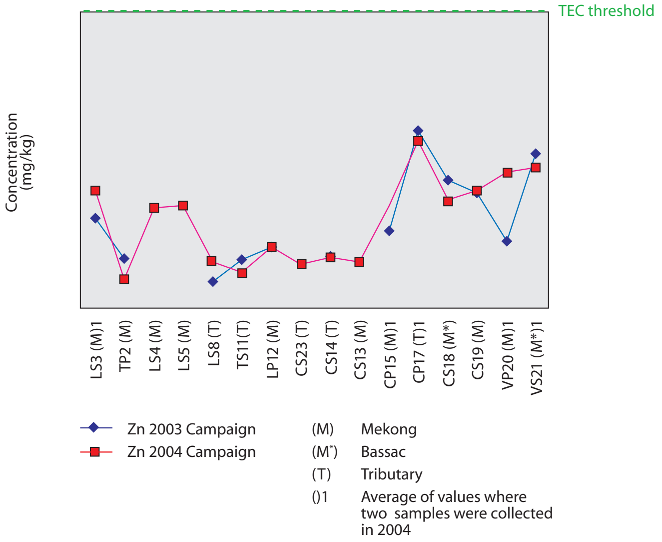

Figure 20. Concentrations of zinc recorded during the 2003 and 2004 campaigns

Concentrations of zinc in the Mekong River and tributaries during both the 2003 and 2004 campaigns were below the TEC threshold (Figure 20). The highest levels are observed at Prek Kdam (CP17). This difference exceeds analytical uncertainty for zinc (approximately 10%) therefore the difference at CP17 is due to some other cause.

Mercury

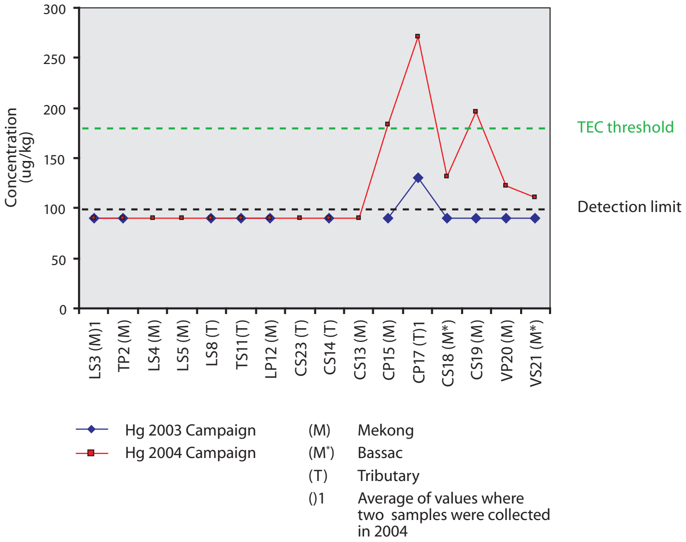

Figure 21. Concentrations of mercury recorded during the 2003 and 2004 campaigns.

Concentrations of mercury at most of the stations sampled in 2003 and 2004 were below the detection limit of 100µg/kg, which is considered high (Figure 21). Mercury was detected at six stations; the TEC threshold was exceeded at three stations: Prek Kdam (CP17) with concentrations 272 µg/kg (average of upstream and downstream stations) in 2004; Neak Leang (CS19) with concentrations in 2004 of around 200 µg/kg; and Kratie (CP15), where Hg concentrations only just exceeded the threshold of 180 µg/kg.

Summary of arsenic and metal contamination in sediments

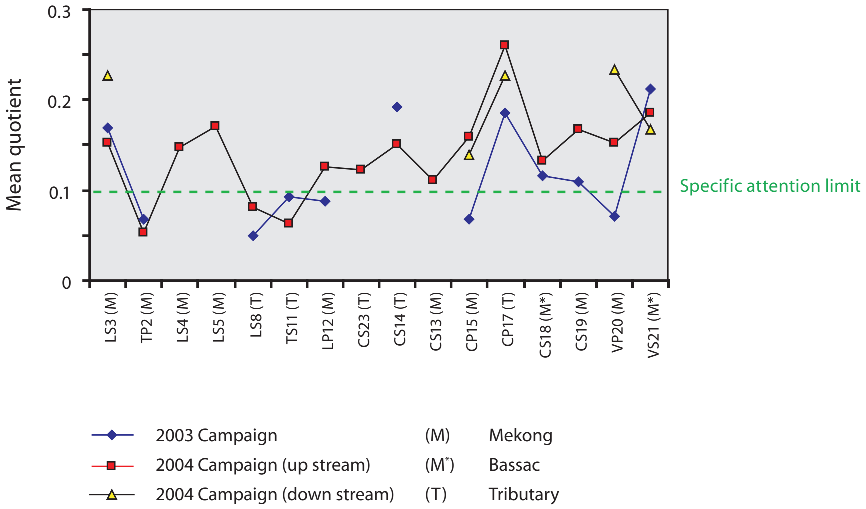

Figure 22. Mean quotient of arsenic and heavy metals recorded during the 2003 and 2004 campaigns.

The overall metal contamination and potential toxicity to benthic organisms is assessed using the 'mean quotient' approach which accounts to a certain extent for additive effects. A significant increase in the toxicity incidence occurs when values are above 0.1 (specific attention limit), at values above 0.5 it is estimated that 80% of the samples are toxic (MacDonald *et al.*, 2000).

Using this approach, it can be concluded that metal contamination occurs at low to moderate levels in the sediments at several sites (Figure 22). No sites exceeded the 0.5 value. Of the stations having data from both campaigns, four stations recorded measurements above the specific attention limit (0.1) in both years:

- Lao/China border (LS3): The metals contributing most to these results were arsenic, chromium and nickel;
- Prek Kdam (CP17): The main contributions to the mean quotient stem from arsenic, chromium, mercury and lead, along with copper and zinc to a lesser extent;
- Chau Doc (VS21): The metals contributing most to these results were copper, nickel, and arsenic;
- Sre Pok (CS14): Chromium was the metal that contributed most to this result. This would appear to be inconsistent insofar that there is little reason to believe there should be metals in sediments in this relatively undeveloped trans-boundary tributary. On the Viet Nam side the Yok Don National Park lies at the international boundary.

Other stations are above this limit, but are not confirmed as they have only one year's data set.

Dioxins and furans in sediments

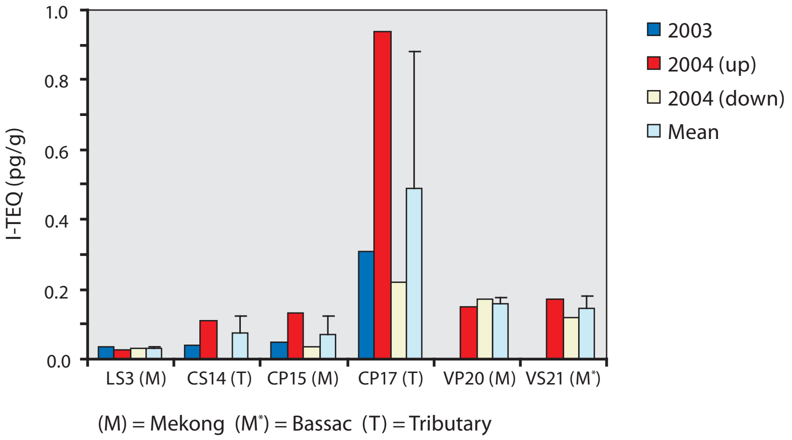

Figure 23. Toxicity Equivalent Index (I-TEQ) variability for dioxins and furans (mean values and standard deviations at stations where samples were collected upstream and downstream of the station in 2004).

Four stations were sampled and analysed in 2003 and 14 in 2004. In the second campaign, sediments were sampled up- and downstream of some of the sites to provide some indication of spatial variance of polychlorodibenzodioxins (PCDDs) and polychlorodibenzofurans (PCDFs). The results of PCDDs/PCDFs concentrations in sediments are presented in terms of their Toxicity Equivalent Index (I-TEQ).

At some stations the difference in I-TEQ between the up- and downstream samples is not large (Figure 23). However, at Prek Kdam (CP17) and Kratie (CP15) there is approximately a four fold difference in I-TEQ concentrations. As the analytical uncertainty for dioxins and furans analysis is around 15%, the observed differences are likely the result of spatial variation.

The I-TEQ values obtained at all the sampled situations in both years are presented in Figure 24 using a threshold of 0.1 pg/g.

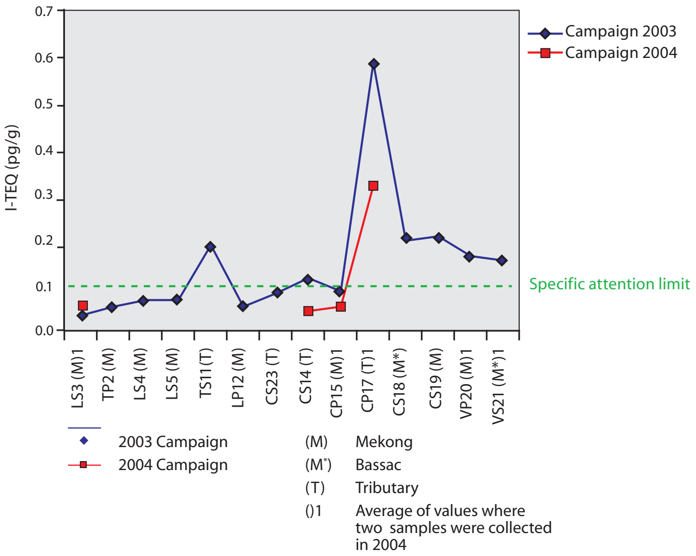

Figure 24. Toxicity Equivalent Index (I-TEQ) values of dioxins and furans recorded during the 2003 and 2004 campaigns.

The six sites with I-TEQ values above 0.1 pg/g are Khong Chiam (TS11), Prek Kdam (CP17), Koh Khel (CS18), Neak Leang (CS19), Tan Chau (VP20) and Chau Doc (VS21). However, this value is lower than the thresholds (0.85 pg/g) in sediment-quality provided by the Canadian guidelines. If the higher value is used, all stations fall below levels that may cause concern. Nevertheless, the higher values observed at Prek Kdam (CP17) merit further investigation. The values downstream from Prek Kdam (in Cambodia) into Viet Nam may indicate transport of some toxins across the border, or they may be generated domestically within Viet Nam.

Other parameters analysed in sediments

Pesticides

The concentrations of all pesticides in sediments sampled during both field campaigns are all below the 20 and 10 µg/kg detection limits used in 2003 and 2004 respectively. These detection limits are, however, well above the equivalent TEC (0.6 to 2.85 µg/kg) and PEC values (1.3

to 1.5 µg/kg). As a result, it is not possible to determine if the sediments are contaminated by pesticides.

Total hydrocarbons

Most of the sites sampled contained concentrations of total hydrocarbons below the detection limit of 10 mg/kg. Figure 25 gives the concentrations of hydrocarbons for the sites with measures above this limit.

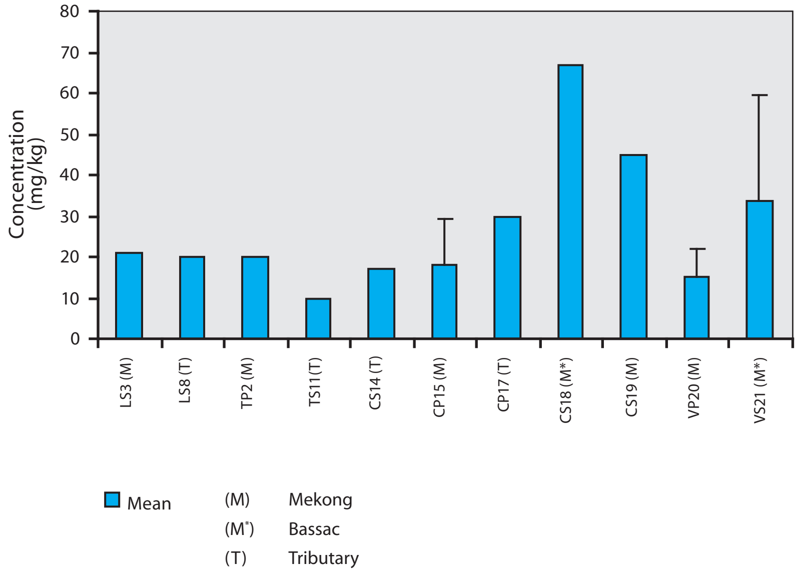

Figure 25. Total hydrocarbons concentrations recorded during the 2003 and 2004 campaigns

The highest concentration of total hydrocarbons was measured at Koh Khel (CS18) at 67 mg/kg. Currently there are no ecotoxicity guidelines for total hydrocarbons in sediments. Therefore, it is not possible to say if these levels are significant or otherwise.

Total cyanides

In 2004, sediment samples were analysed for total cyanides at four stations: the Lao/China border (LS3), Luang Prabang (LS4), Ban Keng Done (LS8) and Kratie (CP15) to determine the influence of mining activities upstream of these sites. Results were all below the detection limit of 0.5 mg/kg.

There are no TEC values available for cyanides. Persaud *et al.* (1992), however, suggest that concentrations below 0.1 mg/kg are acceptable; USEPA (1977) used a benchmark of 0.25 mg/kg for classifying heavily polluted sediments. Unfortunately, the detection limit used in this study is higher than both those values. The presence of cyanides at the levels of concern cannot therefore be evaluated.

PAHs

Total PAHs concentrations were obtained by summing all the results of the different PAHs; ‘non -detections’ were assigned a zero value.

Total PAHs levels could be calculated for only three stations: Kratie (CP15), Prek Kdam (CP17) and Koh Khel (CS18), with total PAHs concentrations of 190, 55 and 50 µg/kg respectively. At Kratie, for example, naphthalene, phenanthrene and benzo(b)fluoranthene were measured at levels of 80, 60 and 50 µg/kg respectively. Naphthalene and phenanthrene concentrations exceed the interim sediment quality guidelines[1] established by CCME (1999-2002).

PCBs

Seven toxic PCBs congeners were analysed in sediments. The concentrations of all were below the detection limit of 10 µg/kg.

The TEL value for total PCBs developed by CCME (1999–2002) is 34.1 µg/kg. The seven PCBs congeners are only a fraction (estimated at perhaps 20–25%) of the total PCBs, therefore it was not possible to draw a conclusion on their eco-toxicological significance. However, as all measured values are less than the detection limit, the risk of harmful effects from PCBs in sediments is low.

BTEX

The BTEX analyses on all the sediments in both campaigns were below the detection limit of 0.05 mg/kg. BTEX guidelines for sediments were not available. However, for the purpose of comparison, in Canada (Canadian environmental quality guidelines) the maximum allowable limit in agricultural soils is 0.05 mg/kg for benzene and 0.1 mg/Kg each for toluene, ethylbenzene and xylene. Based on this evidence, we conclude that BTEX is not significant in Mekong river sediments.

Bioassays

Results from the 1st campaign (2003)

H. azteca bioassays were performed on sediment samples from eight stations sampled during 2003. One sample, from Neak Leang (CS19), was broken during transportation and not analysed. The sediment sample from Kratie (CP15) was broken in transport and was not analysed. Bioassays were performed in two series of tests, which were carried out at different times (Table 11). The first series, included samples from Lao PDR, Thailand, and one of the 2003 samples from the Lao/China border. The second series, that was performed on samples from Cambodia, Viet Nam and the other 2003 sample from the Lao/China border, had to be re-assayed as the validity criteria in the standard protocol were not respected.

The survival rate of *H. Azteca* exposed to sediment samples from three stations was reduced significantly. High mortality was associated with the sediments from the Lao/China Border (LS3) (for which the bioassay was repeated since the mortality was exceptionally high) and to a lesser extent from Tan Chau (VP20) and Kratie (CP15).

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[1] Threshold Effect Levels: Naphtalene: 34.6 µg/g; phenanthrene: 41.9 µg/g (CCME, 1999-2002).

A slight but not statistically significant increase, in the length of *H. azteca* was recorded at some stations (TS11, CP15, VS21 and VP20), possibly because of greater amount of food (organic carbon) naturally present in the field sediment than in the control sediments.

Results from the 2nd campaign (2004)

Sediment samples from 11 stations were collected for the *Hyalella azteca* bioassay. Two samples (one upstream and one downstream stream) from the station at the China/Lao border (LS3). These were analysed separately.

Some samples from both test series had significantly lower survival rates. The stations at the Lao/China border (LS3) downstream, Luang Prabang (LS4), Koh Khel (CS18), Neak Leang (CS19), Tan Chau (VP20) and Chau Doc (VS 21) had significantly lower survival rate than the control (Table 11). Some mortality also occurred in the control samples in both series, however, the mean survival rates of 90% and 78% are acceptable, as the minimum survival required by the standard protocol is 70%.

In the 2004 series, a significant length increase was measured for samples from the following sites: Koh Khel (CS18), Neak Leang (CS19) and Chau Doc (VS21). Chronic toxicity usually leads to a growth decrease, however in this case, the organic content (i.e., food for *Hyalella*) is probably greater in the sediments from the sites than in the artificial control sample.

Table 11. *Survival rates (mean and standard deviation) of* Hyalella azteca *after 14 days exposure to sediment samples from the 2003 and 2004 campaigns*

Test series	Code	2003		2004	
		Mean Survival (%)	Standard deviation	Mean Survival (%)	Standard deviation
I	Si1 (control)	96.0	5.5		
	Si1 (control)			90.0	7.1
	LS3 (1) (Lao/China border)	30.0*	41.2		
	LS3 (upstream)			80.0	7.1
	LS3 (downstream)			64.0†	26.1
	TP2 (Chiang Sean)	90.0	14.1	90.0	12.2
	LS4 (Luang Prabang)			54.0†	11.4
	TS11 (Khong Chiam)	98.0	4.5	72.0	16.4
	LP 12 (Pakse)	98.0	4.5	95.0	5.8
II	Si2 (control)	96.0	8.9		
	Si3 (control)			78.0	8.4
	LS3 (2) (Lao/China border)	0.0*			
	CP15 (Kratie)	82.0*	16.4		
	CP17 (Prek Kdam)			77.5	15.0
	CS18 (Koh Khel)			55.0†	5.8
	CS19 (Neak Leang)			45.0†	12.9
	VS21 (Chau Doc)	96.0	5.5	55.0†	12.9
	VP20 (Tan Chau)	78.0*	1.1	52.5†	12.6

Note: * = Significant difference from the control (Dunnett's test, $p < 0.05$) in 2003.
† = Significant difference from the control (Bonferroni t-test, $p < 0.05$) in 2004.

Summary of bioassay results

Of the seven sites where sediment toxicity was tested in both 2003 and 2004, five had similar effects on the survival rate of *H. azteca*. Two sites had diverging results: i) one of the three sediment samples from the Lao/China border (2004 upstream) did not show a significant effect while the other two samples did; ii) samples from Chau Doc showed an effect in 2004, but not in 2003.

The observed differences between the two years can not be attributed to the minor changes in the methodology (i.e., the age of the organisms at the beginning of the bioassay), since according to ASTM (2000), the sensitivity of *H. azteca* appears to be relatively similar up to at least 24 to 26 days old. The range of ages at the end of the 14-day bioassays in 2003 and 2004 was 16 to 24 days. The differences are probably because the sediments at these stations were not homogenous.

Overall, out of 18 tested sediments sampled at 12 different sites, 9 sediment samples were toxic to *H. azteca*, inducing a significant decrease of its survival when compared to the control. The seven stations and number of toxicity occurrences are:

- Lao/China border (LS3): two (2003, 2004 downstream), out of three samples;
- Luang Prabang (LS4): one sample (2004);
- Kratie (CP15): one sample (2003);
- Koh Khel (CS18): one sample (2004);
- Neak Leang (CS19): one sample (2004);
- Tan Chau (VP20): two samples (2003, 2004);
- Chau Doc (VS21): one (2004), out of two samples.

The results from sites LS3 and VS21 are not conclusive as one sample from each site showed no toxicity response. The differences are likely due to spatial variations at the sampling sites—this may also occur at other sites. Since only a few samples were analysed at each of the seven sites, confirmation of the toxicity potential will require further bioassays. A further consideration is that environmental bioassays are normally carried out as a ‘battery of tests’ using at least three trophic levels (e.g. three from bacteria, algae, invertebrates or fishes) as a single bioassay is not equally responsive to all types of contaminants. The results are usually then pooled to derive a composite ecotoxicological value (e.g. Costan *et al*., 1993).

A significant increase in *H. azteca* length also occurred in samples from three of these sites (CP18, CP19, and VS21). All are located in, or downstream from, areas with high population densities. The increase in length is probably explained by a higher nutritional value in sediments that are enriched by organic matter from waste water and runoff.

6. Conclusions and Recommendations

Synthesis

The assessment of the 2003 and 2004 data was based on contaminants recorded at a limited number of sites with a limited number of samples. This provides a useful, but preliminary, picture of the quality of the river's water and sediments and the potential risks of contamination. Moreover, some of the interpretation tools that were used (e.g., water classification thresholds, contaminant guidelines, threshold effect and probable effect concentrations (TEC and PEC), etc.) were developed in different contexts or for different purposes, and are not necessarily well adapted to the Lower Mekong Basin.

For these reasons, and in order to synthesise the data in a more easily understood form, a multi-criteria approach was employed. This gives a more integrated perspective of the toxicity in the Mekong River. It will allow managers of water-resources to identify potential threats based on a scoring approach an can be used to identify those sites that require more work to raise the level of confidence through more robust statistical techniques. However, while this method provides a valuable insight the results should be treated with some caution because the number of samples used in the analysis was not consistent across all of the sites. Furthermore, the values represent a single time in each sampling campaign and more work is require to establish if these values are representative of longer periods of time or of a larger special area than the immediate environs of the sampling sites.

Multi-criteria analysis

The multi-criteria analysis uses a 'scoring system' in which rankings are assigned based on actual or inferred levels of impacts on the environment.

Only those parameters for which quantifiable results were available were used in the analysis (i.e., heavy metals and arsenic; pH, PCDD/PCDF, and *Hyalella azteca* bioassays). For each parameter, a similar scoring method was used to that used for heavy metals (see page 31). This allowed the derivation of an overall comparison of the stations (see Table 10 for the threshold for scores: 0, 1 and 2).

Table 12 gives the scores for the four parameters—where data were available. The last column to the right gives the standardised score (i.e., the total score divided by the number of parameters where a score could be allocated), in order to take into account differences in numbers of parameters at each station. For ease of examination and comparison, the standardised scores are presented in Figure 26.

The results from the multi-criteria analysis show that the Neak Leang (CS19 in 2004) and Chau Doc (VS21-upstream in 2004) are the most impacted stations. These stations are located near or downstream from heavily populated areas.

Table 12. *Multi-criteria analysis for the Mekong and main tributaries in 2003 and 2004*

Station	Year	Metals and arsenic	PAHs	PCDDs & PCDFs	Tox-HYA	Total	Number of counts	Standardised score
LS3	2003	1		0	2	3	3	1.00
LS3 (up)	2004	1		0	1	2	3	0.67
LS3 (down)	2004	1		0	1	2	3	0.67
LS4	2004	1		0	1	2	3	0.67
LS5	2004	1		0		1	2	0.50
LS8	2003	0				0	1	0.00
LS8	2004	0				0	1	0.00
LP12	2003	0			0	0	2	0.00
LP12	2004	0		0	1	1	3	0.33
TP2	2003	0			0	0	2	0.00
TP2	2004	0		0	1	1	3	0.33
TS11	2003	0			1	1	2	0.50
TS11	2004	0		1	1	2	3	0.67
CS13	2004	0				0	1	0.00
CS14	2003	0		0		0	2	0.00
CS14	2004	1		1		2	2	1.00
CP15	2003	0		0	1	1	3	0.33
CP15 (up)	2004	1	0	1		2	3	0.67
CP15 (down)	2004	0		0		0	2	0.00
CP17	2003			1		1	1	1.00
CP17(up)	2004	2	0	1	1	4	4	1.00
CP17 (down)	2004	2	0	1		3	3	1.00
CS18	2003	0				0	1	0.00
CS18	2004	0	0	1	2	3	4	0.75
CS19	2003	0				0	1	0.00
CS19	2004	1		1	2	4	3	1.33
CS23	2004	0		0		0	2	0.00
VP2O	2003	0			1	1	2	0.50
VP2O (up)	2004	0		1	1	2	3	0.67
VP2O (down)	2004	1		1		2	2	1.00
VS21	2003	0			1	1	2	0.50
VS21 (up)	2004	1		1	2	4	3	1.33
VS21 (down)	2004	0		1		1	2	0.50

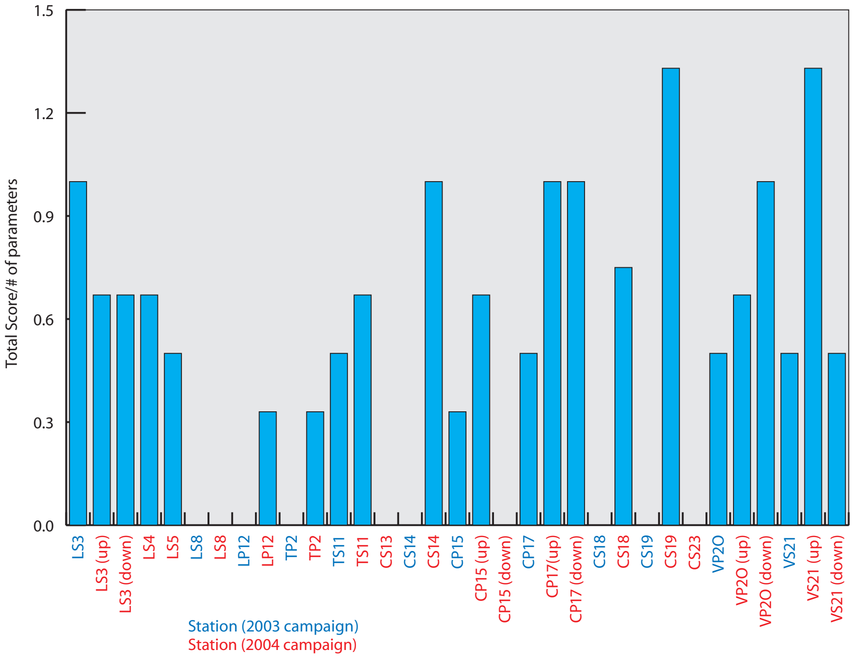

Figure 26. Multi-criteria analysis for the Mekong mainstream and main tributary stations

Prek Kdam (CP17) and the Lao/China Border (LS3) also have high scores. These stations were identified at the end of the 2003 field campaign as the most polluted sites—CP17 for its highest concentrations of total heavy metals and dioxins and furans; LS3 for the highest toxicity observed in the bioassays. However, further investigation is required because of the graet variability of the reults.

This classification is based on only two field campaigns, with varying numbers of parameters measured at each station. Some sites, in a given year, have only been analysed/scored for one type of parameter, while only two stations were analysed/scored for all four types of parameters.

Main recommendations

Benchmark sites

One of the major requirements of this study was to provide data with which to asses the extent of pollution in the Mekong River originating from pesticides and industrial pollutants. This study shows that the Lower Mekong Basin is relatively unpolluted with industrial organic pollutants and metals. However, the data for pesticides are inconclusive because of poor detection limits are available at this time.

Some ‘hot-spots’ identified in this study appear to link to local sources of pollution. However, it is unknown whether elevated levels of pollutants at sites downstream from Phnom Penh are local factors or the result of trans-boundary transport. The study also demonstrated the important role the Mekong River system plays in diluting pollution, such as salinity.

Based on these results, benchmark stations should be located at the six following sites:

- Lao/China border (LS3) on the Mekong River;
- Vientiane (LS5) on the Mekong River;
- Prek Kdam (CP17) on the Tonle Sap;
- Neak Leang (CS19) on the Mekong River;
- Tan Chau (VP2) on the Mekong River; and
- Chau Doc (VS21) on the Bassac.

WQMN programme

This study has provided information about which parameters are most applicable to assess the status of the Mekong River regarding pesticides and industrial pollutants:

- *Sediments:* proved to be very useful and practicable, however, some of the analysed parameters gave inconclusive results. Nevertheless, the following parameters are particularly useful:

  - Heavy metals;
  - PAHs;
  - Organochlorine, organophosphate and triazine pesticides with a detection limit lower than 10 µg/kg;
  - Dioxins and furans (e.g., by using the UNEP 'toolkit' for PCDD/PCDFs would also allow data comparison within the region).

  Moreover, regarding future monitoring programmes, if sediment pollution is to be correctly assessed, replicates, grain-size distribution and total organic carbon analyses have to be included for each site in order to be able to properly compare the results at individual sites and between sites. These parameters need not need be analysed every month, once a year would be enough.

- *Bioassays* also proved to be useful indicators of environmental toxicology. In future two types of bioassay tools should be considered. At sites such as the China/Lao border, specialised test procedures such as TIE[1] (Toxicity Identification Evaluation) can be used to determine what specific chemistry is causing toxic effects. When this is known the source can usually be identified.

  A second approach is the 'battery of tests' approach; this is more commonly used for environmental effects assessment. This will require selecting appropriate species that represent different trophic levels of the Mekong system.

  Although not reported here, the use of diatoms has potential for assessing ecological health. The diatom index can be developed for organic pollution and abnormal forms/diversity used for toxic pollution. This needs development work for the Mekong.

  Finally, analysis of biotic substrates (tissue, bile, liver, etc.) that were planned in this study but not implemented for logistical reasons. Representative species should also be included to assess the impact of toxic pollutants on the food chain and the potential risk for human health. This could usefully include sentinel species that accumulate organic and inorganic pollutants.

- *Water quality data* held by MRC appears to be very similar to that collected in this study. This suggests that the MRC database is adequate for interpretation of routine water parameters. However, analysis of the MRC data and the experience with the regional laboratory contracted to do nutrients and other basic parameters, suggests that greater effort needs to be directed to quality assurance and quality control to ensure that MRC data reach and maintain a high level of reliability.

- *Regional analytical capacity:* The capacity of regional laboratories limits the use of some types of advanced analyses. However, MRC should undertake an evaluation of local

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[1] See, for example, Birkholz *et al.* 2002.

capacities to determine which types of contaminant analyses can be performed reliably within the region.

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