Water Utilization Program - Modelling of the Flow Regime and Water Quality of the Tonle Sap
MRCS/WUP-FIN

DATA COLLECTION REPORT
March 2002, Revised August 2002
Data Collection Report

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ACRONYMS AND ABBREVIATIONS

3D 3-dimensional
ADB Asian Development Bank
ADCP Acoustic Doppler Current Profiler
AusAID Australian Aid
BDP MRCS Basin Development Plan
CHO Cambodian Hydrographic Office
CNMC Cambodia National Mekong Committee
DOFish Department of Fisheries, MAFF, Cambodia
DEM Digital Elevation Model
EIA Environmental Impact Assessment
EP MRCS Environmental Program
FAO Food and Agriculture Organization
FEI Finnish Environment Institute
GEF Global Environment Facility
JICA Japan International Cooperation Agency
LNMC Lao National Mekong Committee
MAFF Ministry of Agriculture, Forestry and Fisheries, Cambodia
MOE Ministry of Environment, Cambodia
MIME Ministry of Industry, Mines and Energy, Cambodia
MLMUC Ministry of Land Management, Urbanisation and Construction
MPWT Ministry of Public Works and Transport, Cambodia
MWRM Ministry of Water Resources and Meteorology, Cambodia
MRC Mekong River Commission
MRCS Mekong River Commission Secretariat
MRD Ministry of Rural Development, Cambodia
NGO Non-Governmental Organization
RGC Royal Government of Cambodia
TOR Terms of Reference
TNCM Thailand National Mekong Committee
TCU Technical Coordination Unit for Tonle Sap, MOE
UNDP United Nations Development Program
VNMC Vietnam National Mekong Committee
WQ Water Quality
WUP MRCS Water Utilization Program
WUP-HAL WUP Basin Wide Modeling (also WUP-A)
WUP-FIN WUP Tonle Sap Modeling (Finnish team)
SUMMARY

1 Summary

Project “Modelling of the Flow Regime and Water Quality of the Tonle Sap” (WUP-FIN) is a complementary project to the Mekong River Commission Water Utilization Programme (WUP). It is funded by the Development Cooperation Department, Ministry of Foreign Affairs, Finland. Project has started on June 4th, 2001.

Project aims at creating means to understand physical, chemical and biological processes in the Tonle Sap and to assist in the maintenance of sustainable conditions of the lake. The main objectives are:

− to support MRCS, NMCs, Cambodian line agencies, and NGO’s by providing an enhanced knowledge base, analytical tools and guidelines, that are based on improved understanding of the interaction between the physical and biological features of the lake and their changes that may occur due to human activities;
− to create means to assist in the maintenance of sustainable conditions of the Tonle Sap system;
− to assist, through on-the-job and other training, in increasing the modelling capability of the MRCS, CNMC and the line agencies and to help create a sustainable modelling group
− to ensure that the modelling framework allows future adaptation to include new modules for analysing and predicting impacts of proposed actions on the aquatic ecosystem, water uses and socio-economic functions.

Project consists of field measurements, modelling, socio-economic analysis and preparation of management tools as well as training program. Advanced hydrological, hydrodynamic, water quality and eutrophication models will be used in the project.

The present report summarizes the additional data collection phase of the project. The data collected includes meteorology, hydrology, water quality, habitats, and socio-economy. In the first analysis the most striking features of the lake are the strong daily cycle of the wind, very damped lake oscillations (seiche), rapid clearing up of the water when the water level is rising in the lake, almost total oxygen depletion in large areas of the floodplain, very sharp gradient in physical and water quality characteristics between the lake and the flood plain and phosphorus limitation of the phytoplankton production when the water level is high.
DATA COLLECTION

The Data Report (November 2001) summarized the data review and analysis as follows:

“An important part of the data collection and review phase of the work has been a plan for the future field studies. Analysis of the existing data reveals that by far the largest data gaps are connected to the watershed and lake processes - for instance rainfall, detailed rainfall-runoff response, floodplain and lake hydrodynamics, mass balances, behaviour of sediments in the lake, flood plain water quality and nature of the primary production. These are essential features that determine the future development of the lake, morphological changes affecting navigation and water levels, condition of the fisheries and response to the upstream changes in flow and water quality.”

As stated above, one of the most critical factors identified from the very beginning of the project was the very limited amount of data available from the Tonle Sap area. This concerns especially the water quality data of the Tonle Sap tributaries, the flood plain and the lake as well as the data on physical processes of lake and flood plain. That is why an extensive data collection programme was started in June 2001 by the WUP-FIN Project in co-operation with the Cambodian Ministry of Water Resources and Meteorology. The data collection in and around the lake has been divided into four separate sectors, from which the means of transportation allows a delivery of the samples to the laboratory in Phnom Penh within 24 hours (see WUP-FIN Inception report, July 2001). Additional data collection results and conclusions were summarized, as well as plan for continuation with cost estimate outlined in the special report “Findings on Tonle Sap & Future Views, March 11, 2002, 18 pages, and presented March 11, 2002, to a full-house audience at MRCS. Presentations stimulated a most lively discussion and were further followed by CEO’s decision to nominate a formal technical coordination group on March 22, for better utilization of the WUP-FIN data collection activity and outputs throughout MRCS (EP, FP and BDP in particular).

The data collection programme will be continued until the end of the project (water quality sampling and field surveys, laboratory analyses and maintenance of automated stations).

1 Field data collection programme

The elements and motivations for the separate data collection items are briefly:

* Water level measurements – Model validation, analyzing flood level and water exchange in different parts of the lake, interpretation and checking of the satellite images for flooding
(measurement sites Kompong Luong, Phnom Krom and Chhnok Tru)

* **Meteorological data collection** – Necessary input for hydrodynamic, water exchange process and water quality analysis as well as the model runs  
(measurement sites Kompong Luong and Phnom Krom)

* **Water quality monitoring and recordings** – Necessary tributary input for the lake model, verification and validation of both the watershed and lake/flood plain models, essential for even basic understanding of the lake processes and dynamics, previous data is almost non-existent  
- monitoring cycle once per month  
- laboratory inter-calibration  
- phytoplankton and zooplankton analyses  
- special surveys in peak flood time (w-quality and –quantity)  
- satellite image analyses  
- wq-recordings

The sampling sites cover the medium and small size rivers pouring into the Great Lake, representing 90 % of the tributaries waters entering the lake, as well as the Tonle Sap river. Part of the sampling sites are located in the flood plain and the lake itself, forming cross-sections over the eastern and western lake basins and wetlands.

* **Recording current meter measurements** – Verification and validation of the hydrodynamic and sediment model of the lake, in open part of the lake in the delta area and in the flood plain

* **Sedimentation measurements and sediment surveys** – estimating sedimentation rates in different parts of the lake and the flood plain, assessment of accumulation of sediments and possible topographic changes

* **Provincial workshops** including field work training (Siem Reap + Pursat) – necessary for project utilization and sustainability, input for development scenario design and management impact studies, input for monitoring program development (water quality and environmental indicators)

* **Fishermen/farmer interviews** – needed for impact and socio-economic analysis and developing links between model results and socio-economic impacts, with special reference to fisheries, agriculture and navigation

### 2 Available measurement devices

2 Aanderaa Instruments data scanners with  
- 2 wind direction sensors  
- 2 wind speed sensors  
- 1 air temperature sensor  
- 1 relative humidity sensor  
- 1 solar radiation sensor
3 Aanderaa recording current meters (RCM9) with
  - acoustic doppler velocity sensor
  - temperature sensor
  - conductivity sensor
  - turbidity sensor
  - optical dissolved oxygen sensor

2 Telog water level recorders

2 YSI (Yellow Springs Instruments) 6000 multi-parameter environmental sensors
  (temperature, dissolved oxygen, pH, turbidity)

2 Marvet Junior temperature and oxygen probes

2 GPS, Garmin type GPS12

3 Year 2001 measurements

The team initiated measurements and additional data collection in the Tonle Sap tributaries and in the lake in the very beginning of the project in June 2001 on, in cooperation with the Ministry of Water Resources and Meteorology and its provincial departments, effectively promoted by the CNMC. Water quality sampling has been made once or twice a month. The selection of the WQ sampling and other measurement sites was made jointly with the local experts, taking into consideration the existing measurement networks and the plan of the national WQ monitoring in the tributaries to start in 2002. The water quality samples have been analyzed at the laboratory of the Ministry of Water Resources and Meteorology for parameters included in the national WQ monitoring programme, with the addition of chlorophyll-a and Secchi depth in the lake. The chlorophyll analyses have been made at the laboratory of the Ministry of Environment. Secchi depth measurements have been done once a week from July on in Kompong Loung and in Phnom Krom by the observers of the provincial Departments of Water Resources and Meteorology. Phytoplankton samples have been collected from the lake, to be analysed in a later phase of the project.

Knowing the difficulties in mobility and transportation in the Tonle Sap area, special attention has been paid to quick transport of the water samples to the laboratory (in less than 24 hours). In order to match the time constraints in the sample transport the sampling programme was divided into four parts based on the geographical location of the sites. In the case of the westernmost provinces the sample transport was arranged by air. In order to minimise the sampling costs the staff of the provincial Water Resources departments has been trained in water quality sampling and sample preparation and are becoming ready to take over the field work. Another issue of concern has been the analysis of inorganic nutrients concentrations and related quality assurance procedures. Laboratory inter-comparison has been initiated between the national laboratories of the Ministry of Water Resources and Meteorology, Ministry of Environment and the laboratory of the Finnish Environment Institute.
Additional campaigns and cooperation tasks by the WUP-FIN in highest flood time have included:

Cooperation with MRCS coordinated discharge measurement missions in the Tonle Sap Lake provinces with the main aim to combine river water quantity and quality results, especially in the time of high discharges (see ANNEX 1 to this report: Water Quality Measurement Plan Connected to the Discharge Measurements in the Tributaries around the Tonle Sap Lake).

The above task has been additionally addressed by the Flood time measurement campaign proposed by H.E. Hou Taing Eng, to measure peak amounts of material input to the Lake, realised by the WUP-FIN team in cooperation with the CNMC (see ANNEX 2: Field Measurement Trip around the Tonle Sap Lake August 27-31.2001).

**Water level measurements** were initiated in Kompong Loung floating village and Siem Reap (Phnom Krom floating village) in June 2001. K. Loung measurements are made in the existing measurement tower. In Phnom Krom two temporary 4 m high gauge stations were built, extending over the water level variation between 2-9 meters (measurement devices were transferred to the upper station before the submerging of the lower one). Additionally, water level recordings were started in Chhnok Tru measurement tower at the lake inlet/outlet area in July.

Measurement accuracy of the water level recorders is 0.1 % of the full measurement range, which is 15 meters in K. Loung and C. Tru and 3.5 meters in P.Krom.

Water level has been measured manually on daily basis by the Department of Water Resources and Meteorology observers in K.Loung (Pursat province) and P. Krom (Siem Reap Province).

**Meteorological data** has been recorded since July at the K.Loung tower (wind, air temperature, relative humidity, solar radiation) and P. Krom (wind). Wind direction sensor at P. Krom station has been malfunctioning at times in August and September.

**Multi-parameter water quality** measurements with YSI6000 probe

The YSI probe was installed at K. Loung measurement tower in the beginning of August for recording turbidity, pH, temperature and oxygen. The sensor head was 1-2 meters below the surface, adjusted according to the water level change.

The other YSI probe was installed in the middle of October inside the flooded forest belt 20 km north of Kompong Loung, with the main aim to observe the dissolved oxygen variability in this narrow zone that separates the low water lake area and the flood plain. According to the momentaneous profile measurements made in the Autumn, the forest belt makes a distinct buffer zone between the fully oxygenated lake waters and highly oxygen depleted flood plain waters. The results are expected to clarify the exchange processes of these water masses and to give guidance for further measurements of physical and water quality conditions in the coming months. Th
eprobe was installed at the depth of 3.5 meters, where high variability of DO concentration has been observed. The depth has been adjusted stepwise along with the falling water level. The installation was made at a tree with no visible indication of the installation at the surface.

Lake water quality monitoring and surveys have been done in a two focal areas, selected on the basis of their accessibility as well as allowing for measuring cross-sectional changes over the lake and the flooded areas (Kompong Loung cross-section and Battambang-Bakpria-Siem Reap cross-section). The measurements in the flood plain have had a certain sample test nature and are rather elementary since there are hardly any data available in these areas so far, Lamberts et al. 1997 being the only detected source. The measurements have aimed at getting the first picture of
- DO concentration distribution
- the rate oxygen deficit and its temporal and spatial changes
- nutrient concentrations and their variability
- presence of internal nutrient load in the low oxygen conditions
- impact of floating vegetation cover in water exchange and mixing, and water quality -wind impact and water exchange between the lake and the flood plain
- turbidity, TSS and secchi depth distribution and changes

A pair of sediment traps has been installed at K. Loung measurement tower to collect direct data on the amount and properties of settling material. Collected sediment samples will be analyzed for total N, total P, TSS, organic/inorganic fraction, tot C (and possibly biologically available P and N fraction).

4 Data collection plan 2002-2003 and cost estimate (USD)

Water level measurements continue in Kompong Loung, Phnom Krom and Chhnok. Throughout the project duration (one Telog water level recorder is kept as reserve or for additional measurement purposes in the project office)

The water level station in Phnom Krom wetland area has been constructed for the project purposes on temporary basis. It is proposed a permanent measurement tower to be constructed in Phnom Krom inside the lake area itself (according to the existing national plan)

Meteorological data collection continues in Kompong Loung and Phnom Krom as before throughout the project (broken wind direction sensor to be repaired at the manufacturer, costs covered by the warranty?)

WQ monitoring in the Tonle Sap River and the tributaries continues once a month in 2002 (leaving possibly out the downstream the towns samples away, although this does not have a great effect in the cost…). The provincial Water Resources departments will be utilized in the sampling programme as much as possible
(collection of samples and sending them to Phnom Penh). This was endorsed by the provincial workshop in Siem Reap in October 2001 (ANNEX 3), as well as the proposal of cooperating between the provincial departments in the monitoring programme (integrating the the needs of water resources, environmental, agricultural, fisheries, industrial etc. point of view. The expectation of coordinating the monitoring activities was directed towards the Ministry of Water Resources and Meteorology/Department of Hydrology and River Works (Mr. Mao Hak) (see Siem Reap workshop minutes in this report).

Two of the sampling sites (Prek Kdam and Kompong Chhnang) belong to the national water quality monitoring programme. There is also the plan to start national monitoring programme in the Tonle Sap tributaries in 2002 (MRCS/EP, CNMC, MWRM). As mentioned above the WUP-FIN project has initiated the tributaries monitoring programme in cooperation MWRM bearing this near future vision in mind.

**WQ monitoring** in selected lake and flood plain sites continues on monthly basis, synchronised with the tributaries programme when ever possible. 2-3 transects from lake middle into the flood plain will be used, starting form the already applied ones (see map). The selection of variables to be analyzed will be kept intact (i.e including chl-a measurements). Phytoplankton samples will be collected at every site for possible later analyzing (most likely at FEI). Secchi depth measurements will be made on weekly basis at Kompong Loung and Phnom Krom.

MRCS Fisheries programme has expressed the need of doing measurements in the flood plain area of the Tonle Sap River which is reported to be an area of the greatest fish catches. To respond to this request, measurements and sampling will be performed in the Kompong Chhnang area still this year. The additional cross-section will be added to the 2002 programme, if practically (financially) possible.

**YSI6000 water quality** probe was installed in K. Loung and in eastern basin flood plain for the falling water level time (November 2001- May 2002). Together with the current meters they record the water and material exchange processes between the lake and the flood plain, as well as the vertical exchange processes (e.g. resuspension).

**RCM9 measurements**
Current and turbidity measurements will be done with the recording meters in the lake outlet area (Chhnok Tru), to detect outflow of waters and sediments from the lake, and to separate, if possible flow and sediment transport differences in the various outlet channels. MRCS Navigation Programme has expressed its interest to this issue, referring to the navigational problems in the lake delta area. The plan of dredging one of the channels to guarantee low water navigation has been mentioned.

Further measurements are planned for the low water time for detecting coastal circulation characteristics, for validation of the HD model, and to derive first estimates of sediment transport patterns. For navigational aspects and possible lake wide dredging plans (shipping route) it is needed to map the likely erosion and accumulation zones. Of course, there are quite limited possibilities to address this
question by the measurements within the project. Still, utilising the gained experience from other shallow lakes and taking use of the model potential it is possible to highlight some of the basic processes and outputs important for the navigational planning.

The security issue is of greatest importance when planning the current measurements. One way, at least to start off is to make the measurements from anchored boats (say over a week), with a guard continuously on the spot. The measurements can be focused to a limited area which allows for simultaneous control of the related instruments.

**Sediment traps** will be installed for lake wide sedimentation measurements (2-3 transects over lake, flooded forest and the flood plain)

- analysis of Summer-Autum 2001 samples at K. Loung will be performed (tot N, tot P, TSS, organic/inorganic fraction, tot C)
- **RCM9 and YSI6000 recordings** will be made during rising flood time, for detecting flood water intrusion in the flood plain over a transect from the lake to flooded forest and to the inside part of the flood plain, recording current dynamics, DO depletion and turbidity variability. The sites will be selected, when possible so that they coincide with sediment traps locations as well as water quality measurement sites. This would ease the practical operations in the lake and allow for an integrated approach to analyse the results (water exchange, material transport).

Cost estimates for the field works is presented below.

<table>
<thead>
<tr>
<th>Cost estimate (USD) sub-total</th>
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<tbody>
<tr>
<td><strong>Focussed topographic survey</strong> (see attachment)</td>
</tr>
<tr>
<td><strong>Water level measurements</strong> in K. Luong, P.Krom and C. Tru</td>
</tr>
<tr>
<td>-materials, maintenance</td>
</tr>
<tr>
<td><strong>Meteorological data coll.</strong> in K. Luong and P. Krom</td>
</tr>
<tr>
<td>-materials, maintenance</td>
</tr>
<tr>
<td>-extra Data Storing Unit to compensate the stolen one</td>
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<tr>
<td><strong>WQ monitoring</strong> in Tonle Sap Lake, River and tributaries</td>
</tr>
<tr>
<td>-monitoring cycle once per month</td>
</tr>
<tr>
<td>-laboratory inter-calibration (standard samples, transport. etc.)</td>
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<tr>
<td>-laboratory material (filters etc.)</td>
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<tr>
<td>-phytoplankton and zooplankton analyses</td>
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<tr>
<td>-special surveys in peak flood time (w-quality and –quantity)</td>
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<td>-satellite image analyses</td>
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<tr>
<td><strong>WQ recordings</strong> in the lake and flood plain (YSI1600 probe)</td>
</tr>
<tr>
<td>-control, maintenance, spare parts</td>
</tr>
<tr>
<td><strong>Recording Current Meter measurements</strong> in the lake and flood plain</td>
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<tr>
<td>Description</td>
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<td>-----------------------------------------------------------------------------</td>
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<tr>
<td>-procurement of 3 optical DO sensors (Aanderaa Optode)</td>
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<tr>
<td>-installation racks</td>
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<tr>
<td>-installation and control of instruments (4 periods)</td>
</tr>
<tr>
<td><strong>Sedimentation measurements</strong></td>
</tr>
<tr>
<td>-sediment traps</td>
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<tr>
<td>-control, maintenance and collection of samples</td>
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<tr>
<td>-sample analyses</td>
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<tr>
<td><strong>Provincial workshops</strong> incl. field work training</td>
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<tr>
<td><strong>Fishermen interviews</strong> (travelling, DSA, facilitator salaries, PRA expert work)</td>
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<tr>
<td><strong>Total</strong></td>
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<tr>
<td><strong>Reserve (of the allocated 184 000)</strong></td>
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ON THE WIND AT TONLE SAP AND ITS ROLE IN LAKE HYDRODYNAMICS

1 Introduction

The water quality modelling of lakes in general and the one of TONLE SAP in particular, has to be built on sound hydrodynamic basis. In fact, though usually at different time and space scales, hydrodynamics has got a great impact on water quality processes, thus determining the fate of the lake.

As is known, the hydrodynamics of TONLE SAP Lake is driven mainly by the backwater effect of River Mekong and the wind blowing over the lake. The role of Mekong is to gradually fill up the lake with water abundant in suspended sediment in the wet season, which is then drained by the river in the dry season. While the water balance is in an annual equilibrium, it is certainly not true for the sediment mass balance.

The role of the wind is mainly to determine the exchange processes at the air-water interface, thus driving the exchange processes at the lake bottom, mixing in the water body, and the interaction between the floodplain and the pelagic areas. The momentum of wind transferred at the lake surface generates waves, turbulence, drift currents as well as water level changes (so-called seiche) and large scale circulations (Simons, 1980).

With its 1-1.5 m depth, TONLE SAP is a definitely shallow lake in the dry season, even according to the most rigorous criteria, whereas moderately shallow when its water level is peaking. Shallowness makes it possible for the surface forces to influence efficiently, though indirectly, the bottom. As one of the main features of shallow lakes, waves generated even by moderate winds can induce shear stress at the bottom and stir up the uppermost sediment layer of the lake bed (see e.g. Sheng and Lick, 1979; Rákóczi and Józsa, 1999; Williams et al., 2000). While held in resuspension by turbulence, large scale horizontal displacements can occur to the suspended material due to the advective currents. As the sediment carrying capacity of the water drops (either in space or in time), siltation begins to dominate. As another consequence of shallowness, wind-induced turbulence can easily destroy temperature stratification thus making the lake homogenous, and influence the so-called turbidity currents when the lake receives sediment-rich tributary waters. Wind is also important in surface gas and heat exchange processes, both of them playing a significant role in lake water quality and ecology.

Most conventional wind-induced hydrodynamic processes are the large scale oscillatory (seiche) and circulatory currents. Oscillations in themselves usually do not result in significant net residual displacement and exchange, but once accompanied with through-flow or wind-induced circulations, their combined influence is
significantly enhanced. While seiche can be generated either by the wind or horizontal atmospheric pressure gradient, circulations are induced primarily by the wind shear stress and shaped by various factors.

Circulations, though always three-dimensional, very often show organised horizontal pattern consisting of large scale gyres. In fact, circulation needs rotation sources to be generated and maintained. Without going into the details, to support the above mentioned gyres such sources can be originated e.g. from bottom slopes relative to the depth (Simons, 1980), irregular wind field (Józsa et al., 1990; Józsa et al., 1998; Jinxiu et al, 1999), irregular lake surface exposure to the wind due to emergent littoral or inundated floodplain vegetation (Sarkkula et al., 1991; Józsa et al., 1999; Podsetchine and Schernewski, 1999) or indirectly from the earth rotation itself (Simons, 1980), though not that much close to the Equator. If some of the factors change then seasonally, it can result in significant change in the hydrodynamic response of the lake. The latter certainly applies also to TONLE SAP, considering its change of tremendous amplitude in water level and the clear differences between winter and summer monsoon wind climates.

In order to set up and in its main modules calibrate a sound modelling system for the lake, it is essential to explore the most important features of the external driving forces. In doing so, wind measurements began at the lake at two characteristic sites mid-July, the recently processed data of which made it possible to take a first look at the wind features in the lake region. As will be seen, despite the relatively short time series valuable information could be gained especially as far as the time dynamics is concerned.

In the present report first a brief overview is given on the general wind conditions of the region. It is followed by describing the main aims of the measurements, the applied tools and the measurement sites. Before going to the analysis proper, a theoretical, at places semi-empirical overview is given on the roughness, the wind profile and the wind shear stress at the lake surface. The analysis and evaluation of the measured time series attempts then to put a light on the space-time structure and complexity of the wind features, that should be considered valid strictly for the observed period of the year only, at least until further measurements in other periods are collected. Far from being complete, the list of references attempts to cover some important items of the literature relevant to the topic and actually being at hand. The last part of the report contains the figures, which were kept large enough to see the important details, in turn difficult to insert them into the main body of the text. Based on this preliminary analysis it is believed that well-planned additional field measurements of the wind (carried out preferably with measuring simultaneously the most important processes induced by that) will provide sufficient information on the characteristic time and space scales, thus providing realistic, at the same time reasonable wind input to the model system under development. It is expected that such an improvement will enhance the accuracy of modelling the lake hydrodynamics on one hand, and the predictability of water quality processes with implications to lake ecology on the other.
2 General wind climate

In this chapter we follow the description of Carbonnel and Guiscafré (1963). As is known Cambodia has tropical monsoon climate which is modified and moderated by the surrounding mountains. In the cold, dry season the continental cooling results in a large, semi-permanent, high pressure anti-cyclone, centred around Lake Baikal. The movement of these extremely cold and dry air masses toward the South and East of Asia forms the winter monsoon. In general the winter monsoon develops in Cambodia in the second half of November, which can be still rainy, accompanied with rather strong North, Northeast winds. On the contrary, in summer the intensive warming produces a large low pressure zone of thermal origin, situated at the foot of Himalayas and extending from the Northwest of India to Indochina, resulting in the large flow of humid, warm and particularly unstable air masses coming from Southwest, which then totally cover Cambodia, and known as the summer monsoon.

As to the changes within the year, in December-January the more or less direct polar air determines the conditions in the country. Then in April, the displacement of the above mentioned Siberian anti-cyclone toward the East modifies the arrival path of the polar air masses, which come then from the East from that time on, but without penetrating too much to the South unlike earlier. From the end of May on, the summer monsoon develops and the general airflow coming from Southwest from the Indian Ocean becomes absolutely dominant. In the South at same time air masses arrive straight from the Southwest trade wind, showing in general South orientation. From October on, starting in the Northeast, most of Cambodia is progressively covered again by the polar air masses. In that time, however, an antagonist Westerly wind, coming from the North of India, affects frequently the Southeast of the country. Considering the main characteristics of the long term wind statistics of e.g. Battambang, somewhat to the West of the lake, January is dominated by winds blowing from the North - East sector; in April it proves very transitory; in July winds from the South - West sector definitely prevail whereas October is again very fluctuating as a turnover of the seasons. In general at least half of the days are quite windy but the average speed seldom exceeds 10 m/s (for more details see Carbonnel and Guiscafré, 1963).

It is also important to note that storms accompanied with short gusty winds can often develop in the rainy season, usually due to the instability produced in the middle of a humid air mass by warming up when contacting an overheated earth surface. These storms burst primarily in the afternoon, and at night at the end of the season. Furthermore, along the inter-tropical convergence zone, at the borders of the equatorial air masses and the tropical maritime air of the North-east trade winds, the convergence due to the contact of the two air masses with opposite origin also supports the storm development. These storms develop in the evolving period of the monsoon, both at the rising and falling parts of the inter-tropical convergence zone. The number of storms can easily go up to 15-20 in May and September.
3 Aim of the measurements

As seen from the brief overview above, the wind conditions are a combination of large scale, slowly varying and locally generated, episodic elements, with considerable seasonal variability. Moreover, TONLE SAP, due to its large extent and water body, certainly creates a local microclimate also influencing the wind. Whatever complexity the wind presents, long and dense enough vector time series from up-to-date standard wind measurements are usually sufficient to derive its main features, provided proper analysis tools are applied. In doing so, the first phase of the field measurements consisted of mounting wind sensors at two sites at the lake and collecting sufficient amount of wind data for a first insight into the typical time and space scales, thus producing baseline knowledge, furthermore, facilitating the planning of further measurement campaigns.

4 Measurement tools

A basic set-up of the mobile and easy-to-deploy wind station of Aanderaa Instruments, Norway, has been adopted for the measurements. The sensors have been proven their applicability and reliability world-wide, even in very harsh conditions. Data collection is controlled by a scanning unit, and data as integral averages of a pre-selected time interval are stored in a solid state memory. In order to find a good compromise between data storing capacity versus length of continuous operation, 20 minutes measuring interval was selected to start with, considered sufficient to capture the wind variability with characteristic time period more than 1 hour. In fact, it is believed that it is close to the minimum duration of a given external forcing to induce a sensible lake-wide response to it.

The wind direction and speed sensors as well as their typical deployment set-up can be seen in Figure 1. The wind vector is measured at high time resolution and vector-averaged values are stored to have more sound information, though in an integrated way, on the time variations. Apart from the average speed, the gust representing short term wind behaviour is also measured and stored.

Reading data out of the data storing units goes the routine way. Raw data needs then some conversion to obtain them in conventional engineering unit. This process is facilitated both with factory-made and other suitable software tools.
5 Measurement sites and periods

The measurement sites as well as their location is seen in Figure 2 and 3, respectively. The site at Kompong Loung (K-L hereafter) was the existing water level gauging station, where the sensor height was at 4 m above the top of the tower. It gave some 15-16 m height above the lake surface at low water, and 7-8 m less when the lake level was peaking. The other station was deployed in the Northwest part of the lake, at the open area – floodplain interface zone, close to Phnom Krom (P-K hereafter at a temporary construction). It was initially at 9 m height above the lowest water level, but had to be moved higher and elsewhere to avoid damaging by the rising water. In its second place it was at 6-7 m above the highest water level. As seen in the photos, the sites were expected to provide information also about the pelagic and littoral wind conditions.

Valuable data collection started late July at P-K and early August at K-L. Unfortunately, after about three weeks the direction measurements at P-K went wrong and from that time on practically speeds are available only. New direction sensor was installed on October 12. However, even the short overlapping made it possible to carry out at least some preliminary investigation on the simultaneous wind behaviour. The continuous, good quality, nearly three months long vector time series at K-L could, nevertheless, serve as a firm basis for directional analysis and spectral decomposition in order to find the characteristic time scales of the wind variability both in terms of direction and momentum, the latter driving most of the lake hydrodynamics, as briefly discussed earlier.
Figure 2. Wind measurement sites: lake station at Kompong Loung (left) and near-shore station at Phnom Krom (right).

Figure 3. Layout of the measurement sites at Tonle Sap. Kompong Loung (K-L) in South-East, Phnom Krom (P-K) in North West.

6 Wind shear stress on the lake surface

Before analysing the collected data it might be useful to give a quick overview of the theoretical and semi-empirical relationships leading to a reasonable estimation of the strength of the momentum flux from the wind to the lake, that is the surface wind shear stress. Once doing that, one will have a better insight to the order of approximation provided by single point wind measurements of given fix height, or even at variable one if the lake water level changes substantially.
6.1 Lake surface roughness conditions

It is probably due first to Charnock (1955) to relate the effective height $h_i$ of the roughness elements of the wavy lake surface to the so-called friction velocity $W_i$ and gravity $g$ as follows:

$$h_i \approx \frac{W_i^2}{g}.$$  (1)

When estimating it for average conditions it leads to a value about 0.01 m which is much larger than the typical thickness of the so-called viscous sub-layer in the air with viscosity $\nu_a$ and friction velocity of 0.30 m/s derived as

$$\delta_v \sim \frac{\nu_a}{W_i} \approx 5 \cdot 10^{-5} \text{ m}.$$  (2)

One can calculate a so-called roughness Reynolds number $Re$ as a combination of (1) and (2) giving

$$Re = \frac{W_i h_i}{\nu_a} = \frac{W_i^3}{g \nu_a},$$  (3)

which goes beyond 100 for practically all reasonable value of the friction velocity.

Therefore, the lake surface is generally in aerodynamically rough conditions. It was later concluded by Wu (1994) by analysing a combined set of data that the water surface reaches its least rough state at about 5 m/s, a transition range from capillary to gravity waves, and becomes rougher when either increasing or decreasing in speed. In the upper range, the so-called roughness height $z_0$ due mainly to the shorter waves on the lake surface can be considered simply as

$$z_0 = \alpha h_i,$$  (4)

providing the well-known, widely used Charnock-formula

$$z_0 = \alpha \frac{W_i^2}{g},$$  (5)

with $\alpha$ as a coupling parameter, occasionally considered to be calibrated, however, providing reasonable results with a value 0.0185, as given by Wu (1982). Recently, a lot of effort has been put into linking the aerodynamic roughness height more directly to the wave conditions, but a overall formula has not come out to date.
6.2 Near-surface wind profile and the wind drag coefficient

Once the roughness height is estimated, without significant differences between air and water temperature that is in neutral stratification at the interface, the vertical distribution of the near-surface, horizontal wind speed \( W(z) \) in terms of height \( z \) above the lake surface obeys the well-known logarithmic law as follows:

\[
W(z) = \frac{W_0}{\kappa} \ln \frac{z}{z_0}, \quad (6)
\]

where \( \kappa \) is the von Kármán constant equal to 0.4. In fact, it starts with zero speed at the roughness height with sharp initial increase, which becomes then more and more gentle with height. Note that this relationship makes it possible to determine both the roughness height and the friction velocity from wind speed measurements taken in one vertical at different heights.

The ratio of the square of the friction velocity and that of the wind speed at \( z \) is known as the aerodynamic drag \( c_z \), corresponding to the given height (see e.g. Plate and Wengefeld, 1979; Graf and Prost, 1979). Using (5) and (6) it is expressed as

\[
c_z = \frac{W_c^2}{W_z^2} = \frac{\kappa^2}{\left( \ln \frac{z}{z_0} \right)^2} = \frac{\kappa^2}{\left( \ln \frac{zg}{\alpha W_s^2} \right)^2}. \quad (7)
\]

The customary wind measurement height is usually 10 m for which the drag formula, combining (5), (6) and (7) is

\[
c_{10} = \frac{W_{c10}^2}{W_{10}^2} = \frac{\kappa^2}{\left( \ln \frac{10}{z_0} \right)^2} = \frac{\kappa^2}{\left( \ln \frac{10 g}{\alpha W_s^2} \right)^2} = \frac{\kappa^2}{\left( \ln \frac{10 g}{\alpha c_{10} W_{10}^2} \right)^2}. \quad (8)
\]

Collecting and analysing a number of data from various sources, Wu managed to derive the following linear relationship between the wind at 10 m and corresponding drag coefficient (see e.g. Wu, 1982), proved reasonable from breeze to hurricane:

\[
c_{10} = (0.8 + 0.065W_{10}) \cdot 10^{-3}. \quad (9)
\]

Surface wind shear stress and input work rate estimation

Now using the relationship

\[
W_s = \sqrt{\frac{\tau_s}{\rho_a}}, \quad (10)
\]
which by definition links the friction velocity to the surface wind shear stress $\tau_s$, and air density $\rho_a$, a series of formulae can be set up all expressing the shear stress in various combination as follows:

$$\tau_s = \rho_a W^2 = \rho_a c_{10} W_{10}^2 = \rho_a \left(\frac{\kappa^2}{\ln \frac{10}{z_0}}\right) W_{10}^2 = \rho_a \left(\frac{\kappa^2}{\ln \frac{10g}{\alpha W_s^2}}\right) W_{10}^2, \quad (11)$$

As an important outcome of the above reasoning, note that by using (5), (6), (9) and (11) the whole set of parameters (friction velocity, roughness height, drag coefficient), finally the wind shear stress and the wind profile itself can be determined in an iterative way, based on wind speed measurements taken at one single, arbitrary, though representative height, provided the boundary layer structure above the lake is developed at least as far as the measurement height. In other words, we are in principle free to choose the anemometer height, which is a great help in most field conditions, when facing severe deploying constraints, or if significant, though slow water level changes occur, both of them relevant to TONLE SAP.

Once the wind speed and the drag coefficients are determined, the local specific value of the rate of work of the wind on unit area of the water surface can be estimated as

$$E_s = \rho_a c_{10} W_{10}^3. \quad (12)$$

If these parameters are known not only locally but all over the lake based on measurements or some functional expansion, the total available work per unit time can be obtained by integrating the specific values over the entire lake surface $A$ as

$$E_{s,t} = \int_A E_s \, dA. \quad (13)$$

7 Analysis of the measurements

In the analysis presented below, as a first approach wind speeds are processed as they were measured, without vertical transformation. All the complete, valuable data set is presented and mainly its temporal and directional structures are looked for. At this stage, however, no selection of long or short term wind events, prevailing from hydrodynamic point of view and worth using as initial model input is made.

The methods used for the analysis are meant to be used all over the present project to handle vector-type time series such as the wind and water currents (Krámer and Józsa, 1998), furthermore, specific water and sediment discharges, or in the wider sense the flux vectors of any kind of measured or calculated substance in the water.
7.1 Methods of analysis

The data processing consists primarily of the special filtering of the measured vector time series, which are then displayed in two ways: as vector time series representation along the time axis or in their directional distribution, the latter using various quantities for weighting. Note that due to some software constraints the 20 minutes raw data were first made twice as dense (that is 10 minutes) by means of appropriate interpolation.

7.2 Low- and band-pass filtering

In order to decompose the wind vector time series to characteristic elements representing any pre-selected range of their kinetic energy spectra over the time period, appropriate numerical filtering techniques are applied. In the present study a Kaiser-type filtering algorithm is used for the so-called low and band-pass filtering of the data. Low pass filtering stands for removing variability with characteristic frequency higher or corresponding time period shorter than a prescribed cut-off value, thus preserving the parts varying slower than that. Band-pass filtering aims at preserving elements with periodicity falling into the range within two chosen cut-off values. Using subsequent ranges the time series can be decomposed into their harmonics, representing different portion of the total kinetic energy content.

This technique makes it possible to find the compounds of the wind most relevant from the energetic point of view for a lake with characteristic response time scale to turbulence, wave, seiche and circulation generation (see e.g. Findikakis and Law, 1999; Luettich et al., 1990; Józsa et al., 2000). In doing so, low-pass filtering removing the compounds with less than 1 hour periodicity, band-pass filtering with 1-3, 3-6, 6-12, and 12-36 hours ranges, as well as filtering providing the compounds with larger than 36 hours periodicity, representing the slowly varying background air flow have been applied. It is the 12-36 hour range that is thought to indicate a daily variability primarily of thermal origin if there is any.

7.3 Vector time series representation

One of the appropriate displaying methods of the raw or filtered data is their vector time series representation along the time axis. In the version adopted here the vectors lay with their foot on the axis and point away from it, but no arrow head is used to avoid disturbing graphical overlapping. At the beginning of the axis a reference scale is given in m/s. Note that vectors represent values valid at the time at there foot point, which needs some care to find at places.

7.4 Directional distributions

The most traditional way to present wind statistics is the so-called wind rose, which gives the simple directional distribution of the wind vectors. Note that by convention the frequency values in percentage are put in the direction where the wind was
blowing from. Once weighting the calculus by the wind speed and its square, one obtains the wind route and energy distribution, respectively. The first is applied usually in air pollution studies where it is important to know the directions to propagate at the largest distances. For lake hydrodynamics, however, the wind energy distribution (a term inherited from the general kinetic energy formula), proportional in fact with the surface wind shear stress is relevant. In the present study the total circle is split into 16 sectors providing 22.5° resolution.

7.5 Evaluation

As to the general characterisation of the wind activity and the order of magnitude of the speed in the measurement period, one could hardly find any calm interval, though the speed seldom approached 10 m/s. The gusts proved about twice as large as the 20 minutes averages, implying high, probably short term instability in the air flow.

Going through the figures in the order they are attached to the report, first Fig. 4 shows the vector time series of the initial measurement period at P-K, when only that single device operated. As can be seen the decomposition resulted in elements of rather distinguishable character. The short time scale (say below 6 hours) elements seem quite episodic whereas the larger scale compounds show much more periodic behaviour, all of them superimposed onto a slowly varying base air flow.

In Fig. 5 and 6 the joint representation of the time series of the whole overlapping measurement time interval is given. What comes out again is that apart from the slowly varying compound, a pronounced, more or less daily periodicity can be detected especially at K-L.

Taking a look at the directional distribution of the rather short but valuable measurement period at P-K, WSW direction prevails, according to the general tendency of the summer monsoon. The various ranges of the spectra do not show significant orientation (being either chaotic or just random in direction) except perhaps to the one containing the daily variation with a N-S dominance, which could be probably explained by the origin of the differences in the warming up of the earth surface. Once the substantial periodic elements are removed, the background air flow becomes even more dominating in the distribution.

The joint representation of the directional distributions for the overlapping measurement period is given in Fig. 7-9. What can be seen is a more than 30° deviation of the direction on average, which might be explained by the large distance between the two sites, and the fact that they are usually exposed to the wind opposite to each other, that is either the upwind or downwind lake side, thus influenced quite differently by the lake micro-climate. Anyway, site K-L shows much more Westerly prevailing wind direction, which remains then so all over the summer measurement period, seen a bit later here. The orientation of the fluctuations with time period larger than 12 hours is strong in the NNE-SSW axis at P-K, whereas less pronounced at K-L.

In order to take a better insight into the details, a two day display of the overlapping period is shown for 3-4 August (Fig. 10-11). One can see the clear, energetic presence
of a daily periodicity, with shorter, episodic, thus as a whole less energetic compound, all “riding” on a slowly varying air flow coming from WNW in this particular case. Similar partitioning can be seen in Fig. 12-13, however, with a SW background air flow this time. Time shifts between the two sites are occasionally significant, due most probably to the distance too large for such wind duration to dominate simultaneously at both places. Occasionally large amplitude short term variations occur in the long term time series, but as a whole the daily variability in amplitude dominates, often even exceeding the magnitude of the slowly varying background air flow.

During the entire measurement period only the slowly varying compound shows clear prevailing directionality, which dominates also when all the compounds are taken into account. However, since the August-October period covered the final period of the summer monsoon and then part of the seasonal turnover, the data were analysed also in monthly intervals, resulting expectedly in more homogeneous behaviour. As one would have expected, a clear change can be observed in October in the slowly varying background air flow turning from Westerly to Easterly direction. Visible orientation is present in the daily variability, with significant differences between the months. August is characterised with an energetic fluctuation along the WNW-ESE, September along the NNE-SSW (though the latter is weaker) and October along the ENE-WSW axes. They certainly do not coincide with the axis of the prevailing, slowly varying wind compound.

8 Conclusions and recommendations

Valuable information could be gained on the wind at time scales relevant in lake hydrodynamics even analysing only the first, rather short period of the ongoing field measurement at TONLE SAP. A characteristic daily variability has been identified superimposed on a slowly varying background air flow, according to the given monsoon season, coloured then by short term, episodic wind fluctuations. Formulae for transforming the wind from anemometer height to 10 m, thus making it possible to estimate the surface wind shear stress are outlined, provided nearly neutral stratification as well as surface boundary layer developed at least as far as the anemometer height over the lake hold.

However, for off-shore winds measured at relatively high near-shore sites, a more robust vertical transformation may be established by taking into account the evolution of a so-called internal boundary layer due to the abrupt change in surface roughness at the lake shoreline (Garratt, 1990; Taylor and Lee, 1984). In fact, this phenomenon alone, furthermore, occasionally modified by large air-water temperature differences (see e.g. Liu and Schwab, 1987) and topographic effects, may create significant fetch dependent wind (Scherzter et al., 2000) and wind shear stress irregularities, especially in the first couple of km (Sarkkula et al., 1991; Józsa et al., 1998; Józsa et al., 1999). Once properly scaled for the lake, taking into account the vegetation-related roughness of the land and the floodplain zone, a reasonable estimation of the wind shear stress field can be established resulting hopefully in hydrodynamic modelling of enhanced accuracy. Unlike at some other shallow lakes (see e.g. Shanahan et al., 1986; Józsa et al., 1990; Jinxiu et al., 1999), at TONLE SAP the relatively flat
surrounding terrain makes it possible to disregard large scale topographic effects in the estimation. Nevertheless, wind and wind stress conditions in the floodplain zone where the inundated surface is either sheltered from or exposed to the wind also in a very patchy way due to the vegetation cover, remain another problem to parameterise properly (see e.g. Starosolszky, 1983).

Having obtained a first insight into the basic time structure of the wind at TONLE SAP, it seems also feasible to generate even very long, realistic wind time series preserving the main statistical features derived from measured data, as model input for long term scenario analysis of the fate of the lake (Józsa et al., 2000).

9 References


10 Figures of wind vector time series and directional distributions
Figure 4. Wind vector time series at Phnom Krom representing the following time period ranges of the spectra in hours (from top to bottom): > 1, 1-3, 3-6, 6-12, 12-36, > 36.
Figure 5. Simultaneous wind vector time series at Kompong Loung and Phnom Krom representing the following time period ranges of the spectra in hours (from top to bottom): > 1, 1-3, 3-6.
Figure 6. Simultaneous wind vector time series at Kompong Loung and Phnom Krom representing the following time period ranges of the spectra in hours (from top to bottom): 6-12, 12-36, > 36.
Figure 7. Directional distributions at Kompong Loung and Phnom Krom in the simultaneous measuring period, representing the following time period ranges of the spectra in hours (from top to bottom): > 1, 1-3.
**Figure 8.** Directional distributions at Kompong Loung and Phnom Krom in the simultaneous measuring period, representing the following time period ranges of the spectra in hours (from top to bottom): 3-6, 6-12.
**Figure 9.** Directional distributions at Kompong Loung and Phnom Krom in the simultaneous measuring period, representing the following time period ranges of the spectra in hours (from top to bottom): 12-36, > 36.
Figure 10. Simultaneous wind vector time series at Kompong Loung and Phnom Krom representing the following time period ranges of the spectra in hours (from top to bottom): > 1, 1-3, 3-6.
Figure 11. Simultaneous wind vector time series at Kompong Loung and Phnom Krom representing the following time period ranges of the spectra in hours (from top to bottom): 6-12, 12-36, > 36.
Figure 12. Simultaneous wind vector time series at Kompong Loung and Phnom Krom representing the following time period ranges of the spectra in hours (from top to bottom): > 1, 1-3, 3-6.
Figure 13. Simultaneous wind vector time series at Kompong Loung and Phnom Krom representing the following time period ranges of the spectra in hours (from top to bottom): 6-12, 12-36, > 36.
WATER QUALITY AND BIOLOGICAL DATA

1 Intercalibration of water quality analyses

The WUP-FIN team initiated water quality sample collection and measurements in the Tonle Sap area right from the beginning of the project in June 2001, in close cooperation with the Ministry of Water Resources and Meteorology (MWRM). The existing data from the Tonle Sap lake is very limited and practically non-existent from the flood plains and the tributaries. The samples have been analyzed at the MWRM laboratory according to the standards of the national WQ sampling programme supervised by the MRCS/Environment Programme. One of the main concerns in the monitoring work has been the quality of the laboratory analysis data. This concerns especially the nutrients, which are of central importance in the water quality and biological process description and modelling work of the WUP-FIN project. That is why the Finnish team has proposed a close cooperation with the Environment Programme to proceed quickly in the data quality assurance. As a first step in comparing the laboratory analyses results, two intercalibrations were organised by WUP-FIN team in autumn 2001 between the laboratories of MWRM, MEDPC and FEI. Two sets of two separate natural samples were collected in October 8 and 21, transported on ice and analysed in the laboratories within the following 24 h. The sampling locations were Mekong River, Tonle Sap River, and the Great Lake near Kompong Loung. The intercalibrated parameters were NO3-N, NO2-N, Tot.N, NH4-N, PO4-P and Tot.P (Table 1).

The results of the first intercalibration in October 8 were relatively good in general. There was a methodological difference in the sample treatment for total nutrient analysis between MWRM and FEI. In MWRM the total nutrient samples were filtered before the analysis, and thus the results lack the fraction of particulate nutrients. These values representing total dissolved nutrients are given in italics in the Table 1. The clearest differences were observed in the results of NH4-N, PO4-P and Tot.P analysis between MEDPC and the other two laboratories.

The second intercalibration in October 21 resulted much higher variation in the NO3-N results than the first intercalibration. The results of MWRM and FEI are already confirmed by the laboratories and no obvious reason for the high variation was found. One possible explanation is confusion in the samples sent to the laboratories, so that the laboratories have analysed replicates of a same sample instead of two different samples. The PO4-P values by MEDPC differed again from the other results. In addition MEDPC PO4-P and Tot.P values are almost identical in all four samples on the contrary to the other laboratories.

In both intercalibrations, the PO4-P results by MWRM and FEI were quite similar. Because the primary production of the Great Lake is likely to be more often phosphorus than nitrogen limited, reliable PO4-P analytics by MoWRAM gives a relatively good basis for further ecosystem studies. Intercalibration will be further continued between the laboratories of MWRM and FEI by analysing synthetic samples in December 2001.
In order to promote the laboratory development, different views expressed on the laboratory improvement have been collected in the ANNEX 4 as a basis for further discussions and measures. It can help specialists to find solutions for improved analysis quality. Many of the necessary measures are in any case quite simple and relatively cheap.

Despite the observed uncertainties and expressed doubts of the laboratory results, the experience of the WUP-FIN team is that the existing and newly collected WQ data, produced by MWRM laboratory, is useful and gives a reasonable background for elaborating the water quality process descriptions and model development in the lake. The committed attitude of the laboratory staff also gives an encouraging starting point for further developments and improvements in the laboratory.

2 Water quality analysis in 2001

Altogether 270 samples have been collected during the summer and autumn of 2001 for analysis of nutrients and total suspended solids (TSS) and other WQ variables according to the national programme in the laboratory of MWRM. The sampling sites are shown in Figure 1. Chlorophyll-a has been analysed from 20 of the lake samples. Only part of the total amount of the samples (70) has been collected in the Great Lake, while most of them (200) represent small and medium size rivers pouring to the Great Lake as well as the Tonle Sap river. The sampling points represent 91% of the catchment area water of the small rivers entering the Great Lake. For quality assurance of the sampling procedure, cross sections of water quality were analysed in rivers of St. Sangke and St. Sen. Water quality variations were observed between the samples, but without consistent pattern between the sides and the middle of the stream. The preliminary results indicate that temporal integration of several samples could be preferable to diminish variation in the results. Water samples were also taken upstream and downstream of the main towns to observe the influence of municipal loading. The differences between samples were, however, quite low and not systematically indicating any point source load from the municipalities. This may be due to the fact that the load tends to discharge to the rivers in an intermittent way during rainy days. In the near future plans the long term measurement of some of the water quality parameter variability in the tributaries is included.

In addition to laboratory analysis, field measurements have been carried out with help of Marvet Junior oxygen probe. It has been used to record 30 oxygen profiles in the open Great Lake, flooded forests and rivers. Hourly time series of DO, turbidity and pH were recorded with two unattended YSI6000 multiparameter environment sensors located in the Kompong Loung water level measurement tower and in the middle of flooded forest ca. 20 km north of Kompong Luong.

The highest values for nutrients and TSS were generally reached at the beginning of the measurement period in June, when the water level started to rise. The high values of TSS indicate that at the beginning of the wet season the pelagic primary production of the Great Lake is more likely to be light than nutrient limited. When the concentration of TSS stated to decrease due to sedimentation in late July improving the light availability
for phytoplankton, the concentration of PO4-P rapidly dropped close to the detection limit of conventional laboratory analysis (Figure 1). While PO4-P was consumed close to zero, the availability of DIN (NO23-N and NH4-N) stayed good. This indicates that when light conditions are adequate for primary production, the first limiting nutrient is more likely to be phosphorus than nitrogen.

The chlorophyll-a concentrations varied between 0.3-14.0 with average of 4.5 ug/l without any clear temporal pattern. The values are relatively low indicating that development of phytoplankton blooms may be controlled in the Great Lake by effective grazing.

Short term evolution of TSS concentration can be seen in the unattended turbidity measurements carried out in the Kompong Loung water level measurement tower (Figure 2). The pH measured on the same site gives us an indication of the intensity of primary production. Both the daytime uptake of CO2 and night time respiration of phytoplankton alters pH of the surrounding water mass. The higher the diurnal variation of pH, the higher the primary production. Figure 4 shows the difference between daily maximum and minimum pH. The highest peaks of diurnal pH variation take place when turbidity goes below 10 NTU units (see Figure 3) indicating the importance of light limitation for the pelagic primary production. Turbidity increased again in the end of the measurement period due to resuspension caused by strong winds.

In August and September the PO4-P concentration remained steadily at a relatively low level, but the concentration of DIN continued to decrease. It is possible that the pelagic primary production is maintained by effective phosphorus recycling. One explanation for the decreasing DIN concentration is that on the contrary to phosphorus, part of the regenerated nitrogen can be denitrified back to atmospheric N2 which is not any more available for most of the algae. The more nitrogen is recycled the higher share of the original amount can be denitrified.

Because of the uncertainty of the reliability of the nitrogen analysis, especially NO3 analysis, we cannot be sure about the absolute nitrogen levels at the end of the sampling period. It is possible that the analysis results by MWRM indicate too high DIN concentrations. If this is true, it may be possible that also nitrogen can be consumed close to zero in the Great Lake. If this is the case, there may emerge nitrogen fixing activity in the form of increasing biomass of heterocystic cyanobacteria during the beginning of the dry season. The microscopic analysis of the collected phytoplankton samples will answer this question later on.

Visual observations and Secchi depth measurements carried out around the Great Lake indicate that sedimentation of TSS is likely to be faster in the vegetation covered flood plains and flooded forests than in the open parts of the lake. The most plausible explanation for this phenomenon is the wave action and current hampering effect of the submerged vegetation, which may also prevent resuspension of already settled sediment material.

According to the oxygen measurements, the open parts of the Great Lake stayed throughout the measurement period well oxygenated from surface to the bottom, and no long term stratification was observed. In the vegetation covered parts of the lake, like flooded forests or other vegetation covered areas where the movement of water is
restricted, oxygen is occasionally consumed to zero in the whole water column. The conditions in the floodplain are shown in the figure 5.

According to unattended measurement carried out in the flooded forest close (200m) to the border of the open lake, anoxic periods did not generally last longer that 24 h at a time (Figure 6). However, our monitoring site represents a transition area where either the water masses of the open lake or from the floodplain can prevail and thus the changes in the oxygen saturation were fast and prominent. It is possible that anoxic period are considerably longer on the floodplain further from the open lake. A transect of oxygen profiles from Battambang along St. Sangke to the Great Lake and finally to Pnom Krom recorded October 3 2001 shows clearly the spatial variation (Figure 7). Oxygen conditions were good in the river and the open lake, but anoxia was frequently observed on the flooded fields. Additional profiles and their locations are drawn in figure 8.

3 Preliminary nutrient and suspended solids balances

First attempts to calculate nutrient and TSS balances for the Great Lake are based on water balance calculations by Carbonnel & Guiscafré (1963), water quality analysis in the Tonle Sap river (Kompong Chhang) by MRC in the year 2000 and our own water quality analysis in the small rivers during May – September 2001. No information has yet been available on direct nutrient loading to the lake by communities or by atmospheric deposition.

The TSS-balance shows that the Great Lake annually retains ca. 4 300 000 tons of suspended solids. This means a sediment load of ca. 500 g/m2 considering the average lake area to be 8 500 km2, and a yearly sediment accumulation of ca. 0.25 mm when considering the density of the packed sediment to be close 2 kg/dm3. According to our water quality data, sedimentation seems to be facilitated by the vegetation cover of the flooded areas. This may indicate that sediment accumulation could be higher in the flooded areas compared to the open parts of the Great Lake.

Phosphorus balance can be calculated both by using the results of PO4-P analysis and the analysis of total dissolved phosphorus. In both cases the Great Lake seems to retain phosphorus; 850 tons of PO4-P and 1 350 tons of total dissolved phosphorus per year. These both values are probably clear underestimates, because we lack information on the municipal nutrient loading. However, our preliminary values can be compared to the fish production of the lake, which is estimated to be 230 000 tons/y (Baran et al. 2001). If we assume the phosphorus concentration of the fish biomass to be 0.5%, the amount of phosphorus removed yearly with the fish biomass would be 1 150 tons.

Nitrogen balance was based on combined results of NO3-N and NH4-N analysis. It shows that the Great Lake retains 8 500 tons/y of dissolved inorganic nitrogen. In addition to the municipal loading, the importance of atmospheric deposition can be considerable in the case of nitrogen. Thus our preliminary estimate is a clear underestimate. If we assume the nitrogen concentration of the fish biomass to be 2.5%, the amount of nitrogen removed yearly with the fish biomass would be 5 750 tons.
Even though our preliminary nutrient balance calculations have serious gaps in the loading information and we know that part of the fish catches consists of migratory species, it can be already stated that a remarkable part of the nutrients retained in the Great Lake ends up to the fish biomass. This also indicates that a major part of primary production of the Great Lake is channelled to the fish production.

**Table 1. Results of the intercalibration between MoWRAM, MEDPC and FEI.**

**INTERCALIBRATION #1 OCTOBER 8 2001**

<table>
<thead>
<tr>
<th>Laboratory Sampling location</th>
<th>MoWRAM Mekong River</th>
<th>MEDPC Mekong River</th>
<th>FEI Mekong River</th>
</tr>
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<tr>
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</tr>
<tr>
<td>Tot.N (ug/l)</td>
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</tr>
<tr>
<td>NH4-N (ug/l)</td>
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<tr>
<td>PO4-P (ug/l)</td>
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<td>Tot.P (ug/l)</td>
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<td>Sampling location</td>
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<td>Tonle Sap River</td>
<td>Tonle Sap River</td>
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**INTERCALIBRATION #2 OCTOBER 21 2001**

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Figure 1. Map of the sampling sites.
Figure 2. Evolution of PO4-P, DIN and TSS concentrations in the Kompong Loung sampling station (KGL1) and in the middle of the Great lake.
**Figure 3.** Evolution of turbidity in the Kompong Loung sampling station (KGL1) recorded by unattended YSI6000 multiparameter environment sensor.

**Figure 4.** Diurnal pH variation in the Kompong Loung sampling station (KGL1) calculated on the base of data recorded by unattended YSI6000 multiparameter environment sensor.
**Figure 5.** Conditions in the flooded forest. Left inside the forest, middle near the open lake and right view from the lake. Observe the calm conditions in the forest compared to the open lake.

**Figure 6.** Variations of oxygen concentration in the flooded forest recorded by unattended YSI6000 multiparameter environment sensor.
**Figure 7.** Transect of oxygen saturation profiles from Battambang to Siem Reap on October 3 2001.

**Figure 8.** Some additional profiles from the floodplain and the lake. The Bakpria site is indicated as BKP1 in the map. The two profiles on the right side are from the eastern basin- in the middle part (WP4) and from the flooded forest at the northern flood plain boundary.
4 Yearly water quality cycle

Figure 9 shows the yearly cycle of water quality from Backprea sampling site. Currently there are altogether 1100 samples in the project database from various points of the river, Tonle Sap lake and Mekong.
Figure 9. Dissolved oxygen, pH, Chl-a and SS from the Backrea sampling station. Beginning of the measurements July 24. 2001.
5 Automatic recordings of daily variations in the Tonle Sap Lake

5.1 Data

The variation of water temperature, specific conductivity, dissolved oxygen, water depth (pressure), pH and turbidity were recorded with recording water meter YSI 6000 every half an hour at two places, viz. at Kompong Loung (point KGL1 in figure 10) and on its opposite northeastern coast at Pim Bang ca. 300 m inside the flooded forest at 3 m’s depth (point PBG1 in figure 9). Recordings of wind velocities (average and gust speeds), wind direction, humidity, solar irradiation and air temperature were simultaneously continued every 20 minutes with the Aanderaa Weather Station off Kompong Loung floating village.

Figure 10. Location of the most important sampling points.
5.2 Results

The weekly results of dissolved oxygen and pH variations at Pim Bang together with wind, radiation and temperature records are shown in Figs. 11 – 13 for the first period of recordings from noon October 20 until noon November 14, 2001, i.e. in the time of the highest water level.
pH, Oct. 24 - 31, 2001

Solar Irradiation, Oct. 24 - 31, 2001

Turbidity, Oct. 24 - 31, 2001
**Fig. 11.** Wind directions, wind velocities $W_S$ and gust speeds $W_{gust}$, dissolved oxygen concentrations, pH, solar irradiation, turbidity and water depth recorded at Pim Bang and Kompong Loung in October 24 (from noon) – November 31, 2001.
Wind Direction, November 1 - 7, 2001

Wind Speed, Nov. 1 - 7, 2001

Dissolved Oxygen, Nov. 1 - 7, 2001

WS (m/s)  Wgust (m/s)

YSI-PimBang DO %  YSI-KGL O2 %
**pH, Nov. 1 - 7, 2002**

- YSI-PimBang pH
- YSI-KGL pH

**Solar Radiation, Nov. 1 - 7, 2002**

**Turbidity, Nov. 1 - 7, 2002**

- YSI-PimBang Turb NTU
- YSI-KGL Turb NTU
Fig. 12. Wind directions, wind velocities WS and gust speeds Wgust, dissolved oxygen concentrations, pH, solar irradiation, turbidity and water depth recorded at Pim Bang and Kompong Loung in November 1 – November 7 (noon), 2001.
Wind Direction, November 7 - 14, 2001

Wind Speed, Nov. 7 - 14, 2001

Dissolved Oxygen Nov. 7 - 14, 2001
**pH, Nov. 7 - 14, 2001**

- YSI-PimBang pH
- YSI-KGL pH

**Solar radiation, Nov. 7 - 14, 2001**

**Turbidity, Nov. 7 - 14, 2001**

- YSI-PimBang Turb NTU
- YSI-KGL Turb NTU
Fig. 13. Wind directions, wind velocities WS and gust speeds Wgust, dissolved oxygen concentrations, pH, solar irradiation, turbidity and water depth recorded at Pim Bang and Kompong Loung in November 17 – November 14 (noon), 2001.

6 References


SCENARIO APPLICATIONS AND EVALUATION (TASK 4) FOR GUIDELINES DEVELOPMENT (TASK 5)

(definition of the links between water regime, environmental indicators and socio-economic functions; translation of model results into agricultural, navigational and ecological impacts; assessment of the impacts of the likely development scenarios on the hydrological, hydraulic and water quality aspects of the Great Lake and on the ecology of the system; developing guidelines for water quality and pollution control strategy for the Tonle Sap Lake)

1 Ecology and impact assessment

1.1 Introduction

Subtask “Ecology and impact assessment” started in November 2001 with two short fieldtrips (Kompoung Thom and Siem Reap) and data analysis (Data Report).

Present research is focused especially on “Definition and quantification of links between hydrography and environmental indicators”. The tasks include:

1. Collection and analysis of satellite data and other aerial photos
2. Determination of the areas of different flooding, soil-type, vegetation cover and exposure.
3. Import of data into GIS
4. Determination of composition and proportion of key-biotopes (habitats)
5. Analysis and synthesis of the local people interviews in respect to the habitats and flood properties and their impact on fisheries
6. Determination of links between hydrological regimes and other factors and littoral habitats including fish production.

As a result of data-analysis, relatively good data sets were found including satellite image information and reports of flood-plain vegetation. JICA-land-use classification is based on SPOT-images from November 1996 to March 1997 and offers a solid base for habitat classification. UNESCO Biosphere program has produced a detailed report of plant communities of the area in 1997 (McDonald et al. 1997). Study of Lamberts & Sarath (1997) distinguished some of the most important habitats for fish production and provided also some important biological background information. However, the relationship between water level fluctuation and habitats was partly unclear mainly due to lacking field data, but also for high interference caused by human influence.
Consequently, there was a quite clear need for additional field research and GIS-work to determinate the relationships between the habitats and water level fluctuation.

In July 2002 a field-team consisting of FIN-WUP staff and local experts visited different areas of floodplain and collected information of vegetation cover and main habitat types. Field work was done within two weeks and concentrated on the areas marked in Fig. 10.
Main aim of the field studies were the following:

- To reach a proper view of floodplain zonation by making transect from national road to lake via rivers and/or paths.
- To determinate the key-biotopes and their proportion on the basis of the JICA-land-use classification
- To check the exact borders of most important biotopes.
- To estimate the situation of the most invasive species (Mimosa, Eichornia) at area.
- To determinate indicator species and status of inundated forest by local interviews

**Fig. 10.** Lake Tonle Sap with different flooding zones. Research sites marked with red dots and observation sites by green dots.
1.2 Results

Habitats

Field study with some additional aerial photos at selected areas showed that JICA classification was relatively valid: largest changes were found at the areas of aquatic vegetation and flooded forest. Time difference (5 years) between the field visit and satellite pictures may be significant in some rapidly growing vegetation types. Especially the zone between the shrub vegetation zone and agricultural areas is varying; these areas were largely classified as abandoned fields covered by grass and shrub. Temporally changes can also occur between (flooded) shrub lands and (flooded) grasslands.

Especially aquatic vegetation has a drifting status (water hyacinth) and therefore rapid changes can occur. In fact aquatic vegetation was completely missing in JICA classes and after field investigation all flooded grass areas situated below elevation between the elevation 1 metre and flooded forests/scrubs were classified as aquatic vegetation. Ground control points in the delta area of the river Stueng Sangkae and lake delta near Chhnok Tru showed that all flooded grasslands situated near water edge, were consisting of emergent and floating aquatic vegetation.

Flooded forests form the most difficult vegetation type to separate. The outlet of the Lake Tonle Sap and especially the delta area nearby which were classified as extensive flooded forest zones are largely transformed to scrublands. On the other hand in the northern part of the lake between Siem Reap and Dei Krahasam well as in the vicinity of Praek Tol the area of the flooded forest is larger. There is a 100-200 m wide zone just above 1.2 m elevation contour (shoreline of Čertezza-survey), which was classified as flooded shrub, but turned out to be the gallery forest. Due to limited possibilities to enter behind flooded tree zone and lack of up-to-date aerial images, it was decided to keep original classification valid.

Based on the field trips, literature and expert interviews following types were distinguished. It should be noted, that it is purely based on JICA-land-use types, which were combined to the functional habitat-groups. Further the habitat groups were linked to elevation model (Čertezza-survey) used in WUP-FIN. Preliminary classification showed the following elevation habitats relationship (Fig. 11).
Fig. 11. Elevation-habitats relationship in Lake Tonle Sap. Habitats modified from JICA-land-use types.

Preliminary classification showed that the floodplain vegetation is highly interfered by human activities. There are different opinions of the origin of scrub-vegetation, but in most places local population stated that it is formed as a consequence of cutting the original forest vegetation for different purposes such as collecting of construction material, fire wood or agricultural production. Some relatively well preserved areas of flooded forests can still been found at the areas, which are protected for fish production purposes.

**Invasive species**

**Water hyacinth**

Water hyacinth is quite common edge forming vegetation in channels, rivers, sheltered bays and later after flooding period among other vegetation. According to local population it has been present since 1980’ies, although in some reports it has been noted to arrive since 1996’ies. Water hyacinth is one of the most troublesome and harmful aquatic weeds, which have been reported causing problems in large lakes, reservoirs and rivers. It favours especially stable standing waters and can cover whole water surface. However, it has never reported to cause problems in the lakes with fluctuating water levels. Interviews of local population strengthened the opinion, that water hyacinth is a minor problem in Tonle Sap. Local population is also widely using water hyacinth for fish attractions and sometimes also as fertilizer of the fields or as a cattle feed.
Giant Mimosa

Giant Mimosa (Mimosa pigra) has caused a lot of problems in tropical Australia and Asia during the last years. It is endemic species from South America and extremely capable to survive in various ecological environments. According to local population it has been seen in the Lake Tonle Sap first in the beginning of 1990. Present field survey showed that it is widely distributed from low-level lake banks (+1.5 m) to the abandoned fields under heavy pasture pressure (+ 6 – 7 m). It can resist inundation for several months and it is able to recover after burning or cutting at various bottom substrates from sand to silt.

Mimosa vegetation was found in diverse places ranging from eroded shorelines to abandoned fields. However, it cannot replace existing vegetation and therefore the areas with dense existing vegetation were practically free of Mimosa. Mimosa pigra has not been invaded in the northern part of the Lake Tonle Sap floodplain, mostly due to the dense vegetation (scrublands, fields) existing on the area. Largest and almost impermeable thickets of Mimosa were found at the areas of abandoned fields circulating in the southern part of the lake. The most abundant Giant Mimosa fields were observed in the Pursat region in areas classified as flooded grass and abandoned fields. Other dense Giant Mimosa stands occur in the delta area of the Tonle Sap. There are also extensive Giant Mimosa areas around Seam Reap.

These areas are pinpointed already in the 1998 by NEDECO (Anonymous 1998b). The report states that Giant Mimosa is only locally problematic in the Tonle Sap area, however on the basis of the field trips it can be said that problems are regionally significant.

Potential area of Mimosa pigra infestation is therefore at least 2 100 km$^2$, which totals 20 % of maximum flooding zone. It can be clearly stated that Mimosa is a major problem, which in addition to natural vegetation cover can also threaten floodplain fishery.

**Impacts and indicators**

Changes in land-use are obviously the most important factors affecting the formation of different habitats. Clear-cutting activities have together with agricultural land clearance caused large changes in natural vegetation types. Indirectly the presence of Mimosa pigra can also be seen as an indicator of human activities, because it covers easily cleared areas. It is therefore very essential that all fields and small scale gardens are kept in their original use. All clearance of vegetation and neglect of rice cropping will offer potential growing area for Mimosa pigra and should be avoided.

Relationship between the water level fluctuation and different habitats are vaguer than in natural ecosystems. Decreased fluctuation of water level will lead to increase of aquatic vegetation and decrease of forest vegetation. Vegetation is mainly terrestrial and therefore unable to act as primary producers under water surface. On the other hand it covers largely the water surface and prevents normal primary production. Anoxia can secure a heavy flux of nutrients and creates reservoir like annual inundation effect.
Therefore the changes in flood durations can effectively change the status of ecosystem and obviously also lower biological productivity.

Typical floating rice varieties are also adapted to rising water level and therefore very sensitive against the changes in water level fluctuation. During the last years several districts have reported huge losses of floating rice production as a consequence of rapidly rising flood. Year 1997-2001 dataset of floating rice production was collected from Ministry of Agriculture. Differences between the yields and different hydrological years were significant varying from 0.9 to 1.8 tn ha-1. On the other hand, the loss of floating rice production measured as a ratio between cultivated and harvested fields correlated negatively with the elevation of flood (Fig 12). During the years of a high flood, significant losses in floating rice production were observed.

![Graph showing relationship between elevation of flood and loss of floating rice](image)

**Fig.12.** Relationship between the elevation of flood (m) and loss of floating rice (%). Loss is calculated as a difference between cultivated and harvested area.

According to preliminary investigations it can be clearly stated that Tonlé Sap floodplain is quite sensitive ecosystem for changes in land-use as well as in changes of hydrology. At least following links were found and selected for further investigation.

- Flooded forests can be found at the lake and river edges, but are in some places transformed to scrubs as a consequence of human activities
- Increased agricultural land-use will increase potential area for Mimosa pigra infestation
- Abandoned fields or areas under high pasture pressure are sensitive for Mimosa infestation
- high flood elevation reduces directly the success of floating rice

2 Socio-economic analysis of Tonle Sap region

The socioeconomic part of the WUP-FIN Project has the following components:

- **Collection and review of existing literature.** A bunch of documents of varying quality is available; still a comprehensive view of overall socioeconomic situation is poor.

- **Collection and analysis of existing data.** Examples include the recent population census and socioeconomic survey which both are openly available as spatial data.

- **Village survey.** A PRA type of approach is used to analyze the local living conditions in a participatory manner. The poverty-laden communities live hand in hand with the degrading environment, causing this destruction partly themselves.

- **Database construction.** A GIS database is constructed on the basis of existing and collected data.

- **A policy model.** A systematic risk analysis of basin development scenarios, key policy options, and consequent environmental and social impacts on different stakeholders and development objectives is carried out.

Main databases found from Tonle Sap area are:

- Population Census of 1998 by the National Institute of Statistics (NIS)
- Socio-Economic Assessment of Freshwater Capture Fisheries: Household Survey (by the Department of Fisheries/MRC)
- Cambodian Socio-Economic Survey - CSES 1999 (by NIS)
- Commune Database (by Seila, 1998-2001)
- Tonle Sap Database (by Oxfam Quebec-America, ~2000)

The village level data is available for all of these databases and is therefore adaptable to GIS.

Besides these more general databases, there exist several other ones having a specific focus on for example food security, nutrition, crop production, health or education. These databases include Demographic and Health Survey (DHS) 2000 by NIS/UNICEF,

There seems also to be a clear pattern between village’s topography and its location related to natural resources. Basically all the villages under the 8-meter contour are situated in proximity of the water bodies, either along Tonle Sap-lake or streams and rivers flowing into it. For villages between 8 and 10 meters this is the case only in western corner of the study area; elsewhere the location of the village does not follow any clear pattern. Villages above 10 meters contour line are normally located along National Roads and in the vicinity of provincial and district headquarters. These headquarters are nearly always situated along the National Roads. This pattern can be used as an indicator to the household types as well: basically all floating villages are situated below 8 meters contour line, and in the zone between 6 and 8 meters most of the villages can be regarded as floating ones.

2.1 Village surveys

Field studies make use of rapid and participatory research methods. Due to the nature of the analysis, the results of the field studies are used to get better understanding of entire study area, not for development of the specific village. The main aim of the study is thus to collect information on different socio-economic indicators, not primarily to concentrate on empowering local people (like basically in PRA). Therefore the approach is more extractive and thus closer to RRA than PRA (Keskinen et al. 2002).

Methods used in the field studies are (in chronological order):

- Key informant interview (semi-structured interview)
- Group discussion (semi-structured interview)
- Participatory mapping (Figure 13)
- Transect walk and observation
- Seasonal calendar and occupational preference ranking
- Time ranking
- Final discussion and analysis of the study

The idea is first to collect more overall information on socio-economic situation through key informant interview. Following group discussion deals especially with issues of livelihood, occupations, natural resources and environmental problems. With the help of this data and information derived from participatory mapping and transect walk, study is
then focused especially on issues of seasonality and recent changes in environment and livelihood. This is done using two different ranking exercises: seasonal calendar and time ranking. In final discussion all derived information is put together and then analysed together with villagers. In this meeting, villagers’ comments on the field study and its results are achieved as well.

**Figure 13.** A participatory mapping session in Prek Takong village in Pursat Province

Different visualisation exercises (mapping and rankings) do not only create a useful final product (map, matrix) but also act as tools for further discussion about the issues of seasonality, environmental changes and causes behind them.

Socio-economic field work and interviews were started in January – March 2002 by detailed collection and analysis of the existing socio-economic data bases (e.g. Population Census 1998 and Household Fisheries Survey (done by the MRCS and the Dept. of Fisheries). In addition, Participatory Rural Appraisal (PRA) type group discussions were carried out in three Tonle Sap villages in April-May to analyze the local living conditions in a participatory manner, looking at indicators like

- occupations and their seasonal variability
- use of natural resources and
- environmental changes.

The surveyed villages were, with different occupational emphasis

- Kampong Preah. Kampong Chhnang province (a floating village)
- Prek Ta Kong, Pursat province (situated on the banks of Pursat River)
- Ansang Sak, Battambang province (situated in the large flood plains)

The results of the village surveys were preliminary analyzed and reported both in English and in Khmer and presented to the MRCS socio-economic staff 26 April 2002 with lively discussion followed. The field study reports have been distributed for comments in the middle of July.
Two examples of the results are shown below on seasonal calendar and occupational ranking (table 3) and time ranking (table 4), as experienced by the field study group of Ansang Sak Village in Battambang province. The seasonal calendar of occupations and environmental factors was done with the group of 17 villagers. Markers (small fruits) using the scale 0-10 were placed in each of the boxes, i.e. villagers decided together which value between 0 and 10 each box gets. Markers indicate abundance or importance of different factors in different months: the bigger number, the more important/abundant the factor. Factors used were decided and agreed together with the villagers.

It is important to notice that the values are comparable only between different months (i.e. within one factor), not between different factors. After seasonal calendar ranking, comparison between different occupations was done through occupational preference ranking. This ranking was carried out in similar way than the actual seasonal calendar. Numbers in parenthesis after each occupation show the results from the preference ranking: the bigger the number, the more important the occupation.

Time ranking was made in a similar way i.e. the values are comparable only between various time periods, not between different factors. Note the steeply declining trend of the villager opinions on the development of environmental and nature resource indicators as well as the level of livelihood. The declining trend over the time axis from before 1990’s until present was even steeper in the two other studied villages.
Table 3. Seasonal calendar and occupational preference ranking in Ansong Sak village, Battambang Province

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2.2 Socio-economic model

The methodology used for this task—Bayesian Causal Networks (Varis 1998, Varis & Fraboulet-Jussila 2002)—is based on the systematic analysis of causal interconnections in a complex environmental-social-economic systems. The objective is to assess risks to various components of the environmental and social system under concern, as consequences of different policy strategies under evaluation.

The social system components consist typically of stakeholders, i.e., different communities and groupings of people that are influenced by the implementation of policies in the studied geographical area. It is not rare that their aspirations and interests are in conflict with one another.

The information from various sources and of varying quality—as outlined above—is condensed in a risk analysis framework, and a multidisciplinary analysis is performed, that reveals the major risks, uncertainties, mismatches of information, and opportunities to find win-win solutions among the various stakeholders and the environment.

At the end of the socio-economic study, a policy model will be used to carry out a risk analysis of basin development scenarios, key policy options and consequent environmental and social impacts on different stakeholders to find win-win solutions among them and the environment. These development scenarios and guideline development tasks will proceed in close co-operation with the MRCS and particularly with the BDP.

2.3 Co-operation between WUP-FIN and FAO/Nature Resource Management Project

A close co-operation contact has been established with the Belgium funded FAO Project “Participatory Natural Resource Management in the Tonle Sap Region”, established in 1995 with the overall objective to “introduce and promote environmentally sustainable integrated natural resources management strategies which aim to improve the socio-economic well-being of the inhabitants of the Tonle Sap basin”. The FAO Project is based in Siem Reap project has given very valuable support and guidance for the planning realisation of the WUP-FIN socio-economic and participatory approaches at the village level.
August 28. 2001

Mekong River Commission Water Utilization Program
Modeling of the Flow Regime and Water Quality of the Tonle Sap
Finnish Environment Institute Consultancy Consortium
(MRCS WUP-FIN project)

Water Quality Measurement Plan Connected to the Discharge Measurement on Tributaries around the Tonle Sap Lake

Background

Government of Japan sponsored MRCS project “Discharge Measurement of Tributaries around the Tonle Sap Great Lake in the Kingdom of Cambodia”, contract No 468/2001, has started the measurements in August 2001. The objective of the project is to carry out discharge measurements at stations on major tributaries of the Great Lake. The work consists of a) surveying of river cross sections and longitudinal profiles, b) discharge measurements and c) checking of staff/slope gauges. The discharge measurements are done between August and December 2001 (see Appendix) 2 – 5 times per month on each of the 19 stations. There are two discharge measurement teams from the Ministry of Public Works and Transport (MPWT) who are traveling around the lake doing the measurements.

Government of Finland sponsored project “Water Utilization Program – Modeling of the Flow Regime and Water Quality of the Tonle Sap” (WUP-FIN) has started measuring the water quality of the tributaries and the Tonle Sap Lake in July 2001. There are four sampling routes – Kampong Loung, Kampong Thom, Siem Reap and Battambang, which will be visited separately. There are altogether 23 measurement stations. The planned sampling frequency is twice a month for each station for August - September, although local conditions and availability of personnel may change this. The weather and water level stations will be serviced during the field campaigns.

Discharge measurements with their high frequency, good coverage of tributaries and possibility to correlate water quality with discharge complement the WUP-FIN measurement program excellently. With a proper training the discharge measurement teams could take water samples and make on-site measurements. The samples can be transferred to Phnom Penh for analysis by taxi or air cargo services.
Objectives

The objective is to gather water quality data during the discharge measurement campaigns.

Data complements national and WUP-FIN monitoring. In WUP-FIN data will be used to calibrate and validate watershed models.

Measurement period

The initial measurement period will cover September 2001. Subsequent measurements will be decided after gaining experience from this first phase.

Personnel and Training

The MPWT field personnel will be primarily responsible for sampling. Ministry of Water Resources and Meteorology (MWRM) laboratory will be responsible for the sample analysis. If possible one person from MWRM should go with each team for the first campaign to train the MPWT people in sampling. MRCS or other experienced people should train the teams for using the MRCS sediment sampler.

Transportation

Two MPWT cars are used for transportation. Samples can be transferred by taxi service or air cargo. This has been proven to work in a field campaign around the Tonle Sap Lake August 27 – September 2 2001. Still another possibility is to use speed boat from Siem Reap.

Specifics of the Measurements

Relative homogeneity of the water quality in the vertical and horizontal can be expected. However this is not necessarily true for TSS. Also homogeneity of the other water quality parameters should be checked if not conclusive evidence of homogeneity is not obtained from the WUP-FIN measurements.

TSS sampling with the MRCS “fish” can be realized either by time- or depth-integration. In majority of cases depth-integration can be used, which is suitable for calculating material budgets. However in all larger tributaries vertical and horizontal profile should be checked at least once by taking additional time integrated point-samples:
- in the vertical surface, middle and bottom
- in the horizontal middle and 0.25 of the total width measuring from the shores.

The other water quality parameters will be analyzed from the “fish” samples also so there is no need to make additional sampling when “fish” is available.
When “fish” is not available in all stations discharge integrated center of the river sample will be taken:

- in 0 – 1 m deep rivers one point sample from 0.6 of the depth (measuring from the surface) is taken
- in 1 – 2 m deep rivers two point samples are taken from 0.2 and 0.8 of the depth; the samples are mixed in equal amounts
- in more than 3 m deep tributaries three point samples are taken from 0.2, 0.6 and 0.8 of the depth and mixed in ratios of 1: 2: 1.

For mixing a bucket should be available.

The samples should be stored in standard ice boxes filled with ice. Ice is readily available in the provinces. The samples should be ideally analyzed within 24 hours of sampling. The analyzed parameters are at least total suspended sediment (TSS) and total nutrients. The sediment analysis procedure must be checked with the experts and the laboratory because there exists different options. When there is no appreciable difference in price all of the standard water quality parameters should be analyzed.

Accurate and clear notes of the following items should be taken:

- arrival and departure times at all sites
- coordinates of the measurement sites
- operations at the measurement sites
- times and descriptions of the measurements
- coding on the water quality sample bottles
- other relevant descriptions of the inundation, water flow, weather conditions, water color indicating source of the water (reddish water from Mekong) etc.

**Action Plan**

Because at this time the flow and material inputs to the lake are at their peak, fast action is important. There are only three necessary actions to be taken:

1) The measurement plan is checked and approved by the CNMC, MWRM, MPWT, MRCS and WUP-FIN experts.
2) The two measurement teams will be provided with necessary equipment (bottles, “fish”, ice boxes, buckets and water samplers).
3) The two teams will be instructed and trained in proper sampling and sample handling procedures. Training for the MRCS sediment sampler (“fish”) will be done in Phnom Penh by experienced persons (e.g. MRCS or Chaktomuk project personnel). Training in water quality sampling will be done by an experienced water quality expert from the MWRM.
Costs

Costs caused by the sediment and water quality sampling will consist of increased work, DSA of the MWRM training person, sample transport and sample analysis. Costs should be shared by the MRCS Environment Program and WUP-FIN.
APPENDIX

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Stations and frequency of discharge measurement in the province of: Pursat, Battambang, Kompong Thom and Siem Reap. Compiled by the MRCS.
Field Measurement Plan around the Tonle Sap Lake August 27. – 31.2001

Objectives of the Field Measurement Campaign

The incentive for the Campaign has come from His Excellency Hou Taing Eng. This is a very important period concerning the Lake because it is receiving the largest amount of material input (water, nutrients, suspended solids, detritus etc.) from the Mekong, tributaries and the floodplain. For fish production this is also the most critical period. For the modeling team the Campaign offers a good opportunity to get acquainted with the specific physical, chemical and biological processes that characterize lake at this important period.

The specific objectives of the Campaign are:

1. Checking of existing topographic data by measuring the location of the shoreline. The existing topographic data can be used to draw lake contour lines corresponding to each water level. The accuracy of these contour lines can be checked in field by measuring the position of the shoreline by GPS.
2. Checking the existing vegetation and land use data by comparing it to observations. Photography along the road will help the documentation.
3. Examining the water flow direction in the tributaries. This will serve as a basic validation data for the models.
4. Examining of the extent of flooding on the side of the road that is further away from the Lake. This will help to estimate extent of flooding from the tributaries or gives some indication about the extent of water flow from the Lake to the surrounding areas when combined with the knowledge about the flow direction of the tributaries.
5. Making water quality sampling where it is feasible. This serves catchment area model calibration and validation and material budget calculations.

Transportation

The team will use CNMC car. The cost of the fuel, driver and necessary repairs will be covered by the WUP-FIN project. The repairs include possible breaks and necessary service but not major accidents which should be covered by car insurance.
Personnel

There are four persons participating in the Campaign:

- Nop Vanna from the CNMC
- Ministry of Public Works water quality specialist
- Teemu Jantunen from the WUP-FIN project
- CNMC driver

In addition there will be persons from the provincial offices who will help the team and facilitate the measurements. Each local officer will travel back to his home base by a taxi when reaching the town where next officer can join the team. WUP-FIN project covers the transportation and DSA for the local officers as well as the other team members.

Measurement sites and specifics of the measurements

The GPS shoreline measurements will be done where it is feasible and possible within the time framework. The guidance of the provincial officers will be invaluable here. The safety of the team members should not be compromised under any circumstances for instance when traveling through land mine areas. The fastest way to the lake may usually be a road, but also boat trips on a tributary to the lake can be considered.

The flow direction observations should be done when the road crosses a tributary.

The water quality sampling measurements should be done at least at the following site near the road:

*Pursat Province*

Boribaur
Stung Peam
Svay Daun Keo

*Battambang province*

Battambang at Battambang
Sisophon at Sisophon
Mongkol Borey at Mongkol Borey
Maung at Maung
Kampong Thom/Siem Reap
Chinit at Kampong Thmar
Sen at Kampong Thom
Staung at Staung
Chikreng at Kampong Kdei
Siemreap at Untac Bridge
Sreng at Kralanh

The water samples will be sent whenever possible to Phnom Penh by a taxi, speedboat or air cargo. The field team is in contact with the laboratory personnel in Phnom Penh by phone so that the laboratory is informed when the samples will arrive in Phnom Penh and can pick them up. The samples will be analyzed in the Ministry of Public Works laboratory. The parameters to be analyzed include at least TSS (Total Suspended Sediments), total phosphorus and total nitrogen. Additional parameters could include pH, NO3+NO2, phosphate, BOD, COD and conductivity. The team saves the samples in ice boxes and tries to send them to Phnom Penh as soon as possible. The additional parameters to be analyzed will be decided by experts in the beginning of the week.

In the major tributaries samples will be taken from the sides and center of the river. The center of the river samples will be taken from 3 different depths: surface, middle and near bottom. This way the spatial homogeneity of the water quality will be checked. When possible there should be also check in the temporal variability of the water quality by sampling in evening and morning also from smaller tributaries. This of course requires that the team will overnight near the sampling site.

It’s important to take accurate and clear notes of the following items:
- arrival and departure times at all sites
- coordinates of the measurement sites
- operations at the measurement sites
- times and descriptions of the measurements
- coding on the water quality sample bottles
- coordinates and times of the photos with numbering of the photos
- other relevant descriptions of the inundation, water flow, vegetation cover, land use etc.

It is impossible to write during the drive!

Travel time

The exact travel times are impossible to fix because of possible road problems and difficulties in estimating the time taken by the measurements. The estimated time is 5 days but the field team should be prepared for 1 – 2 extra days.
Teemu Jantunen  
Remote Sensing and GIS Technician  
MRCS/WUP_FIN

Description of inundation mapping and water quality sampling around the Great Lake Tonle Sap during 27/08 – 02/09/2001.

The aim of the field trip was to map the extent of inundation, to do more comprehensive water quality sampling, to verify the accuracy of the JICA (1999) land use map, to test water sample sending from the field to the laboratory in Phnom Penh and to do other necessary field observations. The field trip lasted seven days (27/09 Monday – 02/09/2001 Sunday) and covered about 15 rivers around the lake, the lake itself in three locations and several sites along the shoreline of the lake. The field trip was done in cooperation with Cambodian National Mekong Committee (CNMC), who provided a 4WD pickup, a driver and field coordinator (Mr. Nop Vanna), and the Ministry of Water Resource and Meteorology (MOWRAM), who provided a water quality specialist (Mr. Chhin Tan).

Inundation mapping was in most cases very slow, because the water level was relatively low compared to year 2000 record floods when the surrounding roads (No5 and 6) were partly inundated. Therefore long distances of paths in very poor condition had to be driven often in walking speed to reach the shoreline. In a couple of occasions local mopeds were used for transport when road too bad for the 4WD pickup. One inundation mapping site mapping usually took from 30min to 1½ hours depending on the distance to the shoreline. Year 2000 record flood extent was also mapped by interviewing the locals to get an idea of its magnitude compared to the present situation. Moreover, in Kompong Thom the local MOWRAM office director had done inundation mapping in the year 2000 and this map was copied.

Comprehensive water quality sampling involved vertical and horizontal cross-profiles from a couple of the rivers and the lake as well as sampling at different times of the day in the same site (evening – morning). Times of water quality sampling were 30 min for one sample and 20 min for any additional samples in the same location, because it takes about 5-10 min to take out all the equipment from the car and to set up the field laboratory etc. Empty drinking water bottles were also used for water samples because the expedition run out of official sample bottles due to the large number of samples taken during the field trip.

Land use map verification was difficult because most common and often the only type of land use along National roads 5 and 6 was paddy fields and closer to the lake everything was inundated. The map verification was done at the same time with other field trip activities and the land use can be verified from by numerous pictures taken from each site. In conclusion it can be said that where the land use map was checked it seemed accurate, reliable and recent.
Wind speed and direction were estimated during the field trip at different times of the day in sampling and mapping sites. At mornings the wind was always completely calm, but a slight breeze builds up during the morning and often 3-5m/s winds are seen at noon and afternoon. Wind direction was most of the NE, but a couple of occasions SW. However, notable is that wind direction was almost always away from the lake. Only one storm was experienced during the field trip (28/9/01 afternoon) and then very strong winds 820-30m/s) and heavy rain occurred.

Water samples were send by using a taxi from Kompong Thom and air freight from Siem Reap and Battambang. Arranging the transport usually took 15min to 1 hour. It was found that taxi is better because it is hard to arrange transport from Phnom Penh airport to the MOWRAM laboratory. However, from distant places like Siem Riep, Sisophon and Battambang it takes long time for a taxi to get to Phnom Penh and therefore reliability of these transports suffer.

Conditions were harsh with poor road conditions along National Roads 5 and 6 and very bad on smaller roads towards the lake. One working day was lost because a bridge was broken and in future field trips these kind of delays has to be prepared for. Boat rental was fairly easy for a reasonable price, but it is hard to find speedboats for faster travel in the lake, which is required especially for longer journeys. Arranging reasonable accommodation was difficult in a couple of occasions, but because the field trip group was not too demanding no problems occurred.

Note: Field trip inundation mapping coordinates and descriptions, water quality sampling sites and land use verification sites can be found from file field_trip_sites2.xls (sheets 1-3), wind conditions from sheet 4 and picture descriptions from sheet 5. Negatives for field trip pictures are in the drawer with other pictures (labelled accordingly). All pictures are already in digital format or scanned into directory wup_fin1/shared/documents/figures/field_trip. About 15 pictures are missing because the film was not developed in time. Field trip site descriptions were also done by Mr. Nop Vanna and these can be found from file Trip around G[1].L.doc.

Field Trip Diary

Monday 27/08/2001 Phnom Penh to Kompong Thom

Observations of the overland flow from Mekong to Tonle Sap were made along the National Road 6. One meter difference in water level between the Mekong and Tonle Sap sides of the Road 6 was noticed and therefore a very rapid flow took place from Mekong to Tonle Sap under the larger bridges. In addition, there are 15-20 smaller bridges in the beginning of the Road 6 where overland flow take place from Mekong to Tonle Sap. Water sampling was done in Stung Chinit and Stung Sen (Kompong Thom). In Kompong Thom more extensive sampling was done with one sample from upstream the town and a cross-profile (4 samples) from downstream of the town. Flood extent mapping was done with the local observer, but there is no road extending far enough towards the lake to enable this and only a canal leading to the lake was found. Year 2000 peak flood extent mapping was done by the head of the local office of MOWRAM (Mr. Cheat Syvutha) and it was copied on JICA 1:100,000 map. This
year the flood extent is going to be mapped by Mr. Cheat Syvutha with a handheld GPS receiver.

Tuesday 28/08/2001 Kompong Thom to Stuong

One more water sample was taken from downstream Kompong Thom to see if possible diurnal changes in water quality exist. All water samples were sent by a taxi to the laboratory in Phnom Penh. Inundation extent checking was done in one point and water quality sampling in Stuong. A bridge was broken about 30km from Stoung towards Siem Reap which forced the expedition to stay in Stoung for night and wait for the bridge to get repaired. Bridge was finally repaired around 17:00, but this was a too late time to continue any further.

Wednesday 29/08/2001 Stoung to Siem Riep

One water sample was again taken from Stoung to see if any diurnal changes exist. JICA land use map verification was done along National Road 6 and inundation mapping in one location. Extensive water quality sampling was done from Stung Siem Reap with one sample upstream (Angkor Wat area), one from UNTAC bridge and one downstream of Siem Reap. Road from Stoung to Siem Reap in a very bad condition and we proceeded at 15km/h for most of the day.

Thursday 30/08/2001 Siem Reap to Sisophon

Downstream Siem Reap the Stung Siem Reap was sampled again in the morning to see possible diurnal changes in water quality. The whole morning was spend in the Tonle Sap lake sampling from the middle, near shore and the flooded forest. All sites were sampled from two depths. All water samples from 29 to 30/8/2001 were send by air freight into Phnom Penh in an afternoon plain. This took over an hour because we were in the airport at lunch time and most of its operations were closed. More water quality sampling was done in Kralang and Tek Thla (Sisophon), in which Tek Thla was sampled from both upstream and downstream. Only Inundation mapping was done in Siem Reap because of the long distance to the lake and lack of roads towards the lake along the Road 6 from Siem Reap to Sisophon.

Friday 31/08/2001 Sisophon to Battambang

Water quality sampling was done during the day in Mongkol Borei and Battambang. One sample was taken from Stung Mongkol Borei, two from different depths from flooded forest in Battambang, one Stung Sangke downstream of Battamang and four (cross-profile) from upstream of Battambang. Inundation extent mapping was done during the speedboat ride in the morning to the flooded forest East of Battambang.

Saturday 01/09/2001 Battambang to Pursat

First in the morning water samples were again sent to Phnom Penh by air freight. Inundation mapping was done in several sites East of Road 5 and a lot of time was
used for the mapping as road conditions towards the lake were extremely bad forcing us to take local mopeds in a couple of occasions. Water sampling was done from three rivers, of which in river Pursat upstream and downstream samples were collected. Noteworthy is that in Svay Doun Keo the river flow was stagnant and there was no flow to Tonle Sap lake.

Sunday 02/09/2001 Pursat to Phnom Penh

The whole morning was spent sampling in the lake. Three samples from different depths were taken from the middle of the lake, two in both shoreline and close to the flooded forest. Water level at the station in Kompong Phnom was 8.27m, sediment trap was emptied and set into the lake for further operation and weather station was also checked. Further water quality sampling was done from Stung Boribor, Kompong Chhnang and Preak Kdam. Inundation mapping was done in one site off Road 5 and after Kompong Chhnang along National Road 5, where inundation extended to the road.
Mekong River Commission

Water Utilization Program – Modelling the Flow Regime and Water Quality of the Tonle Sap MRCS/ WUP-FIN

PROVINCIAL WORKSHOP FOR THE NORTHERN PROVINCES

Siem Reap, October 16, 2001

SUMMARY OF THE DISCUSSIONS

C1: People like to take land to agricultural use, animal composition changed, insects increase and destroy the crop, thus pesticides must be used, with impacts to the lake, farmers’ water intake close to their fields.

Inappropriate fishing and treatment of fish because the environment is calculated bad.

Q2: Is there more urgent further need for new hydrological stations or improvement of the status of the present ones?
C2: Some tributaries flow directly into the lake but measured at upstream only. Stations are needed also close to the lake; otherwise it is difficult to monitor the agricultural effects to the lake.
A2: There are 11 hydrological stations operating now in the lake and its tributaries, viz. Chinit, Sen, Sen further upstream, Chibay, Siem Reap, Kralanh, Sisephon, Mok Borei, Battambang, Pursat and Kompong Loung. If new stations are installed they are always for some objective. Furthermore, hydrological stations can not be founded for occasional short-term purposes but for long-term data acquisition.

Q3: Is it possible to move the movable weather station to another place?
A3: Yes, it is possible but depends on the principles cited above.

Q4: How the work will be connected to further continuation after two years?
A4: This is the main concern of the Project, needs help of the Workshop participants.
Q4+: When MRCS provides models, could e.g. Unesco have a role as a further sponsor after the two years?
A4+: The continuation of the Finnish funding will also be encouraged.
C4++: (long discussion among four people only in Khmer, not translated to English.)

(C = comment,
Q = question,
A = answer)
THE WORK GROUP RESULTS

Four groups: A) Kompong Thom, B) Kompong Cham, C) Siem Reap, D) B.B.Chay
Each of them with the same seven subjects.

1. Which are the actual risks threatening the Tonle Sap Lake environment?
A1) Sedimentation, increase of turbidity as a result;
B1) Deviation from the natural state and behavior, forest cutting, illegal fishery, sedimentation;
C1) Human influences, natural influences, lits and leaves remaining in the area, sedimentation, cut of forests, erosion from upstream;
D1) Catchment changes, flooded waters from China, decrease of forests, rainfall more directly into the lake (as surface runoff), with increased flow velocities, wash out of material into the lake, makes lake more shallow and more turbid, dry season phenomena fast, wet season phenomena wide, reduced fish production, strong evaporation in dry season (further accelerated by global change), increased concentrations of substances, lake ever smaller, destroy of natural resources, industrial plans (meaning also, mainly or only dams?) in the upstream.

2. What kind of environmental changes have taken place in the Tonle Sap Lake recently? What are the possible reasons?
A2) Cut of surrounding forests, fishery reduction, fish die in the nets(??), people living on the lake discharge strong releases affecting water quality, chemicals and pesticides from agriculture, erosion from Mekong, navigation difficulties for big boats;
B2) Denatural change because of peak velocities, velocity decrease by turbidity, forest cuts, color changes, increase of temperature, difficulties to fish species;
C2) Turbidity increase, temperature rise, problems to fish;
D2) Areal variations, function as a through (meaning sink?) not only as a tributary, depth decreases, less volume for fish.

3. Which are the impacts and socio-economic consequences of the environmental changes?
A3) Turbid water not good for irrigation, color changes, rise of temperature, less fish;
B3) Public transport difficulties, tourists suffer from bad water quality;
C3) Level rise breaks structures, agricultural problems to rise;
D3) Laws not very effective, reduction of fish, disappearance of species.

4. What kind of means there are to manage or mitigate the risks?
A4) Forests, people, legislation, everyone to follow the law, mark land (= land use control?), areas for wetlands and irrigation, take out sediments, every year (repeated?), remove the people from water, provide land for them, co-operation, education, advice to people;
B4) Need of education, learning, human resources, environmental education of local people, protection against illegality;
C4) Educate the people, study the problems, take out water from sediments (= sediment of water?), support to move from the lake;
D4) Specific law for the management, its information to all people, participation, behavior change, decentralization, provisional Committees to correspond CNMC acting in the national level, to make a tourist place from the lake.
5. What is the potential of hydrological, hydrodynamic and ecosystem modeling in supporting environmental management of the Tonle Sap Lake?
A5) Show connection between natural resources for economy and the environment, linking together different levels of influences;
B5) The effects of forest cuts, industry, oil releases, environmental development;
C5) Not yet data for that;
D5) (missing).

6. What are the most serious knowledge gaps about the state and development of the lake?
A6) Education, especially of law;
B6) Education system not good, low human resources, lack of technology;
C6) Capacity building, information;
D6) No studies of the impacts, people living in the area do not think, unclear responsibilities, missing budget to protect and to evaluate the impacts, disharmony with the local and horizontal (=sector) administration.

7. Technology and practice of monitoring the water quality and environmental state of the Tonle Sap Lake; a co-operation task for the authorities.
A7) Co-operation with the priorities (meaning perhaps stakeholders?), recommendations for water quality;
B7) Technical and funding support, education, training of students, schools and people;
C7) Staff only for sampling, not for analysis, training in use of instruments;
D7) Several meetings to discuss and agree, e.g. every 6 months, model co-operation and donors.

OBS: Based on subjective, unclear, inaccurate and incomplete notes from translations;
limits between the subjects uncertain;
more accurate contents to be received from the transparencies submitted by the groups.
Improvement of the Ministry of Water Resources and Meteorology Laboratory Facilities

Background

Improvement of the Ministry of Water Resources and Meteorology laboratory facilities and analysis quality has been highlighted since the WUP-FIN project started in June 2001. Data quality is of highest importance to the successful implementation of the project and it has sought assistance of the MRCS Environmental Program (Anders Thuren), MWRM laboratory (Mao Hak) and the Swedish sponsored laboratory improvement project (Lars Lundmark). The present paper tries to create basic understanding of the situation so that the laboratory analysis quality could be improved.

The WUP-FIN project team published Inception Report July 20, 2001. In the report attention was drawn to the state of laboratory. On pages 28 – 29 the situation is described as:

Also the reliability and accuracy of water sample analyses is not on the desired level. The main problem of MWRM laboratory is that it does not have all the modern laboratory equipment which is needed for very high accuracy water analyses. The biggest problems in the laboratory are that the water quality of the distilled water is not good enough and there is not enough refrigerator space and the autoclave has been broken for a long time. Also all the nutrient analyses are done by hand without modern nutrient auto analyser. All the staff working in the MRC laboratory are very motivated and hard workers. During this two years Tonle Sap Modelling Project the laboratory work and quality control can be one important part of training package of the project, produced together with the MRCS and especially the EP. For the success of the MRCS/WUP-FIN project it is highly needed to develop the laboratory work. The cooperation work of MRCS/EP and the WUP-FIN team has already been initiated. The discussions with the laboratory technology expert of the University of Umeå Mr. Lars Lundmark, involved more than ten years in the development of the MRC related laboratories, has presently visited Phnom Penh, have proved to be very
useful. In the discussions, the following absolutely necessary ‘first aid’ measures to upgrade the MWRM laboratory for nutrient analyses have come up:

  - purchase a new autoclave (the old is broken)
  - spectrometer with double beam facility and using 10 cm cyvettes would improve the reliability of analyses of very low nutrient concentrations
  - purchase an Ultra Pure Water system to facilitate analysis of lowest nutrient concentrations
  - purchase a new refrigerator for storing the samples
  - purchase new glassware used only for ‘Tonle Sap’ project
  - purchase an oven to dry the glassware (now in open air) and a closed cabinet to store after cleaning
  - purchase filter paper for filtering the nitrate and phosphate samples.

Project has drafted “Quality Assurance and Control Recommendations” for the laboratories and sampling. It is presented in Appendix H.

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**Situation according to MRCS Environment Program**

Information from Mr. Anders Thuren and Mr. Nguyen Tin from the MRCS EP program are summarized below:

1) There has been an upgrade of the laboratory equipment in the 4 countries. Lars Lundmark has made the upgrade lists and the equipment on the lists has been purchased. According to Anders making a new upgrade lists now is unacceptable because necessary equipment should have been in the original lists. It also takes at least one year to get an approval for new upgrades.

2) Equipment that is available in Cambodia can be purchased more easily. For instance the broken autoclave could be bought locally by the MRCS.

3) According to Mr. Tin there is no need for new oven or refrigerator except for WUP-FIN purposes.

4) According to Mr. Tin the analysis accuracy is not enough for the low nutrient concentrations, especially phosphorus. However it is not important to measure nutrients with such a great accuracy because the low nutrient values indicate limiting nutrients.

5) According to Tin the 10 cm cyvette would be the most important instrument to improve the low concentration analysis accuracy. Double beam facility would bring additional improvement but not so much longer cyvette. Purchase of Ultra Pure Water system would not be needed if the cyvette is purchased.
Situation according to the MWRM laboratory

1) The “Required List of Equipment, Glassware and Chemical” prepared Ms Nhim Sophea from the MWRM laboratory lists exactly the same equipment that has been presented in the WUP-FIN inception report (see appendix). Additionally she indicates chemicals that are urgently needed (Metol, NH3 solution, Detergent, Phenol and HCl) and that are needed in the long run (rest of the chemicals in the list).

2) The oven, refrigerator and cabinet are too small for the everyday needs of the laboratory, not just for the needs of the Tonle Sap project.

3) The autoclave has been broken since 1999 and requests to get a new one have been made to MRCS since then with no results. (November 2001 update: Autoclave is now under purchase).

4) Recording and printing facility for the spectrometer would be useful.

5) Laboratory has not yet received the spare lamps from Hitachi that has been ordered.

Situation according to Mr. Lundmark

1) Most items for Cambodia have not been purchased according to Mr. Lundmark’s suggestions.

2) High quality water (Ultra Pure Water System) is needed when analysing metals with AAS and ions with ion chromatography. The use of high quality water makes analyses in overall much better when e.g. cyvettes are cleaned with it.

3) High quality equipment doesn’t help if the surroundings and conditions are not clean. That’s why for instance drying of the glassware is not very efficient with inadequate equipment in a room where everybody walks about and eats.

4) Good quality autoclave must probably be bought from special company.

5) Recording and printing facility for the spectrometer would be useful to follow each measurement. This would be helpful especially when doubts arise concerning the measurement.

6) None of the laboratories had received spare lamps from Hitachi that have been ordered for them when Lundmark was last time visiting the Mekong countries.
Situation according to the WUP-FIN project

1) WUP-FIN project considers that the basic facilities are not adequate in the laboratory. Upgrade of autoclave, oven, refrigerator and closed cabinet is recommended.

2) The current nutrient analysis accuracy may not be enough for the low nutrient concentration values. The WUP-FIN team considers it especially important to understand the behaviour of the limiting or potentially limiting nutrients and recommends improvement of measurement accuracy. (November 2001 update: intercalibration between the Finnish and Cambodian laboratories has been conducted twice. This may give further indication to the laboratory improvement.)

3) The need for separate glassware and closed cabinet should be considered for the WUP-FIN project.

Recommended actions

Despite of the partly conflicting views presented above at least some basic measures should be taken. What could be done is:

• test equipment according to Lundmark’s suggestions
• get additional expert opinions of the laboratory needs and specifics of the necessary equipment
• agree upon a list of purchases
• agree upon the share of costs
• purchase equipment as soon as possible.
REQUIRED LIST OF EQUIPMENT, GLASSWARE AND CHEMICAL

Prepared by Ms. Nhim Sophea
30 August 2001

I. Equipment and Glassware

1. New autoclave (we need to order it, because there are not available in the stock)
2. Spectrophotometer with double beam facility and using 10 cm Cuvette
3. Ultra pure water system
4. New refrigerator for storing the sample
5. Oven for dry glassware and a closed cabinet to store after cleaning
6. Filter paper for filtering
7. Pyrex 25 ml 100 pieces (for Tot-N)
   Pyrex 50 ml 100 pieces (for NO$_3$+N)
   Pyrex 125 ml 100 pieces (for DO)
   Pyrex 125 ml 100 pieces (for COD)
8. Volumetric Flask 25 ml 100 pieces (for NO$_3$+N)
   Volumetric Flask 25 ml 100 pieces (for Tot-N)
   Volumetric Flask 25 ml 100 pieces (for NH$_4$+N)
   Volumetric Flask 250 ml 10 pieces (for preparation of regent)
   Volumetric Flask 500 ml 10 pieces (for preparation of regent)
   Volumetric Flask 500 ml 100 pieces (for Tot-P)
   Volumetric Flask 500 ml 100 pieces (for PO$_4$-P)
9. Cylinder 10 ml 05 pieces
   Cylinder 25 ml 10 pieces
   Cylinder 50 ml 10 pieces
   Cylinder 100 ml 10 pieces
10. Burette 05 ml 20 pieces
    Burette 10 ml 10 pieces
11. Bottom 1000 ml 100 pieces (for sampling container)
    Bottom 250 ml 100 pieces (for Iron Sampling)
12. Bottle glass with cover
    250 ml 100 pieces 100 pieces for Nutrient Sampling (after filtration)
    500 ml 20 pieces 20 pieces for Keep solution
13. Bottle for DO 100 pieces
    Bottle for Tot-N 100 pieces (Duran 50 ml)
II. Chemical

1. H$_2$SO$_4$  (for NO$_3$+N, Tot-N and COD)
2. Ammonium Molybdate (NH$_4$)$_6$Mo$_{24}$O$_{72}$4H$_2$O
3. Ascorbic acid C$_6$H$_8$O$_6$
4. Potassium Antimony oxide tartrate C$_4$H$_4$KO$_7$Sb
5. Potassium Dihydrogen phosphate KH$_2$PO$_4$
6. Metol
7. NH$_3$ Solution
8. Detergent (Extran MA O3 Phoshatferi MERCK)
9. Ammonium Chloride NH$_4$Cl  (for NH$_4$-N, NO$_3$+N, Tot-N)
10. Phenol C$_6$H$_5$OH (for NH$_4$-N)
11. HCl (for NH$_4$-N, NO$_3$+N, Tot-N)
12. Potassium Peroxodisulphate K$_2$S$_2$O$_8$ (for Tot-P, Tot-N)
13. Cupper Sulphate CuSO$_4$ 5 H$_2$O (for Tot-P, Tot-N)
14. Sulphanilamide C$_6$H$_8$N$_2$O$_5$ (for NO$_3$+N, Tot-N)
15. N-naphtylethylenediamine dihydrochloride C$_{12}$H$_{16}$Cl$_2$N$_2$ (for Tot-P, and Tot-N)
16. Sodium thiosufate Na$_2$S$_2$O$_3$
17. Sodium starch glycollate (Lot.5658610, for DO and COD)
18. Phosphoric acid H$_3$PO$_4$ (for DO and COD)
19. Potassium Permanganate KMnO$_4$ (for DO and COD)
20. Potassium iodide KI (for DO and COD)
21. Potassium iodate KIO$_3$ (for DO and COD)
22. Isobutanol  (for DO and COD)