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EXECUTIVE SUMMARY

This report presents the findings and recommendations of the Hydrogeologist from S.H.E.R. Ingénieurs-Conseils s.a from Belgium at the end of his assignment in Cambodia from 26 September to 13 November 2004.

This ECOSORN Project was established through a grant contract between the European Commission in Brussels (Directorate Asia) and the Royal Government of the Kingdom of Cambodia. The location of the project is: The provinces of Siem Reap, Battambang and Banteay Meanchey Provinces (14 Target districts with 40 communes and their target villages) in the northwestern part of Cambodia.
The Financial Agreement was signed in June 2005, the official start date was December 2005, project closing date end of December 2010.

Total project value is Euro 26 Million (approx. US Dollar 32 Million, out of which the EC contribution is Euro 25 Million and the RGC contribution is Euro 1 Million (latter contribution in kind through seconded government staff, office costs, tax exemptions etc.).

The implementing agency is the Ministry of Agriculture, Forestry and Fisheries MAFF (Executing Authority), main participating agencies are MAFF, MRD (Ministry of Rural Development), MOI (Ministry of Interior), MOWRAM (Ministry of Water Resources and Meteorology), MOWA (Ministry of Women's Affairs) and MLMUPC (Ministry of Land Management, Urban Planning and Construction).

The ECOSORN expected five main results are the following ones:

1. Agricultural, livestock and fisheries production intensified, diversified and increased
2. Economic and employment opportunities developed
3. Empowerment of local communities
4. Improved physical access to available social amenities (including credit) and markets, greater access to potable water supplies
5. Safer and permanent access to arable land
6. and social infrastructures

In the framework of the above point 5 **"**Greater access to potable water supplies" the ECOSORN Rural Infrastructure Section is preparing all its tender documents before embarking on a major four years implementation phase. Due to the new EU contractual rules and regulations for Projects a "Single Package contract" should be prepared, at the very beginning, and be valid for the next four years. To prepare the technical specifications for those tenders it is extremely important to obtain as many opinions and technical feedback as possible before improving the technical specifications and launching the final calls for bidders.

"What will happen after this ECOSORN Project will close its doors." is the certainly the most important question everybody in this ECOSORN Project is now concerned about. This point leads to the sustainability of any new water supply system. For domestic water supply this question can and will only be resolved using the simplest but most sustainable in-situ, low-cost methods and technologies. The most appropriate solution is certainly not a "Top down" imposed one but based on "Demand Driven" and on real demand based from the local people. *The successes of this ECOSORN RIS Water supply component will not rely on new revolutionary approaches but indeed on an accumulation of several minor long lasting but crucial improvement.*

This hydrogeological mission is in full logic with the ECOSORN RIS approaches and its main target therefore is to help and assist as much as possible the ECOSORN Rural Infrastructure Section in its extremely important task.

This report tries, as much as possible, to contribute to that approach suggesting for example to construct dug wells wherever technically possible instead of drilling wells, the use of very cheap technical options to improve the construction of those dug wells, recharge of the dug wells by rain water, to use the simple but very sustainable technology of the so called " Rope Pump" or improve as much as possible the widely used techniques of rainwater harvesting, introducing and promoting as much as possible the new Cambodian ceramic household filter…...
Suggestions are also prepared to select the appropriate domestic water supply system in the different areas of this ECOSORN Project.
Technical Specifications for the construction of dug wells and four Inches drilled wells, already available in this ECOSORN Project, have been checked, reviewed and improved where necessary. They are attached in the Annexes at the end of the present report

With a known extremely versatile subsurface alluvial geology in the Tonle Sap basin and with an almost total lack of knowledge of the target aquifers, "Blind drilling" approach, as it is technically called by ground water professionals, is likely to suffer from rather poor successes rates.
For this reason efforts have been made to try to understand as much as possible the geological conditions allowing the sedimentation of the two layers of the "Old" and " Young" Alluvia the main targets of all the water supply Projects in the area. Understanding those conditions would, without any doubt, help a lot locating future wells.

Because of its important social component hydrogeology for domestic water supply has always a very different approach compared to the normal and classic hydrogeological studies.

In normal hydrogeology the question always asked is the following one:
"Here is land. Where is the best location to dig or drill a well and supply water."

In hydrogeology for domestic water supply the question is just the opposite one since it is totally impossible to shift or relocate a village. Therefore one has to live with those geographic constraints and must try to find the most acceptable, cheap and appropriated but also sustainable options to supply drinking water to the villagers.

In the above conditions the wells are, most of the time, constructed on the grounds of families or social factors and conveniences and absolutely not on evaluation of existing potential aquifers.

At the end of this mission the three main findings are the following ones:

1. A “Water Attitude” towards waters pumped from Limestone aquifers. Several villages of the ECOSORN Project are located over quite shallow Limestone outcrops. The villages have different drilled wells never drying in the dry season. Despite those quite favourable hydrogeological conditions it was reported during the quick field reconnaissance that nobody ever drinks the water of those wells but all the families are harvesting rainwater and in volumes big enough to sustain the needs during the complete dry season.
   The local people report they are very “concerned” by he Calcium carbonate in the water. This is also confirmed by the fact that all the habitants of those concerned villages already requested ECOSORN to receive the so called “ Jumbo Jar “ for rainwater harvesting but, so far, not a single request for a drilled well.

   As a matter the fact is that people just do not drink it so this has implications for any rural water supply Project.
   The main question is therefore “ Should we drill wells in those areas if we know in advance that the people will not drink it. ”

2. Very recently the hazard of Arsenic in Cambodia has been discovered and commented in several scientific papers. In addition to the comment of the hydro geochemistry of the area this report will also try to bring some important information explaining the reasons why Arsenic is found in groundwater in Cambodia.
   As can be observed on the Figure 1 here under this Arsenic hazard is a common and generalised problem in almost all the countries located around the Himalaya Mountains.
   The source of Arsenic is in the sediments lying in the Himalayas Mountains.

   The Figure 1 here under is a very short but extremely clear and visible resume of the Arsenic problems in this part of the world.

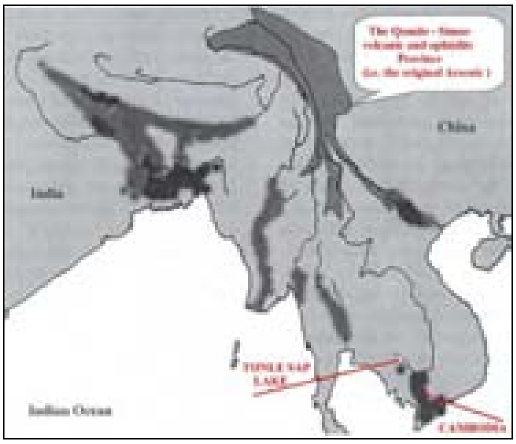

Figure 1: The Current South and South-East Asia areas of known arsenic in ground waters. (Modified from Dr Gordon Stanger - Sept 2005).

3. The above problems linked to the hydro geochemistry of the waters in the Tonle Sap should not overshadow another one, probably thousands folds more important i.e. the bacteriological composition of the waters in all the existing wells and ponds.

Unfortunately so many existing reports confirm that, from a bacteriological point of view, absolutely all the wells are polluted and this is especially true for the whole Siem Reap Area.

The 2005 Paediatric Conference in Phnom Pen (Pediatres du Monde) acknowledged this evidence of important and large scale pollution and resulting death due to water born diseases. Some of their findings reveal that in Cambodia, 75 % of the dead are linked to water borne diseases. In addition the children death rate in Cambodia is 140/1000 and out of those 140 children under five years old 28 die just as a consequence of diarrhoeas. This rate of 140/1000 is the highest amongst all the countries in South East Asia and Cambodia was ranked 180 amongst 192 countries. The main source of this regional bacteriological pollution is from latrines and resulting Coli Forms. On the grounds of the above bacteriological evidences several international donors are now very concerned to finance water supply Projects based on shallow wells. The same donors would indeed, finance future Projects if the water is supplied through deeper drilled wells.

The introduction and promotion by the ECOSORN RIS of the new Cambodian “ceramic” filter should certainly help to resolve those crucial health problems related to the bacteriological composition of the waters.

Schedule and logistic of the present mission

The mission of the hydro geologist expert, Dr Jacques Marchand, took place from 26th September till its return in Belgium on the 19th of November.

Based on the ECOSORN target villages maps received at his arrival, the second week till the fifth week of his mission were devoted to field reconnaissance trips of the ECOSORN targeted Communes and villages in the three Project Provinces.
Field visits to the selected target villages were organized and done with ECOSORN RIS provincial staff (4th of October to 24th of October). It is important to note that for all these villages neither the location nor the amount of planned hydraulics works in each village were provided to the consultant. The villages listed in ECOSORN "Batch One"were considered systematically.

During the above field reconnaissance the Consultant also add the possibility to collect first hand information from professionals directly involved in the respective water sectors of the three "ECOSORN" Provinces.

In Cambodia the raining season reaches its wettest peak from end-August to early November. In other words this mission took place precisely in the middle of the local raining season.

Despite the above adverse conditions the field reconnaissance was never stopped. When the main road from Siem Reap to Banteay Meanchey finally became totally impassable, because of important flood, the consultant used the regular boats to cross the lake and return to the main ECOSORN offices in Siem reap.

During this assignment two presentations were made for several Government staff as well as for the ECOSORN staff. The first one, chaired by Mr Saruth Chan the was made on 09 th October. The second presentation, chaired by Mr Manfred Staab, the Project Team Leader and Rural Development Advisor was delivered on 14 November at the very end of the consultant's assignment.

The Consultant concluded his assignment on Monday 13 November and left Cambodia on Saturday 18 November. During this gap, the Consultant delivered at no charge both a presentation to the ECOSORN staff (14 November) and a review the comments on his Draft Report prepared by the ECOSORN RIS. The ECOSORN Project accepted the consultant's replies, explanations and additional comments to his Draft. This report includes all of them.

The ToR for the mission of the expert, his CV, his successive time sheets as well as the list of persons met during his mission appear from Annex1 to Annex 4 at the end of the present report.

1. Review of existing studies

For the convenience of the reader Annex 5 presents a list of 31 documents consulted to prepare the present report.

Nevertheless we would like to give, here under, some very brief comment on couple of key documents consulted and used for this report:

1. **Rasmussen W.C. and Bradford G.M. – 1977 -** "Groundwater Resources of Cambodia". United States Geological Survey Water Supply Paper 1608 is without any doubt the basic reference for all groundwater studies in Cambodia.

2. The July 1999 Kukusai Kogyo report on **"Groundwater Development in Southern Central Cambodia"** is bringing very interesting comment on a possible general geological model in the southern part of Cambodia.

3. **The 2002 study by S.Tsukawaki** "Environmental Changes of Lake Tonle Sap and the Lower Course of the Mekong River System in Cambodia during the last 6.500 years " – Results of the Tonle Sap 96 Project " (Symposium on Environmental Changes of the Lake Tonle Sap in Phnom Penh, Cambodia) presents new theories on the formation of the Tonla Sap lake.

4. **The March 2003 ADB Report** "Northwest Irrigation Sector Project" is certainly the most complete report so far on some of the areas of the ECOSORN Project. The geological and hydrogeological chapters of this report have been very well prepared and detailed by high level experts and bring very good concepts about groundwater and hydrogeochemistry in this corner of Cambodia. This report also contains many information on the hydrogeology of the "Young" and "Old" Alluvium. From an hydro geological point of view one of their most important conclusions is the following one : *"The distribution of higher yielding wells, very often associated with pockets of sandier material appears to be extremely random with very adjacent wells, just few meters away, producing the usual low yield".*

5. **EC funded Research Programme** – August 1998 to June 2001 "DOMESTIC ROOFWATER HARVESTING IN THE HUMID TROPICS" Prepared by the School of Engineering. University of Warwick - Coventry CV4 7AL – UK. Their site can be found at: **http://www.eng.warwick.ac.uk/DTU/rainwaterharvesting/index.html and http://www.eng.warwick.ac.uk/dtu/rwh/eu.html**

6. **DFID** – December 2000 to 31 March 2003 "ROOFWATER HARVESTING FOR POORER HOUSEHOLDS IN THE TROPICS" - Knowledge and Research project No R7833, School of Engineering,

University of Warwick, Coventry CV4 7AL, UK
http://www.eng.warwick.ac.uk/dtu/rwh/dfid.html.

7. The above two EU and DFID reports present the "State of the Art" and probably the most advanced concepts on Rainwater harvesting in tropical countries

8. The July 2005 **"Offshore Cambodia Areas & Onshore Cambodia Tonle Sap Basin"** paper prepared by the Cambodian National Petroleum Authority is revealing very new information related to the deeper geology of the Tonle Sap graben and surrounding areas. This report also reveals a variety of geophysical maps (paper presented in the Dusit resort – Pattaya- Thailand).

9. The report "**Regional Geology in Khmer Basin"** prepared in 2005 by the Coordinating Committee for Coastal and Offshore Geoscience Programmes in East and Southeast Asia (CCOP) – Bangkok - Thailand is of relevance and provides Tertiary geological basin-scale information on the Regional Geology of the Offshore Khmer Basin as well as for the tectonic of the area. In the absence of geological information for the Tonle Sap area this report could offer very preliminary understanding of the sedimentology in this Tonle Sap basin.

10. The March 2005 **" Holocene history and development of the Tonle Sap, Cambodia "** by Dan Penny of the School of Geosciences at the University of Sydney – Australia presents very new concepts to explain the extremely recent formation of the Tonle Sap lake and its sediments.

11. The report **"A paleo-hydrogeological model for Arsenic contamination in Southern and South-East Asia"** prepared by Gordon Stanger and published in 2005 (Springer – Holland) confirms the existence of Arsenic problems in Cambodia but also in all the countries located around the Himalaya. His very interesting report presents also a possible hypothesis to explain those hydro geochemistry anomalies.

12. The 23 December 2005 FINAL REPORT **"STRATEGIC STUDY OF GROUNDWATER RESOURCES IN PREY VENG AND SVAY RIENG (PHASE 1)"** prepared by the International Development Enterprises Cambodia (in Phnom Penh) for the SEILA TASK FORCE SECRETARIAT RURAL POVERTY REDUCTION PROJECT under the IFAD Loan No.: 623-KH.
Their interesting Final Report presents the results of a very well designed, programmed and completed groundwater

study South of Phnom Penh. Many of their comments and suggestions refer to irrigation aspects.

2. Geology of the Tonle Sap in the context of the Indochinese Region

The two Figures 2 and 3 appearing here under present the simplified geological map of the North-western Provinces of Cambodia as well as the legend of this map prepared by the March 2003 ADB-Northwest Irrigation Project.

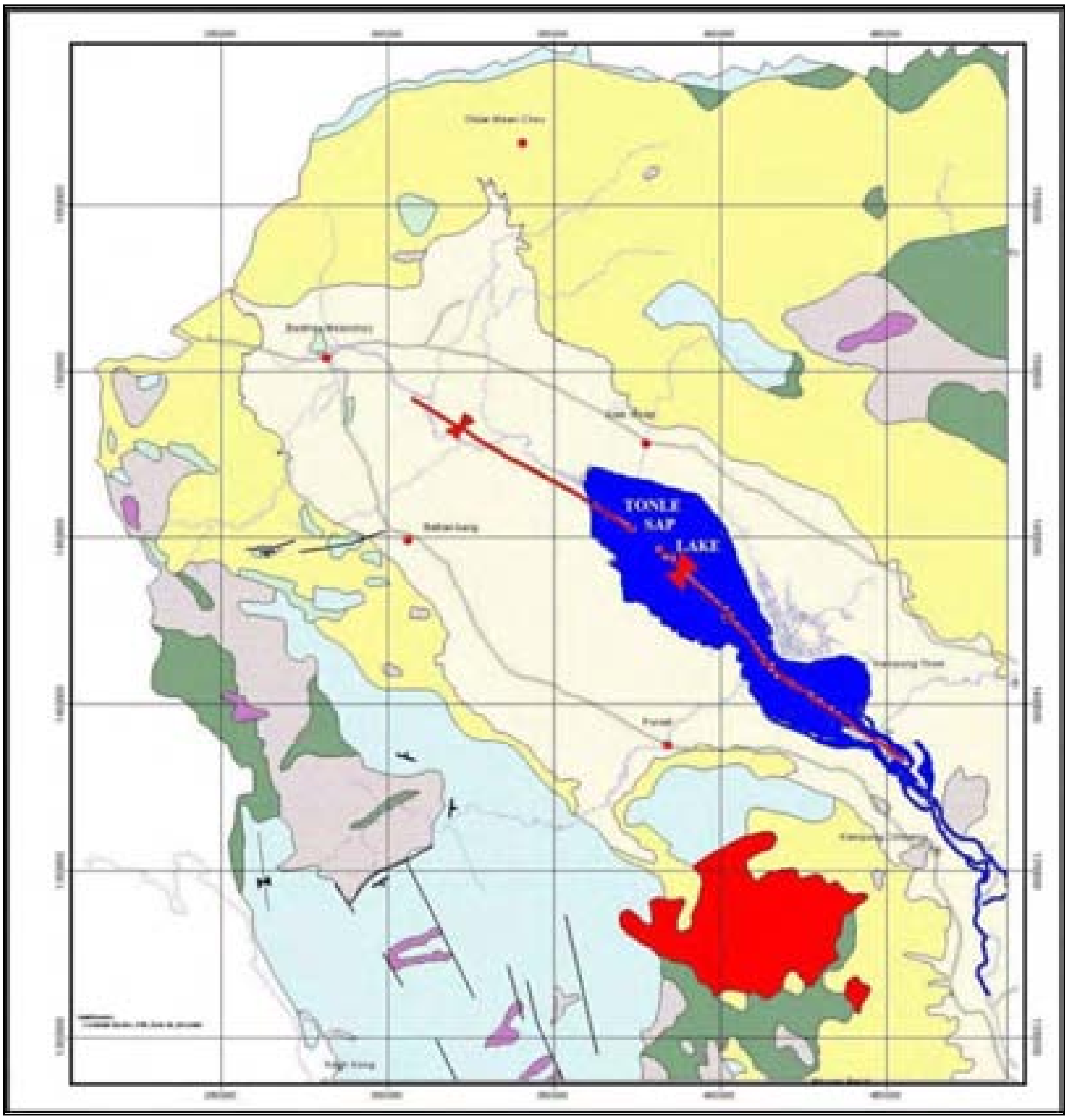

Figure 2: Simplified geological map of the North-Western provinces of Cambodia (Modified from the March 2003 ADB - Northwest Irrigation Project).

Figure 3: Legend of the above Simplified geological map.

The following five most important features can be observed on this very simplified map:

1. In the centre of the map a very large size flat depression or “basin” with a “North–West/South–East trend” lake, the Tonle Sap Lake, roughly in its centre.As can be observed on the above map the Tonle Sap Lake is essentially made up of two primary lacustrine basins i.e. a large Northwest basin and a smaller Southeast basin linked by a relatively narrow strait.

2. Around the Tonle lake a first “crown” of the so-called “Recent or Young Alluvium” of Holocene age.

3. “Older Alluvium” of Pleistocene to Holocene ages and sedimented almost everywhere in this basin. It is extremely important to observe on this map that the “Older Alluvium” is completely surrounding the most recent “Young Alluvium”.

Our very same observation is also confirmed page 44 of the 23 December 2005 IDE FINAL REPORT "STRATEGIC STUDY OF GROUNDWATER RESOURCES IN PREY VENG AND SVAY RIENG (PHASE 1)". Their geological schema is reproduced here under for the convenience of the reader.

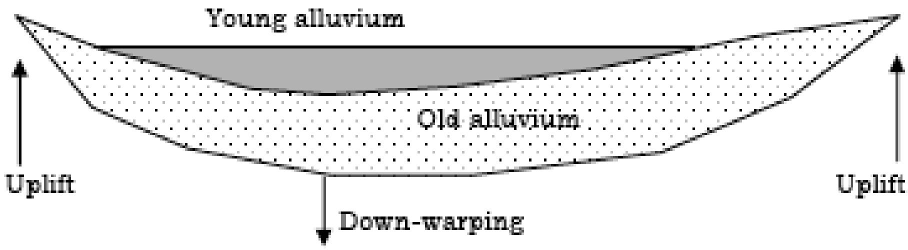

Figure 4 : Relationship between the Young and Old Alluvia (Modified from the December 2005 IDE Final Report "STRATEGIC STUDY OF GROUNDWATER RESOURCES IN PREY VENG AND SVAY RIENG")

4. Patches of older (Palaeozoic) rocks emerging out the vast plain as icebergs from oceans.

5. Ranges of mountains all around the perimeter of this large size depression or sedimentary basin.

In the following paragraphs we will try to explain how this large size Tonle Sap depression, graben (graben is the German word for ditch) or sedimentary basin was formed, where its sediments, the Old and Young Alluvia come from, the possible direction of the river flows, if any, discharging the sediments into the Tonle Sap Lake and through which channels.

From a hydro geological point of view some authors also state that:

We quote here under from the 2003 ADB Northwest Irrigation Sector Project.

*"Recent" and "Older" sediments of the lowland agricultural areas offer the greatest potential for groundwater development. Some sources state, imply or guess that the older alluvium, which probably underlies the recent alluvium in all areas, has less clay, more clean silt or sand, and is therefore more permeable with higher groundwater storage potential. In principle, these sandy areas should have greater infiltration capacity but, conversely, offer less soil-moisture retention. Both the older and younger sediments are poorly defined, with no clear criteria for their differentiation in deep boreholes. Indeed, their respective thicknesses and sub crop topography are completely unknown throughout the project area***".**

On the grounds of the regional characteristics of the Young and Old Alluvium we will also review the hydrogeological implications connected to the existence of those two different sediments.

On those geological and sedimentary grounds we will then prepare some tentative guidelines for future domestic water supply projects in the ECOSORN targeted provinces and villages.

2.1 The relationship between the Himalaya, the Mekong River and the Tonle Sap graben and sedimentary basin

The low relief central area of the Tonle Sap Lake and plains are the central feature of Cambodia's drainage system. Today the lake area drains into the river Mekong through the Tonle Sap during the dry season, while flow reverses during the wet season with a “reverse delta” at the Lake's southeast drainage point.

From a geological point of view this seasonal endorheic (i.e. characteristics of areas in which the river courses do not reach the sea but are slowly disappearing into internal depressions) drainage is totally incompatible and unstable unless it can be justified by a gradual geological subsidence of the lake but, probably most important too, of the areas surrounding the lake.

If continuous subsidence was not taking place the lake would have silted up long time ago and then would have probably behaved just like any normal river.

Whether this subsidence is gradual or episodic, fault bounded or shallow, geologically prolonged or recent, are not yet very well known. It is the opinion of this consultant that the subsidence was probably “Episodic”.

Five or six thousands years ago, during the Early Holocene, did this subsidence facilitate the tidal effects inside the lake through the Mekong River.

It could be surprising for the reader of this report but the answers to these very basic questions have extremely important ramifications for both the sedimentation and consequently for the groundwater resources in any depressions in the world and obviously also for the Tonle Sap basin in Cambodia.

It is precisely for those “extremely important reasons” that, here under, we will, very quickly, review the regional geological conditions leading in the first phase to the formation of the Tonle Sap depression (or graben) and subsequently to its refilling by sediments during its second and successive phases.

Let us start here under by the geological conditions leading to the formation of several depressions, sedimentary basins or grabens around the Himalaya and also in Indochina.

As can be observed on the Figure 4 appearing here under the Mekong River plus six of the worlds largest rivers are all draining from the Tibetan Plateau in the Himalaya. It is important to notice that over half of the world’s population, including also Cambodia, lives in the drainage basins of the above six rivers.

Those seven rivers are the following ones:

1. In the right corner of this Figure, the Mekong, the Salween and the Yangtze drain the central and eastern areas of this Tibetan Plateau. It is also extremely important to observe on this Figure 4 that for hundreds of Kilometres before its

confluence with the Yangbi, the Mekong River is really "sandwiched" in between the Salween (Nu) River on the west and the Yangtze (Jinsha) River on the east. In western Yunnan, the three rivers diverge - the Yangtze turns north, then east, the Mekong turns southeast, then south, and the Salween continues to the south. The Yangbi River drains the area between the Yangtze and the Mekong; Lake Erhai south of the Great Bend of the Yangtze drains into the Yangbi.

2. The Indus drains the southwest.
3. The Bramaputra and Ganges drain the southern and southeastern area.
4. The Yellow river drains the northeastern area.
5. The northern and northwestern areas of the Tibetan Plateau have no external drainage but are characterized by many large lakes.

Figure 5: The seven important rivers draining the Himalaya.

The Mekong River is one of the world's 10th rivers in its length in the world and runs 4,800 kilometres from its headwaters at an elevation of about 5,000 metres in the Tanghla Shua Mountain range of this Tibetan Plateau where it is called the "Dza Chu River" (in other words the "River of Rock") through the Yunnan Province of China, Burma, Thailand, Cambodia, Lao and finally Vietnam.
However, its average discharge of 15,000 m^3/s places the Mekong at the rank of the 8^{th} in the world table of great rivers.

The Mekong River is the heart and soul of mainland Southeast Asia and has great influences upon nature and societies of the Indochina Peninsula.

At the end of the present report we will make some comments about the chemical composition of the ground waters existing in the Tonle Sap sedimentary basin.
As for several sedimentary basins located all around the Himalaya (Bangladesh…etc) the chemistry of the ground waters is directly connected to the formation of the Himalaya and the existence of very special sediments in the area of this Tibetan Plateau.

In addition the Tonle Sap sedimentary basin is itself a geological consequence of the formation of the Himalaya. For the above reasons in the following paragraphs we will describe, extremely briefly the formation of the Himalaya and its very important consequences on Indochina, **Cambodia** and the Tonle Sap sedimentary basin.

2.2 Very brief description of the formation of the Himalaya and the resulting extrusion of Indochina including Cambodia

The formation of the Himalaya and consequently of Indochina can be summarised briefly in the five following steps:

1. Nearly 200 million years ago and at about the same time South America and Africa separated, India separated from Antarctica.
2. India then moved north, slowly closing the existing Tethys Sea.
3. The collision began in the Upper Cretaceous period about 70 million years ago, when the north-moving Indo-Australian Plate (moving at about 15 cm/year) collided with the Eurasian Plate.
4. By about 50 million years ago (Early Oligocene) this fast moving Indo-Australian plate had completely closed the Tethys Ocean, whose existence has been determined by sedimentary rocks settled on the ocean floor and the volcanoes that fringed its edges. Since these sediments were light, they crumpled into mountain ranges rather than sinking to the floor. The Tethys sea floor sediments were pushed up about 10 Kilometres and also uplifting the Tibetan Plateau, a region the size of Alaska, to an average elevation of over 5000 meters over sea level.
5. The huge mass of Asia to the west and north blocked the movements of the Tibetan crustal material in these directions as India pushed into Asia. As a result, the regions north of the Himalayas moved east and southeast along large strike slip faults pushing into central China and Indochina. As India pushed northward hundreds of Kilometers of displacement of crustal rocks occurred to the east and southeast and Indochina was extruded southeastward. The "sandwiched Mekong River", between the Salween (Nu) River on the West and the Yangtze (Jinsha) River on the

East, is a quite clear evidence of those large lateral strike slip faults and consequent displacements and "Extrusion" of Indochina and Cambodia.

For the convenience of the reader the Figure 5 hereunder is a very brief resume through geological time of the formation of the Himalaya and of the sediments of the former Tethys Sea. Later those Tethys sediments will be discharged by the Mekong River and accumulated in depressions like the Tonle Sap graben in Cambodia.

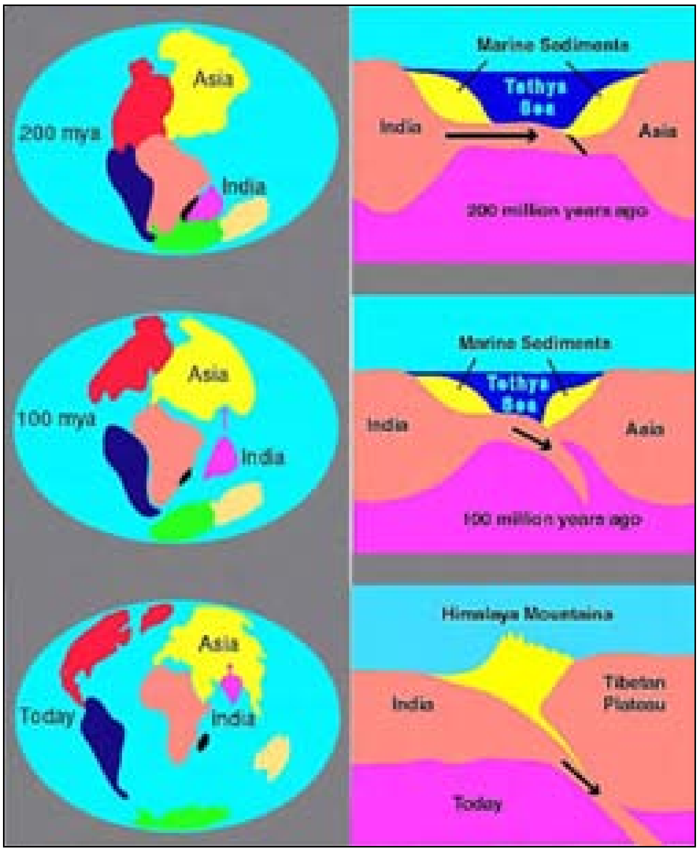

Figure 6: Formation of the Himalaya through geological time
(The Tethys sediments are represented here in yellow).

As a consequence of all the above tectonic movements in the Himalaya the Mekong River and several others very important rivers, appearing in Figure 5 were formed, started to flow, preferentially along large lateral strike slip faults, flushing out and discharging their very fresh "Tethys" sediments into different and newly sedimentary basins or collapsed grabens.

New Tertiary sedimentary basins such as the Tonle Sap basin and the Khmer (now offshore) basin were consequentely born.

The Figure 6 here under presents two types of Tertiary Basins in Cambodia:

1. The "Onshore" Tonle Sap Basin (Red square)
2. The "Offshore Cambodian basin" represented here by a "Blue triangle".

Figure 7: The “Onshore” and "Offshore" Tertiary basins of Cambodia
(Modified from the July 2005 Cambodian National Petroleum Authority
Paper Presented in Pattaya – Thailand).

On this map it is very interesting to notice that the “Triangle shape” of the blue lines is converging somewhere to the Mekong River on the East. As a matter of fact not far from Phnom Penh the Mekong river is making a very sharp 90° turn to the left leaving its “former course” and then flowing towards the South China Sea.

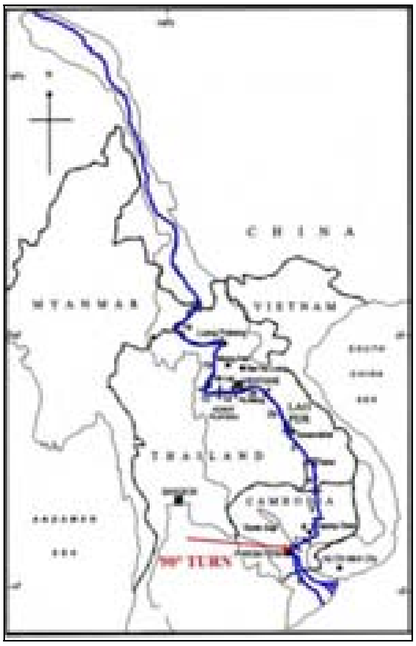

Figure 8: The 90 ° turn of the Mekong River.

The above “Blue triangle” is evidence of the Tertiary North East/South West river flow and of the delta when the Mekong was discharging into the gulf of Thailand and not through Vietnam, as it is now the case.

We should also recall here that the lower parts of many rivers in the area also underwent the large-scale sea level changes in the Quaternary (Pleistocene and Holocene) across the shallow South China Sea.

This observation certainly also has very important impacts for the Tonle Sap graben and sedimentary basin. Later in this report this comment will be further detailed.

The oldest Tertiary sediments found in the "Offshore" basin are Early Oligocene clastics. From a geological point of view those sediments coincide perfectly in the geological chronology. From a sedimentology point of view they also, totally correspond to the formation of the Himalaya, the extrusion of Indochina during Early Oligocene, the formation of new rivers and the very first "Flushing out" of enormous volumes of sediments created by the erosion of the new Himalaya Mountains just formed. It is assumed that this "Offshore" basin could be 6000 to 7000 meters thick.

2.3. Geology of the Tonle Sap sedimentary basin

2.3.1 General comment

The Consultant's logic path for trying to collect information related to the local geology was four folds :

1. Try to understand as much as possible the local geology.

2. Try to discover any possible "guidelines" governing or ruling the sedimentation of the "Young" and "Old alluvium" in the Tonle Sap basin. Those two layers are the most important ones for shallow domestic water supply in the area. If any guidelines could be discovered it would help a lot in the location of any future wells.

3. On the grounds of the above two aspects try, if possible, to clarify the local hydrogeology.

4. Explain the existence, in Cambodia, of sediments containing Arsenic and almost always associated to the formation of the Himalaya Mountains.

The Central Cambodians low lands are mostly covered by Quaternary alluvium and very little is known about the location, formation or morphology of possible sedimentary basins in those areas. In fact the Tonle Sap graben or basin is a very poorly explored area and its geology not yet fully understood since no deep drilling have ever been carried out. Quite detailed studies have indeed been carried out for the very recent sedimentation of the Early Holocene (more or less 7000 years ago).
To improve the geological knowledge of this basin a seismic survey in the lake Tonle Sap is planned this year (2006) and will be jointly carried out by the General Department of Mineral Resources, Cambodia (DGMR), DMR and GSJ/AIST under the "Coordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP)". The main purpose of this seismic survey is to undertake a collaborative seismic study to understand the geology and stratigraphy of coastal lowlands of the

Mekong River. Those new 2006 information will greatly help in the future to better understand the deep geology of the area as well as the relationship between all the sediments present in this basin especially the "Old" and "young" Alluvium.

2.3.2 Recent airborne gravity and magnetic surveys over the onshore Tonle Sap oil sedimentary basin

In the late 1990s, the Japan National Oil Corporation (JNOC) conducted several airborne gravity and magnetic surveys over the onshore Tonle Sap sedimentary basin and Mekong Basins. The survey area covers about 48,000 Km^2 only of the Tonle Sap Area.

2.3.3 Interpretation of the gravity and magnetic surveys of the Tonle Sap oil sedimentary basin

On the grounds of the above airborne surveys two deep sedimentary basin features have been detected. Those lie to the North and West of the Tonle Sap Lake and appear to be related to Tertiary age grabens. Unlike what has been suggested by previous studies, the current lake is not centered over the deepest grabens seen on the gravity data.

The Figures 9 and 10 appearing here under present successively the locations on those low gravity anomalies, the magnetic survey as well as their combined geophysical interpretations.

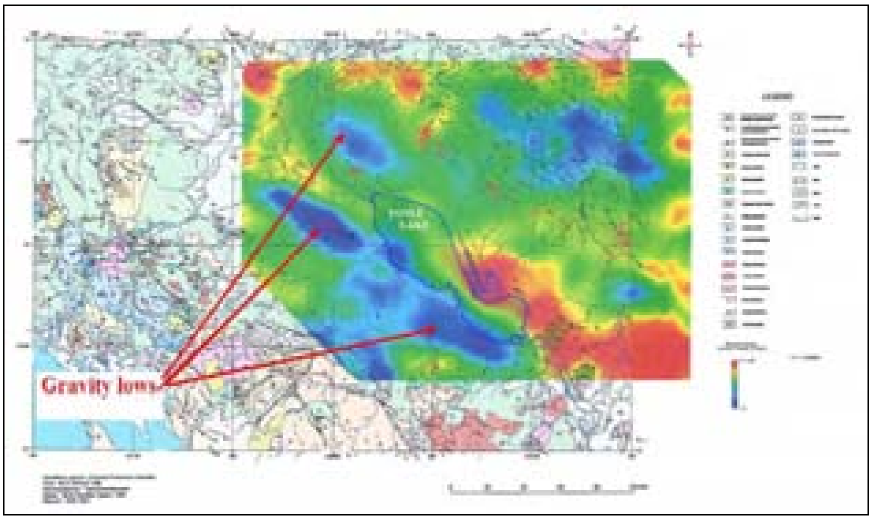

Figure 9: Results of the airborne gravity and magnetic surveys in the Tonle Sap basin showing an "L" shape Tertiary basin. The longer stretch of the "L" is parallel and at the foot of the Cardamons Mountains. (Modified from the July 2005 Cambodian National Petroleum Authority paper presented in Pattaya – Thailand).

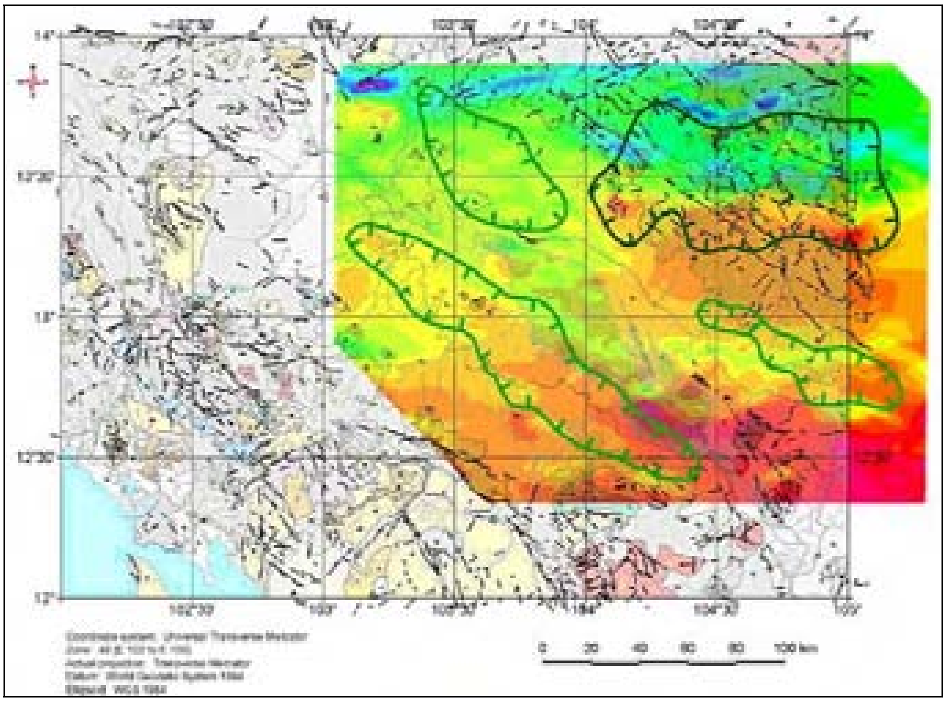

Figure 10: Location of the Palaeozoic (BLACK) and the Tertiary (GREEN) sedimentary basins detected in the Tonle Sap (From the July 2005 Cambodian National Petroleum Authority paper presented in Pattaya – Thailand).

The major faults discovered during the above survey are represented on Figure 11 appearing here under. On this Figure "Thick red line" has highlighted the most important faults, especially at the borders of this graben.

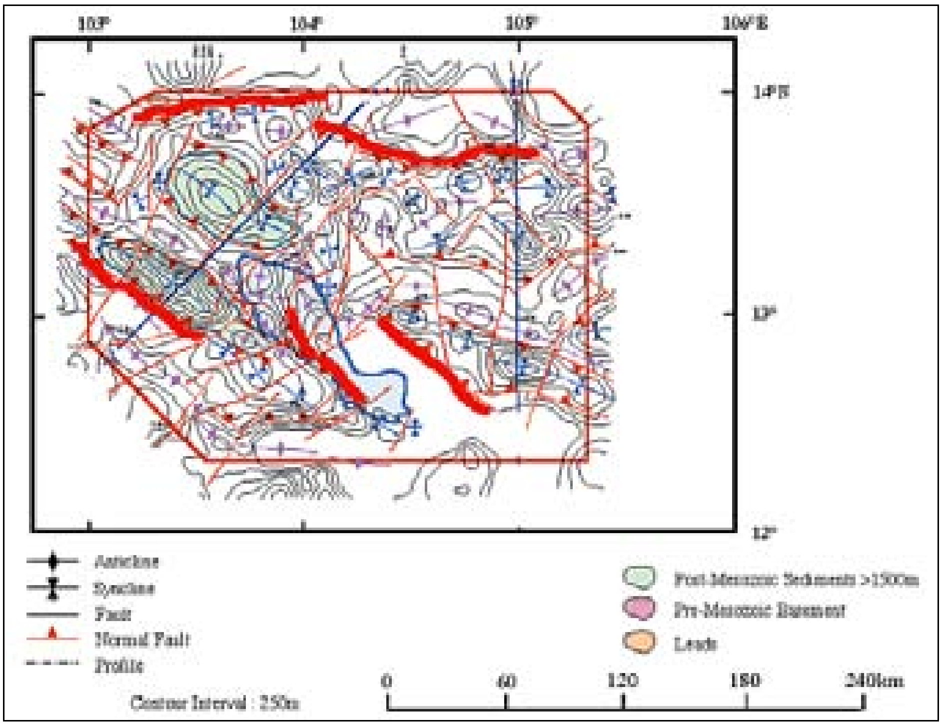

Figure 11: Faults in the deep geology of the Tonle Sap (Modified from the "Coordinating Committee for geosciences programmes in East and South East Asia" Bangkok – Thailand).

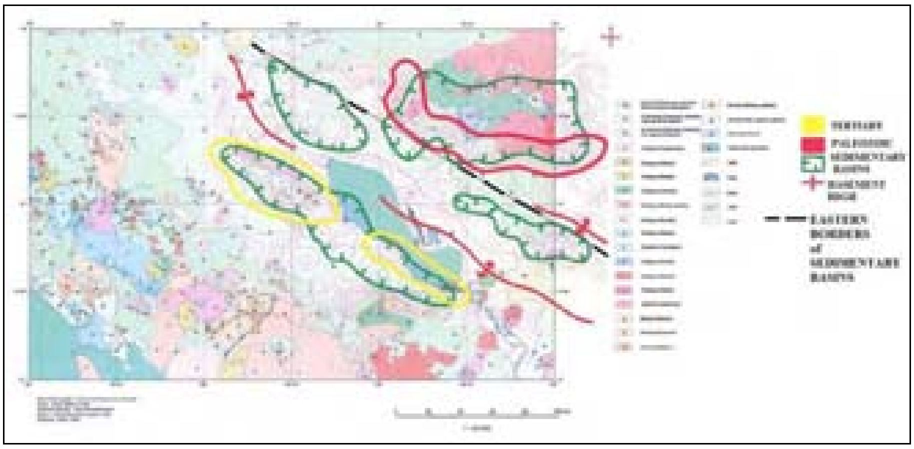

Figure 12: The two sedimentary basins in the Tonle Sap basin
(Modified from the July 2005 Cambodian National Petroleum Authority paper presented in Pattaya – Thailand).

All the existing geophysical information is summarised on the above Figure 12.

From a geological point of view it is extremely interesting to observe on Figure 12 that:

1. The current lake is not centred over the deepest grabens seen on the gravity data but instead in between two grabens.

2. That the Eastern sides of the sedimentary basins located to the East of the lake *(represented in our Figure 12 by black dashed lines)* correspond more or less to the division between the "Old Alluvium" and the "Young Alluvium" appearing on the simplified map of Figure 1 (Presented in Chapter 2 of this report: Geology of the Tonle Sap in the Indochina Region).

It is the hypothesis/opinion of this consultant that those grabens are or could probably be still active today. This hypothesis could therefore explain a differential subsidence in the Tonle Sap basin along our "Black dashed lines." and also explain the observed difference between the "Young Alluvium" completely surrounded by the so-called "Old Alluvium". Without this hypothesis it is a bit difficult to explain and justify the difference between those two different Alluvium and how they sediment this way. From a hydro geological point of view this is quite important to understand.

Since the Young alluvium seems to have no outcrops to the West and are completely circled by the Older alluvium it means they have never been there and that water streams or rivers or seas were not anymore discharging and sedimenting the younger alluvium. Or is there another possibility . It is the opinion of this consultant that the "Younger alluvium" could therefore have a different sedimentation conditions than the "older alluvium".

This hypothesis has extremely important impacts on the sediments in the Tonle Sap basin and consequently on the hydrogeology of the area. In the following chapters we will try to explain this hypothesis a bit more.

2.3.4 The deep geology of the Tonle Sap graben and sedimentary basin

Unfortunately so far no deep drilling has ever been completed in the Tonle Sap. The only available information is from the neighbouring "Offshore Khmer basin" to the West. Its stratigraphy is presented here under starting from the oldest sediments i.e. the Oligocene clastics or the first "Flushed out" materials just reaching the basin after the formation of the Himalaya. For the very same reason the similar sediments are probably at the bottom of the Tonle Sap graben and basin.

1. **Oligocene:** Alluvial fan near basin
2. **Early Miocene**: Fluvial –Lacustrine
3. **Middle Miocene**: Fluvial Coastal plain
4. **Late Miocene-Pliocene-Pleistocene**: Shallow marine

The Figure 13 here under presents some brief information about the stratigraphy in the nearby offshore basin. Obviously, not totally representative of the Tonle Sap basin it could indeed give, in the total absence of information for the Tonle Sap basin, a very preliminary idea of the sedimentation in the Tonle Sap.

For the convenience of the reader in this Figure 13 the sediments from the Early Pliocene to the Pleistocene have been highlighted in green. Their thicknesses are quite constant to the East (from 380 to 480 meters) but are almost doubled to the West (720 to 760 meters). A deeper ridge is also evident from well H-1 to the West to the well 81-1 to the East with the bedrock at more than 3000 meters.

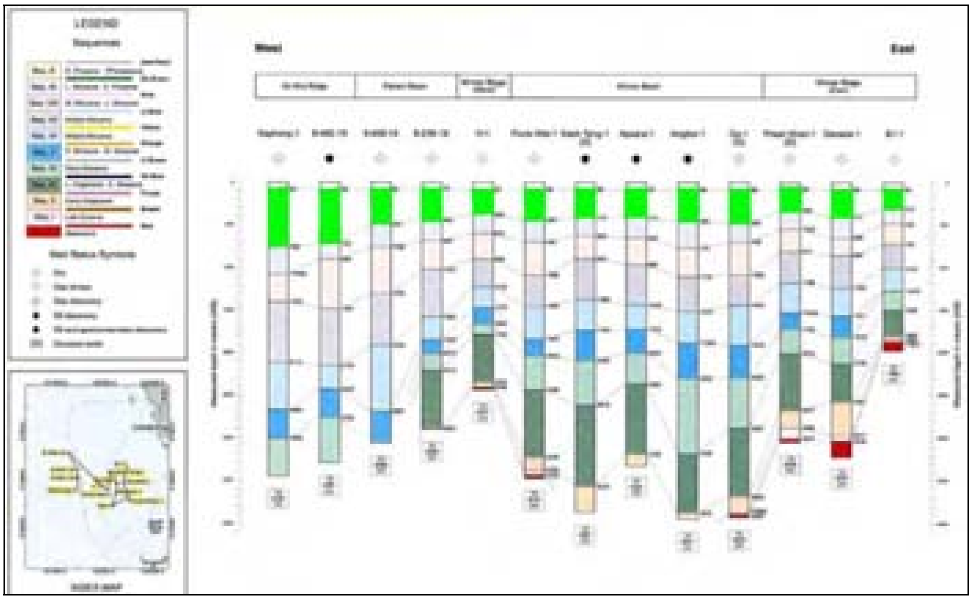

Figure 13: Location of drilled wells and stratigraphy in the Offshore Khmer basin (Modified from the "REGIONAL GEOLOGY IN KHMER BASIN").

Figure 14 here below presents the details of the stratigraphy of well DA-1 (from Blocks 1 & 2). It clearly reveals the complete characteristics of a delta (or paralic) with sedimentation such as swamps, alluvial plains. Paralic is said of deposits laid down on the landward side of a coast, in shallow fresh water subject to marine invasions. Thus, marine and no marine sediments are interbedded.

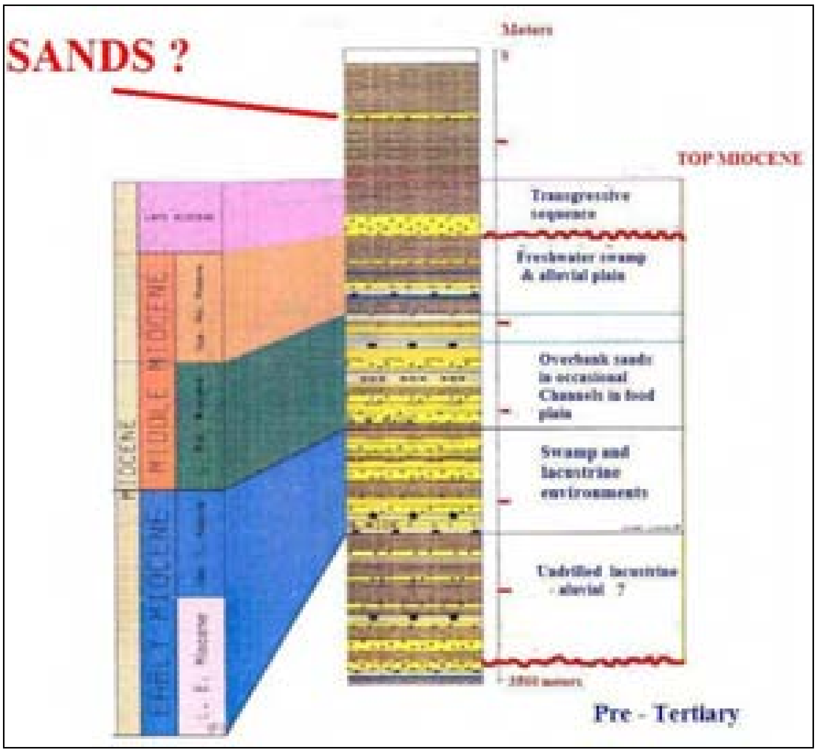

Figure 14: Stratigraphy of oil well DA-1 from Blocks 1 & 2
(Modified from CNPA-REGIONAL GEOLOGY IN KHMER BASIN).

The thickness of sediments in this well is almost 3500 meters. In previous paragraphs we observed that the Tertiary flow of the Mekong was probably a “North-East/South-West” one. Consequently the Tonle Sap basin is “Upstream” to the offshore basin. The general trend of the granulometry of its sediments should always be bigger than the one in the offshore basin. It is also possible that its thicknesses could even be much more important if the subsidence was important.

The stratigrafic information from the offshore basin also reveals that the thickness of the Early Pliocene to the Pleistocene is in the range of from 380 to 480 meters. To this thickness we should add roughly 80 to 100 meters to reach the sea floor. May be this figure could also give a very preliminary idea of the thickness of the Quaternary Old and Young alluvium sediments in the Tonle Sap basin. No evident discordance is appearing between the Tertiary and the Quaternary. For this reason it is also possible that in the Tonle Sap this transition was smooth too.

2.3.5 Geophysical model for the Tonle Sap sedimentary basin

On the grounds of the above very scarce geological information, a preliminary geophysical model for the Tonle Sap basin was nevertheless prepared by the experts of the Cambodian National Petroleum Authority. The Figure 15 here under presents a resume of their tentative model.

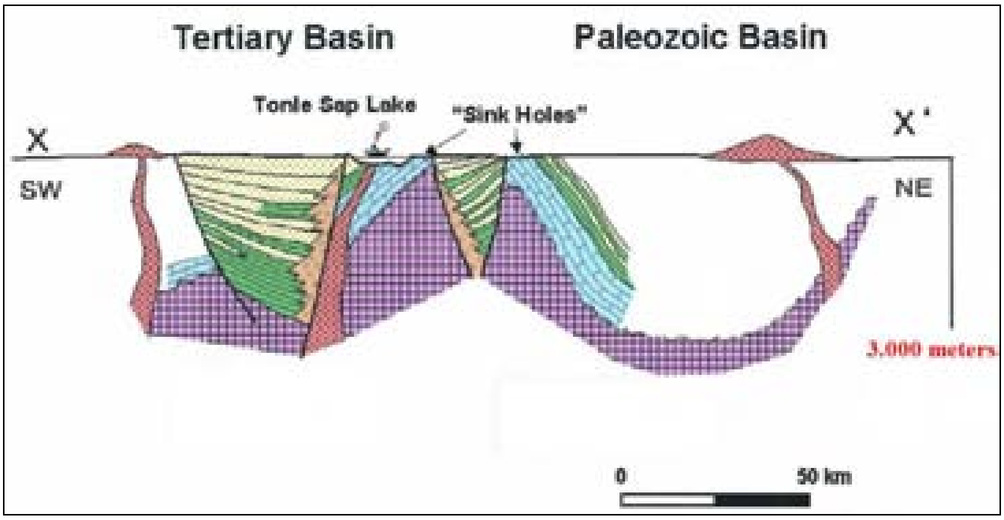

Figure 15: Preliminary SW-NE geological model for the Tonle Sap basin
(Modified from the July 2005 Cambodian National Petroleum Authority paper presented in Pattaya – Thailand).

It is worth observing on their model that the reported thickness of the Tertiary sediments accumulated in the Tonle grabens could be around 3000 meters just like in the neighbouring offshore basin.

2.4. Geology of the Tonle Sap graben and basin

2.4.1 Geological context of Cambodia

In the past the geology of Cambodia was detailed successively by Workman (1972 and 1977), Rasmussen and Bradford (1977), ESCAP (1993) and Vysotsky et al. (1994) amongst others. Only the most relevant points and important features of the Cambodian geology will be presented here under (most of the geological information appearing here under is modified from Dr. D. A. Polya's paper "Arsenic hazard in shallow Cambodian groundwaters" published in October 2005).

According to Workman's paper, in 1977 the Indochina Peninsula mainly consists of the Palaeozoic and the Tertiary (Mesozoic). In the downstream area of the Mekong River, the Quaternary basin is thought to conceal the Tertiary basin (Workman, 1977 and Hutchison, 1989). It is called the Mekong basin that is mostly filled with deposits of paleo- and modern Mekong River.

Although there are significant highland areas to the northeast (Ratanakiri Highlands, Terrain Rouges Plateau and Chhlong Plateau), north (Khorat Plateau) and southwest (Cardamom Mountains) of the country, the topography is dominated by the valley of the Mekong River, to the northeast and south of Phnom Penh, and that of the Tonle Sap drainage system, to the northwest of Phnom Penh. The highland areas consist principally of a wide variety of pre-Cenozoic rocks, collectively referred as "Older Units". These rocks include:

1. Precambrian- Early Palaeozoic granites and high-grade metamorphic rocks (particularly in the northeast of the country);

2. Permian calcareous sandstones and lime stones with interbedded marls, calcareous shale and sandstones;

3. Triassic to mid-Jurassic often red-coloured terrigenous sedimentary rocks, notably conglomerates, breccias and sandstones.

4. Late Jurassic-Cretaceous quartz-rich, clayey and volcanoclastic sandstones, many of which are widespread throughout the country and outliers of which form distinctive hills or `phnom's (Vysotsky et al., 1994).

5. Secondary sediments form substantial several Km-thick sequences overlained by Tertiary sediments, both offshore and onshore, notably in the Tonle Sap and Svay Rieng (southeast Cambodia) regions.

The lowland areas of Cambodia are dominated by Tertiary sediments and lesser volcanics. The oldest of these units are `Upper Neogene-Quaternary' (ESCAP, 1993; stratigraphic unit N2-Q) sediments, namely sands, claystones, siltstones, gravels and laterites. These sediments have limited outcrop, mostly in eastern Cambodia, but also underlie much of the valleys of the Mekong and Tonle Sap regions.

Of similar age are “Pliocene ± Pleistocene” basalts (ESCAP, 1993; stratigraphic unit N2-Q1), again cropping out mostly in the eastern half of the country, notably north of Kompong Chom and also in Mondolkiri Province. Unequivocally though, the later Quaternary deposits are by far the most important in terms of areal extent. Those Quaternary deposits can be sub-divided into:

1. The **“Older Quaternary Alluvium”** deposits (ESCAP, 1993; stratigraphic unit Q2ÿ3), largely consisting of sands, silts and claystones found in the valleys of the Mekong and the Tonle Sap graben and regions;

2. The **“Younger Holocene Alluvium deposits”** (ESCAP, 1993; stratigraphic unit Q4) comprising a mixture of often organic-rich silts, sands and clays. Those Holocene deposits form not only in the inland plains but also on the southwest coast and in small upland valleys.

The thickness of these Holocene and older Quaternary sequences is typically several tens of metres although they may be more than 100 m thick, notably in the “Mekong Groundwater Basin”, an area to the south and southeast of Phnom Penh, roughly bound by the Bassac River to the west, the Mekong River to the north and Upper Neogene Quaternary rocks to the northeast (JICA, 1999 and the December 2005 IDE Final Report: STRATEGIC STUDY OF GROUNDWATER RESOURCES IN PREY VENG AND SVAY RIENG - PHASE 1-).

2.4.2 Geological context of the Tonle Sap basin

The Figure 16 here under presents the geological map of the North-western Provinces. The legend of this map appears in Annex 6 at the end of the present report.

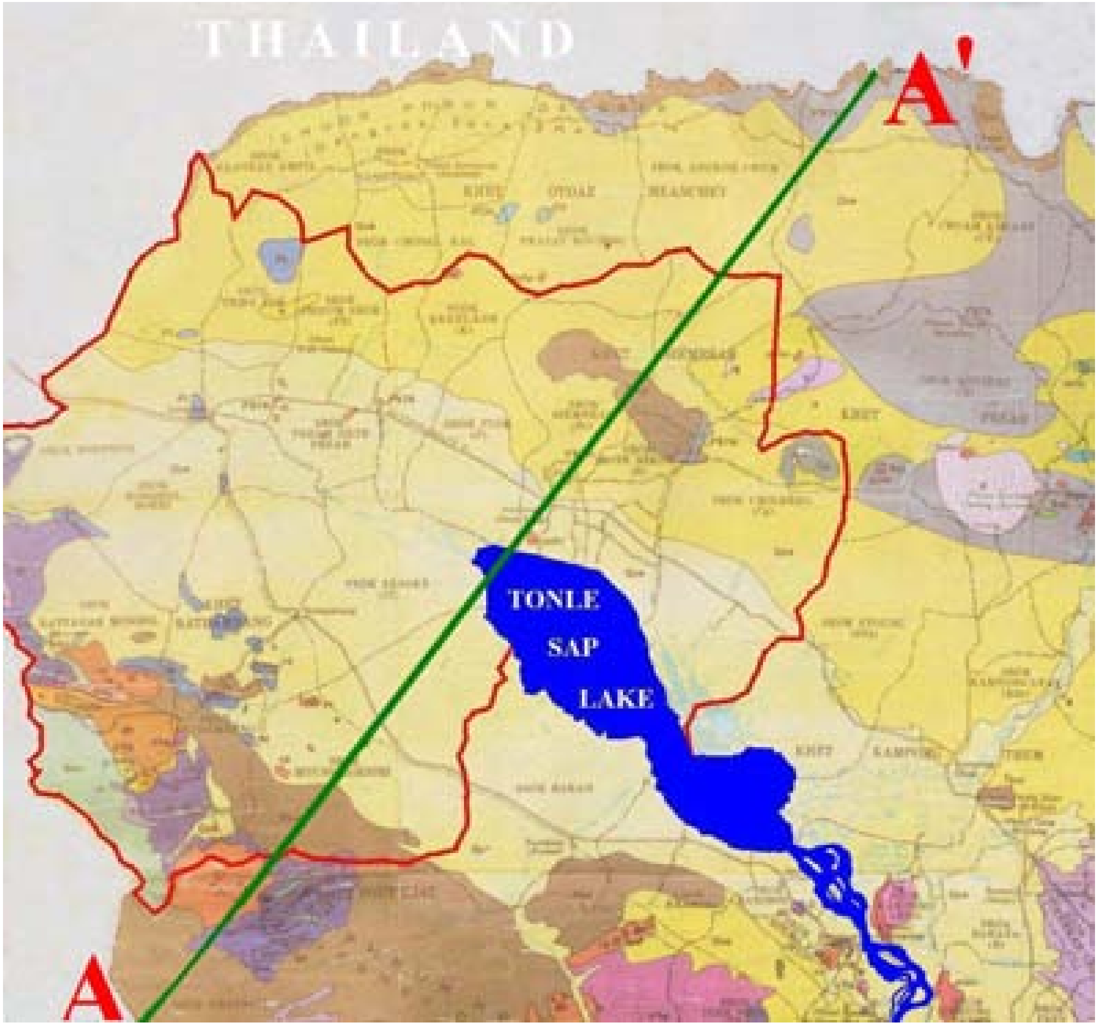

Figure 16: Geological map of the North-western Provinces.

On this geological map the borders of the ECOSORN provinces have been represented in red. In addition a cross section **A-A'** with a South-West/North-East direction is represented by a green line.

It is worth observing on this map that the difference between the "Old Alluvium" and the "Young Alluvium" on the West of the lake is not as clear as it was revealed by Figure 2 the "ADB-Simplified Geological map of the North-Western Provinces of Cambodia" presented in Paragraph 1of this report. The respective thicknesses and subcrop topography of the Old and Young alluvium are so far completely unknown throughout the ECOSORN Project mainly because the paleo-geomorphology of the sea or rivers draining into the Tonle Sap lake probably displayed such a great deal of sinuosity and so many different conditions for sedimentation. In addition, this area was probably subject to tidal movements and sedimentation. On the grounds of the previous geophysical information and of the geological map a tentative model was prepared by the Consultant for the area of the ECOSORN project. The Figure 17 here under presents this tentative model.

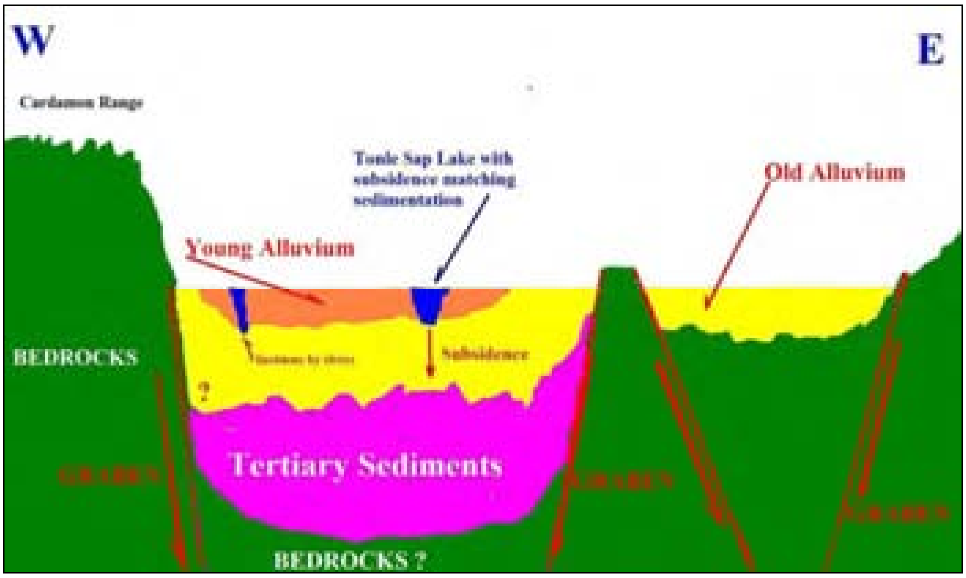

Figure 17: A tentative geological model for the Tonle Sap sedimentary basin.

The following comment can be made for this preliminary model:

1. Probably graben faults on the perimeter of the basin as confirmed by the above Figure 16 “Faults in the deep geology of the Tonle Sap.”

2. A discordance between the Tertiary sediments (represented in purple) and the Quaternary “Older alluvium”, represented here in yellow, but it is not yet confirmed. It is the opinion of this consultant that in this graben the subsidence was probably almost constant through geological time in other words, that there is probably almost no discordance between the Tertiary and the Quaternary.

3. On the above model it is very clear that the “Older alluvium” covers the “Older Alluvium” sedimented all over the basin and below the “Younger alluvium” since 100 % of the basin. It should also be observed on our tentative model that, INTENTIONALLY, no Tertiary sediments have been represented to the right of the model. As a matter of fact it seems they never deposited there.

4. Very recent studies revealed that during the Early Holocene the flooding regime was quite distinct from the current situation and indicate a stronger tidal influence in the lake under higher-than-present sea levels. At that time the lake was clearly influenced by tidal and saline waters coinciding with the sea level transgression of 2.5m that inundated southern Vietnam and parts of southern Cambodia. From the

early Holocene there was probably still a permanent connection between the lake to the South China Sea via the Mekong Rivers. During the sea-level maximum the coastline penetrated well into southern Cambodia and, given the extremely low relief of the lower Mekong River basin, it is quite probable that tidal influence extended inland along the Mekong and Tonle Sap Rivers, and possibly into the Tonle Sap lake itself (the actual average depth of the lake in dry season is only 1.3 to 1.4 meter and its bottom is roughly at 0.5 to 0.7 above sea level). At that time the lake probably supported littoral swamp conditions with colluvial – alluvial outwashes from the surrounding terraces and mountains or alluvial materials carried out by rivers water and this could explain the finer sediments of the "Young Alluvium".

5. Some recent water streams have probably already eroded the sediments of the "Young Alluvium" and are recharging it as well as the underlying "Old Alluvium".

6. It is also possible that some continuous subsidence took place say "Plumb" over the Tertiary grabens and in a certain way facilitated the sedimentation of the "Young Alluvium".

The Figure 18 here under presents this hypothesis.

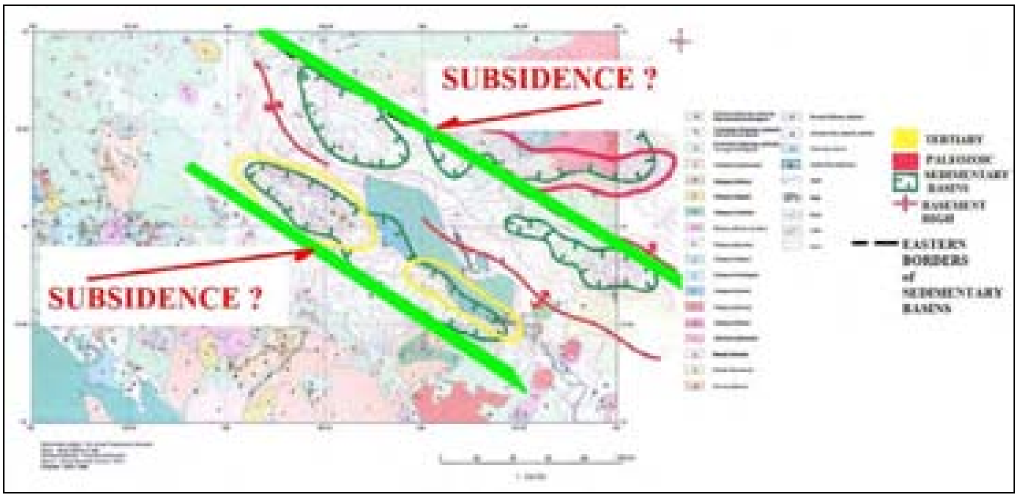

Figure 18: Hypothesis for the possible subsidence at the borders of the Tertiary grabens (Represented here in green lines).

It is really worth comparing here the strong analogy between the simplified Geological map presented in Figure 2, at the beginning of this report, with the topographic map appearing here under on Figure 19.

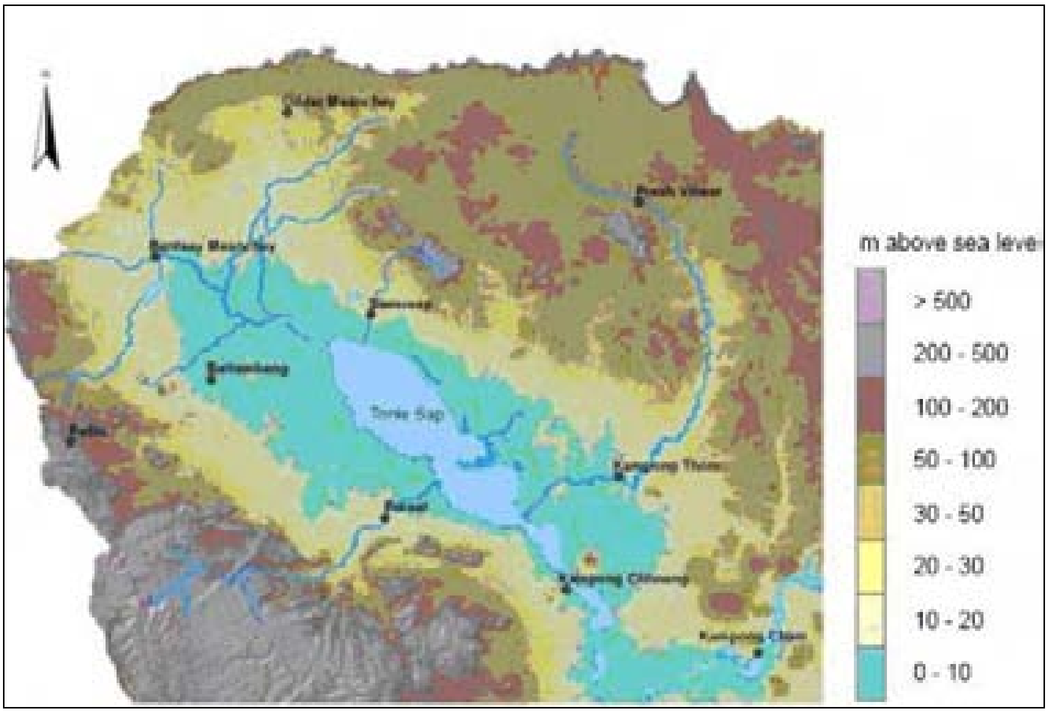

Figure 19: The relation between topography and the "Young Alluvium".

It is striking to notice on this map that the "Young Alluvium" corresponds more or less to the 10 meters contour line and for this reason could probably represent sediments of say a "larger Tonle Sap Lake".

2.4.3 A tentative scenario to explain the sedimentation of the "Old" and "Young" Alluvia.

On the grounds of all the above information a tentative scenario can probably be prepared to explain the sedimentation of the "Old" and "Young" alluvium in this basin. This is quite important because the two alluvia are quite superficial and shallow and for those reasons are the main targets for domestic water supply in this basin.

The explanations could be the following ones:

1. At the beginning of the Tertiary, collapse of the local graben and differential subsidence in a **"L"** shape basin, part of which is parallel to the Cardamoms Mountains (See the above gravity map on Figure 7). This basin is probably receiving sediments from the Mekong River discharging into the Gulf of Thailand but as well through communications with the Sea.

2. At the end of the Tertiary the centred subsidence of the Tertiary basins slows down and is then substituted by a larger subsidence of the whole basin allowing the "Old" alluvium to sediment almost everywhere. At that time the basin was probably (**.**) a very flat and large size horseshoe shape, shallow "Bay" receiving sediments from the Mekong River and from the Sea. The sedimentation was probably

limnic and paralic at the same time i.e. freshwater and brackish swamps, over bank sands in occasional channels as well as alluvial plains. Obviously this type of sedimentation always shows intensive and very quick lateral inter digitations of all the sediments entering into the basin.

The result of the above sedimentation is very variable and always shows an extremely complicated subsurface alluvial geology. In a nutshell: '<u>there are no rules for the local sedimentation</u>' for this "old" alluvium.

The FAO Figure 20 appearing here under could represent conditions of "Swamps sedimentation" existing at that time in the Tonle Sap basin.

Figure 20: Swamps (http://www.fao.org/docrep/003/X9550E/img/Swamps.jpg).

3. The "basin wide scale", continuous subsidence is probably taking place throughout the Pleistocene and forms the "Old" Alluvium.

4. At the Holocene it seems that the "basin wide scale", subsidence stops. A new subsidence centralised in a "Corridor" takes thus place. The large, flat and shallow "Bay" of the Pleistocene shrinks, probably into a very long and large lake, with connection with the Sea and allows the sedimentation of the "Young" Alluvium in the central part. The conditions are probably "swamps like" with freshwater and brackish water plus fine sediments such silts. As far as we can discern this new subsidence seems to take place "Plomb" over the old Tertiary basins.

5. The actual Tonle Sap Lake could thus represent a 'relic' of all the previous Tertiary basins of the Pleistocene 'bays' and/or of the successive Lake or Lakes.

2.4.4 Geological model in the South of Cambodia

In July 1999 the JICA Project "Study on groundwater Development in Southern Cambodia" also prepared a geological model. For the convenience of the reader and to allow quick analogies and comparisons between the two different geological settings the JICA model for the South is presented here under in Figure 21.

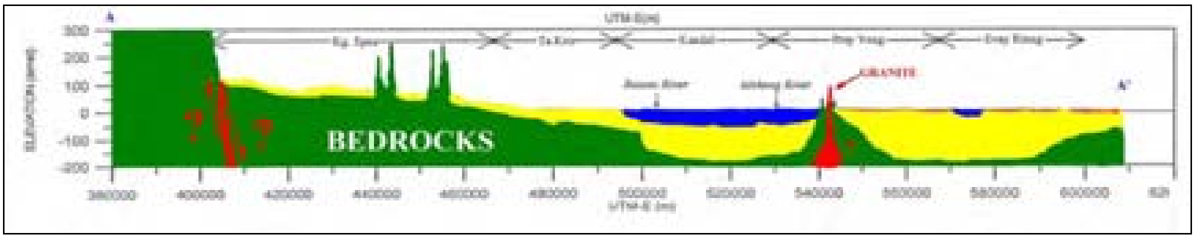

Figure 21: Geological model in Southern Cambodia (modified from page 4-12 of the July 1999 KOKUSAI KOGYO "Study on Groundwater development in Southern Cambodia")

The very same model is also reproduced page 41 of the December 2005 IDE Final Report: STRATEGIC STUDY OF GROUNDWATER RESOURCES IN PREY VENG AND SVAY RIENG - PHASE 1-).

3. The different possible technical options for practical, cheap and sustainable domestic water supply

In the Executive Summary of this report it is stated that : *"The other and probably the most important problem with domestic water supply is without doubt the sustainability of any new water supply system". "What will happen after this Project will close its doors?"* is certainly the most important question any person in charge of development Projects should always be concerned about.

This important question can, and will only, be resolved using the simplest but most sustainable technologies for water supply. Obviously each option should match the prevailing, local conditions in the different target areas of the ECOSORN Project.

In the following paragraphs this report will try to give as many practical advises as possible starting from the very old tradition of ponds, through rainwater harvesting, dug a drilled wells, most appropriate water supply system in an area, etc.

3.1 Digging very large size ponds

The local people probably have over than 3000 years of experience in this technique. The very large size ponds dug around Angkor Wat and so many temples and other places are just evidences of this extremely long tradition. Obviously it works but all efforts should always be done to protect, as much as possible, the bacteriological quality of the waters stored. Use of fences to avoid cattle grazing around the pound is a first and very cheap step to improve the quality of the water.

3.2 Rainwater harvesting

This technique is extremely well known by the people living in this corner of our "Blue Planet". The local people are almost using it daily and in some areas of the ECOSRN project it is the sole source of drinking water throughout the whole year. In large areas of the Tonle Sap basin, rain water is the only water source of adequate quality for domestic consumption, but rain water is available only during a part of the year, and safe storage facilities are required to keep a sufficient quantity for the dry season, without risking secondary contamination. The very basic principle is presented in the Figure 22 here under.

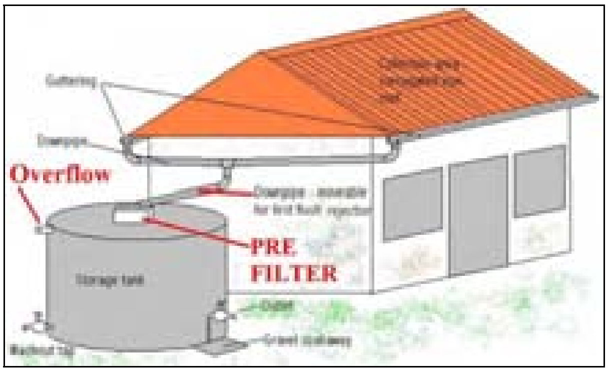

Figure 22: Basic principles of rainwater harvesting
(Modified from the EU "DOMESTIC ROOFWATER HARVESTING IN THE HUMID TROPICS").

Taking 20 litres per person/day as the absolute baseline for the demand of good quality water, a storage tank of about 20 m³ would be thus required to last a family of 6 persons over the 5 or 6 months of the dry season. Most families in rural areas are too poor to purchase such a tank, and the smaller tanks which are now in use everywhere in the area are opened every day and thus exposed to unnecessary secondary, mainly organic pollutions. When whole the stored drinking water has been consumed, either water has to be bought, and in some instances transported over several kilometres, or low quality water has to be used, which of course has impacts on public health. From the above it is obvious that the supply of potable water to rural households, in problem areas, is at present an extremely urgent and important problem. For the above reasons the consultant would like to suggest that in the future the "ECOSORN Jumbo jars" be improved by couple of cheap but very simple, sustainable and easily maintained features. Those suggested features are the following ones:

1. All future "ECOSORN" jars should be automatically equipped with two "Built-in" pipes at the bottom. A cheap plastic valve must be attached to one of those pipes while the second pipe would allow for future interconnections between

the jars. In the future, local people should collect the water through that valve avoiding therefore opening the jar daily and introducing, not always, very clean containers to collect the water they need.

2. On top of the jar an overflow pipe should, preferentially, discharge in the nearby dug well if any.

3. The lid should cover very well the jar and be equipped with a hole allowing the gutter to discharge inside the jar.

4. Debris, dirt, feather and dust will collect on the roof of a building or other collection area. When the first rains arrive, this unwanted material will automatically be washed into the tank. This will cause contamination of the water and its quality will be unfortunately reduced. Many Rain Water Harvesting systems therefore incorporate a device for diverting this "First flushed" water so that it does not enter the tank.

5. There are a number of simple systems, which are commonly used, and also a number other, slightly more complex, arrangements. Although the more sophisticated methods provide a much more elegant means of rejecting the first "Flushed waters" field practitioners always recommend that very simple, easily maintained systems be used, as these are more likely to be repaired if any failure occurs.

6. The simpler ideas are based on a simple manually operated arrangement whereby the inlet pipe is moved away from the tank inlet and then replaced again once the initial first flush has been diverted. This method has obvious drawbacks in that there has to be a person present who will (always) remember to move the pipe.

7. Slightly more sophisticated methods include arrangements such as those shown in Figure 23 below, where the stopper in the inlet chamber can be removed to allow the first flush to be diverted.

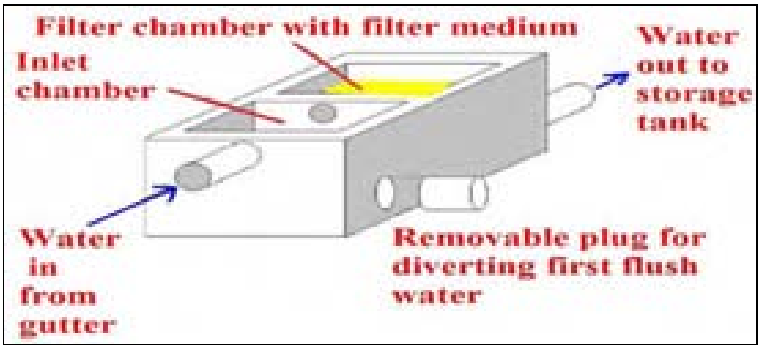

Figure 23: Simple rainwater filtration system

8. Other systems use tipping gutters to achieve the same purpose. The most common system, as shown here under in Figure 24 uses a bucket which accepts the first flush and the weight of this water off-balances a tipping gutter which then diverts the water back into the tank. The bucket then empties slowly through a small-bore pipe and automatically resets. The process will repeat itself from time to time if the rain continues to fall, which can be a problem where water is really at a premium. In this case a tap can be fitted to the bucket and will be operated manually. The quantity of water that is flushed is dependent on the force required to lift the guttering. This can be adjusted to suit the needs of the user.

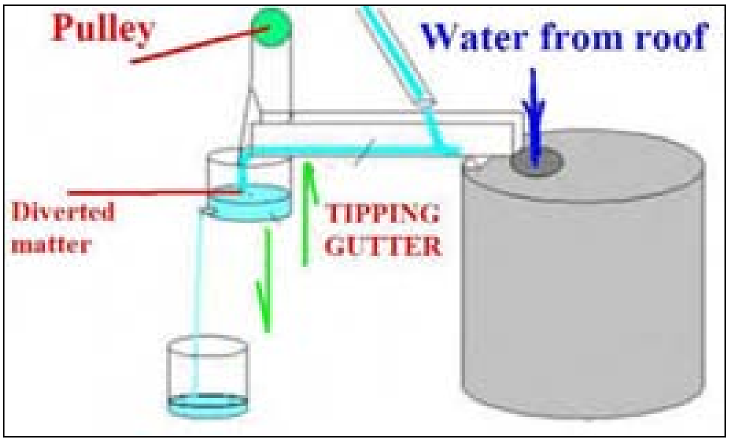

Figure 24: The "Tipping gutter" device.

9. The simplest tool is probably the "Large size lateral pipe" connected to the gutter. The very first volumes of rainwater enter this large pipe and it is only when the large size pipe is full and is overflowing that the rainwater can then flow into the jar. The Figure 25 here under presents a sketch of this device.

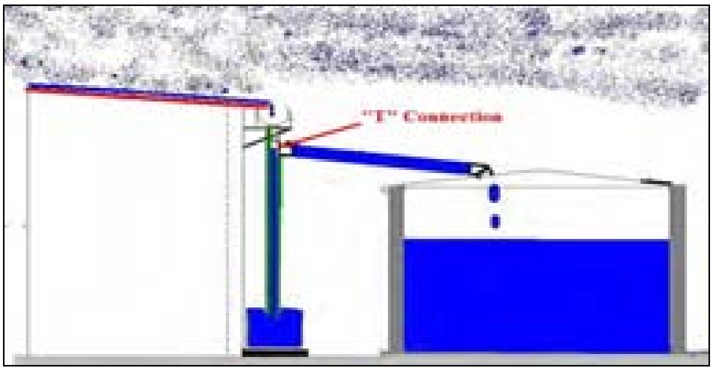

Figure 25: The cheap "Large size lateral pipe" device to flush out the dirt of the roofs.

10. A cone shaped mosquito net installed on top of the ECOSORN Jumbo jars would filter the rainwater avoiding that dead leaves or feathers accidental enter into the jar.

11. If possible all jars interconnected from bottom through the "Built-in" pipes. Many small scale local entrepreneurs already started to interconnect their jars and are selling water from rainwater harvesting or from sallow wells.

12. In schools or other communities piling and cementing concrete rings together and then interconnecting those cylinders would create very quickly quite cheap but important rainwater water storage.

The four Figures 26 to 29 appearing here under are presenting couple of the above suggested, cheap features designed to improve as much as possible the quality of the harvested rainwater.

Figure 26: "Built-in "connections" at the bottom of the jars allowing for discharge and future interconnections

Figure 27: Small scale entrepreneurs interconnecting jars and selling water (In this case from a shallow well).

Figure 28: Local small "Entrepreneurs" selling water.

Figure 29: Rainwater harvesting in schools.

3.3 GPS position for any future ECOSORN RIS wells

The ECOSORN Rural Infrastructure Section collected numerous well information documents that were combined in ‘folders’. Most of these folders contained lots of documents mainly well data. The Consultant went through these large folders and realized that no geographic coordinates was available for all listed wells and that this was a serious limitation of the available information. It is quite obvious that it would take months (especially during the 2006 raining season) for several ECOSORN field officers equipped with motorbikes and GPS to revisit all the old sites in order to obtain their respective geographic positions. In the past, several large groundwater studies implemented in the area also confirmed this concern. In the ADB report it is stated that : “*Because of the absence of grid position the enormous amount of data in MOWRAMS ground water database is superficial, unusable and absolutely useless for assisting future water projects…*”. Therefore a very important and general advise for all future ECOSORN RIS actions would be that all well position be recorded with a GPS device in either the WGS84 or UTM 48. This is a mandatory requirement.

Due to the lack of geographical positions for well data, the consultant tried to obtain as much geological information as possible at a wider scale i.e. for groups of villages. This was highly facilitated by the input of the private sector involved in the Water Sector of the three Provinces contemplated in the ECOSORN Project.

3.4 The dug well option versus the drilled well one

For the future actions of the ECOSORN RIS the consultant would like to suggest that wherever and whenever technically feasible and possible the option of large size dug well, still producing at the end of the dry season, is always preferred instead of the drilled well alternative. From a practical point of view for local people the dug wells are much more sustainable and far easier to maintain. Here under we present some comments on this approach.

1. As opposed to Four Inches I.D. drilled wells, large size excavated dug wells are generally constructed at locations where aquifers (water bearing geologic formations) are both shallow and low yielding. An aquifer that yields only 4 litres per minute will indeed produce roughly 6000 litres per day.

2. To compensate for low-yielding aquifers, large diameter bored wells serve as storage reservoirs to provide water during peaks of high demand (always very early in the morning and the evening only).

3. An excavated well with a diameter of 1 m, a total depth of 15 m and a water depth of 10 m contains approximately 8000 litres of water i.e. a volume probably largely enough for the daily use of a small village.

4. Many of the so-called “drying wells at the end of the dry season” could very easily and very quickly be brought back to production by just deepening them a bit more. This could very easily be achieved by filling them first with quite clean sand, re-dig them and then install the deepest porous concrete rings well below the lowest water table at the end of the dry season. Compared to in-situ formation or clay, sand is always a material very easy to dig out from any well. Some sand will indeed remain trapped outside the concrete rings but will also act as a “lubricant” to ease the sinking of the concrete rings.

This recovery operation is represented here under in the three following Figures 30 to 32.

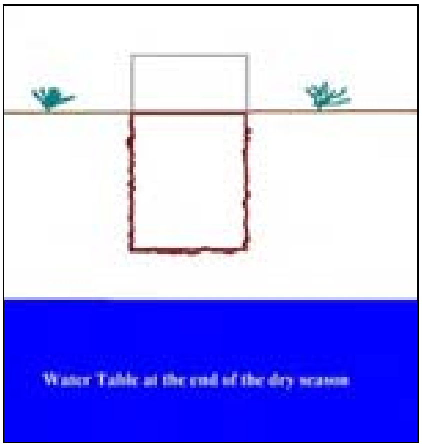

Figure 30: A well drying at the end of the dry season.

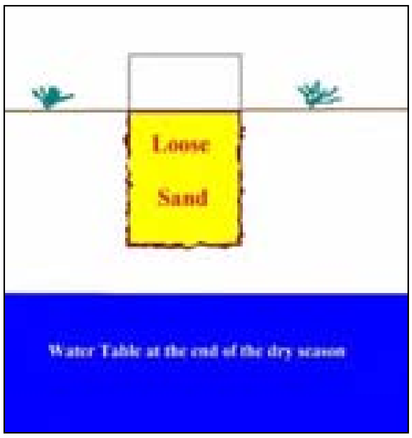

Figure 31: The very same well but full of loose sand and ready for re-digging.

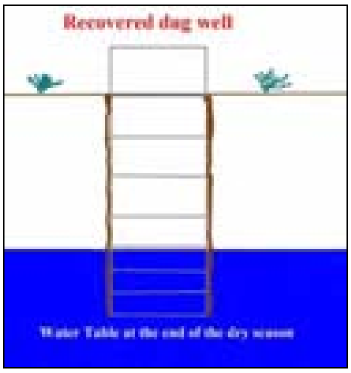

Figure 32: The above well after its recovery.

The Figure 33 appearing here under compares the two different options of drilled wells versus large size dug or excavated wells.

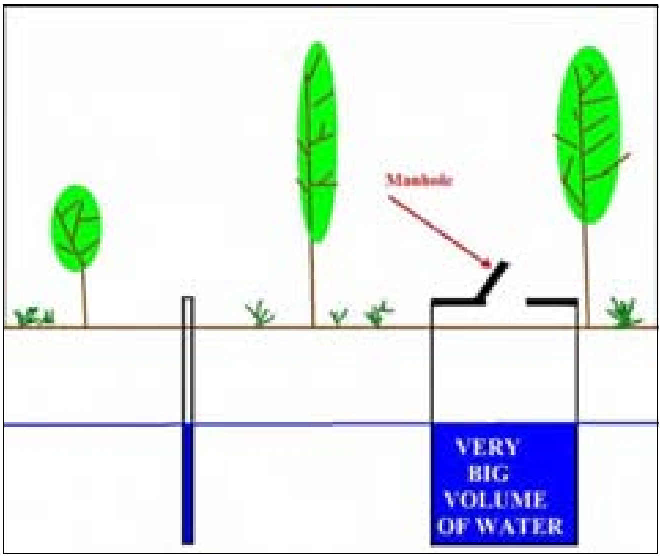

Figure 33: The dug well option versus the drilled well one

On the above Figure 33 it is worth observing the existence of a lid and a "Man hole" in the option of the dug well. Although a very simple tool, this manhole has indeed an extremely important role for the maintenance of any well. In case of problems a local person could always enter inside the well and repair it.

As it will be described here under, "Rope pumps" will probably be installed during the course of this ECOSORN Project and those pumps also require a lid covering the well.

All the above features and suggestions have been fully integrated in the final design of the future ECOSORN well and combination wells. Those designs will allow the different options for the rope pump or of the bucket and windlass or both options according to the real request of the local people (Demand Driven).

The two Figures 34 and 35 appearing here under present two technical drawings prepared by the ECOSORN RIS also checked, reviewed and modified where necessary by the consultant.

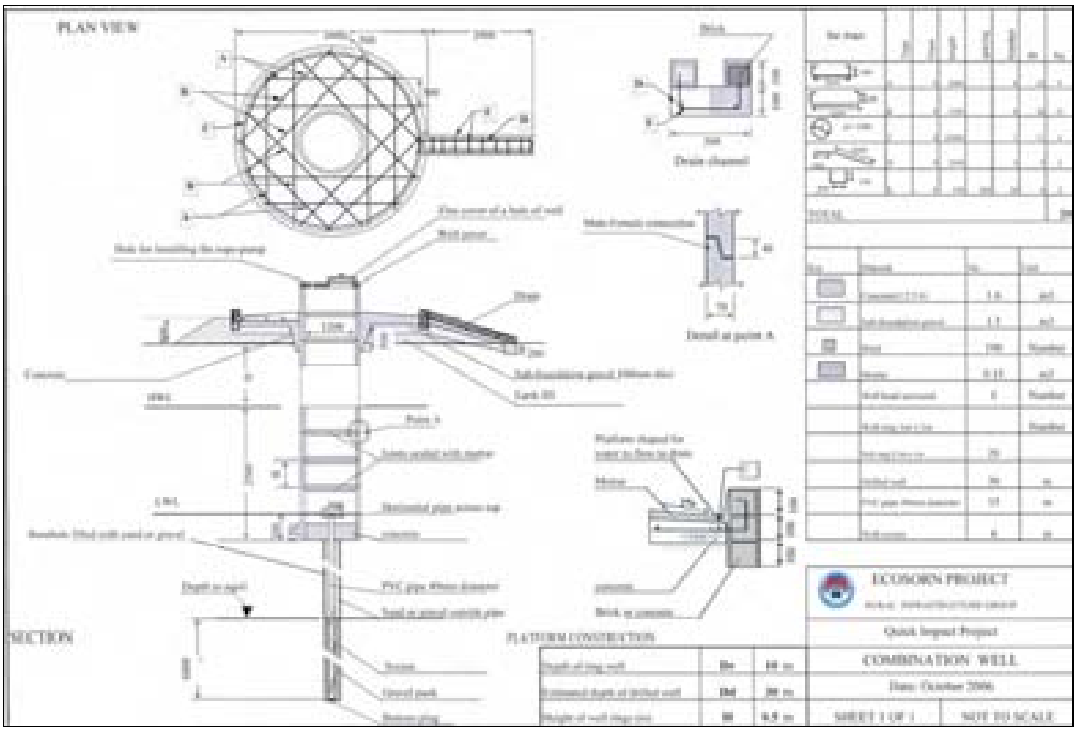

Figure 34: ECOSORN RIS Design of a combination well.

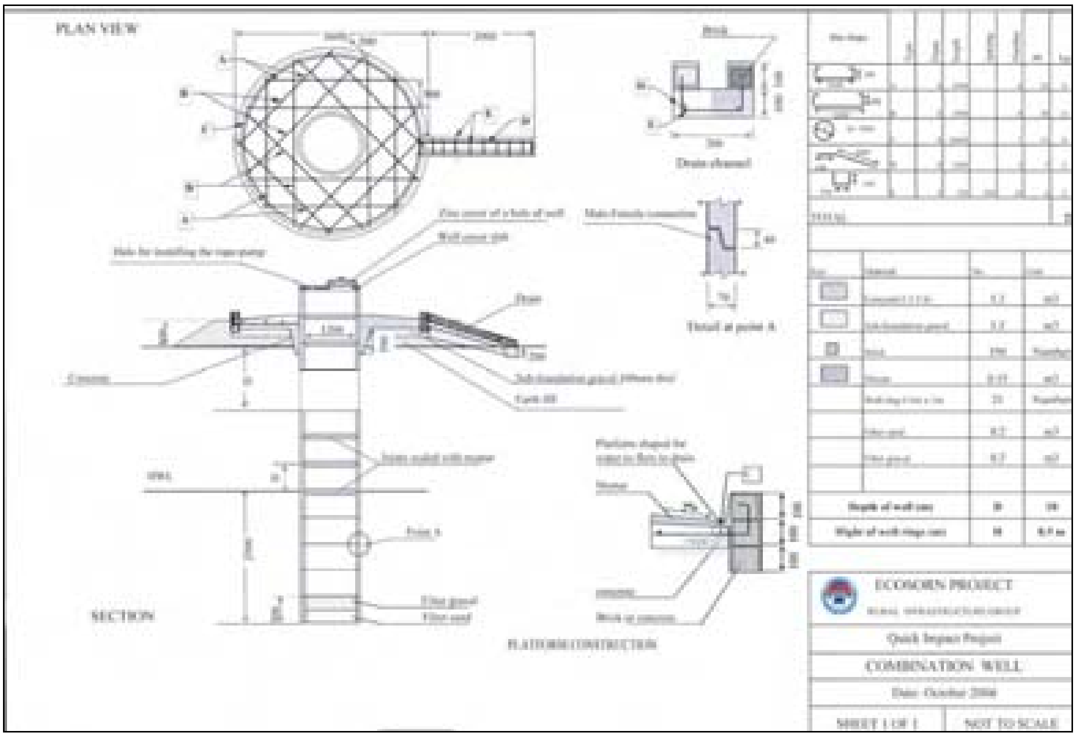

Figure 35: ECOSORN RIS Design of a dug well.

The presence of a man hole insures the long term sustainability of any dug well. For drill wells facing any technical problems such as sand intrusion because of poor design or uncompleted development operations or incrustation and clogging with jelly-like masses of Iron and Manganese hydroxides, it is quite often necessary to remove the VLOM pump inside it, try to repair the well by backwashing or addition of chemicals such as Calgon. If all the efforts to repair the well were not successful the only option left would be to re-drill a new well. This approach is certainly an expensive one and not the most sustainable option. Another very important factor in favour of the option of dug wells versus drilled wells is that a “Rope Pump” could be installed on the lid of the dug of the new ECOSORN wells. Figures 36 and 37 here under present a Rope pump produced in Cambodia and its technical data.

Figure 36: A rope pump installed in Cambodia.

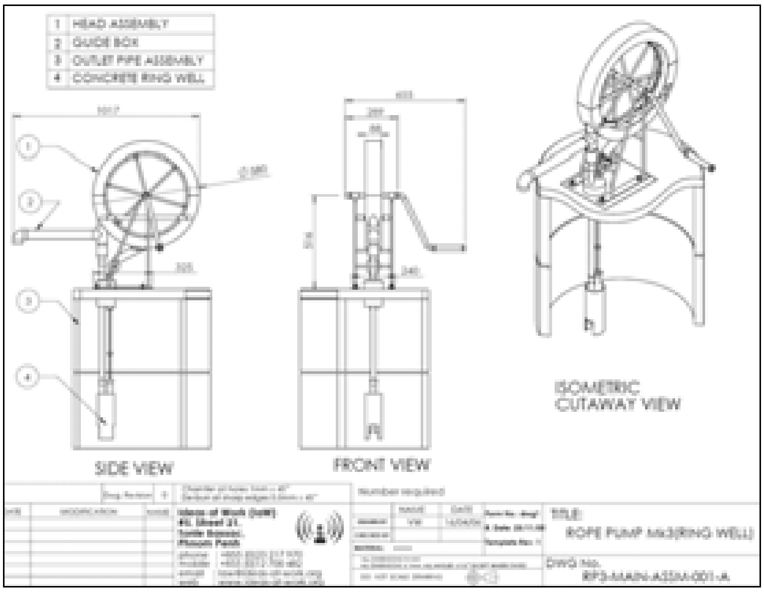

Figure 37: Technical information of the Cambodian Rope Pump.

From a bacteriological point of view, the lid on top of a well is an additional and extremely important feature since it is protecting the quality of the water. As we will comment at the end of the present report several studies in Cambodia mention that almost all the wells already show important bacteriological contamination. The lid is also the base to receive the rope pump. Figures 38 and 39 here under reveal the real hygienic conditions of two dug wells observed by this consultant during his quick field reconnaissance.

Figure 38: A well contaminated by garbage.

Figure 39: A well filled with garbage.

3.5. General comment about wells in the Tonle Sap area

Shallow groundwater is intensively exploited in the area to provide drinking water. Near surface wells typically have a depth to water table of between 2 and 6 metres, and clearly derive their yield from local recharge of either ground-filtered surface water or lateral groundwater flow through the more sandy horizons of the surrounding alluvium. Reports from several other projects reveal that:

1. Eighty percent of the near surface wells and boreholes are considered positive (and the dry wells are consequently 20 %

as can be observed in red colour on Figure 40 appearing here under).

2. Seventy percent of the productive wells discharge between 0.3 and 1.0 litre per second.

3. The remaining 10 % have discharges between 1.0 and 3.5 litres per second.

The distribution of higher yielding wells, very often associated with pockets of sandier material appears to be extremely random with very adjacent wells, just few meters away, producing the usual low yield. Those pockets of sands represent in fact the over bank sands in occasional channels as well as in alluvial plains or beach deposits sedimented during the Pleistocene “Old alluvium”.

The above results clearly reveal extremely variable near-surface geological conditions as a result of the very normal alluvial and meandering types of sedimentation in this Tonle Sap basin. In this geological setting it is extremely difficult to predict, in advance and with high precision the exact type of wells to be constructed.

The Figure 40 here under presents a resume of the above information based on a combined sample of 368 wells constructed respectively in the Siem Reap and the Battambang Provinces.

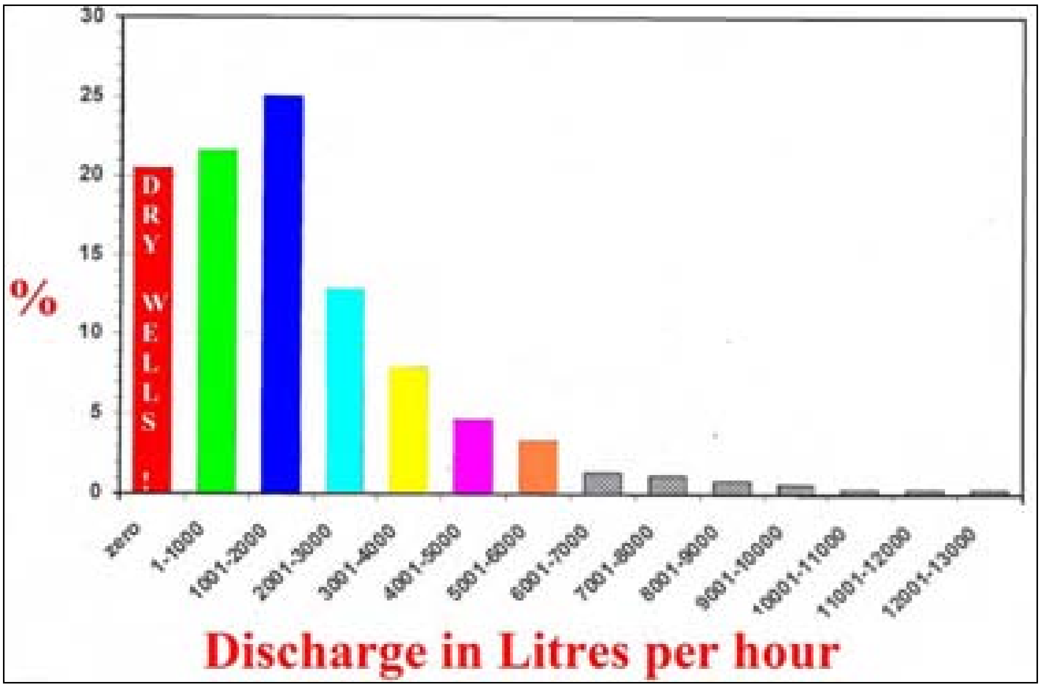

Figure 40 : Distribution of yields from 368 shallow boreholes in Siem Reap and Battambang Provinces (Modified from the 2003 ADB – Northwest Irrigation Sector Project)

3.6 Technical advises for the construction of dug wells

Dug wells are holes in the ground dug by shovel or backhoe. Historically, dug wells were excavated below the groundwater table until incoming water exceeded the digger's pumping or bailing rate. Since it is so difficult to dig beneath the ground water table, dug wells are not very deep. Typically, they are only 3 to 10 meters deep. In the area of the ECOSRN Project the dug wells very often are not more than 7 meters deep. Professionals from the Water Sector confirmed that this is justified by local 'beliefs' of a 'Naga'. For the very same reason many diggers prefer not to dig deeper as soon as they reach the water table.

The most important problem relating to the shallowness of the dug wells is that they may go dry during the dry season when the water tables drop. Some technical options to ease the digging below the water tables will be presented here under. To improve as much as possible the deep digging below the lowest water table the digging of the ECOSORN wells should always take place during the dry season in Cambodia.

3.6.1 Technical advises for design of dug wells and drilled wells

In the previous Chapters comment have been made on the observed large-scale contamination in the area of superficial aquifers mainly by Coli Forms from latrines. Being so shallow, dug wells have the highest risk of receiving additional local contamination. To minimize the likelihood of contamination, the dug wells should have certain features. Those features help to prevent local contaminants from travelling along the outside of the casing or through the casing and into the well. Those features are the following ones:

1. The well should be cased with a watertight material (for example, tongue-and-groove precast concrete) and a cement grout or clay sealant poured along the outside of the concrete rings to the top of the well.

2. The well should be covered by a concrete curb and cap that stands about at least 50 cm above the ground.

3. The land surface around the well should be mounded so that surface water runs away from the well and is not allowed to pond around the outside of the wellhead.

4. In case of suspected difficult hydrogeology below the concerned area a shallow "Hand-Auger" exploration hole could always be constructed before initiating the heavy digging works. Without any fluid (water or mud) "Hand-Auger" could probably reach 7 or 8 meters below ground surface. With the addition of a drilling fluid and a swivel on the auger it could probably penetrate down to 12-15 meters.

3.6.2 Technical advises to improve digging below the water table

It should be reminded here that the sinking, as deep as possible, of the porous concrete rings below the lowest water tables at the end of the dry season will be one of the most important keys of future successes of the ECOSORN activities.

It is so difficult to dig below the water and a lot of attention and care must therefore be dedicated to this very crucial part of the construction. To achieve this digging in the water zone submersible pumps are always used. The pumps require a generator at the surface. If the incoming flow of water is too important the pumping operations could indeed result into a very long and quite expensive operation. For this reason quite often the contractors would prefer to stop the digging. Anyway this digging is extremely important since it will guarantee the long-term sustainability of the new wells. This operation will also require a good and constant supervision from ECOSORN staff to guarantee that the porous rings are sunk well below the lowest level at the end of the dry season.

Without attention to adequate digging, the ECOSORN RIS activities will get back to square one i.e. the normal projects with lot of failures and a lot of wells not producing any water at the end of the dry season. If the ECOSORN RIS wants to achieve successful wells which are sustainable and cheap to operate it is mandatory that the adequate digging approach is well supervised.

The consultant is well aware that most of the local companies are strongly oriented towards extremely low-tech, shallow water-well construction and/or drilling and probably are not yet equipped with bailers. Nevertheless, if deeper hand digging is getting really impossible or far too expensive because of the cost of pumping then the option of the very cheap, in-situ built “Bucket bailer technique” to sink the concrete rings as deep as possible could eventually be considered. The success of many of the ECOSORN RIS wells could depend of this very simple feature and factor. A very brief description of the “Bailer bucket” is presented here under.

The “bailer bucket” is a long piece of heavy pipe with a check valve at the bottom and a rope or cable attached to the top. Quite often the bottom of the “bailer bucket” is torched cut with “teeth” to increase its penetration capabilities. The bailer bucket is alternately raised and dropped in a hole partially filled with water. The bailer bucket works far better under water than in dry sediments. When using the bailer in dry sediments it is absolutely imperative to pour water in the hole to ease and facilitate the digging works. Penetration of the bailer bucket is accomplished by a combination of hydraulic and mechanical actions. The slurry of cuttings and water enter the bailer as it is repeatedly dropped. These are prevented from leaving the bucket by the check valve. The “Bailer bucket” is then raised to the surface for emptying and the operation repeated. This very cheap equipment could easily be fabricated locally in areas of the Project. This “Bucket bailer” technique is presented here under:

1. The well is dug the traditional way until it reaches the local water table.

2. Then a simple tripod equipped with a free fall winch is installed on top of the well. As observed during the consultant’s quick field reconnaissance similar tools are quite common in the area to drive in concrete posts as foundations (see Figure 42 here under in the Bantaeay Mancheay area). Those winches could very easily be modified to use a bailer bucket in a dug well.

3. Like percussion drilling the well is then bucket bailed as deep as possible below the dry season water table to install the filter (porous concrete rings).

4. The concrete rings automatically sink down when sediments are bailed out of the well.

5. The concrete porous rings installed deep enough will assure continuous production over the years.

The Figure 41 here under presents a sketch of this “bailer bucket” technique while Figure 42 presents a winch in Beanteay Meanchy which could very easily be transformed to operate a “Bailer bucket” to deepen as much as possible the wells.

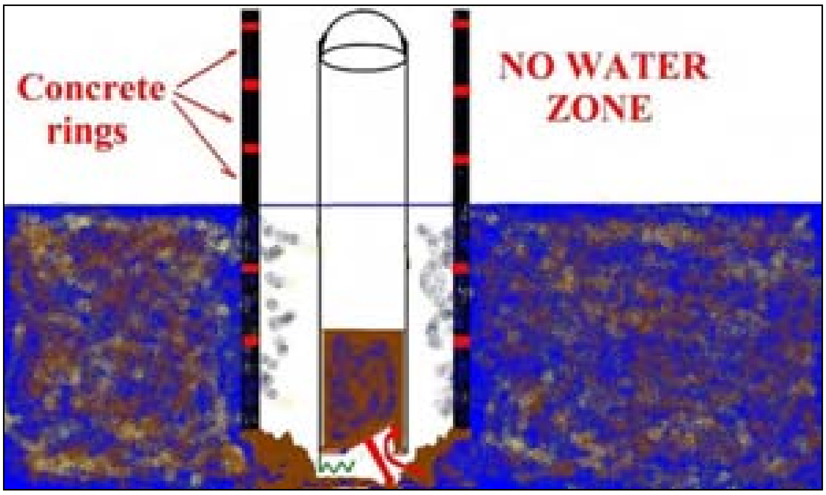

Figure 41: The “Bailer bucket technique” to dig deep enough below the water table.

Figure 42: A simple "Free fall" winch observed in Banteay Meanchay which could easily be modified to be used for a bailer bucket in a well.

3.6.3 Technical advises to re-dig the so called "Drying wells at the end of the dry season"

As already mentioned here above so many of the so-called "drying wells at the end of the dry season" could probably be brought back to production by just deepening them a bit more. The first operation is to fill the wells with quite clean sand. Once the wells are full of sand, digging jobs proceed as for a normal well. Digging loose sand in those conditions is always a quicker job compared to any normal digging. The deepest concrete rings should now be installed well below the lowest water table at the end of the dry season. This well could therefore easily be recovered. Proceeding this way, ECOSORN RIS would certainly save a lot of time in the implementation of its programme and collect additional successes.

3.6.4 The so-called "Combination well" in the North-Western Provinces.

Lot of comments are made in the North-Western Provinces about the possibility to use the so-called "combination wells". It is essentially a traditional dug well in the upper part. Once this dug well is completed a deeper well is drilled in its centre. Figure 43 here under presents a sketch of a combination well.

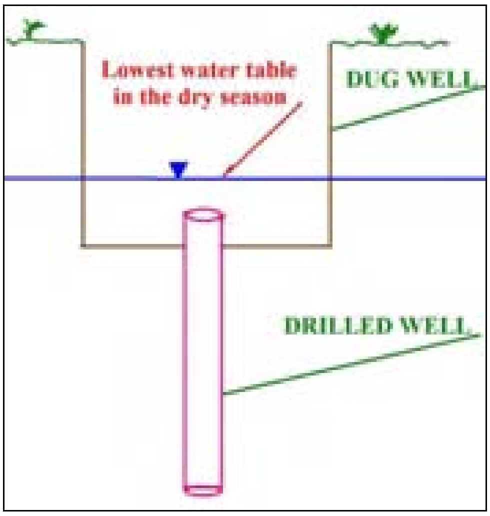

Figure 43: Sketch of a combination well

It is indeed true that such a combination well could improve the yield of some dug wells constructed in areas with extremely low yield. In addition the large size dug well in the upper part could act as a reservoir to store the water when local people are not using it. Nevertheless, couple of important technical factors must be also included in the design of those combination wells.

Those technical factors are the following ones:

1. The upper dug well must always be constructed deep enough below the lowest dry season water level otherwise, at that time, no water will enter the dug well and no pumping will be possible with a "Rope Pump" as suggested by the ECOSORN – RIS.

2. If the dug well is not deep enough the only option to pump water at the end of the dry season would be the installation of a VLOM pump inside the deep drilled well.

Some additional caution measures should always be considered when constructing such combination wells because the drilled well could penetrate different confining or semi-confining layers and enters into deeper aquifers with different water tables.
In the absence of artesian aquifers this could induce unnecessary hydraulic connections. Those hydraulic conditions are presented here under. It should also be added here that those hydraulic connections could also occur with any classic drilled well. So far only one artesian well was reported in the whole area of the Tonle Sap. Therefore the most plausible hydrogeologic case in the area is represented in the Figure 44 appearing here under.

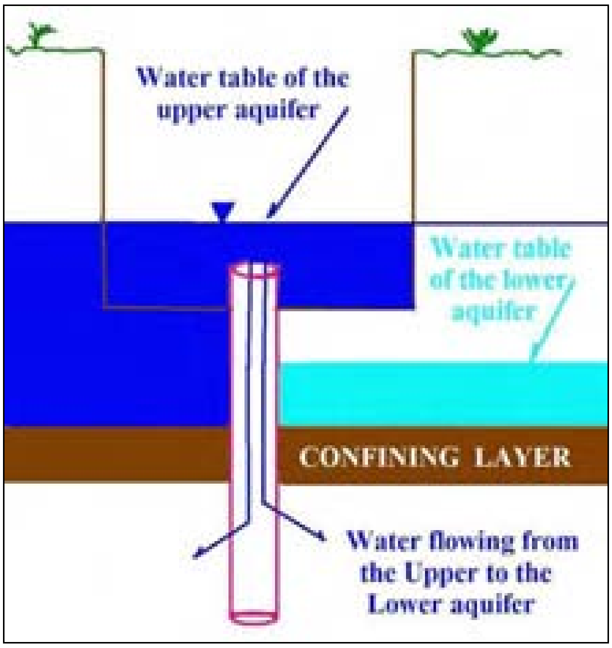

Figure 44: A combination well drilled through a confining layer and offering possible hydraulic top-down connections between aquifers.

3.6.5 Recharging harvested rainwater to the dug wells

In the previous paragraphs we mentioned about rainwater harvesting. Rain can be harvested for storage in containers either above or below the ground or even for re-charging groundwater levels. If there is a dug well, the local groundwater can be re-charged using this service well. A dry or an abandoned well could even be used to store some water. This “Additional” rainwater storage would certainly help many dug wells to go for an extra time during the dry season.

Rainwater harvesting for recharging the dug wells requires that the water is kept as clean as possible and not contaminated with sewage or other dirt flowing into recharge-pits. Water from the rooftops is considered to be the cleanest. As mentioned before very simple and cheap filters would help keeping out some dirt.

The overflow of the above mentioned ECOSORN RIS jars should be of rather good quality if all the suggested minor recommendations and improvements are included. For those reasons the consultant would like to recommend that wherever feasible very simple pipes and filters be constructed and that the overflow of the normal or “Jumbo” ECOSORN RIS jars is discharged into the dug wells. Figure 45 here under presents a dug well recharged by rainwater.

Figure 45: Rainwater recharging a dug well.

3.6.6 Technical Specifications for the construction of ECOSORN dug wells

In the course of this mission the Technical Specifications for construction of the future ECOSORN dug wells prepared by the ECOSORN Project, have been reviewed and improved to simplify as much as possible the Project's construction procedures. In those reviewed Technical Specifications particular attention is focused on the sinking of the porous concrete rings five meters below the lowest water level at the end of the dry season. Without any doubt, this five meter sinking of the porous concrete rings is the most imperative requirement to reach future successes for the ECOSORN RIS. At this stage, it is still almost impossible to predict in advance the lowest water levels at the end of the dry season. For this reason the final depth of any new ECOSORN dug well will be fixed on site, as stipulated in the reviewed Technical Specifications, by the ECOSORN field officers in charge of the supervision of the construction of the dug wells. Those reviewed technical Specifications for dug wells in the ECOSORN Project are attached in Annex 7 at the end of this report.

3.6.7 Hand drilled wells

Like dug wells, hand drilled wells pump water from the water-saturated zone in shallow aquifers or aquifers above the bedrock. Hand drilled wells can be deeper than dug wells. They are typically 9 to 15 meters deep and are usually located in areas with thick sand and gravel deposits and where the ground water table is very near to the ground's surface (5 to 10 meters). In the proper hydrogeological setting, hand drilled wells can be easy and relatively inexpensive to install. Hundreds of those have already been constructed by local people in the areas of Prey Khpos of the Bavel Commune in Battambang Province. As observed during the quick field reconnaissance, simple VLOM or suction pumps are commonly used in this area.

It would also be preferable that a grout sealant is poured along the outside of the well pipe but is not always technically easy to implement. The hand drilled wells should be capped with the same kind of large-diameter concrete platform used for a dug wells and mentioned here above.

3.6.8 Drilled wells

Drilled wells penetrate about 30 to 150 meters into the local formation or bedrock (Limestone) where is not deep in the Tonle Sap basin. The casing is usually plastic pipe, Four Inches in diameter that extends into the aquifers. This casing should also extend at least half a meter above the ground's surface. A sealant, such as cement grout must be poured along the outside of the casing to the top of the well to act as a sanitary feature. It is better if this sanitary cement grout is injected from bottom to top. In addition the well is capped to prevent surface water from entering the well.

In almost all existing reports much is said about the low technological expertise of the local contractors (such as page 49 - 8.4 Groundwater Development of the ADB Northwest Irrigation Sector Project) and consequently deep drilling expertise is in great need of upgrading.

It should be reminded here that, in fact, most of those local contractors gained their own experience only working with international relief and emergencies operations. The scope of those emergency campaigns is not always the sustainability but indeed the 'rushed' emergency to deliver drinking water as quickly as possible to the local populations.

The "State of the Art" technology problems are not always their priorities or the long-term sustainability of the wells. Most of the time their wells were purposely constructed for low-yield domestic purposes and therefore drilling operations stopped as soon as the expected yield was obtained even though much higher yields could probably have been possible at greater depths. Also during those campaigns all the wells were, for obvious time and money saving reasons, narrow bores most of the time designed specifically to achieve low yield.

Very much in line with the above comment the experience of the staff of the former ADB Northwest Irrigation Sector Project with one of the best available contractors in the Tonle Sap area, indeed fully confirmed their good knowledge of local conditions and excellent capabilities to improvise, a skill obviously learned from their past experience during the previous emergency campaigns but on the other side also strongly highlighted needs for technical training in almost every drilling aspect. Specifically, this includes deep drilling procedures, drilling log compilation, down-hole geophysics, pump technology, drilling fluid controls, alternative well development techniques, aquifer testing, and advanced well design. Figures 46 and 47 here under present some details of the construction a small drilling rig operating observed by the consultant in the area of the Sankai River.

Figure 46: Details of a local small drilling rig.

Figure 47: The drilling rig nearby the Sankai River.

The same difficulties will probably arise during this ECOSORN RIS campaign but it could probably also open the door for better 'on-the-job' training for the different drilling contractors involved in its implementation. Before the arrival of the consultant in Cambodia, the ECOSORN RIS already prepared its Technical Specifications for their Four Inches I.D. drilled wells. As stipulated in the ECOSORN Specifications:

1) "*The Expected average borehole depth will be in the range of 25 to 100 meters. This depth is only indicative and is not a contract specification*".

2) "*The drilling diameters will be the following ones:*
a) 150 mm (6") in rock formation,
b) 200 mm (8") in sediment or weathered zone".

To suit the requirements of the ECOSORN RIS Project those technical specifications have been reviewed, checked and modified where necessary. In those reviewed Technical Specifications for drilled wells, special attention is given to the gravel packing under reverse flow and to the sanitary grouting of the wells. The reviewed specifications for the ECOSORN Four Inches I.D. drilled wells appear in Annex 8 at the end of the present report.

3.6.9 Costs of the different infrastructures to be installed in the future by ECOSORN

The following costs should be considered as very preliminary, tentative average costs for the different options which will be implemented in the future by the ECOSORN RIS.

1. Ring Well: from 350 US to 650 US $

2. Four Inches I.D. drilled well: from 300 up to 1500 US $
3. Combination well: from 500 to 750 US $
4. Rope pump: 85 US $
5. Pond: from 1.0 to 1.2 US $ per cubic meter
6. Jumbo jar: 40 US $
7. Rainwater tank for a school: +/- 1500 US $

3.6.10 The “Rope pump” as a suggested cheap and sustainable pumping device for the future ECOSORN RIS actions

The most important target of the ECOSORN RIS is without any doubt the long-term sustainability of all the infrastructures it will implement in the next four years.
From a sustainability point of view the first appropriate and wise decision is obviously to construct dug wells wherever possible and restrict, as much as possible, the construction of drilled wells only to areas where no other technical options are feasible. Obviously, rainwater harvesting is also an option which could be applied almost everywhere in the project area. The second very important decision for the success of the Project is to equip all those dug wells with a very cheap but indeed most sustainable pumping device.

The so-called “Rope pump” is definitively the best pumping device in the prevailing conditions. Those pumps could easily be ‘do-it-yourself’ made by any person in the field with a minimum of mechanical knowledge. The skills to repair a bicycle are probably far enough to construct a rope pump and so many persons in the Cambodian countryside already do have those skills. In addition the Cambodian private sector already started to produce those pumps on a larger commercial scale. The mechanical principle of the rope pump is briefed in the Figure 48 appearing here under.

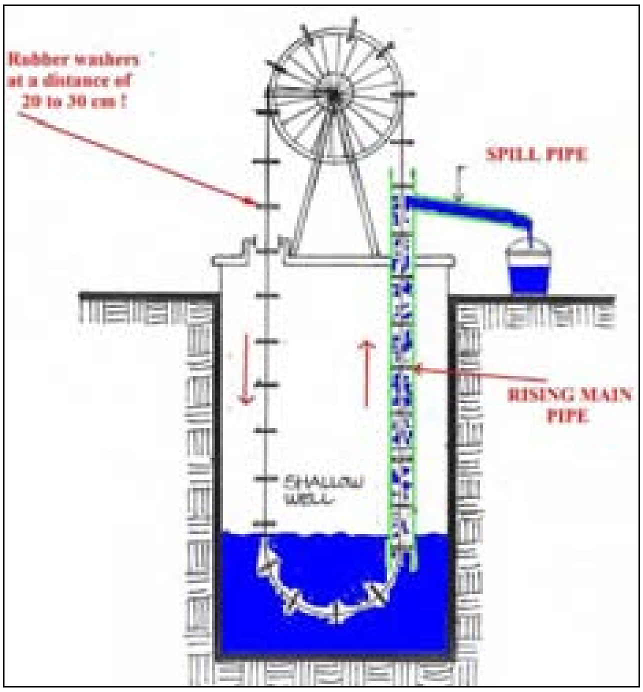

Figure 48: The mechanical principle of the Rope pump.

Just for the convenience of the reader this consultant would like to present here under a very short comparison. Nicaragua, a country of Central America, has an area of 2/3 of Cambodia and a population of only 50 % compared to Cambodia. Because of the low cost and the excellent sustainability of the rope pumps more than 50000 rope pumps have so far been installed all over Nicaragua. If we compare the above figures of Nicaragua to Cambodia it means that at least 130000 to 150000 rope pumps could easily be installed in Cambodia.

A very important 'side effect' of the rope pumps is that their installation requires a lid on top of the dug wells. This lid is also a very great improvement to protect the bacteriological quality of the water in the wells. Without the lid it happens quite often that garbage are thrown down the dug wells. This is not without impacts on the health of the local people. During the consultant's quick reconnaissance several dug wells have been observed in very poor sanitary conditions and with garbage floating at their surface.

3.6.11 A Vertical Electric Sounding device to improve the rate of success of the wells

The implementation of this major scale, four year EU construction programme of dug wells or drilled wells in a quite difficult, versatile geological environment - i.e. with local fluvial sediments (mainly arenaceous) inter-digitised with Mekong (argillaceous) sediments like the ones existing in the Tonle Sap, and with reduced geological information - will inevitably include a certain percentage of failures.
All over the world, groundwater Projects intensively using the support of scientific, shallow to intermediate depth geophysical investigations also face some failures in their implementation. Obviously efforts should be done to minimise this ratio of failure to the minimum.

It is the opinion of this consultant that the cost of a Vertical Electric Sounding (VES) device for shallow to intermediate depth investigations (down to 100 meters below ground surface) would probably be much less than the total cost of all the future failures.

Nevertheless, the introduction of such VES equipment will also induce several important and crucial logistic problems in the ECOSORN Project such as: "Who will be the final owner of this expensive tool." is the question to be asked before embarking on such a decision.

It should also be reminded here that for very practical logistic reasons (raining season) this VES device could only be operated during the local dry season. For the above logistics reasons it is the opinion of this consultant that, at this stage, it is probably not yet worth importing and using a VES device.

4. Description of the hydrogeological conditions for each of the three Provinces (based on information from the private sector and on the quick field reconnaissance)

4.1 Location of the areas of the ECOSORN Project

Figures 49 to 52 appearing here under present successively the location of the three Provinces contemplated in this ECOSORN Project and also the details of the targeted Communes and villages in each of the three Provinces (Batch1).

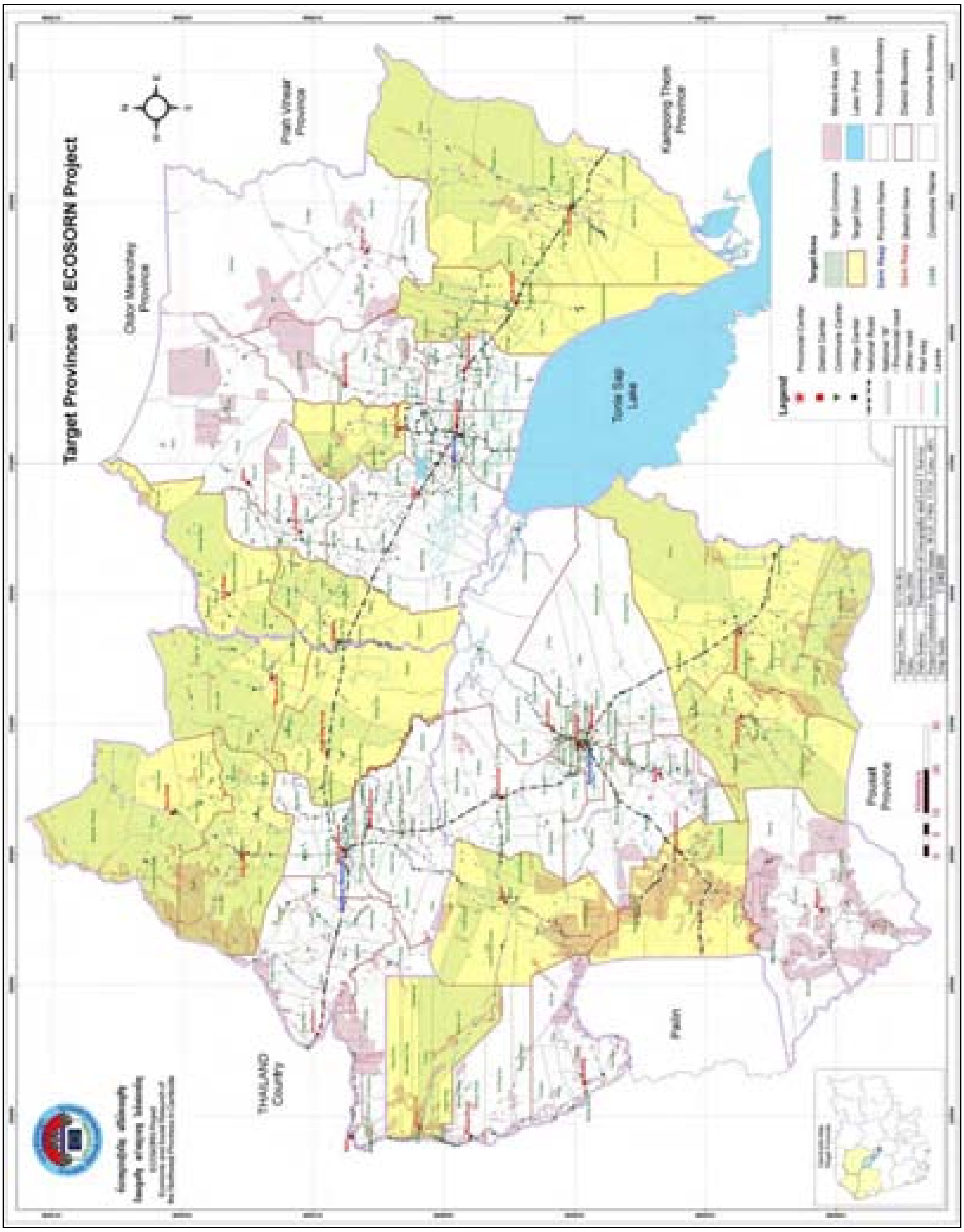

Figure 49: The target Provinces of the ECOSORN Project.

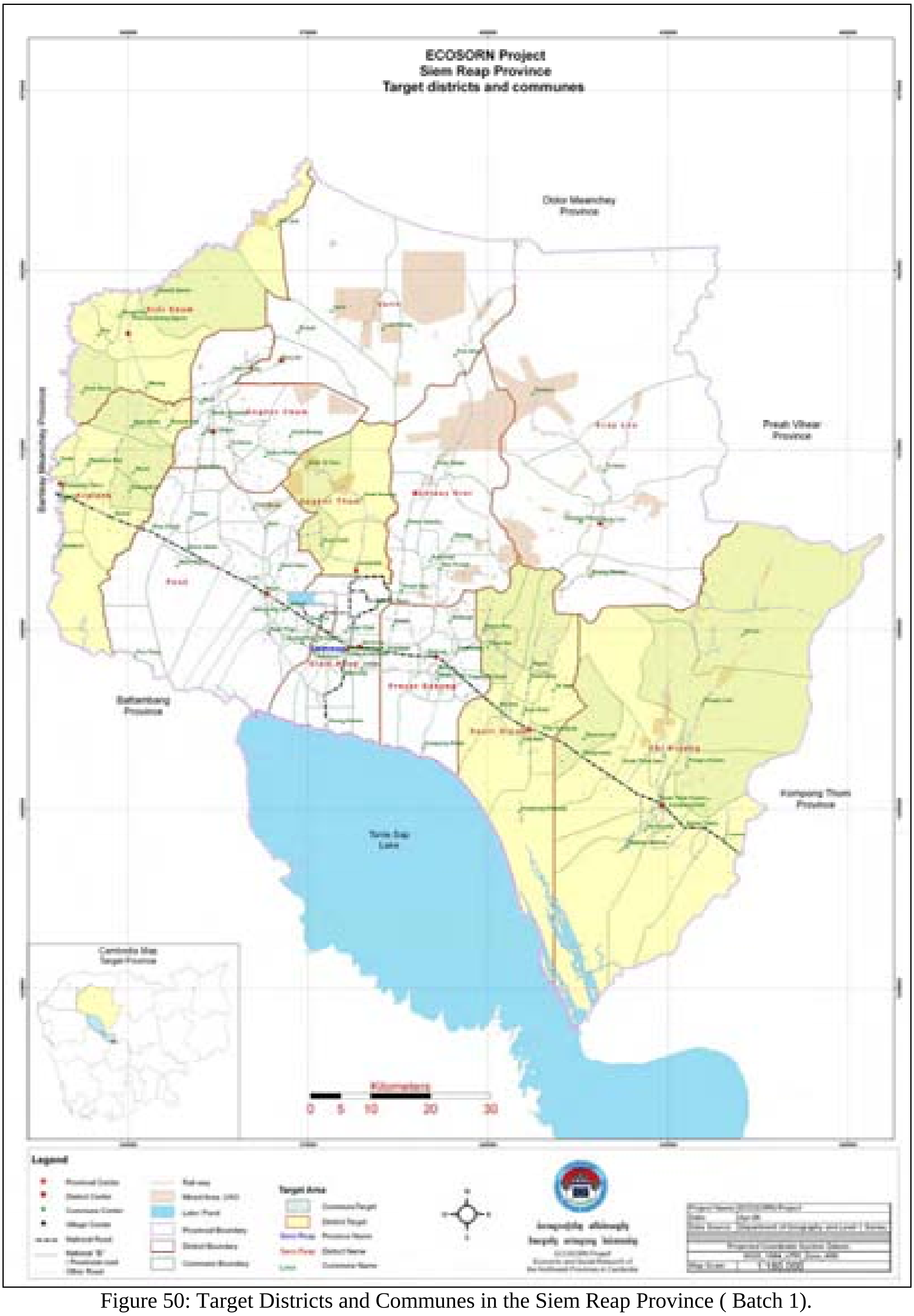

Figure 50: Target Districts and Communes in the Siem Reap Province (Batch 1).

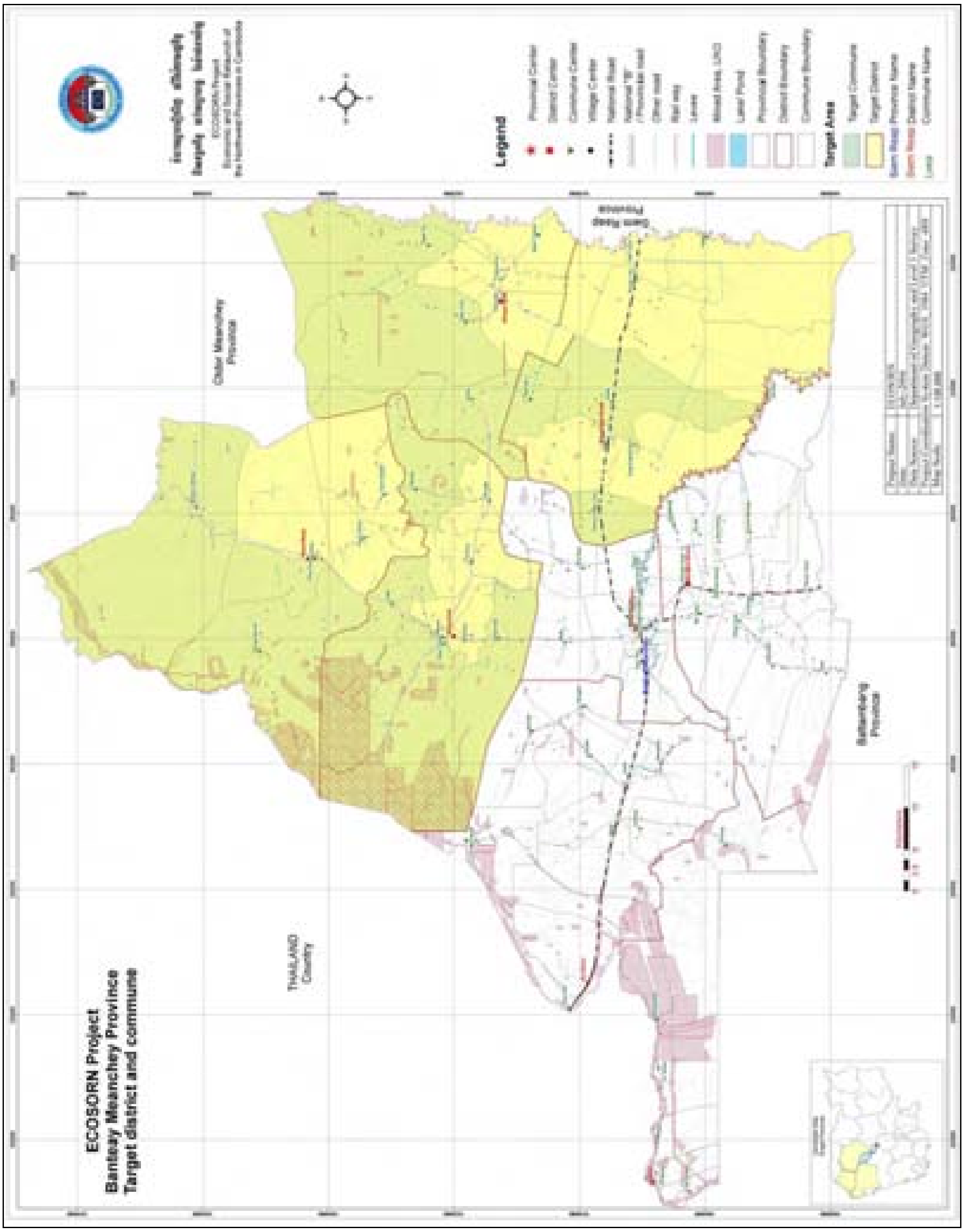

Figure 51: Target Disctricts and Communes in the Banteay Meanchey Province (Batch 1).

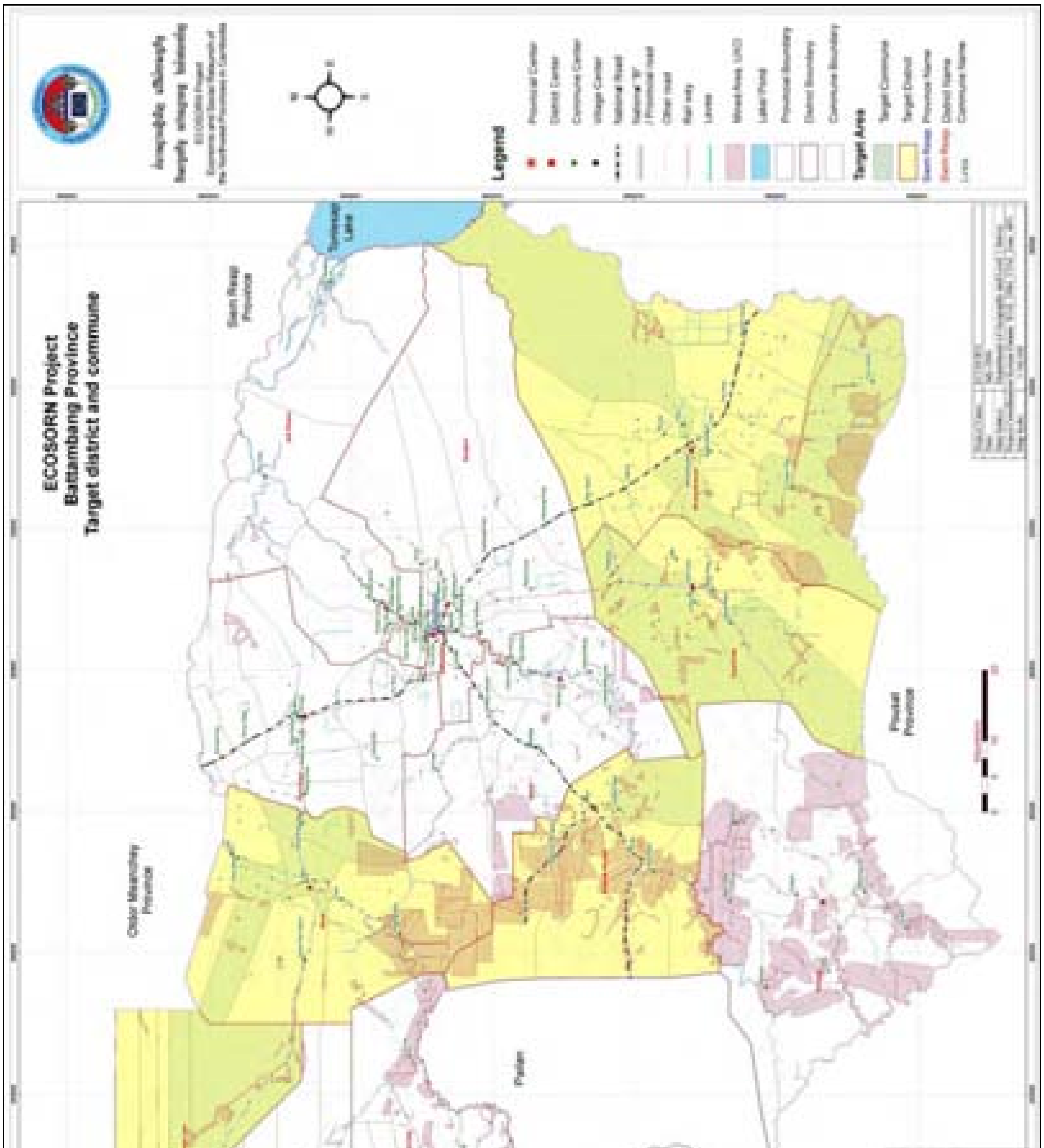

Figure 52: Target Districts and Communes in the Battambang Province (Batch 1).

From 04th to 24th of October field visits to the selected target villages were organized and carried out with ECOSORN RIS provincial staff. The villages listed in Batch 1 were considered systematically.

4.2 General comment after the quick reconnaissance survey

During the Consultant's quick field reconnaissance the villages listed in the ECOSORN Batch 1 were considered systematically. In addition to those field visits and in an attempt to obtain "first hand information" meetings were also organised, in the three Provinces, with the private sector involved in the local water sector. The two following comments can indeed be made after that quick field reconnaissance:

1. The first impression after the quick hydrogeological reconnaissance could include a quite important distortion factor. In many locations the ratio dug wells versus drilled wells is probably not very representative of the real hydrogeological "In-situ" conditions. It should be recalled here that, in this part of Cambodia, so many of the existing wells, have been drilled during the successive waves of emergency and humanitarian aids. Their main target was only to produce "some drinking water" and in the shortest possible time. To achieve their target in such a short time drilling is certainly the only approach, which can offer rather good probabilities of immediate success. Drilling allows creating very quickly a deep hole and the installation of a VLOM pump. If water is not discovered in the upper aquifer then drilling a bit more will probably produce some water from lower aquifers. May be so many of those drilled wells could, indeed, have been substituted by dug wells. The only case where a very clear picture exists is when a village is 100 % supplied by drilled wells. It is probably an evidence that no other alternative was ever feasible in this specific village. In those prevailing conditions the blending of dug wells with drilled wells in any village is not always a totally convincing information.

2. The first hand information delivered by the different persons involved in the private sector also includes certain degree of say "business orientation" since people involved in drilling know much more about drilling and are of the opinion it is the only option. Obviously the reversed approach is also valid for the persons involved only in wells digging. Nevertheless their respective practical information reveals indeed, to be very accurate and helpful and is included in this report.

3. At the very beginning of the mission, the subject of hydrogeological database - MOWRAM & MRD information was reviewed with RIS after consultation of the data. The lack of geographic coordinates for all listed wells was considered a very serious limitation. Therefore and to achieve the mission objectives within the allocated time, a key report from the ADB was requested and obtained with assistance of ECOSORN Project Director. The report was given to the consultant, through RIS Civil Engineering Adviser, on the 13th of October. This important Report fully confirms the above limitation in the use of the MOWRAM & MRD information (Refer to Chapter 3.3 of this Report).

4.3 Information from the local private sector involved in the respective Provincial water projects together with information from other sources.

The information collected from the private sector involved in water projects in the three different Provinces can be summarized in the different maps and Tables appearing here under. Their information is essentially qualitative and based on their very long experience in the area. However during the consultant’s quick field reconnaissance their information revealed to be very accurate. Other very interesting sources of information, such as the recent key report from the ADB, are also presented here under. These ‘combined’ sets of information could be used as preliminary guidelines to launch a campaign for construction of dug wells or drilled wells.

4.3.1 The Siem Reap Province

During the consultant’s mission two different sets of information have been collected for the Siem Reap Province. A first one ‘very geographically’ oriented was obtained in the offices of PDRD in Siem Reap with the help of the local private sector involved in the drilling and digging of wells. Their geographic information contains a multitude of small size patches of areas advisable for dug wells, areas where drilled wells could be constructed and areas known to be, so far, without any groundwater potential. Their information confirms the extremely versatile hydrogeological conditions existing in the area. Figure 53 here under presents nine of their most important information about the area. The very detailed maps containing all their “First hand” practical, field information are archived in the offices of ECOSORN RIS.

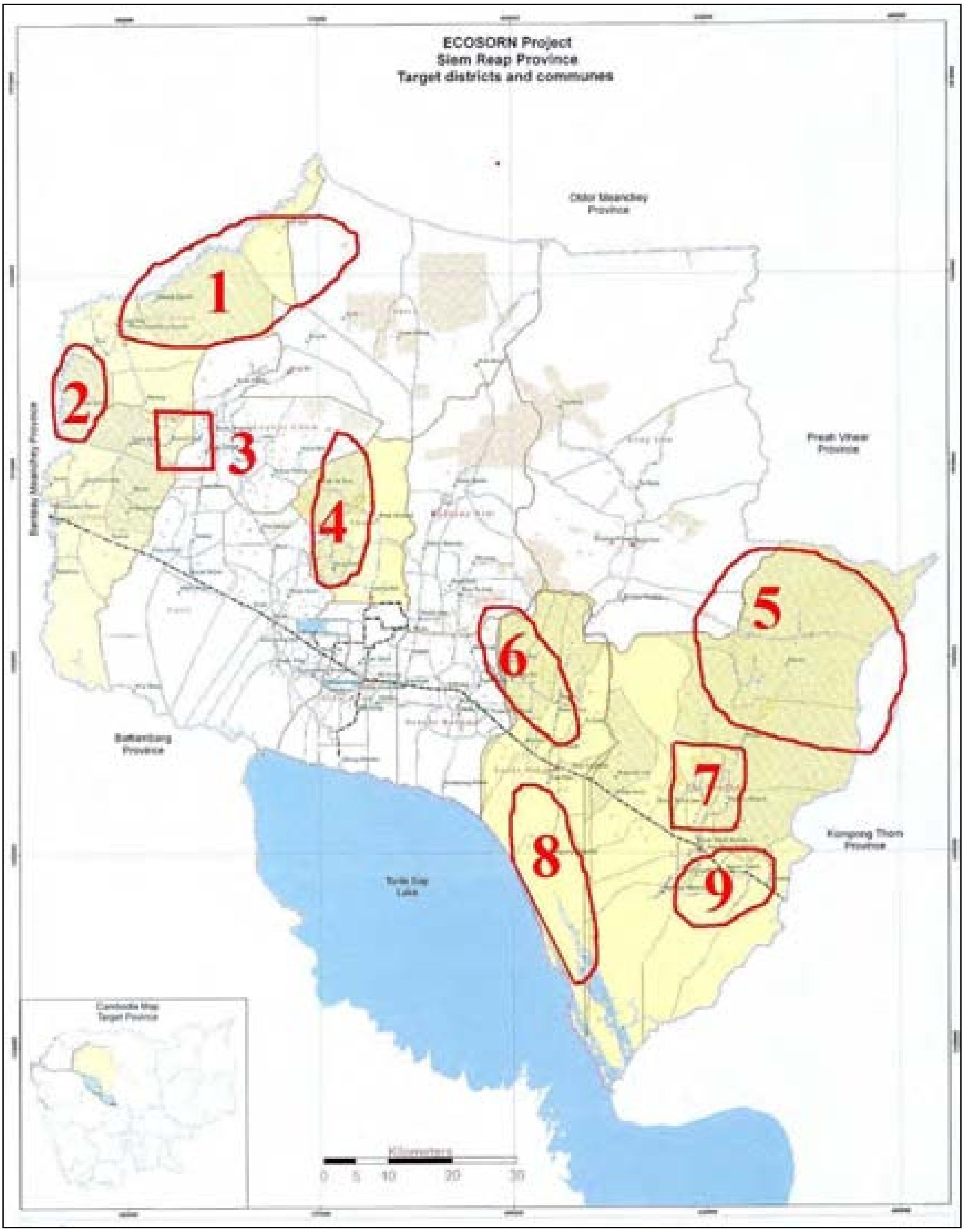

Figure 53: Resume of the water information and recommendations from the private sector involved in the constructions of dug wells and drilled wells in the Siem Reap Province.

Their technical advises for the nine above areas are the following ones:

1. Area N° 1: Drilled wells should be constructed in this area.
2. Area N° 2: Favourable for water potential.

3. Area N° 3: Area better for drilled wells although some dug wells have also been constructed here.

4. Area N° 4: Area in which dug wells could be constructed

5. Area N° 5: Difficult area because of the presence of many rocks.

6. Area N° 6: Dug wells could be constructed in this area.

7. Area N° 7: Area in which it will be probably more difficult to find water.

8. Area N° 8: A difficult area for water. Many of the dug wells do not have enough water.

9. Area N° 9: Area not good for water potential.

The second set of information for the Siem Reap Province was received from the private sector organisation "Teuk Saat Organization". Their very long experience in drilling activities, but also in important campaigns of dug wells construction, allows them to draw some qualitative conclusions but much more at a Provincial level.
For this reason their information could probably be used in priority to programme future campaigns of drilled or dug wells. Their qualitative information is presented in the Table 1 appearing here under.

Table 1: Qualitative information for the Siem Reap Province.

Number	District	Ratio of ring wells (dug wells)	Ratio of drilled wells	Other alternatives	ECOSORN TARGET COMMUNES
1	**Kralanh**	**50 %**	**50 %**	**Jar or ponds**	**Roung Kor, Snoul and Saen Sok**
2	*Pouk*	*80 %*			
3	*Siem Reap*	*100 %*			
4	*Angkor Chum*	*50 %*	*50 %*		
5	**Srei Snam**		**90 %**	**Jar or ponds**	**Tram Sasar and Slaeng Spean**
6	**Angkor Thom**	**100 %**			**Chub Tatrav and Svay Chek**
7	*B. Srei*	*70 %*	*30 %*		
8	*P.Bakong*	*100 %*			
9	**Soutr Nikum**	**30 %**	**60 %**	**10 % with Jar or ponds**	**Chan Sar, Khnar Pou and Popel**

10	**Chi Kaeng**	**40 %**	**60 %**	**Jar or ponds**	**Khvav, Pongro Kraom, Pongro Leu and Ruessei Lok**
11	*Svay Leu*		*100 %*		
12	*Varin*		*100%*		

4.3.2 The Banteay Meancheay Province

In Banteay Meancheay two different sets of information have also been made available to the consultant by the private sector. For the convenience of the reader they are successively presented here under. The first set of information is a qualitative one and is presented here under. Their information is divided into the two Tables 2 and 3 appearing here under. The Table 2 presents the areas in which water can be found while Table 3 indicates the areas with no water.

Table 2: Communes in the Beanteay Meanchey Province where water can be found.

Districts	Commune	Dug well	Drilled well	Other Option
Phnom Sok	**Poychar**			**Rainwater.**
	Chiek	*YES*		
	Ponley	**YES**	**YES**	
	Poy Snoul	*YES*	YES	
Svay Check	**Phkoam**			
	Sla Kram	**YES**	**YES**	
	Roloap			
	Saroung			
Preah Net Preah	*Preah Net Preah*		YES	
	Poy Snay	*YES*	YES	
	Rohal		**YES**	
	Sreas	*YES*	YES	
Thmar Pouk	**Banteay Chmar**		**YES**	
	Thmer	*YES*	YES	
	Thmas Diekass		YES	

Table 3: Communes in the Beanteay Meanchey Province where water can not be found.

Districts	Communes where water can not be found	Other option
Svay Check	*Ta Pho*; **Svan Cheik** ; *Ta Baen*	Rain water
Thmov Pouk	*Thmov Pouk ; Beoung Trokouss* ; **Kouk Romiet**	Rain water

Preah Net Preah	**Chnour Meanchey ; Team kam** ; *Phum Liep*	Rain water
Phnom Srok District	*Phnom Dei*	Rain water

The Table 4 here under presents the list of ECOSORN Banteay Meanchey villages together with their respective existing water supply systems. This more detailed list could also be used to programme future actions.

Table 4: Table of dug wells and drilled wells in Banteay Meanchay.

District	Commune	Village	Dug well	Drilled well	Rainwater harvesting
Svay Chek	Phkoam	Phoam	**YES**		
		Ampil	**YES**		
		Mau			
	Sia Kram	Sia Kram		**YES**	
		Kamnab		**YES**	
		Toap Siem			**YES**
	Svay Chek	Khvav			**YES**
		Kouk Khvav		**YES**	
		Roka Thmei		**YES**	
		Ta ong Lech		**YES**	
	Treas	Doun Nouy	**YES**		
		Chaeng		**YES**	
Thma Puok	Banteay Chhmar	Kouk Samrong		**YES**	
		Kbal Tonsaong		**YES**	
		Banteay Chhmar Cheung			**YES**
		Banteay Chhmar Lech			**YES**
	Kouk Romiet	Ta Lei	**YES**		
		Thmei	**YES**		
		Thma Chhart			**YES**
	Kumru	Kumru		**YES**	
		Prei Veang	**YES**		
		Ta Yueng	**YES**		
Phnum Srok	Nam tau	Nam Tau		**YES**	
		Thmei Tboung		**YES**	
		Thmei Cheung	**YES**		
		Paoy Ta	**YES**		

	Paoy Char	Ong			
		Trapeang Thma tnoung	**YES**		
		Sam Bour		**YES**	
	Ponley	Porram Bonn	**YES**		
		Kouk Ta Sok	**YES**		
		Ta Vong	**YES**		
		Svay Sar		**YES**	
Preah Net Preah	Chhnour Mean Chey	Kouk Treas			**YES**
	Rohal	Snay		**YES**	
		Anlong Thma		**YES**	
		Popel		**YES**	
	Tean Kam	Tean Kam Lech			**YES**
		Ou			**YES**
		Tean Kam Tboung			**YES**

4.3.3 The Battembang Province

Figure 54, appearing here under, was prepared following technical discussions with the private sector involved in the construction of water wells in the Battambang Province plus the consultant quick reconnaissance and field visits. All the “First hand” information from the private sector was indeed fully confirmed during the successive field visits. The map on Figure 54 presents a resume of the hydrogeological situation of the ECOSORN target villages located in the Battambang Province. Two green patches with question marks have also been represented on this map. They represent the areas with higher hydrogeological “hazards” discovered recently by the ADB Nortwestern Project (see here under). The ADB information was also fully confirmed by the local private sector and became even more evident during the consultant’s quick field reconnaissance.

South to Battambang and along a line more or less North-East/South-West it is quite difficult to find any water potential. The private sector reported that in the past, so many dug wells and several drilled wells failed in this area. It seems that in this area the only possible option solution would therefore be very “Careful drilling” plus rainwater harvesting (large size ponds or jars).

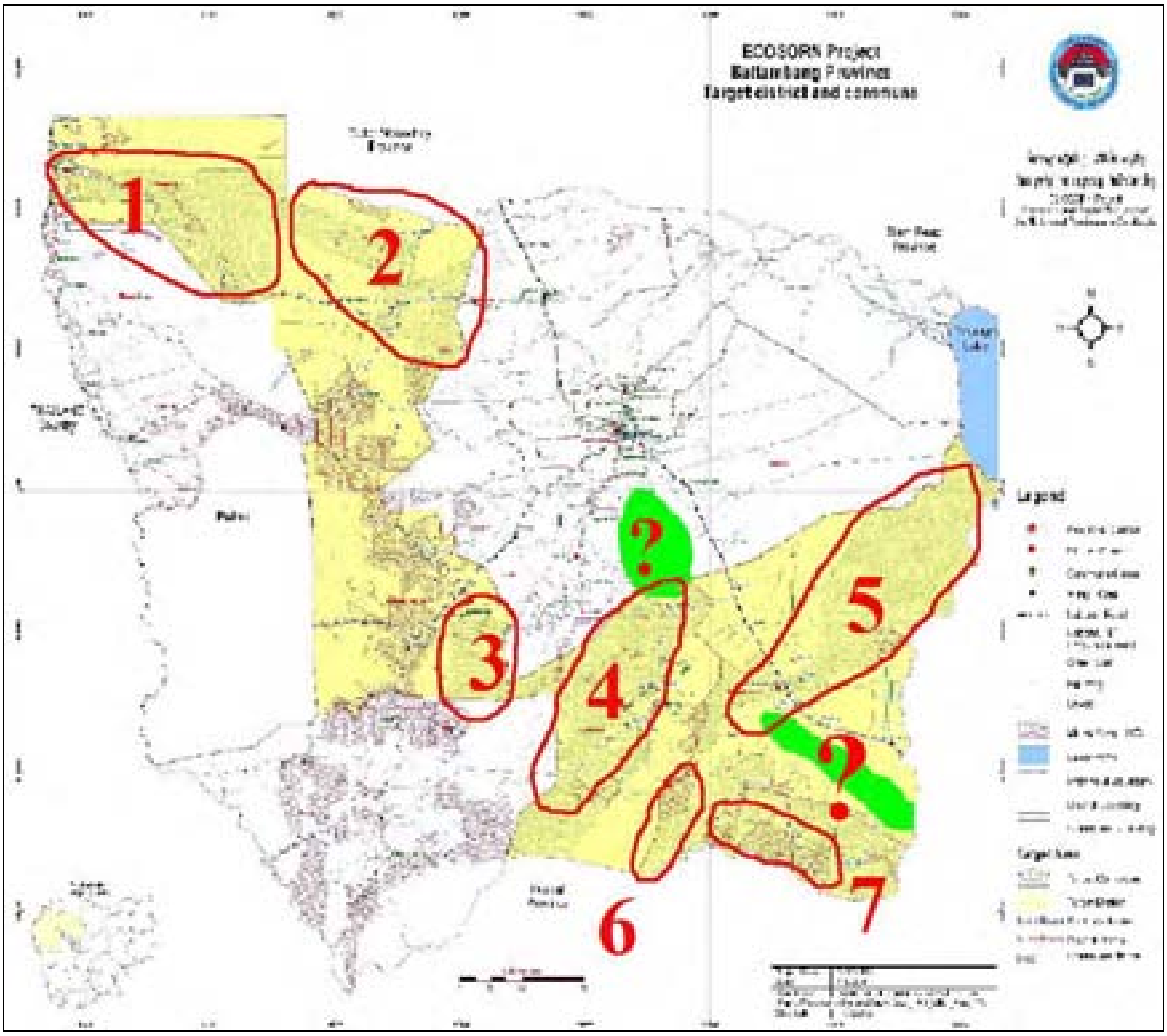

Figure 54: Resume of the water information and recommendations from the private sector involved in the constructions of dug wells and drilled wells in the Battambang Province
(The two green patches with questions marks represent the ADB areas with hazards for water investigation).

The details are the following ones:

1. Area N° 1: Wells drilled in limestone rocks. However local people never drink the water from their wells. The only possible and practical option here seems to be "Rainwater harvesting" for human use.

2. Area N° 2: Everything possible in this area. Hundreds of 12 to 15 meters shallow dug wells or hand drilled wells with water table at more or less 6 meters.

3. Area N° 3: Several 40/50 meters deep wells drilled in limestone. A small scale-drilling contractor is quite active in this Sankai River area. Some people reported they do not drink the water from the limestone wells.

4. Area N° 4: This area is quite close to the "Hazard" area mentioned in the ADB report. Many drilled 60/70 meters deep wells. Around Dounba village wells drilled in limestone. And local people reporting they do not drink the water from limestone wells.

5. Area N° 5: In Chrey area very low density of villages and extremely difficult to get water even using drilling. In this area Rainwater harvesting should be the best solution. In Moung Russei no water even through drilling . Some local people truck and buy water here.

6. Area N° 6: In Preaek Chik area drilled well is probably the only possible alternative here.

7. Area N° 7: In the past in Prey Tralach drilling tentative but quite difficult and un-successful. People using ponds or truck the water. Some dug wells could probably be feasible in some rare locations here.

4.4 The ADB Northwest Irrigation Sector Project description of the hydrogeological conditions in the ECOSORN Project areas

In addition to the above information this report present here below other pertinent information related to the hydrogeology of the different areas part of this ECOSORN Project. A recent and very complete description for the Siem Reap, Banteay Meanchey and Battembag Provinces was prepared in 2003 by the hydrogeological teams of the ADB Northwest Irrigation Sector Project. Their excellent description is quoted here under to confirm the Consultant's conclusions that the hydrogeology of these areas is complex due to a versatile geology. We quote from their Annex A page 41.

4.4.1 Siem Reap

From the ADB Northwest Irrigation Sector Project description of the hydrogeological conditions in the ECOSORN Project areas : *"As in the western lowlands, usable hydrogeological information is sparse. Hydraulic gradients are intermediate between those of the western lowlands and Pursat. Headwater catchments are of relatively subdued relief and consist of a higher proportion of argillaceous rocks than elsewhere. The volcanic rocks are a westward extension of the much more extensive volcanic outcrops of more easterly provinces, but despite rapid weathering, do not seem to contribute greatly to either the sedimentary load of local rivers or to their hydrochemistry. <u>On the basis of available evidence, the success rate of shallow wells and boreholes in Siem Reap is much the same as in Pursat and Battambang, i.e. just short of 80%</u>".*

4.4.2 Banteay Meanchey

From the ADB Northwest Irrigation Sector Project description of the hydrogeological conditions in the ECOSORN Project areas : *"In Banteay Meanchey the hills are of lower relief, are less extensive, and contain a higher proportion of volcanic material (of non-linked high porosity; probably of low permeability unless heavily fractured)."*

Figures 55 to 57 appearing here under show successively the Numulitic Jurassic Limestone outcropping just outside the ECOSORN office in Banteay Meanchey and a volcanic structure North of the large size pond located in the village of Slakram and the Basaltic-Andesitic rocks collected by the local people for construction purposes.

Figure 55: The Jurassic numilithic limestone quarry just outside ECOSORN office in Banteay Meanchey.

Figure 56: In the foreground the reservoir in the village of Slakran. A volcanic structure is visible to the left in the background.

Figure 57: Andesitic-Basaltic rocks collected by the local people for construction purposes.

From the ADB Northwest Irrigation Sector Project description of the hydrogeological conditions in the ECOSORN Project areas : *"In this area a large proportion of the fluvial drainage originates in Thailand, and hydraulic gradients are low, resulting in finer grained sedimentation. Large areas consist of fine grained but permeable silt, but anecdotal evidence points to a low success rate amongst shallow well construction. Extensive tracts of flat land would facilitate shallow to intermediate depth geophysical investigations, but until and unless this is done there is little that can be said about the areas's groundwater potential."*

From the ADB Northwest Irrigation Sector Project description of the hydrogeological conditions in the ECOSORN Project areas : *"Reconnaissance visits gave the impression that laterite was much more extensive than in other parts of the project area, but this aspect requires quantification. Lateritic horizons have not had time to develop within the recent sediments. A consequence of the low hydraulic gradients seems to be longer mean residence times of surface water, higher evaporation rates, and hence poorer quality water in many areas, but again, this impression requires detailed confirmation".*

4.4.3 Battambang

From the ADB Northwest Irrigation Sector Project description of the hydrogeological conditions in the ECOSORN Project areas : *"Somewhere between Talo and Svay Donkeo there is a change in alluvial character towards finer sand derived from nearby eroding hills. Upper drainage basins between Svay Donkeo and Battambang are of lower altitude and more varied lithology including rhyolite, dacite, limestone, quartzite, conglomerate and meta-sediments. Of these the 'Upper Indosinias' formation predominates, and is the major contributor to alluvial sediments. As one would expect there is a gradation form coarser sandy or silty alluvium near the hills front, to more argillaceous sediments further downstream. However, a chronostratigraphic change in facies has also been reported, which gives rise to similar contrasting lithologies between upstream and downstream areas.*
Here, in the absence of laterite, no reliable criteria have been established to distinguish between recent and older sedimentary facies. Similar characteristics

could equally be due to fluvial sorting of contemporaneous sediments, or to stratigraphic contrast between younger and older sediments. In western Battambang there are major limestone outcrops exhibiting tower karst features, which, if structurally projected below the surrounding alluvium, has the potential to be an important deep aquifer. Other lithologies, including various igneous formations, have minimal aquifer potential, but seem to be of relatively minor extent."

4.5 The ADB map of higher hydrogeological hazards and problems

Following all their long hydrogeological investigations in the North Western Provinces the recent ADB Project prepared a map revealing the areas of higher hydrogeological uncertainties and risks about groundwater. In those areas, it is highly advisable to proceed for groundwater drilling *only after geophysical surveys and preliminary investigations through exploratory drilling.*

As can be observed on the ADB map appearing here under several of the areas with higher hazard for groundwater do effectively overlap with some ECOSORN target Communes or villages. The Consultant's quick reconnaissance survey noticed several areas with hydrogeological problems especially around Koas Krala and Moung Ruessei in Battambang. Those observations are in fact totally confirmed by the ADB map of higher hazard as well as by the "First hand information" received from the local private sectors. Figure 58 here under presents the ADB map of higher uncertainties and hazards.

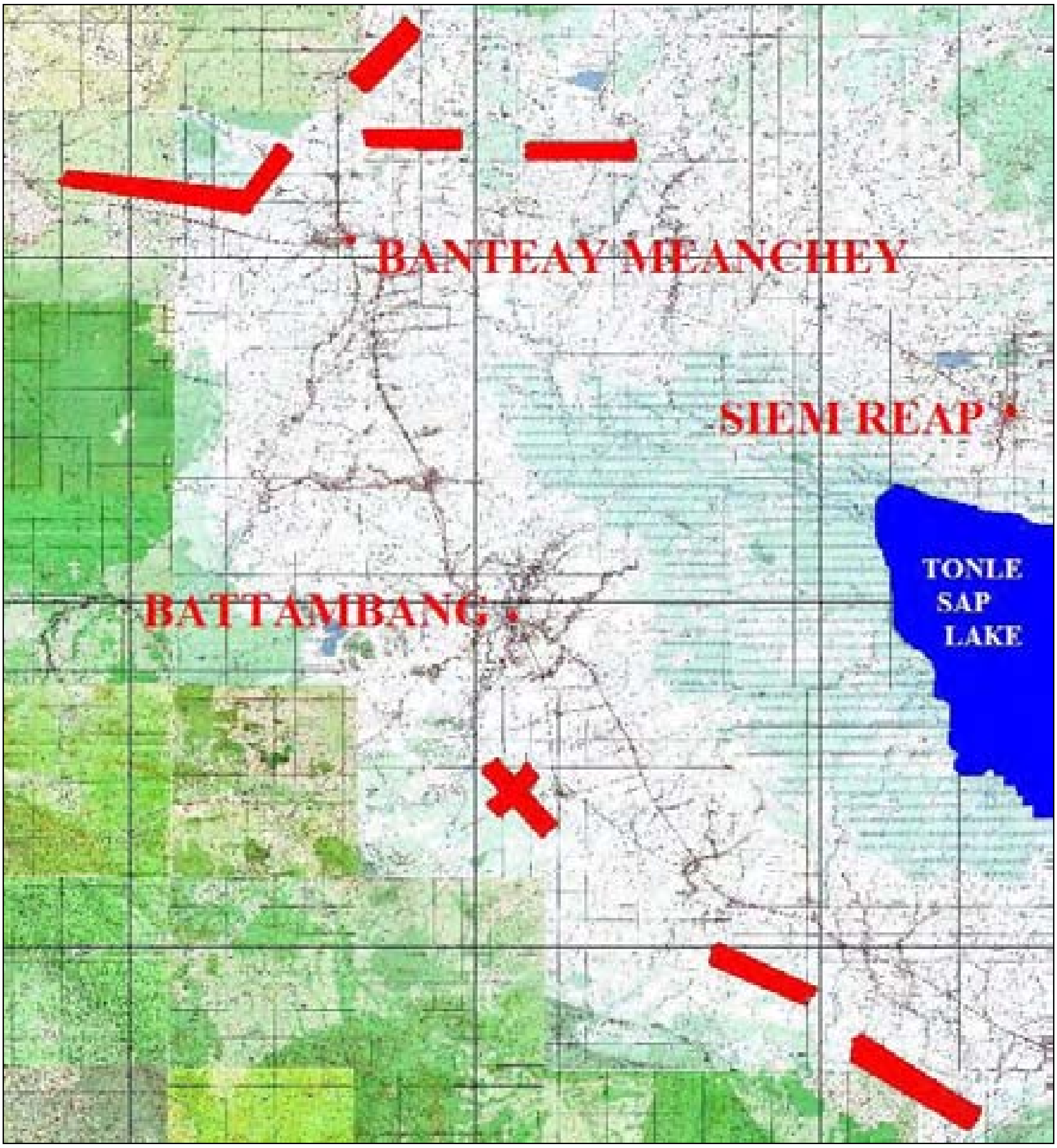

Figure 58: Appearing in red on this map the areas which could show hydrogeological problems in the North-Western Provinces. Consequently those areas would require deeper investigations. (Modified from the March 2003 ADB Northwest Irrigation Sector Project).

4.6 Recommendation for the coming ECOSORN RIS domestic water supply activities

On the grounds of all the above information the following suggestions can be made for the future water supply activities. The suggestions are presented in the following Tables successively for the Siem Reap the Banteay Meanchey and the Battambang Provinces.

Table 5: Suggestions for the Siem Reap Province.

Commune	Villages	Possible					Others
		Dug well	Drilled well	Mix well	Jar	Pond	
Svay Chek	Kouk Kak	✓	✓				The water table is 6-7 m depth in dry season
	Kandoal	✓	✓				
	Preah Kour		✓				Deep ground water table
Chob Tatrav	Prasat	✓	✓				The water table is 6-7 m depth in dry season
	Trapeang Touk	✓	✓				
	Toap Svay	✓	✓				
Chan Sar	Svay Sar	✓	✓				The information from PDRD and contractors confirm that it is possible to construct dug wells here.
	Kansaeng Leu	✓	✓				
	Back Kamphleung	✓	✓				
Khnar Pou	Chob	✓	✓				
	Bos Thom	✓	✓				
	Chhouk	✓	✓				
Popel	Koul			✓			Water table 7-8m depth in dry season
	Popel Lech					✓	Drilling 40m depth (PDRD)
Pongro Kraom					✓	✓	Information from PDRD and contractor confirm it is difficult to find ground water (Hard rock at 5-6 m depth)
Pongro Leu					✓	✓	
Khvav					✓	✓	
Russei Lok	Yeang		✓	✓			
	Spean Toch	✓					Possible for dug wells 7-8m deep
Roung Kou					✓	✓	OK for drilling wells 30-40m deep. Not good for dug wells (PDRD)
Snuol					✓	✓	
Saen Sokh					✓	✓	
Tram Sasar	Thlok				✓	✓	Difficult to find groundwater, drilling 40-50m depth (PDRD).
	Neang Sroang				✓	✓	
Slaeng Spean	Preah Khsaet				✓	✓	Difficult to find groundwater, drilling 40-50m depth (PDRD).
	Chamkar Chek				✓	✓	

Table 6: The Banteay Meanchey Province.

Commune	Villages	Possible					Others
		Dug well	drill well	Mix well	Jar	Pond	
Chhnour Meanchey	Kouk Treas				✓	✓	Difficult to find groundwater . Not enough water in a 80 meter well .
Tean Kam	Tean Kam Lech				✓	✓	Difficult to find groundwater
Rohal	Snay		✓		✓	✓	The water quality is not good for drinking because it contains Calcium plus Magnesium plus Iron
Poay Char	Poay Ta Ong	✓	✓				Groundwater source from infiltration from the Trapang Thma Resevoir
Ponlei	Pu Ramban				✓	✓	Groundwater difficult to find
Sla Kram	Sla Kram				✓	✓	Groundwater tasting bitter. Smell of H2S
Svay Chek	Kouk Kvav	▪	✓		✓	✓	Groundwater tastes bitter
	Roka Thmei				✓	✓	The water quality is not good for drinking ince it contains Calcium plus Magnesium and Iron
Treas	Treas	✓	✓				Good quality groundwater
Kum Ru	Kum Ru	▪	✓		✓	▪	Groundwater available some places. The water of the ponds not clean and affected by soil
	Prey Veaeng	✓	✓				Good quality groundwater
	Ta Yueng	✓	✓				Good quality groundwater
Kouk Romiet	Thmei	✓	✓				Good quality groundwater
Banteay Chhmar	Banteay Chhmar Cheung				✓	✓	Groundwater difficult to find

Table 7: The Battambang Province.

Commune	Villages	Possible					Others
		Dug well	Drill well	Mix well	Jar	Pond	
Moung	Ou Krabao				✓	✓	No groundwater
Chrey	Chong Samnay				✓	✓	No groundwater
Preaek Chik	Prek Taven	✓	✓				Few wells. Water containing Calcium and Magnesium
Prey Tralach	Muk Rea Pir				✓	✓	No groundwater
Chhnal Moan	Krang Svath				✓	✓	No groundwater
Thipakdei	Ta Thok				✓	✓	No groundwater
Doun Ba	Prey Phneas				✓	✓	No groundwater
	Doun Ba				✓	✓	No groundwater
Andeuk Heap	Svay Chour		✓		✓		In this area very difficult to construct ponds because of the vertical permeability. Some wells with Calcium and Magesium. People using the Sankai River
	Serei Voan		✓		✓		Ditto
	Thma Prus		✓		✓		Ditto
	AndeukHeap	✓	✓		✓		Ditto
Prey Kphos	Kbal Thnal	✓	✓				Good quality groundwater. 110 hand drilled wells here .
	Prey Kphos	✓	✓				Good quality groundwater
Khnach Romeas	Khnach Romeas	✓	✓				Good quality groundwater
	Prey Sangha	✓	✓				Good quality groundwater
Bavel	Donn Aov	✓	✓				Good quality groundwater
	Svay Chrum	✓	✓		▪	▪	Good quality groundwater
Sampov Lun	Thnal Bot	▪	▪		✓	✓	Because of the presence of Calcium plus Magnesium local people here do not use the water from the wells for drinking.
	Thnal Bambek	▪	▪		✓	✓	Ditto + not a single ring well here.
Tasda	Tasda	▪	▪		✓	✓	Ditto
	Chamka Lhong	▪	▪		✓	✓	Ditto + not a single ring well here . They have 30 drilled wells

4.7 An additional option for the ECOSORN RIS water supply activities

On the grounds of all the above it is quite clear that the local superficial geology is of extremely variable conditions. In addition there is, so far, a total lack of knowledge of any deep aquifers (if any.) its dimensions and properties. Nevertheless to increase as much as possible the rate of success of the ECOSORN RIS water supply activities the consultant would like to suggest the following additional approach of recovery of drying wells:

1. In many target villages there are unlined "Wells drying in the dry season". Those wells are indeed very good indicators that an aquifer underlies the area of the village but because of the low construction technologies used in the past, those wells were not sunk deep enough below the dry season water table.

2. Re-fill those wells with sand and re-dig the wells sinking the porous concrete rings deep enough below the lowest dry season levels. Digging the sand would be much faster than digging for a new well and ECOSORN would certainly save a lot of time doing this way.

3. Re-digging should also bring very quickly higher ratios of successes. The local populations would also benefit of this sustainable improvement brought in by ECOSORN RIS.

5. Irrigation aspects

From all the above Chapters it is very clear that, so far, there is very limited information on groundwater availability in the Tonle Sap area. However from an irrigation point of view some information is available, essentially for the Kompong Chhnang Province. On one side the survey of the Kompong Chhnang Province concluded, overall, we quote: *"Alluvial and Pleistocene aquifers yield small amounts and inferior water quality, high in iron and salinity. Arsenic is locally contained. Basement rock aquifer has greater yield and good water quality. Exploration is difficult."*

On the other side the ADB North-Western Project hydrogeologists were a bit more positive in their assessment of the groundwater potential of the area, although they also commented that *"deep groundwater is of widespread availability but only occasionally of sufficient yield to be useful for agriculture"*. They also strongly suggested the needs, as was the case for the Kompong Chhnang Province Study for substantial surveys of groundwater availabilities before any development proceeds.

For the Tonle Sap area it may be concluded that the available information is so far, not sufficient to establish whether the groundwater resource, at a particular location, would be sufficient to support and more important, to maintain any agricultural development at the end of the dry season or for extended drought periods. The risks of over-extraction, reliance on groundwater would be quite unwise and risky until more information has been assembled.

In these circumstances, groundwater does not yet appear to be available in the quantities required for even supplementary irrigation of rice, but it could be available in small volumes sufficient for irrigation of household or small land with high cash crops (vegetables, fruit trees, etc.) using for example the "Rope pump" suggested in the previous Chapters. This pump could be used to irrigate small plots. Further to the South of the ECOSORN Project the IDE Final Report "STRATEGIC STUDY OF GROUNDWATER RESOURCES IN PREY VENG AND SVAY RIENG (PHASE 1)" mentions that in general, pumping equipment used in the communities include hand-pumps, treadle-pumps and engine-powered pumps.

As far as we can discern, efficient techniques such as drip lines technology, is already available in Cambodia and would/could be suited for the Tonle Sap area. As regards irrigation purposes there is also an additional technical bottleneck and we would like to briefly mention it here under. Using simple, light, centrifugal suction pump water can be "Extracted" from quite shallow aquifers only. The water tables of those aquifers should practically be in the range of 6.0 to 7.0 below ground surface. (This is indeed the hydrogeological condition around the Bavel area in the Battambang Province).

The IDE FINAL REPORT for the "Strategic Study of Groundwater Resources in Prey Veng and Svay Rieng (Phase 1) " mentions on page 55 that *"in some places and in order to pump groundwater, villagers need to "dig in" their pumps by placing them at the bottom of a 2-3m deep hole. This enables them to reach groundwater levels below the normal pumping limit of 6-7m"*.

Obviously this digging is an option but not without some associated risks. Many information from other parts of the world also reveal that many farmers lost their pumps due to unexpected flooding (rains) filing their 2-3m deep hole. In addition long exhaust pipes must be installed to avoid dangers linked to asphyxia by heavy combustion gases.

In the North-western countryside there are a lot of local transports and it is very easy to imagine, that in the evening, the local farmers would load their light suction pumps on a local transport and bring them home. When the water table is deeper than 6.0 or 7.0 meters below ground level it is not any more the same situation and a submersible pump must be lowered inside the dug well or the drilled well. Consequently, on the surface a "diesel" engine must be installed. Its power is transferred down the well using a hollow shaft or an electric submersible pump connected to a genset. This system requires a heavier structure on the grounds with at least a small pump house to protect the diesel engine and the generator set from any thieves.

Following technical discussions with the private sector it was confirmed that the most important problem in the area is that nobody can predict in advance the real water level at any place. This incertitude has important implications on the cost of the pumping device to be used. They confirm that a simple suction pump, allowing pumping from water tables at 6 or 7 meters deep costs around 30 US $. This cost is multiplied by 15 if an Afridev pump is to be used. The cost for a submersible pump plus its generator and the pump house would be much higher. From a financial point of view it is the opinion of this consultant that, at this stage, the above option is not yet very practical in this area.

6. Hydrogeochemistry and bacteriological aspects

Some details will be presented here under successively for the four most important chemical elements related to the waters of the ECOSORN Project as well as for the extremely important bacteriological aspect of the waters.

6.1. Iron

One of the distinctive features of Cambodian groundwater is the unusually high incidence of high iron concentrations of up to about 20 mg.l-1. Upon groundwater extraction the water becomes immediately aerated and oxygenated, thereby converting the iron from soluble colourless (ferrous) to orange-red insoluble (ferric) species. This typically occurs over the space of a day. When freshly drawn, the water is often of "crystal clear", but darkens to a turbid orange colour over the space of an hour or two. Within 24 hours most of the iron has flocculated and precipitated as an orange sludge, leaving the "over-floating" water almost clear again.

The potential risk from this problem within the project area is unknown. For potable water supplies the obvious solution would be to chlorinate the wells prior to sealing and commissioning, to aerate as much as possible the pumped water and consequently induce the precipitate of any iron, and to avoid the use of iron-rich groundwater with drip or sprinkler irrigation systems.

From the health perspective, iron-rich groundwaters always taste bad, so consumers tend to prefer the iron-free surface waters from ponds and rivers. The latter may taste much better, but in fact represent very high risks of imparting damaging microbiological infections. Hence iron has an indirect effect upon health.
The WHO limits for total iron, of 0.3 mg.l-1, is based "upon taste perceptions" rather than physiological significance. In this regard the use of the "Rope pumps" could also improve the negative impacts of Iron. During the spinning process a vortex is created and the water could therefore be quite aerated As a result this vortex could induce the flocculation of the Iron.

6.2 Calcium

Waters containing high content of dissolved Calcium and Magnesium are described as "hard". It is very important to notice that hard waters are not health hazards and risks, but instead only a minor nuisance because of mineral build up on plumbing fixtures and poor soap and/or detergent performance. International heath organisations even state that in fact hard drinking water generally contributes a small amount toward total calcium and magnesium human dietary needs. The same organisations further state that in some instances, where dissolved calcium and magnesium are very high, water could be a major contributor of Calcium and Magnesium to the diet. Areas with hard water are known to provide as much as 30 % of the daily needs for calcium just per eight glasses of drinking water. Adults should consume 1000-1200 mg of calcium per day. People think mostly of milk to obtain this essential mineral, but it can also be found very easily in the water supply. The human body needs calcium to develop strong teeth and bones. With that, Calcium can combat osteoporosis and other bone disorders. It also helps in regulating nerve transmission, blood coagulation, and muscle contraction. Calcium intake through water sources is shown to protect against death from acute myocardial infarction (heart disease), especially in women. It also protects against rectal and gastric cancers.

Despite the above positive aspects many people in the ECOSORN Project still refuse to drink the “Calcium” water pumped from drilled wells constructed in limestone aquifers. This problem in the North-western areas must be considered much more as an *“attitude bottleneck”* towards water but absolutely not as a chemical or health Calcium hazard in the area.

6.3 Arsenic

Recently, in Cambodia, much concern has been expressed over Arsenic in groundwater. Most alluvial areas of Cambodia have traces of Arsenic in the groundwater, but very high concentrations, in the order of 100 to 1000 µg.l-1, are only found in the southeast within the Mekong flood plain adjacent to the main Mekong channel, where the water table fluctuates several metres each year. In a few of these places the Arsenic concentration can reach concentration between 400 and 750 ppb. Similar figures have not yet been found in the Tonle Sap area.

The Tonle Sap has about a dozen small rivers flowing into it, in addition to the Tonle Sap River itself, but there is only one very small area in the southwest where arsenic is typically 10 to 30 ppb. In addition, much of the local groundwater has such a high iron concentration and consequently a “bad taste” that the local people just do not drink it. So automatically Arsenic is not a hazard for the drinking water in this area.

Recent analyses of water samples, carried out by the ADB North-western Project, have been compared with four other local and regional surveys to provide a sample of 947 arsenic analyses. Their statistical analysis of the existing data confirms that:

1. Eleven percent of the wells and boreholes showed measurable concentrations of Arsenic.
2. About four percent had unacceptably high concentrations.
3. None of the measured Arsenic results from the North-Western Project gave any cause of concern.
4. Of those samples analyzed within their ADB project, the highest arsenic concentration detected was about 20 µg.l-1, at Kandoeung Meas, (Bakan district, Pursat)
5. Other works have detected a single sample with 30 µg.l-1, (Ministry of Rural Development data).

The Table 6 here under presents a summary of their evaluation of the available chemical analysis.

Table 8: The Iron-Arsenic Relationship in ground waters
(From the ADB – Calculations from JICA and Ministry of Rural Development).

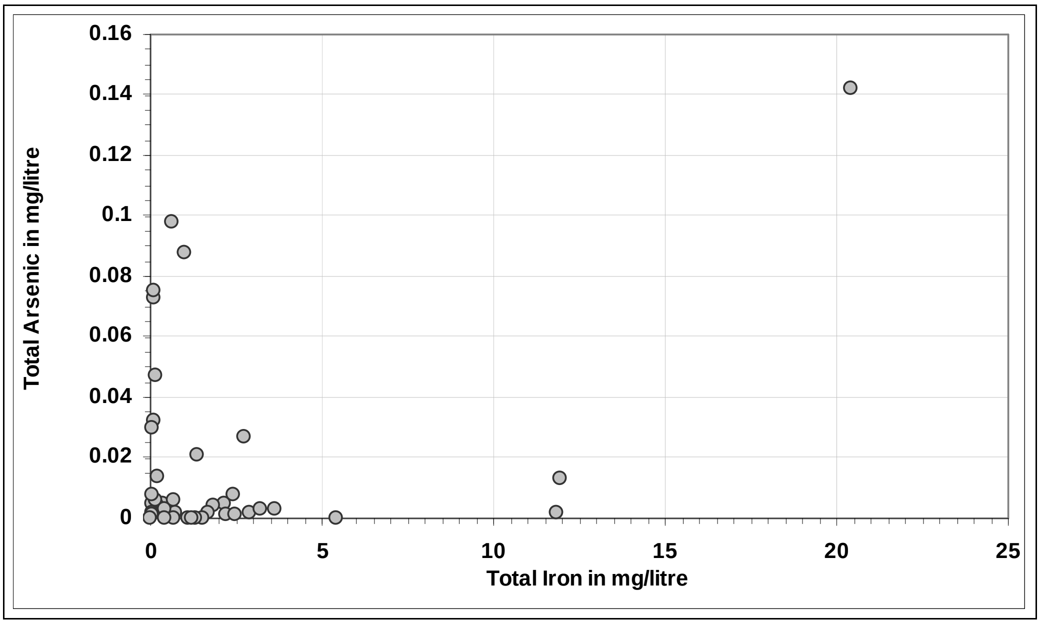

Figure 59 here under presents a map of Cambodia prepared in October 2005 and revealing the observed concentrations of Arsenic found in groundwater.

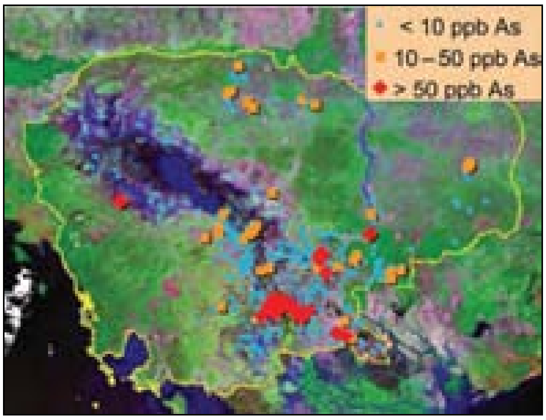

Figure 59: Arsenic concentration in Cambodia
(From D.A. Polya Oct 2005).

The following Figure 60 represents the spatial distribution of Arsenic hazards in hydrologic basins located all around the Himalaya. As can be noticed on this map all these basins receive water and sediments from a single "source" i.e. the rocks of the former Tethys Sea outcropping in the Himalaya.

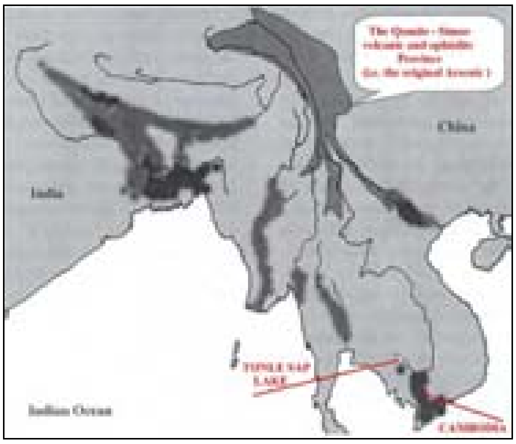

Figure 60: Arsenic hazards all around the Himalaya
(Modified from Dr Gordon Stanger – Sept 2005).

6.4 Fluoride

According to the Chapter 10.2.3 of the ADB Report " Fluoride in both surface and groundwaters is safe throughout the Project area". This information is re-confirmed by data from the January 2001Report "Drinking water quality assessment in Cambodia" in which all results for the Siem Rap Province are < 1 mg.l-1 (WHO standard is 1.5 mg.l-1 for drinking water). The same conclusions also appear in the 2003 Report "Fluoride data in Cambodia" (**http://www.oralhealthcambodia.com/menu%201/rePources.htm**)

For the convenience of the reader the Fluoride levels expressed in mg/l for samples collected by the above study are presented here under successively for the Siem Reap, the Banteay Meanchey and the Battabang Provinces. It is worth observing the important differences between the samples and their respective duplicates.

Siem Reap Province :

SRP 1 Duplicate SRP 6: 0.89
SRP 2 Well : 0.43
SRP 3 Well : 0.66
SRP 4 Open well : 0.68
SRP 5 Urban GW : 0.15
SRP 6 Well : 0.35
SRP 7 Well : 0.85
SRP 8 Open Well : 0.06

Banteay Meanchey Province :

BM 1 Duplicate of BM 6: 0.3
BM 2 Well : 0.22
BM 3 Urban SW: 0.76
BM 4 Well : 0.76
BM 5 Well : 0.10
BM 6 Well : 0.20
BM 7 Well : 0.06
BM 8 Well : 0.9

Battabang Province :

BBG 1 Duplicate of BBG 5 : 0.49
BBG 2 Well : 0.15
BBG 3 Well : 0.46
BBG 4 Open Well : 0.28
BBG 5 Well : 0.62
BBG 6 Urban SW : 0.71
BBG 7 Well : 0.67
BBG 8 Well : 0.11

6.5 Bacteriological aspects of the water

Most of the water quality data available, so far, in the Tonle Sap area is based on hydrochemical grounds *and/but* not on bacteriological or microbiological ones. Available data from Public Health seem to indicate that nobody is dying as a result of hydro chemical pollutions while so many people throughout the country (mostly infants in poor areas) die as a result of microbiological water pollutions. Similarly, non-fatal illness from enteric and parasitic water-borne diseases vastly exceeds illness from hydro chemical pollution. It is reported that in Cambodia 75 % of the dead are linked to water borne diseases.

The most recent information on assessment of microbiological pollution in rural parts of the project area is obtained by analogy with the better monitored provinces of Kampong Chhnang and Kampong Cham, as reported in the February 2002 " The Study on Groundwater Development in Central Cambodia " JICA-Ministry of Rural Development, Cambodia. In their report they mention: *"Almost all the dug wells and combined (dug and drilled) wells were polluted by Coli Form and bacteria"*.

The very same report also reveals a variable incidence of Coli form pollution in "sealed" drilled wells, ranging from 15% up to 88%. Their quantitative analysis of 71 domestic wells in O'Chrov yielded the following results:

1.	No faecal coliforms per 100 mls	27%
2.	1 to 10 faecal coli forms per 100 mls	27%
3.	11 to 100 faecal coli forms per 100 mls	22%
4.	More than 100 faecal coli forms per 100 mls	24%

In addition to the above information the 2005 Paediatric Conference in Phnom Pen (Pediatres du Monde) acknowledged the evidence of a very important and large-scale pollution and resulting death due to water born diseases. The children death rate in Cambodia is 140 / 1000 and out of those 140 children under five years old, 28 die just as a consequence of diarrhoeas. This rate of 140/1000 is the highest amongst all the countries in South East Asia and Cambodia was ranked 180 amongst 192 countries. The main source of this wide scale bacteriological pollution is from latrines and resulting Coli Forms. On the grounds of the above evidences several international donors are now reluctant to finance any water supply Projects based on shallow wells. The same donors would indeed, finance future Projects if the water is supplied through deeper drilled wells.

From the above it seems therefore very wise to automatically assume that all open wells in rural areas are, to some extent, bacteriological contaminated. The drilled wells, even those with an outward draining concrete apron, must be suspected of bacterial contamination until demonstrated they are not.

The above statistics alone should be the dominant influence upon all water quality policies and programmes, **and overshadow and eclipse in importance** all the above discussions on hydrochemistry of Calcium, Iron, Arsenic or Fluoride. As mentioned here under the introduction and promotion by ECOSORN RIS of the new Cambodian “ceramic” filter should certainly help to resolve those crucial health problems related to the bacteriological composition of the waters.

6.6 The Cambodian ceramic filter

In an attempt to improve the bacteriological quality of the water this ECOSORN RIS Project will try to induce the use of the new Cambodian “Ceramic” filter. It is an extremely cheap device (more or less 8 US $). Without any doubt this simple device would increase the general awareness of the local people towards risk factors and risk-behaviours. Most important of all it would automatically improve the quality of the waters used to drink.

Figure 61: Cambodian ceramic filter to improve the bacteriologic quality of the water.