The Dynamics of Water Management of Angkor, Cambodia, 9th to 16th Century

Roland FLETCHER1, Damian EVANS2, and Matti KUMMU3

Abstract:
Recent research has uncovered an impressive feature of Angkor: an extensive hydraulic network stretching across a thousand square kilometres. Although Angkor’s hydraulic and hydrology are not nearly as well understood as its religious architecture, it seems as though this system may have played a key role in the city operation and may also have played a role in the demise of this urban complex in the middle of the second millennium CE. Airborne synthetic aperture radar (AIRSAR-TOPSAR) data have been used to create a GIS database of the network of canals, reservoirs and embankments used to manage water in Angkorean times. Using the GIS database, TOPSAR elevation model and powerful hydraulics and hydrological models it is possible to investigate how the hydrological network was developed, how it worked and why and when it collapsed. Understanding the water management of the Angkor area will help us to better understand how the urban complex operated and may offer new information about the decline of Angkor.

Key words: Angkor, historical water management, AIRSAR, Tonle Sap Lake, hydrodynamic modelling, history of water

1. INTRODUCTION

The water management in Angkor is based on three sources of water: Tonle Sap Lake, ground water, and natural rivers. The recent research has uncovered an impressive feature of Angkor: an extensive hydraulic network stretching across a thousand square kilometres. It seems that this system may have played a key role in the city operation.

The water management can be divided to different zones depending on the elevation and also to different scales depending on the group of water users. The scales of water management are house level, village level, and city level. The Greater Angkor area can be divided into three hydraulic zones: upper, middle and lower. In the upper zone, the water was taken from the natural rivers running from the Kulen Mountains and spread to the North-South aligned channels. In the middle zone, the water was collected in big barays, water reservoirs, and temple moats for multifunctional purposes. The lower zone operated like a drainage system for the temple area and disspread water down into the Tonle Sap Lake.

The French archaeologist Bernard-Phillippe Groslier (1967; 1974; 1979), among the first to recognise that Angkor was a ‘hydraulic city’, proposed that the settlement’s decline in the 15th and 16th centuries might be attributed to the failure of that water management system. He proposed an integrated programme of archaeological research that took into account both the ‘vertical’ dimension (e.g. traditional excavation techniques) and the ‘horizontal’ dimension, exemplified by his (1979) time-sequence series of maps derived from aerial survey. The Greater Angkor Project (GAP), a collaborative project between the University of Sydney, the

1 Associate professor, School of Archaeology, University of Sydney -- rolfletc@arts.usyd.edu.au
2 Archaeological Computing Laboratory, Spatial Science Innovation Unit -- evans@acl.arts.usyd.edu.au
3 Department of Water Resources, Helsinki University of Technology -- matti.kummu@iki.fi

Ecole française d'Extrême-Orient (EFEO) in Siem Reap, and APSARA, the Cambodian body responsible for overseeing the monuments at Angkor, has been pursuing many of the same questions since 1999, using more sophisticated remote sensing techniques than were available to Groslier (Fletcher 2001; Pottier 1999).

The historical water system of the area is investigated with the help of radar images, digital elevation model, aerial photos, field studies and coring. Airborne synthetic aperture radar (AIRSAR-TOPSAR) data have been used to create a GIS database of the network of canals, reservoirs and embankments used to manage water in Angkorean times. Combining that with comprehensive field studies the three-dimensional (3D) hydrodynamic model is possible to build for investigate water levels and currents, inundation of the flood plains, suspended sediments, erosion, and sedimentation in the systems.

2. NATURAL ENVIRONMENT AND HYDROLOGY

Angkor is situated north of the Tonle Sap Lake (also known as the Great Lake), in the northwest of Cambodia in Southeast Asia (Figure 1). In the north the Kulen Mountain region sets a boundary to the area and watersheds while from the south area is bounded by the Tonle Sap Lake, the biggest fresh water lake in Southeast Asia. The plain terrain between Lake Tonle Sap and Kulen mountains is very shallow with the average slope of 0.1 % while the elevation varies from 3 to 60 meters above the mean sea level (a.m.s.l.). The Kulen Mountains rise to heights between 300 m and 400 m from the mean sea level having the highest point is at the elevation of 490 m.

![Figure 1. Situation of Angkor and the Lower Mekong Basin boundaries. (Modified Sarkkula et al., 2003).](image)

The main temple area is situated approximately 20 km north of the Tonle Sap Lake and the elevation varies between 20 and 30 m a.m.s.l. To the south of the temples, the area is bounded by the lake and the 8-12 km wide floodplain. The floodplain reached up to some 11 m a.m.s.l.
The level of the lake ranges between 1 m at the end of the dry season and 7 – 11 m a.m.s.l. at the peak of the rainy season. The area of the study region is around 2885 km² and it is situated between latitudes 13°04' - 13°44' and between longitudes 103°36' - 104°13'.

The climate in the study area is tropical, being dominated by seasonal winds or monsoons. The wet southwest monsoon arrives around May with heavy clouds and thundershowers, and usually continues until November, with rain occurring almost daily during this season. The dry northeast monsoon normally starts from November and continues until April.

2.1. Hydrometeorology of Angkor

Annual rainfall in Siem Reap town varies between 900 and 1,800 mm/year with an average of 1,425 mm/year (data from 35 years, 1922-2002; MRCS, 2003). The wet season (mid April to October) brings on average some 88 % of the annual rainfall in the Siem Reap region. Occasionally annual exceptions occur particularly March and November, at the border of the traditional wet season, in which heavy storms occur and large rainfall is recorded. The precipitation varies a lot within the Angkor region. Highest rainfall occurs at the Kulen Mountain with an average of 1854 mm/year. The lowest rainfalls occur on the Tonle Sap floodplain at Phnom Krom and on the high plain at Banteay Srei with an average rainfall of 1183 mm/year and 932 mm/year, respectively (only data for years 2001-2002 is available).

The annual average open water evaporation rate in the region is 1693 mm. The rate is highest in March and April and lowest in August and September. Yearly average temperature for the region is 28.2 °C and it varies from the coolest December to the hottest April while the monthly average temperature ranges between 25.3 and 30.6 °C, respectively. Relative humidity varies in Siem Reap region from 63.2 % in March to 81.3 % in September. The annual average humidity is 73.2 %. From December to March, the polar winds prevail in Cambodia from NE - E. During the wet season, the wind blows from SW. From beginning of October the polar NE – N winds start to dominate again in the area. The yearly average speed in the Angkor region is 2.52 m/s. (source: Siem Reap Weather Station, years 1998-2002).

2.2. Ground water and geology

Ground water is a very important part of the water management in Angkor. The area has very good sources of ground water. It is easily accessible as the water table lies between depths of 0 and 5 m below the ground level during the wet season and dry season, respectively. The ground water table is presented in Figure 2 (JICA, 2000; JSA, 1996; and JSA 2002).

Figure 2 shows the ground water level at Bayon, Angkor Thom. The seasonal variation is clearly visible in this data and it represents the average behaviour of the ground water in the region. The results are relatively similar to the measurements taken from Angkor Wat (JSA, 2002) and Banteay Srei temple (Dr. Friedli
4, personal comm.). The area has large ground water storage with bedrock situated about 50-60 meters below the ground surface (JICA, 2000). The upper two layers, younger and older alluvium aquifers, have very good ground water potential while the third layer (30-50 m below the ground surface), called Pleistocene formation, seems to have a very poor ground water potential. Thus, the aquifer is some 30 – 50 m deep in the lower plain (JICA, 2000)

---

4 Dr. Roland E. Friedli did a comprehensive study of geophysics at the beginning of year 2003 for the Banteay Srei Conservation project.
Around the Tonle Sap Lake, the ground water stages may vary dramatically (order of tens of meters) even in very short distances depending on the depth of the bedrock and the characteristics of the soil layers. Hence, the Angkor area is an optimal place for the capital because of good access to the ground water.

2.3. **Tonle Sap Lake**

The Tonle Sap Lake is the largest permanent fresh water body in Southeast Asia. The Tonle Sap River connects the lake to the Mekong River and joins it at Chaktomuk junction near Phnom Penh, after which the river immediately splits into the smaller Bassac River and the larger Mekong River. The area is globally unique and the lake has an extraordinary hydrological system. In the wet season, the Tonle Sap River changes its direction and flows to the Tonle Sap Lake instead of from the lake because of the flooding of the Mekong River. The lake functions as a natural flood water reservoir for the Mekong system.

The area of the lake varies between dry and wet season from 2700 km$^2$ up to about 15 000 km$^2$ while the depth of the lake increases from less than one meter up to 7 - 9 m. During the wet season, the volume of the lake increases from about 1.3 km$^3$ up to 60-80 km$^3$ depending on the flood intensity. The bottom of the lake lies approximately 0.5-0.7 m above the mean sea level. Hence, during the year the surface of the lake varies between 1 m and 10 m a.m.s.l., respectively.

The recent studies by Mildenhall (1996), Tsukawaki et al. (1997), and Penny (2002) show that the sedimentation rate during the last 5000 years has been approximately 0.1 mm/year in the lake proper. Thus, no significant sedimentation is occurring in the dry season lake area. Sedimentation is heavier on the flooded forest and flood plains in the vicinity of the lake proper and the rivers (MRCS/WUP-FIN, 2003). Hence, during the Angkorean time the bottom of the dry season lake was only some 10 cm below the present bottom level. Thus, no significant changes have occurred in the morphology of the dry season lake during the last thousand years.
The Tonle Sap Lake had a very important role to play in the history of Angkor. First of all it was an important source of nourishment. Today the lake provides about 60% of Cambodia’s total supply of protein. The Tonle Sap ecosystem is believed to be one of the most productive inland waters and one of the most fish-abundant lakes in the world (Figure 3). Flooded forests and shrubs offer shelter and breeding grounds for fish and other aquatic animals (Bonheur, 2001). The annual flood also creates good conditions to cultivate floating and recession rice. Hence, the Tonle Sap Lake is a crucially important source for food and living in Cambodia present day as it was for Angkor in the past.

The lake was also a very important part of the transportation network for Angkor; e.g. goods, food and people were easy to move from one place to another. The location of Angkor is optimum for the city. It is safe from the flood, but at the same time very close to the lake even during the dry season. The floodplain is relatively narrow in the Angkor region (averaging some 12 to 14 km), compared to the other parts of the lake where it can be quadruple (e.g. Battambang region, west side of the lake). Hence, it was possible to come easily and quickly by boat up to the city by the present Siem Reap River (Angkor period, channel), probably during the dry season as well.

2.4. Ecology of the area

Presently the ecology of the Angkor area can be divided into three groups. Firstly, the flood plain consists of rice fields and flood forest. Secondly, the plain which consists of mostly shallow water rice cultivation and bush land, and finally, the hills and forest area which starts north of the gentle plain area and extends up to the Kulen Mountain’s waterfalls and thick forest.

2.5. Water sheds

At the present time, the Angkor hydrological area consists of three watersheds: Puok, Siem Reap and Roluos. Before the Angkor period, the region was divided into only two main watersheds, which were Puok (including most of the present Siem Reap watershed) and Roluos. The total area of the hydrological region is 2885 km². Angkor changed the whole natural waterway by making offtake channels to the south from the Puok River. One of the offtakes was the present Siem Reap River (point F in Figure 5 shows the place of the offtake). The most probable reason for this channel was to take more water down towards the East Baray. Before the Siem Reap offtake existed, the baray was fed by one of the tributaries of Roluos River. The other of the major offtakes was the Great North Channel.
3. MAPPING THE HYDRAULIC FEATURES

In particular, the AIRSAR-TOPSAR datasets acquired over Angkor by NASA/JPL in September 2000 as part of the PacRim 2 mission have allowed researchers to ‘see’ Angkor in a different way. Building on years of aerial photograph interpretation by Christophe Pottier (1999) of features in the south of the Angkor plain, the radar data have uncovered a network of previously unknown hydraulic features – both natural and cultural – in the north of the settlement, which have since been mapped in some detail (Figure 5). Combined, the two datasets provide a more comprehensive picture of Angkorean hydraulic than has been available in the past, and hypotheses about its operational limits can now be tested with direct reference to GIS databases of hydrological features (both modern and Angkorean) and a precision digital elevation model.

3.1. Southern Angkor

The first step in modelling hydrology at Angkor was to build on Pottier’s (1999) typology of large-scale archaeological remains and create a GIS database for features the north commensurate with his GIS database of features in the south. These features include:

- Channels, both artificial and natural
- Temple and moat locations
- Household ponds or trapeang
- Larger water storage devices such as the great reservoirs or baray
- Angkorean field structures (and thus the extent of irrigated land)

3.2. Northern Angkor

Data collection

The AIRSAR instrument is built and operated by the Jet Propulsion Laboratory (JPL) under contract to the National Aeronautics and Space Administration (NASA). On 21 September 2000, a series of AIRSAR data were acquired over the Angkor plain. The instrument was mounted in a DC-8 aircraft deployed by NASA/JPL as part of the PacRim 2000 Mission, and covered approximately 7000 sq km of terrain on the day. The Angkor overflight was highly successful and has produced datasets of very high quality, clarity and integrity (Fletcher et al 2002, JPL 2002).
**Identification of the features**

Angkorean features were therefore identified visually using 3-band colour composite images, the TOPSAR DEM and various image products derived from these data. Once identified, they were manually mapped into a GIS database. This process also allowed for careful differentiation of Angkorean features from modern ones by reference to the ZEMP (RAF 1995) and JICA (1999) GIS databases.

Ground verification was undertaken using maps derived from the GIS database, printed radar images overlaid with the modern map grid, and precision GPS units. The 2003 field season of GAP also made use of Ultralight plane for low-level aerial survey in areas that were otherwise inaccessible due to land mines or dense vegetation.

![Figure 5: Structure of Angkorean archaeological and hydraulic features showing the locations mentioned in this paper (Evans, 2002 – the current study in the map means the study made by Evans).](image)

**4. WATER MANAGEMENT**

The water management can be divided to different zones depending on the elevation and also to different scales depending on the group of water users. The most dominant hydraulic features in Angkor are the huge water reservoirs, barays, to where water was led by wide channel network from the natural rivers. The temple mounds control the main temple area. At
the village level, trapeangs are strongly related to the temples, and at the house level the people got the water from small ponds during the dry season.

4.1. Hydraulic features

In the Angkor area, the hydraulic features can be classified as follows:

- a square mound surrounded by a ditch, with associated peripheral secondary mound (temple of house mound)
- a rectangular basin usually named "trapeang", with elevated surrounding bank made with its excavation
- a big rectangular water reservoir named “baray”
- and linear structures associating dikes and canals

**Temple/house mound:**

Almost every temple has its own moat into which water was normally collected from rain and ground water sources. The moats are square or rectangular and are generally oriented E-W and N-S. The size of the central mound varies from 25 to 70 m on side, according to the periods and, of course, the richness of the founder. It dominates the plain from at least 3m high, whereas peripherals mounds are generally lower, sometimes hardly exceeding only a meter above surrounding rice fields (Kummu & Pottier, unpublished).

**Trapeang/pond:**

Due to the long dry season, the collection and storage of the water is very important for the people of the area. At the household level this is done by building small ponds adjacent to the house where rainwater and groundwater can collect. For village use, a bigger pond, trapeang was built. The sizes of trapeangs vary from 2 to 20 ha. Normally trapeangs were also related closely to the temples.

**Baray:**

In the urban area, in Temple zone, the water was collected in the big barays by channels. Angkor area has four barays: Indratataka (Baray of Loley), East Baray, West Baray, and Jayatataka (North Baray). The vast majority of these features, barays and trapeangs, have a length width ration of 2:1 and are generally aligned E-W (Evans, 2002). Trapeangs were dug into the ground, fed by rain and ground water, and are unrelated to the channel network, while the barays were basically not dug and fed by channels and rainfall (Fletcher, 2001).

The reservoirs, barays, trapeangs and moats probably had multifunctional purposes. The uses could have included ritual uses, aesthetics, water supply for humans and animals, transport, irrigation, drainage, defence, health, fishery, and washing.
**Linear features:**
- tangential to the slope:
- parallel to the slope:

Channels were crossing over the whole landscape. The channels were generally very shallow and wide, some 1-2 m deep and 30 – 40 m wide. Normally the road(s) lined the channel on an embankment(s) about 1 - 2 m above natural land surface. The sides of the embankments were probably used for living as well as it is possible to get the house above the floods in rainy season. Some channels had only one embankment on the side of downward slope and those probably have the main purpose as a road. Thus, the linear hydraulic features were normally for multipurpose uses as well.

### 4.2. Construction of hydraulic features

Normally the water was controlled in the Angkor area by earth embankments. Not much evidence has been found that they used laterite constructions or sluice gates for controlling flows. However, there are couple of laterite constructions which probably has served as water control features. One is situated at the Ban Penh Reach channel, which has a low-level offtake from the Siem Reap just downstream from the junction of the Siem Reap with the Puok. The other one is Krol Romeas (misleading as having the same name as the animal compound next to Preah Kanh temple), which is situated at the east end of East Baray and probably functioned as an inlet or outlet for the baray.

### 4.3. Hydraulic zones

The Greater Angkor area can be divided hydrologically into watersheds and sub-watersheds as described in Chapter 2.5 and the water management can divided to three difference scales as described in Chapter 4.1. However, in the case of Angkor it is essential to divide the study area also into hydraulic zones based on elevation to better understand the hydraulics, hydrology and management of water of the area. There are three main hydraulic zones: upper, middle and lower. Two of the zones can be divided into two sub-zones: the upper comprising of upper plain and mountain areas and the lower comprising of floodplain and upper drainage zone (Kummu, 2003). Each zone has its typical natural hydrological and cultural hydraulic characters irrespective of the watershed borders.

- In the upper zone (also known as Collector zone), the water was taken from natural rivers that ran from the Kulen Mountains and then spread to the North-South aligned channels. The main water source for the Angkor area is the Kulen Mountain region from where all three rivers of the area are sourced.

- In the middle zone (also known as an aggregator and holding zone or temple zone), the water was directed by the Collector zone’s N-S channels towards the zone of the barays using a wide channel network. The water was collected mainly in large barays, water reservoirs. The total volume of the barays was approximately 80,000,000 – 120,000,000 m³. Further appraisal for how this worked, exactly, is needed, but the collector function is apparent.

- The lower zone (also known as Drainage and dispersal zone) operated as a drainage system for the temple area and dispersed the water down into the Tonle Sap Lake.
Some main components of the area are e.g. SE channel and SW channel running from
the SW corner of the West Baray to SE and SW, respectively. The former Siem Reap
Channel (today river) and Angkor Wat Channel are the main structures for
transporting the water to the lake from the Temple Area. SW-S and SE lined channels
were fast and slow channels, respectively.

The total area of the hydrological study region is 2885 km\(^2\) and it is presently made up of
three watersheds. The cultural water system covers approximately 1000 – 1500 km\(^2\). The
water system was mapped in the two lower zones by Pottier (1999) using the aerial photos
(Finnmap, 1992) and in the upper, Collector zone using the new technique based on the radar
images and GIS by Evans (2002) as described in more detail in Chapter 3.

Figure 6  Hydraulic zones of Angkor region. From north to south: Collector zone (Mountain
area and upper plain), Temple zone, and Drainage zone (Upper drainage zone and
floodplain). (DMA, 1963; Certeza, 1964; JICA, 1999; and Evans, 2002).

4.4. Advantages and disadvantages of the water management in Angkor

\textbf{Advantages}

The situation of Angkor is optimal from a hydrological point of view. The Tonle Sap Lake
was very close to the city but still the city was safe from its floods. The lake offered an
excellent source of nourishment and potential for transportation. The floodplain was also very
fertile for growing rice. Also the Kulen mountains assure good water supply to the rivers all
year round.

Ground water in the area is close to the surface even during the dry season, unlike in many
other places around the lake. Thus, the Khmers had easy access to water all year round,
guaranteeing water for drinking and bathing even during the driest dry seasons. Also the
significant public health benefits of high water tables cannot be ignored (Himel, 2001; ref
Goodman, 2001). Regular bathing in the family ponds was noted to have taken place by Chou
Ta Kuan (Chou, 2001) at least twice a day.

The very gentle slope of the plain created an excellent terrain for managing the water with
artificial channels and reservoirs. The Khmers were exceptionally good at managing the water
and moving it from one place to another. The channel network was built with care and spread
over a 1000 km$^2$ area (Evans, 2002) – some of the channels and reservoirs (e.g. West Baray, though the water is not flowing to the Baray along its original route) are still in use today.

**Disadvantages**

Although, the closeness of the Great Lake had its advantages it also had disadvantages. For example, it decreased the area of flooded fertile fields. Hence, the potential of the rice cultivation using the flood water was limited in relation to the closeness of the main temple area.

Even though the Khmers were excellent water engineers, they could not avoid normal problems relating to erosion and sedimentation in the canals and channels. Also, the changes in land use may have affected the hydrology of the area. The more people there are the more rice that is needed. Thus, probably large areas of forest had been turned to rice fields to feed the growing population in Angkor. This may have affected the local hydrological cycle in many ways. The surface flow increased with the sediment flux to the rivers, causing several problems on downstream channels and reservoirs.

5. **METHODS USED TO INVESTIGATE THE WATER MANAGEMENT IN ANGKOR**

The methods used for the Angkor water system studies are field studies, coring, Ultra-Light plane, aerial photos, AIRSAR-TOPSAR data, two hydrological models and 3D hydrodynamic model. In this chapter, those methods are briefly presented.

5.1. **Field methods**

Field studies are an essential part of the study. They offered a lot of information that is not possible to get from anywhere else. To get a good view of the hydraulic network, individual structures and features, as well as to understand better the local nature, hydrology, and habits of the people the comprehensive field studies are necessary to do.

The net sedimentation in the ancient channels can be determined with the help of coring (Player, 2002), but the exact sedimentation rates can be defined only from the features that have been wet since they were constructed using radiocarbon dating (Penny, 2002).

Palaeo-environmental data have been collected from features, such as moats and trapeangs, which have been wet since they were constructed. The work has been conducted by Dr. Penny. With the radiocarbon method, it is possible to date the sediment layers and thus calculate the net sedimentation for each period.

The Ultralight plane is used to carry out precise checks on problem locations quickly and more safely than is always possible on the ground. The size of the area and areas to where it is difficult or even impossible to go because of the land mines and lack of paths make the use of ultra-light plane very useful. With the plane it is possible to get a view over the landscape from the height of 1 000 m or then a very close look to the details from the height of couple of tens of meters. The potentials of the Ultralight are incredible for the areas like Angkor where the hydrological and hydraulic features are spread over 1000 km$^2$ and the access to the places is difficult or even impossible from the ground.

5.2. **AIRSAR-TOPSAR data and aerial photos**

Aerial photos have been used for identifying the hydraulic features during the field work. Pottier (1999) produced the archaeological maps of southern Angkor (Figure 5) with the help of aerial photos taken by FINNMAP (1992).

Airborne synthetic aperture radar (AIRSAR-TOPSAR) data have been used to create a GIS database of the network of canals, reservoirs and embankments used to manage water in the
Angkor period in Northern Angkor (Evans, 2002; and Fletcher et al, 2002). Together with Pottier’s (1999) mapping an exhaustive hydraulic map over the Greater Angkor area have been created (Figure 5).

The TOPSAR digital elevation model (DEM) is critical for understanding the dynamics of the fluvial environment. The data have a 5x5m ground resolution and can resolve sub-metre differences in elevation in areas of low topographic relief. The data, radar images and DEM have proven particularly useful in the discovery and analysis of Angkorean hydraulics and hydrology.

5.3. 3D Model Package

The hydrology and hydrodynamic of the Angkor area are investigated with the help of mathematic modelling. Based on a GIS database and TOPSAR elevation model, a three-dimensional (3D) EIA Flow Model (Virtanen et al., 1998; and Koponen et al., 2003) has been set up for simulating water levels and currents, inundation of the flood plains and suspended sediments. Distributed hydrological model, VMOD (Lauri & Virtanen, 2002), applied to the watersheds have been used for the boundary flows of 3D Flow Model (MRCS/WUP-FIN, 2003). The models have been calibrated for the present hydrological and meteorological conditions of the study region and have been applied for the ancient land use, meteorological, and morphological conditions of the watershed as accurately as possible within the bounds of current knowledge. Using the model, sedimentation and erosion rates can be defined for the area using different historical scenarios for landuse and climate, allowing archaeologists to test hypotheses about the decline of Angkor against rich and complex datasets.

Some of the most valuable uses of the model in the study area are (Evans & Kummu, 2003):

- flows and currents in complex channel network
- reconstruction of the water system
- influence of the land use changes scenario analysis
- sediment accumulation and filling of the channels, both in short term and centuries timescale
- erosion rates in the channels and canals, especially in Siem Reap River and Great North Channel
- sedimentation rates in the Barays
- the river floodplain vegetation effects to the currents and sediment concentration

These results will be used for the archaeological, hydraulic and hydrological analysis of the area. With the analysis, it is possible to get more information about the water system, an estimation of how significant that system was in the city’s operation, and to indicate whether or not the demise of the hydraulic network implicated its urban environment in the middle of the second millennium CE.

6. CONCLUSION

Some thousands of features were mapped in the northern part of Angkor in this analysis, confirming the value of AIRSAR as a tool for the reconstruction and modelling of ancient hydrological systems. Together with Pottier’s (1999) maps of the south, a comprehensive picture of hydraulic on the Angkor plain – natural and cultural, modern and ancient – has emerged (Figure 7).
The area of Angkor is made up of three watersheds. It has been proved to be essential also to divide the area to three hydraulic zones based on elevation to better understand the hydraulics, hydrology and management of water of the area. Each of the zones has its typical characteristic in hydraulic and water management fields. The water management can be divided again into three levels: house, village and city levels.

The situation of Angkor is perfect from water management point of view: ground water is close to the surface the year round, the Tonle Sap Lake offers an excellent water way to Angkor, secure food supply and fertile floodplain to cultivate rice. The Angkorean engineering were very skilful to manage water but they had also difficulties with erosion and sedimentation in channel system.

With the help of GIS database of hydraulic features, TOPSAR digital elevation model, comprehensive field studies, and mathematical models the historical water management can be better investigated and understood.
REFERENCES


