

DRAFT ONLY. NOT TO BE CITED.

The Water Management System of Angkor: The implications of new evidence.

A/Prof Roland Fletcher

Department of Archaeology, University of Sydney

Director – Greater Angkor Project

Keynote address for “Water in Mainland Southeast Asia” : across-disciplinary workshop organized by the Centre for Khmer Studies (CKS), Siem Reap, Cambodia, and the International Institute for Asian Studies (IIAS), Leiden/Amsterdam

Centre for Khmer Studies, Siem Reap – Cambodia, November 30 - December 2, 2005

ABSTRACT

The nature and even the existence of a water management system at Angkor has been the subject of considerable debate since the 1970s. Recent work at Angkor by the EFEO and the Greater Angkor Project has acquired substantial new evidence relevant to this debate. The entire Angkor region has been mapped revealing an urban complex covering about 1000 sq km. Residence was located on occupation mounds scattered across the landscape and also along the linear embankments and channels of a vast water management network. That system would have provided risk mitigation for the impact of both high and low seasonal rainfall, helping both to control flooding and to supplement rice production in poor monsoon seasons. The new evidence has implications for our understanding of the internal operation of the system, the role of the network in relation to state power and the debates about intensification in the economies of agrarian urban societies.

PAPER

THE WATER MANAGEMENT SYSTEM OF ANGKOR: THE IMPLICATIONS OF NEW EVIDENCE.

Roland Fletcher
Dept of Archaeology
University of Sydney

THE EXTENT OF ANGKOR AND ITS WATER MANAGEMENT NETWORK

The mapping of Angkor by EFEO and the Greater Angkor Project has shown that the main group of great temples lies at the centre of a vast, dispersed, low density urban complex containing a linear network of embankments and channels (Fig 1). Occupation debris has been found along the embankments (Fletcher et al 2003). The linear network is also superimposed on an apparently random extensive distribution across the landscape of individual structures - the *prasat*, *trapeang* and occupation-mounds (Evans 2002). The configuration of the embankments is also different in the north and the south while, by contrast, the various individual structures are both generally similar and consistently dispersed throughout the region.

The network covers about a 1000 sq km and extends from north of Bantei Srei in the northeast and Nokor Pheas in the northwest, through the great barays around Angkor Thom, and southwards to the shore of the Tonle Sap. The network has three main sectors, as identified by Kummu - a northern zone where water was spread out across the landscape and its flow rate was reduced, a central zone around the temples where water was held in the *barays* or reservoirs, and a southern zone between the centre of Angkor and the lake where water was either dispersed rapidly to the lake or distributed slowly from west to east across the slope of the landscape (Evans and Kummu 2003)

The initial integrated map of the region and its cultural features was developed by combining the survey of Christophe Pottier (EFEO) from 1992 to 1998 with data from the AIRSAR mission flown during the wet season of 2000. In September 2000 NASA/JPL (JPL 2002) carried out a comprehensive AIRSAR aerial radar survey of about 7000 sq km of territory extending from the Kulen and Khnor hills in the north to just south of the southern shore of the Tonle Sap and from the longitude of Beng Melea westwards towards Battambang. The purpose of the survey was to study the extent and assist in understanding the demise of Angkor (Dayton 2001; Fletcher 2001; Fletcher and Pottier 2002). The 3000 sq km of this survey that specifically covers Angkor has been analysed over the past three years (Evans 2002; Fletcher, Evans and Tapley 2002). The large perspective made possible by the comprehensive AIRSAR coverage is required to understand the nature and overall operation of the water system in Angkor. Focusing on the central part of Angkor, (e.g. Egawa 1999; Nakamura 2000) prevents a recognition of the crucial role of the northern half of Angkor and the function of the Great North canal and its subsidiaries. These are clearly visible on the 1994 radar image from the space shuttle *Endeavor*, which was

commissioned by the World Monuments Fund. They were in part, mapped on the ZEMP GIS database (Engelhardt 1996) and are also partially represented on Claude Jacques map of Angkor in 1978.

The new, provisional map of Greater Angkor has been prepared at the University of Sydney by Damian Evans, combining the radar data with the survey work of Christophe Pottier in a GIS database. Mapping of Angkor continues both in the EFEO and by the Greater Angkor Project (GAP).

NATURE AND OPERATION OF THE NETWORK

The field research of the EFEO and GAP has shown that the operation of the water management network depended on elaborate structures and configurations of banks and channels. In effect the system used huge quantities of the only available bulk material - sand with a small admixture of clay - to reduce the flow rate of the incoming water, to disperse it and to then concentrate masses of still water for redirection across the landscape.

In the main, a distinction between road embankment and canal bank and water distributor channel may have had little meaning in Angkor as most embankments would have functioned to re-direct water across the landscape. All embankments that run across the lie of the land (i.e. approximately E-W or NW to SE) would have acted as barriers to the movement of water in the monsoon season. The 20-40 km long E-W embankments in the north would have created extensive ponds on their northern side. Where N-S and E-W banks meet, water would be trapped on the eastern side. Furthermore, any embankment running NW to SE, such as the "road" from the old core of Yasodharapura to the NW corner of the Indratataka (Fig 1), would have shunted water across the lie of the landscape by blocking the flow downslope to the SW. The SE canal that extends from the SW corner of the West Baray, among others, only has a substantial bank on its southern side.

Once the entire network from the lake to the hills is presented on a single map it is apparent that the great *baray* are the middle zone of a huge water management system (Fig 2). The northern zone between the hills and the major *baray* is a collector and flow management system for spreading water across the landscape and also directing it southwards down major canals. The canals have right angle turns or cross canals into which water could be shunted to slow it down or speed up its flow as required and remove suspended sediment. From the canals, water was shunted to large holding basins. Such basins occur just to the north of the NE corner of the West Baray. They have two parallel N-S banks and are 200-300m wide and as much as 2 to 4 km long. Rather than just being canals to take water somewhere, they are probably better understood as basins to bring large amounts of water to a halt and then bleed the water off into other channels, as and when required. The network would have played a crucial role in slowing down and dispersing the monsoon water, thereby shielding the urban complex from disruption by flooding. From these basins the water could then be moved southwards either into bypass channels or into the *baray*.

The central zone of the network is the band of major *baray* and temple moats that were built from the 9th to the 12th century AD across the width of Angkor from Bantei

Sra to Chau Srei Vibol. These now appear as a set of massive water storage units fed by the northern collector system. What has become apparent from excavations in the banks of the West Baray is that these great structures were built very systematically and were not merely heaps of sand and clay to hold water for ritual display. While the East and West Mebon and the Neak Pean leave no doubt that the *baray* had a ritual meaning the West Baray, for example, was also a meticulously built piece of engineering (Fletcher *et al* 2003: Fig 6). There is an intake channel 25m wide in its north-east corner, fed by canals from the north and east (Fig 3). A channel also cuts through the southern portion of the east bank of the *baray* and another channel cuts across the SE corner of the *baray* to enter feature CP807 to the south. There has been much remodelling of this south-eastern sector outside the *baray*. There are some indications that east-west channels may have run along the southern side of the south bank of the *baray* (Pers comm. Terry Lustig), in association with the problematic “bastions” found by Pottier (1999). Further evidence of a precise function for the *baray* is the grid of channels south of the SW corner of *baray*, identified by Pottier (2000) and previously mis-identified as the boundary of a pre-Angkorean “city”.

The southern zone of the network is a suite of dispersor and distributor channels. The most obvious set is associated with the West Baray and consists of a channel running to the south-west - the shortest, steepest and therefore the quickest dispersal route to move water down to the lake; and a channel to the south-east, the SE Canal/Road, that goes all the way to the south of Roluos and then on to the Damdek “canal” and beyond. The SE Canal/road is the slowest route the water could take and still flow, suggesting that this was a distributor canal to spread water across all of the land south of the canal down to the dry season edge of the lake.

Another dispersal canal run from the Angkor Wat moat down to Phnom Krom. The Siem Reap river may now follow part of the course of another former dispersal canal from the East Baray down to the same terminus by the lake. South of Siem Reap town, where the Siem Reap river diverges to the east the line of an abandoned channel is still visible as a row of occupation-mounds passing west of Vat Attvear and also by a buried channel that is exposed in cross-section in the ditch of the new ring road at Kar Kranh. The channel was about 40 to 50m wide and only 1-2 m deep. This channel is probably the original line of the post 14th C Siem Reap. Below it there is an earlier channel of unknown date (Fig 4) (see below East Baray Addition).

The Rolous group deserves further attention as it has a *baray* (the Indratataka) and also a major channel running due south to the lake that would have acted as a dispersal channel. The village of Kompong Plok is located at the southern end of this channel. It also has what may be distributor channel as well, previously interpreted as a road. The linear embankment leading south-east from the centre of Angkor to the Indratataka and the Angkorean road running SE from the SE corner of that *baray* would have channelled water to the southeast in the same way as the SE canal/road from the south-west corner of the West Baray. In addition, a poorly preserved, and probably early channel runs westwards towards Vat Attvear. These appear to be elements of a whole early network around the Roluos group. If it was like the later system based on the East and the West Baray there should also be remnants of a 9th century AD collector system of E-W embankment to the north of Roluos.

RELEVANCE OF THE NETWORK SYSTEM TO THE “IRRIGATION” CONTROVERSY

The identification of a vast, water management network is of critical significance for the debates of the past twenty-five years about water management, ritual, irrigation, intensification and state control at Angkor. The function of the *baray* and the great temple moats became a matter of dispute following the insightful paper by van Liere (1980), which proposed that the massive water features of Angkor were either not necessary for irrigation or did not have the characteristics required to be an irrigation system. The issue polarized, rather surprisingly, into an English-speaking non-utilitarian “ritual” posture and a “French”, supposedly utilitarian, hydraulic civilization viewpoint. In 1998 Acker summarized the “English” perspective. He pointed out that the purported irrigation system would not have produced enough rice to be worthwhile because too small a proportion of the total population of Angkor could have been fed. He estimated that up to about 200,000 people could have been fed out of Groslier’s putative population of a million or more.

The irony of the debate, as pointed out by Pottier (2000) and by Eileen Lustig (2001), is that the dispute involves both a misapprehension of the data and is built on a set of false premises. In his surveys Pottier has located great canals and inlets and outlets of the *baray*. The Greater Angkor project has excavated a meticulously-built masonry spillway, at least forty meters wide, at Bam Pen Reach in northern Angkor (Fig 5). Eileen Lustig (2001) has made the case that the network was not for yield intensification but for risk mitigation. Different calculations lead to a similar scale of support to the Acker estimate through to a lower population for Greater Angkor overall of about 750,000 (Fletcher *et al* 2003: Fig 9). What is critical is the issue of how valuable a relatively small reliable yield can be, rather than a claim for high yields from a system that the “ritualists” apparently assume had to be for intensification or else had no pragmatic function. A small, secure yield from irrigation is crucial to avoid the risk of crop losses in a year with a low monsoon rainfall. The Angkor network sufficed to make-up the liable shortfall.

The technical and social premises of the “non-utilitarian” viewpoint need to be reappraised. Key technical and evidential assumptions of the Acker-van Liere perspective, specifically about the absence of inlets and outlets for the great barays and the absence of distributor channels, are empirically invalid. The Jayatataka has a feeder canal running to its NE corner and both the major barays also have inlets and outlets in their eastern walls (Pottier 2000: 103). Pottier’s comprehensive surveys have also shown that immense channels derive from the West Baray and from the Angkor Wat moat and may also derive from the initial layout of the East Baray. Furthermore, the social premises are problematic. Groslier, who is the epitome of the French viewpoint, never advocated a sharply defined utilitarian view (Pottier 2000: 101). Nor is it easy to see how anyone who worked at Angkor for many years could possibly deny the ritual component. The immense E-W, N-S orientation of the Angkorean landscape would, in itself, suffice to require the recognition of a cosmological component. Groslier just wrote about the ritual and operational interpretations on different occasions in his numerous books and papers from the 1950s to the 1980s.

There is also a conceptual flaw inherent to the debate being premised, both by previous opponents and proponents in the Angkor debate, on the Wittfogel hydraulic civilization thesis of the 1950s that state power was built on intensification of yields from irrigation. Groslier (1979) apparently presumed that irrigation was the foundations of central state power in the standard Wittfogel model (see 1981 edition). Higham in 1989 and in 2001 presents the inverse that because of the instability of the Khmer state, the lack of centrality and the power of the other grandee families (1989: 322-35, 345, 353-4; 2001: 156-161, 165) the rulers in Angkor could not have built a large-scale, engineered irrigation system. But the non-centrality thesis simply inverts and therefore repeats, the assumption that there is a direct correlation between social form (i.e. degree of state power) and material form (*ie* scale of irrigation engineering) whether to make a claim for the presence or absence of large-scale irrigation. However, there is a logical alternative. Constructing a massive risk-management system for irrigation from the 8th to the 12th century AD would have served the ruler in Angkor precisely because the state did not generally wield absolute power over the great provincial lords of the Khmer world. Non-correspondence between the scale of social power and the scale of a hydraulic system also makes operational sense, given that we know the ease with which agrarian urban societies can build huge structures (White 1974). The need for large irrigation works to provide food for a relatively small number of people would be a corollary of limited state power. The interesting question and possibility that arises is whether that relationship existed throughout the history of Angkor. If state power increased markedly *eg* after the accession of Jayavarman VII (circa AD 1180 to the 1210s), then a different system and a failure of that system may have occurred during the second half of the history of Angkor from the late 12th to late 16th C AD.

HISTORY OF THE NETWORK

The network has a complex and surprising history. A model of that development is outlined below (Figs 6-11). The development began in the SE spreading north and then west, with the last major additions from the early 12th C onwards being along the central axis. These later additions include a dispersor canal from Angkor Wat and finally the creation of the southern half of the canal, which the Siem Reap river now partially follows southwards past Angkor Thom and down to the lake. The system appears to have developed closure, turning back in on itself from the 12th C onwards. Significantly the later canals down the middle of southern Angkor were dispersors to assist getting rid of water from the centre of the urban complex.

Roluos network (Fig 6)

The Roluos network as currently observable includes a *baray*, the Indratataka, various channels and moats around the Bakong, a major N-S canal to the south running to the lake and a canal to the west running in the direction of Vat Athvear. To supply the *baray* a canal would have been required to bring water from the north. This is the track of the current Roluos river which now flows north-south in a slightly meandering channel. Just to the west of Chau Srei Vibol there is a marked change in the channel direction. The upper part of the Roluos, north of the road to Chau Srei Vibol, follows a NE to SW direction similar to the flow direction of the upper Siem Reap and the Puok river. The implication is that the lower Roluos is following the line

of the old canal (8th-9th C AD) that tapped water from the original Roluos river to the north. If this was the case then a hypothesized original river, like the Puok, may have flowed NE to SW. It would have debouched to the lake somewhere between Wat Hepkha and Phnom Krom. On this configuration the western canal would have been a means to return diverted water to the hypothesized old river.

East Baray addition (Fig 7)

In the late 9th C the East Baray was added to the north of the Roluos network, fed first by a river the NE that was blocked by embankments to the north and east of the NE corner of the *baray*. The next stage was the addition of supply through an offtake from the old-Puok river to the north. This offtake was a zig-zag canal that came down to a major E-W bank north of the *baray* then turned east and south to enter the NE corner of the *baray*. There may also have been a canal running to the west from the NE along the north side of the north bank of the *baray*, but its course is as yet uncertain. Water was taken out of the *baray* through the middle of the east bank. There may also have been a dispersor canal from outside the SW corner of the *baray* but the path whereby water got to such a dispersor is unknown. A possible route is along a canal south of the south bank, following the line of the *asrama* established by Yasovarman I (Pottier 2003).

Since the offtake for the East Baray was cut it has progressively captured the water of the former Puok river. The name Siem Reap is now used for the entire channel from the Kulen, down the offtake, then passing west of the East Baray and down to the lake. The decapitation of the Puok is of significance for the late history of the network (See below Siem Reap Addition).

West Baray addition (Fig 8)

The West Baray is served by a second offtake from the Puok, the North Canal. At the present time the remnants of this canal commence at the Kror hills and run down to the north end of the north causeway of Angkor Thom. This, however, is not the early 11th century configuration. The southernmost half kilometer is a later addition aligned precisely on the N-S axis of Angkor Thom and the portion of the North canal north of the Puok may also be later addition.

The 11th century format required, at minimum, an offtake from the Puok and a series of canals to bring the water to the NE corner of the *baray* through a series of right angle turns. At that point water was either taken into the *baray* and/or could have been taken along a channel on the north side of the north bank of the *baray*. At the western end of the *baray* the channel and embankments are extremely complex and the path water might have taken is unclear. It is noticeable, however, that the SW corner channel grid projects to the west of the western bank of the *baray* suggesting that it could also take water from the north around the western end of the *baray*.

At the eastern end of the West Baray there is an outlet channel in the southern part of the east bank but it is not known whether this is the original outlet. Any water taken out through the east bank could have been taken around the SE corner and then westward along a canal just south of the *baray* to the SW corner canal grid. From

there the SW dispersor goes directly to the lake and the SE canal/road could distribute the water eastwards to the Damdek.

Angkor Wat addition (Fig 9)

The Angkor Wat addition may have had two stages. Coring by Christophe Pottier (pers.comm.) indicates that the dispersor canal from the SW corner of the Angkor Wat moat may predate feature CP 807. Water from the *baray* could have entered CP807 through the curved channel that cuts through the SE corner of the *baray* bank. CP807 would then have served both to hold water to take it to the enclosure east of Angkor Wat and then down the north side of the old embankment that runs down to the Indratataka. Excess water could have been diverted into the dispersor canal and taken to the lake near Phnom Krom.

Jayatataka addition (Fig 10)

When the Jayataraka *baray* was added in the late 12th C it was supplied with water by a canal offtake from the North Canal running eastwards through a series of right angle turns to an entry in the NE corner of the *baray*. There is no evidence of an outlet in the east bank of the *baray* those Ta Som could perhaps be near the location of one. It is also unclear where any water taken off the east or even the south side of the *baray* would have gone as it could only be returned to some part of the earlier Siem Reap canals north of the East Baray. There is no recognisable link to either a dispersor or a distributor canal. This raises the possibility that the Jayatataka was only a representation of a *baray* and was perhaps only functioning as a holding basin and evaporation surface to cope with excess water from the North Canal. If this was the case then the Jayatataka may have served to stabilise water flow down an extended North Canal because the portion north of the Puok river could be much later than the original southern part that served the West Baray from the 11th C. That the North Canal was modified in the late 12th C is indicated by the modification to its southernmost end to bring it into alignment with Angkor Thom. The Jayatataka addition may therefore have been a means to deliver more water to the West Baray from an extension north of the Puok river. The northern extension would have tapped streams coming off the Khor hills that flowed to the SW. This extension tapped a new source. The previous developments all used water flowing off the Kulen hills to the east.

Siem Reap addition (Fig 11)

The diversion of water eastwards in the Angkor Wat addition would only have been possible if the channel in which the Siem Reap river now runs was not present in the 12th C. The indications from a 14th C vegetation deposit below the Siem Reap canal at Kar Kranh and the late date for the Splean Thma (Fletcher *et al* 2033: 115-7) east of Angkor Thom are consistent with this channel being late. The implication is that the full diversion of the Siem Reap southwards through the barrier wall between Angkor Thom and the East Baray was the last major addition or alteration to the overall network. A key issue to pursue is whether the line of this canal south of Angkor Wat follows the line of an old dispersor canal of the late 10th C. This is problematic because the Kar Kranh section shows that the earliest channel in that location was

completely buried before the final, straight dispersor was built. It is significant, however, that coarse sand deposits occur below the final canal and also completely fill it suggesting that rapid water flow was occurring in the area south of Angkor Wat from at least the 14th century onwards and eventually overwhelmed the last great canal of Angkor. That the canal was built apparently to dispose of water rapidly, not conserve and distribute it may be indicative of the changes and stresses which the network was facing from the 14th to the end of the 16th century AD.

CONCLUSIONS

The extensive area survey of Angkor by the EFEO and by the Greater Angkor Project illustrates how a comprehensive and consistent data collection procedure can help to resolve a major interpretative issue. A water management network with three distinct interconnected operational zones for control, storage and distribution has been identified. The old debate about whether or not there was a functional water management network in Angkor that would have assisted flood control and irrigation is at an end, replaced, fortunately, by further developing issues about the role of system, its development and its relationship to the demise of Angkor.

The network can be parsimoniously understood as a multi-purpose risk mitigation system for dealing with the impact of the monsoon and for maintaining the supply of rice in poor monsoon seasons. Its magnitude relates to the use of sand as a means to control water – a remarkable feat of engineering. The proposition about its role in mitigating shortages of rice production leads to a debate about the role of irrigation in agrarian states and the complex relationship between material systems and social agency. The vast scale of the network is an intriguing corollary of its technology and of the lack of stability in the medieval Khmer state. How the network was managed and the degree to which the state ever participated directly in its day-to-day operation is a key issue and may itself be central to what eventually happened to the network. There are indications that the network had developed into an involved system. The late additions increasingly served to dispose of water rather than to hold and distribute it, suggesting that from the 12th century onwards Angkor was perhaps, having to cope with increased water flow from the northern catchment.

Acknowledgements

My thanks to the staff of APSARA, who are members of the GAP field teams. In the field we have had an invaluable collaboration with Heng Than, Khieu Chan, Tous Somaneath, Chai Ratchna, Ea Darith, Chai Visoth and Srun Tech - especial thanks for many long, hard days on research. I am also indebted to the APSARA staff who manage the administration for the project in Cambodia, for their participation, advice and help. Thanks also to the many University of Sydney members of the Greater Angkor Project and the international volunteers who work with the project each year. In Sydney special thanks to Martin King for his varied, hectic and vital assistance.

My particular thanks to Dan Penny, Mike Barbetti and Christophe Pottier of EFEO, and Ros Borath, the Director of the Department of Monuments and Archaeology, who are the current co-directors of the Greater Angkor Project; and to Damian Evans the

current deputy director. My appreciation and thanks also to Ang Choulean, the Head of the former Department of Research and Culture and his deputy Im Sokrithy for their work with the project.

For technical assistance and advice my thanks to JPL and Horizon Geosciences, AINSE, Concept Aviation, and the various agencies and departments of the University of Sydney, specifically the College of Science and Technology, and the College of Humanities and Social Sciences, the Faculty of Arts and the School of Philosophical and Historical Inquiry. The encouragement offered by the Cambodian government and the support of the Australian embassy is much appreciated. The Greater Angkor Project is supported by grants from the Australian Research Council and ANSTO/AINSE.

----- ■

References

- Acker R. 1998. New geographical tests of the hydraulic thesis at Angkor, *South East Asia Research* 6: 5-47.
- Bray F. 1986. *The Rice Economies. Technology and Development in Asian Societies*. Oxford: Basil Blackwell Ltd.
- Coe M.D. 2003. *Angkor and the Khmer Civilisation*. Thames and Hudson: London
- Dayton L. 2001. *The Lost City*. *New Scientist* 169 (No. 2273): 30-33.
- Delvert J. 1961. *Le Paysan Cambodgien*. Mouton: Paris.
- Egawa, Y. 1999. *Newly acquired topographical maps for the Angkor Archaeological Area and an interpretation of the ancient infrastructure*. *Renaissance Culturelle Cambodge* 16: 293-319.
- Engelhardt R.A. 1996. *New directions for archaeological research on the Angkor Plain: the use of remote sensing technology for research into ancient Khmer environmental engineering*. *Indo-Pacific Prehistory: The Chiang Mai Papers*. Vol 1. *Bulletin of the Indo-Pacific Prehistory Association* 14: 151-60.
- Evans D. 2002. *Pixels, Ponds and People: Urban Form at Angkor from Radar Imaging*. Unpublished BA (Hons) Thesis. Department of Archaeology: University of Sydney.
- Evans, D. and M. Kummu. 2003. *Modelling Cultural and Natural Hydrology Using Radar Imaging at Angkor*. ICGRHWE conference, Three Gorges Dam, China, September 16-19 2003.
- Fletcher R.J. and C. Pottier. 2002. The Gossamer City – a new enquiry, *Museum International* 54: 23-27.
- Fletcher R.J. *et al.* 2003 Redefining Angkor: Structure and environment in the largest, low density urban complex of the pre-industrial world, *UDAYA* 4: 107-21.
- Fletcher R.J. 2004. Materiality, space, time and outcome, in J.R. Bintliff (ed.), *The Blackwell Companion to Archaeology*: 110-40. Oxford: Blackwell.
- Fukui H. 1999. *Groslier's hydraulic society theory of Angkor in the eyes of an agroecologist*. *Southeast Asian Studies* 36(4): 546-54.
- Gaucher J. 2002. *The City of Angkor. What is it?* *Museum International* 54 (1): 28-36.
- Groslier B.P. 1974. *Agriculture and religion in the Angkorean empire*. *Etudes-rurales* 53-56, Jan-Dec.: 95-117.
- Groslier B.P. 1979. La cité hydraulique angkoriennne: exploitation ou surexploration du sol?, *Bulletin de l'École Française d'Extrême Orient* 66: 161-206.
- Helmerts K. 1997. *Rice in the Cambodian Economy: Past and Present*. In Nesbitt H.J. (ed.). *Rice Production in Cambodia*. Manila: International Rice Research Institute.
- Higham C. 2001. *The Civilization of Angkor*. London: Weidenfeld and Nicholson.
- Jacques C. and M. Freeman. 1997. *Angkor. Cities and Temples*. Thames and Hudson: London.

- Kummu, M. 2003. *The Historical Water Management of Angkor, Cambodia*. World Archaeological Congress 2003. Washington DC, June 2003.
- Lustig, E. 2001. *Water and the Transformation of Power at Angkor, 10th to 13th Centuries A.D.* Unpublished BA (Hons) Thesis, Department of Archaeology: University of Sydney.
- Nakamura H. 2000. *Baray as a storage for buffer water in the Angkor period*. *Journal of Sophia Asian Studies* 18: 91-97.
- Nesbitt H.J. (ed.). *Rice Production in Cambodia*. Manilla: International Rice Research Institute.
- Pottier C. 1999. *Carte Archéologique de la Région d'Angkor. Zone Sud*. Ph.D thesis, 3 vols. Université Paris III – Sorbonne Nouvelle (UFR Orient et Monde Arabe).
- Pottier C. 2000. Some evidence of an inter-relationship between hydraulic features and rice field patterns at Angkor during ancient times, *Journal of Sophia Asian Studies* 18: 99-119.
- Pottier C. 2003. « About Yaçovarman's Buddhist açrama in Angkor », *The Buddhist Monastery: A cross-cultural survey*, Pichard P. & Lagirarde F. (éd.), EFEO, Paris, pp. 199-208.
- Sahai S. 1970. *Les Institutions Politiques et L'Organisation Administrative de Cambodge Ancien (VI-XIIIth Siecles)*. PEFEO LXXV.
- Stott P. 1992. *Angkor: shifting the hydraulic paradigm*. In J. Rigg (ed). *The Gift of Water* pp: 47-58. School of Oriental and African Studies: London.
- Tapley I., T. Milne, R. Fletcher and D. Evans. 2003. *An AIRSAR Analysis of Angkor, Cambodia. Paper presented at the 30th International Symposium on Remote Sensing of Environment*, Honolulu, Hawaii, November 10-14 2003.
- van Liere W.J. 1980. Traditional water management in the lower Mekong basin, *World Archaeology* 11: 265-80.
- van Liere, WJ 1989, Mon-Khmer approaches to the environment. In *Culture and environment in Thailand: a symposium of the Siam Society*, (ed. Siam Society), Siam Society, Bangkok. pp. 143-60.
- Wittfogel K. 1981 edition. *Oriental Despotism*. New York: Random House.

HOLD

The urban complex was apparently supported by extensification of rice production through the clearance of forest, while the water management system could have delivered water for a risk minimisation strategy that would have guaranteed the supply of rice in poor monsoon years (Fletcher et al 2003: 116) .

The system was on such a large scale that it must surely have been ordered into being by the rulers of Angkor. But its components could then have been run at the local level with the state exploiting the system as an asset through civil and temple taxation (see Sahai 1970 for taxation).

Analyses of rice production in Cambodia emphasize that returns from rice production are poor (Bray 1986; Helmers 1997; Nesbitt 1997 e.g. p. 177), particularly in the Angkor region. If more rice is needed as population increases then the only way to obtain it is to clear more forest for rice fields. The selective factor that was affecting the rate and scale of the expansion of Angkor was the extensification of rice production. This has implications for the demise of Angkor because its expansion into

its hinterland to acquire more land for rice eventually led to the occupation of the lower slopes of the hill ranges north of Angkor.