DID TRADITIONAL CULTURES LIVE IN HARMONY WITH NATURE? LESSONS FROM ANGKOR, CAMBODIA

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Archaeology, ethnology and related fields have comprehensively debunked the myth that so-called 'traditional' societies lived in harmony with the natural environment. However, it is often assumed that pre-industrial societies impacted on the environment in a way that was less invasive, or of a smaller scale, than modern developed or developing societies. Recent archaeological and geomorphological research at the medieval Khmer capital of Angkor reveals that the impact of this low-density pre-industrial city on the natural environment was profound.

1 Introduction

Angkor in Cambodia, previously seen as a collection of great temples and separate town enclosures, has now been shown to be a vast low-density pre-industrial urban complex. The city of Angkor covered over 1,000 km^2 (Figure 1), and may have been the most extensive city of its kind in the world (Fletcher *et al.*, 2002, Fletcher *et al.*, 2003; Evans, 2002; Pottier, 1999). Now a World Heritage site, Angkor contains hundreds of temple structures including the renowned 12th century Angkor Wat. The impact of this pre-industrial city on the natural environment is both immediately obvious and of great significance for the past and the future. The impact is most clearly demonstrated in the massive, convoluted and delicately balanced system of canals, reservoirs and embankments that were used to regulate and distribute surface waters. In their efforts to control water flow, the Angkorian 'engineers' diverted water from existing river systems, sometimes resulting in entirely new catchments. The adverse environmental consequences of these profound modifications to the natural environment may have played a decisive role in destabilising Angkor, leading to its eventual collapse.

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 ISBN 978-951-22-9102-1
Kummu, M., Keskinen, M. & Varis, O. (eds.): Modern Myths of the Mekong, pp. 81-94

The Greater Angkor Project, a joint research project coordinated by the University of Sydney with the École Française d'Extrême Orient and APSARA, the Cambodian Government's heritage authority for Angkor, is investigating the history of the development and decline of Angkor. This work encompasses a multi-disciplinary investigation of the pattern of growth and decay of the infrastructure, including its road and water network. The implications of the creation and modification of the Siem Reap 'River', which passes through Central Angkor, is one of the foci of this investigation.

This paper considers some of the adverse environmental implications that may have arisen from the creation and modification of the Siem Reap River. In doing so, it seeks to illustrate the extent to which so-called 'traditional' societies can impact upon the natural environment.

The notion of harmony between 'traditional' societies, however that may be defined, and the natural environment, has a strong tradition in Western thought. While in some cases, extant 'traditional' perspectives on or approaches to environmental management may be more effective than many 'modern' alternatives, the notion that these societies had no or little impact on the environment, and that large-scale environmental modification is only associated with the industrial world has been thoroughly falsified by research in archaeology, anthropology, ethnography and related fields. This paper considers a specific case of the impact of pre-industrial urbanism.

2 The Siem Reap River

The Siem Reap River, and Central Angkor itself, lie on an alluvial fan fed by the Puok River, which originally flowed southwest from the Kulen Hills to Lake Tonle Sap (Figure 1). Today, the Siem Reap River has captured virtually all the flow of the Puok River, diverting it southwards through Central Angkor, with the channel upstream of the point of capture now considered as part of the Siem Reap River as well. Groslier (1979, p.164) has postulated that this wholesale diversion of the river

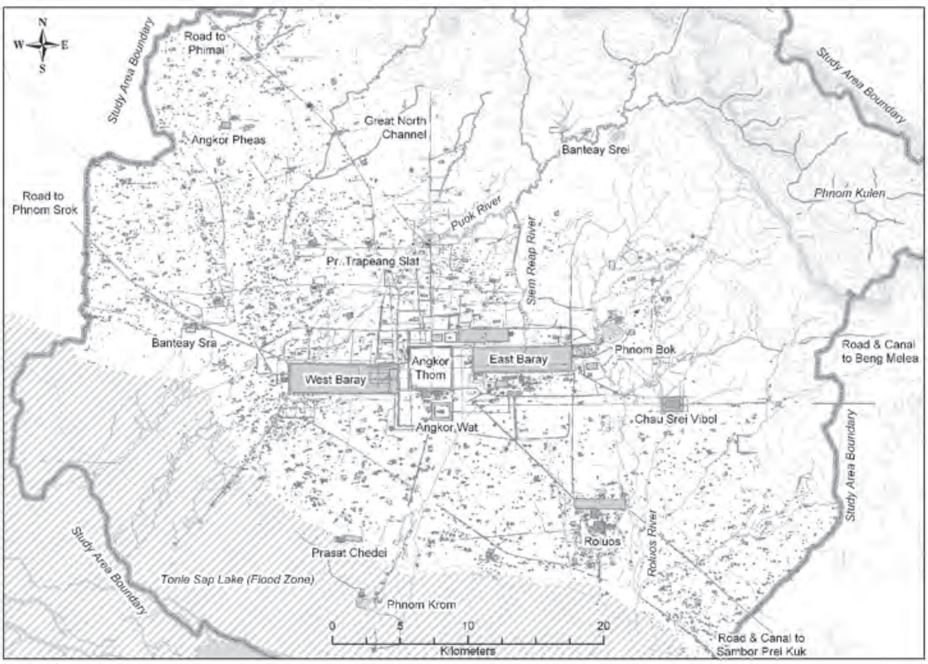

Figure 1 Water network of Central Angkor (Pottier, 1999; Evans, 2007).

was deliberate, but as shall be discussed below, the initial diversion may have been only partial.

There is little doubt that the Siem Reap River was "dug by the hand of man", as Groslier (1979, p.164) has pointed out. Parts of this watercourse are still straight today, unlike the other natural rivers running down this same alluvial fan. Furthermore, where the Siem Reap River leaves the Puok River, it passes out of the Puok's floodplain and through higher ground. A natural watercourse on an alluvial fan does not normally do this.

From the Puok River, the Siem Reap River runs southwards to the north side of the north bank of the Yasodharatataka, or East Baray, where it turns right to run westward along straight channels between the East Baray and the Jayatataka, a smaller baray to the north. Then it turns to flow due south, after passing either through or around the end of a demolished wall and embankment. On its course, it passes many temples, including Angkor Wat, before turning to the south-southwest to run through Siem Reap town. It then breaks up into a number of distributary channels which eventually reach the Tonle Sap Lake.

The investigations of the role of the Siem Reap River have revealed indications of what appear to have been adverse environmental impacts during the history of Angkor.

3 Adverse environmental impacts

3.1 Impact 1 – Cutting down of the Siem Reap channel

Where the Siem Reap takes water from the Puok, it has cut down into the alluvium by about 6-8 m. However, the natural behaviour of rivers on alluvial fans is to accrete rather than erode. It is suggested that since natural channels on this alluvial fan meander, the main reason for this down-cutting is that the Siem Reap was constructed in sections of straight channel. Water travelling along meandering pathways loses energy more quickly than when going straight. With a straight channel, the water will tend to run faster and erode its bed. This will cause it either to cut down to make its slope shallower, or erode its banks to widen its channel. One or both of these processes could reduce the velocity to such a level that material carried down from upstream will deposit in the bed and banks of the channel. Ultimately, the rate of erosion of the bed and banks will be balanced by the rate of deposition of material brought down from upstream. This process follows what is known as the Principle of Minimum Stream Power, whereby a stream will adjust itself so that its rate of energy loss approaches a minimum (Song & Yang, 1980). In this case, the channel has cut down rather than widened.

The environmental consequences of this down-cutting may have been severe. A number of channels which appear to have diverted water from the Siem Reap (Figure 2) could no longer have functioned as the channel lowered its level. It is interesting to note that a recent study of sediments accumulated in the West Mebon temple within the West Baray reservoir indicate that flow from the canal network decreased in the late 13th century (Penny, Pottier *et al.*, 2007). It is possible that this may be related to a change in the level of the Siem Reap River relative to its distributor canals as the river incised.

3.1.1 Modelling the sedimentation and erosion processes

To check this hypothesis, the sedimentation and erosion processes in the Siem Reap channel have been modelled, using a model developed by Tuomo Karvonen, Water Resources Laboratory of Helsinki University of Technology. This model solves the Saint Venant equations numerically using the MacCormack Method (MacCormack, 1969). Inputs for the model are the cross-sections and longitudinal profile of the channel, the upper boundary inflow, the lower boundary, the bottom slope, and other parameters such as sediment load through the upper boundary.

Levels (heights) of the Siem Reap River bed were recorded with the help of a Trimble Geoexplorer CE GPS System and a Leica Total Station Positioning System (TPS) 1100. Using this information, the

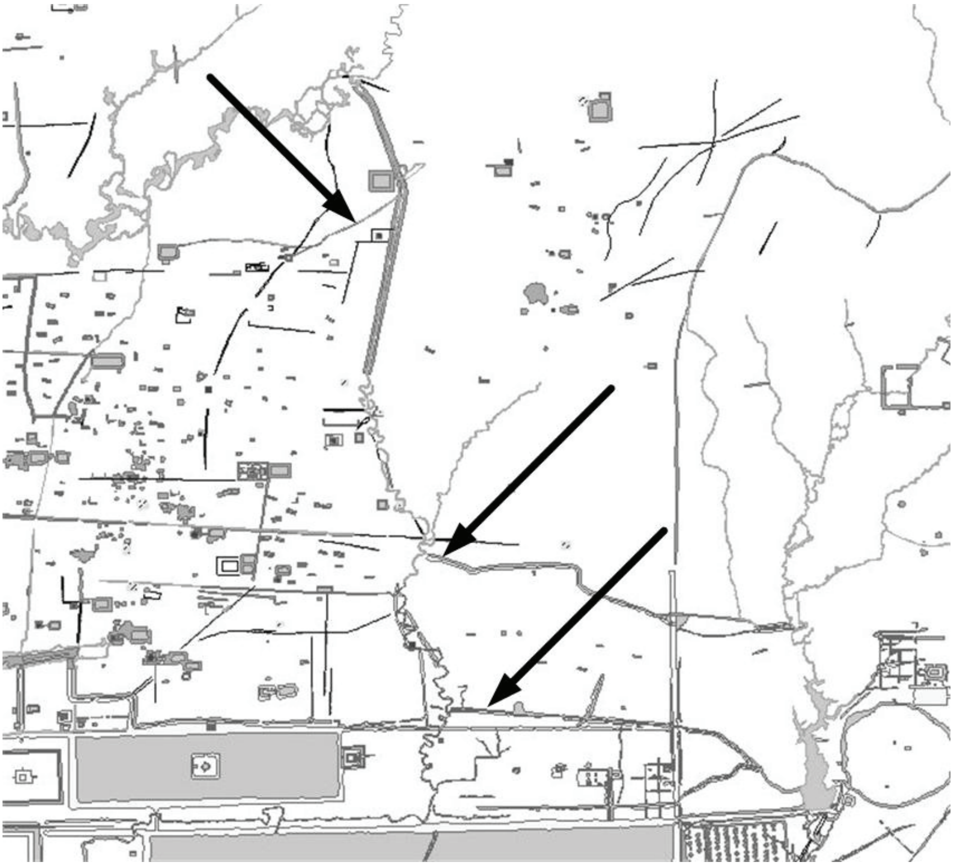

Figure 2 Possible off-takes from the original Siem Reap (Pottier, 1999, p.101, n.294; Evans, 2007).

model assumes that the channel of the Siem Reap has had its greatest erosion just downstream from its junction with the Puok River, some 8 m below the original level. About 15 km downstream from this junction, channel has eroded about 4 m below the original level, while there is no little or no erosion at Siem Reap township, 25-30 km downstream from the junction. The results of the modelling correspond to these measured values quite well (Figure 3).

Figure 3 suggests that the artificial channel has eroded along its upper part and accreted in its lower part downstream of Siem Reap town, so that its stream power is similar to that of other watercourses on the alluvial fan. If the stream power has now dropped to that of the other watercourses, it would follow that most of the down-cutting has ceased.

3.1.2 Bam Penh Reach

The Siem Reap channel seems to have been originally constructed to take water from the Puok near the village of Bam Penh Reach, about 15 km north of central Angkor. Upstream of this off-take, the channel passes along a floodplain incised into the alluvial plain (Figure 4). The floodplain appears much as floodplains of other rivers in the area, and indeed the floodplain itself continues down to the Tonle Sap lake in a south-westerly direction, whereas the Siem Reap River itself turns through several 90° bends before passing into the left bank of the floodplain. From there, its incised channel runs southwards to the East Baray.

It would seem that this series of 90° bends results followed a deliberate design. It can be observed that the sections of channel between each bend

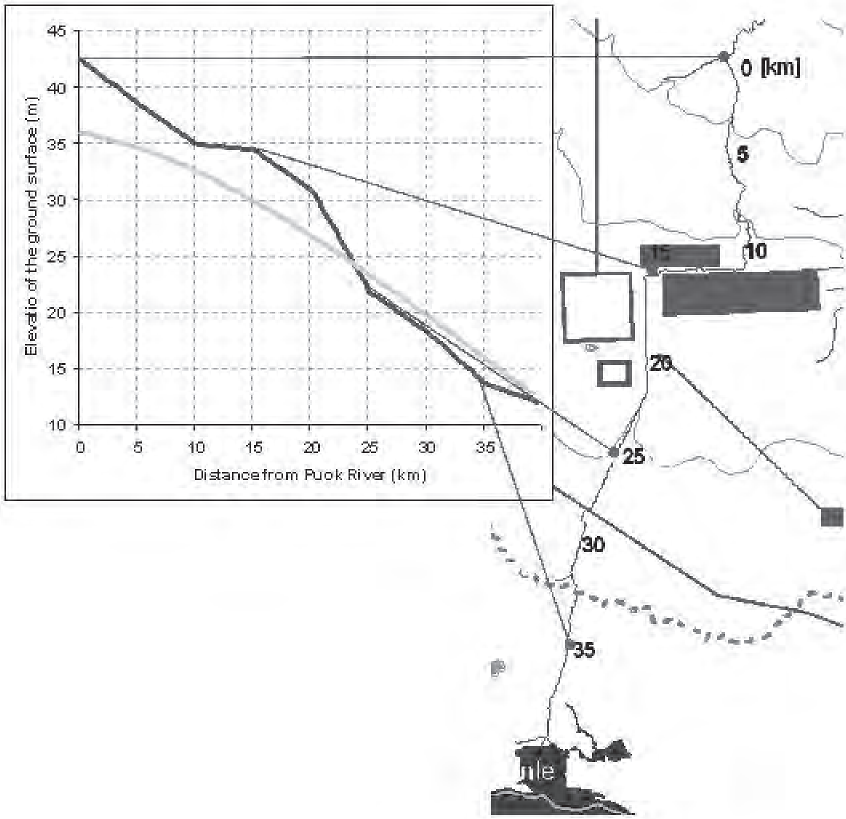

Figure 3 The result of mathematical modelling of the down-cutting of the Siem reap Channel. The dotted line is the original long section inferred for the bottom of the channel, while the solid one is the bottom of the channel after it stabilises. (Map adapted from Figure 1)

appear straight, and parts of it seem to have been lined with laterite blocks. Furthermore, it might be noted that there is a similar – and wholly artificial - hydraulic arrangement where the Siem Reap River turns to run southwards between the East Baray and Angkor Thom, again branching off a westward-flowing watercourse.

When the Bam Penh Reach area began to be investigated in 1999 to try to understand the reasons for the down-cutting, the investigators were soon directed to some in-situ laterite blocks that had been uncovered by a Khmer Rouge working party in the mid-1970s. The Greater Angkor Project investigations since then have indicated that these blocks appear to be part of a large platform sloping down westwards at between 5° and 10°, at the base of a large natural or artificial watercourse.

Topographic and sub-surface survey, excavation and coring indicate that the platform could be at least 48 m wide and is about 85 m long (Figure 5). The eastern end of the structure has the form of an offtake from what may have been a laterite-lined channel, presumably the forerunner of the Siem Reap River of today, now some 20m to the east. Further investigations are needed to determine if there is any association between the platform and the outcropping blocks of laterite marked to the southeast on Figure 5.

The western edge of this platform has the form of a spillway about 1½ m high (Figure 6), and was apparently designed to pass large volumes of water, consistent with what may have been all or part of the Puok River in flood. If the off-take to the Siem Reap River was built at the same time as this platform, this may mean that water was flowing in three directions: to the west along its original channel, along an offtake from the Puok at the start of the Siem Reap channel, and over the spillway, again to the west, to skim off excess flow in the Siem Reap channel in times of peak floods. To confirm this however, needs further study.

An interesting feature of the spillway is that its laterite blocks are assembled with vertical and horizontal keys, seemingly designed to resist the forces of water flowing westwards (Figure 7). This mode of keying is a common feature of the temples of Yasovarman I (Boisselier, 1966, p. 112), which supports Groslier's (1979, p. 173) contention that the Siem Reap's off-take from the Puok was to provide water for the East Baray, built by Yasovarman or Rajendravarman (Groslier, 1958, p.110, n.2; Groslier, 1979, p.176; Pottier, 1999, p.101, n.294). This suggests that the Siem Reap channel and the water structure at Bam Penh Reach were constructed around the 10th century. We note here that the discovery of this spillway structure provides a negation of Van Liere's (1980, p. 274) assertion that the Khmer had limited hydraulic technology and did not know how to build permanent structures in monsoon rivers.

3.2 Impact 2 – Blocking the Bam Penh Reach structure

There are several additional indications that the construction at the junction of the Puok and Siem Reap Rivers was not designed originally to divert all of the flow from the Puok. The stratigraphy above the laterite spillway at Bam Penh Reach, which includes many disturbed laterite blocks and rubble, indicate that part of the platform was destroyed and the channel in which it sat was completely and deliberately filled in, blocking the

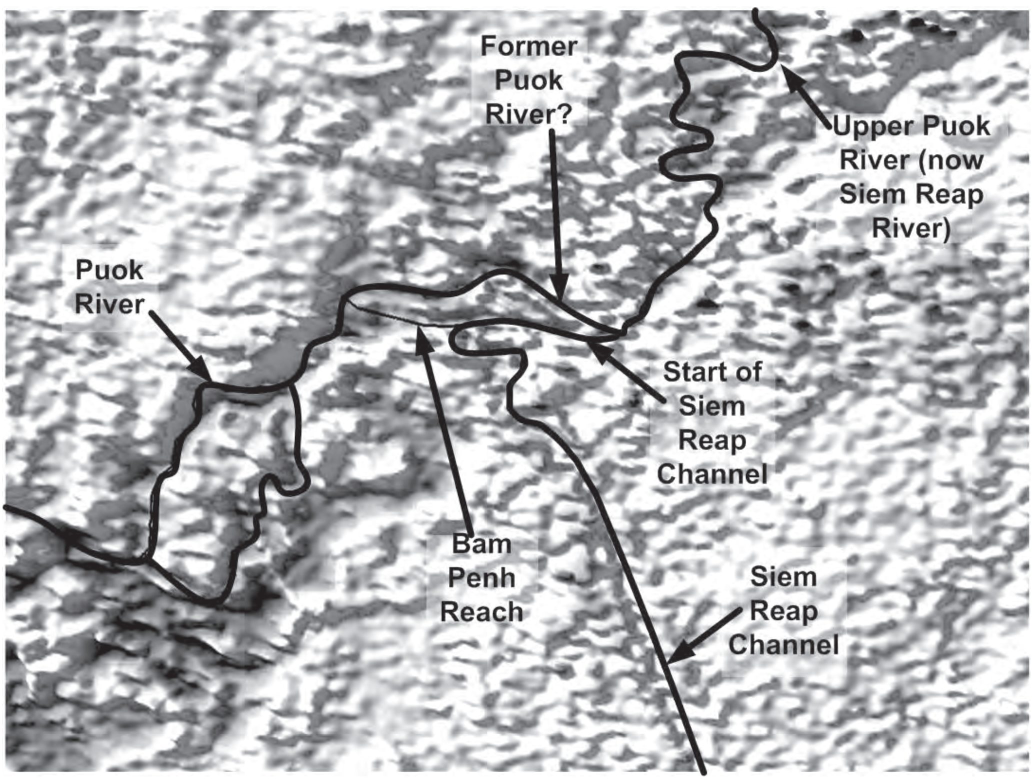

Figure 4 Siem Reap channel where it leaves the floodplain of the Puok River. Digital elevation model derived from AIRSAR-TOPSAR radar interferometry dataset acquired over Tonle Sap Basin, Cambodia during PacRim AIRSAR mission, September 2000. (Fletcher, Evans *et al.*, 2002)

westward flow of water. It appears that at the least this filling may have caused the dry-season flow of the Puok to divert to the Siem Reap. If it did so then the change would have impinged upon the communities of the downstream section of the Puok River who relied on having a perennial flow for their subsistence.

3.3 Impact 3 – Breaking out from the Siem Reap channel

A third reason to think that the original diversion by the Siem Reap channel from the Puok River was only partial can be seen from those sections of the Siem Reap's original channel which did not cut down and are still visible today. These sections adjoin the current watercourse where it later broke away from its original confines before cutting down into the alluvium. These break-outs may have resulted from the volume of flow being too great for the capacity of the channel caused either by the channel silting up or the volume of flow increasing. Indeed, it is possible that both happened; that is, the channel eroded at its upstream end and the eroded material deposited further downstream.

It is likely that the channel would have been originally designed to carry the flow that was diverted in the first phase, that is, when the Bam Penh Reach spillway was first built. It may even have coped with the additional flow resulting from filling in the spillway channel. However, once enough of the Puok was directed southwards along the Siem Reap during the peak of the rainy season to start the erosion, this in turn could have increased the proportion being diverted to such an extent that it destroyed much of the Siem Reap channel as a sustainable piece of infrastructure.

We do not yet know what purpose a full diversion rather than a partial diversion might have addressed. Further modelling is now desirable to explore, among other things, whether the initial partial flow would have been sufficient for the Indratataka and the East Baray, and whether extra flow could have been needed for the West Baray.

3.4 Impact 4 – Toeuk Thla Baray

Downstream of Bam Penh Reach, the Siem Reap skirts a water tank about 300 m square, known as Toeuk Thla Baray (Figure 8). This water tank is very deeply excavated into the regional alluvium and, given its base appears to be always below the water table, it is presumed to have always held water. Its bottom is about 10 m below the crest

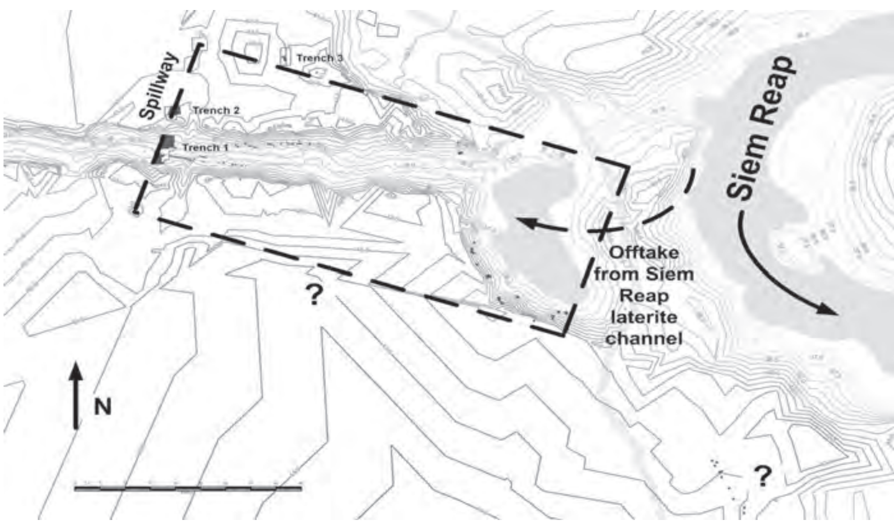

Figure 5 Possible extent of platform near presumed junction of the Siem Reap Channel and the Puok River. Outcropping laterite blocks shown in black.

Figure 6 Spillway and Bam Penh Reach channel. Excavation nearby indicates base of spillway is about 1½ m below the crest.

Figure 7 Vertical and horizontal keys in spillway construction.

of the surrounding embankment, a depth rarely encountered for Angkorian reservoirs. The only known structure with such a high side wall is the West Baray but this is built entirely above ground.

Such a large excavation would have involved considerable effort for a local community. The reason for such a large expenditure of effort is unclear, as the area is remote from central Angkor, and there is only one small temple in the immediate vicinity, suggesting there was no major centre of habitation or other item of strategic or economic importance nearby during the Angkorian period. The implication is that there are at least two phases of excavation in Toeuk Thla Baray, the first when the water tank was excavated initially and the water table was much closer to the surface. The second could have been when the Siem Reap

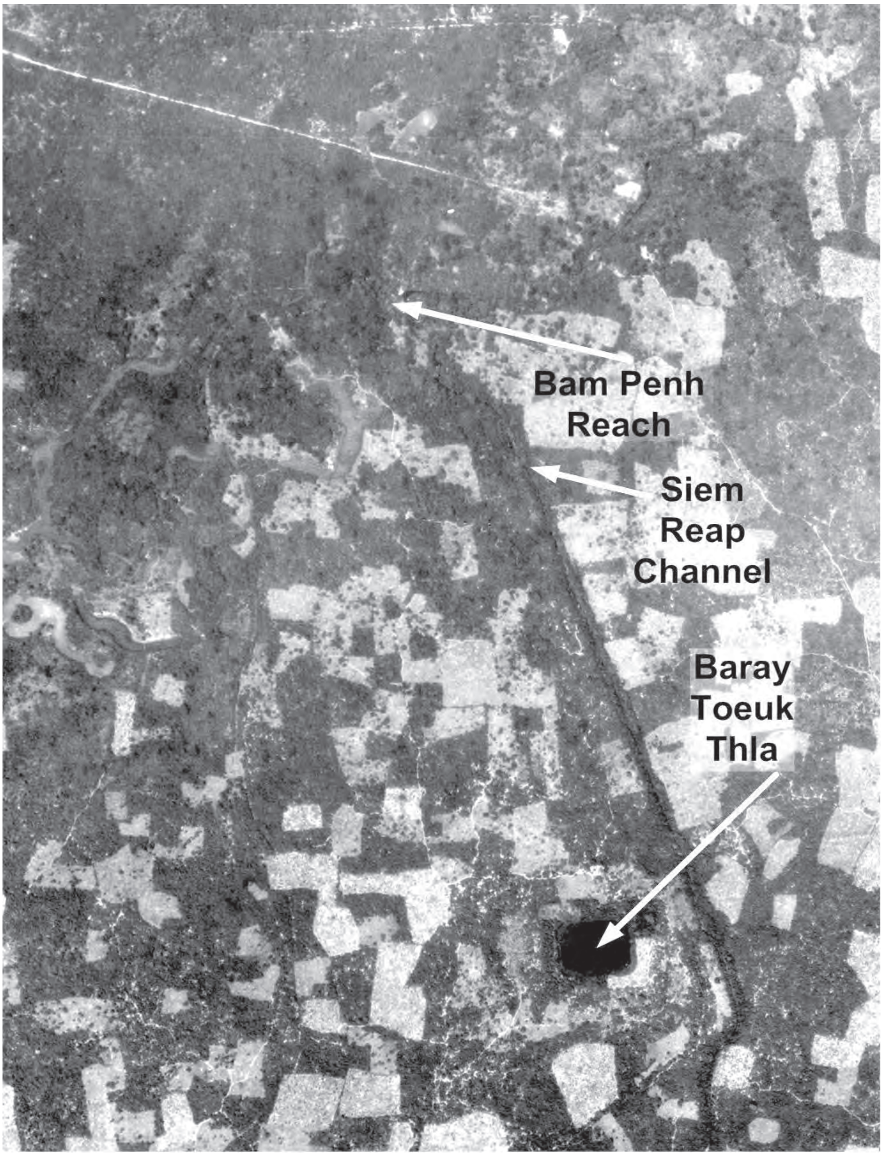

Figure 8 Location of Toeuk Thla baray.

channel began to cut down, immediately to the east. This would have depressed the groundwater level nearby, effectively reducing water levels within the water tank, and local people may have regularly removed more soil from the base of the tank whenever it started to dry out (Figure 9).

Drill cores of sediment extracted from the baray indicate that water levels fell markedly at some point in its history (Figure 10). The stratigraphy of the cores reveals a period of soil development within the reservoir, indicating that it was partially or entirely dry for a sustained period of time. A charcoal fragment found below this ancient soil has been radiocarbon dated to the mid- to late 14th century, suggesting that the final drying phase – which we hypothesise was related to the end of the down-cutting of the Siem Reap, and hence the final work of removing soil from the base of the tank - began at this time.

3.5 Impact 5 – Spean Thmar Bridge

Where the Siem Reap River flows due south between Angkor Thom and the East Baray, it passes the Spean Thmar bridge (Figure 11), which is on the alignment of the road leading eastwards from the Victory Gate of Angkor Thom across the Siem Reap channel. This bridge has been constructed with sandstone blocks which appear to have come from disused Bayon style religious structures, suggesting that it was built during or after the 13th century. However, today the river does not pass under the bridge. Instead, it now cuts into the left bank and skirts the bridge on its eastern side, as well as cutting down by about 3 m.

Some preliminary investigations of the area just upstream of the bridge where the old channel is visible indicate that the Spean Thmar spanned a small artificial channel running due south. Again, neither this artificial channel nor the openings in the Spean Thmar Bridge itself would have been large enough to cope with the full flow of the Siem Reap during the peak of the rainy season. This suggests that initially only part of the flow of the Siem Reap (or some other source of water) was directed along here. It is not clear along which channel the rest of the flow of the Siem Reap was directed.

If most of the flow of the Puok was directed down the Siem Reap channel, some time later, it would not have been able to get through the openings in the Spean Thmar Bridge quickly enough, and it

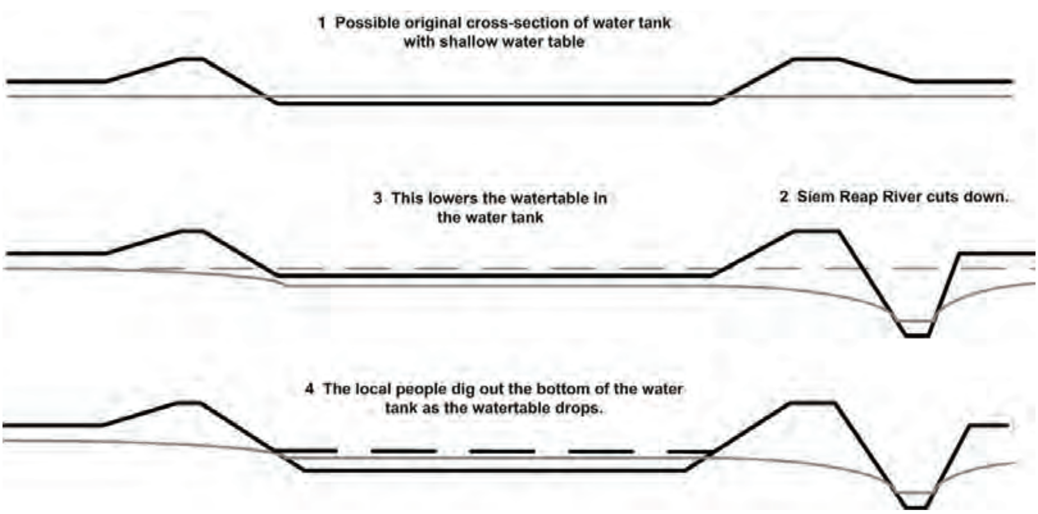

Figure 9 Possible sequence of progressive digging out of Toeuk Thla baray.

would have banked up against the bridge. Either the water would have then overtopped the bridge and gouged into the bank, or the Angkorians would have constructed the eastern diversion around the bridge before sending the full flow of the Siem Reap down this channel. The channel appears to have then cut down further until it stabilised at a new level below the bed of the original channel. This new level would have been where the stream power of the now increased flow would have been at a minimum. If this was connected with the behaviour of the Siem Reap channel near Baray Toeuk Thla, this minimum stream power could have been attained at around the mid- to late 14^{th} century.

4 Discussion

The evidence collected so far indicates that there was an original, partial diversion of water from the Puok River into the Siem Reap channel in the 10^{th} century which could have been sustainable in the sense that the diversion may not have led to water flows large enough to initiate downcutting. It may be that the next stage of blocking the Bam Penh Reach spillway and diverting more dry-season flow down the Siem Reap still did not overload the channel. However, it would presumably have had an adverse impact on the communities of the lower Puok River. At some time after the 13^{th} century, flow may have been directed south between Angkor Thom and the East Baray, at the time when the Spean Thmar bridge was constructed.

As the Siem Reap diverted more and more water away from the Puok, ultimately, the flow running through the Spean Thmar Bridge was greater than its capacity, and the river diverted or was diverted around it (Figure 12).

If these latter effects were a consequence of the same final diversion of the river out of the Puok River floodplain, they must have happened some time after the building of the Spean Thmar bridge, that is, from the 13^{th} century onwards, and some time before the down-cutting stopped in the second half of the 14^{th} century. The open question is whether the increased flow that ultimately by-passed the bridge was a result of a planned increase in the water flow down the Siem Reap, or was a result of an inescapable cumulative increase in water flow as the Siem Reap progressively captured more of the flow of the Puok.

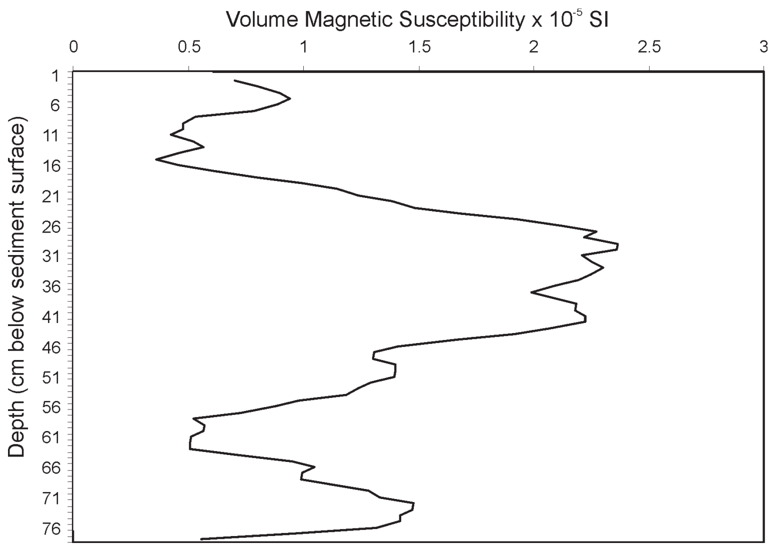

Figure 10 Rise in magnetic susceptibility of soil at base of Baray Toeuk Thla indicating development of strong pedal structure of soil and hence a possible drying out between about 20mm and 40mm.

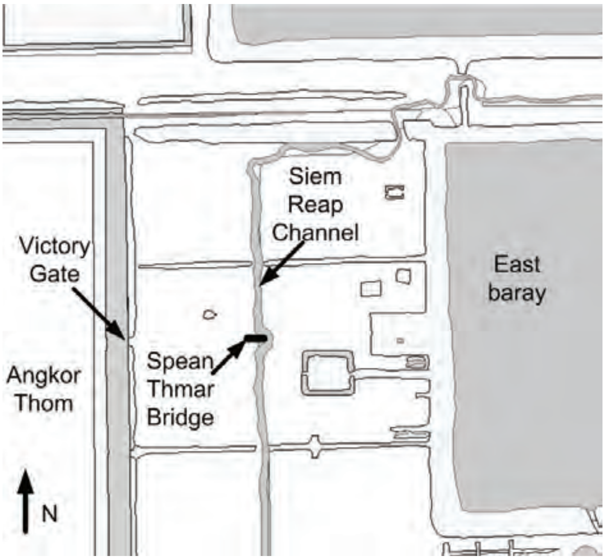

Figure 11 Siem Reap channel skirting around Spean Thmar Bridge (adapted from Pottier (1999) and Evans (2007).

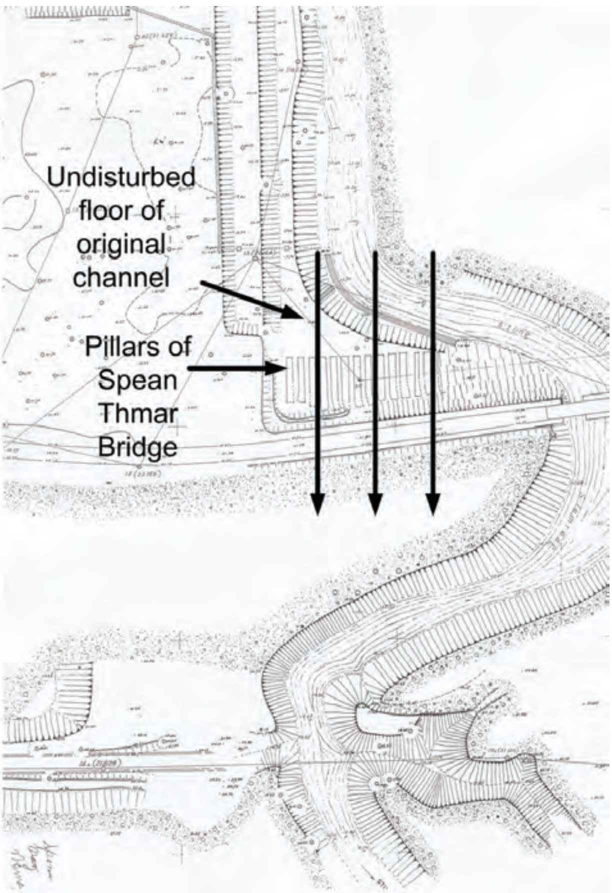

Figure 12 Water flowed between the pillars of the bridge. Undisturbed floor of original channel is just upstream of skirt of bridge. (Pottier, 1993, Pl.49)

5 Conclusions

As a pre-industrial settlement, Angkor is unique in terms of its scale and impact on the natural environment. Recent mapping of the extent of urban environment at Angkor has revealed that its water management infrastructure covered an area in excess of 1,000 km^2. In order to 'feed' this enormous and convoluted water management system, the Puok River was truncated and its seasonal flow captured, probably only partially in the first instance, but ultimately creating an entirely new catchment. Massive engineering structures such as that discovered recently at Bam Penh Reach were required to control this system.

The subsequent capture of the majority of Puok River flow by the newly created Siem Reap channel - intentional or not – led to dramatic incision in the upper to middle reaches of what became the Siem Reap River. This would have had a significant effect in central and southern Angkor, as higher discharge and larger sediment loads moved through the system, and on communities of the downstream Puok River, whose access to seasonal flow in the Puok River would have been greatly reduced. Clearly, Angkor represents an excellent illustration of the profound impact that a pre-industrial, agrarian, 'traditional' society can have upon the natural environment. The extent to which these environmental impacts brought about conditions inimical to viable social life at Angkor, as first proposed by Groslier, remains to be demonstrated in detail.

Acknowledgements

This research is part of the Greater Angkor Project, a collaborative research project by the University of Sydney, Ecole Française d'Extrême-Orient and APSARA, *the Cambodian government body responsible for the management of the Angkor World Heritage site. Funding was provided by the Australian Research Council (Discovery Projects Grant # 0558130). This work has received funding from the Academy of Finland Project 211010.*

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