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Some Evidence of an Inter-relationship between Hydraulic Features and Rice Field Patterns at Angkor during Ancient Times

Christophe POTTIER*

This presentation today will tackle some questions relating to the ponds, reservoirs and hydraulic features located in the Angkor region and their possible relation to land use and territory planning during the ancient Khmer period. The subject is too wide to detail here and numerous interrogations should anyway be left unsolved for a lack of reliable data. I will only raise some significant points that could provide not definitive answers, but only elements of answers and possible orientations for further research and investigations.

I would also like to specify as a preamble that the following observations are based on my own research into Angkorean territorial planning, especially on the study and intensive exploration of the south area of Angkor -between the two main barays and down to the Tonle Sap lake. This was realised from 1993 to 1999 as part of an EFEO program and has been submitted as a Ph. D. thesis at the Sorbonne University in Paris. Its main subject did not focus on the *Cité Hydraulique* problem, but this debate being obviously closely related with territorial management in Angkor, I could not just give this problem a miss, especially in relation to the large barays. It brought me to deal with matters related to B. P. Groslier's thesis of the *Cité Hydraulique*, and to re-evaluate existing and contradictory opinions on this thesis.

Therefore today, I will present some elements related to this re-appraisal of the Hydraulic City debate, first by pointing out some doubtful arguments raised against the hydraulic thesis, then by producing an overview of some new or previously unpublished data. This data could

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modify appreciably our understanding of the ancient hydraulic features. Among them are some elements which provide evidence of an inter-relation between hydraulic features and rice field patterns at Angkor during ancient times, suggesting that they were parts of the same general system.

The hydraulic debate: a dialogue of the deaf?

The hydraulic thesis elaborated by B. P. Groslier and carried on by J. Dumarçay, originated from the observation and interpretation of various remains of several hydraulic features, especially the barays in -and outside- Angkor. The available remains rarely allow a clear study of all the characteristic elements altogether. Consequently, the hydraulic model is only a kind of restitution made by crosschecking various data collected in numerous partially preserved sites. Except for the barays dykes which are usually the easiest identifiable characteristic -even if their configuration largely vary- other hydraulic components are much less obvious. For instance, any aqueducts are supposed to have vanished (Dumarçay 1994, 371) and the erosion of the dykes filled the periphery canals, making their identification and analysis problematic. In short, a real lack of precise data still remains on the barays and their associated features and configurations. A first impression suggests that the scarcity of evident physical remains unables us to confirm any hydraulic function for the barays. This complete absence of physical evidence has created an easy and convenient argument to contest the reality of any hydraulic function and the hydraulic concept as a whole.

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A recent essay by O. de Bernon (1997) tried “from the outside” to demonstrate how and why the *Cité Hydraulique* debate is deadlocked. This paper also indirectly illustrated, partially to its cost, the artificial aspect of the debate, which I consider is being biased by the large gap existing between theoretical implications and a dearth of tangible evidence on which any thesis could be based. In a simplified manner, supporters of the utilitarian baray thesis are called on to present all technical details in a way compatible with the modern occidental hydraulic science; while on the other, advocates of the symbolic function should at least “justify the gigantism” of such features differently from just putting forward a claim for any Gods pleasure. Moreover, this “dialogue of the deaf” becomes more complex, as the first supporters are automatically considered as out-of-date disciples of Wittfogel. The theocratic theory of Wittfogel exerted of course its influence on B. P. Groslier’s hydraulic thesis, especially on its conclusions about the political system supposedly needed to run such a huge hydraulic complex (1974, 111-112). But it may be quite unfair to confine B. P. Groslier’s thesis to a simple application of the Wittfogel theory. The patient elaboration process of the hydraulic thesis (from the 1950’s to 1979) was grounded in B. P. Groslier’s long experience of Khmer studies and various research in different fields. Of course, nobody can assume that just because B. P. Groslier stayed at Angkor for a long time, that is enough to guarantee the validity of his thesis. Everybody here can remember the famous example to the contrary and the real revolution caused in Khmer studies by P. Stern in the 1920s, an Art historian who had never left his Parisian office desk. But we should note that the Hydraulic City debate started on the basis of some non-spe-

cific and general publications produced by B. P. Groslier (1966; 1967; 1974; 1979). As this author did not publish more precise studies on the subject, we have to content ourselves with these texts, even if they only reflect one limited part of the data on which the interpretation was based. Therefore, some important points - for example, the detailed configuration of the barays- have never been completely defined and accurately developed, making it easy to contest the conclusions of B. P. Groslier. My recent investigations convinced me of the necessity for a re-appraisal of some challenged points, not to assume the whole of the B. P. Groslier thesis, but simply to precise and clarify some part of the debate and then, maybe, avoid too much time and effort being wasted in futile dispute.

Not a drop of water...

We should of course spend at least some minutes on the arguments of W.-J. van Liere, the first writer who reacted against the B. P. Groslier hypothesis. W.-J. van Liere wrote a paper in 1980 and gave a lecture to the Thai Historical Society in 1981, published the following year as a paper with close similarities with the first one. Ironically, B. P. Groslier's 1979 article about the Hydraulic City is not mentioned in the bibliography of these two papers, so we are not even sure that W.-J. van Liere ever read it. Nevertheless, it can be supposed that B. P. Groslier's 1974 paper has been read as it's included in the 1980 paper. Any careful reading of the W.-J. van Liere's papers should make a distinction between the short and abrupt assessments left unjustified and the other more developed reflexions. In the first group are found some remarks on

outlets, canals and the barays (written indiscriminately barai (1982 p. 45) or baray (p. 38) but systematically and only called "temple ponds"!). Other arguments insist on what should have been "the agriculture of the Khmer's" (p. 39) based on receding-flood agriculture and bunded fields.

W.-J. van Liere's paper is quite affirmative in general, especially on technical matters relating to Angkorean hydraulic features. It should be noted that his assertions have been generously cited in the most recent papers pertaining to the Hydraulic City debate (R. Acker see below, E. Moore, and very recently again by H. Fujiki).

No physical evidence

The most obvious affirmation of W.-J. van Liere is the complete absence of any outlet or intake structure, of any distribution system or canal:

"Nowhere are temple-ponds or city moats equipped with distribution systems to water surrounding rice fields. (...) The present author does not know a single case where a temple pond was equipped with a distribution system to water the fields, although he has examined all the major ponds from aerial photographs and many of them on the ground. (...) The present author has never seen a permanent off-take structure to regulate the outflow from a Khmer dam..." (van Liere 1980, 274; similar sentences in 1982, 45-46) Some remarks must be made about this affirmation often reused by later writers. First, even if the W.-J. van Liere affirmation was true, and it is not (see below), that should not mean that such kind structure did not

exist. On a logical point of view, the presence of something can be seen as proof, but the absence of something is not proof in itself that such a thing did not exist. For instance, no evidence of any ancient common houses has ever been found in Angkor, but it's quite difficult to imagine that common people were living without any habitat. Epigraphic interpretation is also a subject where one has to deal with the discovered texts, but without concluding definitive assessment from any absence of texts. More recently, the discovery of kiln sites at Angkor (near Sra Srang) showed that it may have been a mistake to previously think that pottery activity was located only outside Angkor. We should also note that one only knows what has been discovered, and more precisely, only what has been the subject of research. For instance, it would have been quite dangerous to make conclusions on the absence of a temple in some area considered as *empty* in the previous inventories made in the early part of the 20th century. Since then, many archaeological sites and temples have been discovered (Banteay Srei for instance, was discovered by chance in 1914), simply because no investigation or accurate methodologies have been employed in this area. I'm afraid that it could be the same case for the hydraulic structures, and except for some pedestrian ground surface investigations conducted by G. Trouvé in the 1930s, no research has been conducted on this particular subject on the ground and no excavation has ever taken place.

On the other hand, we should note that W.-J. van Lier's affirmation is false: some hydraulic structures existed. Of course, these different elements have been found at various sites and, on my knowledge, there is not a single site yet where all these kinds of structures have all been

noticed together. It may be still difficult to generalise from these detailed elements; nevertheless, hydraulic features existed during Angkorean time. "Nowhere are temple-ponds or city moats equipped with distribution systems to water surrounding rice fields" only strongly suggests that W.-J. van Lier never went to Beng Mealea (a temple similar to Angkor Vat east of Angkor and south of the Kulen hill). There, the walkways crossing the moat are real bridges, with arches allowing water to flow from one moat quarter to another; and from the bottom quarter, a canalisation well constructed in laterite was buried under the main road, clearly in order to take the water from the moat to the rice fields below (photo. 1)¹⁾. This may be one of the most obvious examples of that kind of outlet, but there are various other ones in Angkor²⁾ (Angkor Thom especially in the south-west corner, east baray³⁾, Veal Rach Dach⁴⁾) and elsewhere outside Angkor⁵⁾.

Similar conclusions can be reached about the so-called "absence" of distribution canals: various research conducted since the 1930's showed that such structures did in fact exist, even if they were not very numerous. W.-J. van Lier seems to have ignored B. P. Groslier's 1979 paper and the G. Trouvé's 1937 map, and he may not have seen the canals indicated on them. Some corrections should be made to these maps, but most of these canals clearly exist and are still visible on the ground.

A scientific "a priorism"

Another aspect of W.-J. van Lier's affirmation is also doubtful and should be accepted with

great caution. This author considers that “the Khmers just did not have the technology to build (hydraulic works necessary for a) sophisticated state-controlled irrigation system” (1980, 274; 1982, 38-37). Here, one should note that W.-J. van Lieré conceptualised *necessary hydraulic works* in respect of modern hydraulic knowledge and “engineering science”. This kind of uncontrolled comparison and analysis brings in directly some value judgements which are inappropriate for any understanding of the subject. The same kind of “a priorism” judgement has often been made about Khmer architecture, concluding that the Khmers were *good* architects but *bad* builders: the result of these bad builders is finally not so *bad*? Angkor Vat is still standing after 800 years! This approach simply ignores the criteria on which any analysis should be made: 20th century scientific knowledge or 10th century Khmer values? Moreover, the inaccuracy of this W.-J. van Lieré’s assessment is obvious as he contradicts himself: after explaining *why* the Khmers were not able to build sizeable dams, he proceeds to offer some examples of such a Khmer dam large enough to change the course of a river (1980, 271 & 274; 1982, 38-39 & 41-43). And anybody who has seen the Praptos Bridge (Spean Praptos) or the Spean Ta Ong can only conclude that, even if the Khmers had limited knowledge, they had enough of it to build very impressive and massive structures.

Anyway, one can easily notice the contradiction between a sentence like: “hydraulic works were severely restricted by the limited technology of the Khmer” (van Lieré 1980, 274) and reality. Simply remembering the huge size of the West baray, it appears that the ancient Khmers were not really *restricted*. In fact, one could paraphrase this author, considering that

“modern hydraulic science severely *restricted* the understanding of Khmer hydraulic works”.

The alternative W.-J. van Lieré

Stating that “not a drop of water from these temple ponds was used for agriculture” (1982, 38), W.-J. van Lieré demonstration does not avoid gratuitous assertion⁶⁾ but develops an interesting tentative outline of Angkorean agriculture, insisting on the role of the receding-flood, bunded fields and small size ponds. As many writers have already pointed out, since the late 19th century, the location of Angkor near the Tonle Sap is very significant, both for the richness and ease with which to cultivate flooded lands and for its proximity to this huge reservoir of protein. It is also well known that some earlier settlements in this area were located on the edge of this annually inundated area, something not under-estimated by B. P. Groslier as he excavated some of these early settlements (1979, 162-167 & 191). The only problematic point is that, at the present time, nothing yet proves that the “*tnubs*”, the U shaped reservoirs visible south-east of Siemreap, are ancient enough to be Angkorean⁷⁾. It’s clear that they are older than the 20th century as they appear on the first maps. However their typology does not fit at all with the usual Khmer earthworks, suggesting a late influence⁸⁾. The bunded fields, accurately described by W.-J. van Lieré in his 1989 paper, are effectively characteristic of Khmer rice field patterns and are easily visible in the Angkor region as in any other Angkorean areas. On that point, W.-J. van Lieré confirms with B. P. Groslier’s opinion (1986), both estimating that the evolution from *agro-cities* to the *ceremonial cities* of the Angkorean period is based

on a migration of cultivable lands, from low and naturally flooded areas to higher alluvial terraces previously covered by forest. This evolution implied a new agricultural pattern about which W.-J. van Lier notes: « curiously enough, the reclamation of the forests and the layout of the bunded rice fields was not executed in a haphazard way, but in an orderly, very dogmatic pattern. Individual fields were small and square, and grouped into large square units, which, where possible, became still large blocks. This is the 'square block system' of land use » (1989, 149-151) which suggests at least a "cooperative effort at the village level" (1980, 271). Nevertheless, the strict orientation of these numerous square blocks is not at all a *curiosity*; in fact, my recent work in the Angkor area showed that most of these rice fields blocks follow a firm geometry; each of them being based on the orientation of a small temple considered as a "village shrine" or, as epigraphic evidence suggests, the shrine of the village chief (Pottier 1999, 64-65). Here is a key point where we have the evidence of a strong link between agriculture and religion, a deep inter-relation between functionalism and symbolism. It becomes obviously fruitless then to try to separate the approach favouring "the service of Gods" from the approach favouring "the service of man" (van Lier 1980, 279). The last point developed by W.-J. van Lier moves in the same direction: the author analyses the agricultural potential of the numerous small ponds spread in any Angkorean area. These ponds, called *trapeang*, are effectively still used for crops and vegetables often cultivated on their edges, but their use for rice cultivation appears to be more limited (Pottier 1999, 125-133). The only point unseen by W.-J. van Lier is that most of these trapeangs are also strictly associated with small temples,

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usually placed on their main access. This close association is also corroborated by epigraphic evidence. Indeed, many trapeangs are typical "temple ponds", a denomination used by W.-J. van Lier himself. Here again, it is clear that religious structures had close relations with functional designs and that we just cannot separate them arbitrarily as W.-J. van Lier has tried to do, forgetting incidentally some precautions taken by B. P. Groslier who always claimed that any functionalist analysis could only give one partial aspect of the more complex world of the Khmers' (1974, 111-112; 1979, 195).

Economic and spatial analysis

The scope of my present dissertation does not allow me to examine all the other interesting contributions published to contest the Hydraulic City concept. We will only examine one example here, a recent paper by R. Aker (1998). This writer refutes the B. P. Groslier's thesis through two "geographic tests": the first by attempting to evaluate the significance of the Hydraulic City in terms of the percentage of "Angkor's population which would have been fed by the institution of hydraulic agriculture". The second, by considering the consistency of the hydraulic thesis through the spatial and chronological repartition of the various barays. Ironically, R. Aker underlines the necessity to test the B. P. Groslier's thesis "particularly (because) there are no observable physical survivors from Angkor's supposed irrigation works, aside from the barays themselves" (1998, 16), quoting the W.-J. van Lier assessments without testing or checking them once. Nevertheless, this paradox does not really affect the value of the method-

ology used by R. Acker, at least for his first test.

The productive impact of the Hydraulic City

The first test presents numerous detailed calculations in order to “determine the difference that hydraulic irrigation would have made to Angkor’s subsistence” (R. Acker 1998, 17). As it is not within the scope of this paper to recall and quote all the steps of his demonstration, the reader should refer directly to his calculations for precise and valuable data. In summary, R. Acker’s calculations do not differ significantly from B. P. Groslier’s ones (1979, 190-191) except on one important point: the surface of the hydraulic zone. B. P. Groslier estimates the surface at 116,000ha, 75% of it (86,000ha) being used for agriculture (1979, 190). R. Acker demonstrates that this zone is only around 33,000ha (or 25,500ha for rice production; 1998, 19 & 40-42). A quick look at the B. P. Groslier’s map number 7 could have given faster but similar result⁹⁾: the B. P. Groslier textual estimation is clearly too high, compared with its own graphics. As R. Acker’s surface estimate appears more accurate, so we will keep it¹⁰⁾.

The final result of these calculations is the percentage of the total population of the Angkor region, which could have been fed by the surplus generated by hydraulic agriculture. The result of R. Acker’s calculation is clear: low percentages (9.3%, 12.6% during a dry year) suggesting a poorly effective hypothetical hydraulic system and consequently raising doubts about the hydraulic thesis. Meanwhile, this calculation also raises some comments. First, a preliminary remark is required about the necessity to keep in mind the relatively low reliability of the size

of the population of the Angkor region. Based on the total surface supposed to have been cultivated (including “les cités hydrauliques” -the hydraulic zone-, “la banlieue hydraulique” -rain fed rice zone-, and “l’arrière-pays” -dry rice culture zone-), B. P. Groslier roughly¹¹⁾ estimated a total *maximum* population of 1,900,000 in order to compare it with contemporary human densities in the richest areas of Cambodia (1979, 190-191). R. Acker revised and reduced the figure to 1,588,000 (1998, 21-22) using the same ratios, but extracted his final percentage and his test conclusion directly from this doubtful and fragile figure. Nevertheless, the main issue of such a general and hypothetical calculation relates to *what is finally compared?* R. Acker chooses to compare the theoretical hydraulic surplus with the Angkor region as a whole, more than 4,000sqkm (a surface corresponding approximately to an area of around 63km by 63km). Considering that Khmer settlements are spread continuously up to the Thailand border on the one side, and down to Kompong Thom on the other, one should ask why the comparison conducted by R. Acker *only* takes 4,000sqkm into account?¹²⁾ But even if we follow R. Acker’s choice to *limit* the comparison to only 4,000sqkm, it means that the hydraulic system established below the barays is compared with a much broader area, out of scale and where the “hydraulic zone” represents only 8% of the surface. In this respect, heavy calculations are not really needed, as it is obvious that any potential of the hydraulic system is lost and diluted, and finally under-estimated and denied. In addition, R. Acker’s comparison finally amounts to assuming that the ancient Khmers decided to install or not the hydraulic system in accordance with these 4,000sqkm. Or, in other terms, the hydraulic system would have been decided

when all the 4,000spkm were already occupied and in use... which is definitely impossible for evident spatial and chronological reasons.

I am convinced that we should come back to some more reasonable estimation, to Angkor itself, and precisely to the very area concerned by the hydraulic works. Then, an evaluation of the potentiality of the hydraulic system should be, if not more accurate, then at least more representative. This calculation can give us a direct and honest idea of the real surplus and potential created by the system where it was supposed to have been applied. In order to calculate this new percentage, we will follow all R. Acker's standards¹³⁹. The new result is quite interesting: regular rain-fed agriculture could have provided rice for *only* 140,000 people compared to 288,000 people with the hydraulic system! There, the percentage is about 205%. In other terms, the hydraulic system allows an "extra" population of 148,000 people, doubling the production rate on any land where it is applied. One can only be surprised that R. Acker didn't underline this obviously very positive result in favour of the hydraulic thesis, and just indicated it briefly hidden in a neutral foot note (1998, 21 n. 19).

Incidentally, as we are dealing with theoretical calculations, it would also be interesting to evaluate even approximately what kind of work these 148,000 additional people could do. For instance, and just to illustrate their potentialities, they could build such a thing like the West baray in 3 months¹⁴⁰... Meaning that the cost of human labour could be very easily paid off in a short period of time. And as new barays were not built every 3 months, every year it freed a lot of hands for other specialised activities, such as war or building. Finally, I tend to consider

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that the hydraulic thesis endures quite well the first test of R. Acker, even if I remain doubtful about the reach of such theoretical calculations without further detailed data.

The spatial and chronological logic of the Hydraulic City

The second test focuses on "the placement" of the barays in order to evaluate if they are, or not, capable of providing their maximum theoretical benefits in terms of irrigation. This subject is deeply related with a key and general problem about our understanding of the history of territorial planning and the evolution of land use during the Angkorean period. And it would be particularly detrimental to consider it only in terms of hydraulic profitability as it obviously also involves other parameters, even if much of them are still unknown. In his 1979 paper, B. P. Groslier tried to provide an explanation of the sometimes confusing spatial chronology of Angkor, based mainly if not only, on an environmental approach, close to the *determinist* geographic school¹⁵¹. Naturally, this reductive approach alone cannot then provide a comprehensive view of the complexity of the Angkorean settlement history.

Nevertheless, R. Acker's conclusions from the second test are: 1/ "there was no hydraulic master plan into which each of the barays had to fit" 2/ "the difficulties incurred in attempting to explain the spatial relations of the different barays to each other and to the surroundings of Angkor vanish once the hydraulic thesis is discarded" (1998, 28).

The first conclusion does not seem highly relevant as -to my knowledge- nobody really thought that a "master plan" ever existed for Angkor, a site occupied at least during 6 cen-

turies. On the contrary, Angkor has often been considered like a palimpsest.

The second conclusion considers that the “accumulating anomalies” observed in the placement of the barays is a “mark (of a) thesis on wrong tracks”, and it is better to abandon it. Of course, this opinion could be seen as a facilitating procedure, avoiding any difficulties by discarding not only the central problem - the hydraulic thesis- but also indirectly other related ones. For instance, denying any hydraulic function to the barays does not help us at all to explain the irregular placements of the barays themselves. In fact, it makes the problem even more difficult if the barays become only some symbolic and temple-related features: most of them are precisely not related with any temple by common geometric association ¹⁶⁾. Similarly, if we should follow the solution recommended by R. Acker each time we encounter difficulties or anomalies in Khmer studies, many research fields would be abandoned.

Moreover, R. Acker’s conclusions are sometimes biased by the general point of view adopted and by the ignorance of the possible role of some hydraulic features associated with some barays. Unfortunately, time is too short today to offer a precise description of the different barays in their environmental-hydraulic-religious context. And I’ll just indicate here that, sharing some remarks of R. Acker on some apparent “anomalies” and some other potential function for the barays (especially flood protection) does not seem enough to discarded the hydraulic thesis as a whole. With this level of knowledge, it would be premature to “throw the baby out with the bath water” without further investigations. In particular, other alternatives, if they solve the theocratic problem by simply ignoring it, have not yet provided a beginning

to explain the history of land use and territorial planning in Angkor.

Evidence of ancient hydraulic features and land use: the West Baray

We could still spend a lot of time on the theoretical debate, but as I mentioned at the beginning of this dissertation, we should also save some efforts to go out into the field and deepen our knowledge of the various hydraulic remains. This will tangibly widen our scope of understanding. I am personally convinced that field research in Angkor so far, has not already provided everything we need in order to draw concrete conclusions. We have a duty to wait. My recent work has concentrated on building a new and more accurate “tool” to develop my studies on ancient territorial planning in the Angkor region. This tool of investigation consists of a new archaeological map of the Angkor region on the scale of 10,000, and based on the cross-checking of three different methodologies: an analysis of previous documentation, intensive remote sensing identification and a full-scale ground checking and exploration survey. In this respect, since 1993, I have tried to collect direct data on any physical remains of archaeological features. This includes of course temples and barays, but not only them. “Civilian” features have also been inventoried: ponds, mounds, terraces, dykes, canals, roadways, ancient parcels, boundary stones, bridges... every available feature relating to ancient land use and the environment. This data was then synthetised to produce this new archaeological map, providing a stronger base for spatial analysis works (Pottier 1999). With its high percentage of previously

unidentified sites (62%), this map offers an accurate tool with which to study ancient land use development.

Among the various results that I am presenting today, some elements provide evidence of an inter-relation between hydraulic features and land use during ancient times. One of the most obvious cases is related to the West baray so I'll focus on it and present new data, which could help to re-appraise its role in the agricultural development of its area.

The experiments of the 1930s

A large amount of documentation has been collected by the Ecole Française d'Extrême-Orient during its long presence in Angkor since 1908, some published mainly in its bulletin (BEFEO), others remaining unpublished as the -usually monthly- "Rapports de la Conservation d'Angkor" (RCA) or the daily "journal" of the various curators. Since 1992, both documents are available for scientific research respectively in computer and microfiche format. Among other treasures, one can find in these archives some papers relating to two experiments conducted in 1934 and 1935 by G. Trouvé and the *Service Hydraulique de l'Indochine* to empty the West baray (RCA Marchal, 03-04/34, Trouvé, 02-06/35; Marchal, 07/35). These experiments are very instructive and demonstrate the possibility to draw, to control and to use the large quantities of water contained in this baray. Testing the irrigation hypothesis was only one of the two main purposes of the studies made in 1934 and 1935. The other reason was to temporarily empty the baray -surely the most important in G. Trouvé's view- and to explore the

archaeological remains located at the bottom. However, G. Trouvé partially failed (and died at the end of the experiment) because the study was stopped before the baray was completely drained. Nevertheless, the *Service Hydraulique de l'Indochine* succeeded in demonstrating the baray's potential for irrigation. And from these very experiments originated the projects undertaken in the late 1930s and 1950s to refill the West baray and to use it for the purpose of irrigation that one sees today.

A basic outlet

G. Trouvé's trials demonstrated without doubt that heavily built outlet structures were not an absolutely necessary condition to draw water from the barays, and that simpler solutions could have been practiced, including a breach in the dyke. This solution has been proposed by B. P. Groslier (1979, 168) but raised strong oppositions from W.-J. van Liere and other hydraulic engineers who qualified this solution as "technically impossible". However, empiricism being the best teacher, the engineers would have to revise their view, as the technic successfully used by G. Trouvé was particularly simple. More precisely, a breach had been dug in the south dyke, near the south-west corner of the baray; then, a pipe was installed with a sluice at its entrance, supposed to control the draining process. In fact, gulying and erosion were simply controlled by adding planks and branches. For closing, the pipe and the breach had just to be filled up. Even if the ancient Khmers did not invent any concrete pipe, their technical knowledge was largely sufficient to build one with laterite equipped with a wooden sluice.

This is not a theoretical guess as I encountered this type of canalisation for example, passing through the northern dyke of the baray at Lolei (Pottier 1999, 100-102).

Such a *heretical* solution for any modern engineer has some evident advantages: it's simple and it works. One should note however that it weakens the dyke. Incidentally, that is what happened in 1935, when the refilled breach broke during the following rainy season. Nevertheless, it was easily repaired, the earth was compacted more carefully and this incident did not re-occur. Incidentally, the erosion of the dyke also revealed some strong wooden structures originally built in the core of the dyke, probably to reinforce its stability and to guide its construction.

This simple solution is also interesting because we can then consider not only one outlet but also various other ones in other part of the dyke. Some support can be found in favour of this hypothesis in G. Trouvé's map and remote sensing analysis: the dyke shows various traces that could have been a result of breaches.

The impact of the irrigation experiment

It is more difficult to consider the impact that these experiments had on the irrigation of the fields situated below the baray. Nevertheless, the 1935 study was significant enough for the *Service Hydraulique de l'Indochine* to justify the refilling of the baray a few years later (Goloubew 1941, 6). On that particular aspect of the irrigation study, archaeological reports are not very precise, and not enough data is available to determine the exact extent of the

flood. But some information is worth while and worth examining.

The first experiment started 31st of March 1934, with the water level at 20.85m, and the sluice has been open between 10 and 15cm in hight. The final level to reach was estimated at 19.98m (50cm lower than the lowest water level in the dry season) and supposed to be reached after 25 days. Water was simply ejected through the breach in the fields below the baray. However, this operation was halted only 22 days later, because of the increasing number of complaints by villagers whose field preparations were threatened by the flooding. At that time, the level in the baray was only 23cm lower, the water level decreasing by only 1cm per day.

The second attempt came much closer in succeeding: started earlier in the year than the previous experiment, on 14th of February 1935, it lasted until July when it too had to be stopped. After a month of early and heavy rain, the water level in the baray stopped to decrease significantly and neighbouring rice fields were already well inundated. Once again, the farmers had begun to complain. Regretfully, H. Marchal (who replaced G. Trouvé after his death on 18th of July) did not mention the final level reached. However, the 1935 experiment opened the baray for at least 150 days, suggesting with 1cm a day rate of drainage, a final decrease of only 1.5m or 6 Million cubic meters of water¹⁷. We cannot conclude anything based on these general estimates, and the real impact of the irrigation remains uncalculated, the main problem being to determine the surface covered by the flooding of the baray. Interestingly, one detail in the reports shows that a second harvest was reaped in 1934 (H. Marchal indicated in April disturbance to farmers "menacés dans la préparation de leurs cultures »). Additionally, we should

note that the real problem is not to learn more about the way water is drained from the baray, but about how was it provided and distributed to the land below. It is for this very reason why the first experiment in 1934 had to be interrupted so early, nothing having been planned south of the baray and the water was blocked by the present day RN6 road. This problem was obviously taken into consideration the following year, probably with the realisation of a canal crossing the RN6 in the axis of the breach.

The south-west angle of the baray

One should note that the canal network created by the French hydraulic engineers in the 1940s to distribute the water demonstrated that such a canal did not in fact exist previously. However, an ancient network existed but its remains have not been renovated. Remote sensing from stereoscopic aerial photos and ground exploration has shown the existence of a sophisticated network which can be divided into three components: one special configuration of the baray's dyke at its south-west corner, one perpendicular canal network and two long channelling canals.

The perpendicular canal network

The most visible feature is certainly the perpendicular canal network located south and around the south-west corner of the baray (fig. 1). Inventoried under code number CP483, this feature is highly visible by remote sensing and can still be seen on the ground. It is composed

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of a regular pattern of five vertical canals (V1 to V5 from West to East, 1600m long) and 3 horizontal canals (H1 to H3 from South to North, 2700m long). These canals, each 40m wide, create a rectangular shape isoclinal with the baray's orientation. The outside line of this feature has been identified in previous research as the remains of an old square moated pre-Angkorean capital called "Bantay Chhoeu" by B. P. Groslier (1979, 167 & map 2 & 3). Indeed, my recent research demonstrated the impossibility of such a hypothesis and the necessity to propose a later date for the canal pattern (Pottier 1999, 119-121 & 141-148).

The dyke configuration at the south-west angle of the baray

One of the arguments presented here is the existence of a precise and close relation between this canal pattern and a specific configuration of the baray's dyke. We noticed that the dyke's shape is regular on all its length, except at the south-west angle, where its configuration is very specific (fig. 1). There, the dyke presents a regular succession of "breaks" or "recesses" corresponding to seven rectangular mounds 180 by 70m regularly spaced out 180m apart from each other along the dyke. Five are located on the south side of the south dyke, one at the corner and the last on the West Side of the western dyke (T7 to T1).

There, one can observe that T7 matches exactly V5, and T2 corresponds with V2. The distance between V2 and V5 is effectively 2,000 m, corresponding exactly with the length of the six mounds and five spaces between them. T2 to T7 being very regularly located between V2 and V5, indicates that this succession of mounds was closely linked with the canal network

CP483. In fact, both canals and mounds are clearly some elements from the same project: the realisation of the West baray.

Two long canals

Two long canals, around 40m in width and still visible from the air and on the ground, complete the hydraulic network of the baray angle (fig. 1). The first one (CP570) starts at the angle of H1/V1 and leads directly to the lake, following the faster slope for 8km, towards the direction of Vat Méchrey CP697. The second one (CP504) originated from the angle H1/V4 stays perpendicular to the slope and close with the contour line, goes south-east for at least 27km, crossing the present day stung Siemreap¹⁸⁾ and continuing down to the south part of Hariharælaya. Both canals starting from the CP483 feature are obviously parts of the same project even if their functions seems to be quite different (see below).

If we now consider these features from a functional point of view, the initial evidence suggests that they are closely dependent upon the baray itself and the topography. It is then logical to argue that these features represent a hydraulic extension of the baray, and finally that these features formed part of one general hydraulic system established in 11th century of which the baray is most visible part.

Considering the experiences of the 1930s, we can observe and reconstitute the organisation of these remains in the case of water released from the baray. At first, one should note that the breach created in 1934 was particularly located at one "recess" of the dyke, a logical choice

which could probably have been the one made by the ancient Khmers. In this case, regular mounds indicate quite precisely where water was usually released. This could also confirm that various outlets could have been used jointly, as we mentioned before, as a solution to reduce the erosion of the dyke without interfering with the quantity of water released. The CP483 canals network then controlled this water. But this network was already and foremost a distribution device that could have been also used as a protective buffer area. This network could have been able to receive and collect other sources of water, especially through the external extensions of H2 or V1. Water contained in CP483 was shared between close areas below it or further downstream through two main directions: to the south-west using the canal CP570 leading to the lake, and to the south-east with CP504 canal. Various elements suggest to me that the first canal's purpose was as a conjunction of water circulation, security and protection in the case of flooding, irrigation and eventually drainage. CP504 appears much more devoted to irrigation: perpendicular to the natural slope, it flows down slowly and, incidentally, stops running water from the north. This canal was also able to provide water for a limited number of secondary canals flowing down to the south-west¹⁹⁾. One can remark the analogy of this system with the one realised since the 1940s and the renovation of the West baray by modern engineers²⁰⁾...

From the baray to the rice fields

We traced the watercourse from the baray to the canals; but a final question remains: is there

any relation between these canals and rice production during the ancient period? Here again, the West baray area contains elements to strongly suggest a positive answer. My recent studies also focused on the analysis of ancient parcel patterns, their development and their chronological inter-relations (Pottier 1999, 63-71 & 112-115). One of the results showed that old parcel patterns were strictly geometrised and clearly generated by some important elements as temples, pounds, canals or roads. This is so often the case that we can use morphological analysis in order to determine not only their typology but also some chronological relative relations between non-isoclinal patterns. In short, morphological analysis using remote sensing allows us to determine the surface of the fields “generated” and associated by a geometric and organized object (temple, canal...).

Applying this methodology to the area south of the West baray, the parcel patterns appear chaotic at first, especially when compared with the area of the eastern baray. But behind this first impression, two distinct areas can be noticed: just south of the baray is an orthogonal pattern isoclinal with CP483, and then, below it and down to the inundated area, is a distorted and complex “mosaic” of bunded fields including irregularly oriented “square blocks”. I will not touch on the first group today because, in spite of their more regular shape, their more complex chronology is not directly relevant to irrigation. Focusing on the area south of CP483, one can observe that the “mosaic” indicates that bunded fields covered all that area (fig. 2). But two different types of pattern have been employed: the one generated by the shrine is oriented relatively exactly to the East; the second shows a pattern more adapted to the topogra-

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phy. In fact, the distinction becomes more difficult in the southern part: a majority of pattern orientations follows a slow but sensible fan-shaped distortion from the H1 of CP483, and between the two canals CP570 (215°) and CP504 (120°). *Horizontal* lines of the pattern are linear and straight near CP483 (except some probably pre-Angkorean remains like Anluong Ok CP480). Going south, these lines evolute and become curves. Their orientations vary from 55° at the east (corresponding with the orientation CP709 secondary canal) to 90° near Kôk Prasat CP476, or even to 103° on the west (environs of Kôk Ta Khéng 756) where the parcels are sometimes perpendicular to the CP570 canal. There, it becomes more difficult to distinguish between the elements that generated the fields’ morphology, if it is a shrine or the general fan-shaped pattern. Luckily, the archaeological and architectural remains of the shrines suggest that most of them²¹ are related to the 11th century, the baray construction period, and could be contemporary to the fan-shaped pattern.

Each side of this area, *outside* the fan created by CP483 and the two canals CP570 and CP504, the parcel orientations change radically, except some limited and narrow zones near the canals. It is then clear that these very fan-shaped generated rice fields are closely related and generated by the canals associated to the west baray. In other terms, we have here an “arborescence” running from the baray to its dyke, to a collecting and controlling canal network, to distribution and derivation canals and finally to the bunded fields.

Conclusion

At this stage of the research, I am afraid that “a conclusion” is not really an appropriate term. Indeed, what I underlined above is the profound lack of precise data still missing in order to provide a truly valid understanding of ancient territorial planning in Angkor. Focusing on a single, small part of the hydraulic aspect, nothing has been said about how the Khmers had seen their environment -physically and spiritually- and how they managed it. We did not mention the chronological inter-relation of many features. To take again the case of the West baray, we did not mention for instance, how some additional hydraulic functions have been added and some others reduced a century later, indicating a multi-purpose hydraulic network²²⁾. However, we saw above that a relationship existed between the baray and the ancient rice fields, and we concluded that one of the reasons why the baray was constructed was to develop banded fields on lands remaining -partially- empty. Nevertheless, this link of causality should not be over-estimated, as it is most probably not the only one. In this respect, geographic tests are biased if they strictly concentrate on the sole aspect of hydraulic efficiency. I would strongly suggest not to separate so quickly the various parameters and to put aside for some time theoretical dogmatism and Wittfogel's ghost. A hydraulic thesis is not really needed to suggest a strong religious and political influence in Angkor: the number and size of the temples and other territorial features should be sufficient to appreciate that. Angkor's urban planning being closely linked to territorial planning - at least until the 12th century- the Hydraulic

City debate would benefit from an integrated approach, larger in scope and based on more precise data.

End Notes

- 1) This canalisation is forgotten in Hansen 1969, pl. 12.
- 2) Pottier 1999, 104-111.
- 3) Trouvé RCA 10/32 ; 1933a, 1122 & fig. 55. Dumarçay 1992, 138-139 & fig. 16.
- 4) Trouvé 1933, 1120-1121 & fig. 52.
- 5) Thmar Dap on the Phnom Kulen (Boulbet & Dagens 1973, 33 and Dagens pers. com.). See also: Aymonier (1900, 322 & 401) & Lunet de Lajonquière (1907, 132 & 336; 1911a, 363).
- 6) It's for instance quite difficult to see any archaeological or epigraphic evidence which could corroborate this unexplained affirmation: “When the water supply was limited, much of it was reserved for sacred purposes” (van Liere 1982, 274).
- 7) These reservoirs called *tnubs* by van Liere (1980, 273) are actually called *tum nop*.
- 8) One should also note also that these U shaped reservoirs are used only in some limited areas, and for instance not in the western part of Siemreap where 4,000ha receding-flood rice are presently cultivated with additional irrigation from the West baray (Siemreap Dpt of Hydraulogy, pers. com. 08/2000). Production rate being around 2,4 tonne/ha, these 4,000ha produced then a similar quantity of rice that the 8,000ha rain-fed rice cul-

tivated below the West baray.

- 9) The convenient graphic scale allows an estimate around 38,000ha, without adding the Damdek area of about 13,000ha.
- 10) About other calculations, different results but similar conclusion, see: Moore, 1989, 212-213.
- 11) In his chapter dealing with the Hydraulic City potentiality, Groslier spends nearly one third of his text warning about the relatively poor viability of his estimations: "il est inutile de se faire des illusions sur la valeur de ces chiffres (... et) comme, de toute façon, c'est actuellement la seule manière de fixer des ordres de grandeur sur la rentabilité de l'entreprise, il n'était sans doute pas inutile de l'exposer" (1979, 191).
- 12) Enlarging the studied area could have been far more conclusive against hydraulic thesis, reducing the final percentage and indicating an even lower potential of the Angkor Hydraulic City. If we follow this kind of large calculation, and we apply a similar ratio everywhere in the khmer empire, I'm afraid that the result indicates that the khmer civilisation was the most populous country on the planet at that time. For instance, the "50 millions" banded rice fields noted by van Liere (1980, 271) could suggest, with this kind of calculation, an unrealistic population of at least 40 millions people!
- 13) An hydraulic area of 33,000ha, 25,500ha cultivated in rainy season, only 14,000ha in dry season, a productive rate of 1,46 tonnes of rice/ha with hydraulic culture, 1,1t/ha for normal rain fed rice, each tonne feeding 5 people during one year. One should note that the

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estimate of dry season cultivated area doesn't take into consideration any possibility of refilling of the baray, which could eventually increase slightly the final result.

- 14) Groslier estimates that the realisation of the West baray needed 2 millions m³ of embankments (1974, 102). If we evaluate generously the baray dyke as 10m high (at the top), 125m large (at the base) and 20km long, the quantity of earthwork needed should be around 12.5 million m³. The present daily work rate of the International Labor Organisation in Siemreap is 1,5m³ per worker for earth moved less than 20m long. If we use a lower rate of 1m³ a day, 85 days will be needed with 148,000 workers.
- 15) Due to the methodology used, this study clearly shows some weakness, especially about the difficulty to reconstitute the primitive environment and natural hydraulic regime, before khmers re-ordered them with their huge works.
- 16) How can we explain the position of East baray with the Phnom Bakheng, or the West one with the Bapuon, or the clear differential axis between the Veal Rac Dac and the Prah Kahn temple?
- 17) This calculation is based on the water surface in the baray indicated on 1930s maps.
- 18) Of course, this implies that the present day Siemreap river didn't exist at that time (Pottier 1999, 22-23).
- 19) One canal of that type is clearly visible (CP709); other remains less obvious (for instance near CP622).
- 20) That could also suggest that baray's irrigation could have also been used for the flooded

area and for receding rice cultivation as it is practised today. In that case, the percentage of the R. Acker first test to the very area below the baray could -theoretically- pass from 205% to something around 300%...

- 21) Kôk Ta Yâ CP577, Kôk Mân CP479, Tuol Kou C478, Kôk Prasat CP476, Kôk Ta Chhâkk CP477, Vat Pama LL508 and Kôk Prasat 755.
- 22) Pottier 2000.

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Photo. 1 Laterite canalisation passing through the south bank of the moat of Beng Mealea.

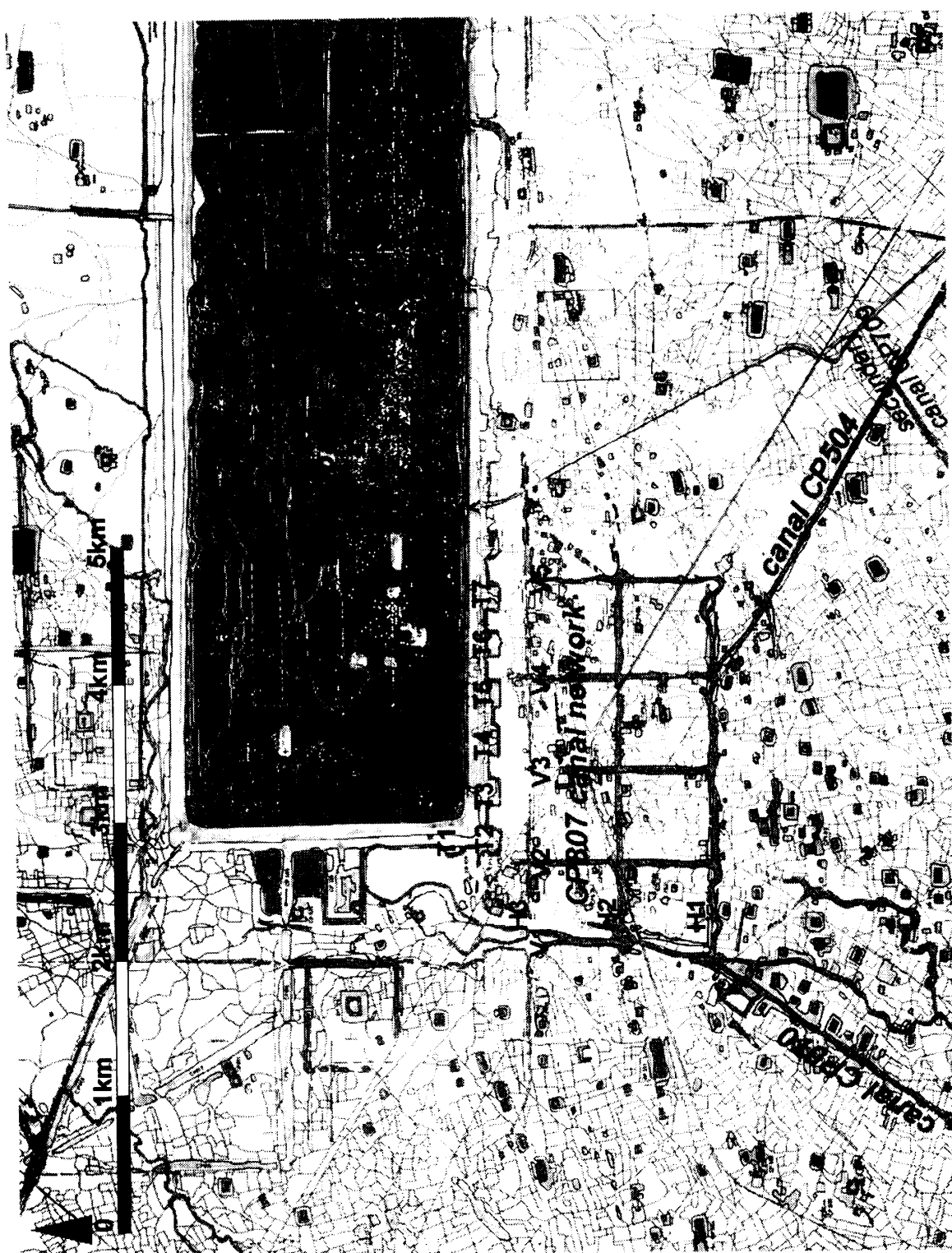


Fig. 1 South-west angle of west baray.

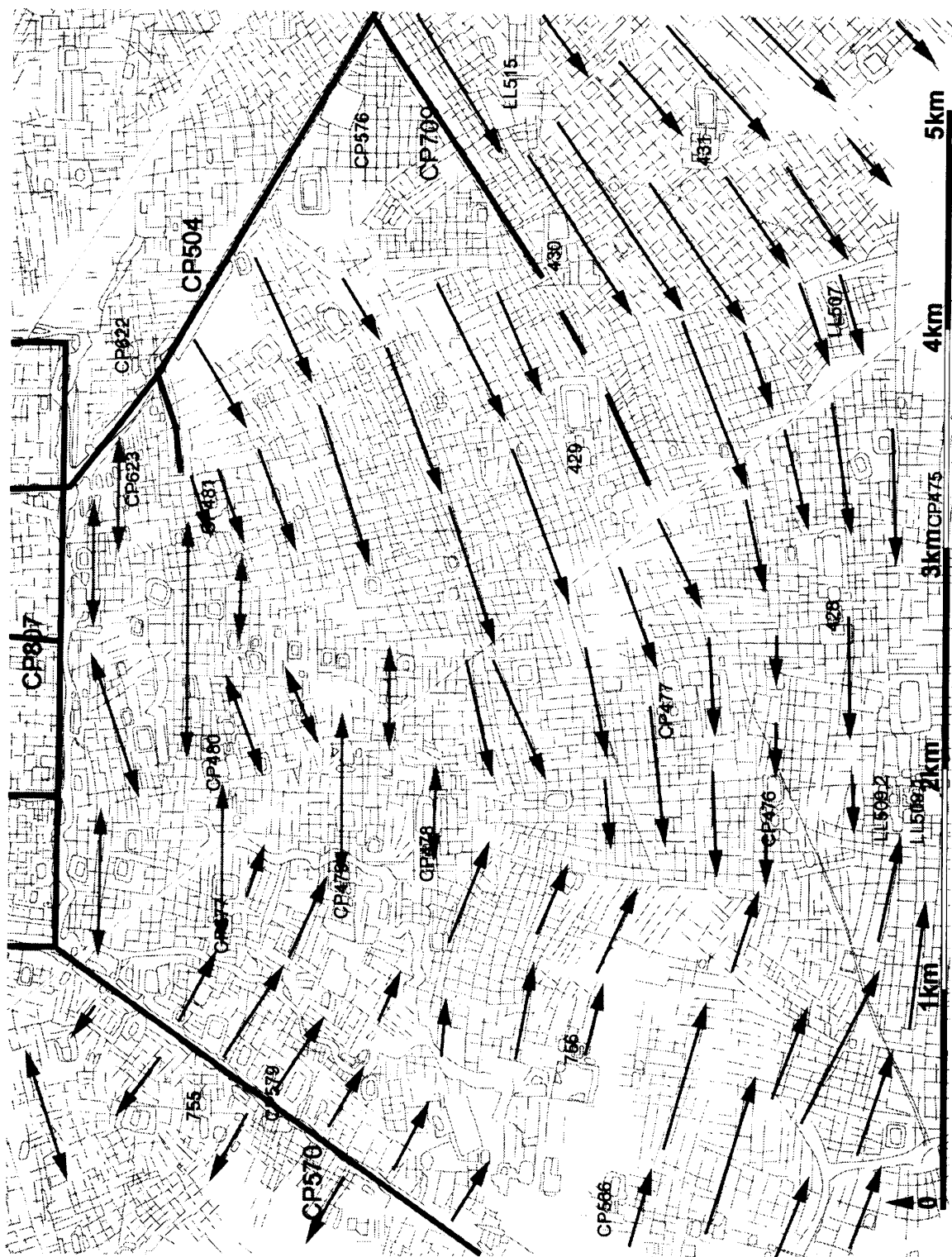


Fig. 2 Rice fields pattern south of west baray.