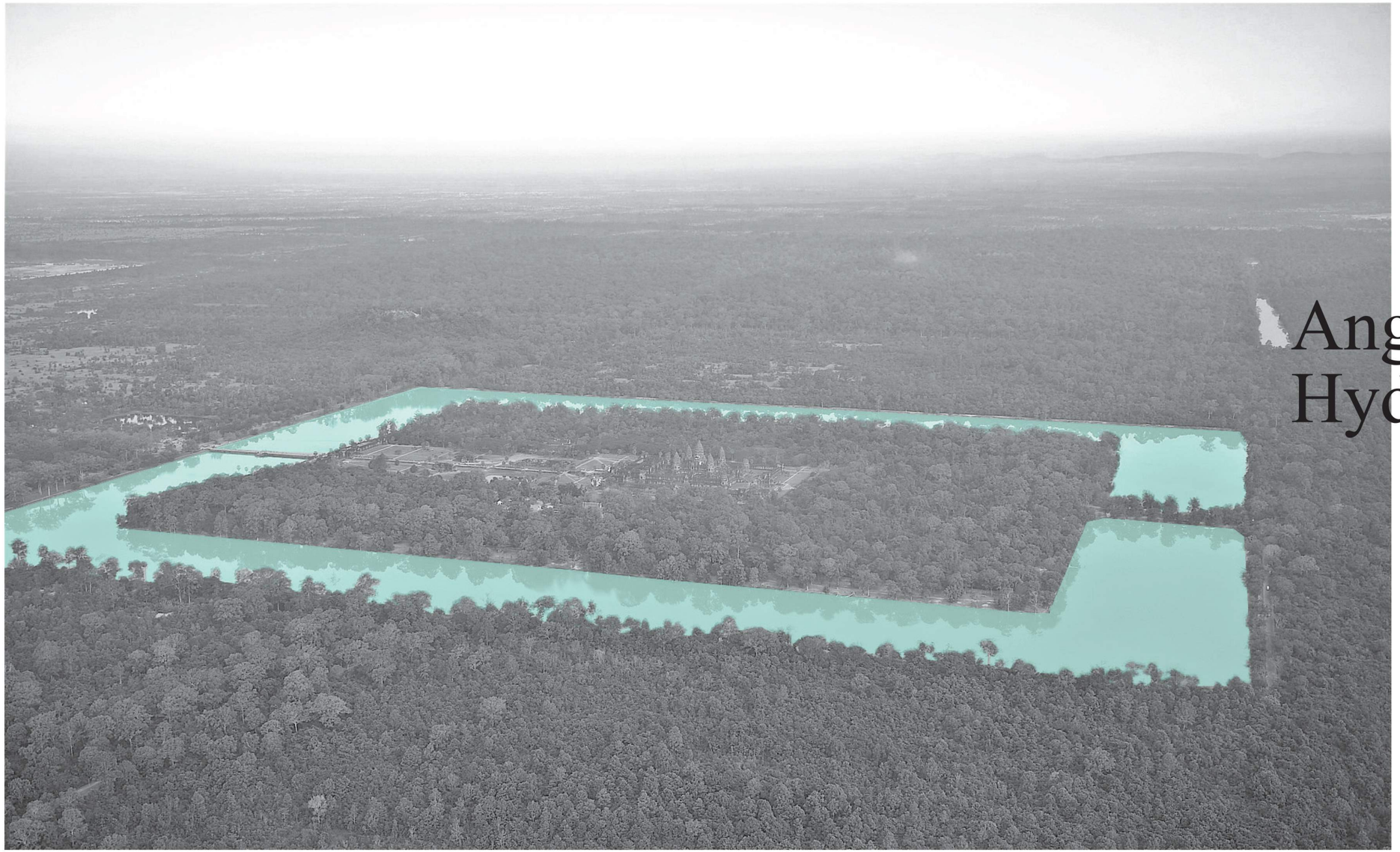


# Angkor Hydraulic City

The world's most extensive medieval sacred water management network of the ancient Khmer Empire.

Krit Thienvutichai

**Figure 1** Angkor Wat aerial view

# Context & Climate.

**Location:** Siem Reap,Cambodia

**Network area:** Approximately 2500 sq.km.

**Climate zone:** Tropical wet and dry
Dominated by monsoons

**Climate & Weather Averages**

| | |
|---|---|
| Mean High t°: | 30°C |
| Mean Low t°: | 25°C |
| Mean t°: | 27°C |
| Humidity: | >90% |
| Annual Rainfall: | 1425 mm per year |
| Evaporation: | 1690 mm per year |
| GroundWater: | 0 m below ground level (wet season) |
| | 5 m below ground level (dry season) |


**Figure 2** Country scale map

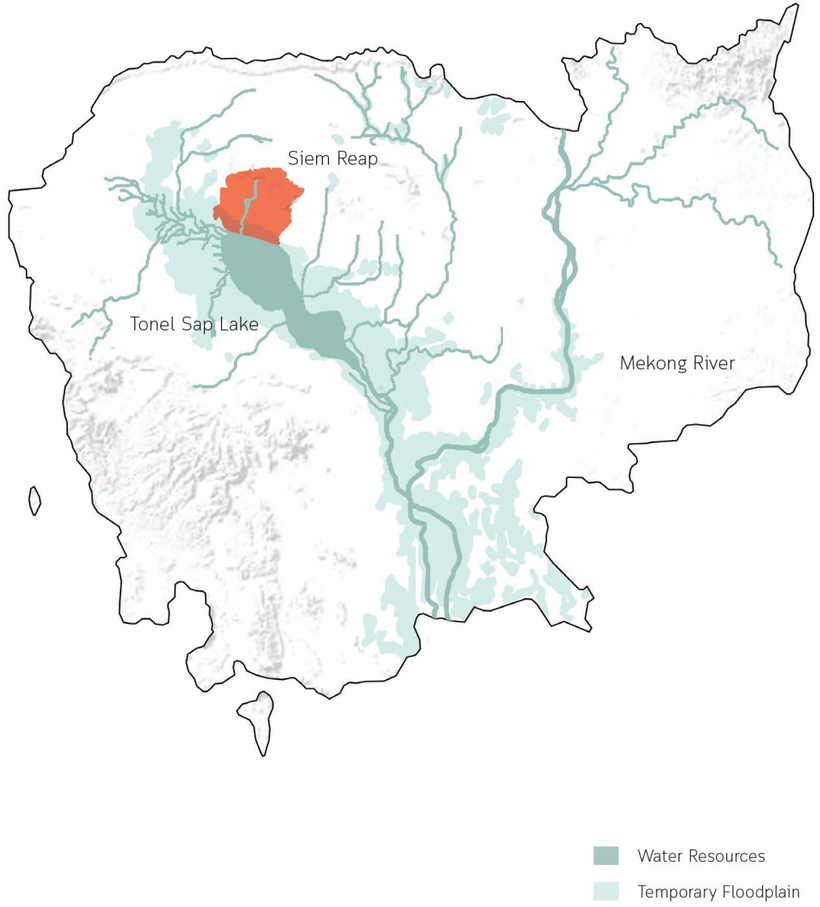



**Figure 3** Regional scale map

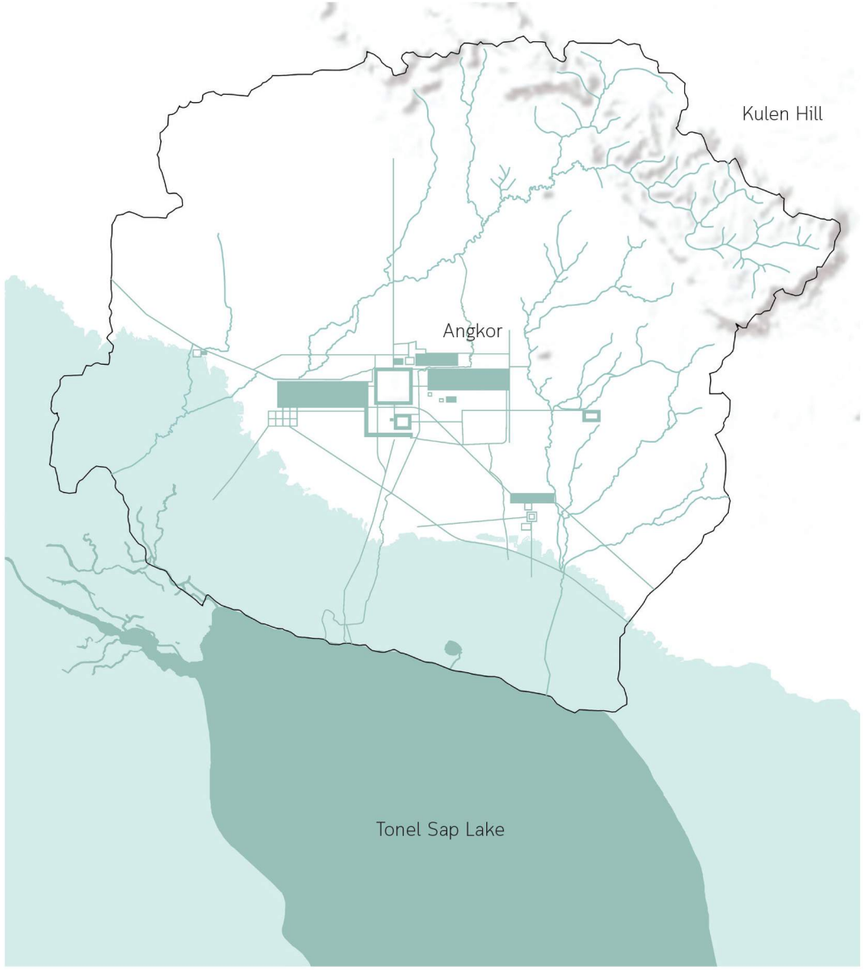



**Figure 4** City scale map

Angkor is one of the most important archaeological sites of Southeast Asia. With impressive monuments, several different ancient urban plans and large water reservoirs, the site is a unique concentration of features testifying to an exceptional civilization (UNESCO).

The iconic stone temples were constructed on an artificial layer by removing the existing soil and replacing with the new technique of combining two physical properties of sand and water to support heavy load. Studies indicate that Angkor region is the best location, as underground water is close to the ground surface (Acker, 2005). In order to assure the sustainability of underground water and the temples, water management networks were introduced as part of culture to safeguard the Angkor region and to be used in daily life.

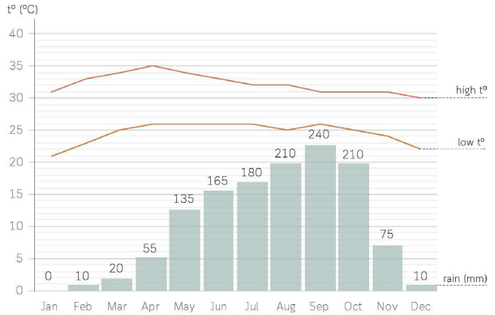



**Figure 5** Climate graph - annual rainfall & temperature

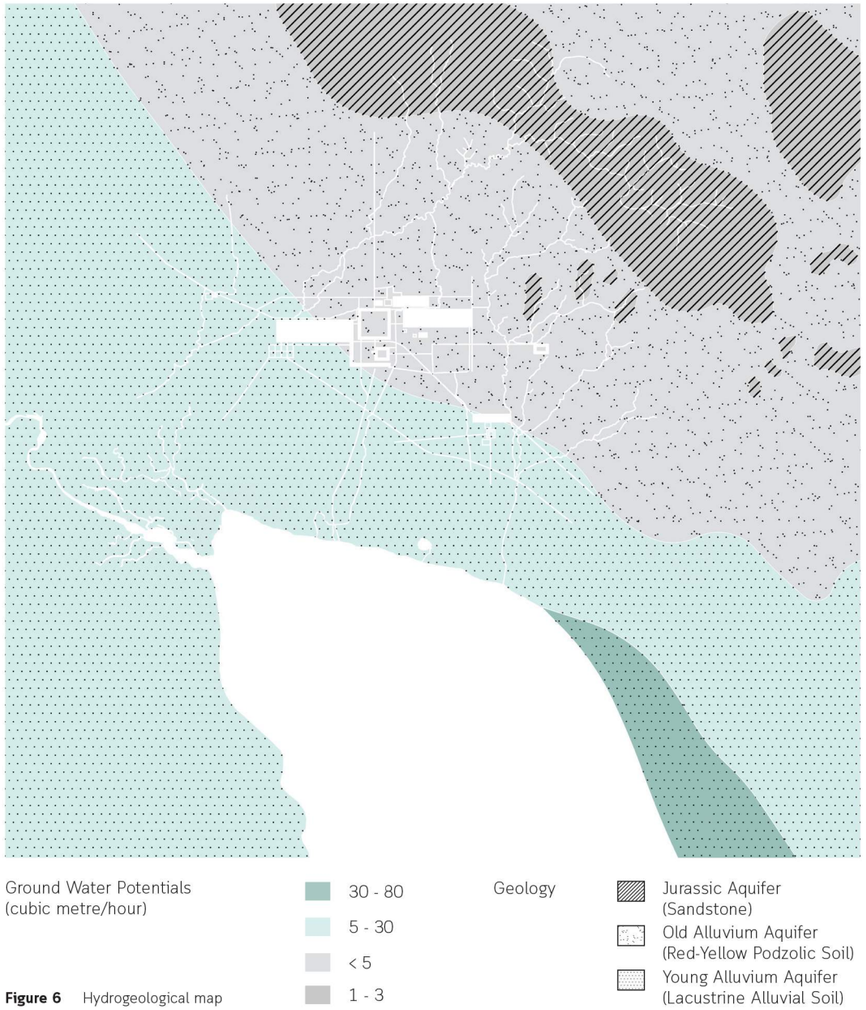



**Figure 6** Hydrogeological map

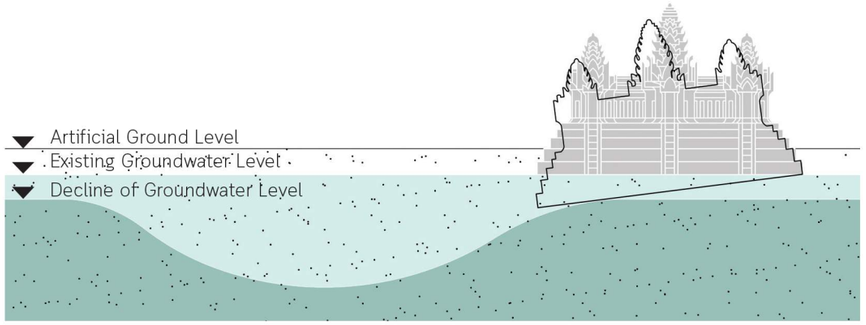



**Figure 7** Temple construction related to underground water level

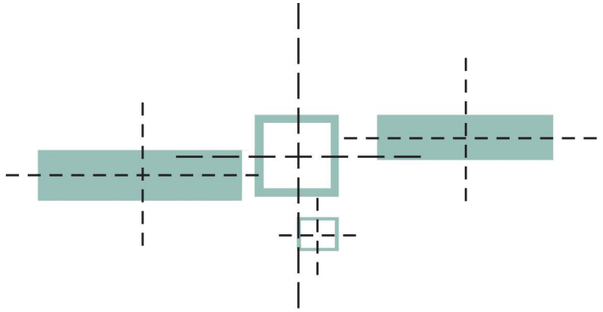
# Sacred Water.

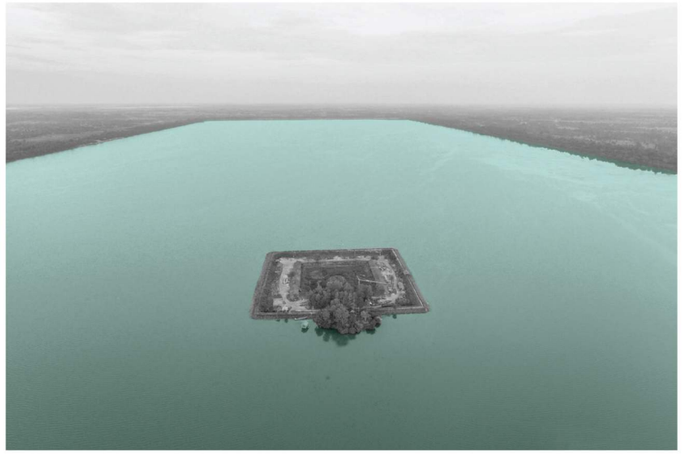
To assure that the temple would still have a sound foundation if there was any variance in underground water level, each temple is surrounded by a moat which plays a pivotal role in its stability : it collects the run-off water from the temple during the monsoon and recharges the sand underneath the temple (Hang, 2014).

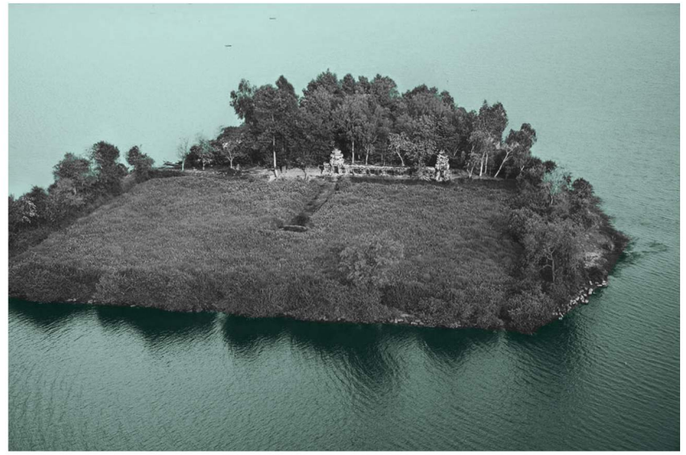
**Figure 8** Reflexive effect of Angkor Wat from surrounding moat

Since water resources played a vital role for safeguarding the Angkor region, it was treated and celebrated as part of traditional culture and part of beliefs instead of enforcing by laws or need. “ People were more likely to look after the water system, what was actually an engineering requirement was transformed into religious duty. In the Khmer tradition, the moats are considered as the ocean and the temple as Mount Meru, the dwelling of the god (Hang, 2014).

Apart from the functional aspect, water management structures were shaped by cosmological beliefs that assign the meaning to the center of the sacred geometric forms. In Hindu, the sacred intersection of vertical and horizontal axis was a portal to divine realms, to unite with the god, and the place from which the entire universe was believed to have originated from.







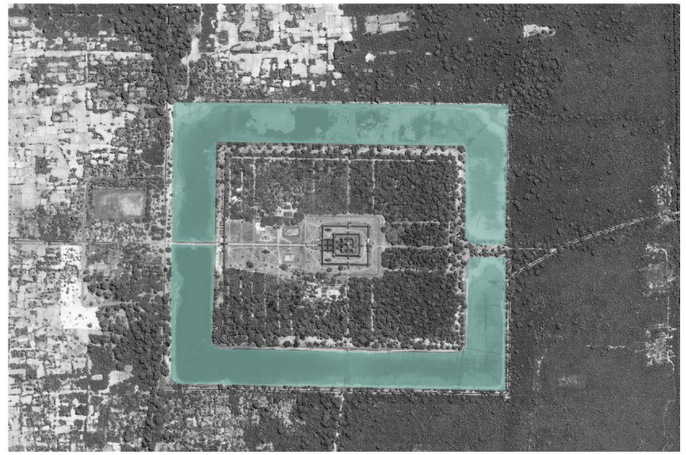


**Figure 9** Intersection axises and geometric form of water management structure (above)

**Figure 10** Baray - Large artificial regtangular water reservoir (top left)

**Figure 11** Mebon - Island temple at the center of the baray (top right)

**Figure 12** Naek Pean - Island temple at the center of north baray (bottom left)

**Figure 13** Geometric form of Angkor Wat aerial plan (bottom right)

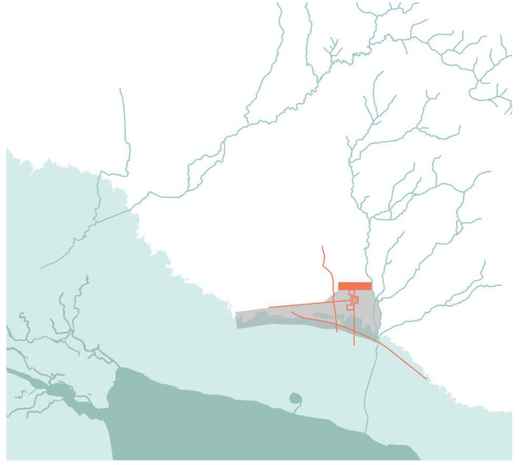
# Development.

Groslier summarized his interpretation of the development of the landscape, introducing the expression of hydraulic city to explain the impact of the water management at Angkor. With the aerial discovery of the extended channel system, a set of five maps displaying the area from pre-Angkorian times to the final foundations and constructions were finally published as a result in 1979 (Sonnemann, 2011).

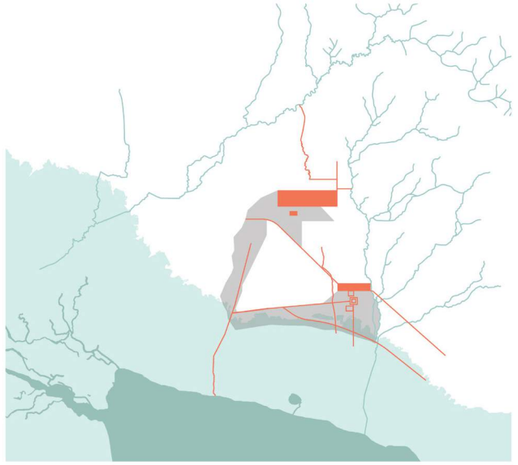
No one has any idea what the city actually looked like, whether the houses were clustered together or spaced far apart. All we can say for certain is that Angkor was a rich and populous settlement (Bracken, 2010).

Assumed Urban Settlements

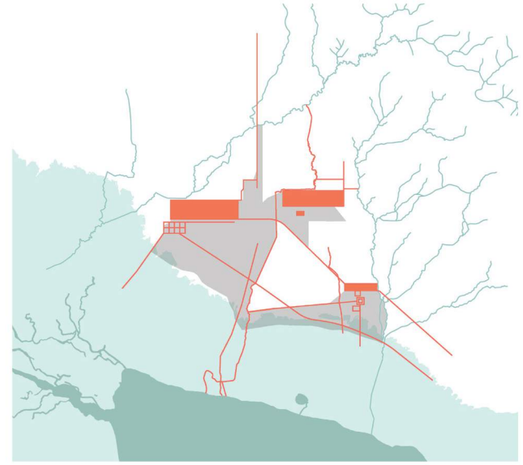
Water Management Development



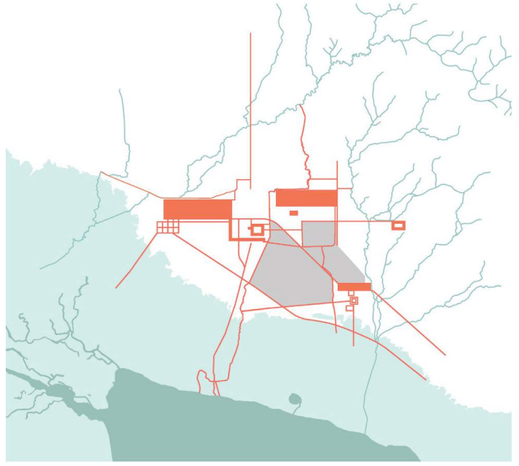
8th-9th Centuries- Roluos Network



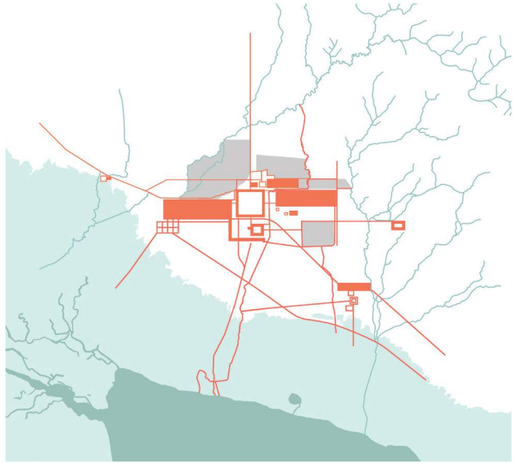
Late 9th century - East Baray Addition



11th century - West Baray Addition



Early 12th century - Angkor Wat



Late 12th century - Angkor Thom

**Figure 14** Urban Development with water management transformation maps interpreted based on Groslier, 1997 and Fletcher, 2008

# Catchment Area.

During the 9th century, when the development at Rolous became the capital, the demand of water increase. In order to meet this demand, Pourk watershed was channeled and diverted by a construction of laterite spillway creating new man-made watershed, Siem Reap. Nowadays the region is supplied by three watersheds, the Rolous, Siem Reap, and Pourk with their catchment areas of 1031.84 square kilometers, 836.74 square kilometers, and 935.62 square kilometers respectively.

Water management in Angkor was based on 4 sources of water : (1) natural rivers (2) ground water, (3) precipitation (4) Tonle Sap Lake

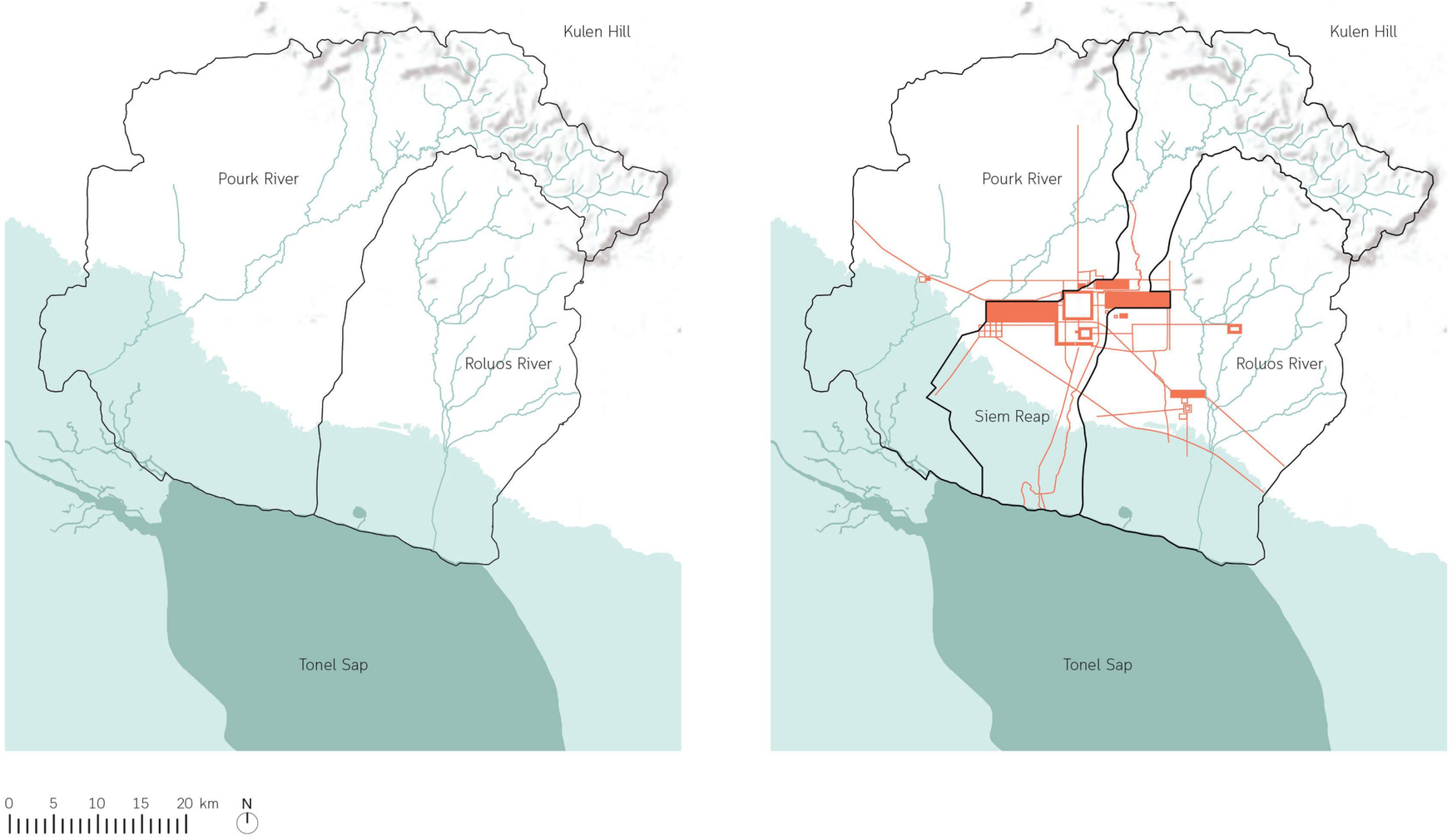


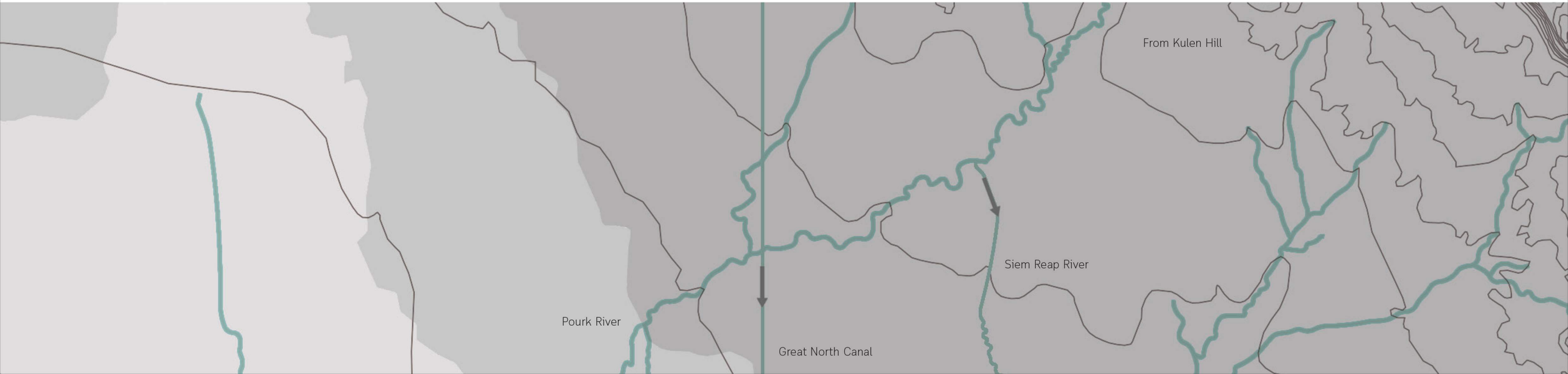

**Figure 15** Catchment area ( Watershed development )

# Water System Plan.

The hydraulic city was classified into three principle zones, with their existing topographic conditions of hydrogeology and elevation, functioned as one large system to supply the whole region. In the collector zone, the water was taken from natural rivers originating in the Kulen Hills primarily by north-south aligned channels. In the aggregator and collector zones, water was stored mainly in the earthen embankments of barays, temple moats and small reservoirs (trapeang), mainly from rain and groundwater sources. The drainage and dispersal zone is the area that operated to disperse the water down into Tonle Sap lake and also provide water for irrigation and consumption for villages and farmland in the south (Kummu, 2009).

0 5 10 km N

Collector Zone
Aggregator & Holding Zone
Drainage & Dispersal Zone
Floodplain Zone



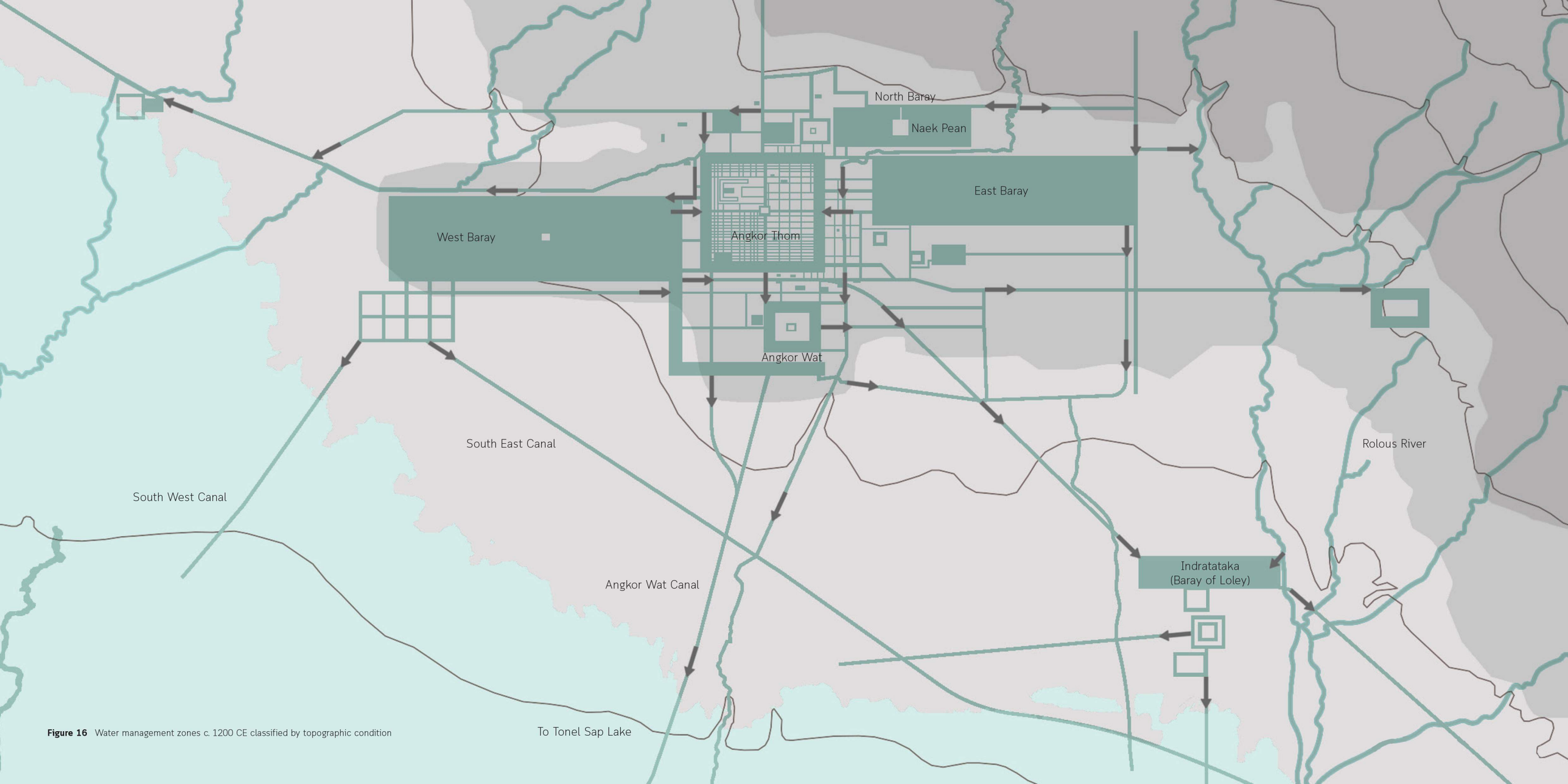


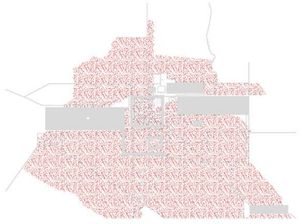

**Figure 16** Water management zones c. 1200 CE classified by topographic condition

# Typologies.

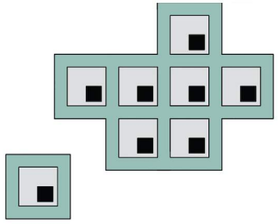
Water management typologies in this paper are divided in three principle management levels : household level, village level, and city level represented typical structures with plan and section drawings together with their associated programs.

In the household level, houses were built on small mounds raised above flood level. Small ponds were dug into the water table level in order to collect and store water for daily use purposes. Water for consumption was assumed as separated system due to hygienic issue using water jar for rainwater collection but in dry season underground water in the ponds was also needed.

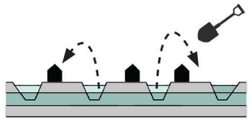
In the village level, water was collected and stored in bigger ponds (trapeang) and moats. Almost every temples also had it's own moat or trapaeng nearby which had significant function of maintaining underground water resources to stabilize temples' foundation. The surrounding moats also functioned as defensive interventions for the village inside the Angkor Thom and trapaeng also served for recreation around the surrounding edges which could transform to festive spaces in dry season.

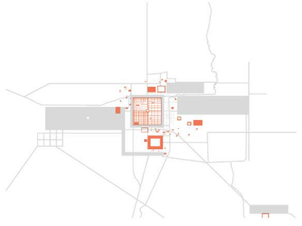


Household Level

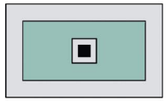


House mound

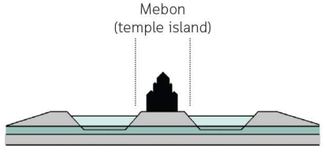


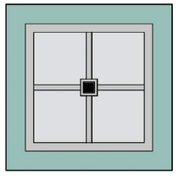


Village/Temple Level

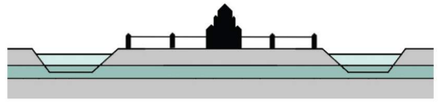


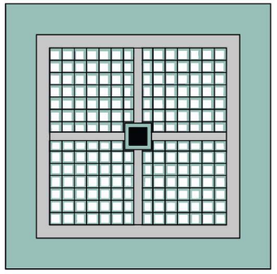
Trapeang (pond)



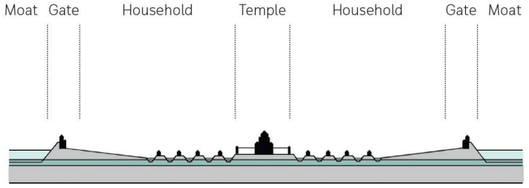



Temple + Moat



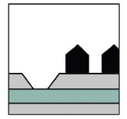


Village + Temple + Moat

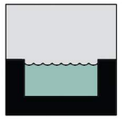



Rainwater Harvesting (consumption)

Daily Uses



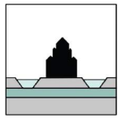
Underground Water Use (dry season)



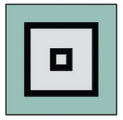
Retention (resource)

Recreation

Natural Representation



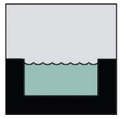
Temple Stabilization



Cultural Representation

Recreation

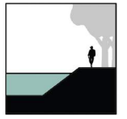
Cultural Festive Activity



Retention (resource)

Defensive Boundary

Cultural Representation

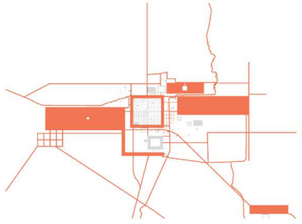


Recreation

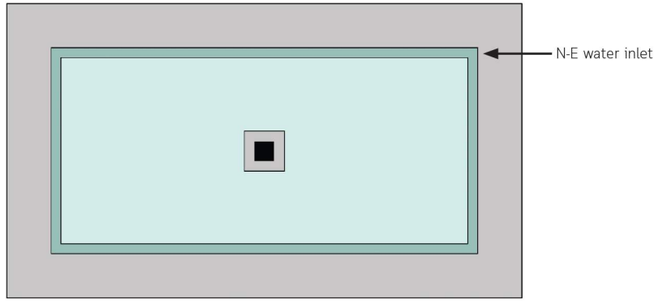
In the city level, two major water management features of Baray and linear water channels formed up the complex intercommunication network of the city. Four barays were the major water storage resources of the city fed by the artificial channels originating from the natural rivers and also directly by rainfall. The main role of the west baray is to recharge the ground water and to assure the irrigation while the east baray served as main water resources for the city of Angkor Thom. Shallow channels of 1-2 m. depth and rather 30-40 m. width criss-crossed the whole landscape kept the water as high as possible in order to supply the baray.

Ordinary water level

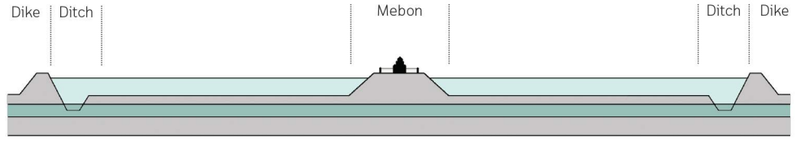
Underground water level

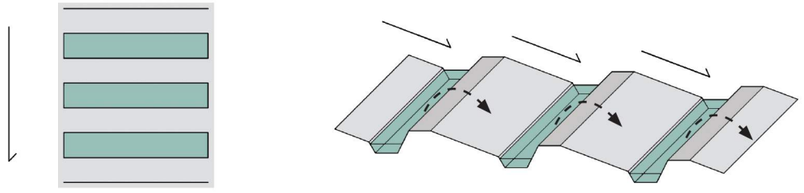


City Level

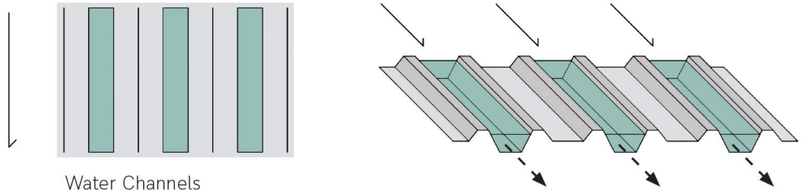



Baray (water reservoir)



Water Channels
(perpendicular to slope)



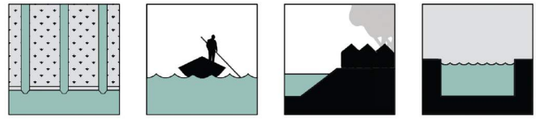
Water Channels
(parallel to slope)

Retention
(resource)

Recreation

Natural
Representation

Cultural
Representation



Irrigation

Transportation

Attract
Settlement

Dispersal
(flood control)

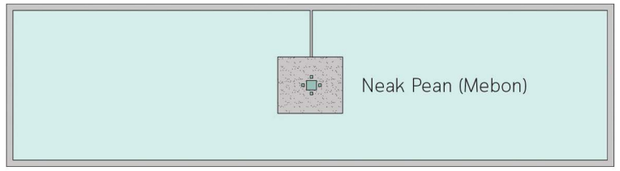
**Figure 17** Schematic illustration of typical water management structures and associated programs classified by levels. (adapted from Pottier, 1999 and Kummu, 2009)

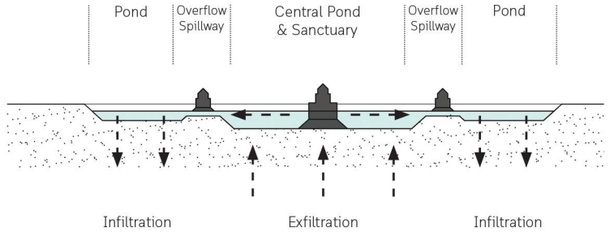
# The Neak Pean.

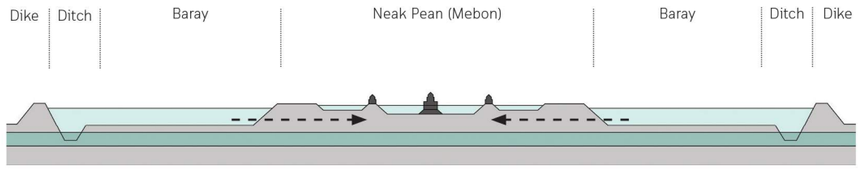
The island temple was located at the center of north baray. The temple consists of five basins (ponds) which water from north baray infiltrates the biggest central basin, then when the water reaches the spillway level located in the chapel between the central basin and the surrounding basins, it starts to overflow and fills the small basins. The flow of water into the five basins linked to the north baray provides one of the best illustrations of the hydraulic system which shows the ancient Khmer techniques of infiltration and exfiltration (underground flow) to recharge the groundwater, moat and basins (Hang, 2014).

The temple island used to function as a hospital. The central pond symbolizes a mythical lake in the Himalayas whose water is thought to cure all illness. The water overflows from the central pond through chapels to fill up four small ponds with healing water. The ancient Khmers may have believed that bathing in its successive ponds would have restored balance within the body and cured illness, or at least washed away sin. Medical plants were also found around the island from the past until today.

The Jayatataka (north baray)



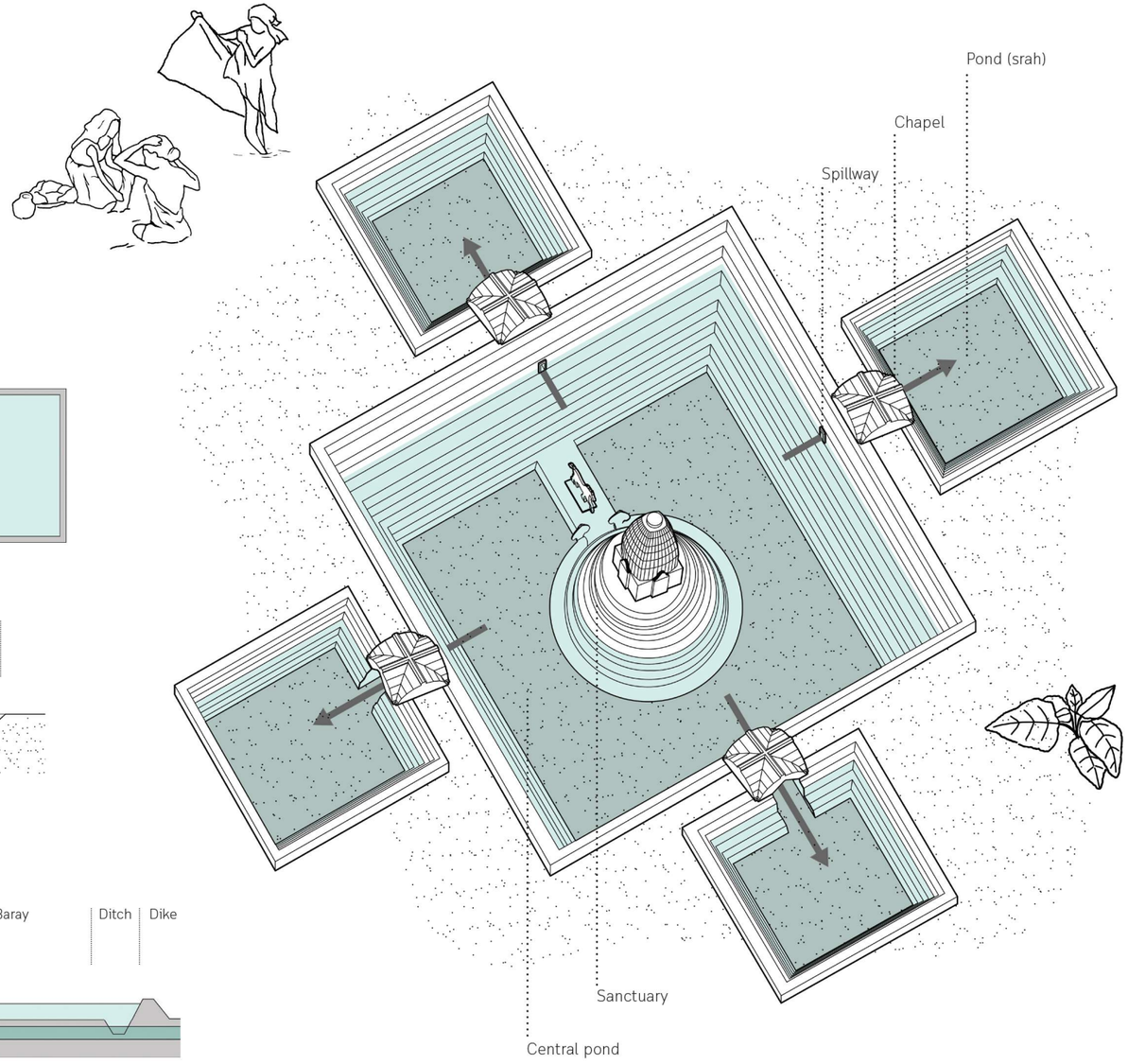




**Figure 18** The Naek Pean water management structure

# Conclusion.

No evidences from the time of Khmer empire mention either floods or droughts, and nor do the people have any memory relating to such disasters (Hang, 2014). The success of the ancient hydraulic system to optimize water resources relies on the distinguished combination of functional use and belief. There is still no exact conclusion for today on the fall of the empire but some evidences indicate that it could related with the change of religion. In the 15th century, people disbelieved in the sacred of the past religion which result in the abandonment of the system. The system was left deserted with no effort to rebuild the empire after the invasion of Ayutthaya. Recently (2012), some partк of the system were renovated back to function and proved that the system could manage the challenges of drought and flood for the region.

**Functional Values:** Practical and simple rectangular forms of water network were used to construct as backbone of the urban structures. Water acts like arteries of the empire providing multi-purpose services.

**Landscape Values:** With intellectual knowledge of the Khmer ancestors combining the system with beliefs, the engineering requirement was transformed into religious duty to look after the cultural landscape.

**Strategic Values:** The location of the empire was chose by the understanding of the topographic conditions including soil types, underground water level and elevation which allowed Angkor to have water supply for all year round.

**Material and Tangible Values:** The surrounding water was considered as the key element to safeguarding the stability of the temples as the artificial ground was invented using a combination of sandy soil with underground water.

**Ethnographic and Identity Values:** Angkor is selected by the UNESCO as one of the most distinctive archaeological world heritage site of the world with unique concentration of monuments in remarkable relation with water network.

**Figure 19** Aerial photo of current Angkor water management system