

An aerial photograph of the Borobudur Temple complex in Indonesia. The temple is a large, circular, stepped pyramid structure made of dark stone, with numerous smaller stupas arranged in concentric circles. The image is taken from a high angle, showing the intricate geometric layout of the temple. The text "Borobudur Temple" is overlaid in the top left corner.

Borobudur Temple

*The waterworld inside the hill
beneath Borobudur Temple*

11/11/2013

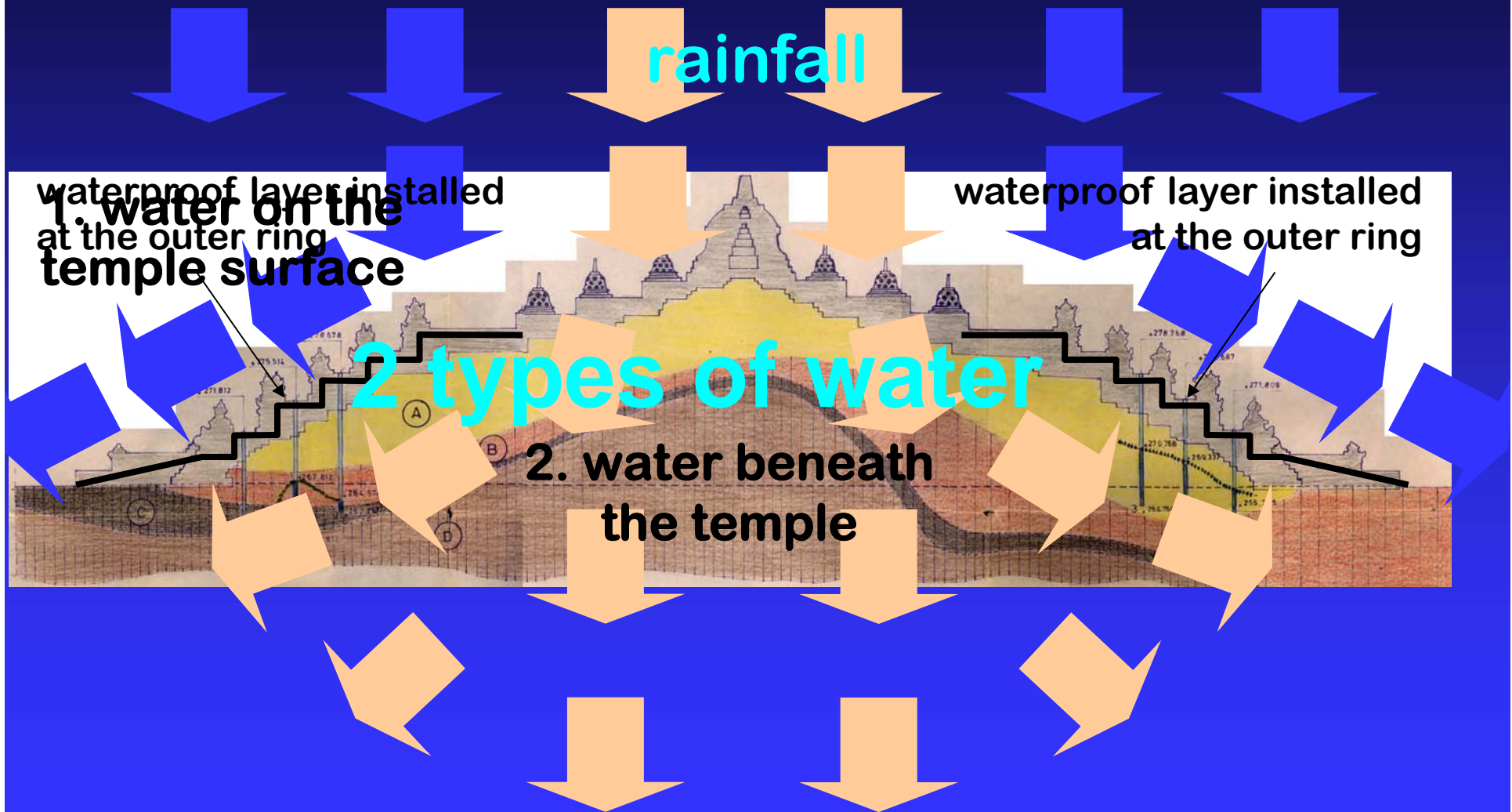
luk.staff.ugm.ac.id

Ir. Djoko Luknanto, M.Sc., Ph.D.
Luknanto@ugm.ac.id

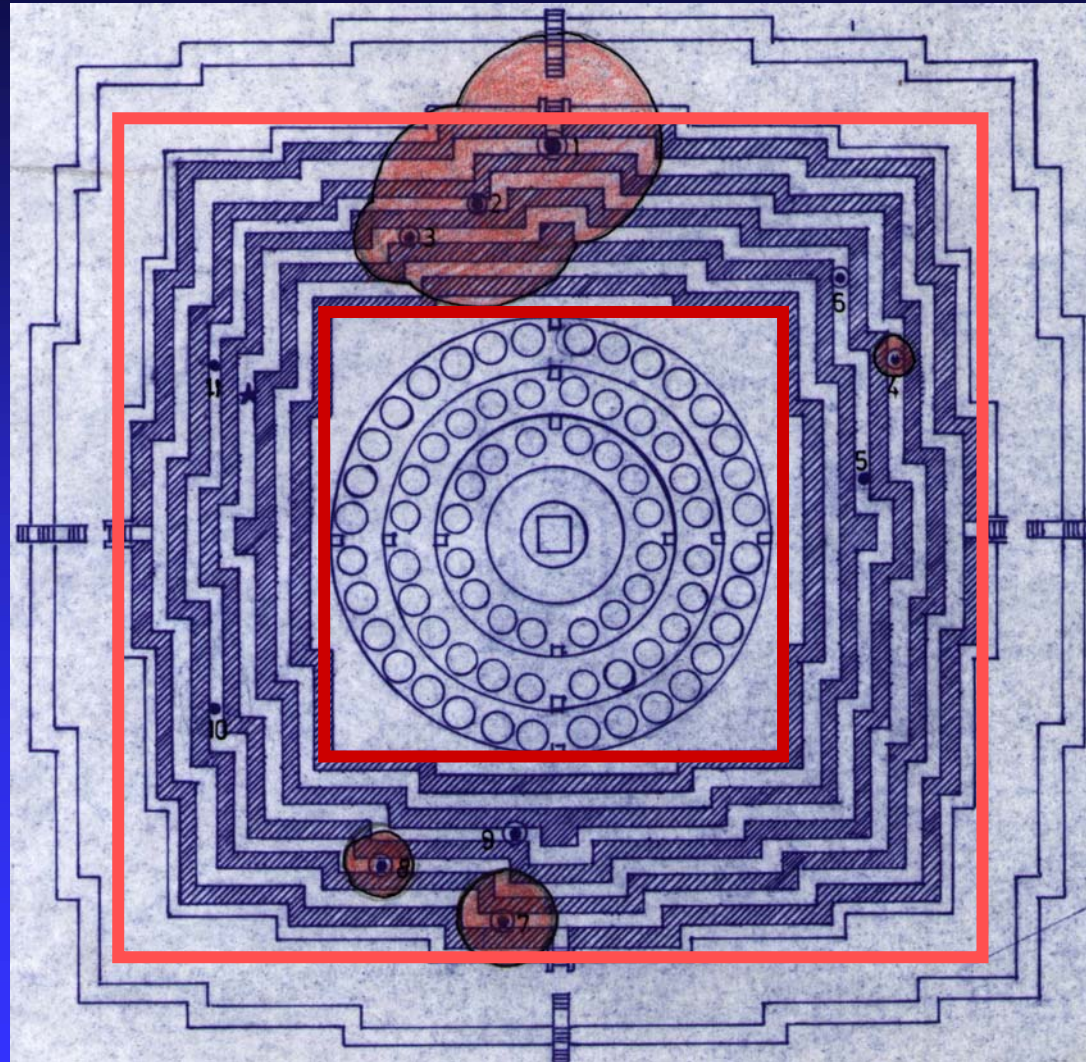
Objective of the study

- To monitor surface-water and groundwater at Borobudur temple to avoid the detrimental effect to the temple.
- To recommend necessary action in the future to monitor water more accurately to sustain the well preserved Borobudur temple at its surrounding area.

Water at Borobudur Temple



Plan View of the Temple

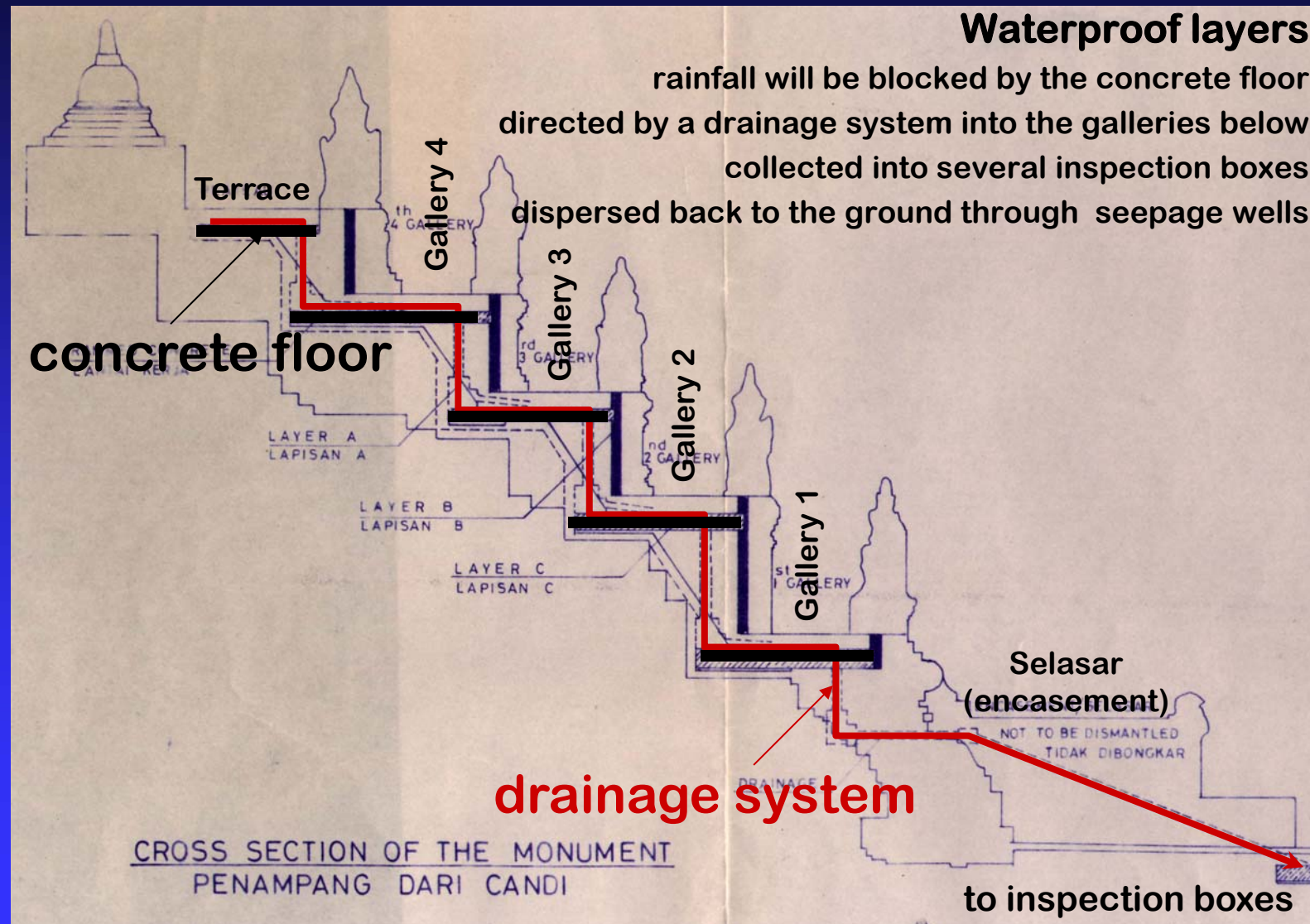


- at inner ring (terrace)
 - ◆ rainfall goes directly to the soil below the temple
- at outer ring (galleries)
 - ◆ rainfall block by waterproof layer.

There are 2 types of water

1. **Groundwater beneath the temple**
 - small amount of it will eventually flows back through water filters to the surface of the temple
 - Most of it will stay as part of the greater groundwater system for a period of time
2. **Surface run-off on the temple surface**
 - block by waterproof layer and directed to the drainage system
 - eventually surface water will go to the seepage wells at the the temple yard

Surface Water



Surface Water Observation

Field data observation by Borobudur
Conservation and Research Center (BCRC):

- ◆ climatological data (rainfall and evaporation)
- ◆ drainage system
- ◆ inspection boxes and seepage wells
- ◆ waterproof layers
- ◆ water meters

Groundwater Observation

Indirect field observation of groundwater has also been done by BCRC:

- ◆ water filters
- ◆ surface run-off volume
- ◆ water in the inclinometers

Water Filters



- Water filters are used to protect the groundwater below the temple from coming out directly to the temple floor, picking up soil particle beneath the temple along the way.
- Up to present the water filters performs well to avoid the piping at the soil.

Water Meters

- to measure the volume of surface run-off on the temple floors (BCRC installed 8 water meters in the inspection boxes surrounding the temple)



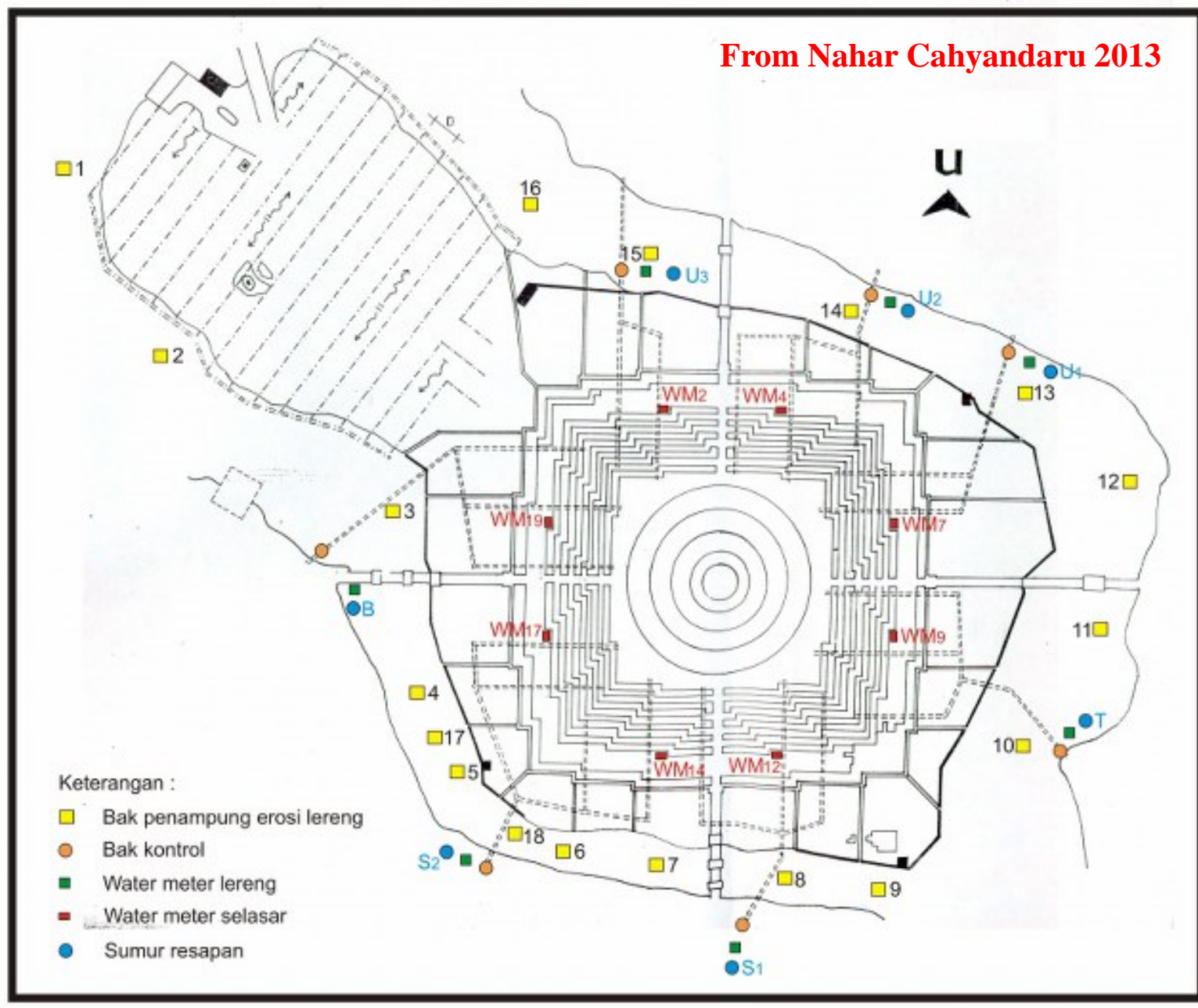
■ before installation



■ after installation

Map of all water related measurements

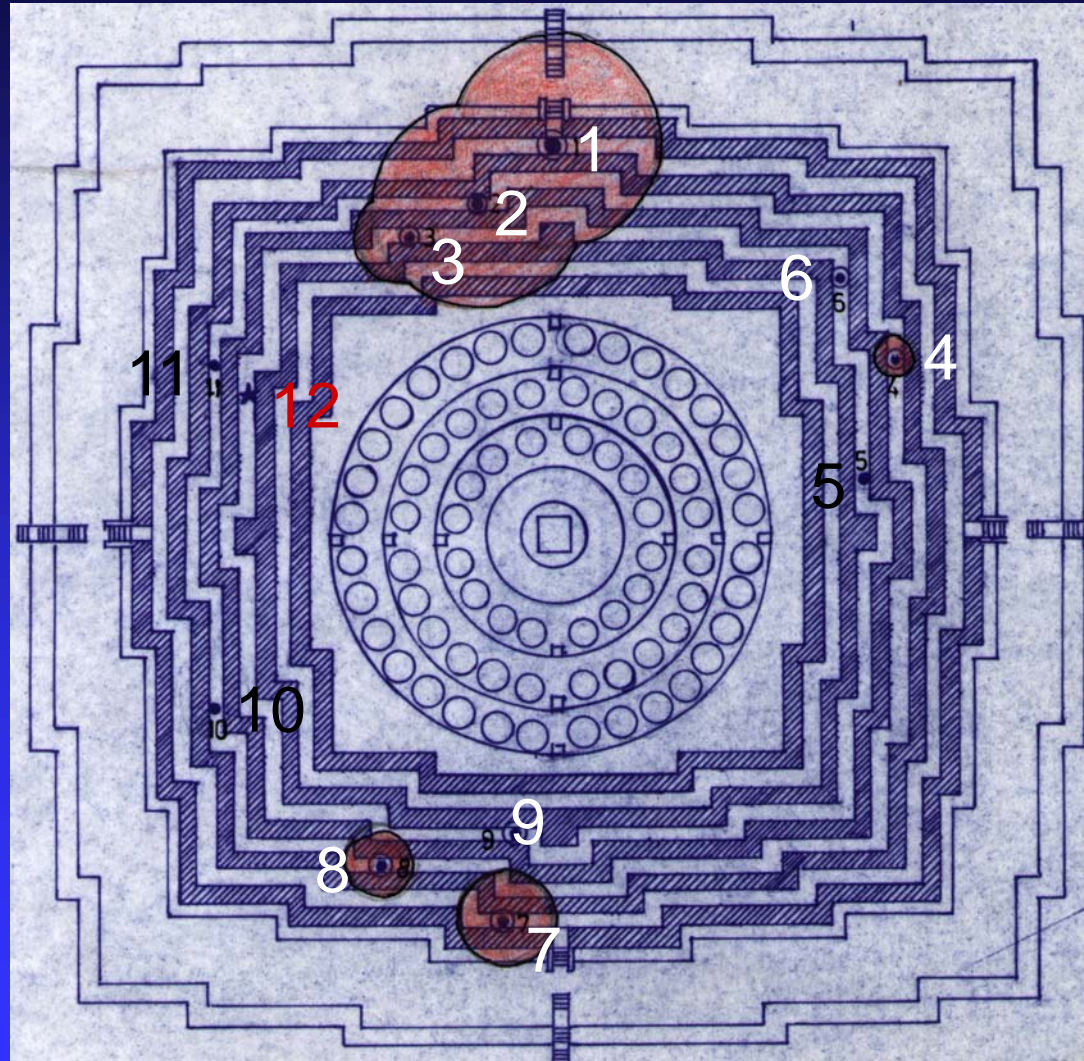
From Nahar Cahyandaru 2013



Inclinometers

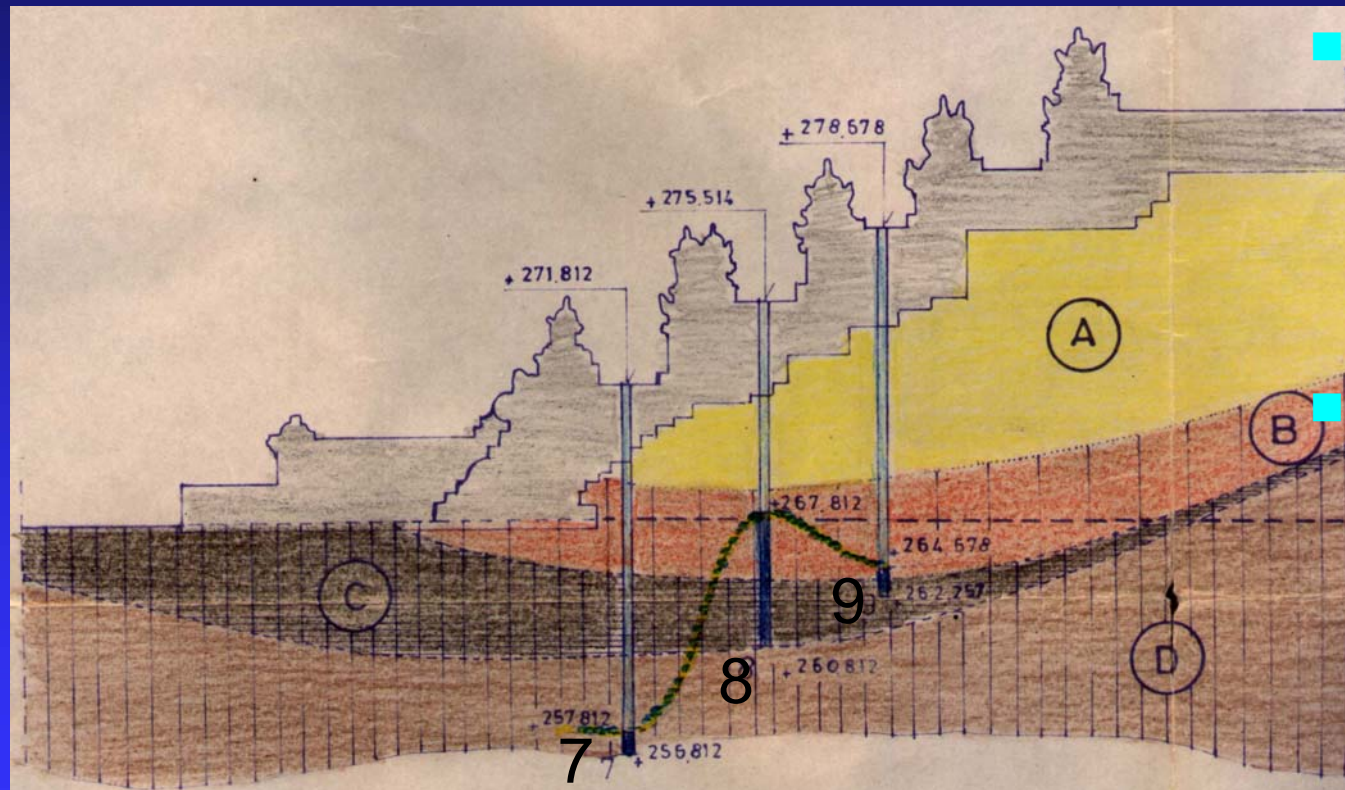
- inclinometer is not appropriate for groundwater monitoring
- inclinometer is a device to measure horizontal movement of a structure
- at Borobudur temple the inclinometers were used to measure the horizontal movement of the temple and to monitor the groundwater table.
- there is no device to monitor directly the groundwater table.

Location of inclinometers



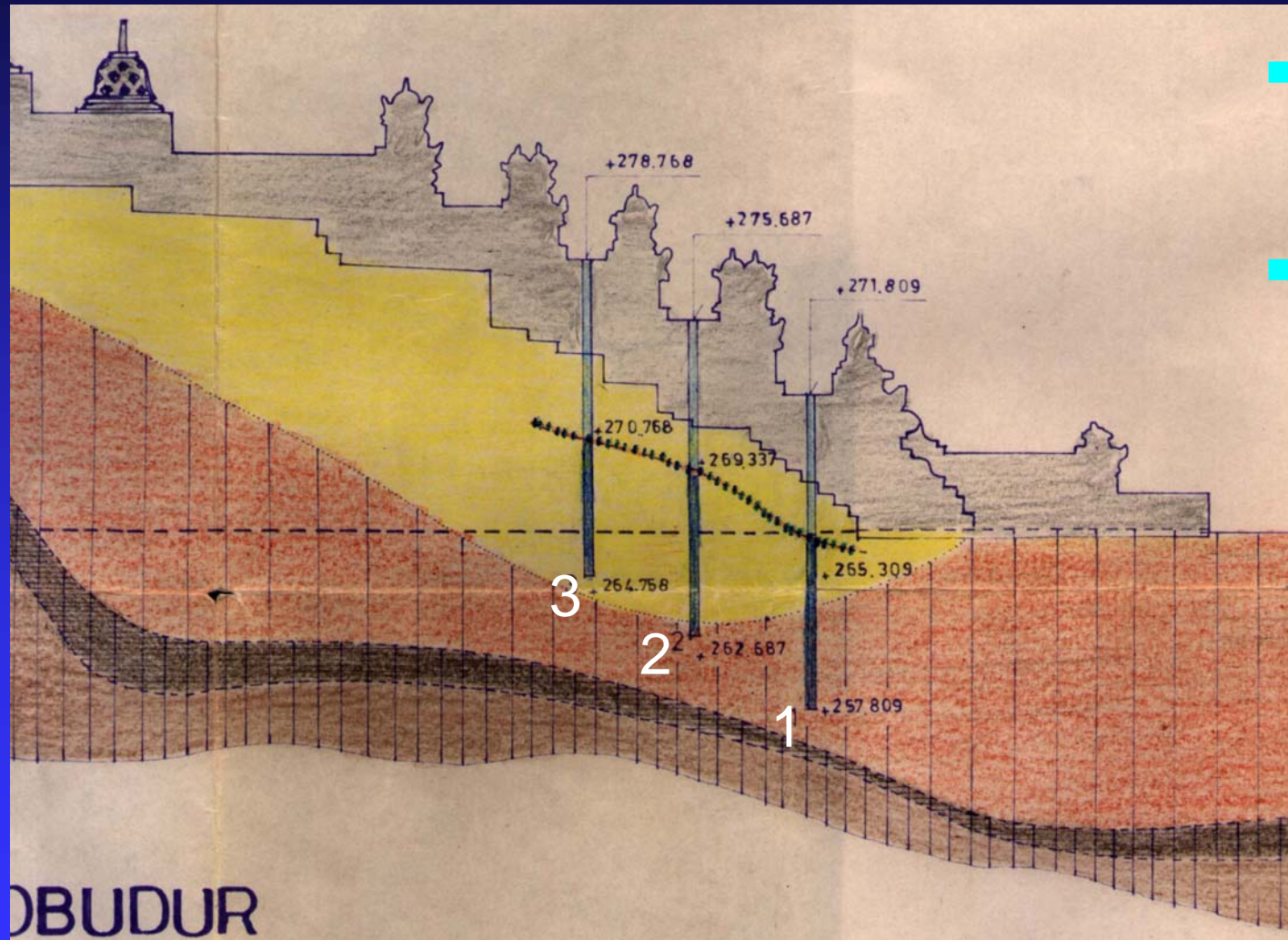
- inclinometers are available at 12 location:
 - ◆ there is water inside: 8 locations (w/ circle)
 - ◆ there is no water inside: 3 locations (w/o red)
 - ◆ multifunction 1 location (no 12)
- From the inclinometer data, it is very difficult to estimate the groundwater table

Waterlevel at inclinometer 7-8-9



- there are no specific pattern on inclinometer 7-8-9
- the groundwater table could not be predicted

Waterlevel at inclinometer 1-2-3



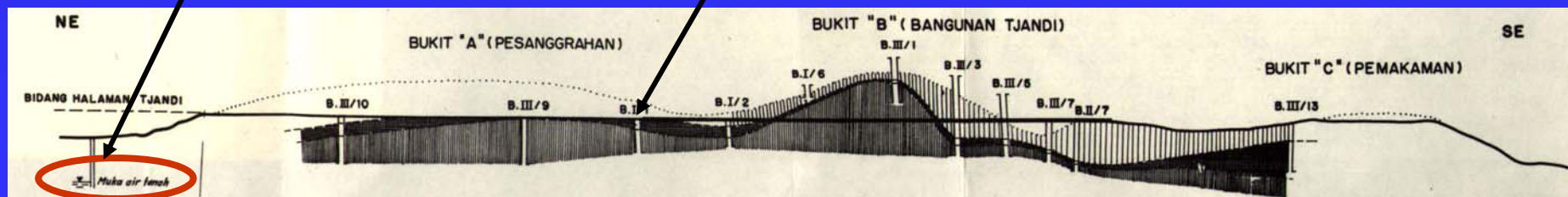
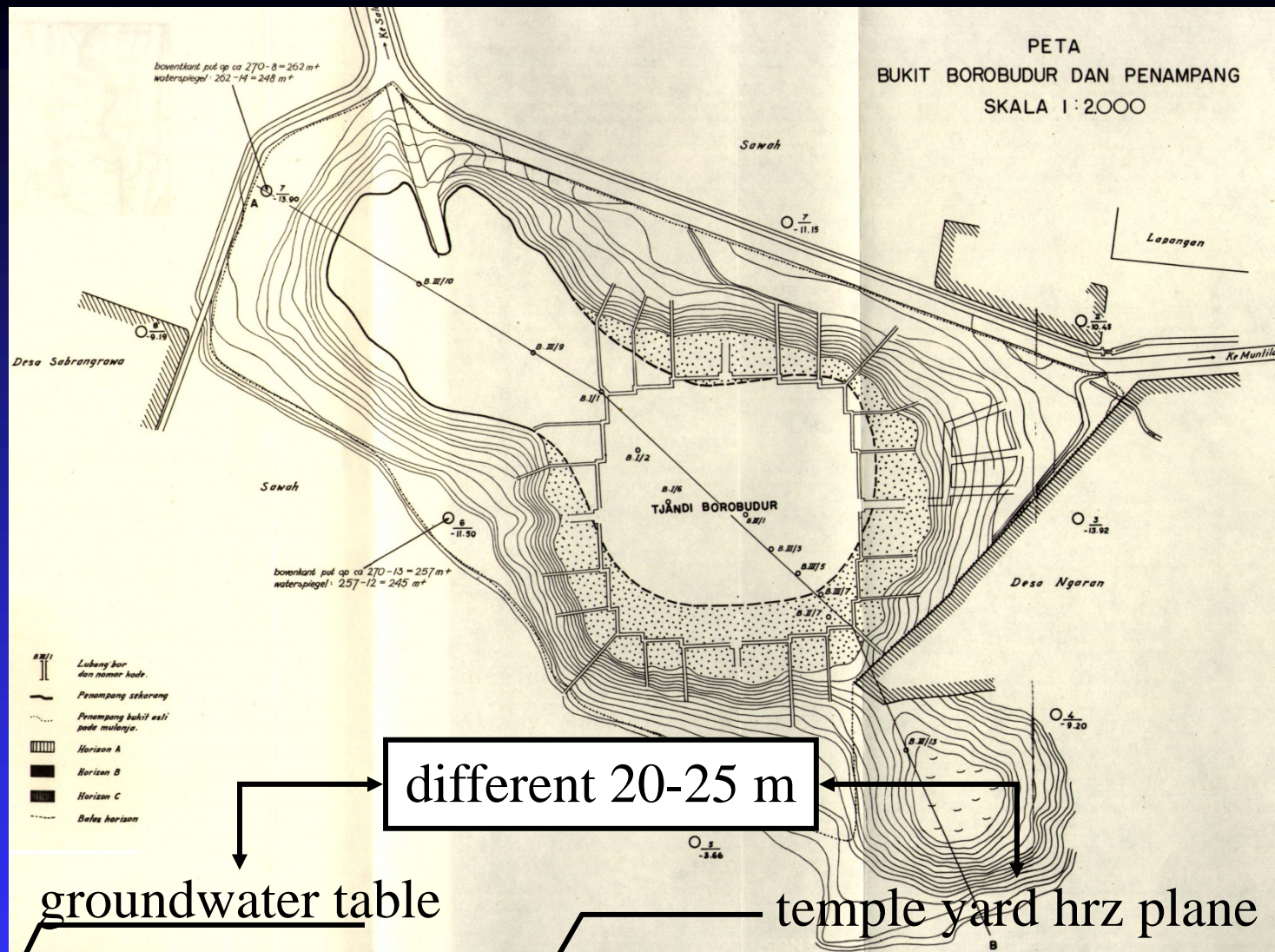
- more regular pattern on inclinometer 1-2-3
- this might be the correct groundwater table for Horizon A

Groundwater tables

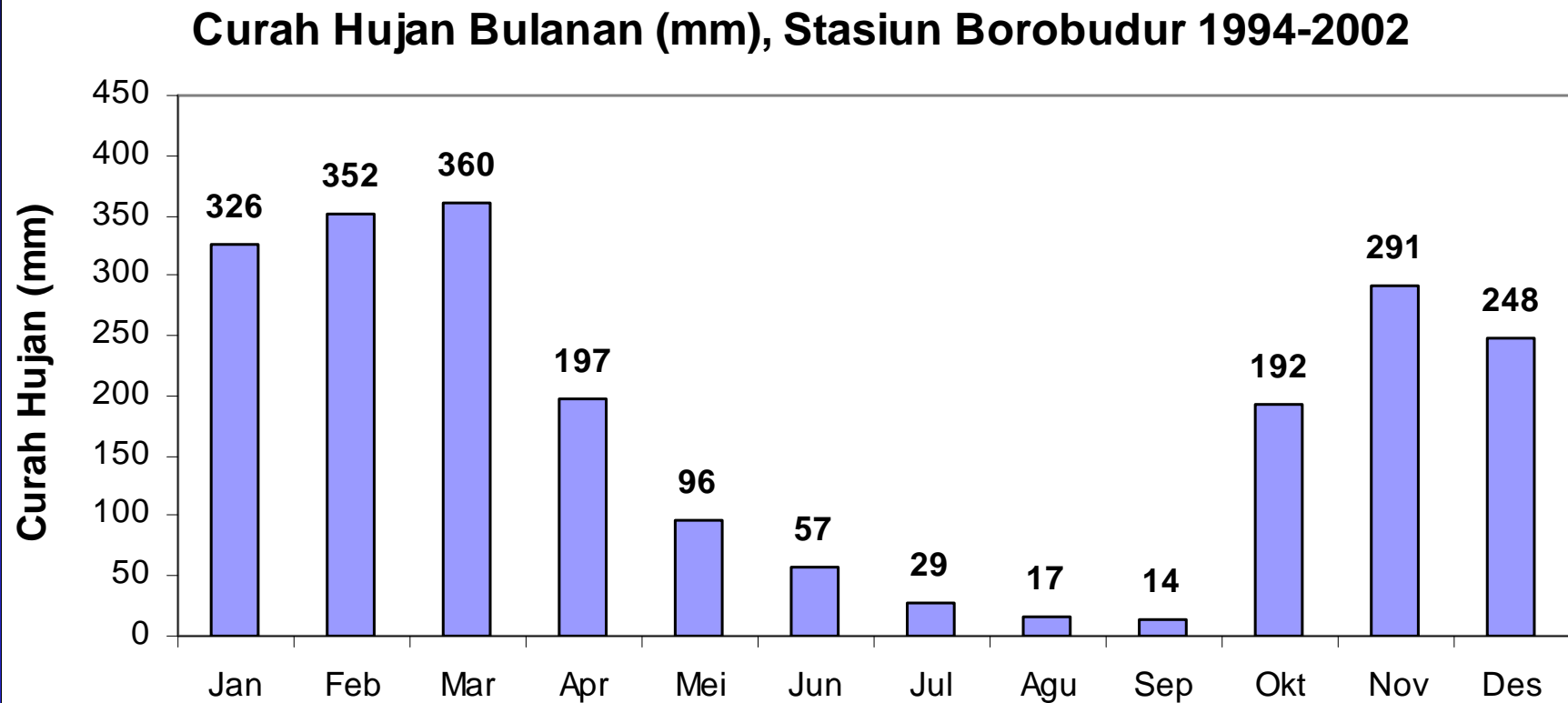
There are two groundwater tables at Borobudur Temples:

1. Groundwater table at the hill beneath the temple, and
2. Groundwater table at the villages surrounding the temples

The water level different between these two tables is more than 20-25 m.



Monthly Rainfall (mm), at Borobudur 1994-2002



Groundwater Flows

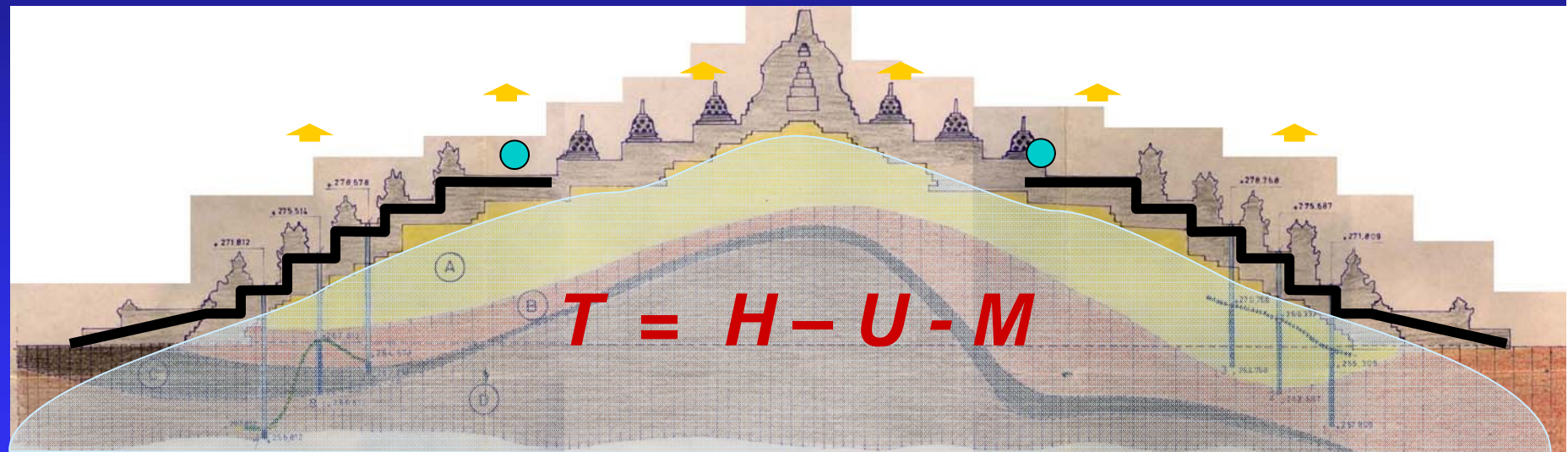
- according to groundwater hydraulics, water flows from locations with higher energy to a lower one
- at rainy season there might be groundwater pressure to the temple wall
- groundwater flow pattern are quite complicated, since there are 4 layer of soils with different characteristic.



Consideration

- It is very difficult to monitor the groundwater table without the appropriate devices
- Indirect measurement of the groundwater volume cannot exactly predict the groundwater table
- Observation of the groundwater table using inclinometers are not appropriate

Water Balance at Borobudur temple



↓ rainfall (H)

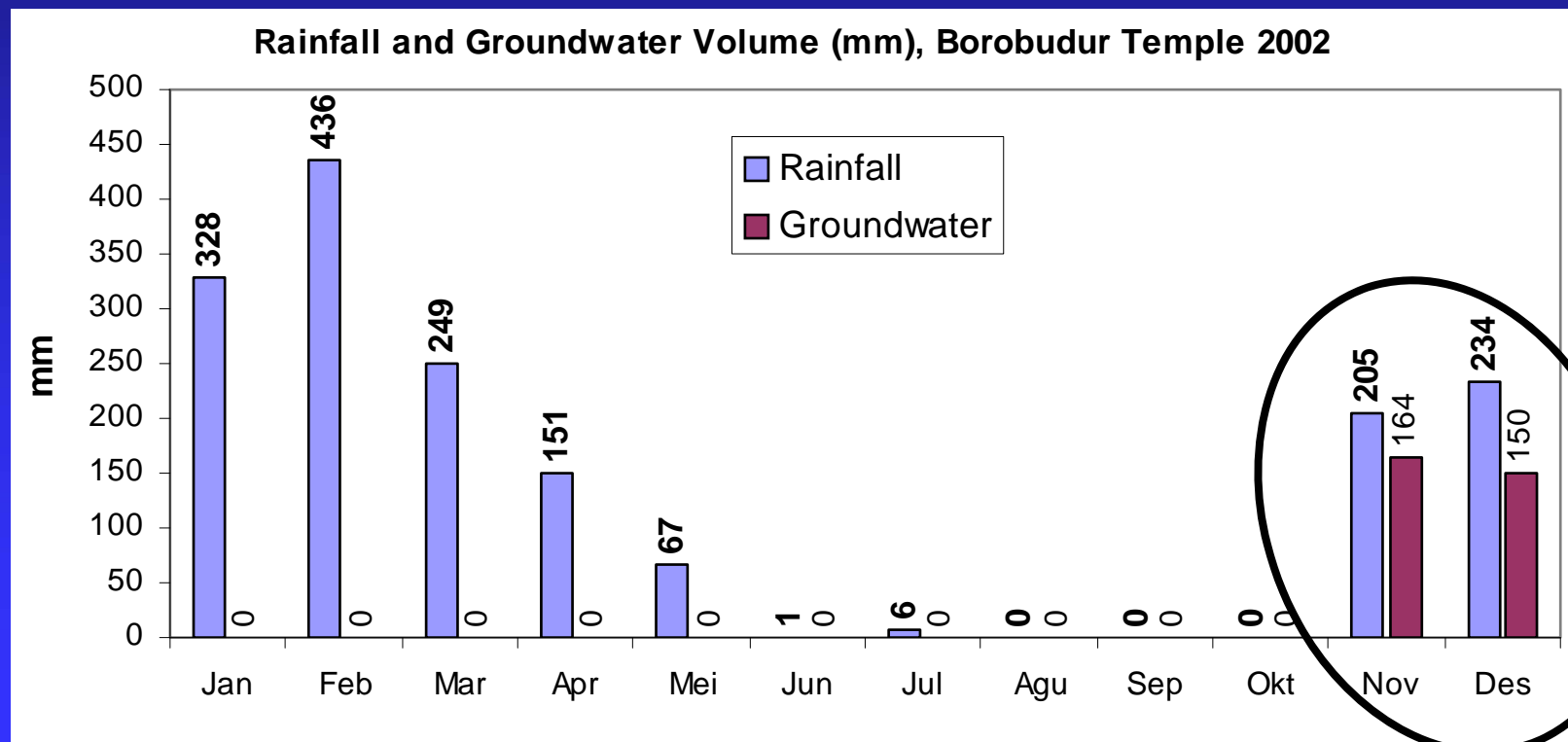
● surface run-off (M)

↑ evaporation (U)

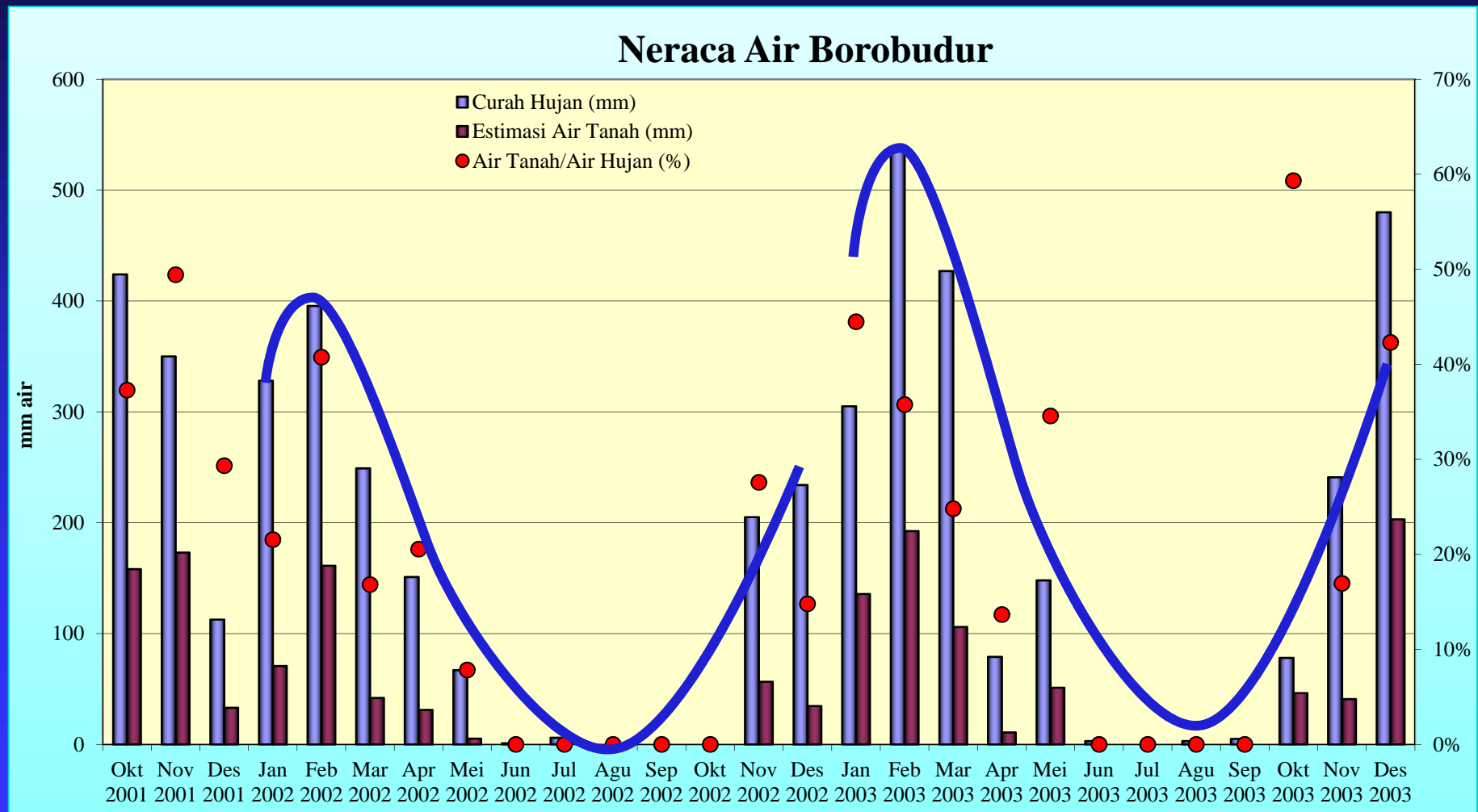
■ groundwater (T)

Groundwater Volume

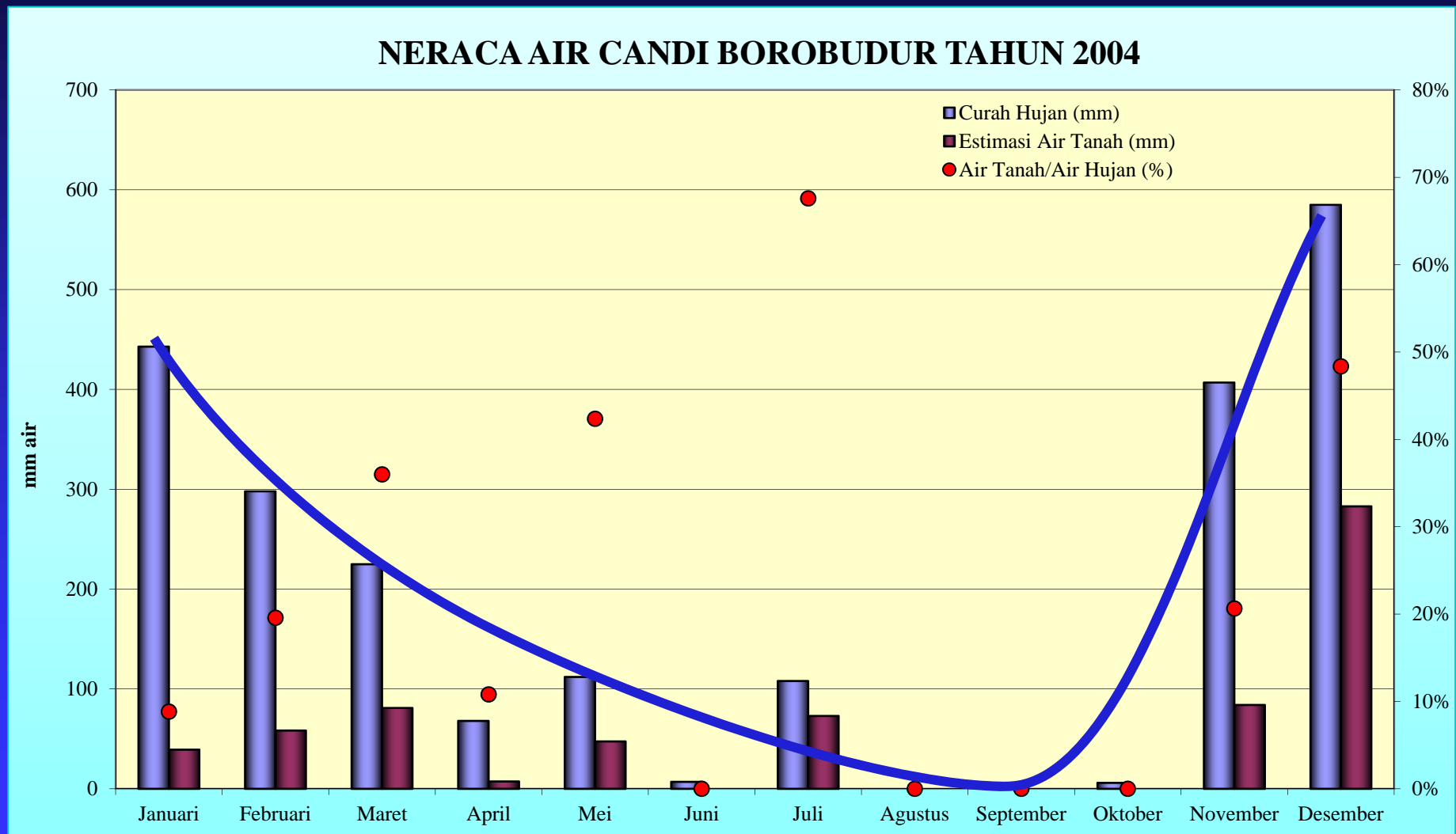
- With the use of simplified water balance, monthly volume of groundwater (mm) can be calculated



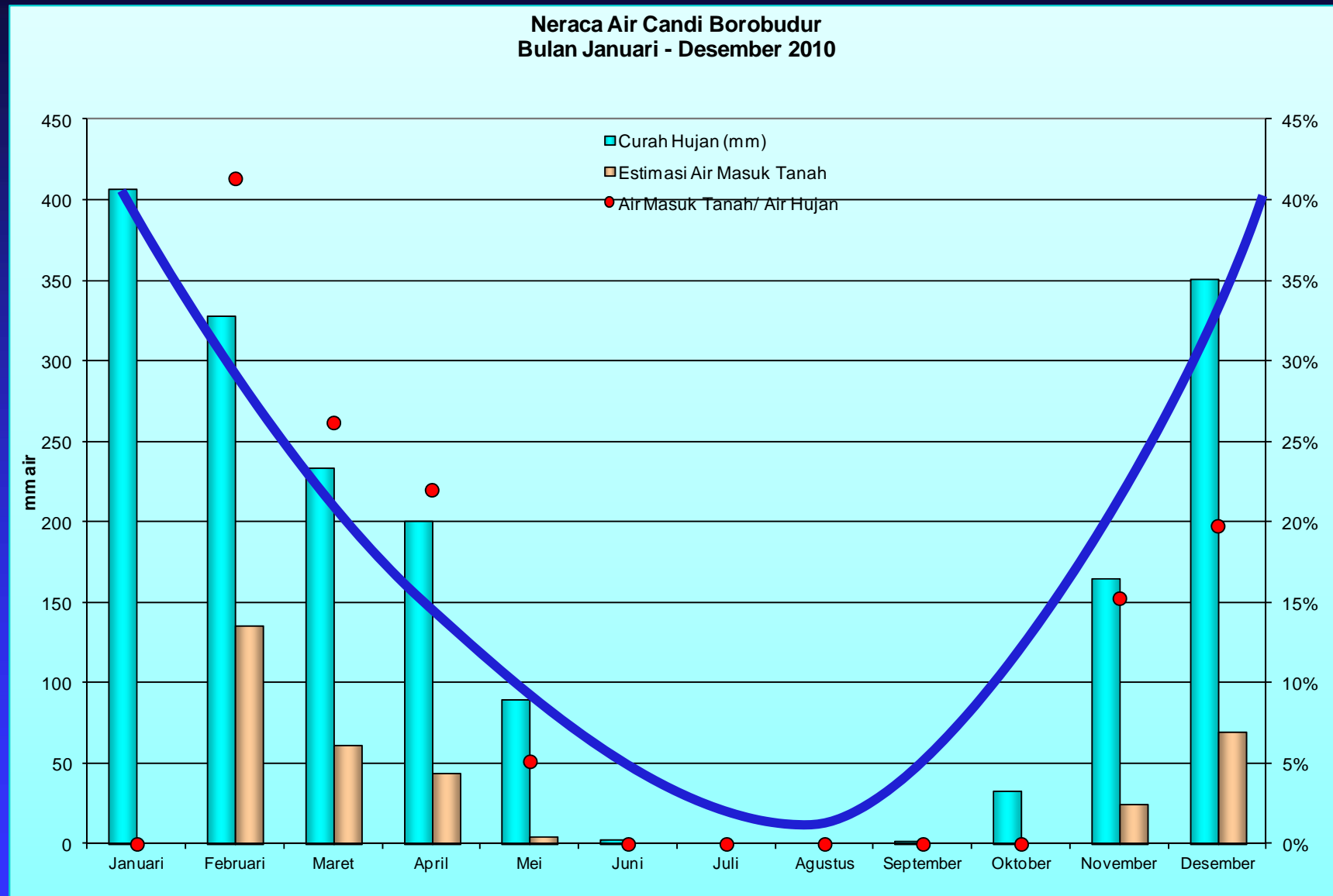
Estimation of groundwater, at Borobudur Oct 2001-Des 2003



Estimation of groundwater, at Borobudur 2004



Estimation of groundwater, at Borobudur 2010

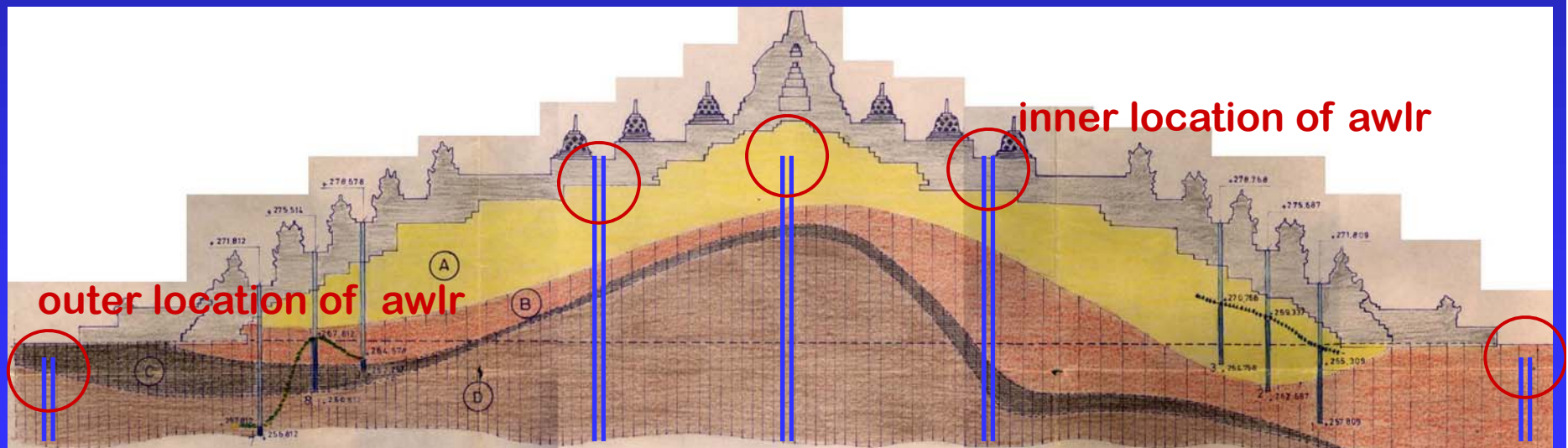


Recommendation

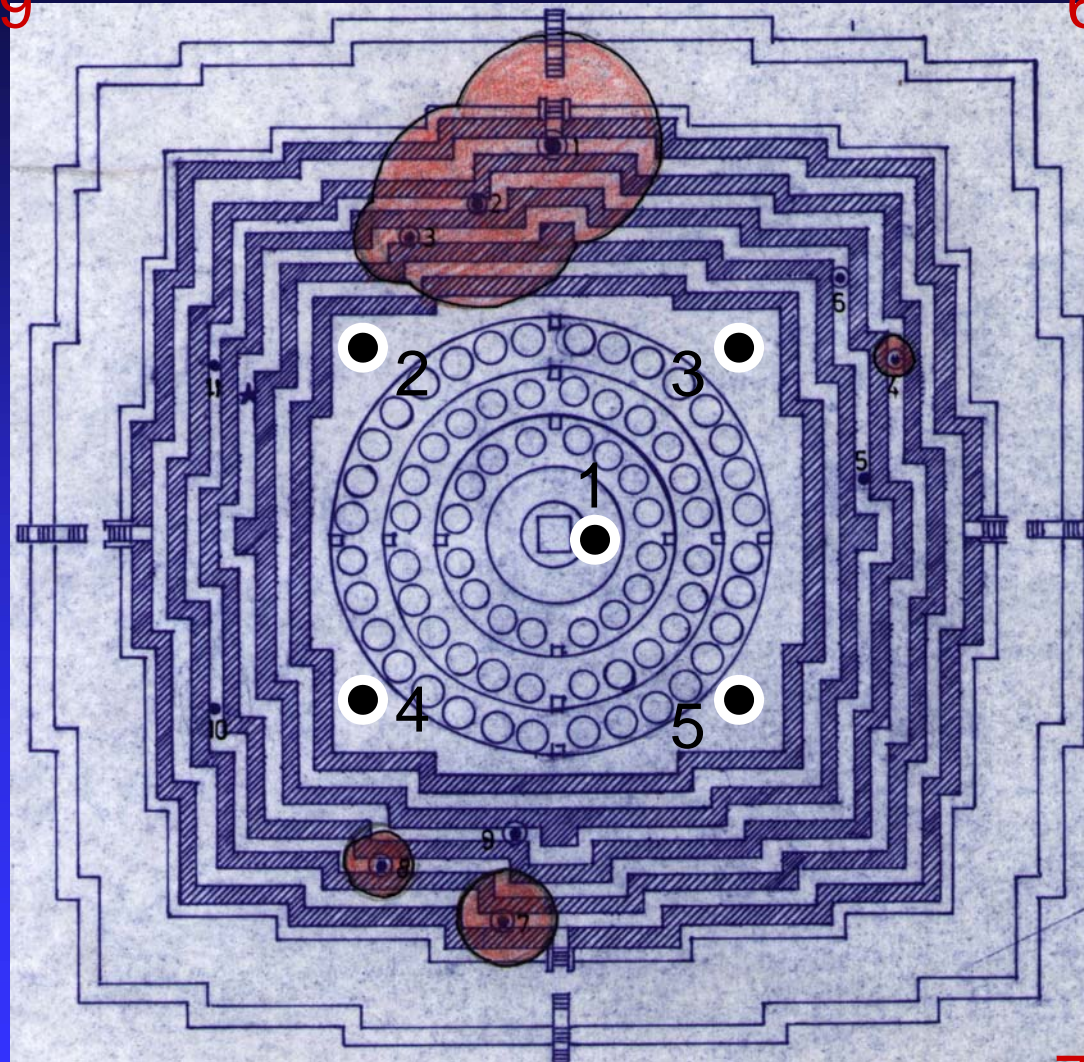
1. The surface water monitoring at Borobudur may still be carried with the improvement of water discharge measurement devices.
2. Direct measurement of groundwater table at the hill beneath Borobudur temple must be carried out using appropriate devices.
 - a. For the time being, the study can only suggest the preliminary layout of the monitoring groundwater table, as describe in next slides.
 - b. The depth of the monitoring devices can not decided at present, since more study from Item a has to be done first.
 - c. More geological investigation shall be done in the future, especially on the hill below the temple in the North-South direction. This geological data is very important when the study of the groundwater hydrodynamic is carried out in that direction.

Location of AWLR

- at the inner and outer rings of the temple
- simple to install
- never destroy any single feature of the Borobudur temple
- the depth of the AWLR will be decided after the more rigorous studies has been done

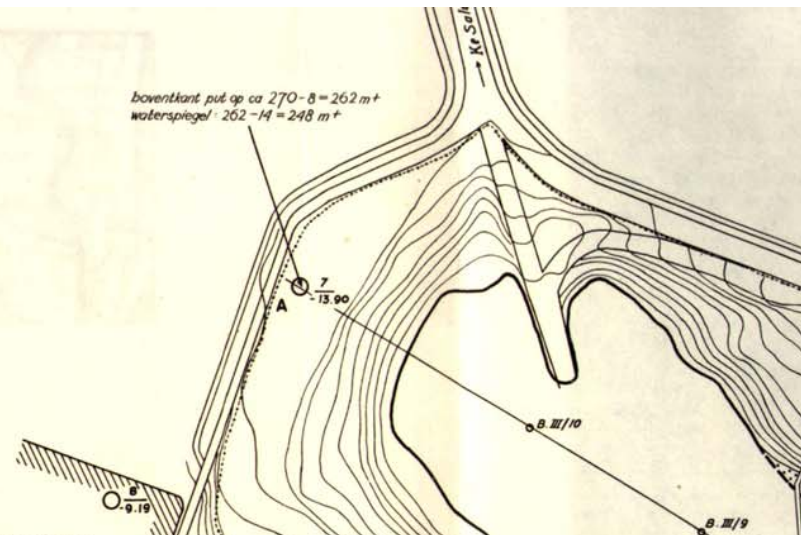


Plan View of AWLR



- Needs 9 AWLR:
 - ◆ 1 at the center
 - ◆ 4 at the circumference of inner ring
 - ◆ 4 at the circumference of outer ring
- The exact location will be decided based on the simplicity of the installation

PETA
BUKIT BOROBUDUR DAN PENAMPANG
SKALA 1 : 2.000



The End

- Penampang sekarang
- Penampang bukit asli pada mulanya.
- ▨ Horizon A
- Horizon B
- Horizon C
- Batas horizon



0 5
-3.66

Related Web of Borobudur Temples

The Lovely Indonesia Tempo Doeloe

- <http://luk.tsipil.ugm.ac.id/itd>

Borobudur temples:

- <http://luk.tsipil.ugm.ac.id/Borobudur>
- Year 2013 ← this presentation
 - ◆ <http://luk.tsipil.ugm.ac.id/proyek/Borobudur/2014/BorobudurTemple-Water.swf>
 - ◆ <http://luk.tsipil.ugm.ac.id/proyek/Borobudur/2014/BorobudurTemple-Water>
 - ◆ <http://luk.tsipil.ugm.ac.id/proyek/Borobudur/2014/BorobudurTemple-Water.pdf>
- Year 2003:
 - ◆ <http://luk.tsipil.ugm.ac.id/proyek/Borobudur/2003/Borobudur6-Jul-2003.htm>
 - ◆ <http://luk.tsipil.ugm.ac.id/proyek/Borobudur/2003/Borobudur6-Jul-2003.pdf>
 - ◆ <http://luk.tsipil.ugm.ac.id/proyek/Borobudur/NeracaAir2001-03.pdf>