

# Climate Change and Safety of Underground Infrastructures

## Bangkok Metro during 2011 Severe Flooding and Proposed Underground Structure for Better and Resilient Bangkok

**Safety versus Economics**  
**Cost-efficiency of tunnel safety measures**

Workshop organized by ITA COSUF,  
in cooperation with the National Italian Committee  
of PIARC, under the auspices  
of the Italian Higher Council of Public Works

Organizer

In cooperation

**COMMITTEE ON OPERATIONAL SAFETY OF UNDERGROUND FACILITIES**  
ITA International Tunneling and underground space Association

WORLD ROAD ASSOCIATION  
MONITORIALE DELLA MOBILITÀ

Under the auspices of

*Consiglio Superiore  
dei Lavori Pubblici*

22 June 2012, CNR Building - Marconi Room - Piazza Aldo Moro 7 - Rome

**Zaw Zaw Aye**  
**Executive Vice President**  
**Seafo Public Company Limited**



# Summary of Presentation

- Overview of Bangkok and Bangkok Metro
- Climate Change and 2011 Severe Flood in Thailand
- Flooding and Safety of Bangkok Metro
- Proposed Multi-Service Flood Tunnel System (MUSTS) for Better and Resilient Bangkok

# Overview of Bangkok & Bangkok Metro

# Thailand – located in Southeast Asia



# Overview of Bangkok & Bangkok Metro

- Bangkok : Capital of Thailand
- Established in 1782 (230 yrs)
- Population : Over 10 million  
(15% of Thailand : 65 million)
- Area : 1,590 m<sup>2</sup>  
(3% of Thailand : 513,000 km<sup>2</sup>)



# BANGKOK in Bird's Eye View



# Major Transportation – mainly by Road



# Travel Demand in Bangkok and its vicinity

commuters mainly travelled by buses and private car

Total

17.2

Mill. Trip/day



Bus 3.5%

6.5

Mill. Trip/day



MRT 4%

Sky Train

0.5

Mill. Trip/day

Subway

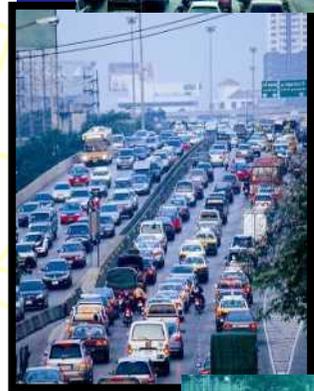
0.2

Mill. Trip/day

Private Car 60%

10

Mill. Trip/day



# Elevated Structure – Industrial Ring Road

Government invested heavily in road construction



# Bangkok Traffic in Rush Hours

People use more cars for daily commuting causing more traffic jams

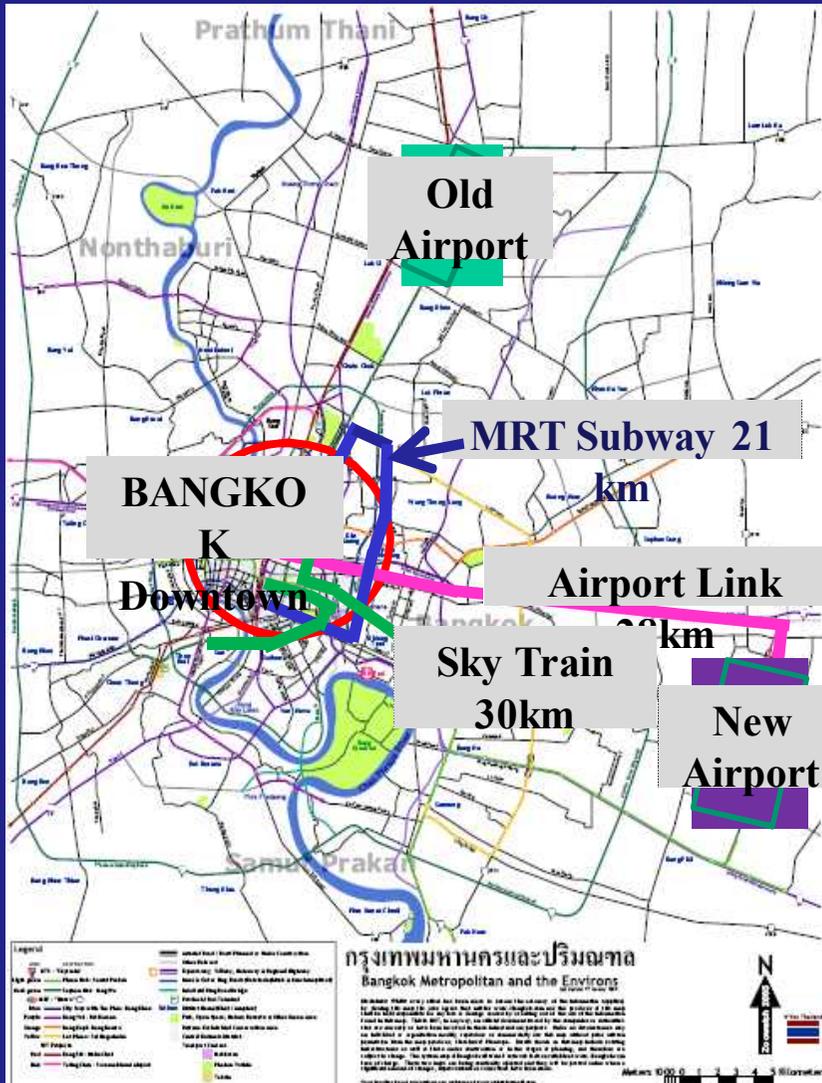


# Bangkok Traffic at Night

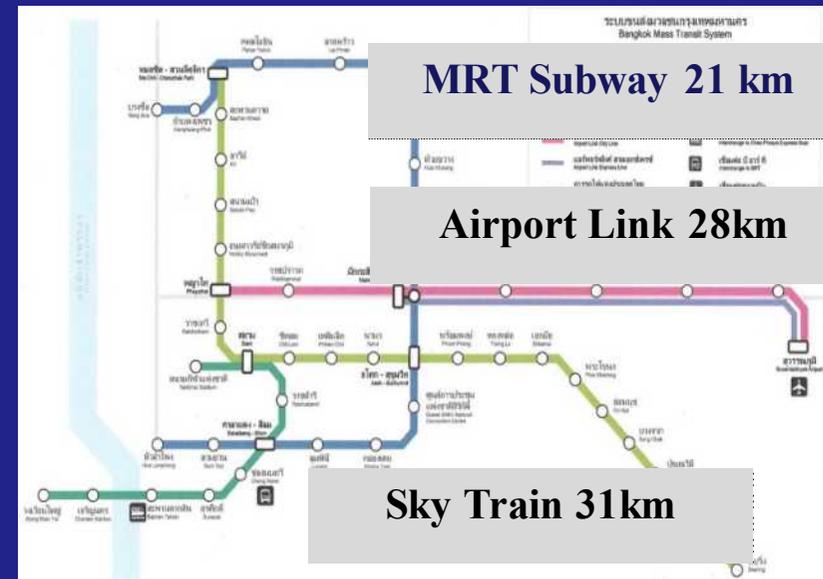


# BANGKOK Mass Rapid Transport Network

Government started to invest in MRT in 1994



Total Length of MRT Network = 80km  
 3 Elevated Lines and 1 Subway Line  
 Subway = 21 km

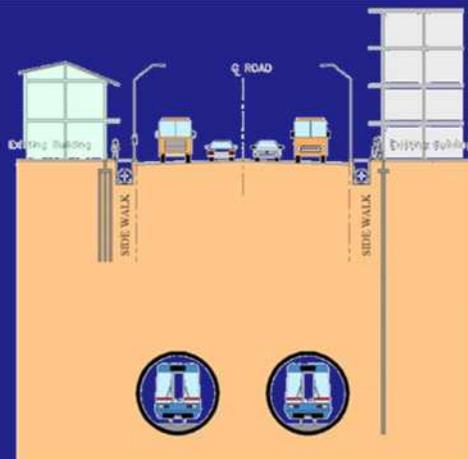




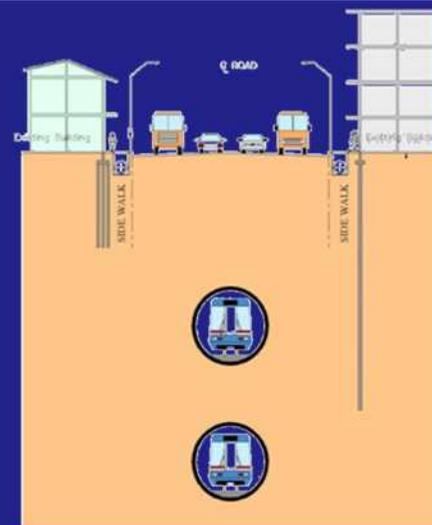
# Bangkok Underground MRT

## *Project Overview*

- Twin Bored Tunnels (Diameter = 6.3m)
- Tunnels were bored by EPB TBM



**Parallel**



**Stacked**

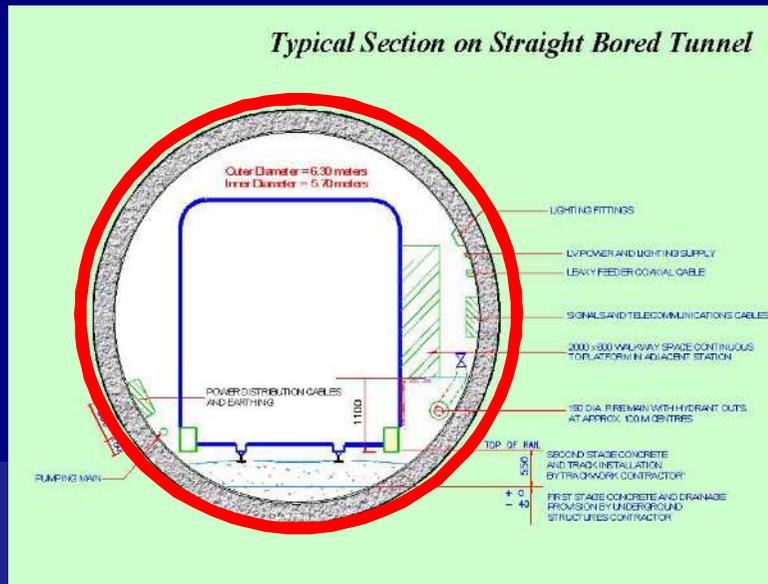
# EPB TBM and Tunnel Construction in Progress

## TBM PARAMETERS : EPB



Over-cut: 10 & 15mm at front & rear body  
Diameter: 6.46 meters  
Total cut diameter: 6.47 meters  
Tail void: 80 mm  
Backfill grouting: spot grouting

*Typical Section on Straight Bored Tunnel*



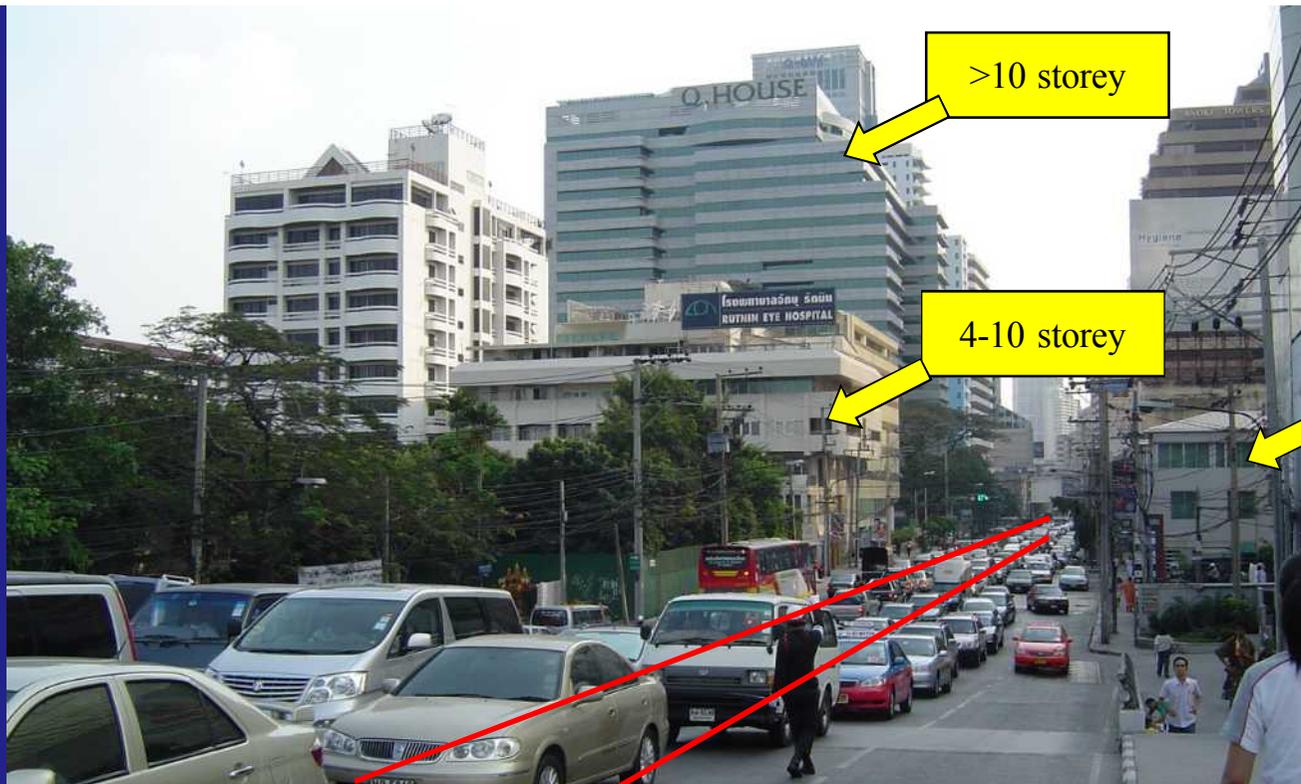
# Segment installation



# MRT STATION BOXES

- 18 Underground Stations constructed by Diaphragm Wall support Top-down method





>10 storey

4-10 storey

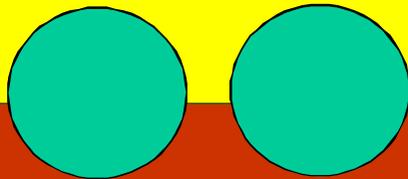
< 3 storey

Fill

Soft to Medium Clay

Stiff clay

First Sand

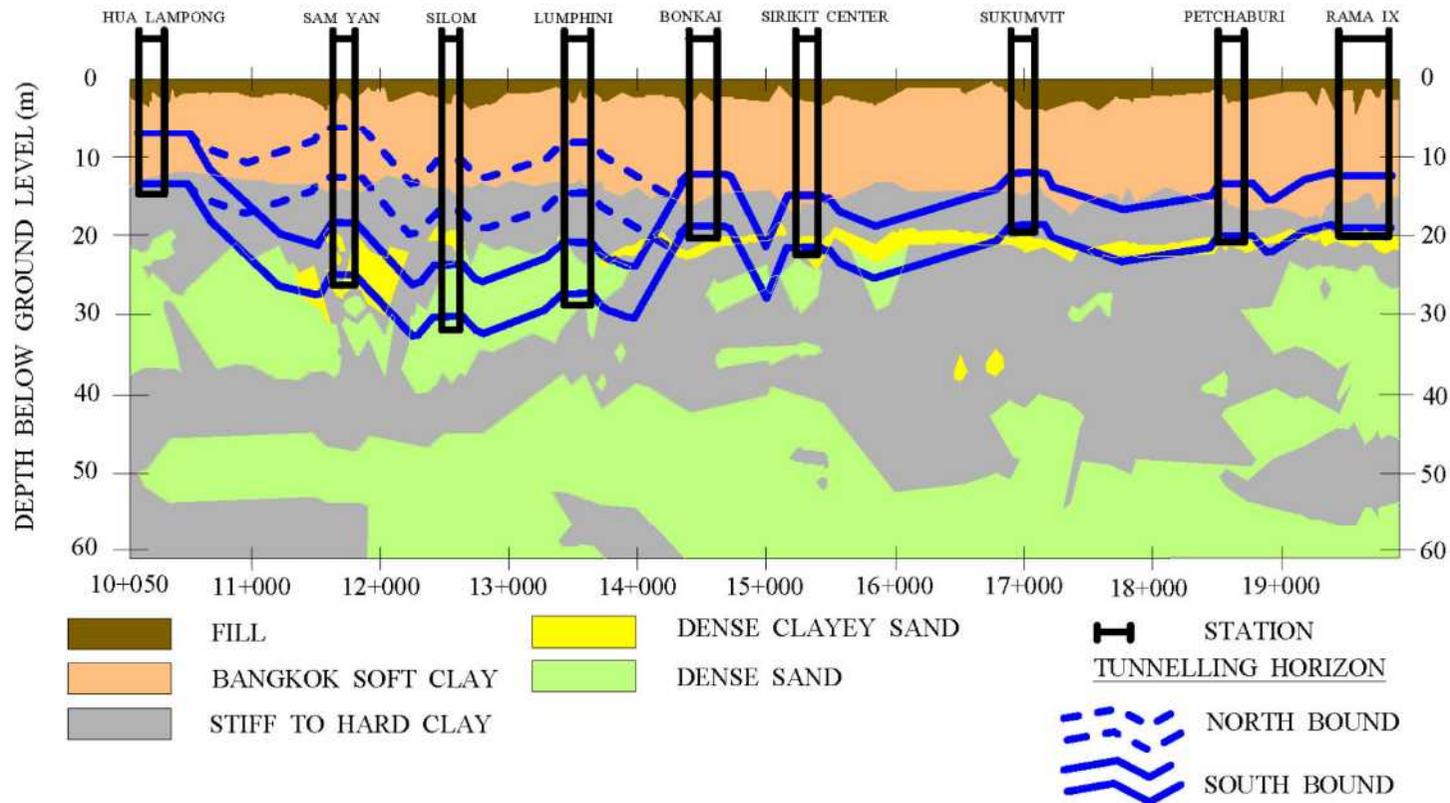


- Tunnels passed through congestive urban area where various types of buildings and structures exist

- Clear distance between adjacent building and tunnel is less than 1.5m at some locations

# Tunnel alignment 20 to 30m below ground level mainly in soft to stiff clay

## Subsurface Condition of South Section



# Completed Tunnel



# Climate Change and 2011 Severe Flood in Thailand

# Historical Floods in Thailand

- 1942 flood : 1.50m flood height : stayed for 2 months
- 1983 flood : Several cyclones, flooded for 3-5 months  
damage 200 million USD
- 1995 flood : 5,400m<sup>3</sup>/s flow, 100 million USD damage in  
Bangkok, 1.6 billion USD outside Bangkok
- 2010 flood : damage 1.6 billion USD



**in 1942**



**in 1983**



in 1995

# 2010 Flooding in Bangkok

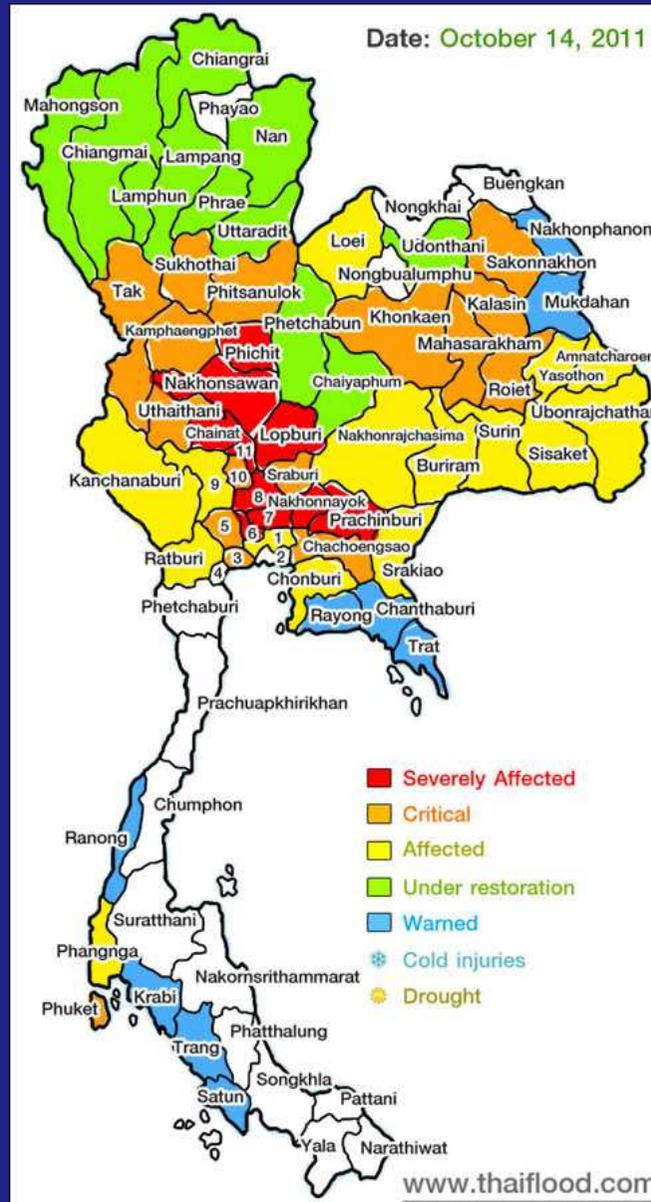


## 2011 Thailand Most Severe Flood Crisis

- The world's fourth largest disaster (cost) as of 2011
- The worst natural disaster in recent Thai history (cost)
- Damage amount 45 Billion USD
- Over 12.8 million people were affected
- Over 6 million hectares of land were under flood water for 1-3 months (11% of the whole country)

# Flood Affected Area (11%)

<b>Severe</b>
<b>Critical</b>
<b>Affected</b>
<b>Warned</b>



# Flooding in Ayuthaya Province (100 km north of Bangkok)



# Flooding North Bangkok and along river bank



เวลาประมาณ 14.00 น. 13 ตุลาคม 2554  
บริเวณริมแม่น้ำเจ้าพระยา หน้า วัดเฉลิมพระเกียรติวรวิหาร จังหวัดนนทบุรี

# Flooding in Industrial Estate 90 km north of Bangkok



# Flooding in Northern Bangkok



# Flooding in Main Road of North Bangkok



# Flooding in North Bangkok (1m to 2m floodwater)



# Flooding in Bangkok



# Flooding in Bangkok Affected to daily life of people



# Flooding in Bangkok Main Road Evacuation in Critical Area



# Flooding in Bangkok (near old airport)



## Flooding inside Underpass Tunnel

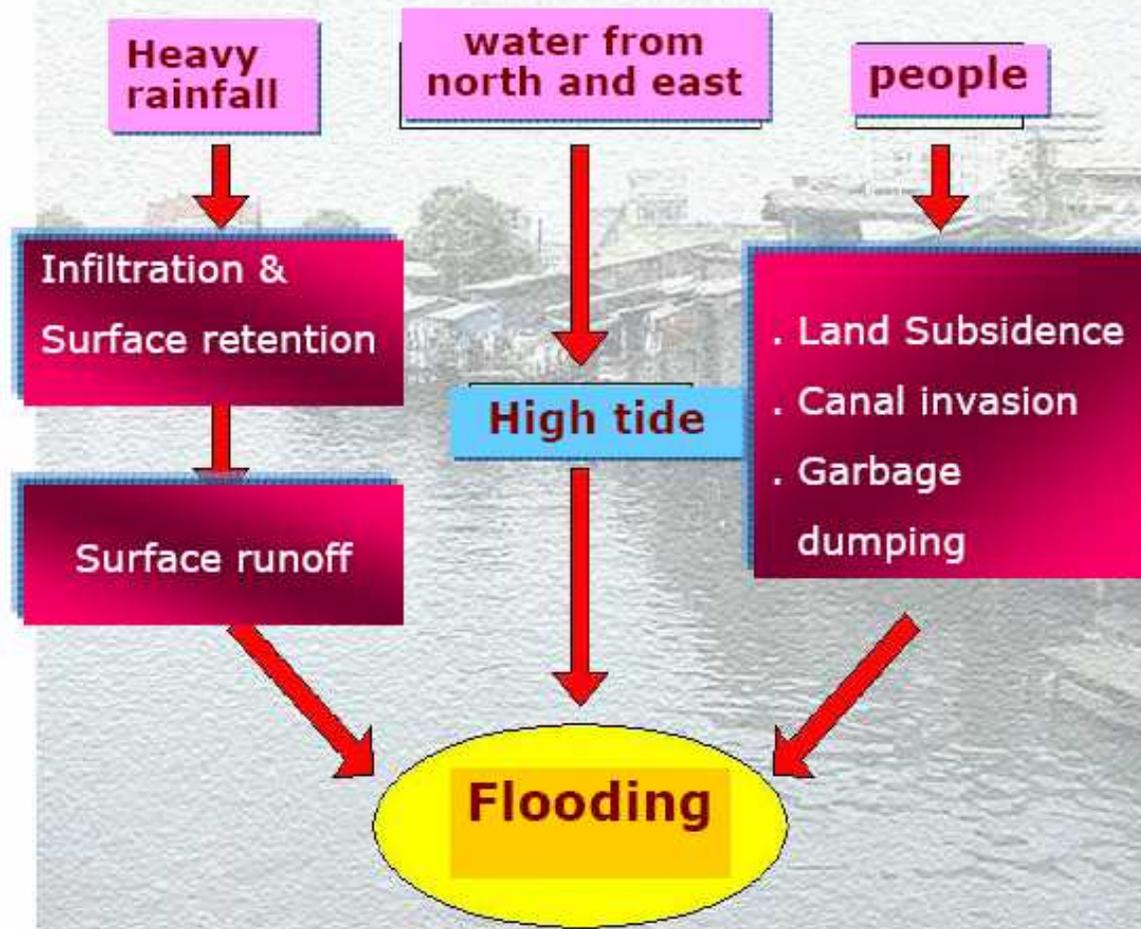


## Major Causes of Severe Flooding in 2011

There are 3 main factors contributed to the severe flooding in upstream provinces and Bangkok itself.

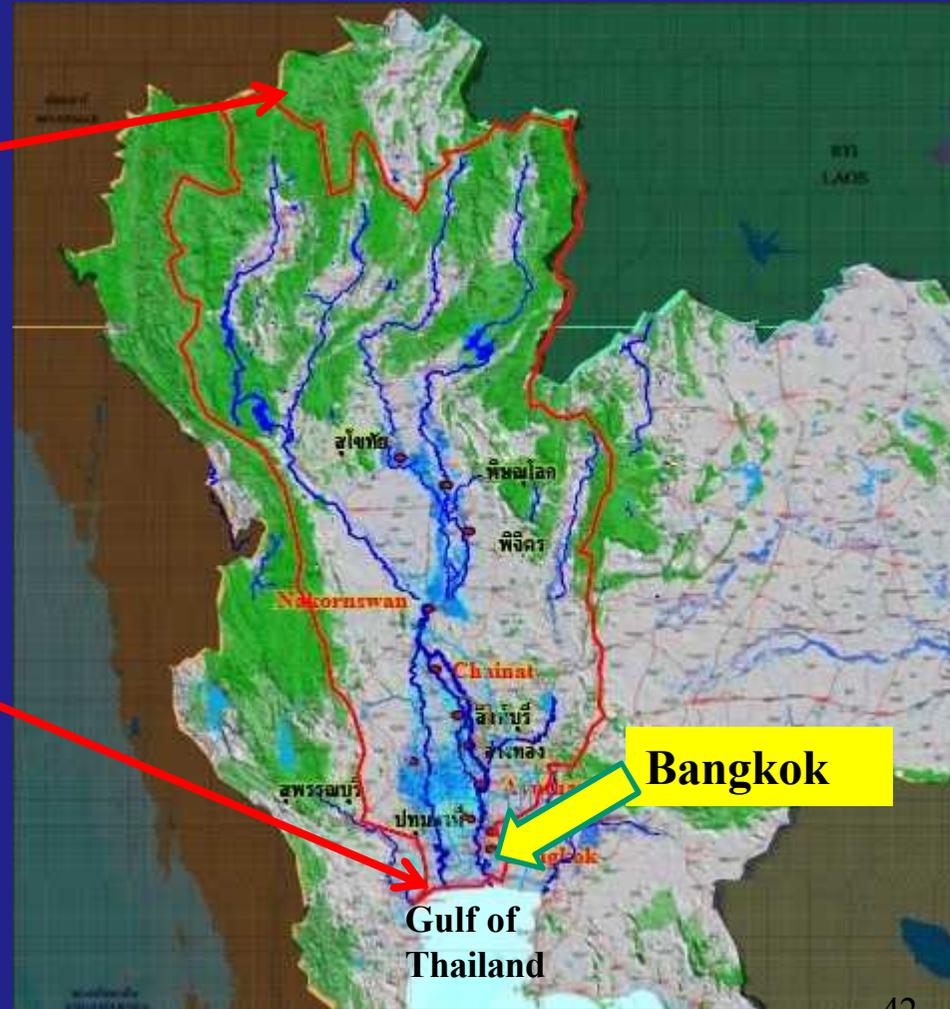
- (1) Excessive rainfall from major typhoons
- (2) Excessive release of water from upstream dams
- (3) Insufficient flood drain system in Chaophaya Basin including Bangkok

# Causes of Flooding



# Chaophaya Basin

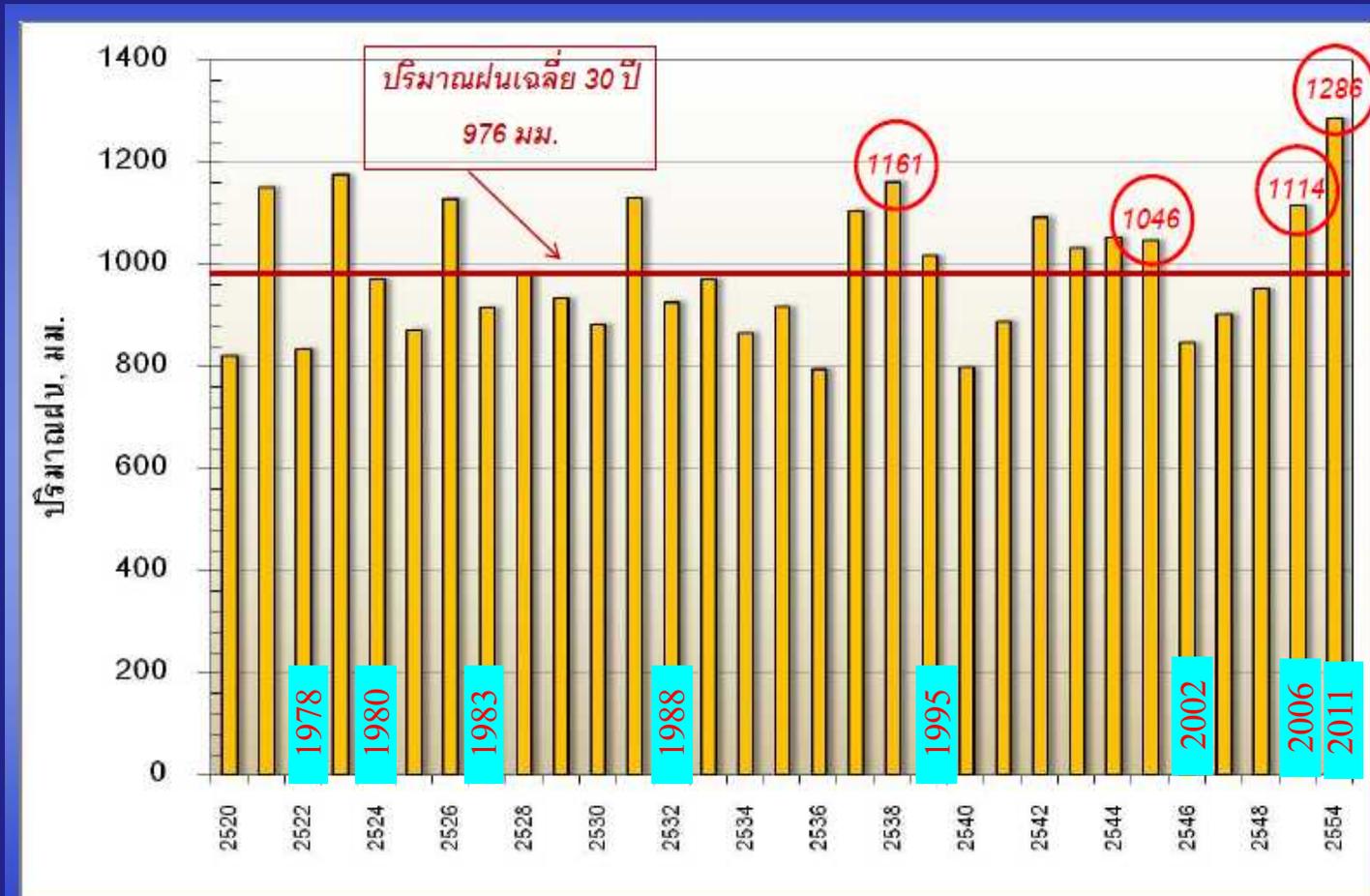
Covers entire central part of Thailand



# Average Annual Rainfall in the Chao Phraya River Basin

Rainfall of Chao Phraya river basin of 2011 was 1,286 mm, the highest in 30-year records,

Rainfall in mm

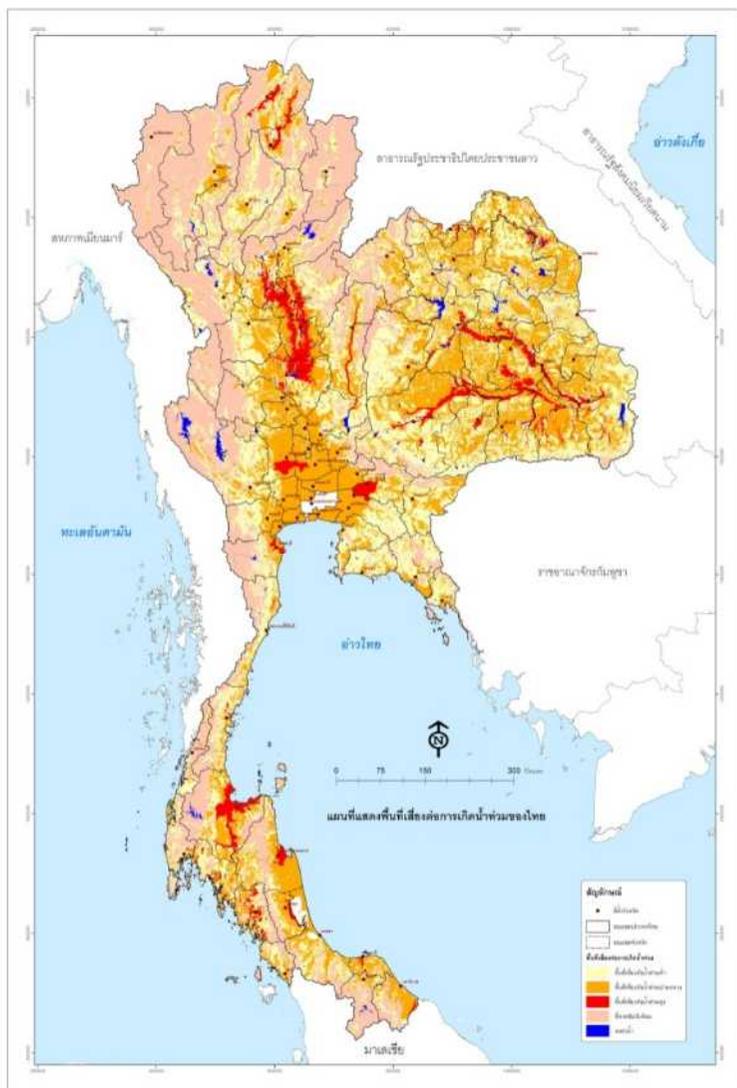


ที่มา : ข้อมูลน้ำฝนจากกรมอุตุนิยมวิทยาและกรมชลประทาน

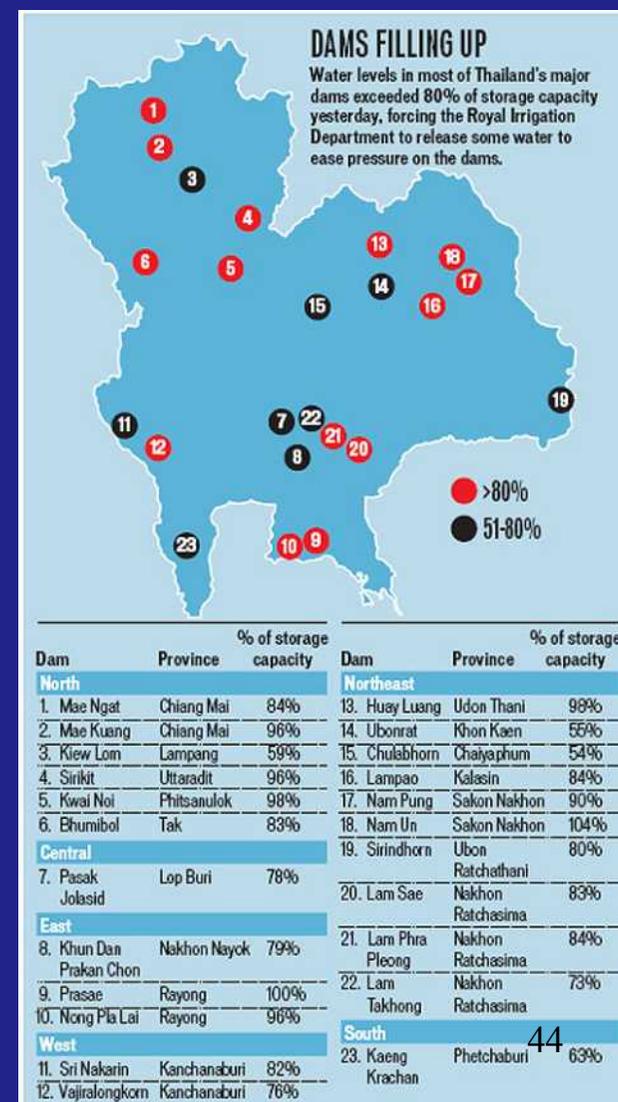
หมายเหตุ ปริมาณฝนย้อนหลัง 30 ปี อ้างอิงจากสถานีวัดน้ำฝน 728 สถานี ปริมาณฝนปี 2554 อ้างอิงจากสถานีวัดน้ำฝน 65 สถานี

# Excessive Water Storage in Dams

## Severe Flood Affected Area in Thailand (2010)



## Dams with over 90% storage capacity (September 2011)



Source: Royal Irrigation Department

POSTgraphics

# Two Major Reservoirs Bhumibol and Sirikit Dam

## Bhumibol dam

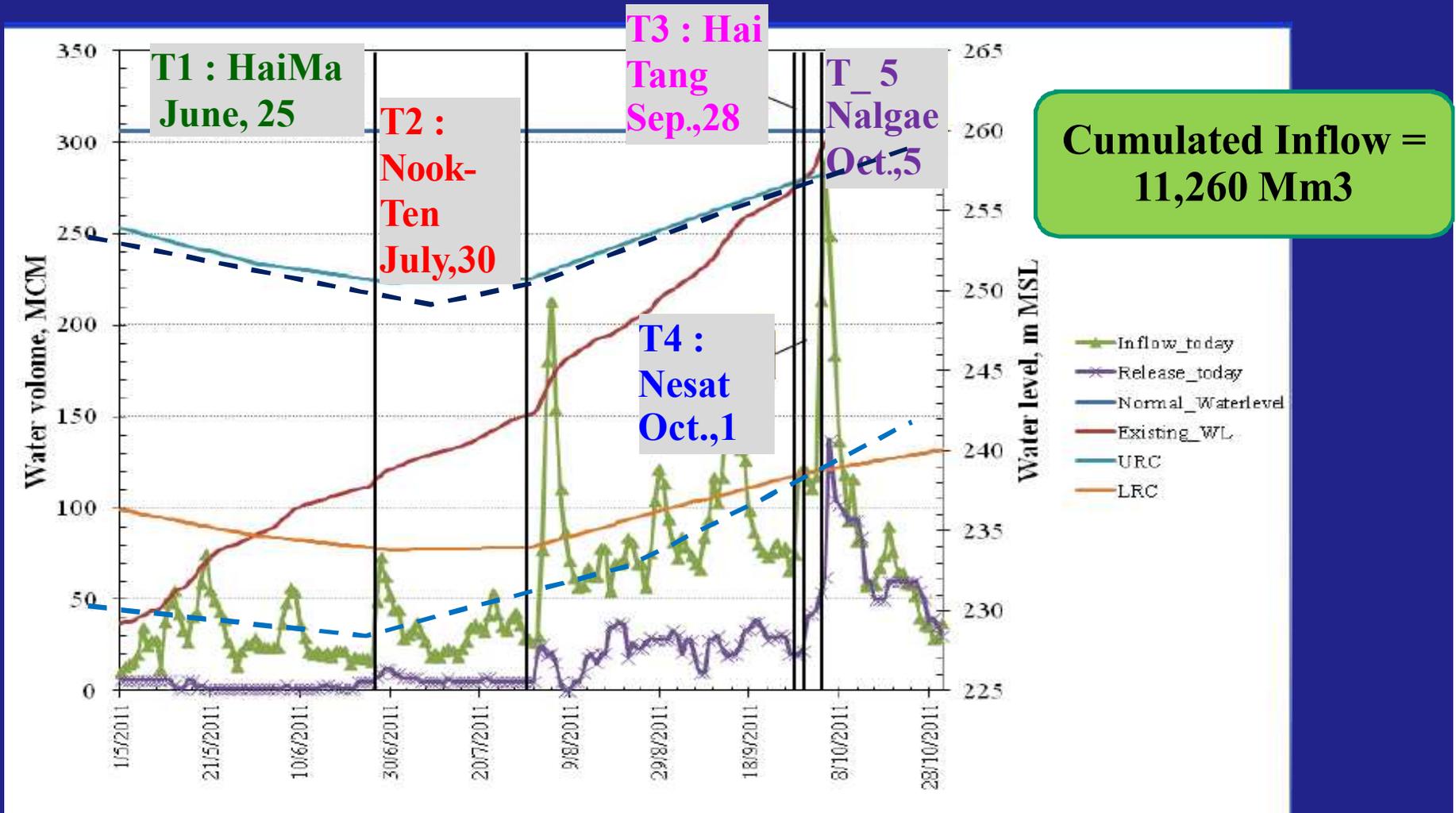
- Type : Arch Gravity Dam  
(H=154m, L=486m, W=8m)
- Capacity : 13,462,000,000 m<sup>3</sup>
- Catchment : 26,400 km<sup>2</sup>
- Surface Area : 300 km<sup>2</sup>

## Sirikit dam

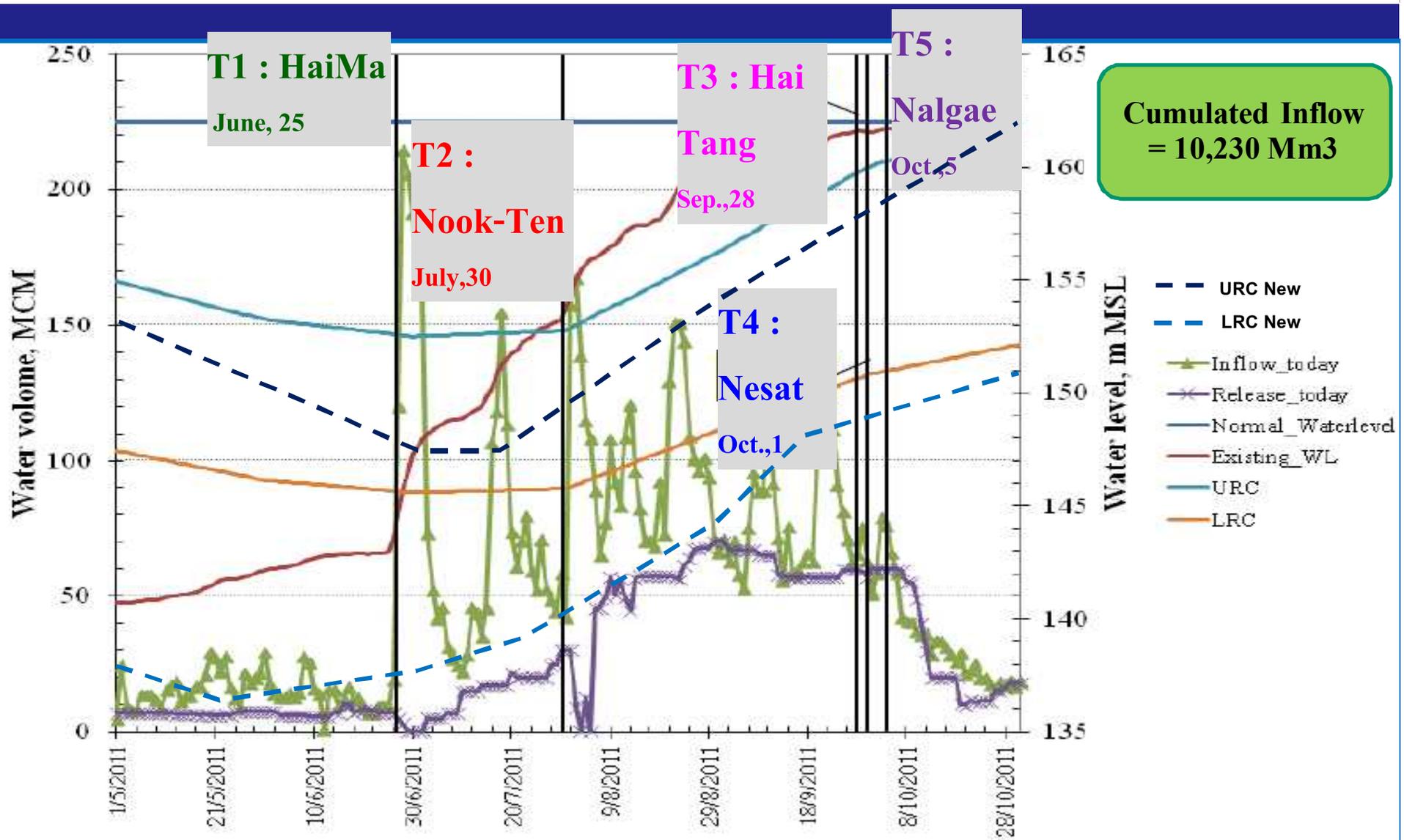
- Type : Embankment Dam  
(H=114m, L=800m, W=12m)
- Capacity : 9,510,000,000 m<sup>3</sup>
- Catchment : 13,130 km<sup>2</sup>
- Surface Area : 259 km<sup>2</sup>



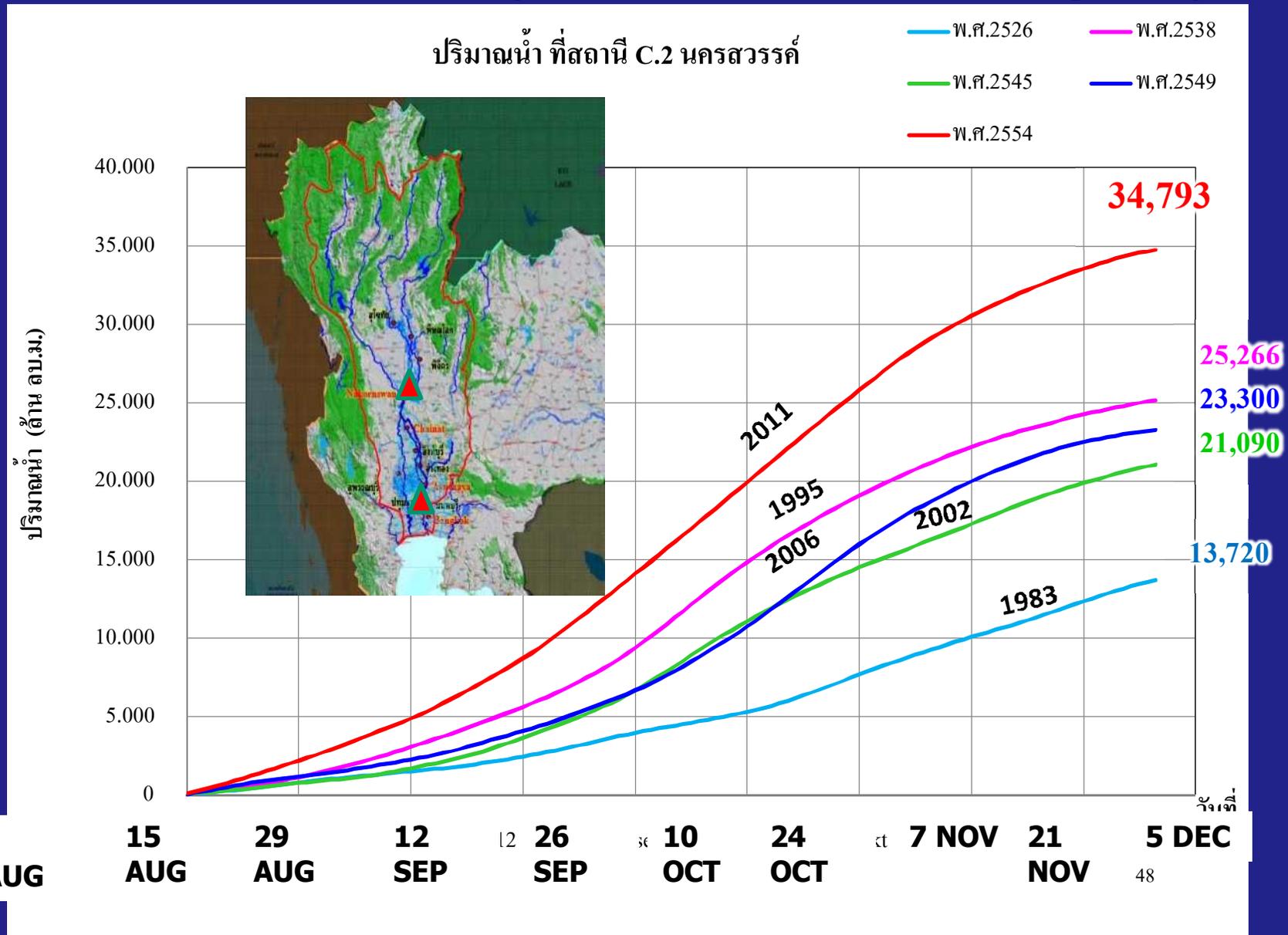
# Water Inflow into Bhumibol Reservoir by 5 Typhoon from June to October



# Water Inflow into Sirikit Reservoir by 5 Typhoon from June to October

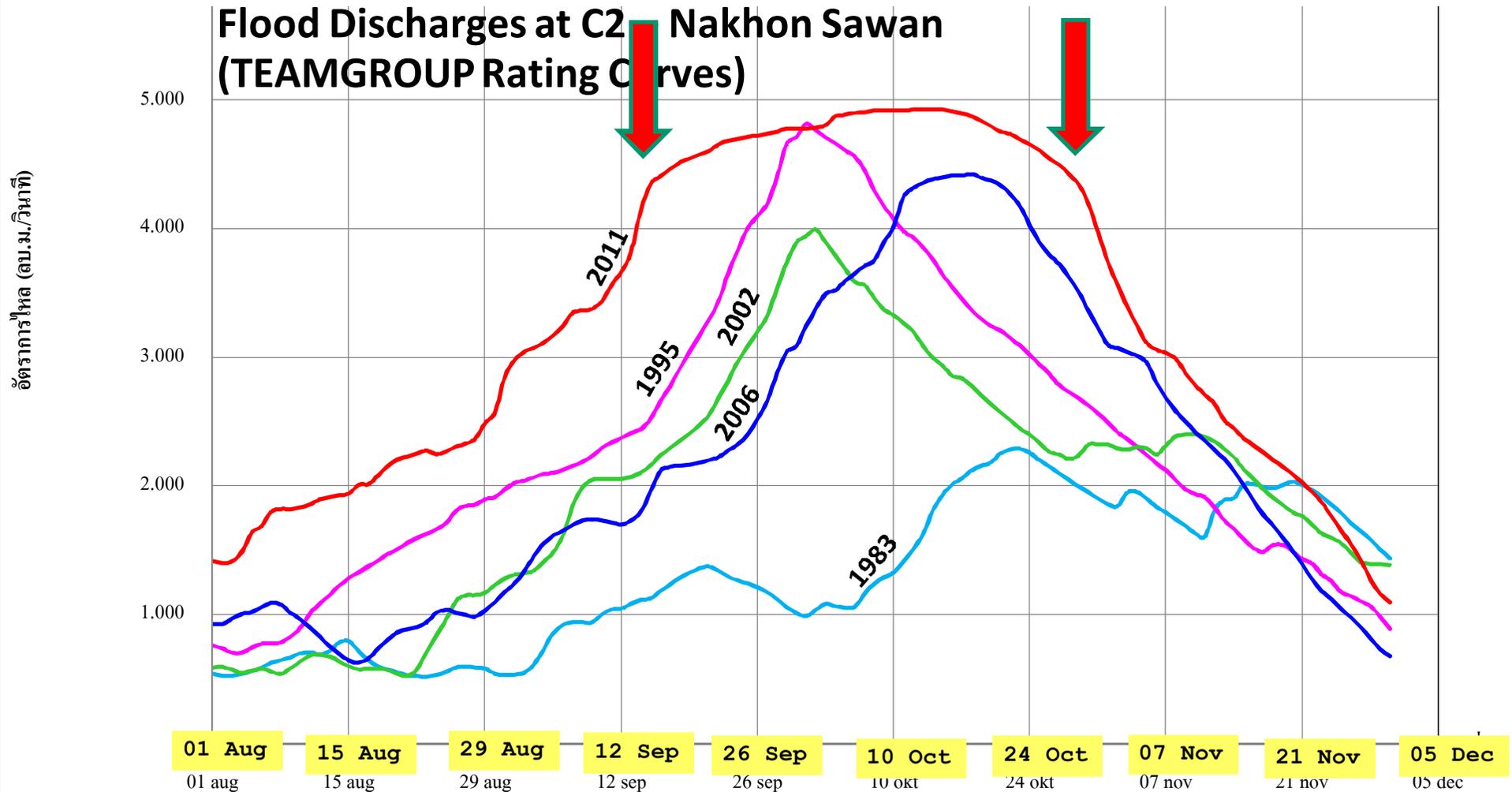


# 50 Years Highest Flood Volume at Nakhonsawan (230km north of Bangkok)



# Flood Discharge at Nakhonsawan (230km north of Bangkok)

**Mm<sup>3</sup> / Day from September to end of October 2011  
was highest volume and duration**

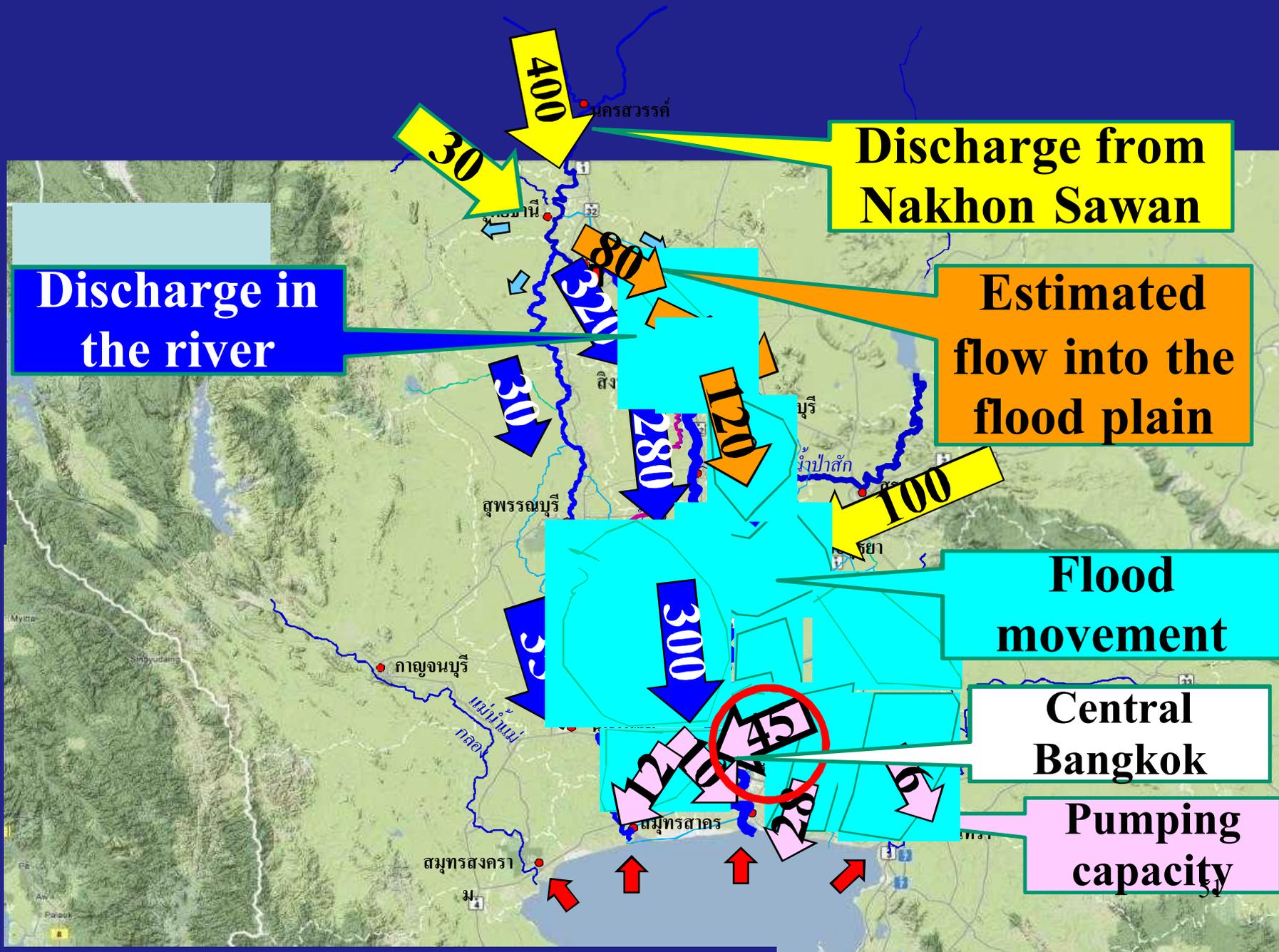


## **Movement of Water toward the sea (passing Bangkok)**

Excessive Water from North of Chaophaya Basin flowed to downstream and to the sea by 2 main ways ;

- Flowing via existing rivers and canals
- Overflow into floodplain

# Flood Discharge (Mm<sup>3</sup>/d) and Flood Movement



# Floodwater Movement

(1) Discharge in the river (2) Overflow to flood plain



# Floodwater Movement by Roads and Underground Drainage Pipes



# 2011 Severe Flood in Bangkok

## Canal Network around Bangkok

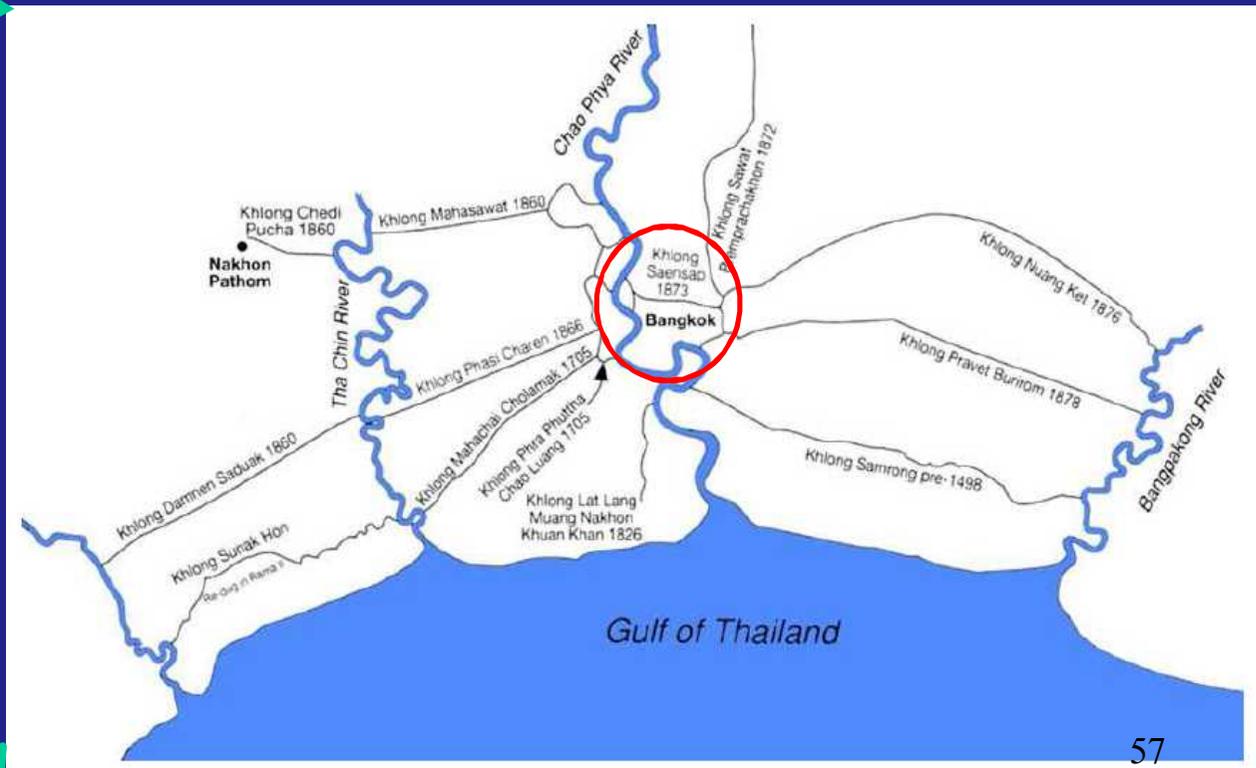
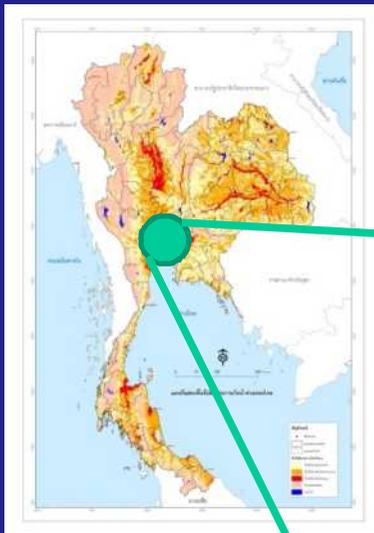
- BMA lies 1,564km<sup>2</sup> along River Bank
- Main Drainage is network of Canals
- Total 1,655 Canals (2,606 km)
- Canal width : 2m to 50 m
- 54 Major Canals with width over 20m
- Collection drainage pipes U-Shape Box or Round Type

## Main Rivers from North flow into the sea through Bangkok and nearby provinces



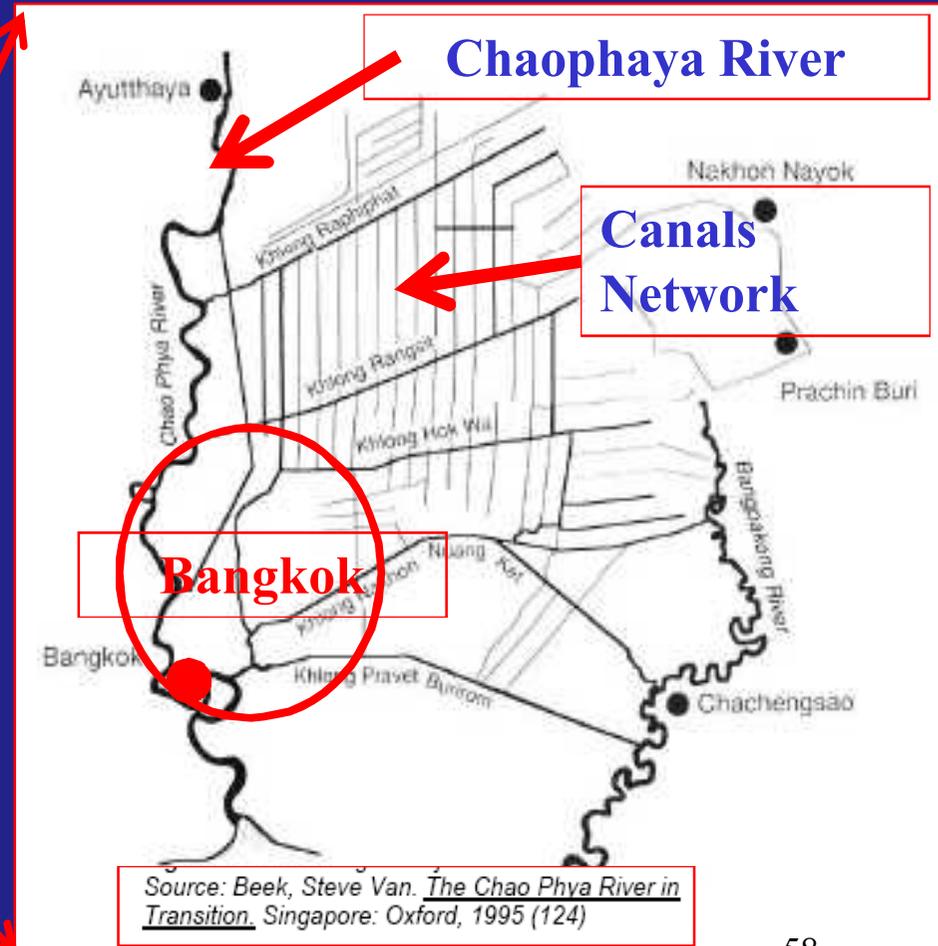
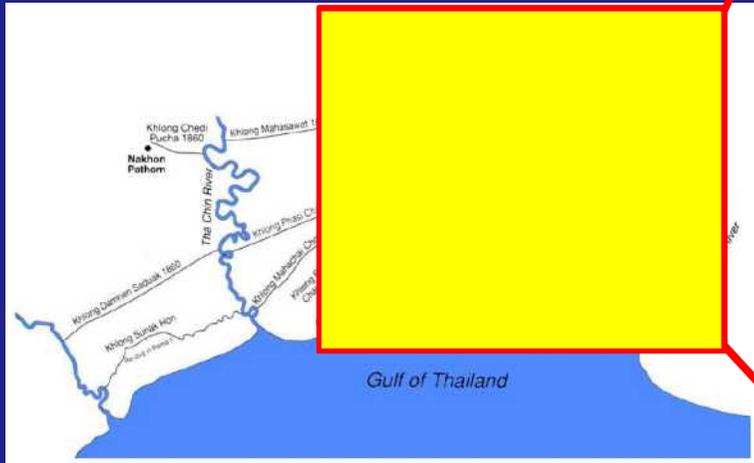
# Chaophaya Lower Basin Waterway Network

## 3 Major Rivers and Main Canals



Source: Beek, Steve Van. *The Chao Phya River in Transition*. Singapore: Oxford, 1995 (122)

# River and Canals in Bangkok and territory



# Bangkok Main River – Chaophaya



# Canal Network

## Major canal



## Small canal



# Rapid Urbanisation of Bangkok (Human Factor in Flooding)

# Bangkok in the past



## Bangkok in early 1990



## Bangkok in 1950



# Growing Bangkok and Environmental Impact

Bangkok in 1950



Bangkok in 2012



# Arial View of Bangkok in the past and present

**1950**



**2012**



# Arial View of Bangkok

1950



2012

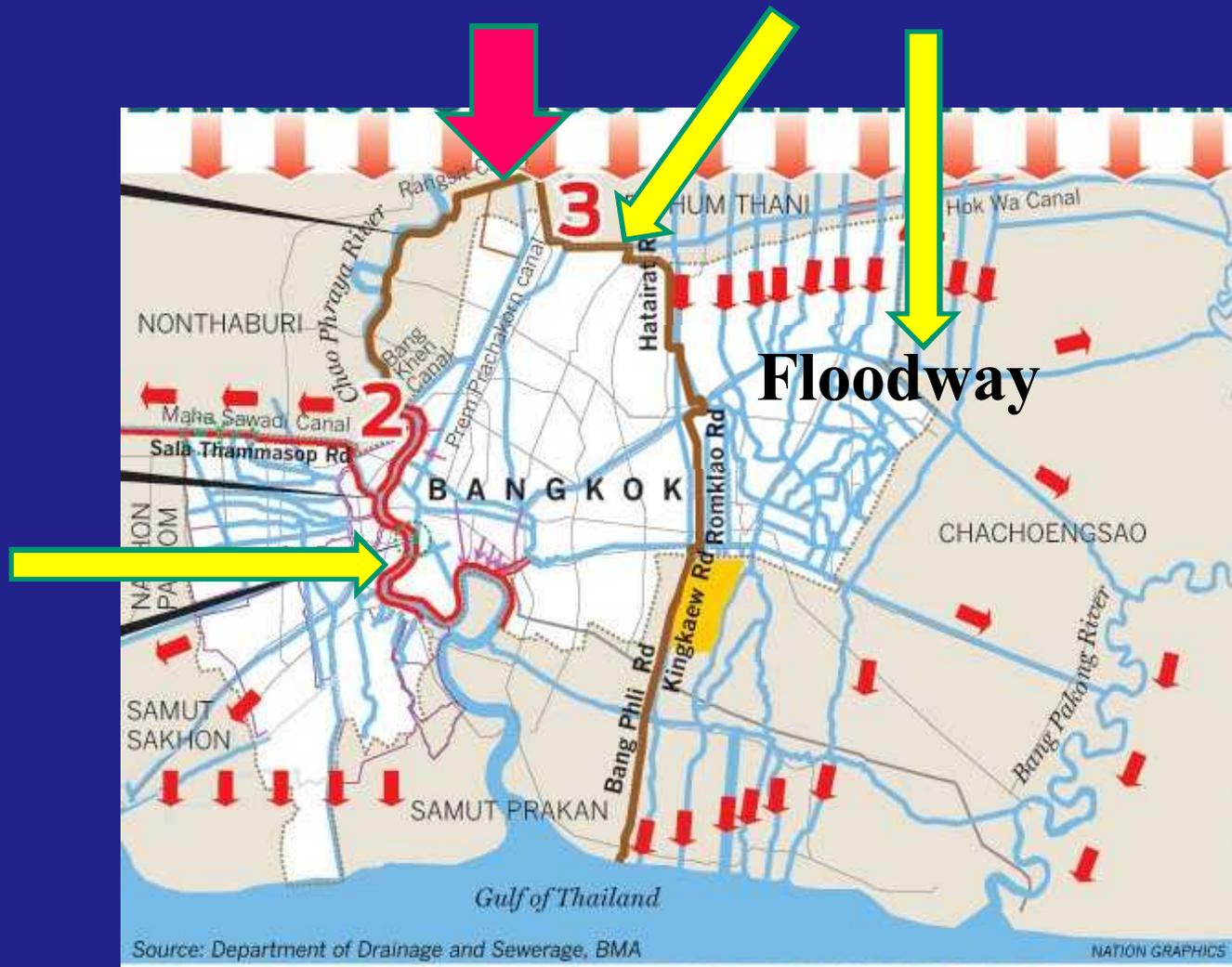


# Chaophaya River



# Overview of Bangkok's Flood-Prevention Plan

- Dyke and Floodwall along Chaophaya River
- Dyke (roads) along northern and eastern Bangkok
- Eastern Bangkok planned to use as Floodway



# Bangkok Flood Protection Plan

**Outer Area : Dyke, Floodway, temporary retention ponds**

**Inner Area : Water control gates installed in canals**

**Middle Area : Flood drain tunnels**

**• Inner Area •**  
Bangkok's City Core Area



**Pumping Station**

- pink-colored dot: permanent station
- green-colored dot: temporary station

**• Outer Area •**  
Rural Area Surrounding Bangkok




**• Middle Area •**

Left:

- rainwater retarding pond
- drainage tunnel to discharge rainwater




Upper:

- flood plain

Middle:

- agricultural canal

Lower:

- King's Dike

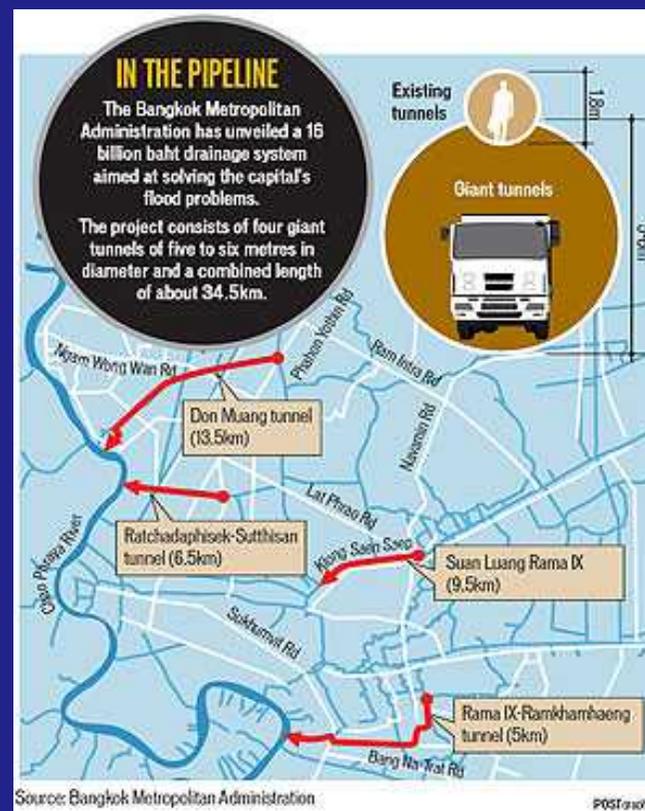
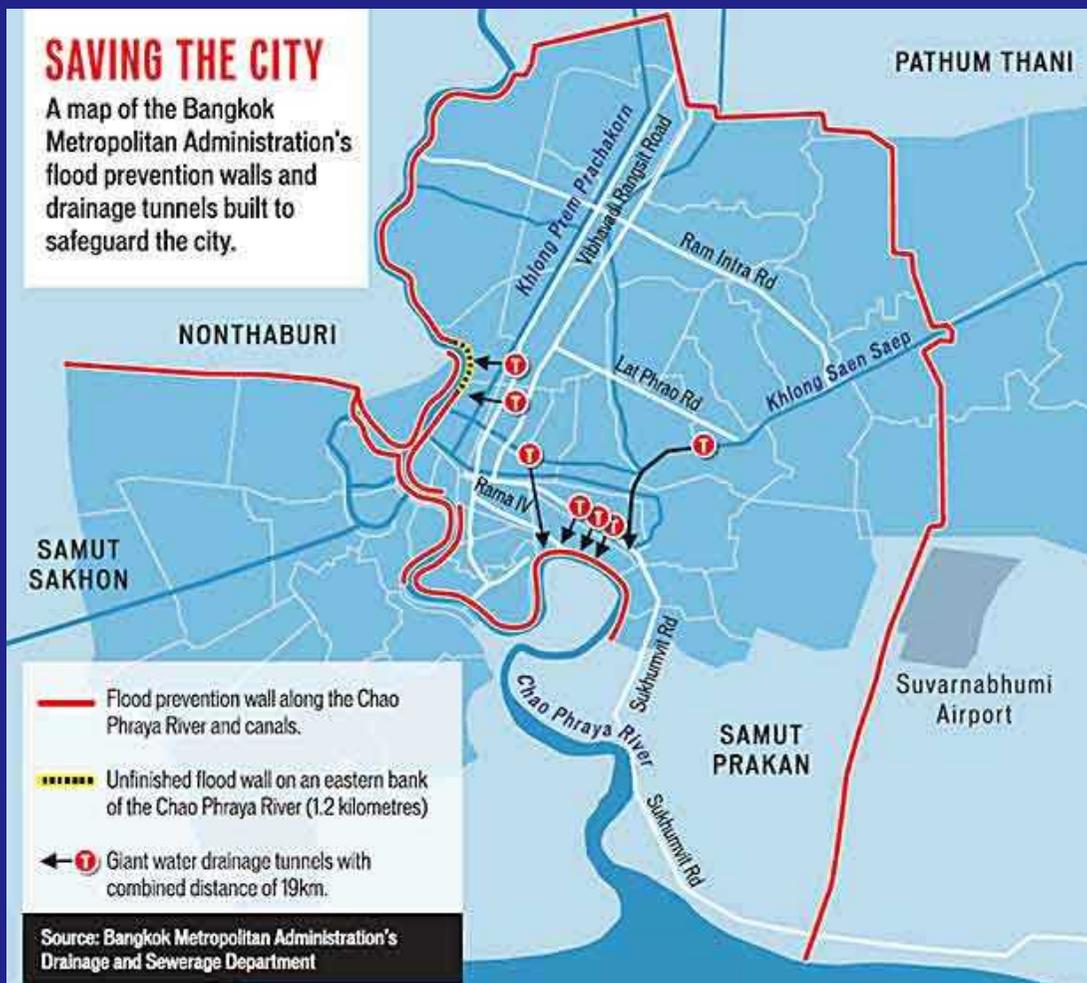


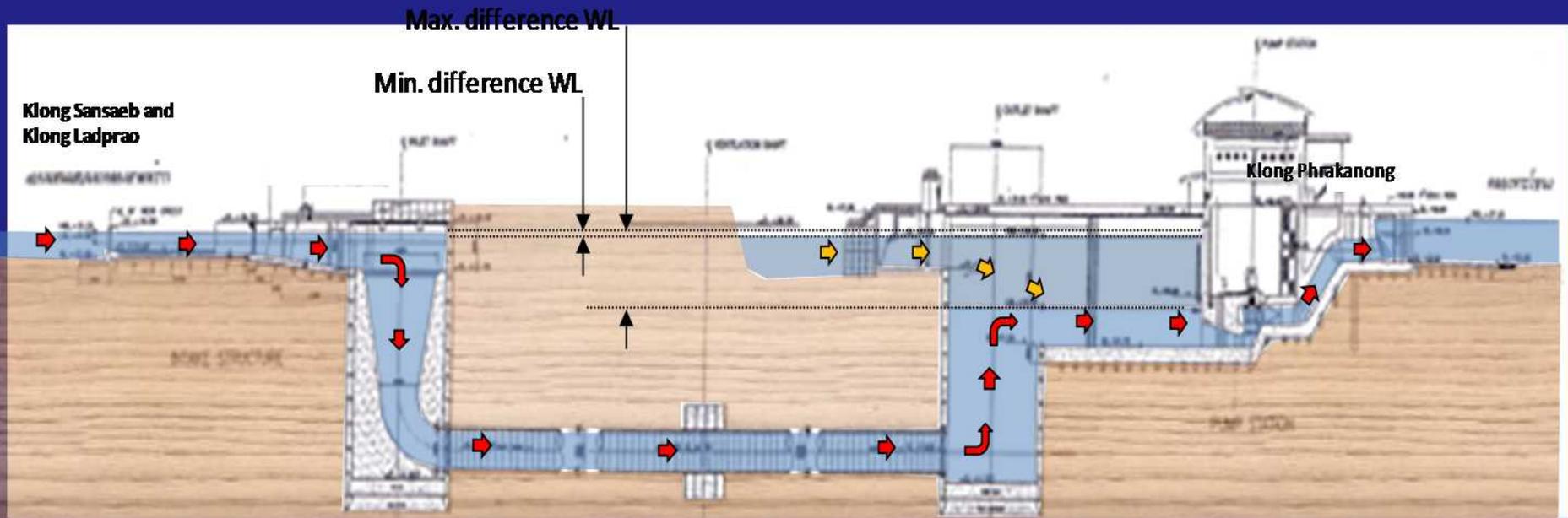
# Bangkok Flood Protection Plan

## Pumping Stations & Water Control Gate



# Flood Tunnels in Bangkok





รูปตัดตามยาวของแนวอุโมงค์ผันน้ำ

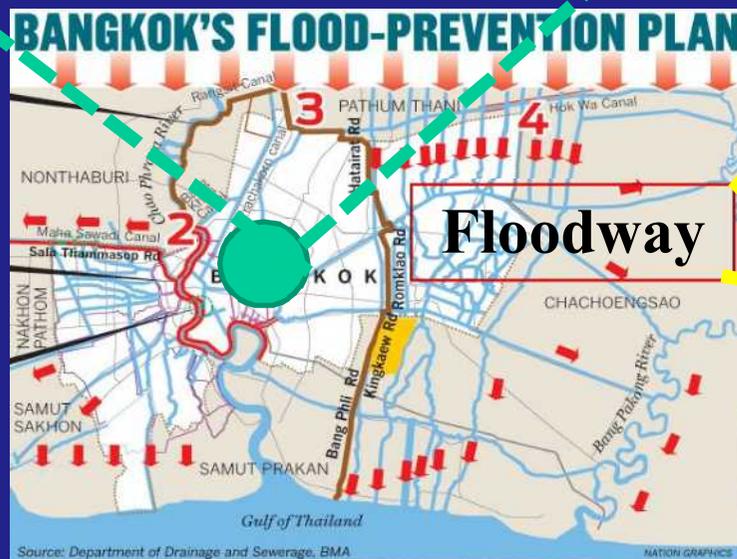


# Rapid and extensive urbanisation of Bangkok play key role in Flood Protection Plan

City Center (highly populated metropolitan)



Existing Land Use in Floodway (factory, residents etc.)



# BMA Initial Plan of Protecting Bangkok

- Initial stage of floodwater coming from the north BMA had simple plan
- Drain floodwater from East and West of Bangkok to the sea to protect Central Bangkok



# Final Defense

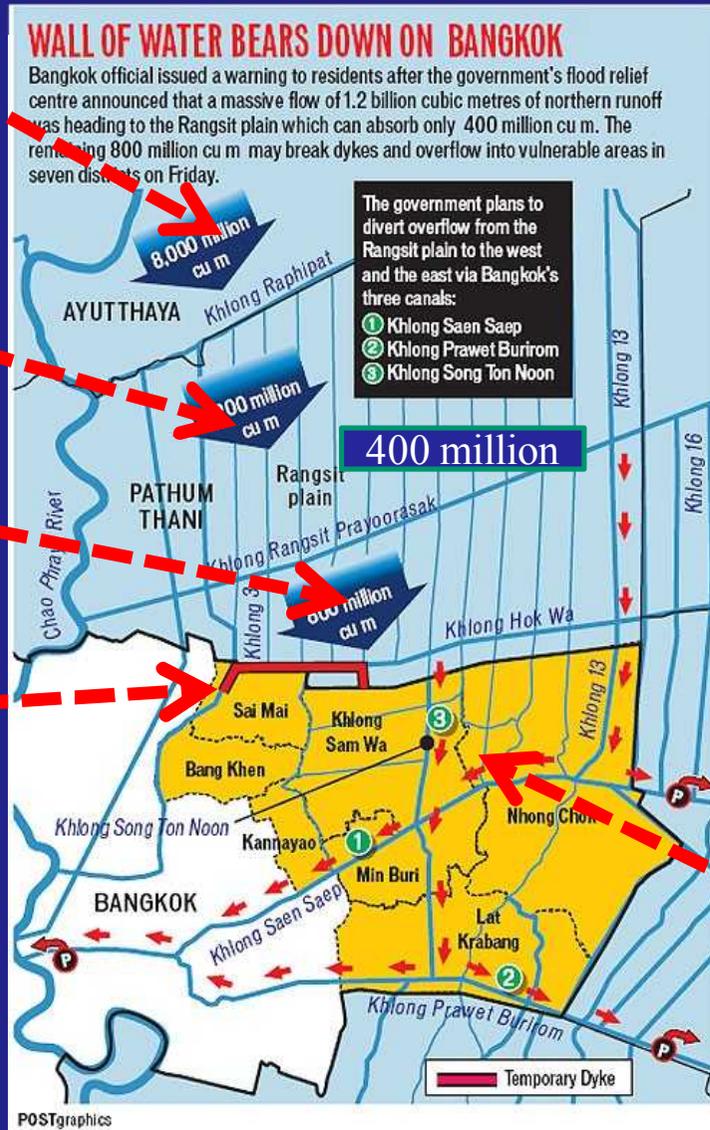
- Total 8 billion m<sup>3</sup> water was coming toward Bangkok
- 800 million m<sup>3</sup> may break dyke and overflow into inner area

8,000 million m<sup>3</sup>  
80 km north of Bangkok

1,200 million m<sup>3</sup>  
50 km north of Bangkok

800 million m<sup>3</sup>  
20 km north of Bangkok

Temporary earth dyke and sand bags to block water



Pumped and drained to major canals

# Emergency Flood Walls



Sand Bags

# Emergency Flood Walls





## Protection for Car



# Ayuthaya and Pathumthani (20km north of Bangkok)

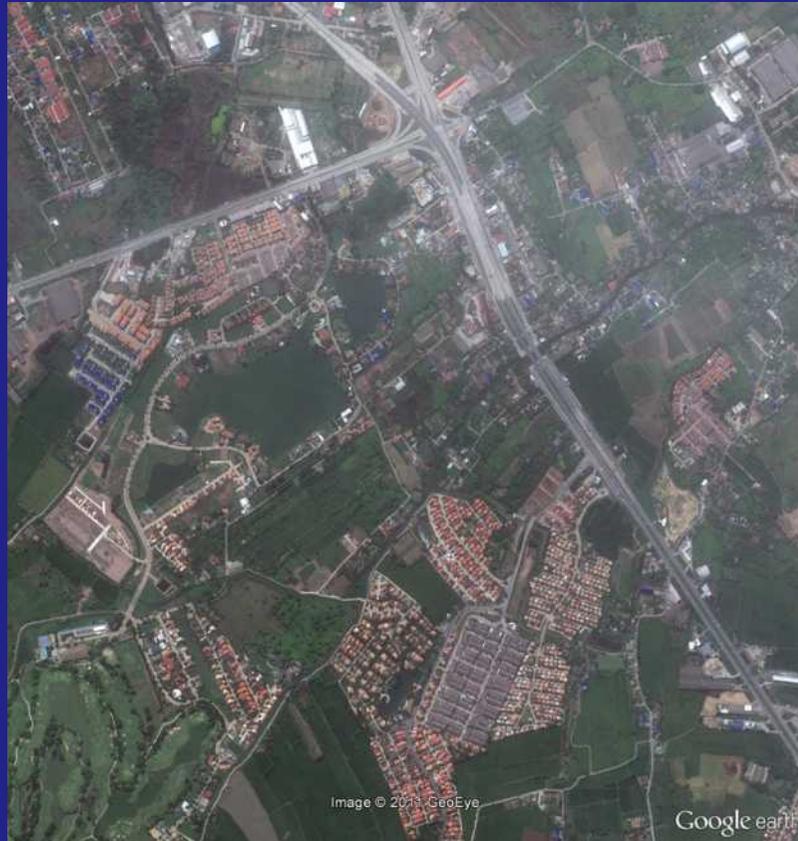


July 2011  
(no flood water yet)

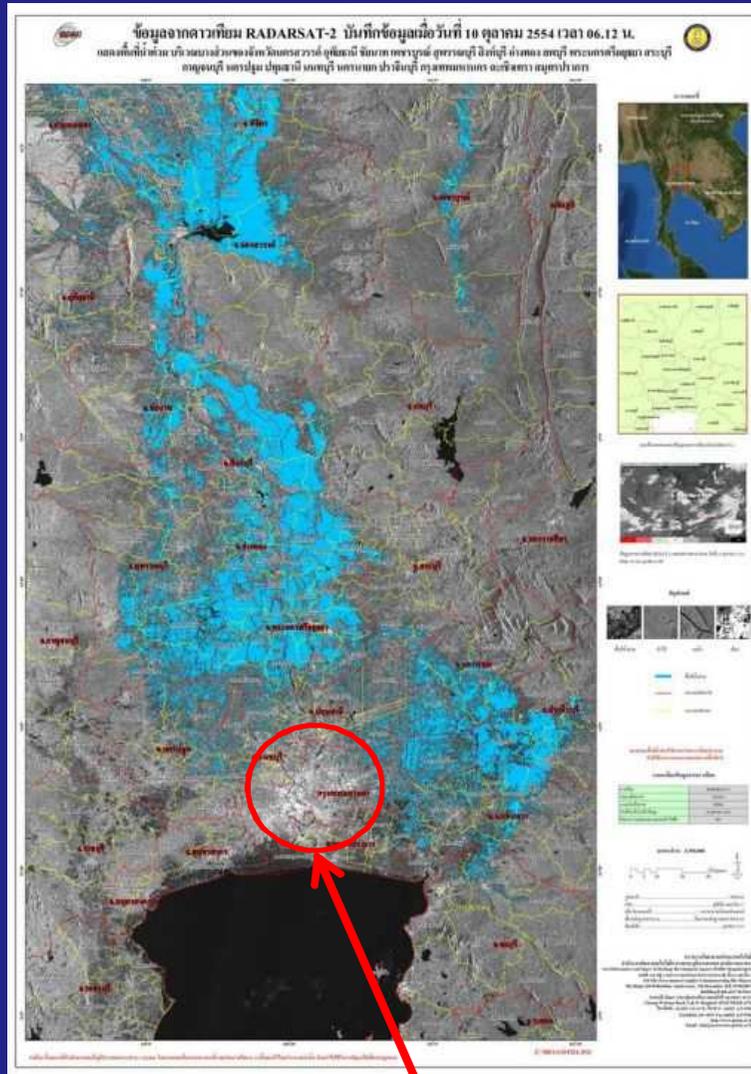
October 2011  
(completely flooded)



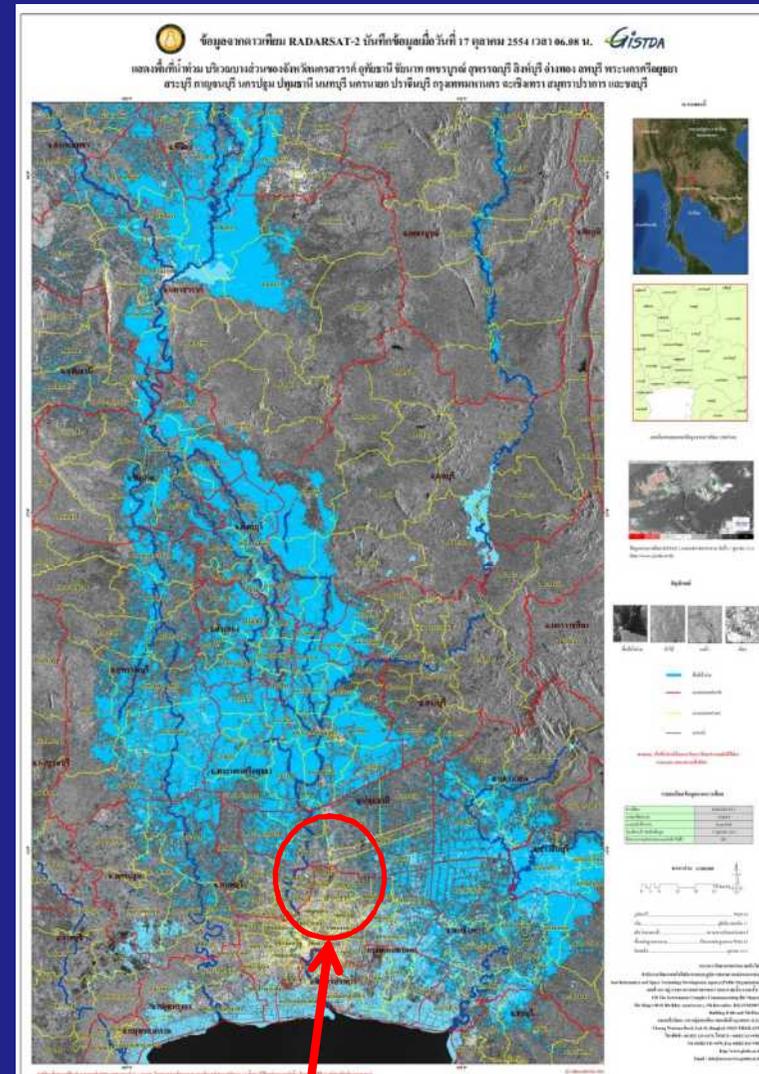
# Arial View of Flood



10 October 2011

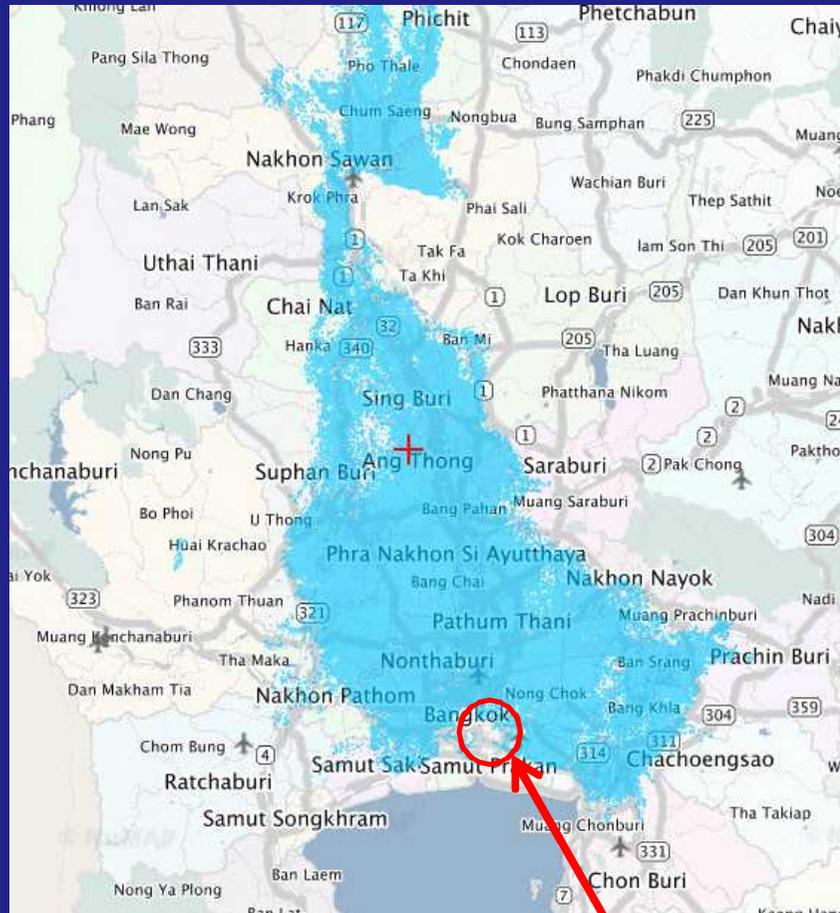


17 October 2011

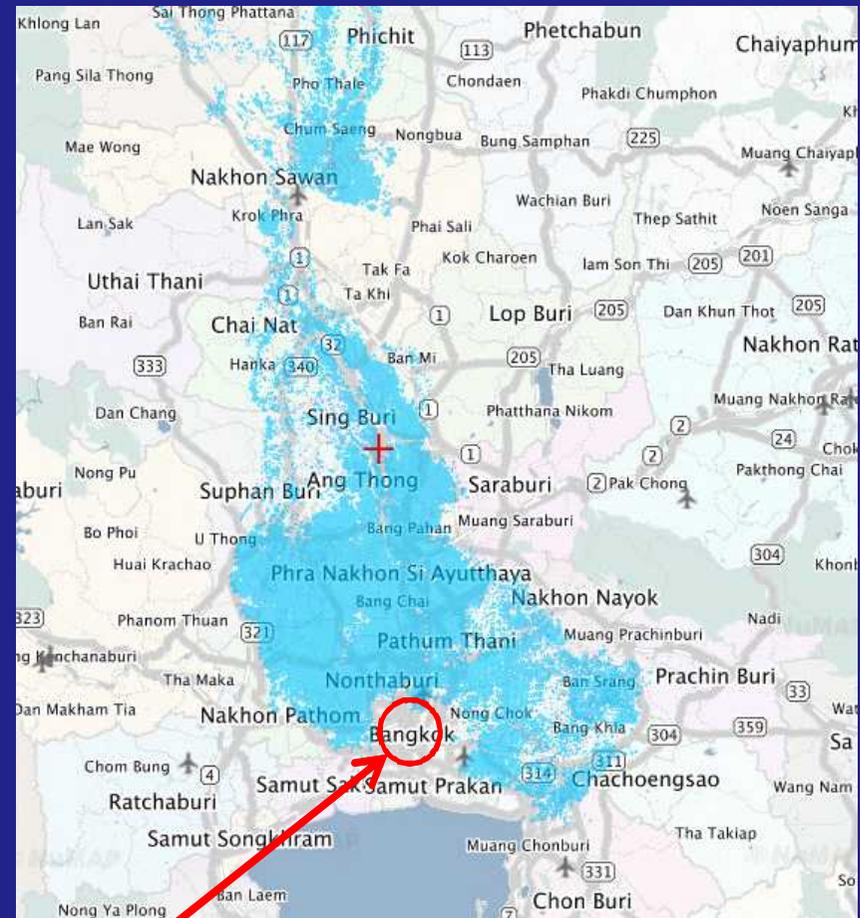


City Center of Bangkok (not flooded)

**20 November 2011**



**18 December 2011**



**City Center of Bangkok (not flooded)**

## BANGKOK'S FLOOD-PRONE AREAS

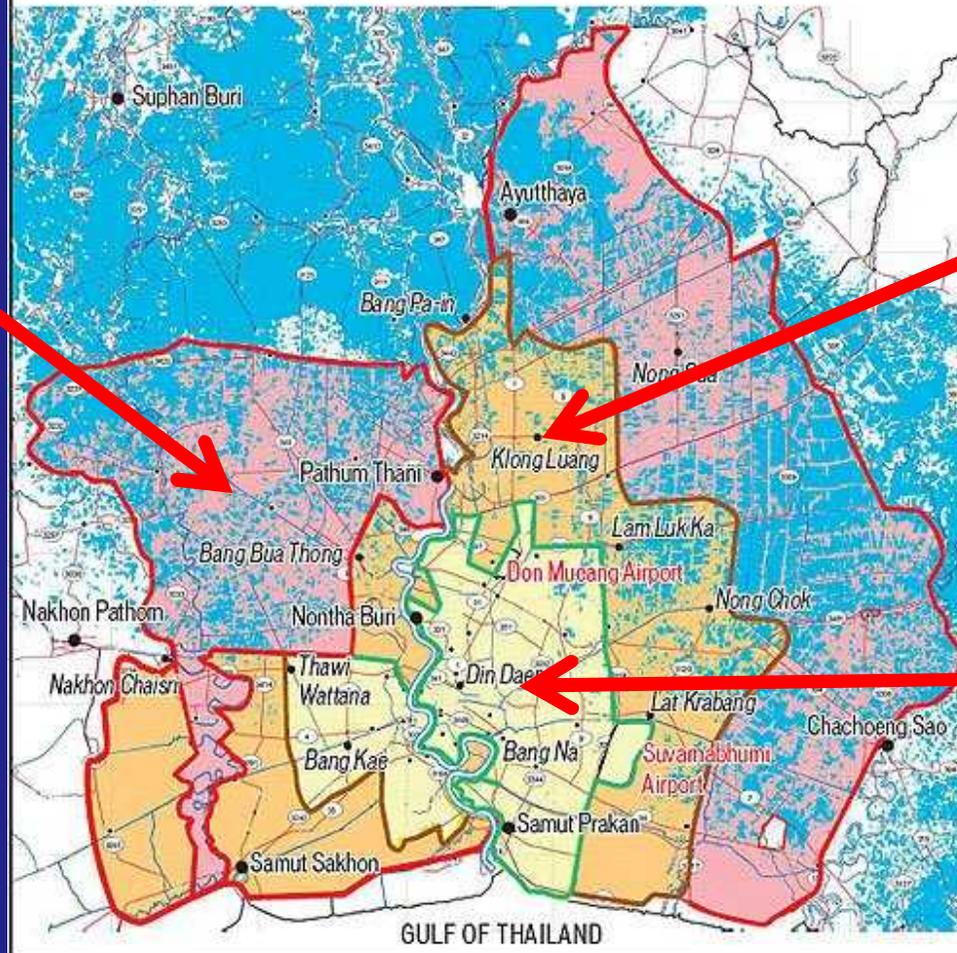
Flood risk areas in Bangkok, studied by Team Group, a water management consulting firm.

 Already flooded

 Level 3 (highest risk): Areas outside flood barriers and along river basins which were hit by major flooding in 1995. Possible flooding is around 1-2 metres

 Level 2 (high risk): Areas inundated in 1995 and which authorities have tried to protect this year by diverting of water and building floodwalls. Possible flooding is around 1-2 metres

 Level 1: Moderate risk areas that did not flood in 1995, but face risk this year. Possible flooding is around 50 cm



**Level 3  
Highest Risk  
1-2m Flood**

**Level 2  
High Risk  
1-2m Flood**

**Level 1  
Moderate  
Risk  
50 cm Flood**

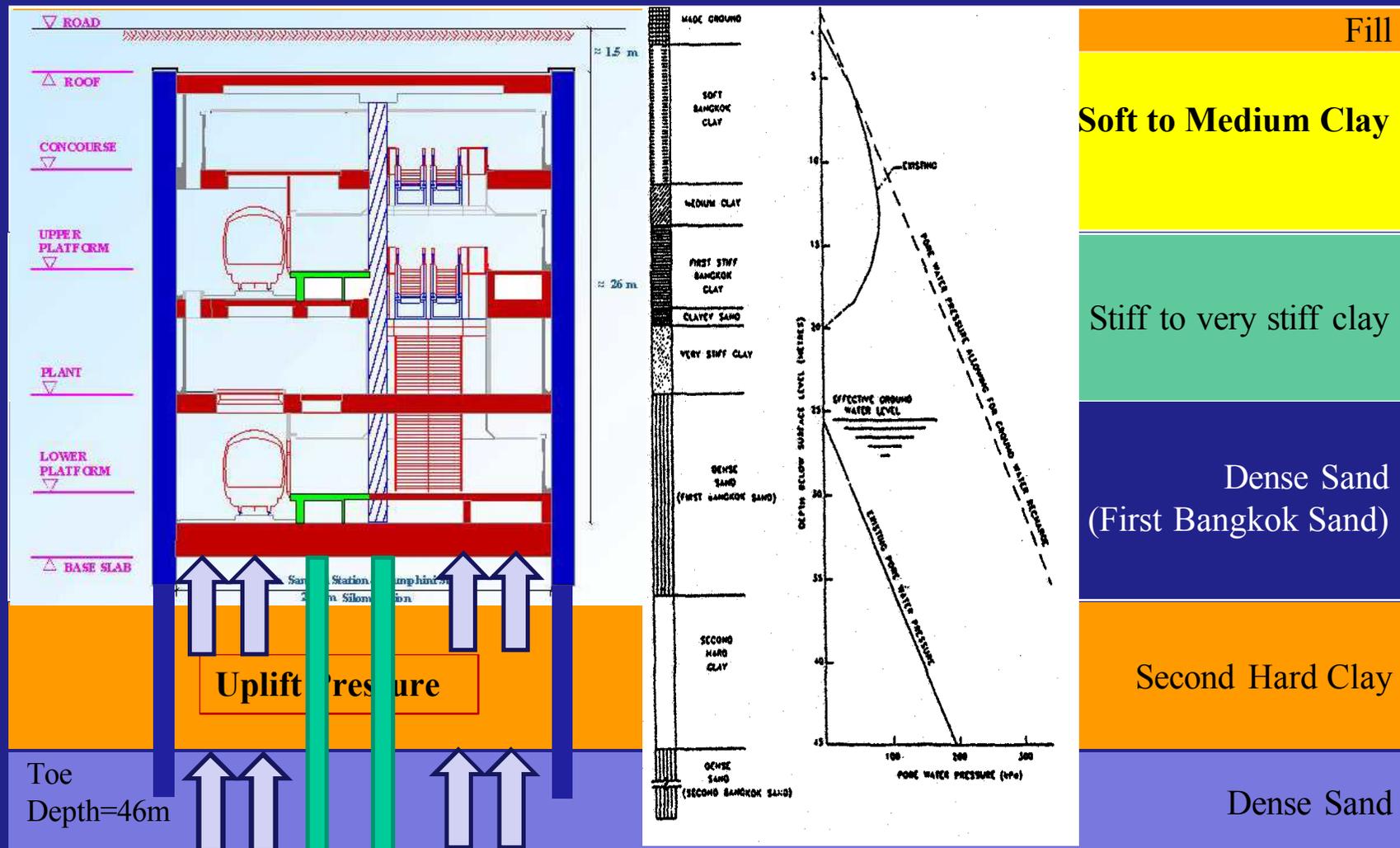
# Flooding and Safety of Bangkok Metro

- Geotechnical related risk caused by flooding
- Risk of Water inflow and flooding in Stations and Tunnels

# Geotechnical Related Risk Groundwater : Uplift Pressure

During Construction : Potential blow-out at base : cut-off by dwall and relief well

Permanent Stage : Design base-slab to resist uplift pressure, design pin-piles against floatation



# Risk of Flooding in Stations and Tunnels

## 3 Key Issues

Item	Risk Factor	Control Measure
1	Flood water flowing into the stations from entrances and ventilation buildings	Entrance Podiums and Ventilation Building walls were designed for street flood level of 100 years maximum rainfall in Bangkok
2	Leaking of flood water into station through roof slab and construction joints due to excessive water pressure	Water proof roof slab and joints
3	Leaking of flood water into tunnel through segment joints due to excessive water pressure	Tunnel segmental joints were constructed under water proofing requirement

# BANGKOK'S FLOOD-PRONE AREAS

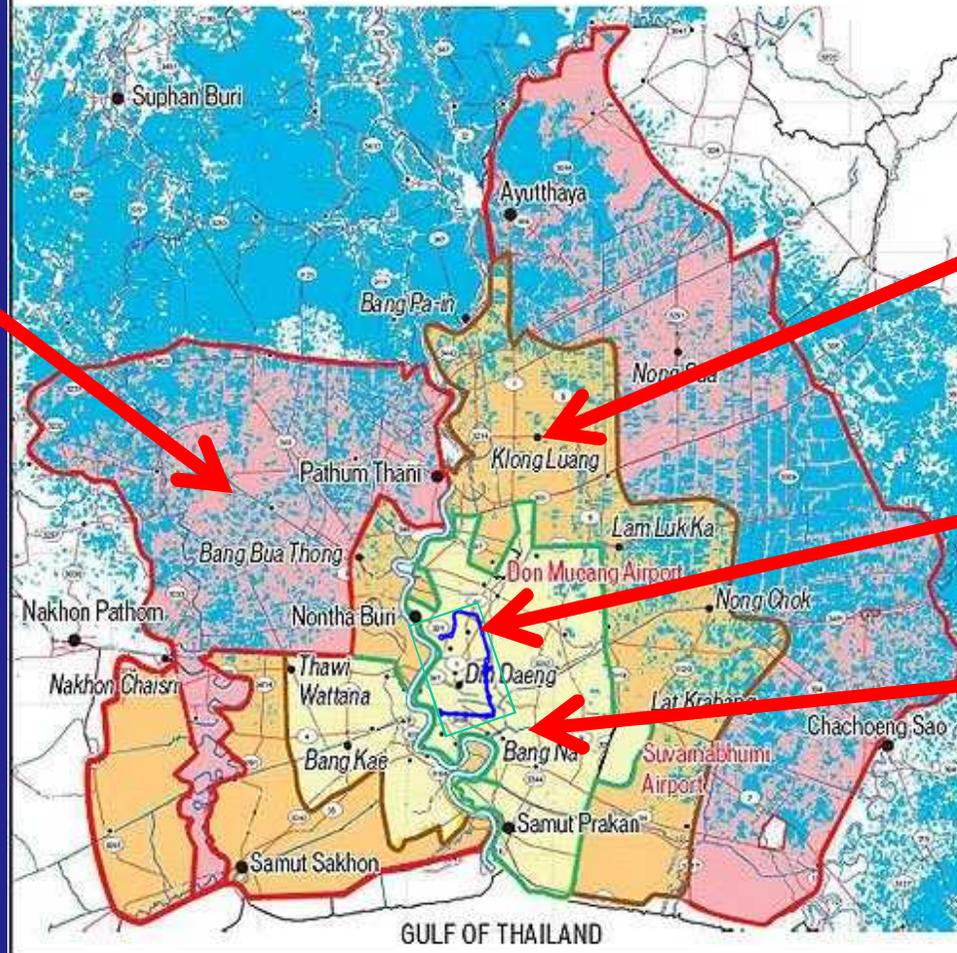
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**Level 3  
Highest Risk  
1-2m Flood**

**Level 2  
High Risk  
1-2m Flood**

**Subway**

**Level 1  
Moderate Risk  
50 cm Flood**

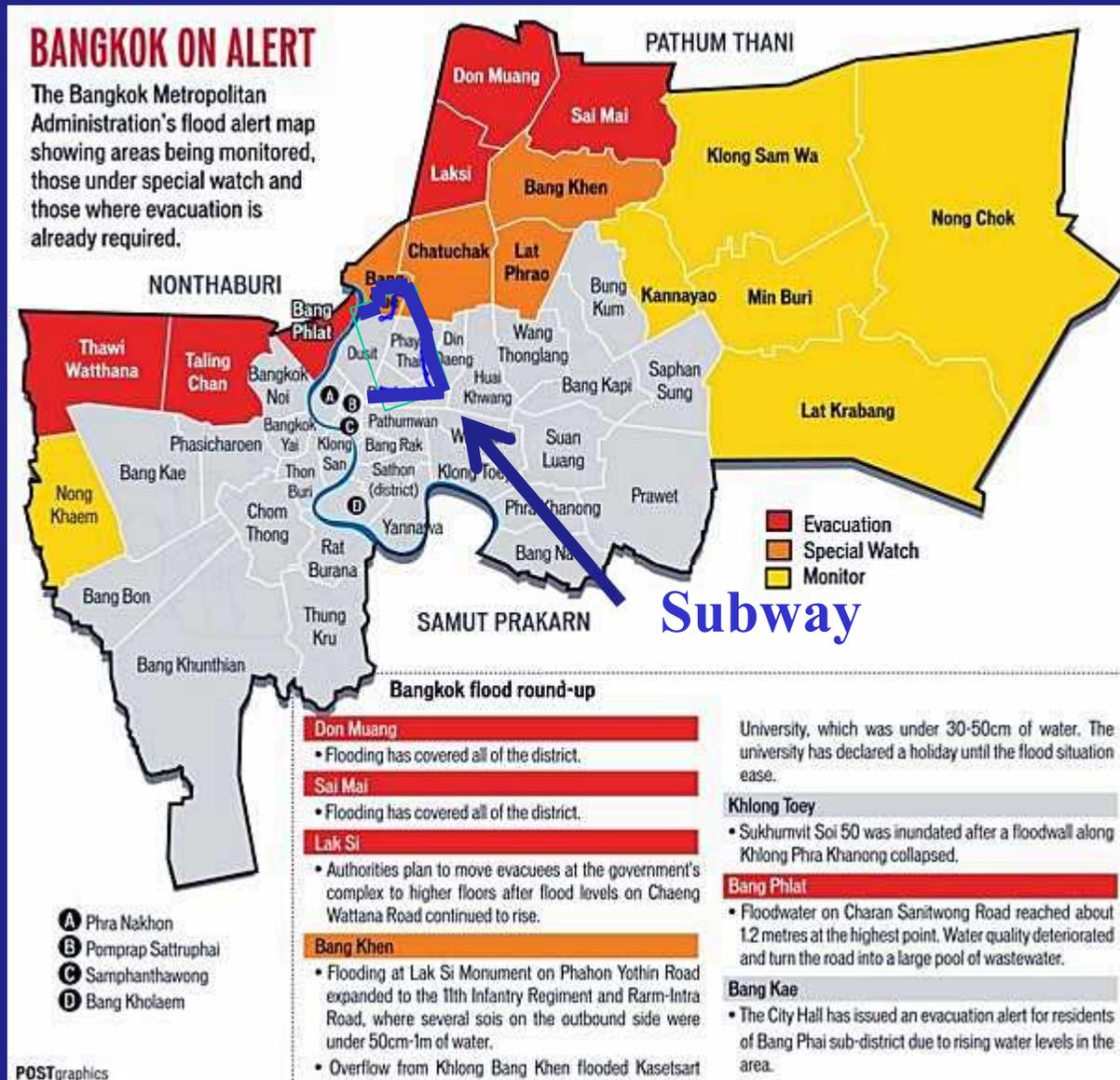
# Risk of Flooding in Stations and Tunnels

**Flood covered all district (flood water 1-2m high)**

Flooding in most area (flood water 0.50 – 1m)

Flooding in most area (flood water 0.50 – 1m)

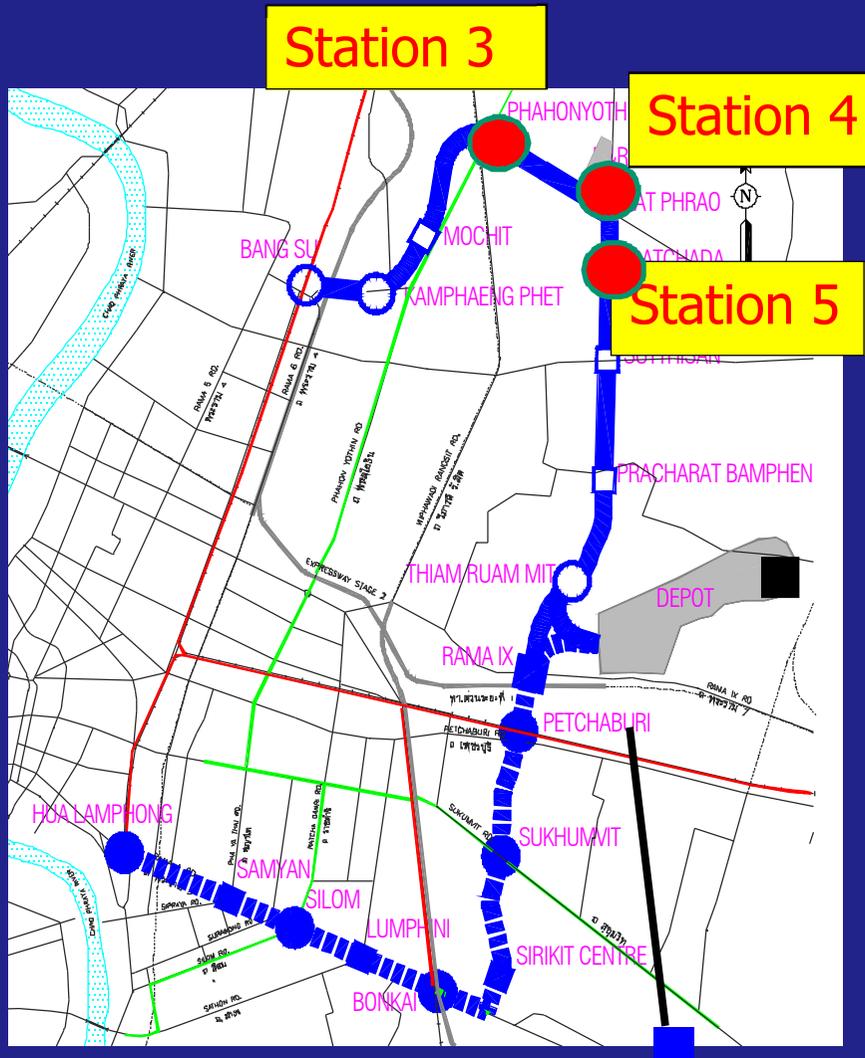
Warned



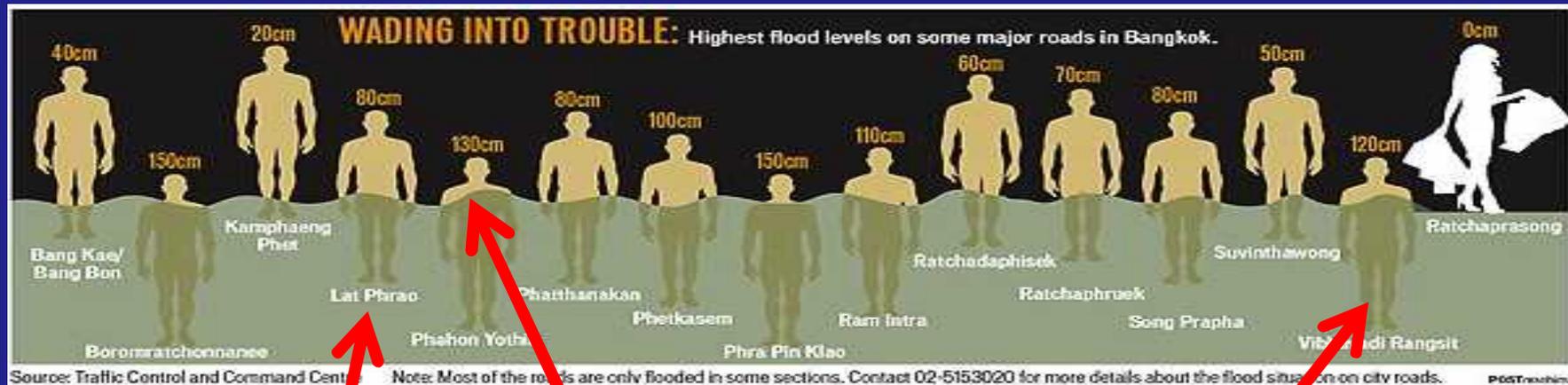
# Critical Subway Stations

1 km from Station 3  
Flood Water 130cm high

1 km from Station 4 Flood  
Water 80cm high



# Critical Flood Area close to Subway Stations



**1 km from Station 4  
Flood Water 80cm high**

**1 km from Station 3  
Flood Water 130cm high**

**700m from Station 3  
Flood Water 120cm high**

# MRT all entrances are designed for street-flood level of 100 years maximum rainfall (1 – 1.50m)



## Station 3 (Phaholyothin Station)



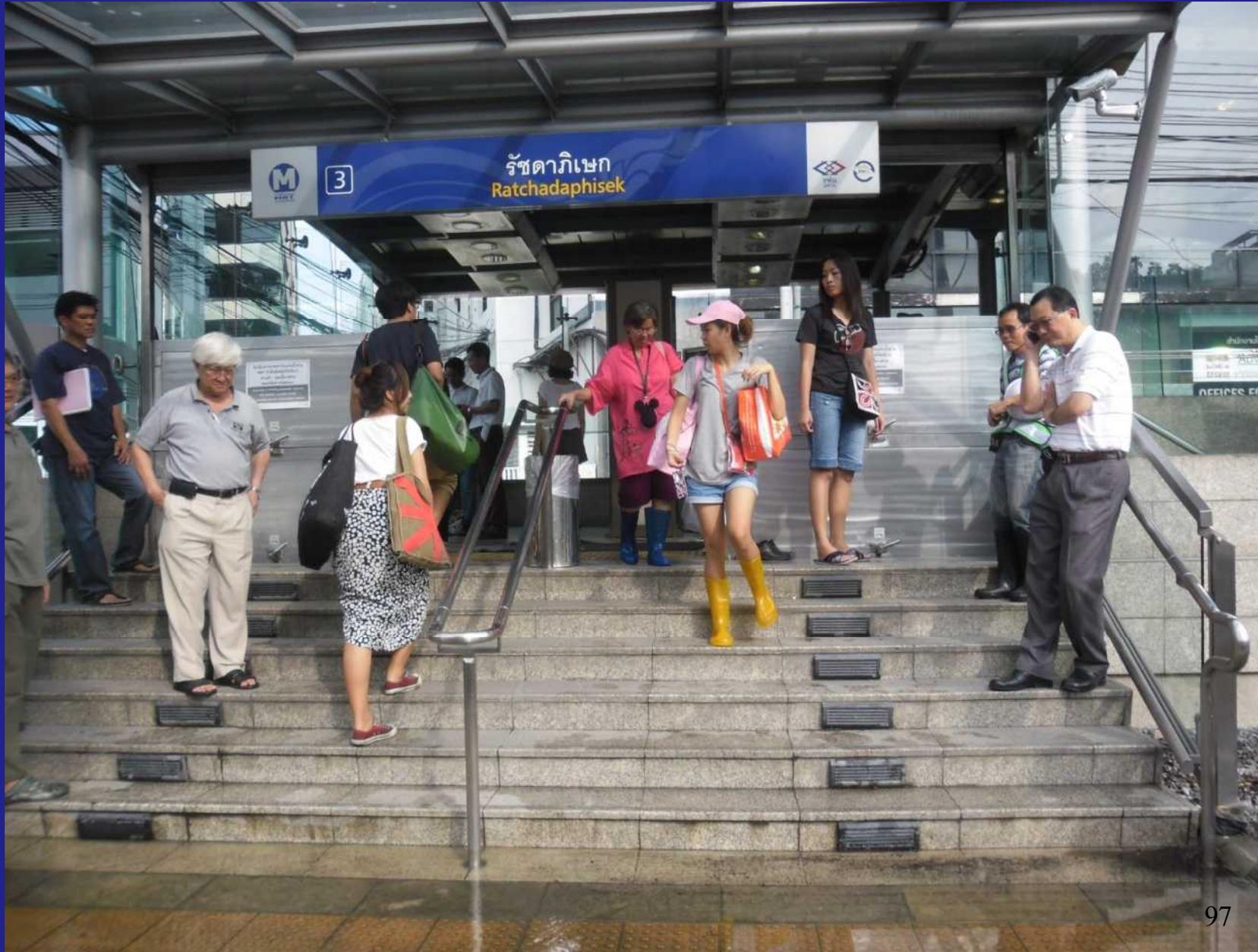
## Station 3 (Phaholyothin Station)



# Station 4 (Ratchadapisek Station)



# Station 4 (Ratchadapisek Station)



## Station 4 (Lat Phrao Station with Park & Ride Building)

Normal Day  
busy traffic



Flooding Period  
no public transportation



## Station 4 (Lat Phrao Station with Park & Ride Building)

Normal Day  
busy traffic



Flooding Period  
no public transportation



# In front of Station 3 (Phaholyothin Station)

- During flooding travelling within Bangkok by car is not practical
- Metro is useful transportation for many commuters

Normal Day  
busy traffic



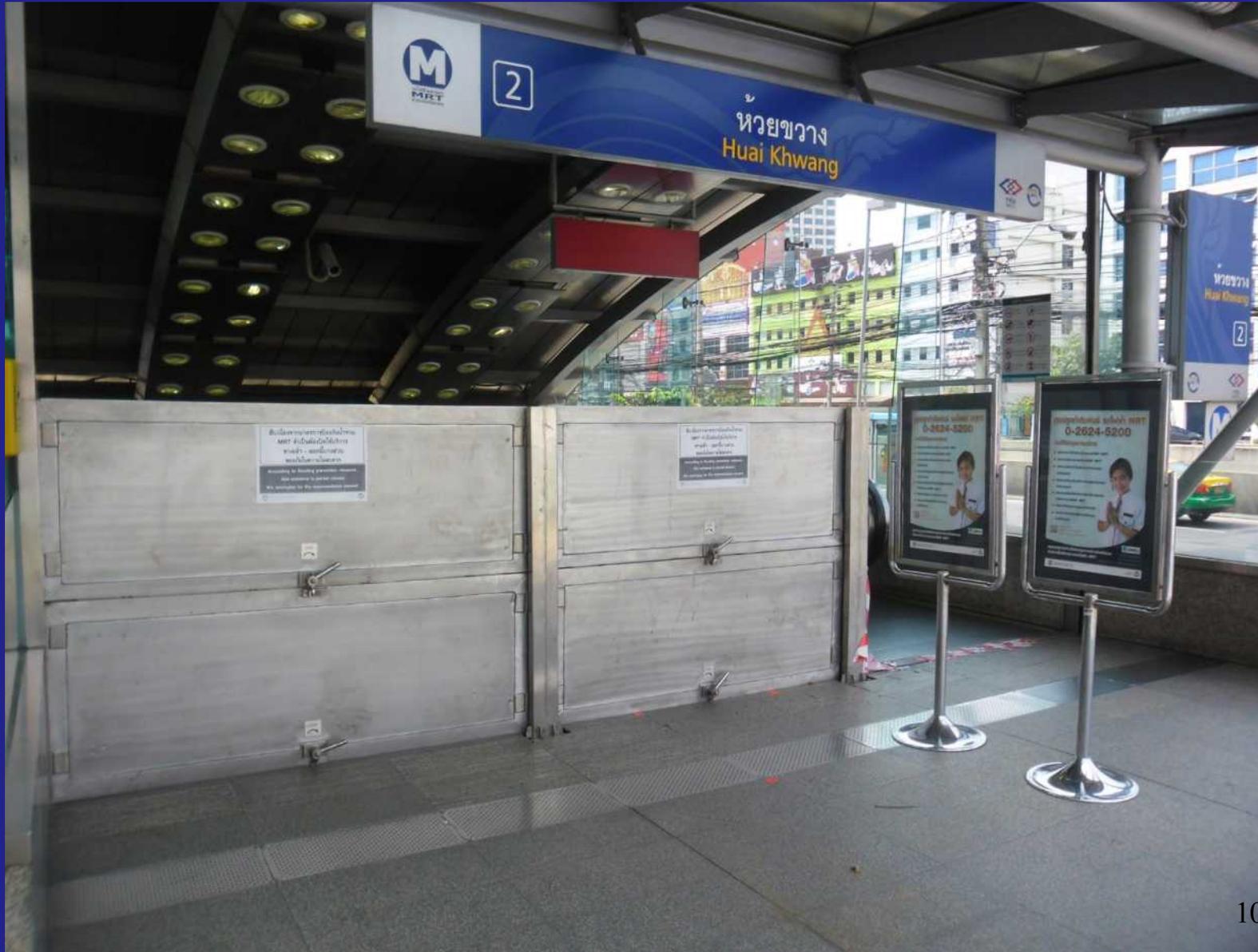
Flooding Period  
only trucks and some buses



# Entrance in Some Stations Closed by Stop-Lock



# Entrance in Some Stations Partially Closed by Stop-Lock



# Water Leaking from Joint between Station and Machine Room



# Ventilation Building (Ratchadapisek Station)



# Flooding and Safety of Bangkok Metro

## Proposed Multi-Service Flood Tunnel System (MUSTS)

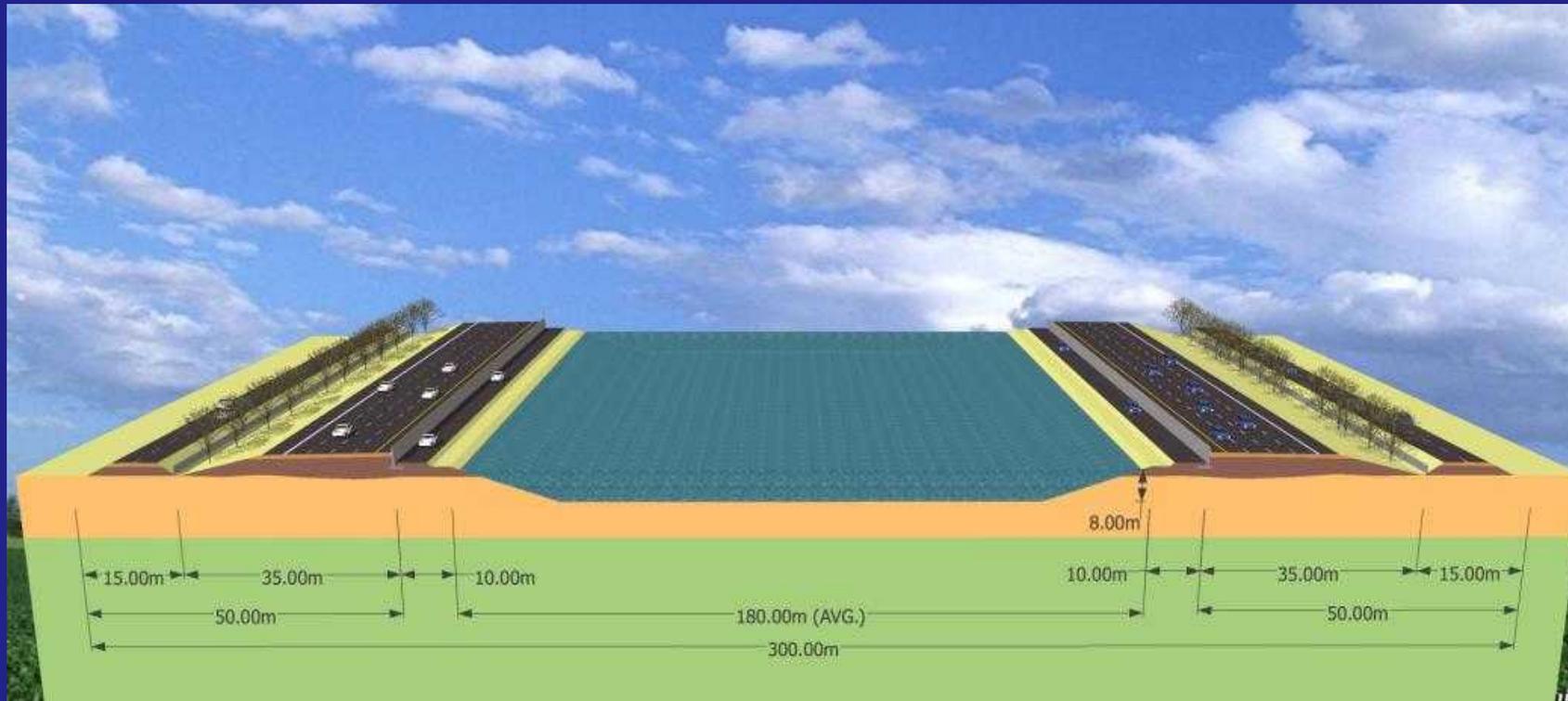
## Practical Solution for Flood Protection for Bangkok

Type	System	Practicality and Effectiveness
1	Open channels or canals on the ground surface	Not practical in every area considering current land use (e.g. Bangkok suburban and urban land use). Expensive to appropriate the land owned by ordinary citizens or private sectors
2	Subsurface canals or shallow underground structures	Practical to implement but relatively ineffective due to limited flood drain capacity
3	Large Flood Drain Tunnels	Practical and effective in most area and land use especially in Bangkok. Minimum land appropriation required

# Alternative 1

## Man-made River Solution

Length : 100 km, width : 180m, depth : 8m



### Problems

- Government needs to buy land from private owners (too expensive and difficult)
- Many bridges need to construct along 100km river to cross
- Loss of valuable surface area

# **Multi-Service Flood Tunnel System (MUSTS)**

## Multi-Service Flood Tunnel System (MUSTS)

- Double-deck Cut & Cover Tunnel (similar to 2 level basement)
- Approximately 100km (Bang Pa-in to Samut Prakarn) under existing Eastern Outer Ring Road
- Top-down construction method (similar to subway station construction) can be used so that minimum disturbance to existing Eastern Outer Ring Road
- Upper deck can be used as motorway during normal, minor and moderate flood conditions
- Can be integrated with Power Generation facility

**Western Outer Ring Road**



**Nonthaburi**

**Bang Pa-in**

**Eastern Outer Ring Road**

**Proposed Flood Drain Tunnel**



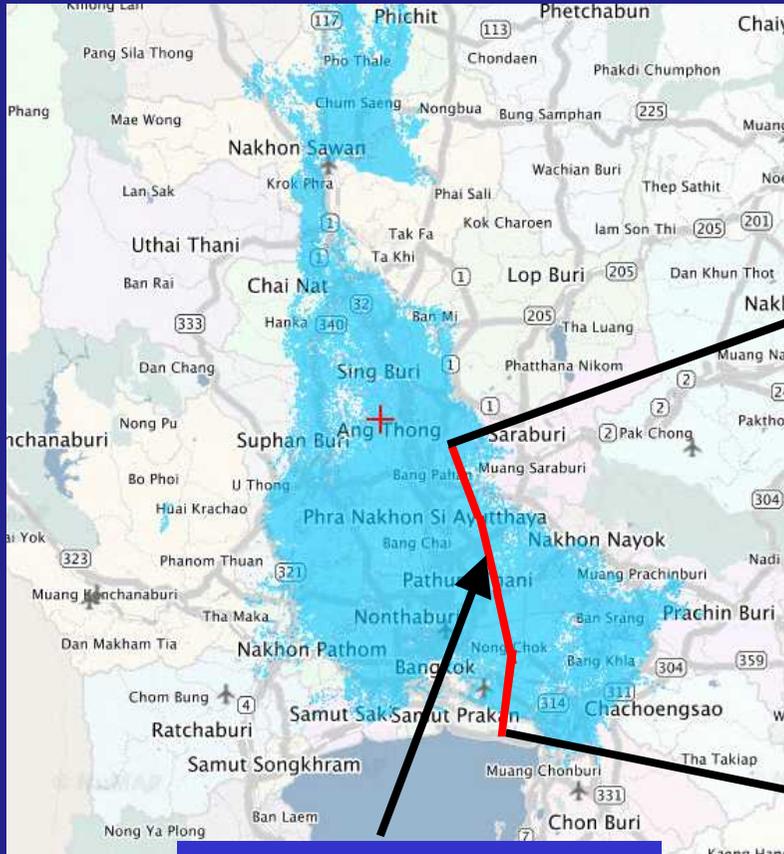
**Bangkok**

**Samut Prakan**

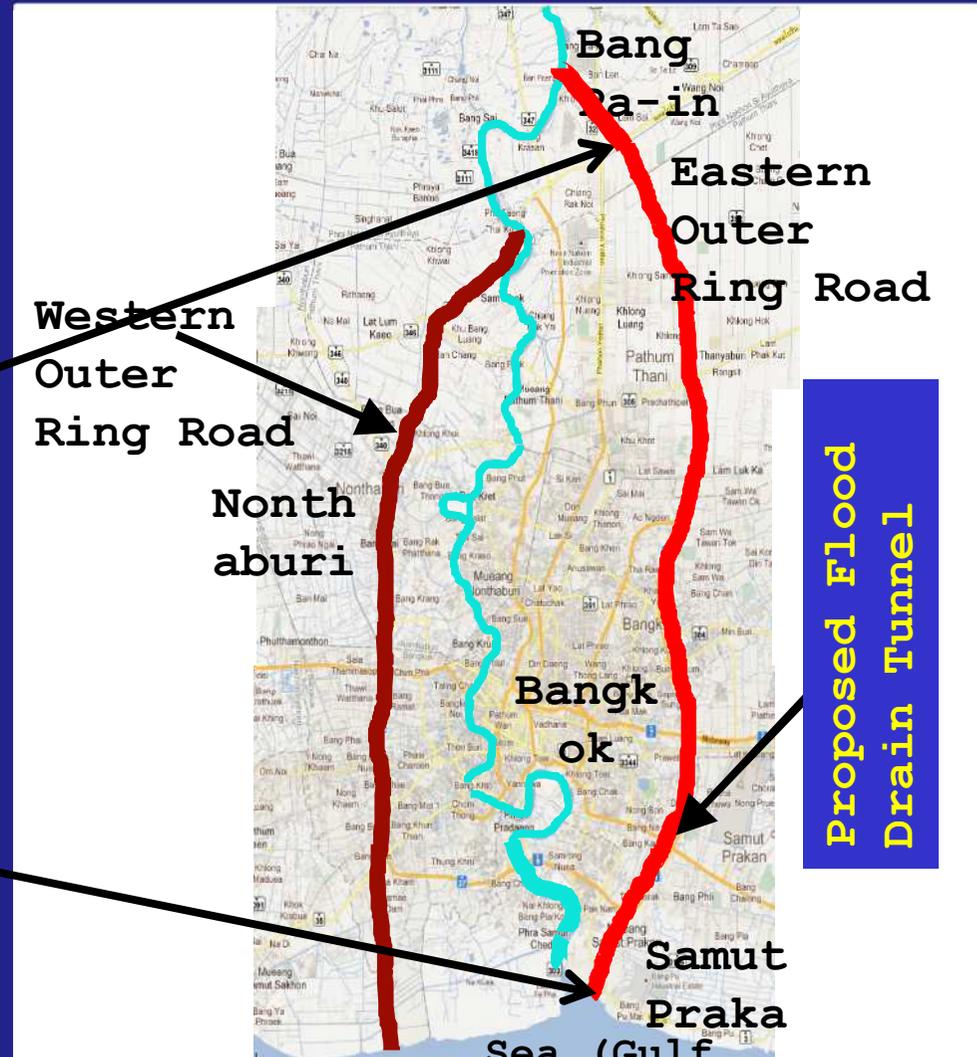
**Sea (Gulf of Thailand)**



# Proposed Alignment of Multi-Service Flood Tunnel System (MUSTS)



**Proposed Flood Drain Tunnel**



**Western Outer Ring Road**

**Eastern Outer Ring Road**

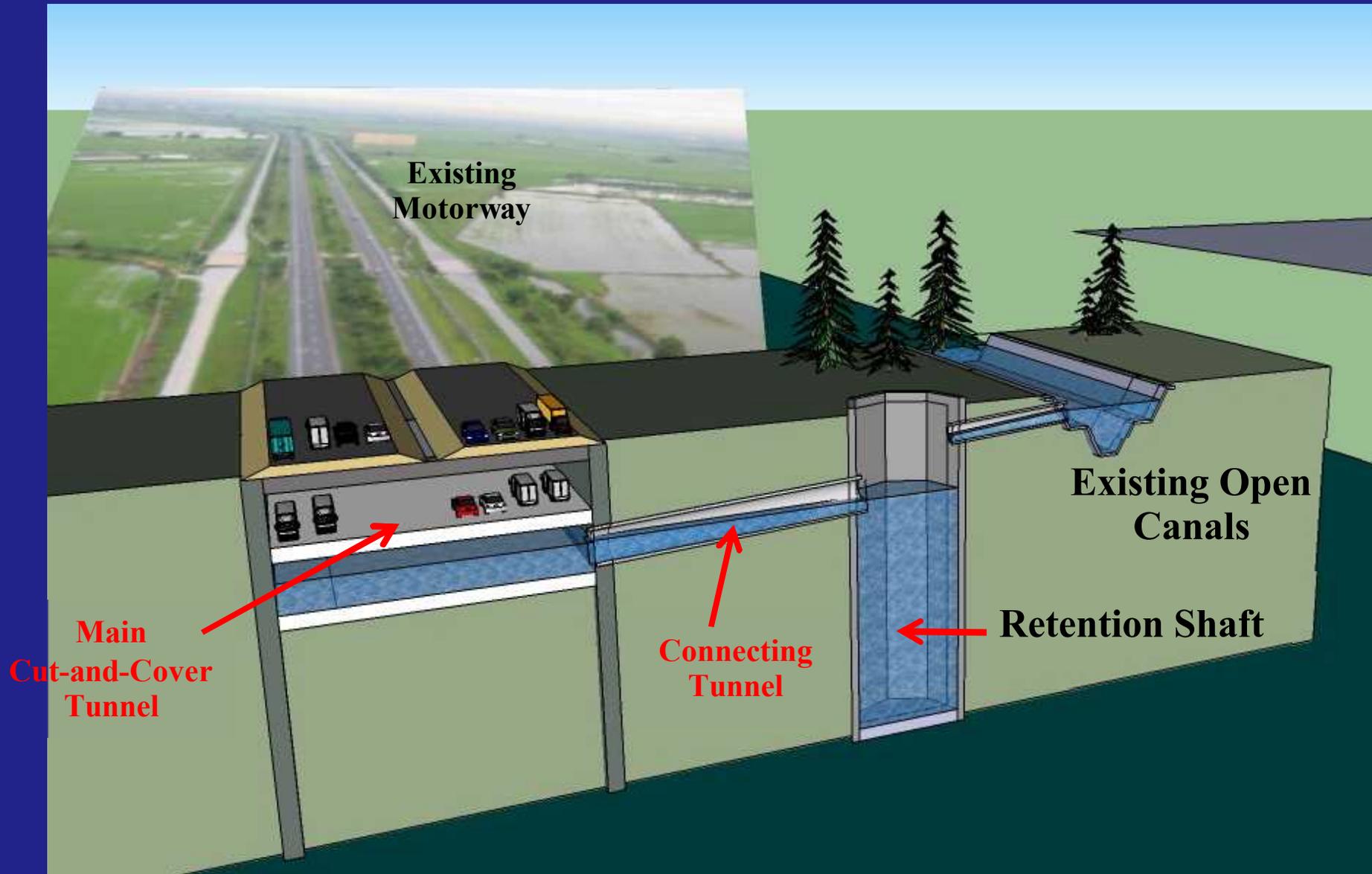
**Proposed Flood Drain Tunnel**

**Samut Prakan Sea (Gulf of Thailand)**

# Eastern Motorway

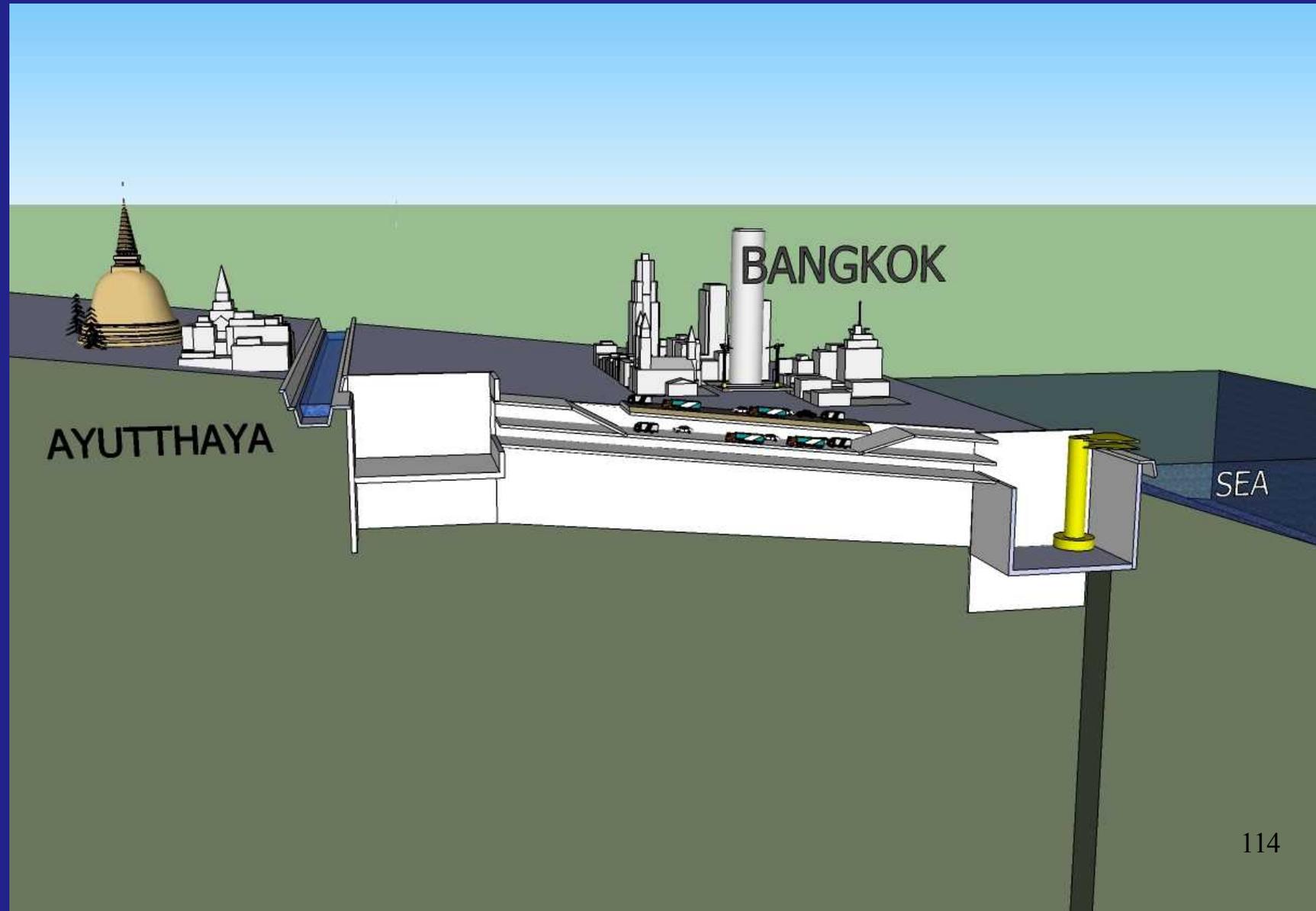


# Typical Section of Multipurpose Underground System (MUST)



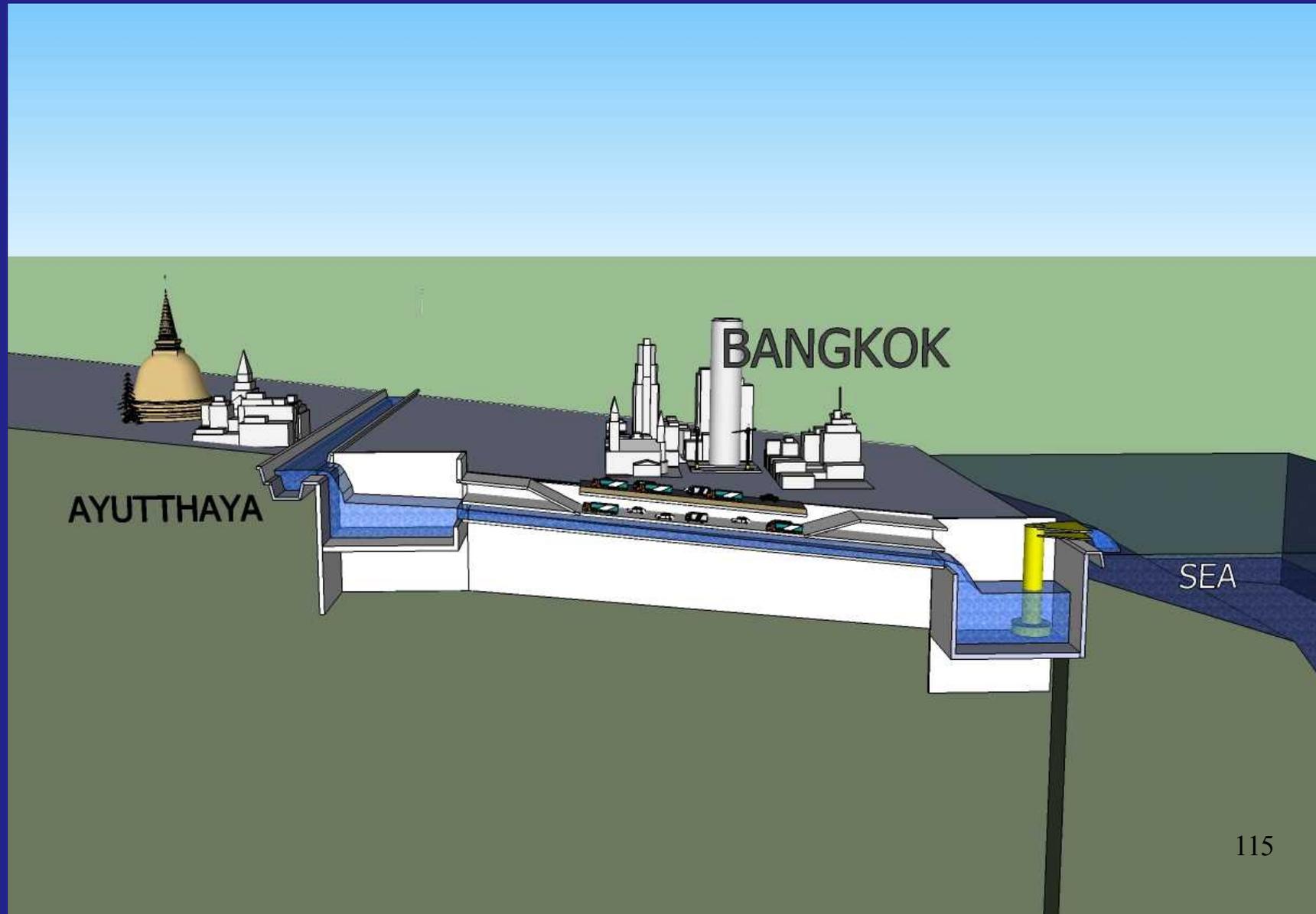
# Normal or Minor Flood situation

(Lower Deck will be used for water flow and Upper Deck will be used as Road Tunnel)



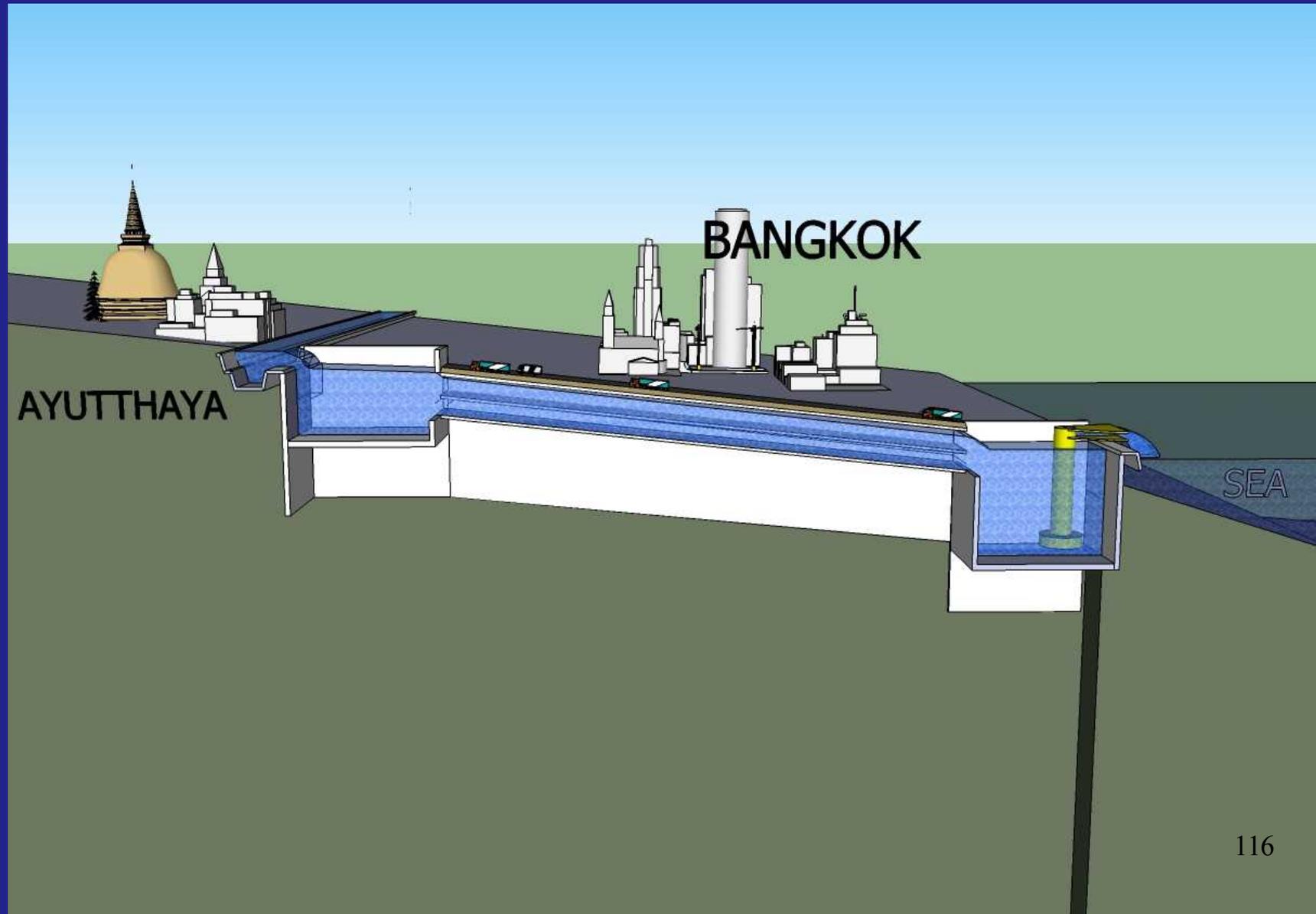
# Moderate Flood situation

(Lower Deck will be used for water flow and Upper Deck will be used as Road Tunnel)

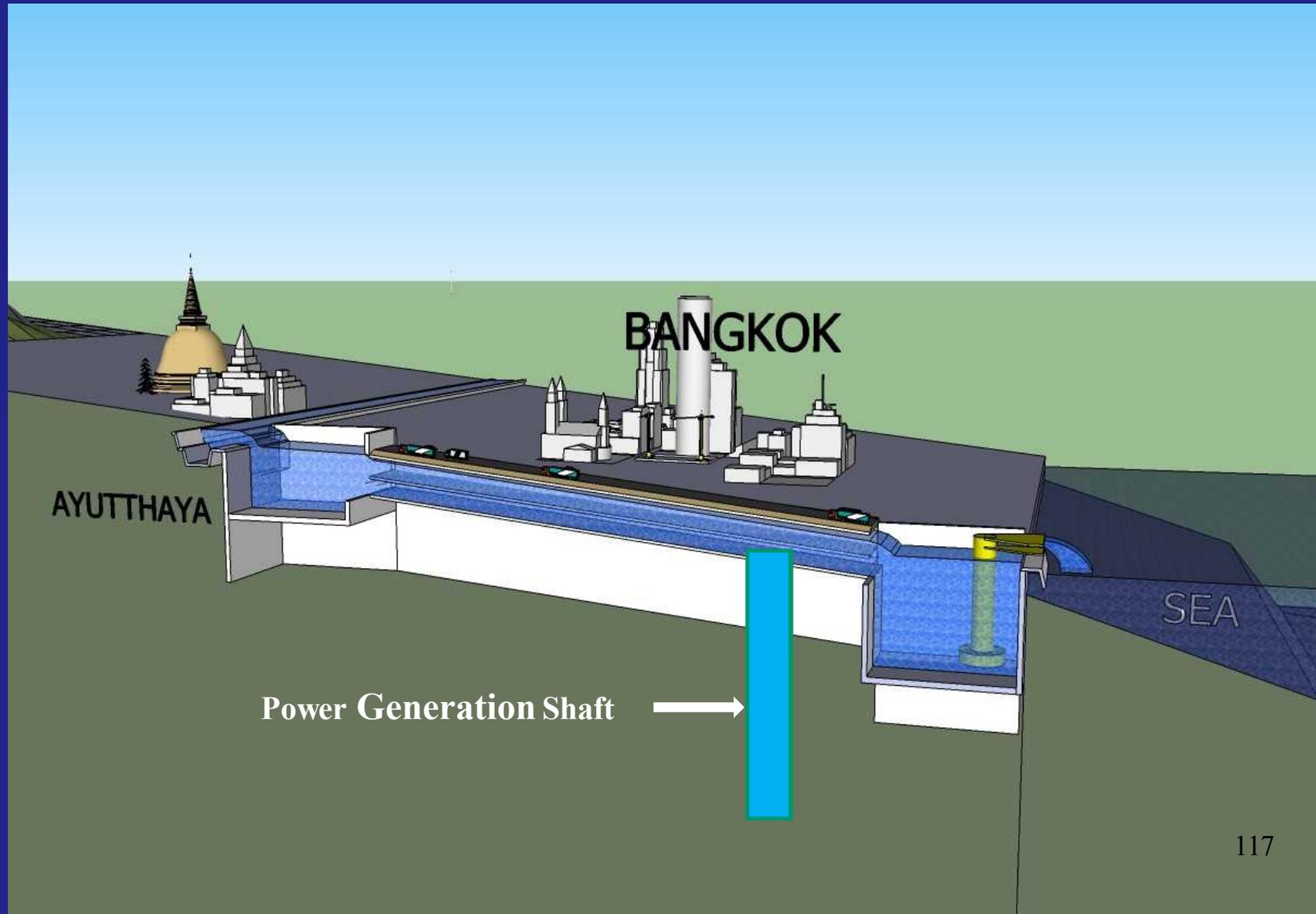


# Major Flood situation

(Both Lower and Upper Deck will be used for water flow)



# Power Generation Facility can be integrated



## Key Advantages of MUSTS

Large volume of floodwater can be drained out in short time due to high hydraulic gradient (1,500 m<sup>3</sup>/s, 129,600,000 m<sup>3</sup>/day)

Minimum land appropriation is required – practical for existing land use in Bangkok and nearby provinces

Can be Integrated with existing drainage system so as to enhance flow rate in existing system

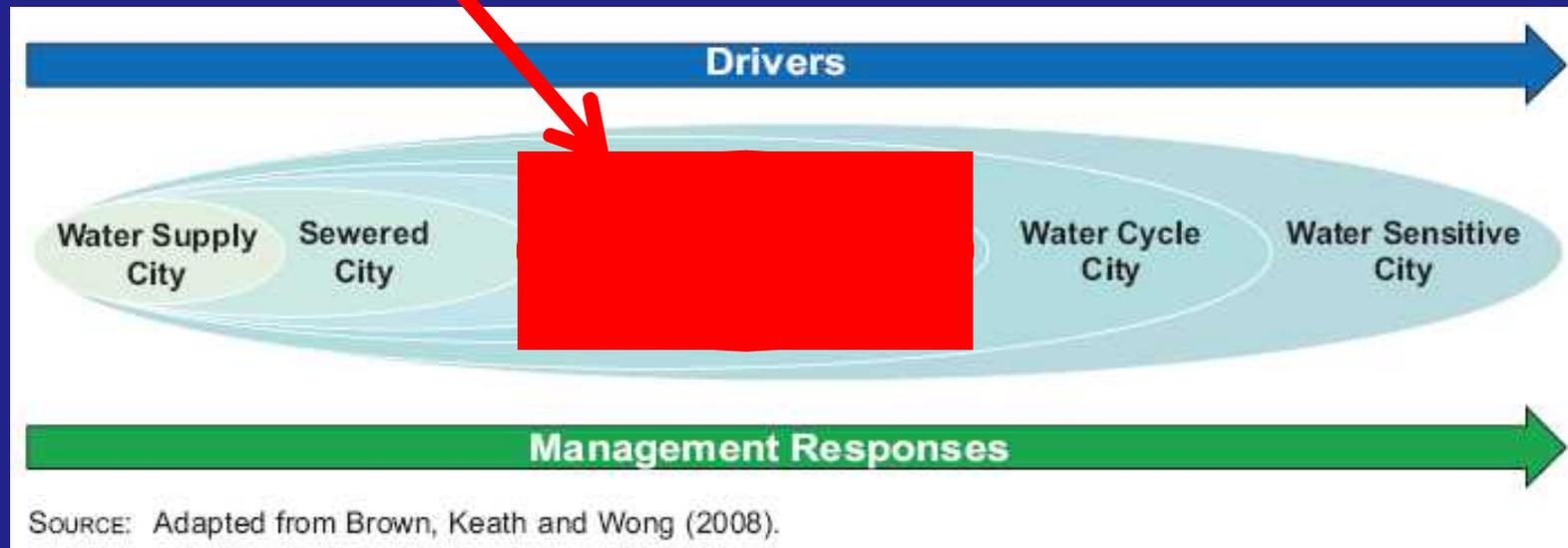
Minimum land appropriation is required – practical for existing land use in Bangkok and nearby provinces

Can be applied as multi-service system for maximum benefits of the public

# Future of Bangkok

- Bangkok has passed Water-Supply city, Sewered City and now at the stage of Drained-City to Waterway-City
- to drive from Flood-Resilient City to Water-Sensitive City

**Bangkok in 2012**





**THANK YOU FOR YOUR ATTENTION**