

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

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

In cooperation

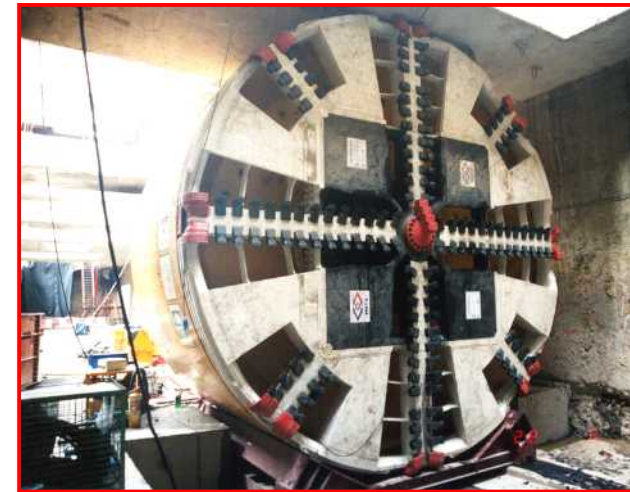
WORLD ROAD
ASSOCIATION
COMITTEE
DE LA ROUTE

Under the auspices of

*Consiglio Superiore
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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 m²
(3% of Thailand : 513,000 km²)



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

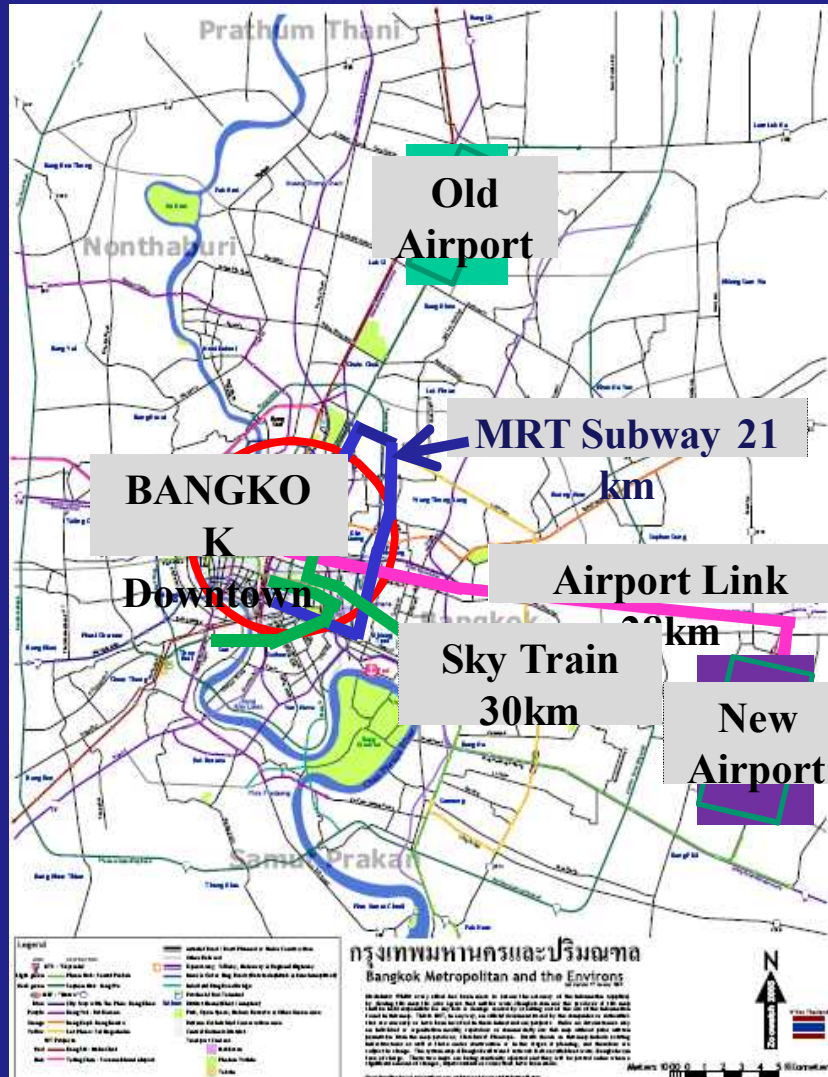


Bangkok Traffic at Night

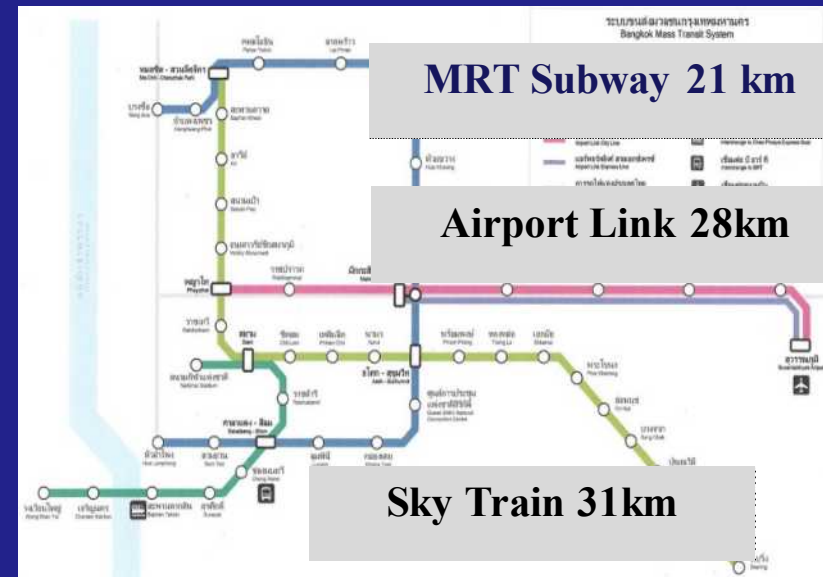


BANGKOK Mass Rapid Transport Network

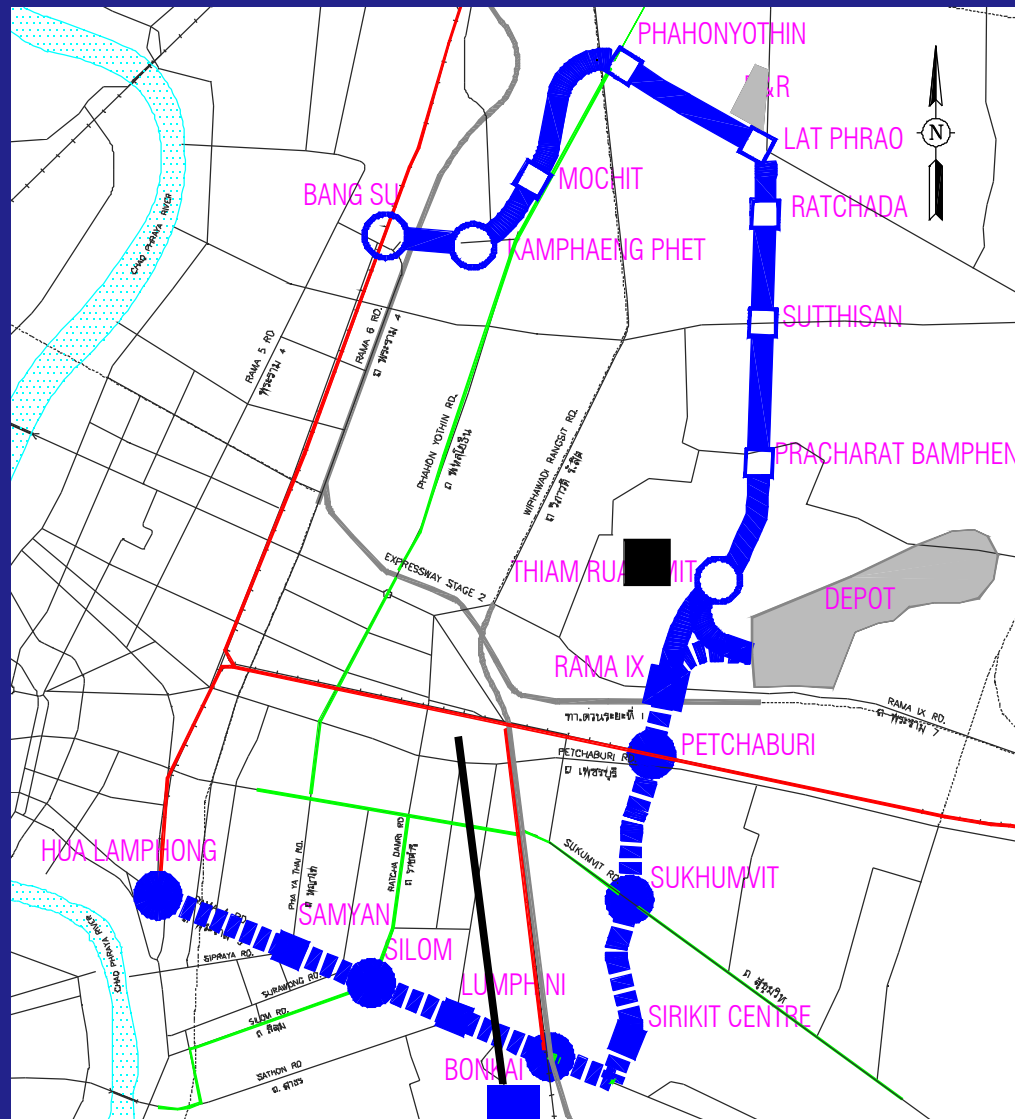
Government started to invest in MRT in 1994



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



Bangkok Underground MRT BLUE LINE (Initial System Project, ISP)



- UNDERGROUND 20 KM
- 18 STATIONS
- TWIN TUNNELS INT. DIA. 5.7 M
- 1 PARK & RIDE

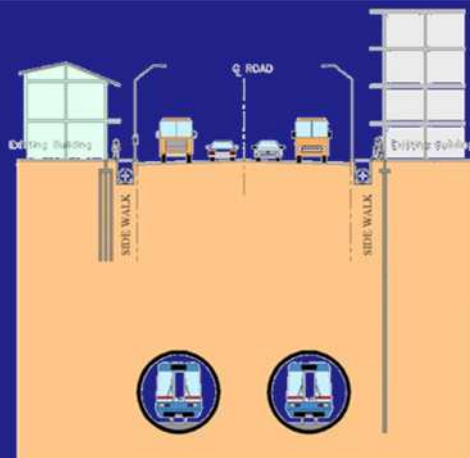
LEGEND :

- ISP : SOUTH SECTION
- ISP : NORTH SECTION
- INTERCHANGE STATION
- STATION
- SRT
- BTS

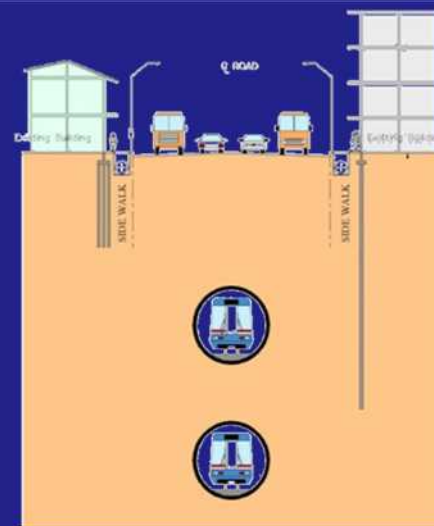
Bangkok Underground MRT

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

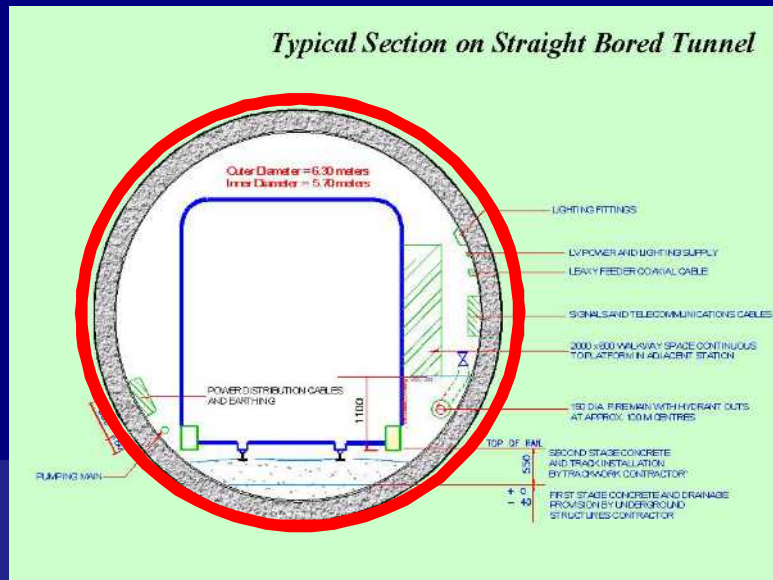
Diameter: 6.46 meters

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





Fill

Soft to Medium Clay

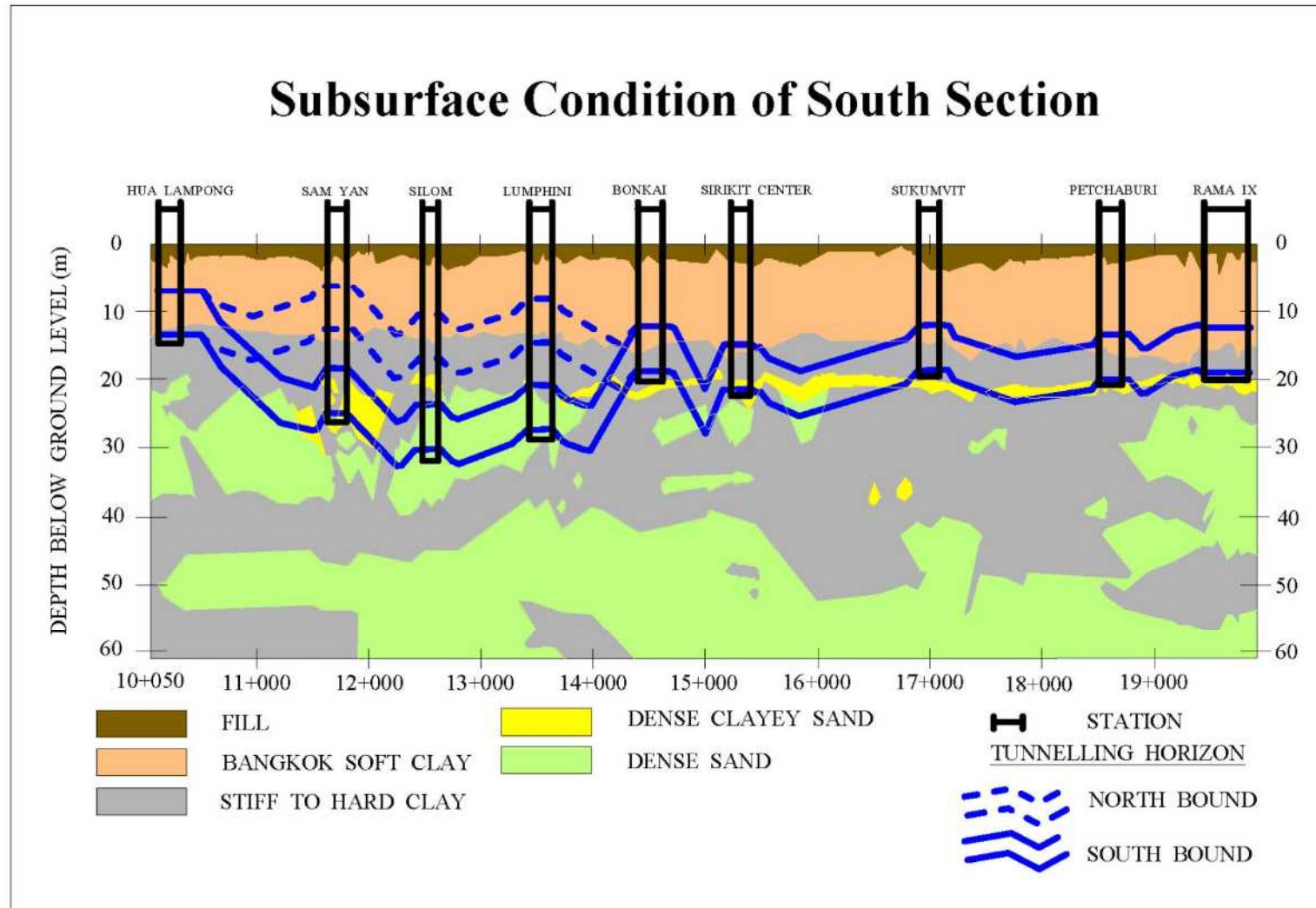
Stiff clay

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



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 : 5,400m³/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

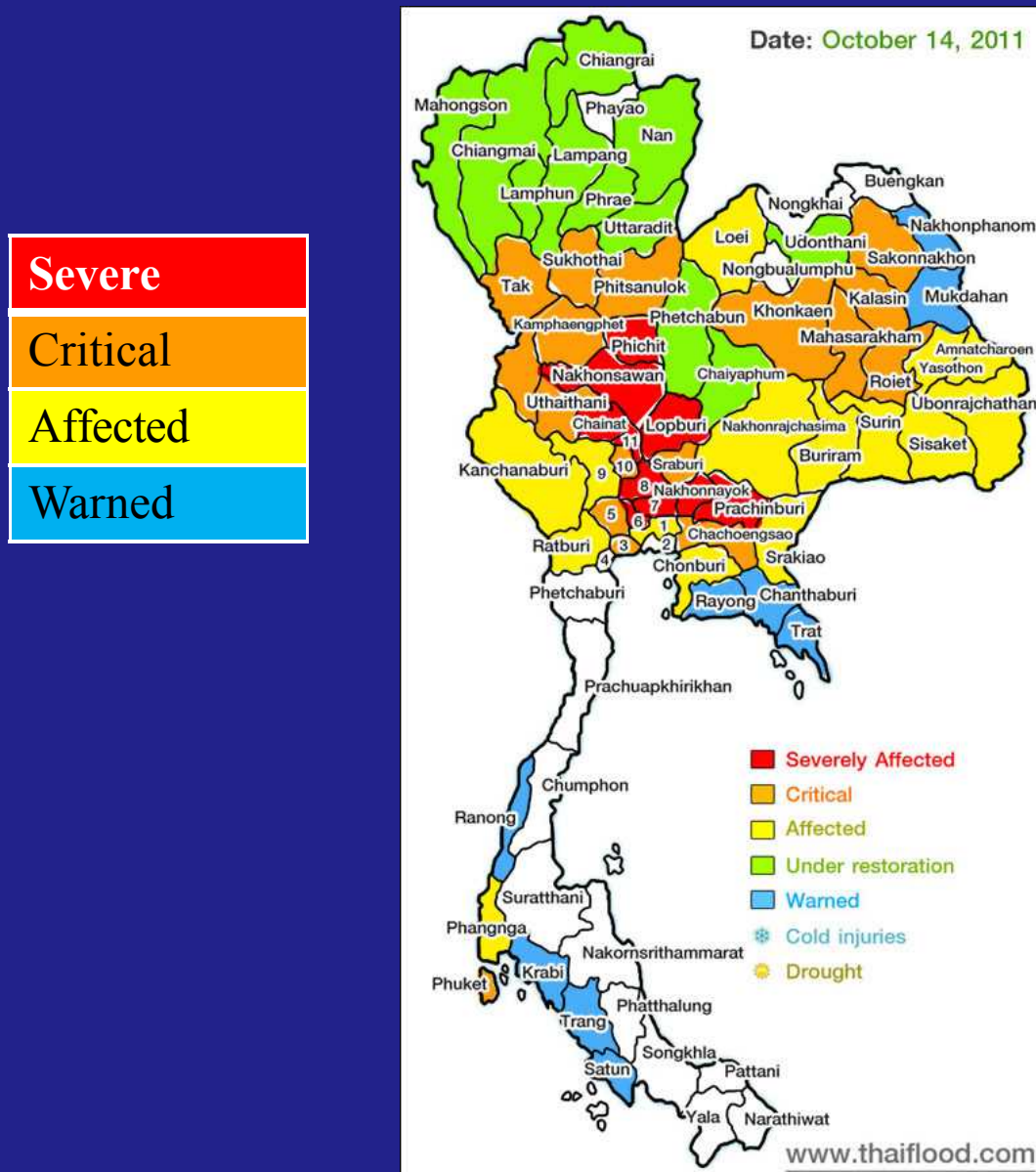
2010 Flooding in Bangkok



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%)



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

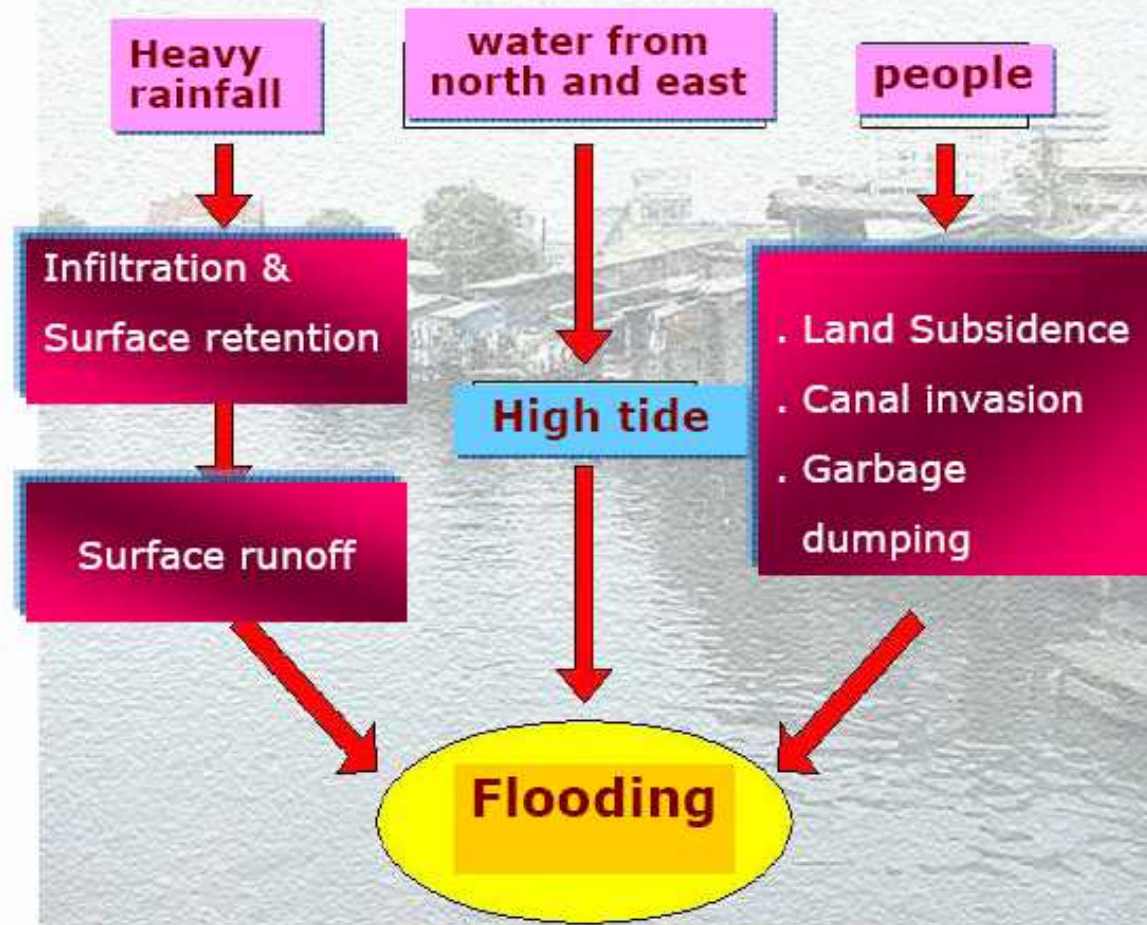


Major Causes of Severe Flooding in 2011

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

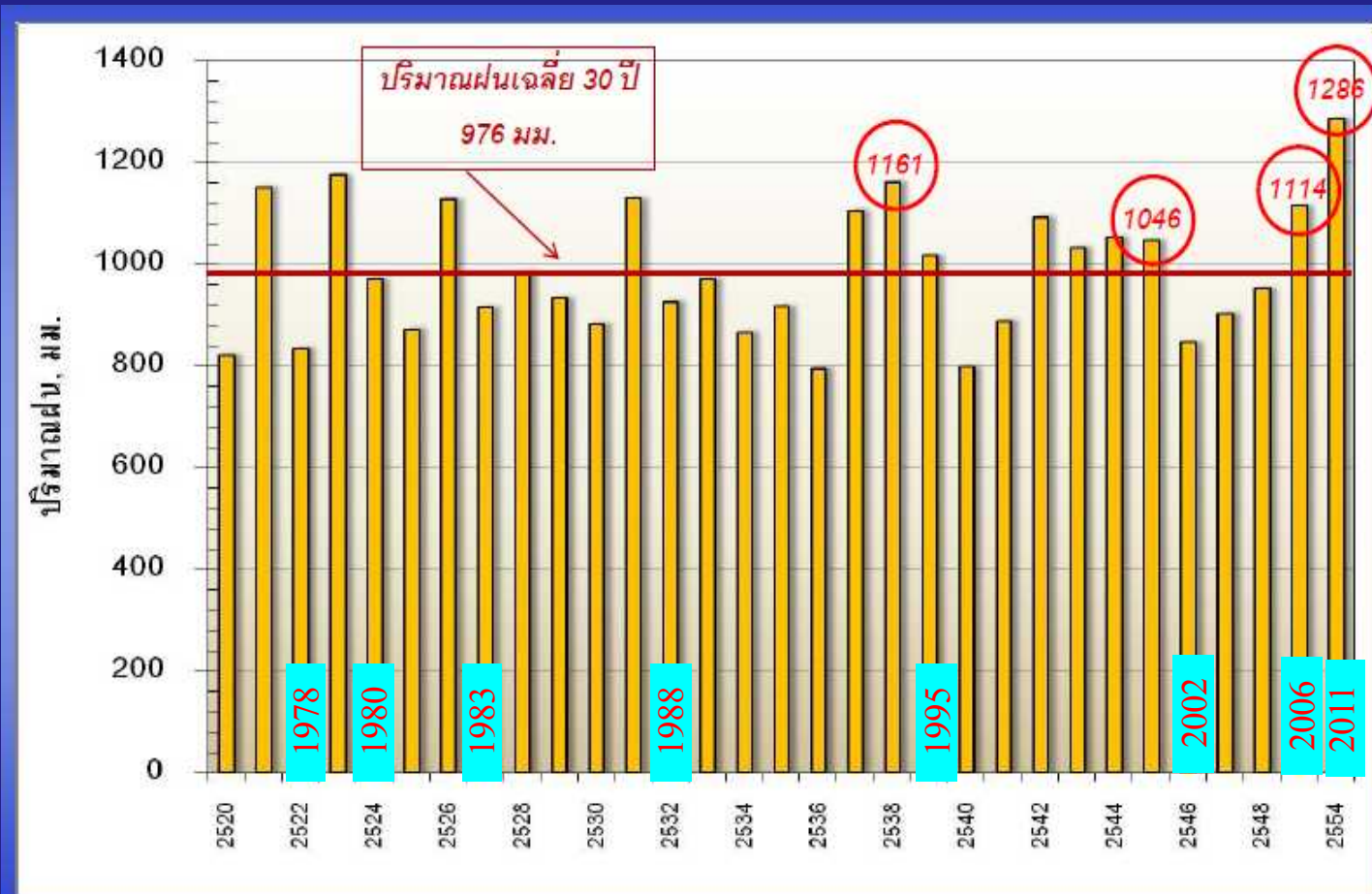
Causes of Flooding



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

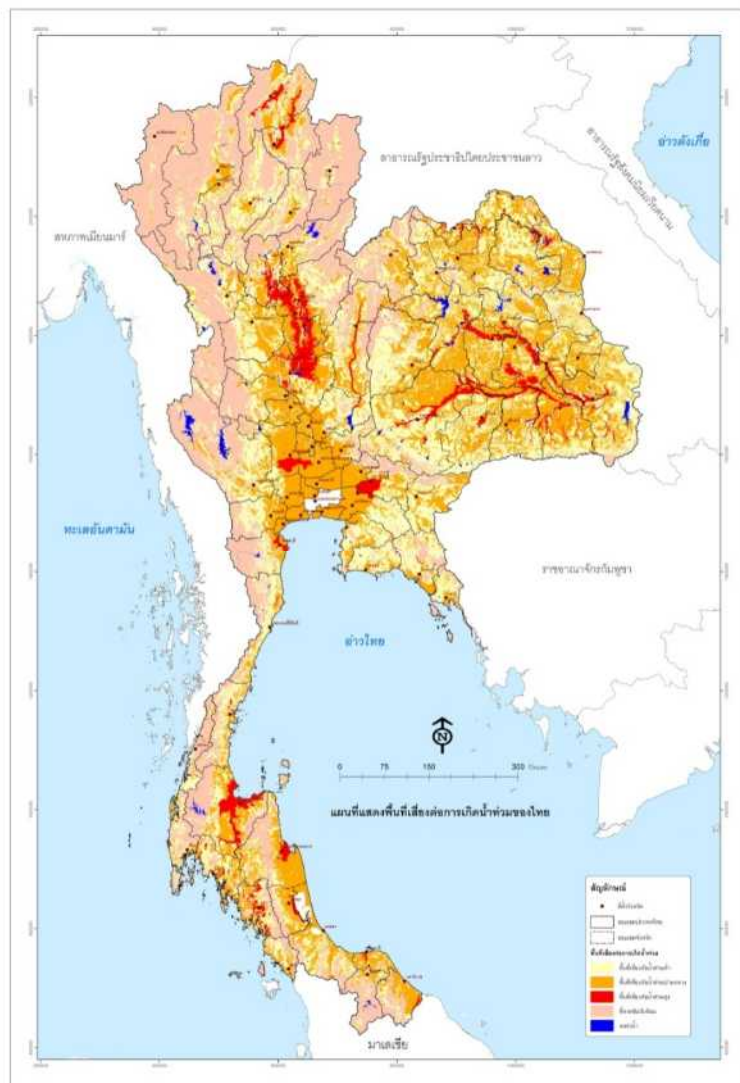


ที่มา : ข้อมูลน้ำฝนจากกรมอุตุนิยมวิทยาและกรมชลประทาน

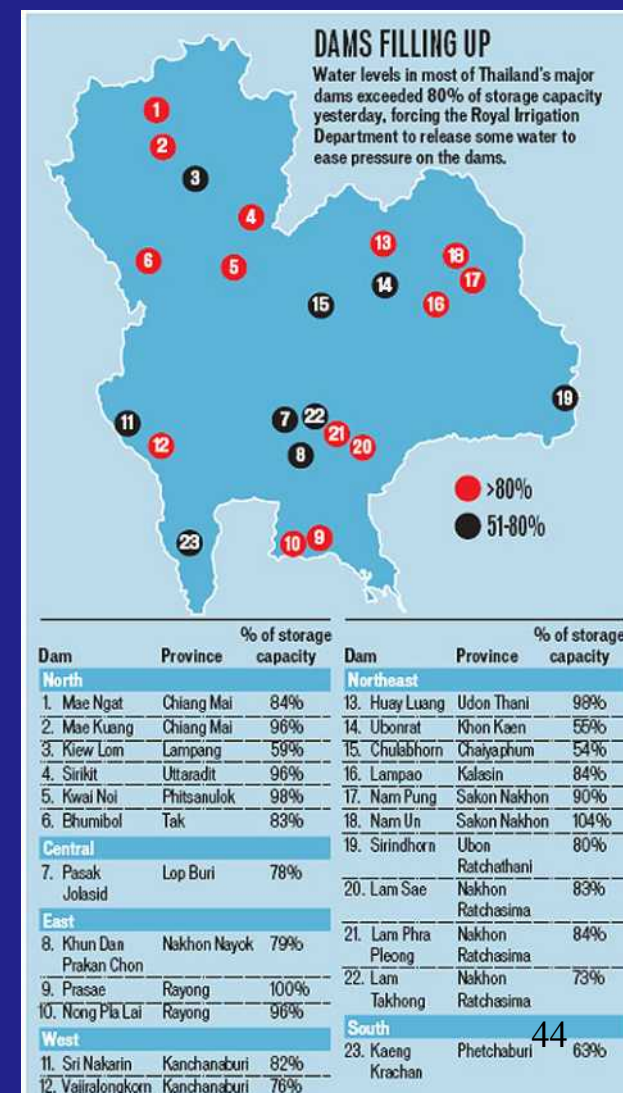
หมายเหตุ ปริมาณฝนย้อนหลัง 30 ปี อ้างอิงจากสถานีวัดน้ำฝน 728 สถานี ปริมาณฝนปี 2554 อ้างอิงจากสถานีวัดน้ำฝน 65 สถานี

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

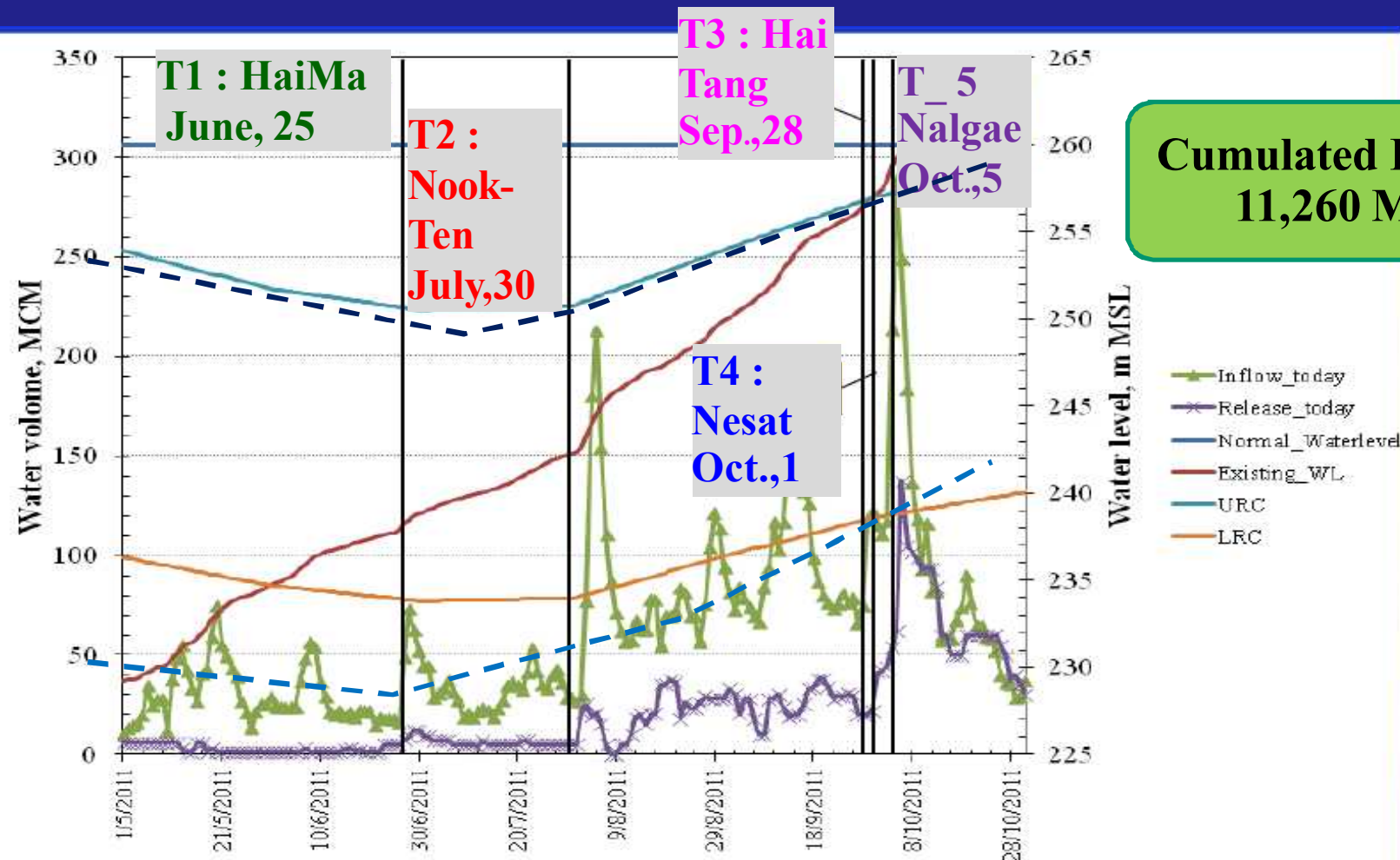
- Type : Arch Gravity Dam
(H=154m, L=486m, W=8m)
- Capacity : 13,462,000,000 m³
- Catchment : 26,400 km²
- Surface Area : 300 km²

Sirikit dam

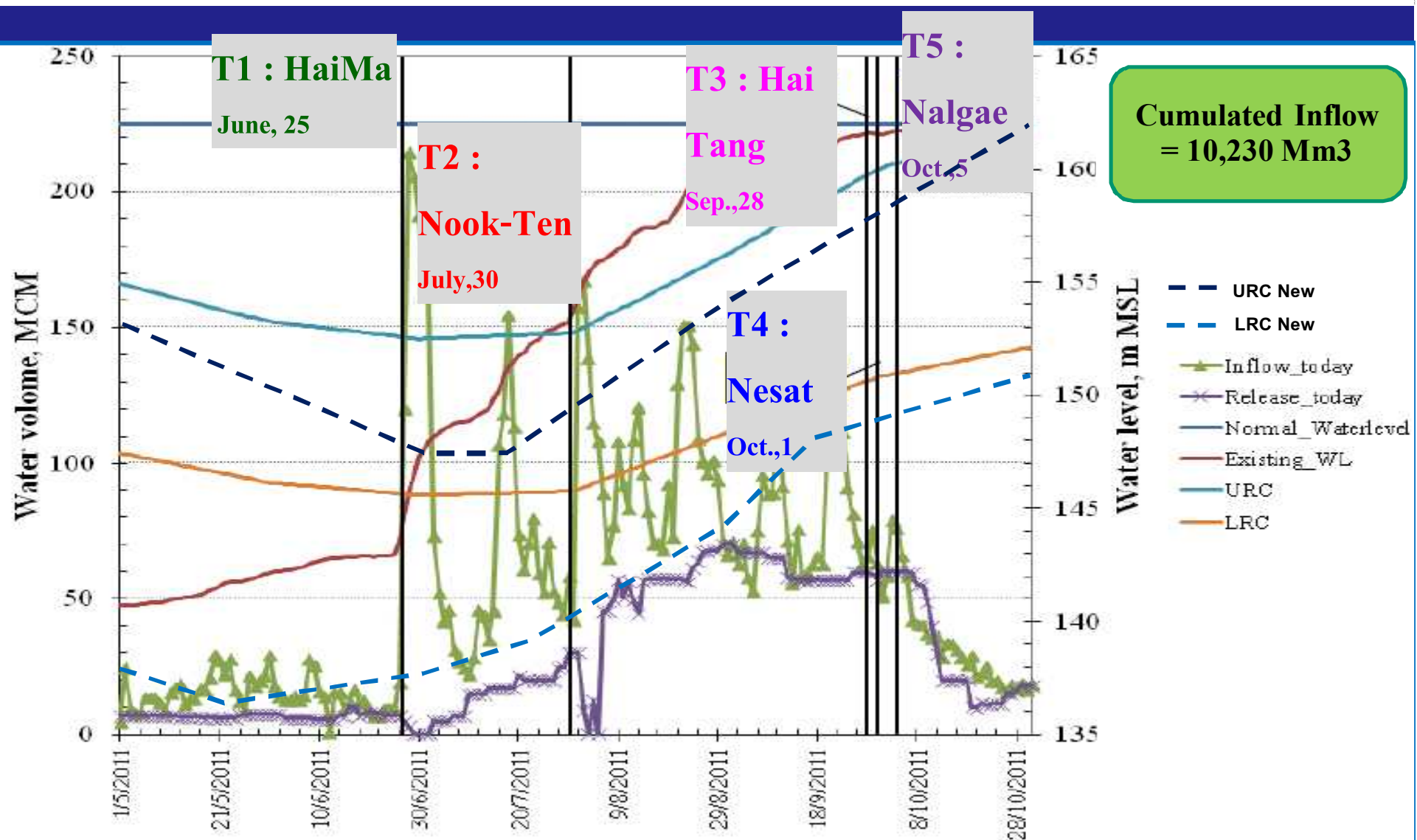
- Type : Embankment Dam
(H=114m, L=800m, W=12m)
- Capacity : 9,510,000,000 m³
- Catchment : 13,130 km²
- Surface Area : 259 km²



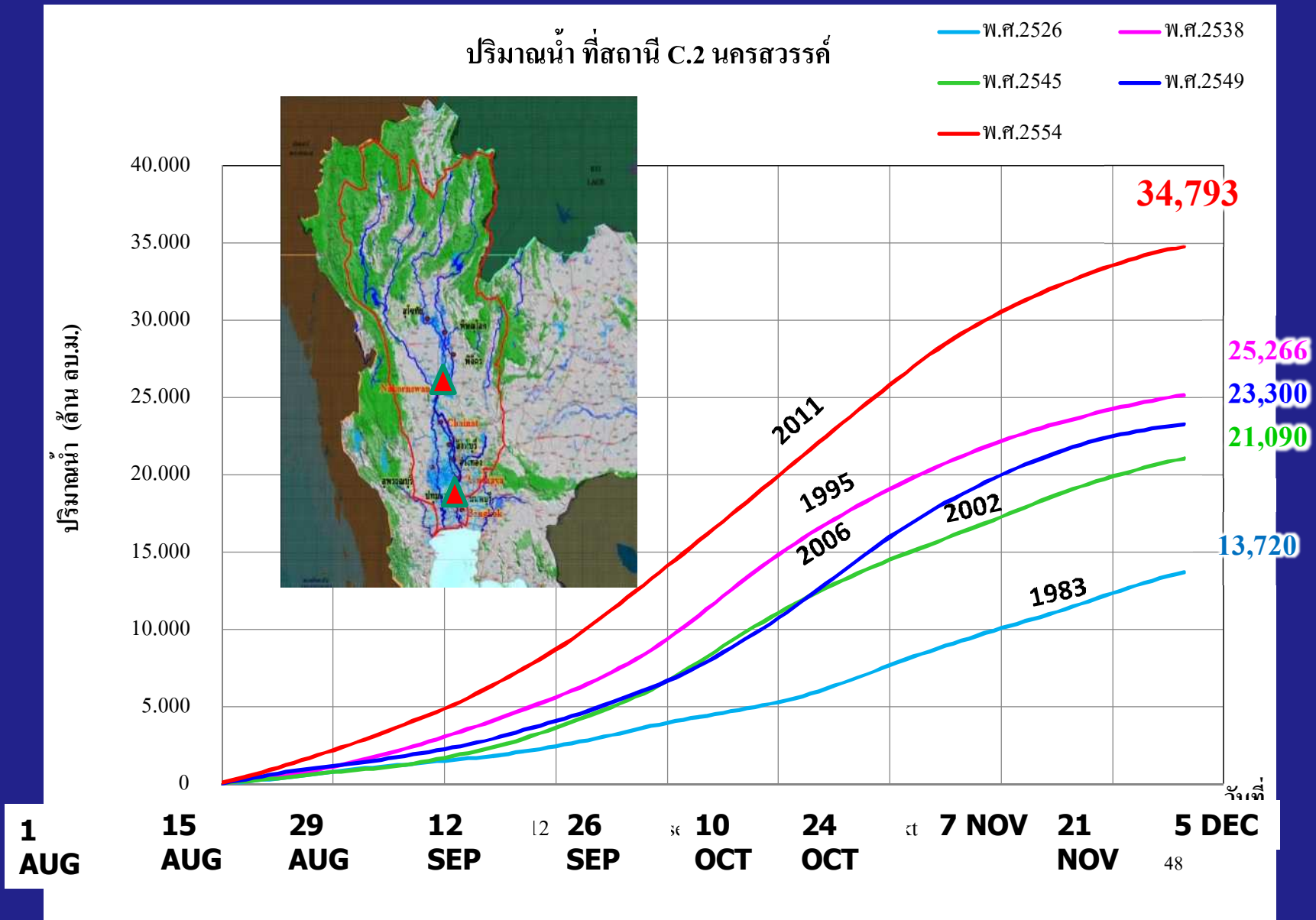
Water Inflow into Bhumibol Reservoir by 5 Typhoon from June to October



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

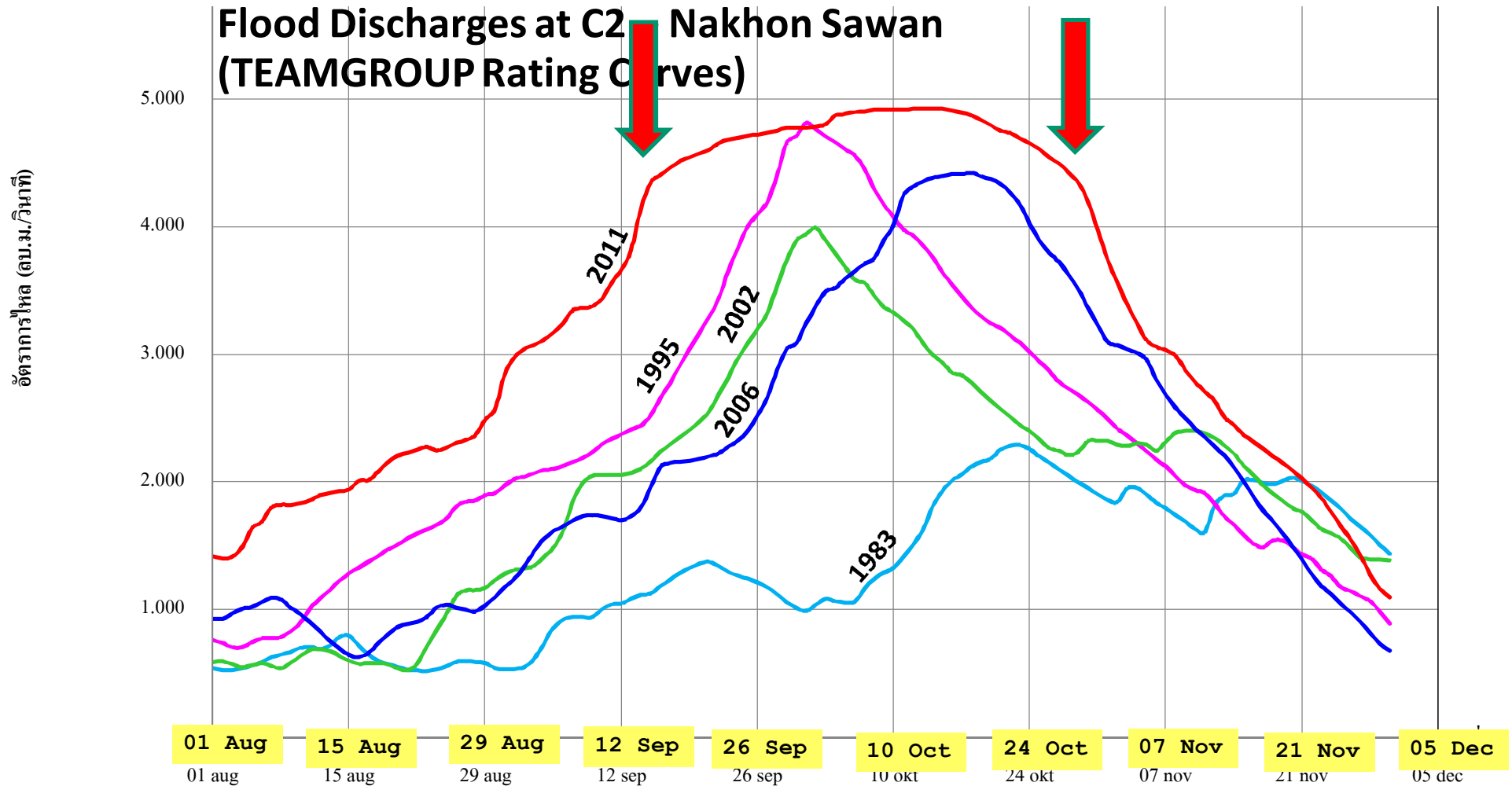


50 Years Highest Flood Volume at Nakhonsawan (230km north of Bangkok)



Flood Discharge at Nakhonsawan (230km north of Bangkok)

Mm3 / Day from September to end of October 2011
was highest volume and duration

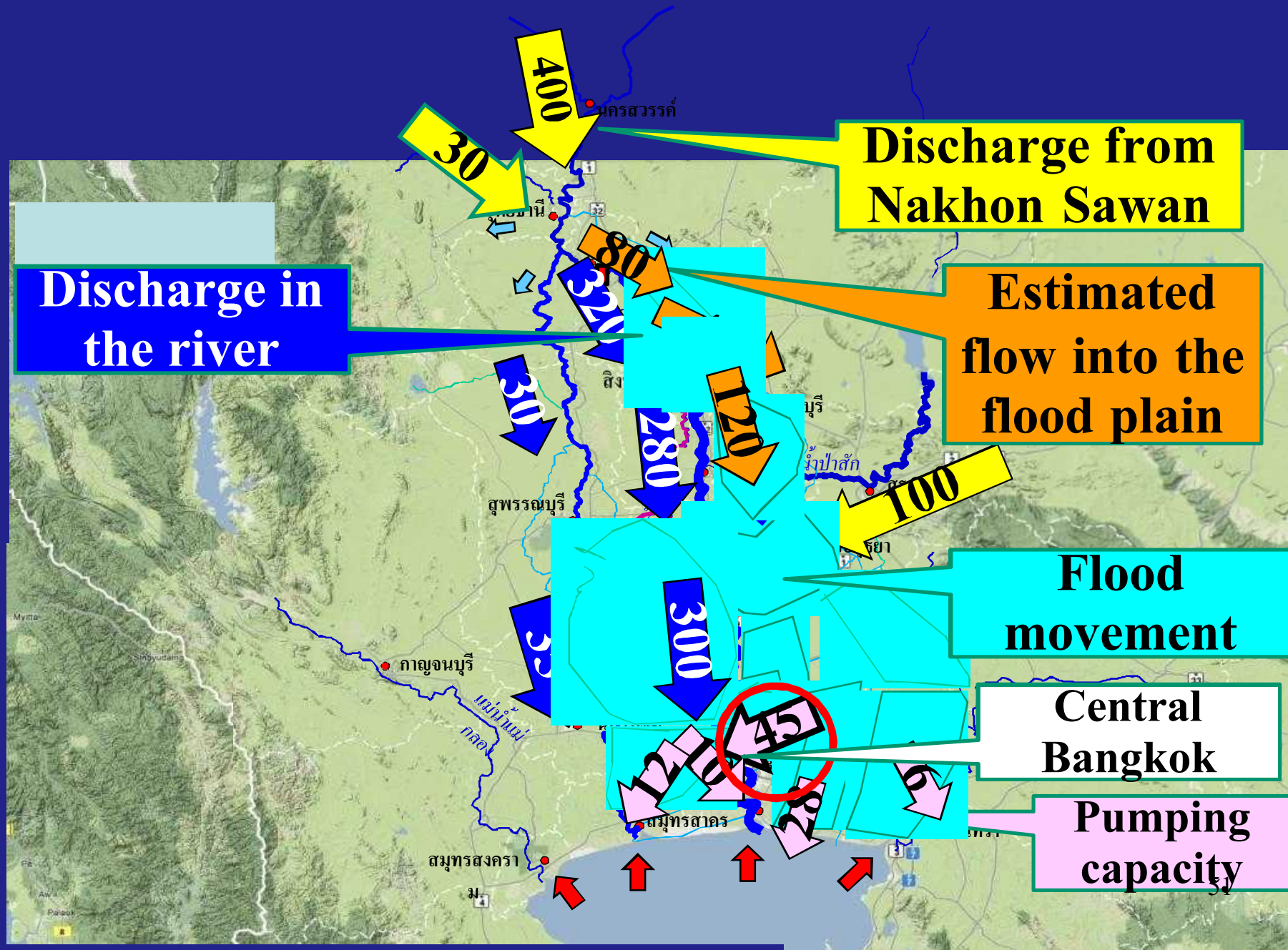


Movement of Water toward the sea (passing Bangkok)

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 (Mm3/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 1,564km² 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



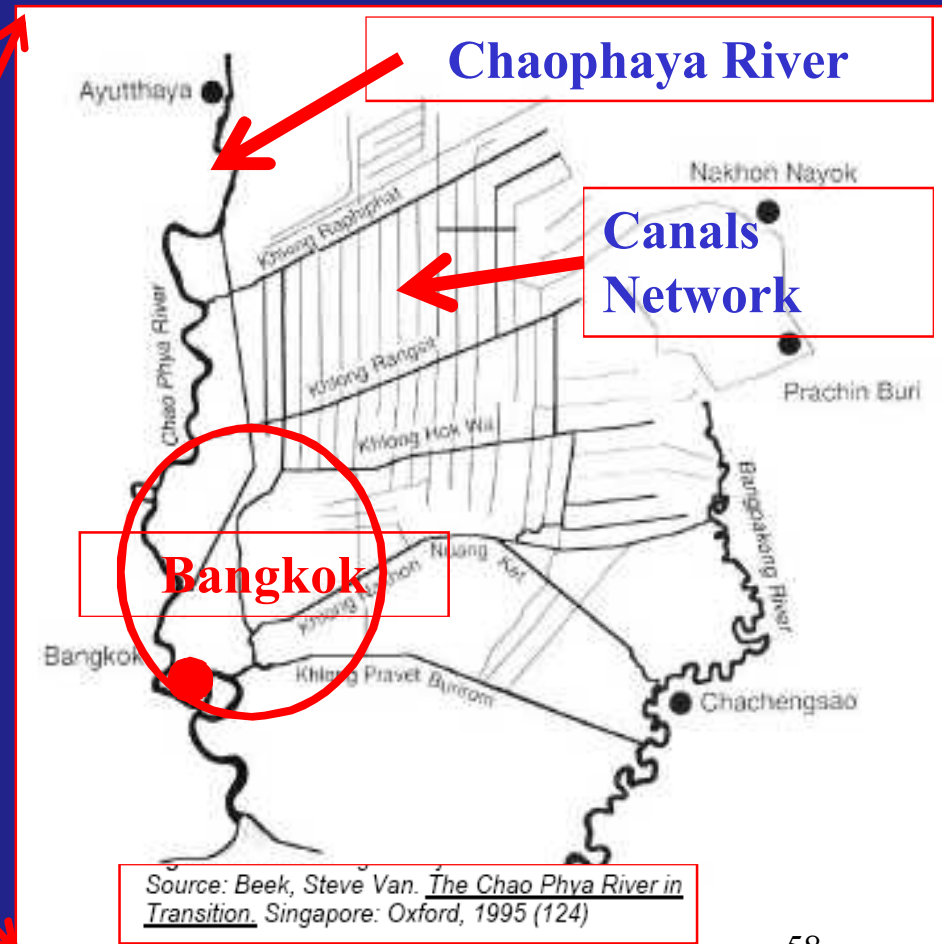
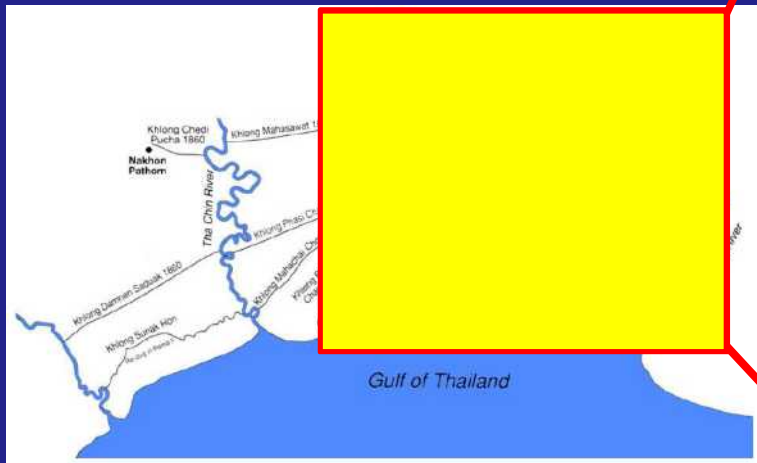
Chaophaya Lower Basin Waterway Network

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

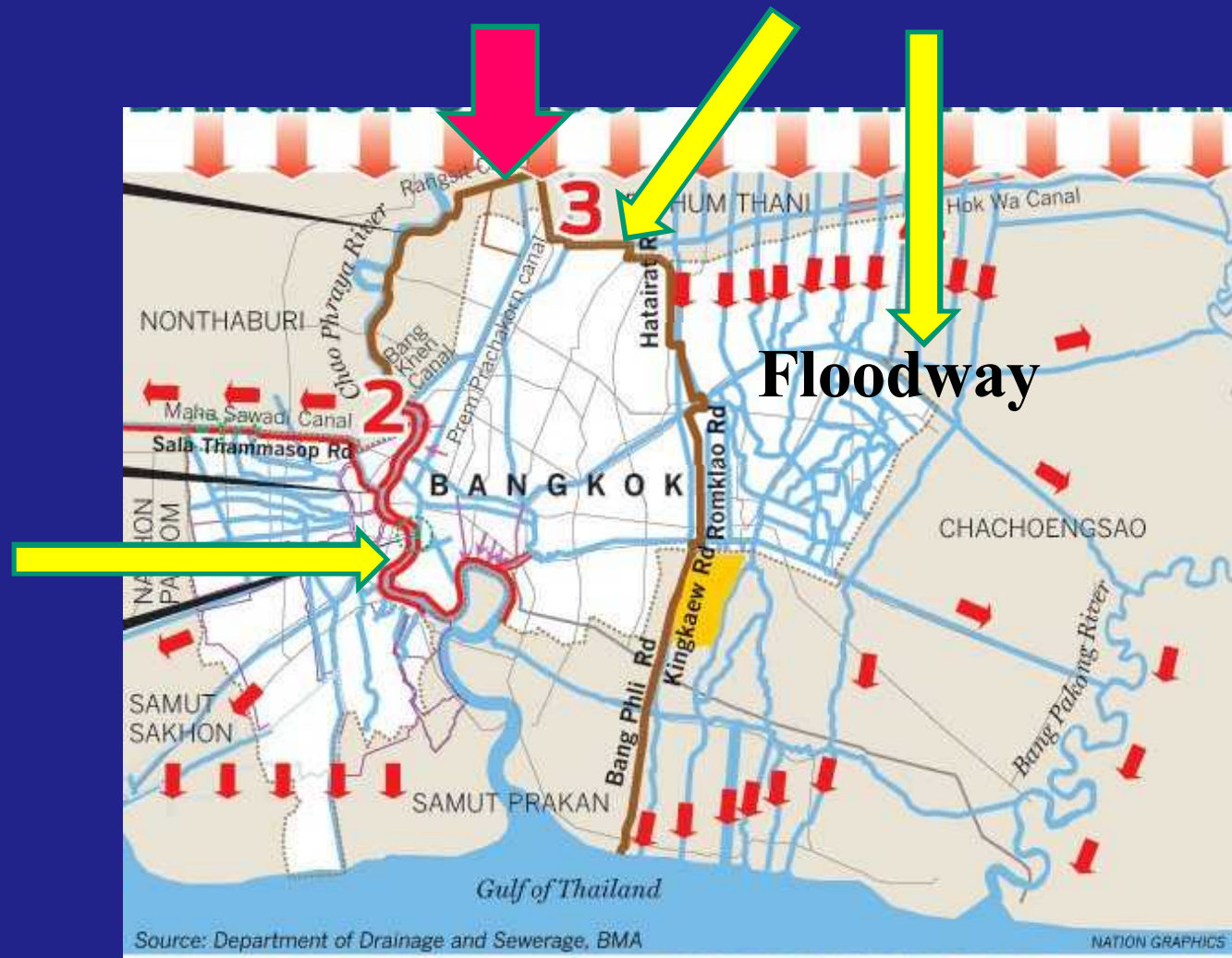


Chaophaya River



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

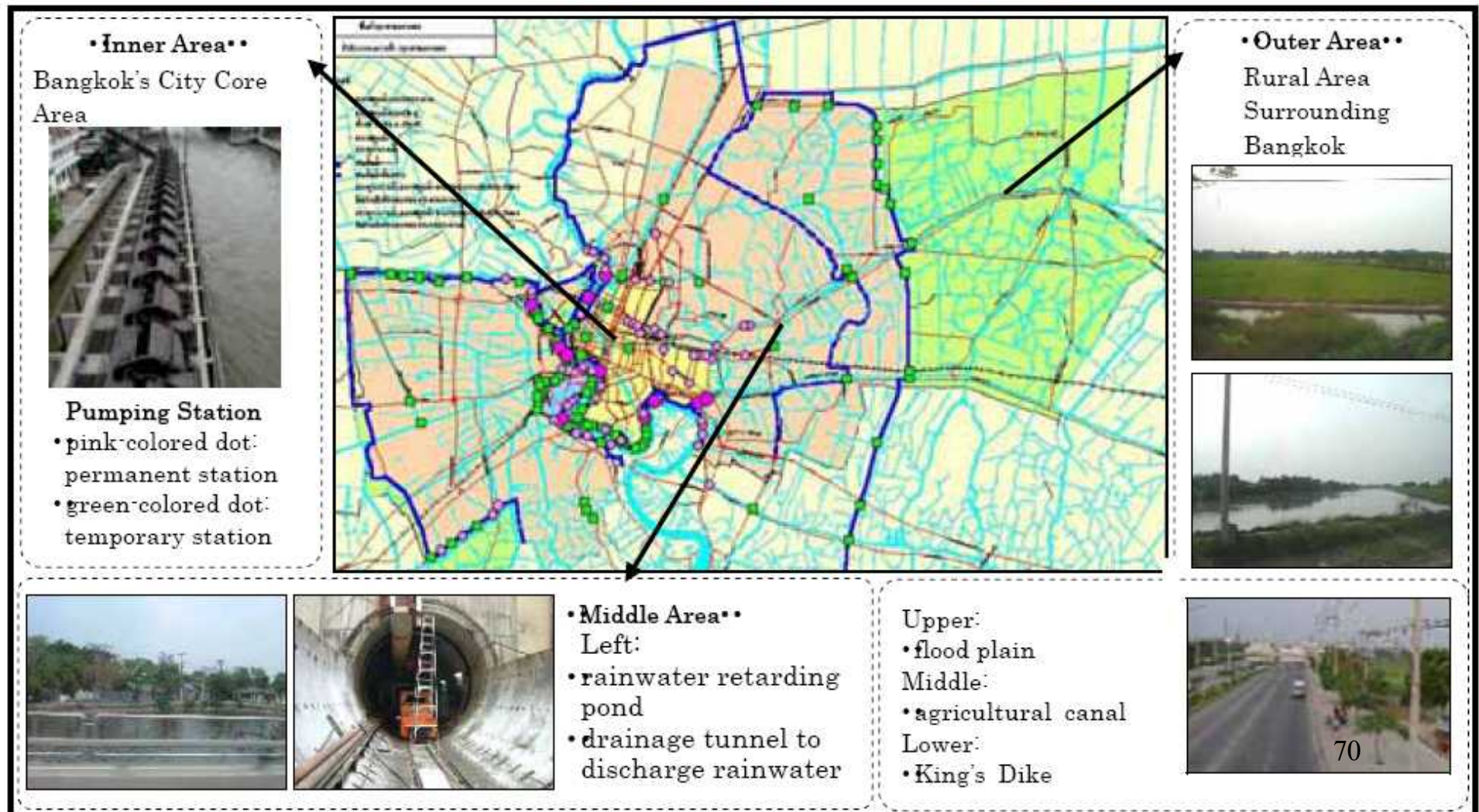


Bangkok Flood Protection Plan

Outer Area : Dyke, Floodway, temporary retention ponds

Inner Area : Water control gates installed in canals

Middle Area : Flood drain tunnels



Bangkok Flood Protection Plan

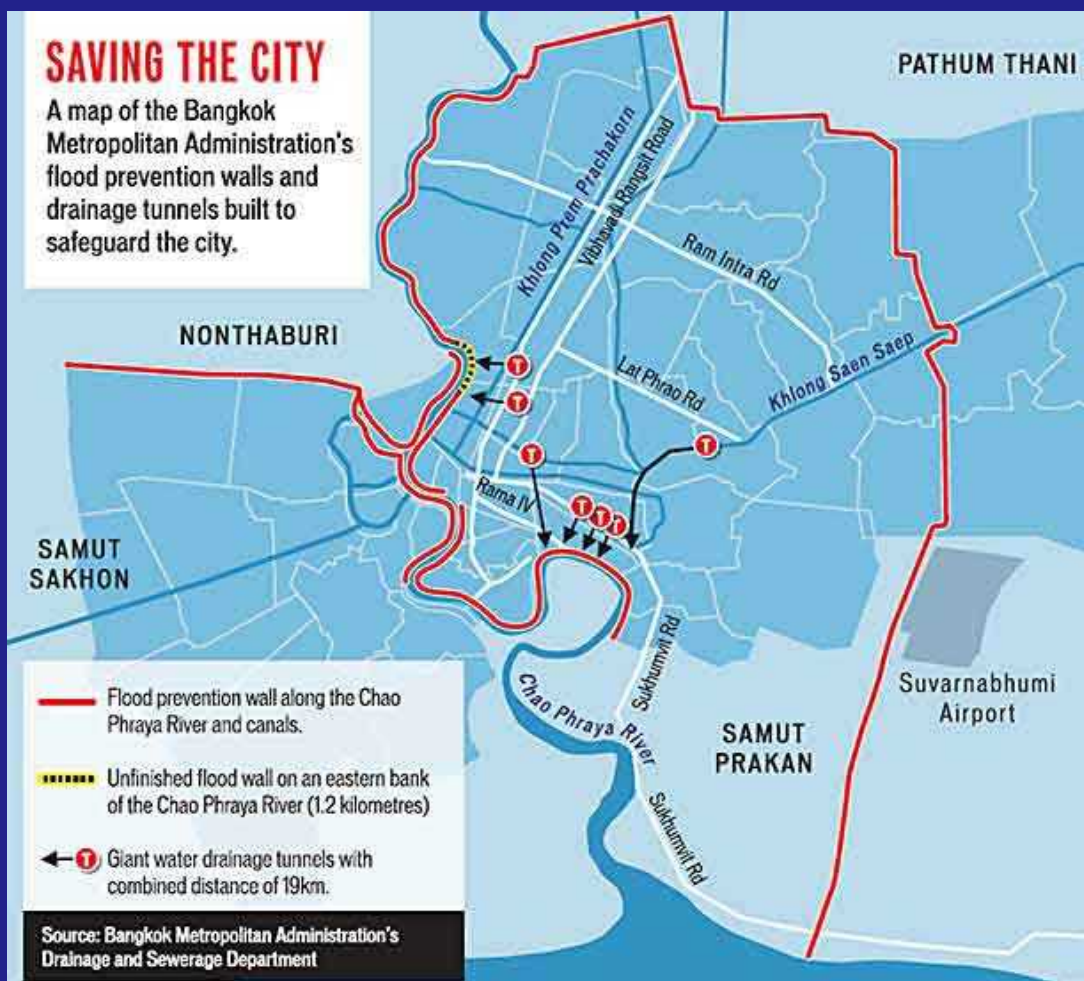
Pumping Stations & Water Control Gate



Flood Tunnels in Bangkok

SAVING THE CITY

A map of the Bangkok Metropolitan Administration's flood prevention walls and drainage tunnels built to safeguard the city.



IN THE PIPELINE

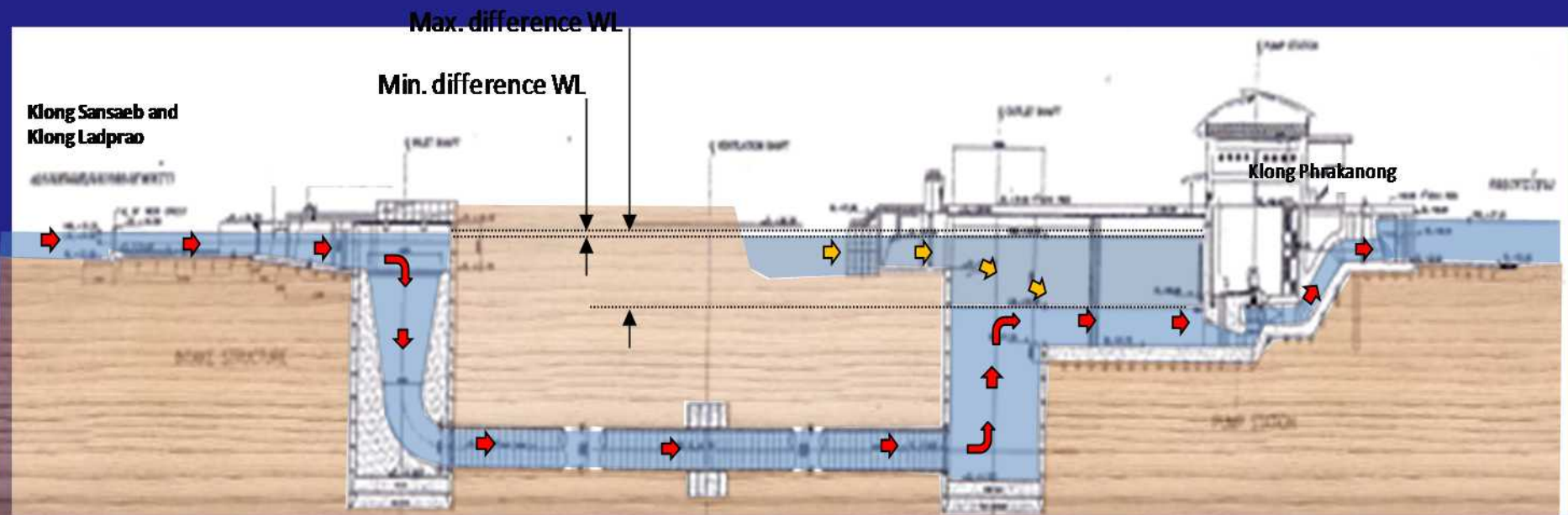
The Bangkok Metropolitan Administration has unveiled a 16 billion baht drainage system aimed at solving the capital's flood problems.

The project consists of four giant tunnels of five to six metres in diameter and a combined length of about 34.5km.



Source: Bangkok Metropolitan Administration

POSTgraphics



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

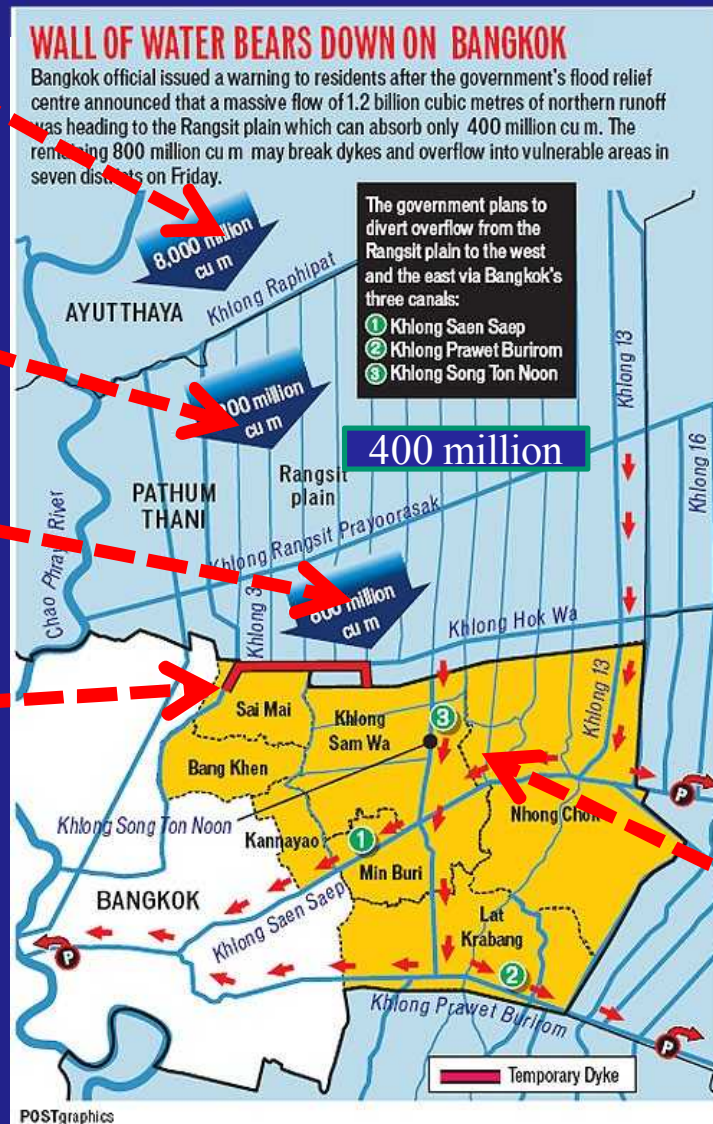
- Total 8 billion m³ water was coming toward Bangkok
- 800 million m³ may break dyke and overflow into inner area

8,000 million m³
80 km north of Bangkok

1,200 million m³
50 km north of Bangkok

800 million m³
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)



SPREADING DISASTER

Two massive runoffs (in blue) are threatening north and west Bangkok
 ① The Rangsit runoff which is now inundating Don Muang and Vibhavadi Rangsit Road
 ② The runoff from Nonthaburi which is expected to hit Thon Buri late this week



July 2011
(no flood water yet)



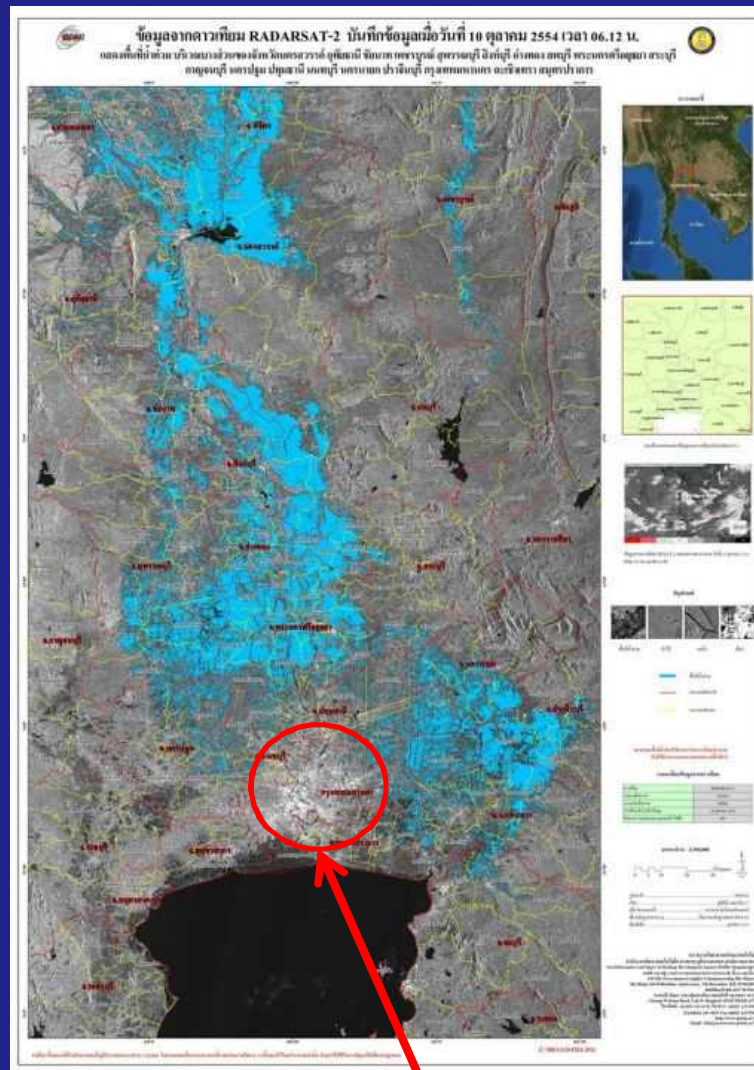
October 2011
(completely flooded)



Arial View of Flood

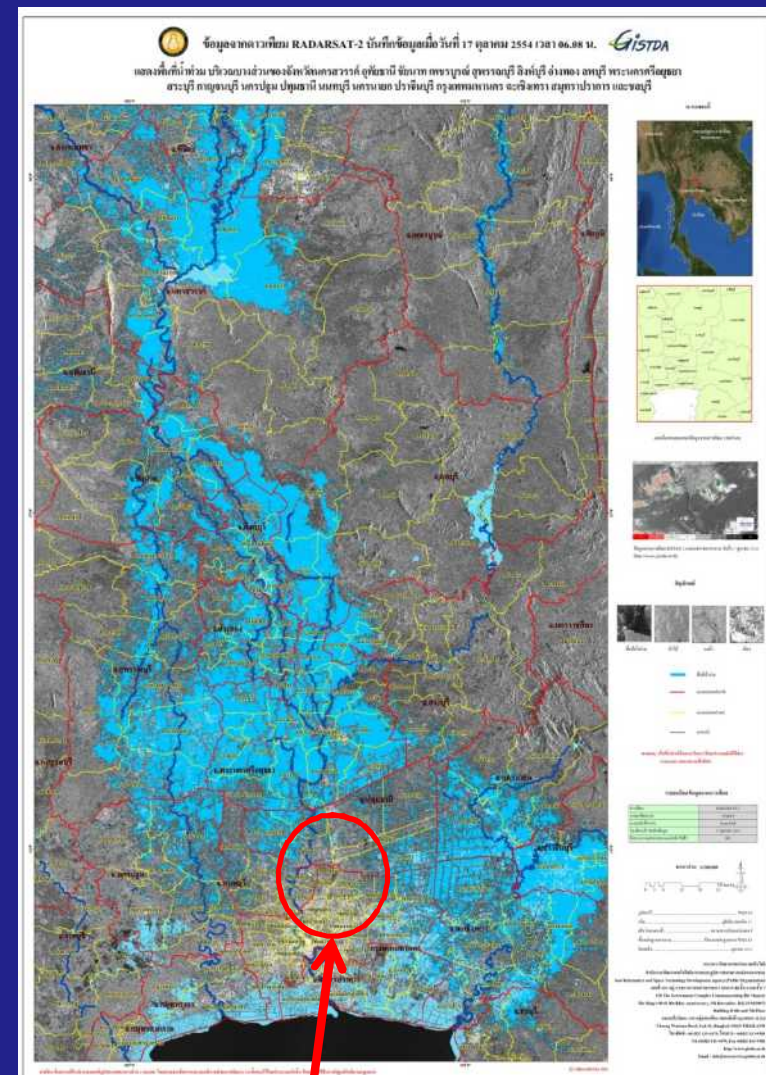


10 October 2011

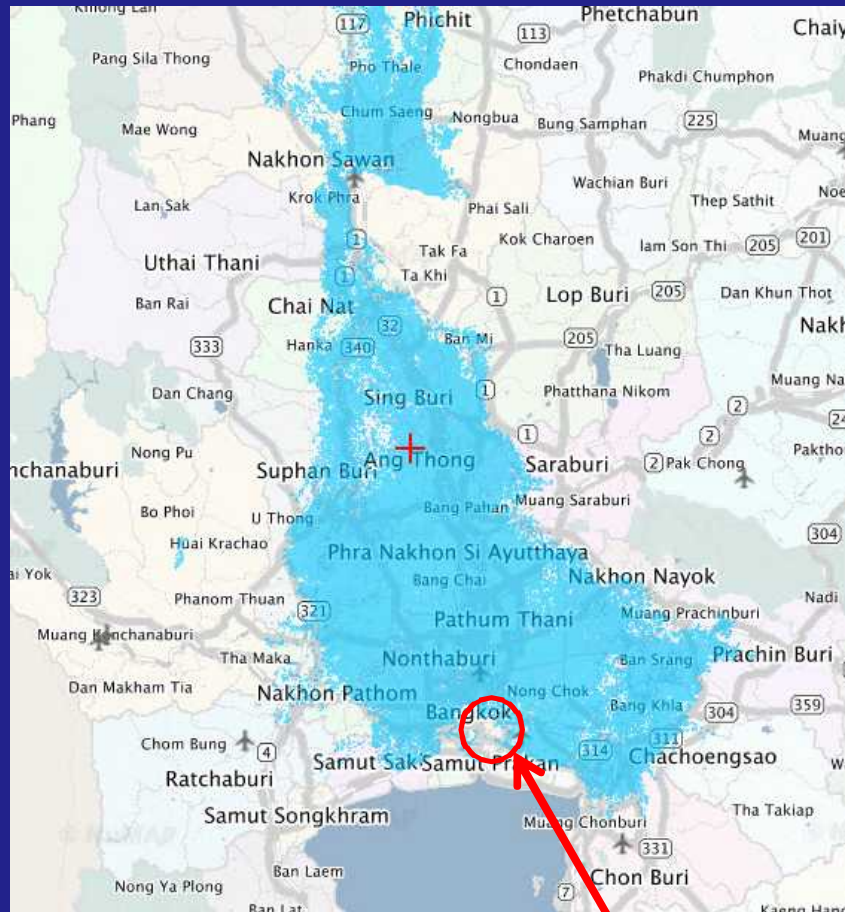


City Center of Bangkok (not flooded)

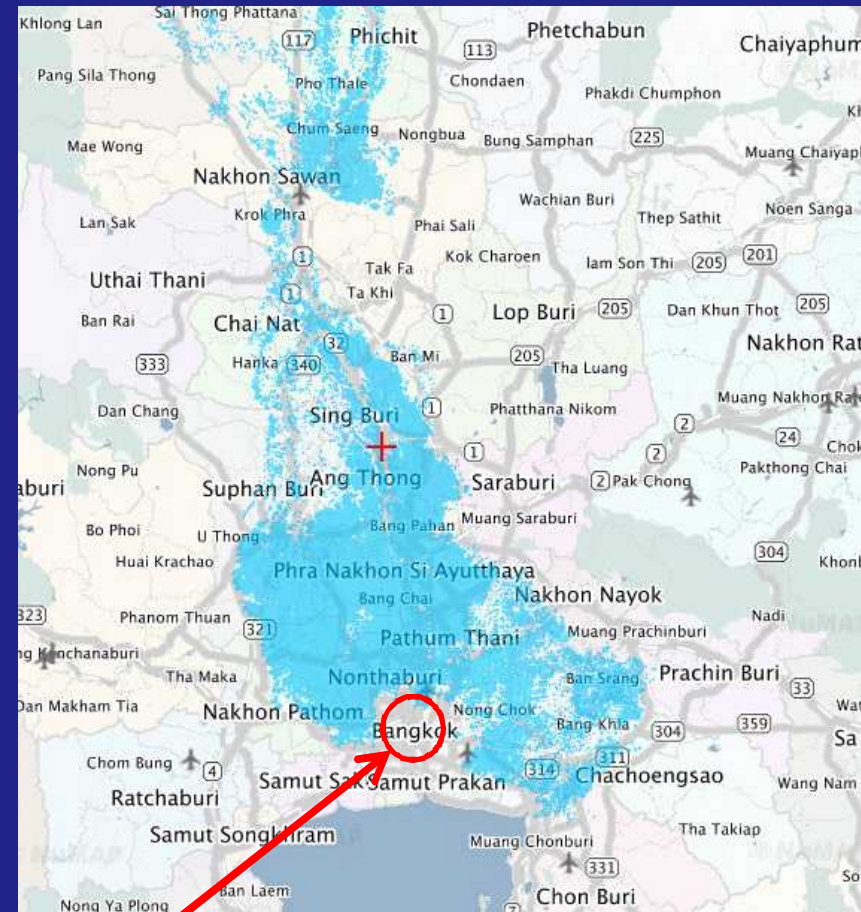
17 October 2011



20 November 2011




18 December 2011




City Center of Bangkok (not flooded)


BANGKOK'S FLOOD-PRONE AREAS

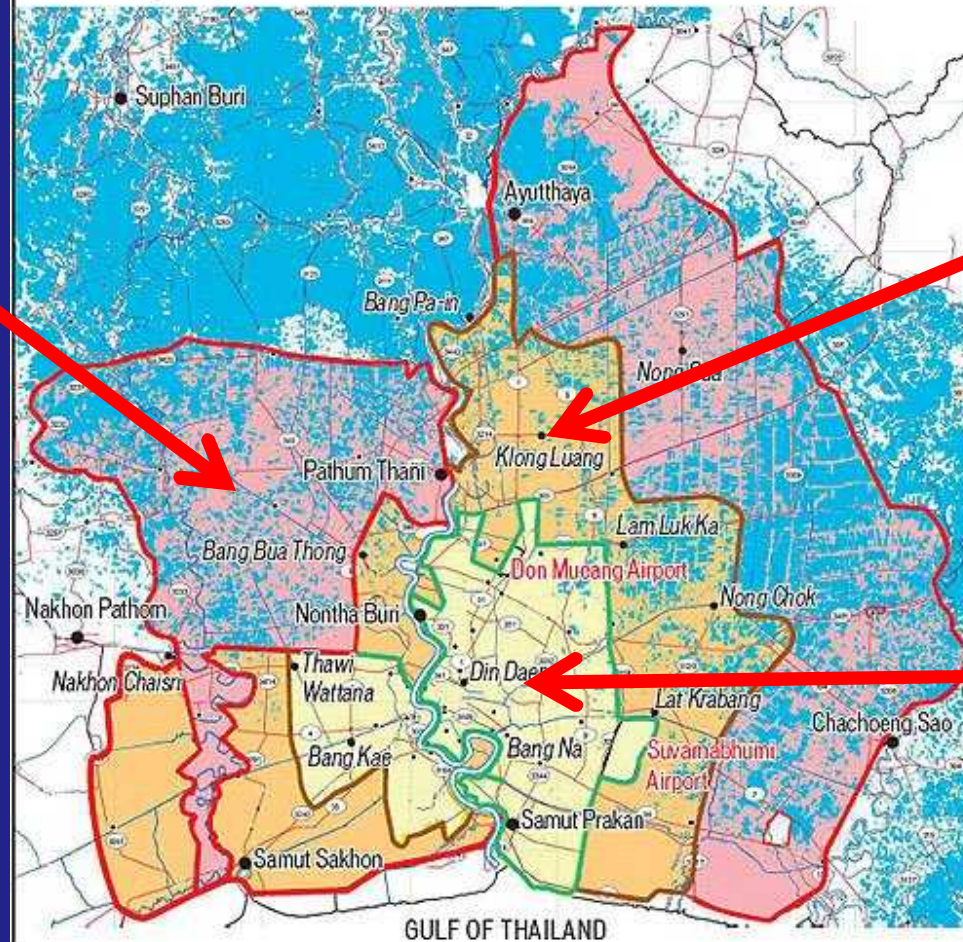
Flood risk areas in Bangkok, studied by Team Group, a water management consulting firm.

 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

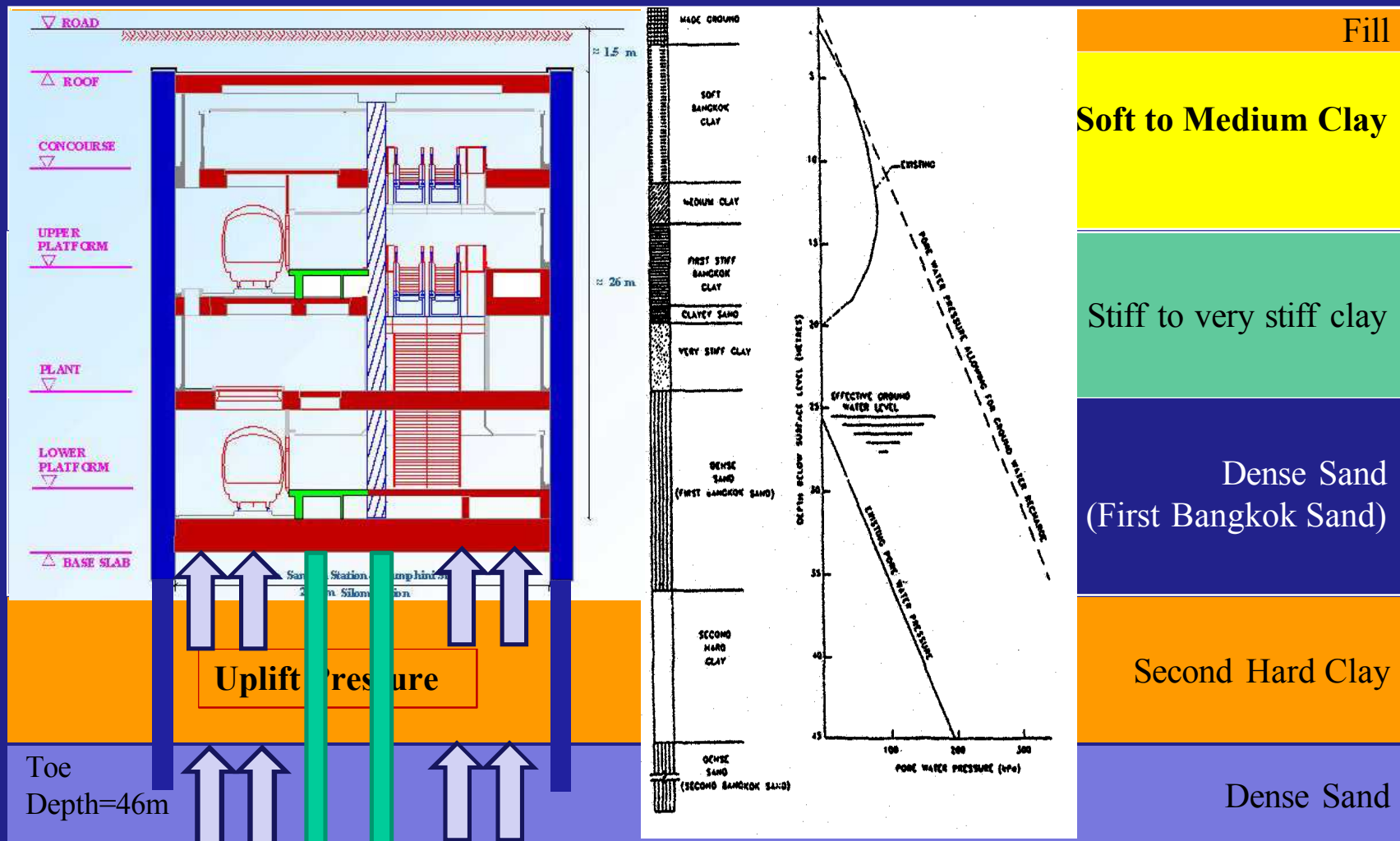
- Geotechnical related risk caused by flooding
- Risk of Water inflow and flooding in Stations and Tunnels

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

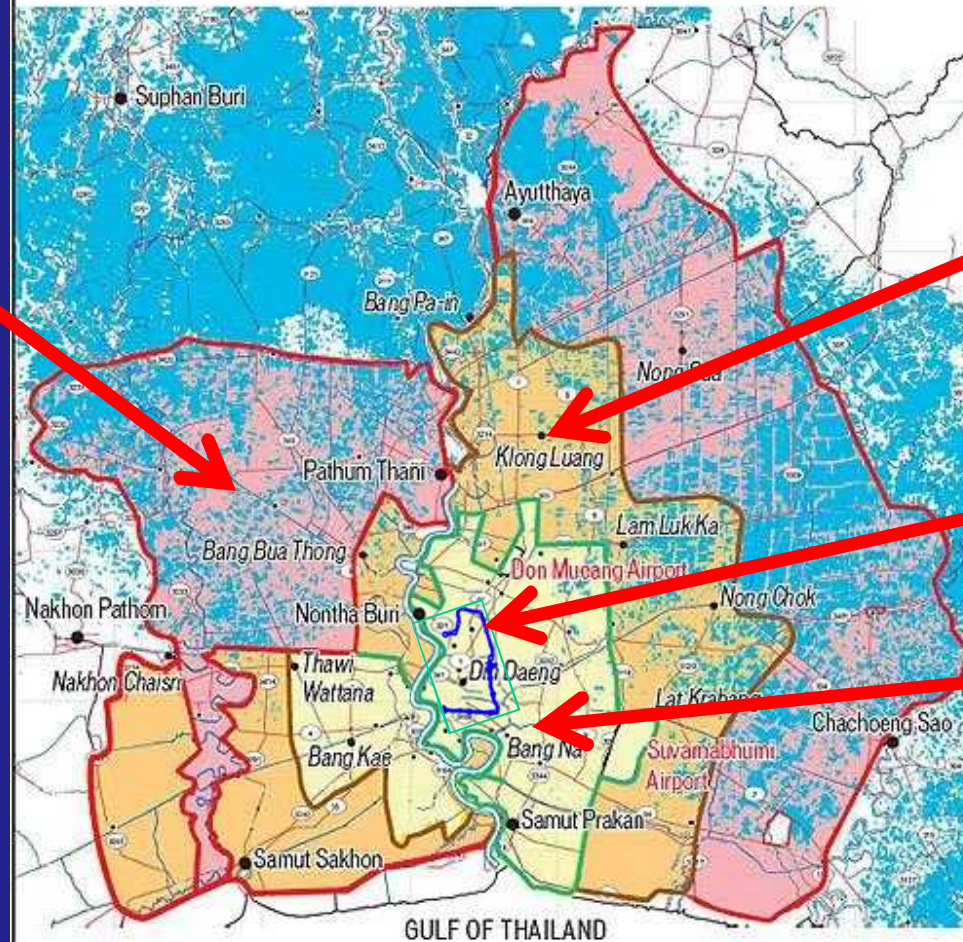
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**Level 3
Highest Risk
1-2m Flood**

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

Subway

**Level 1
Moderate Risk
50 cm Flood**

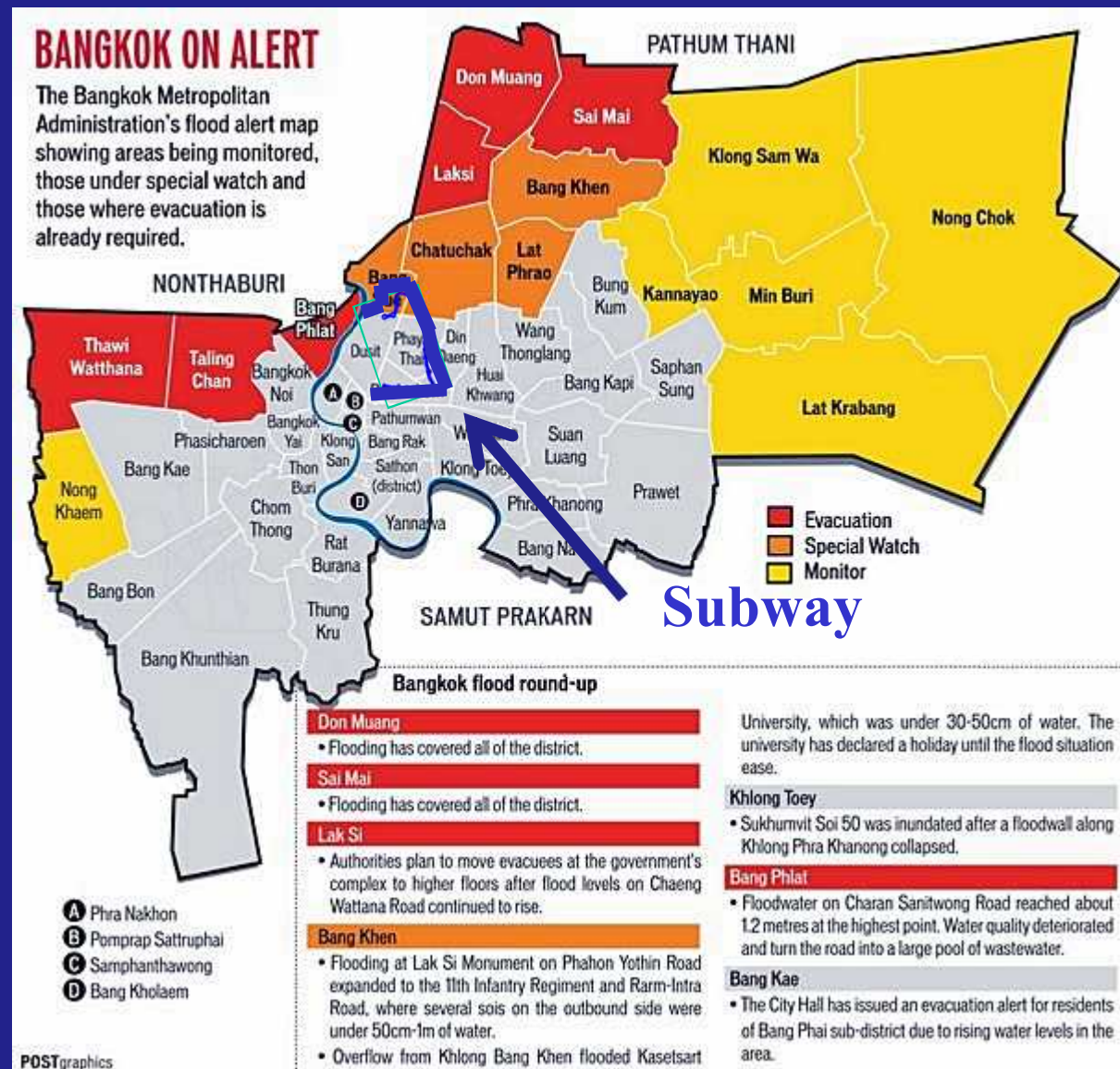
Risk of Flooding in Stations and Tunnels

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)

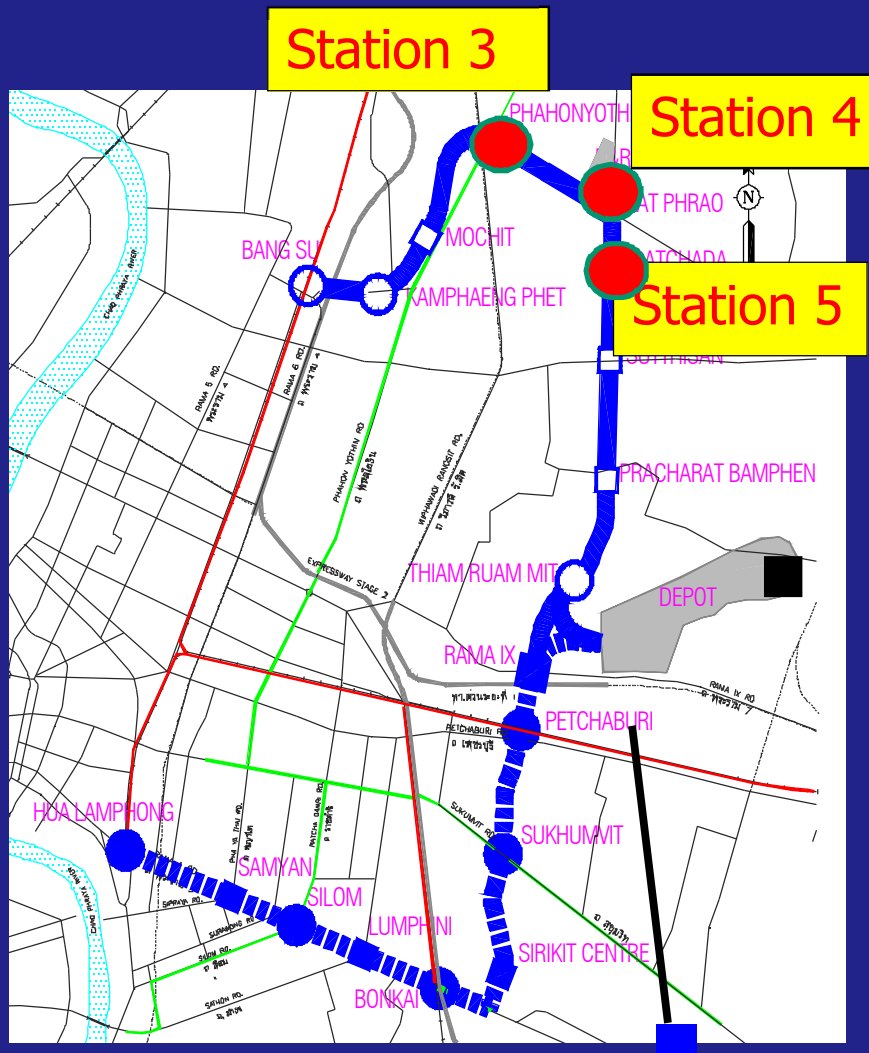
Warned



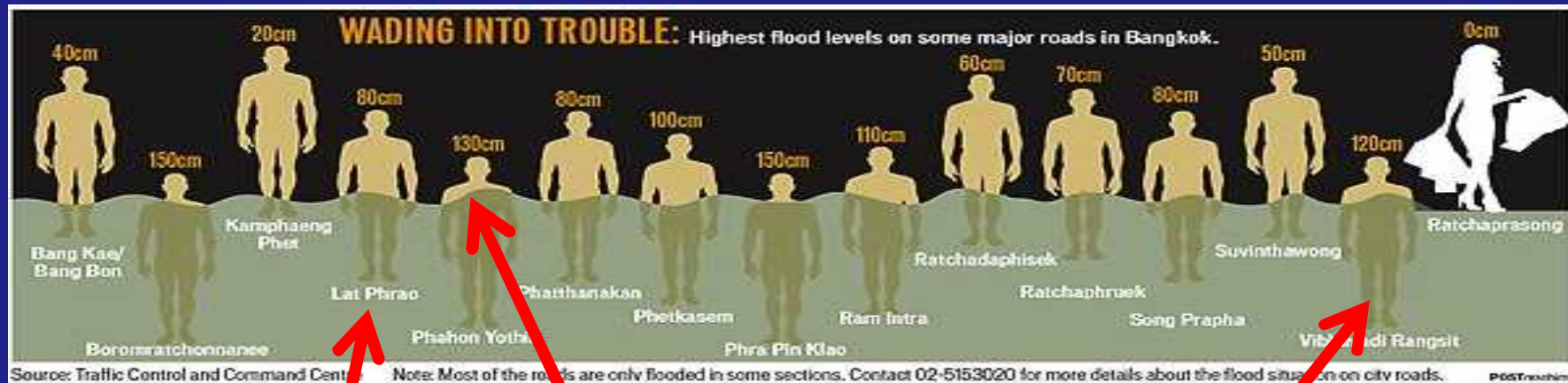
Critical Subway Stations

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 (Ratchadaphisek 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



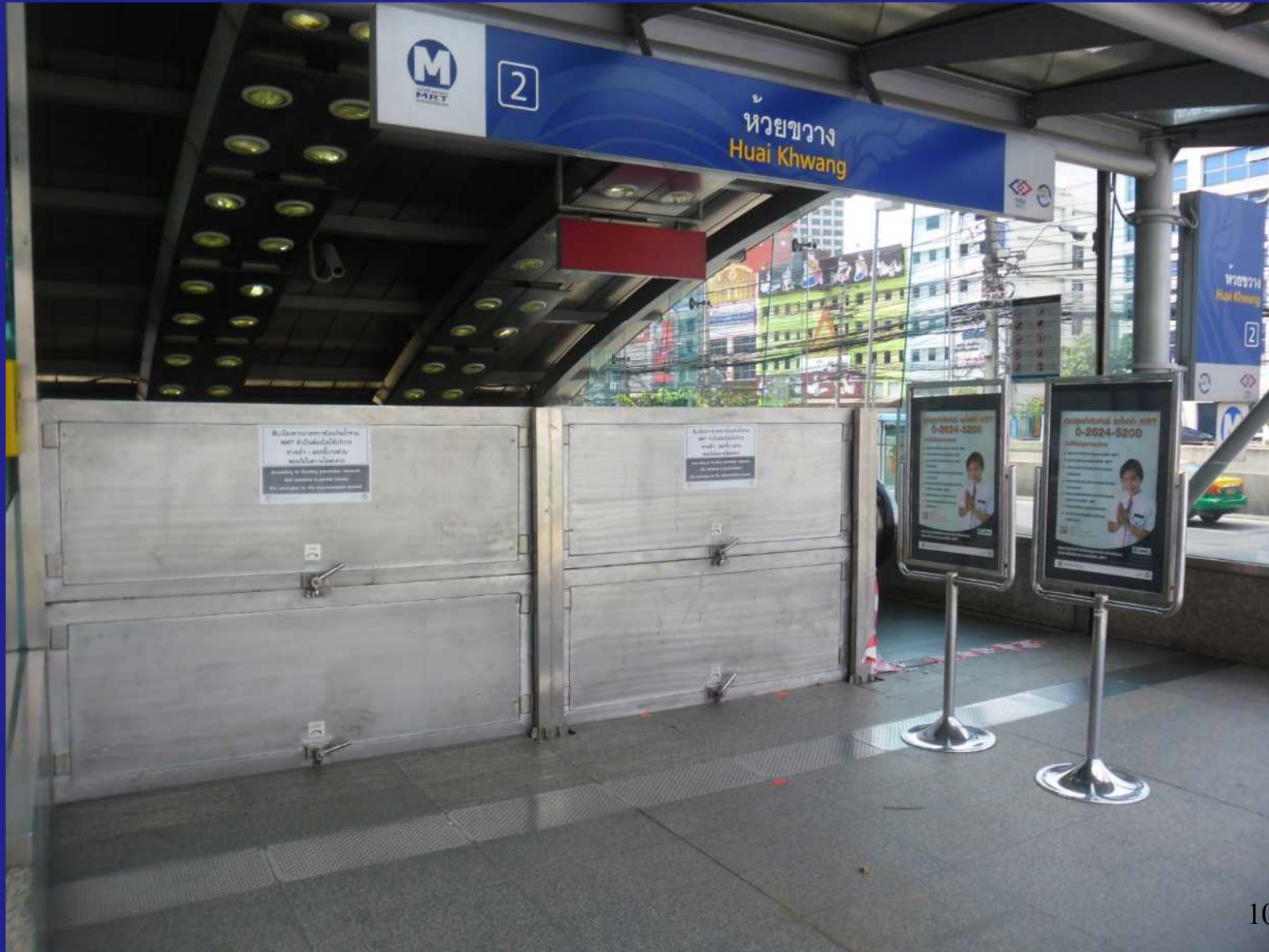
Flooding Period
only trucks and some buses



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)

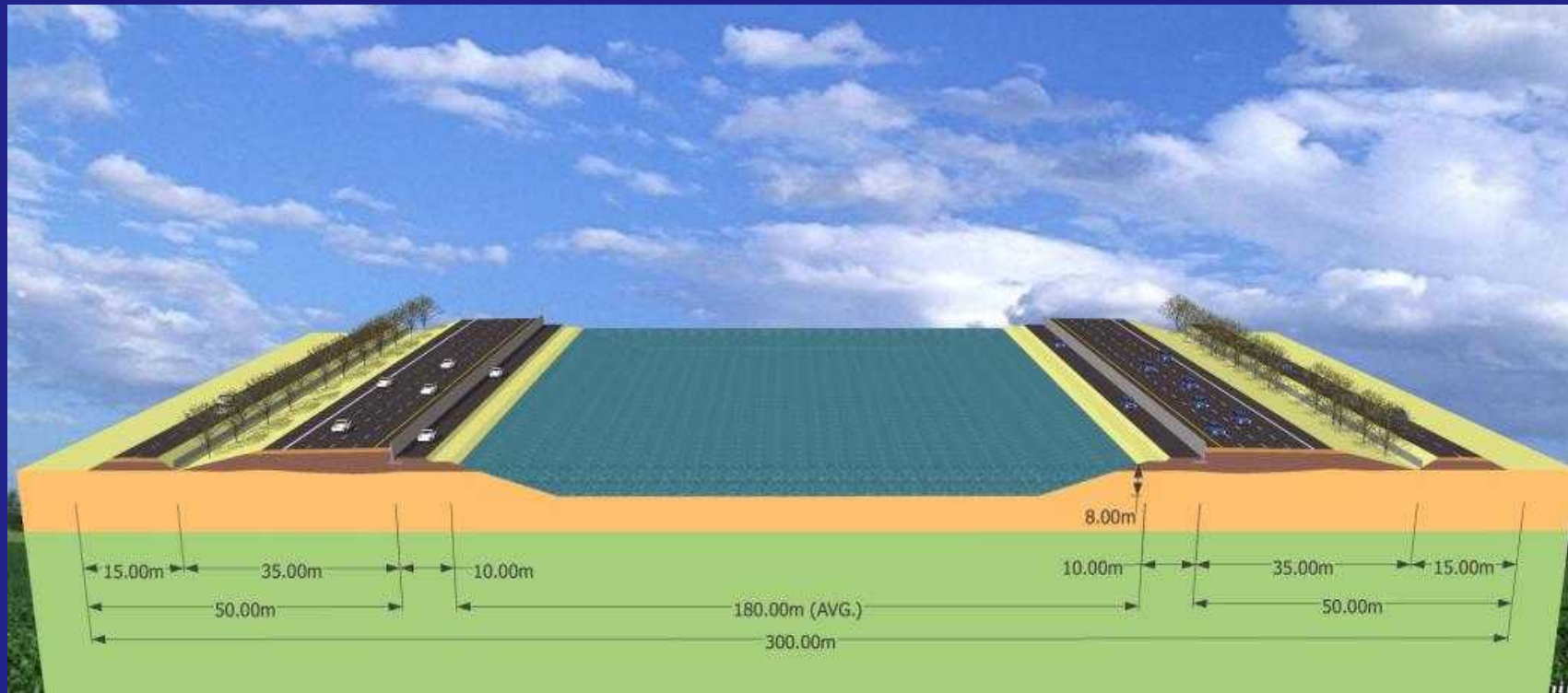
Practical Solution for Flood Protection for Bangkok

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

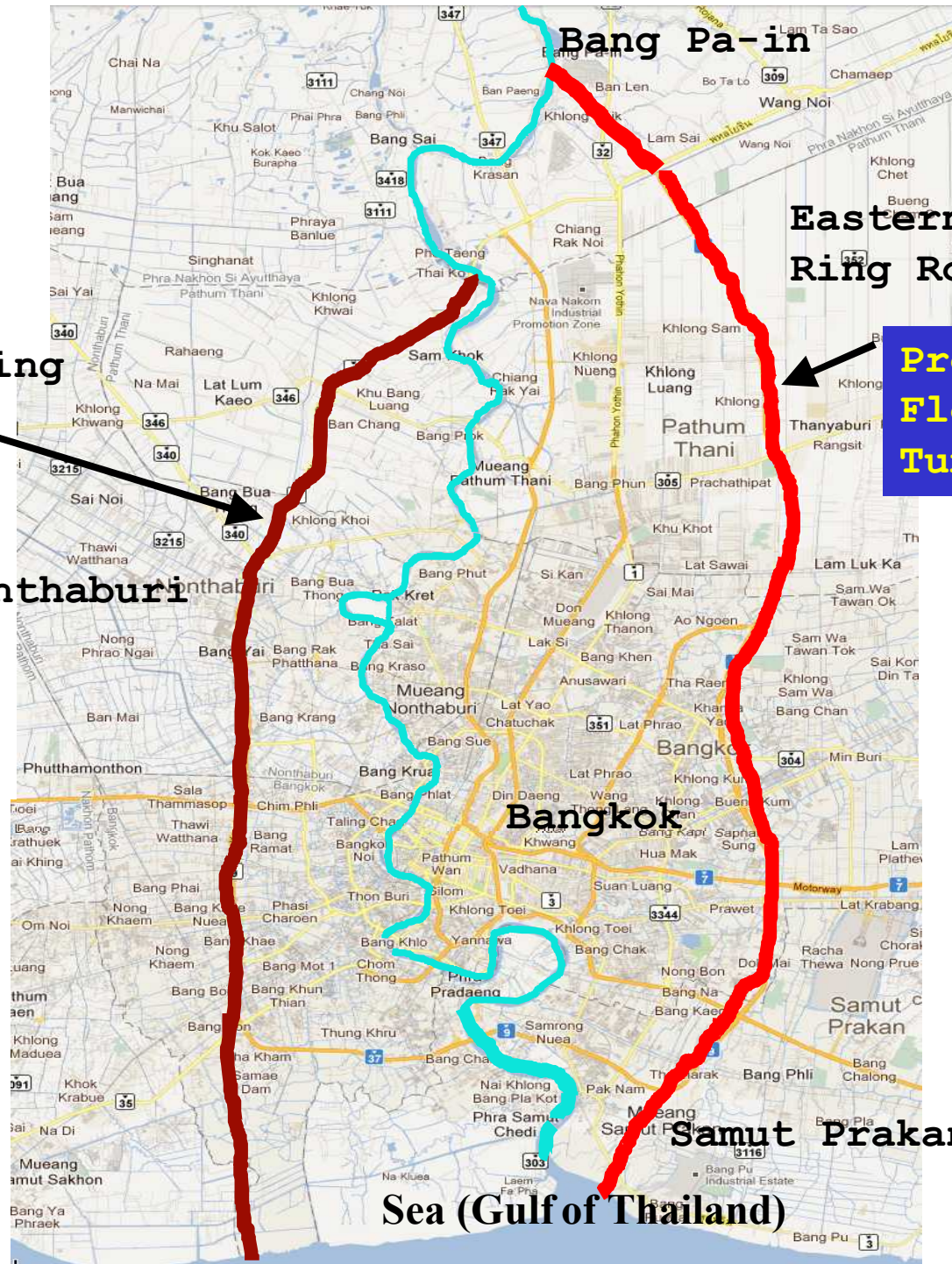
Proposed Flood Drain Tunnel



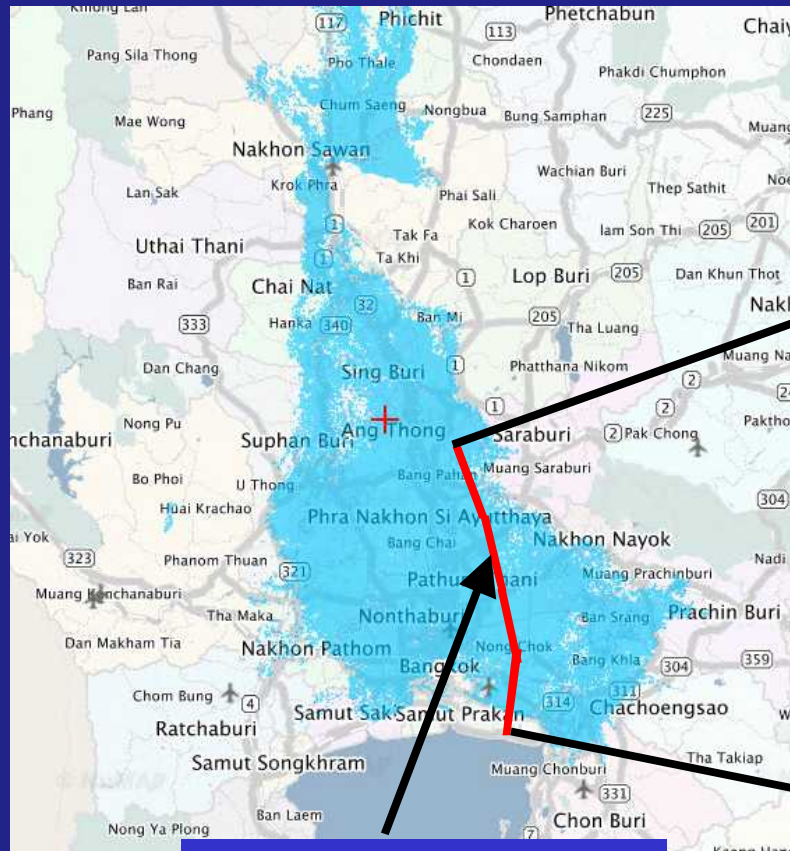
Bangkok

Samut Prakan

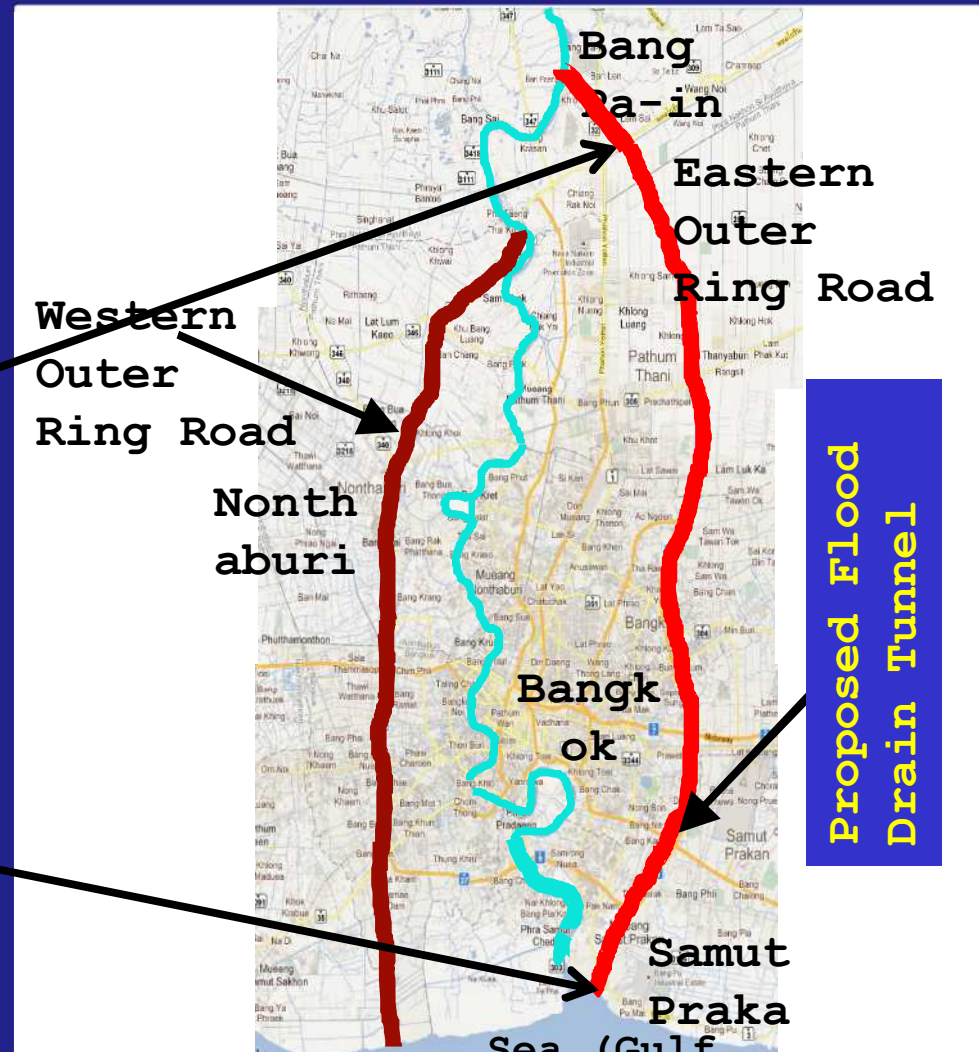
Sea (Gulf of Thailand)



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



Proposed Flood Drain Tunnel

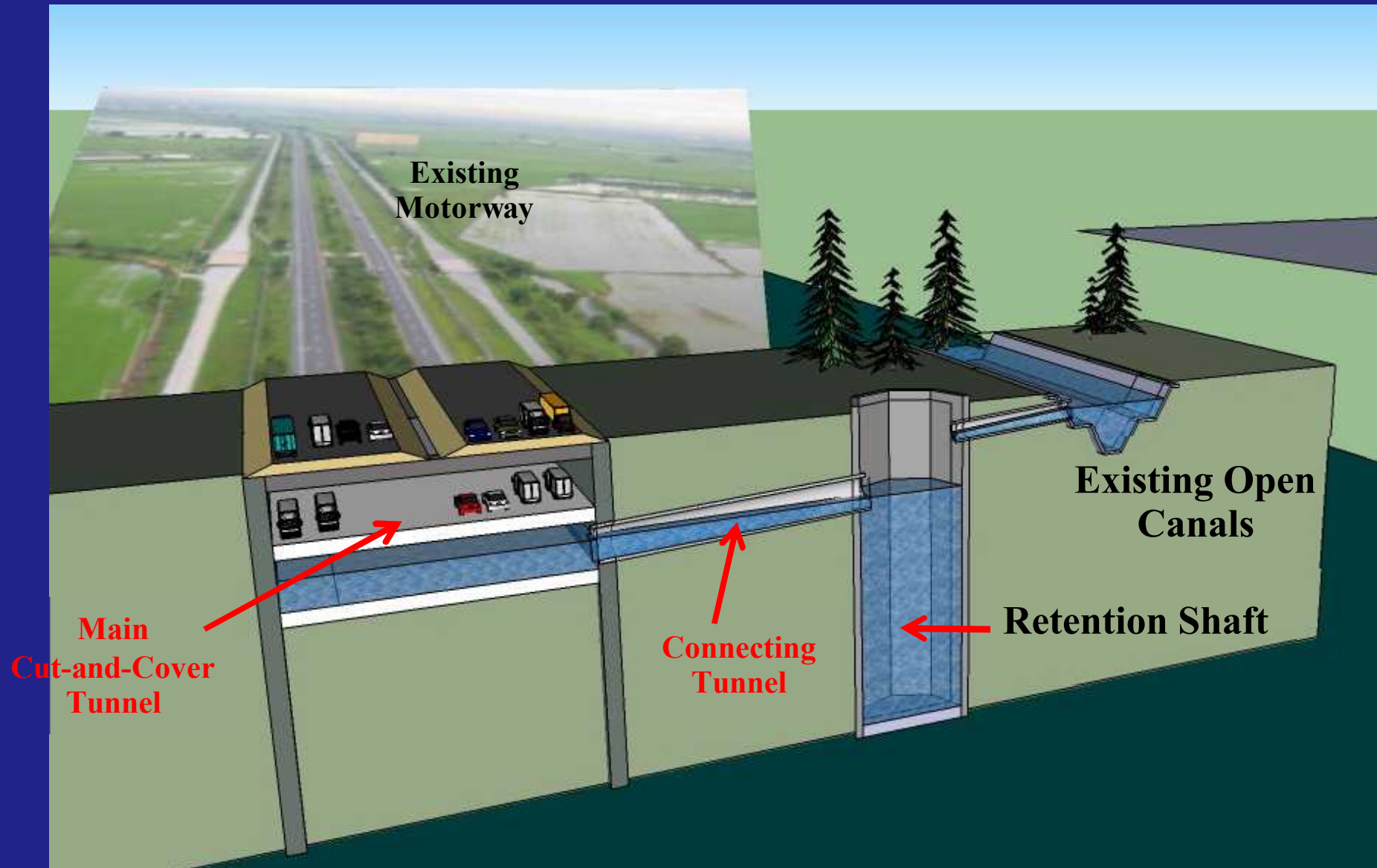


Proposed Flood Drain Tunnel

Eastern Motorway

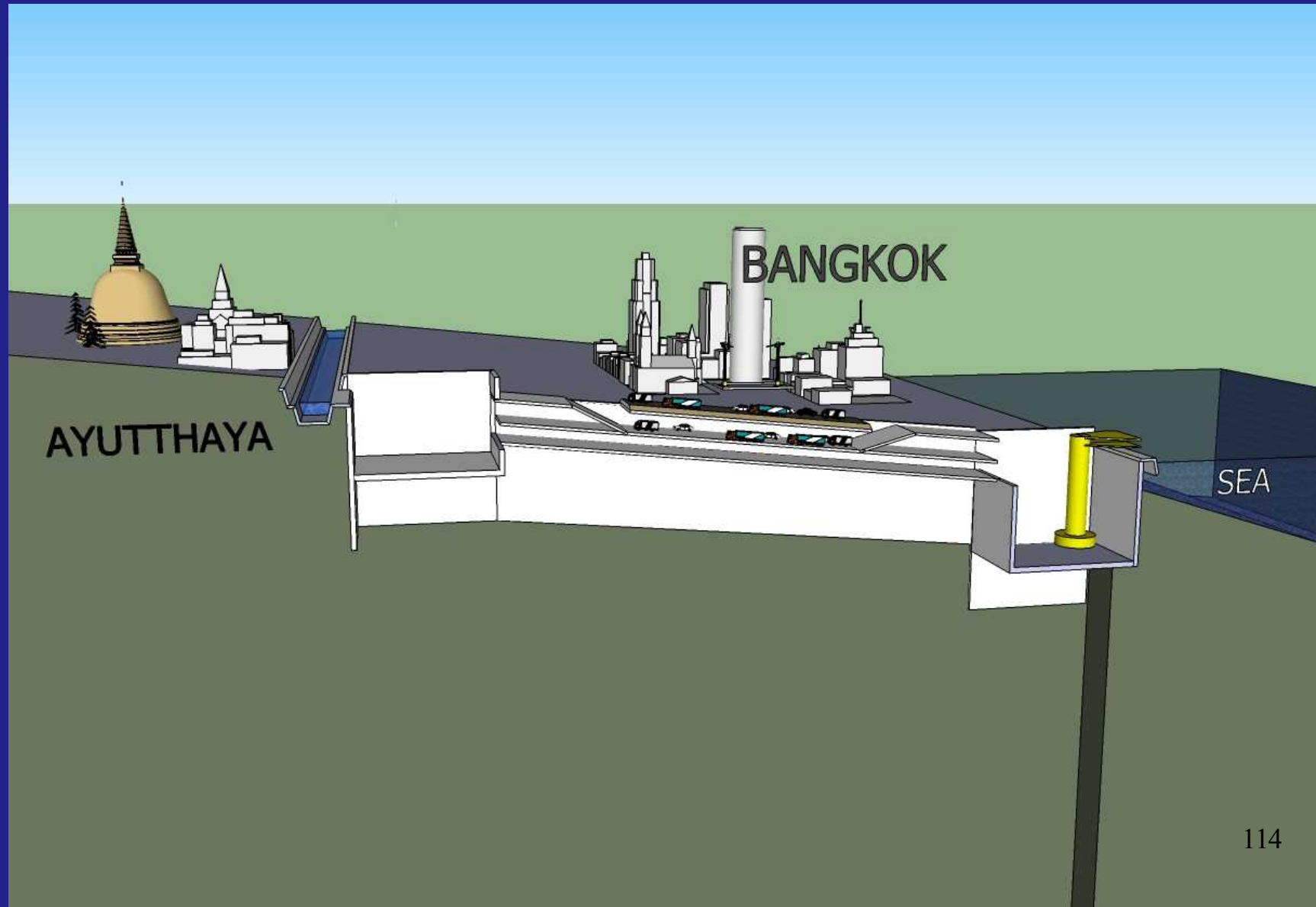


Typical Section of Multipurpose Underground System (MUST)



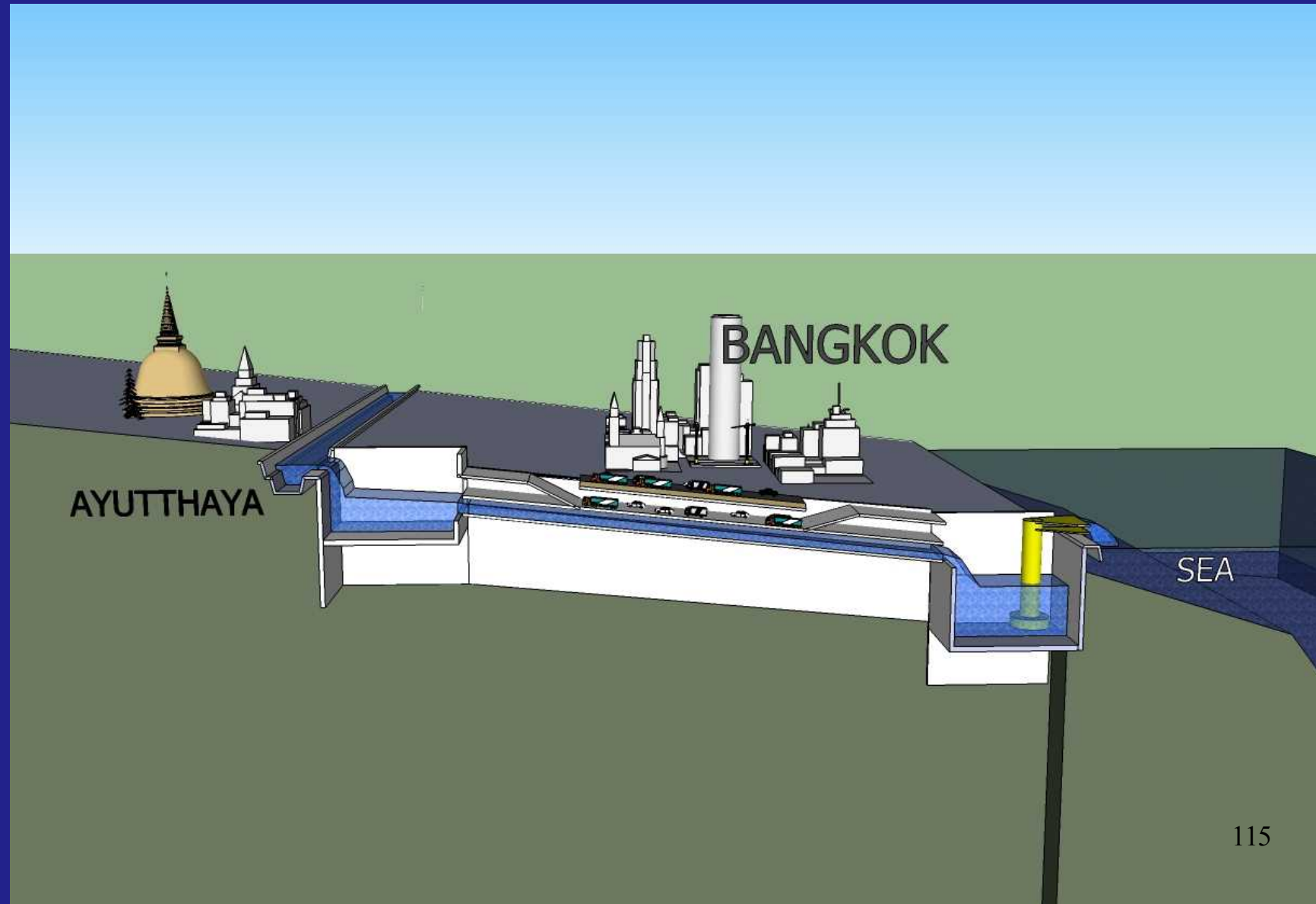
Normal or Minor Flood situation

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



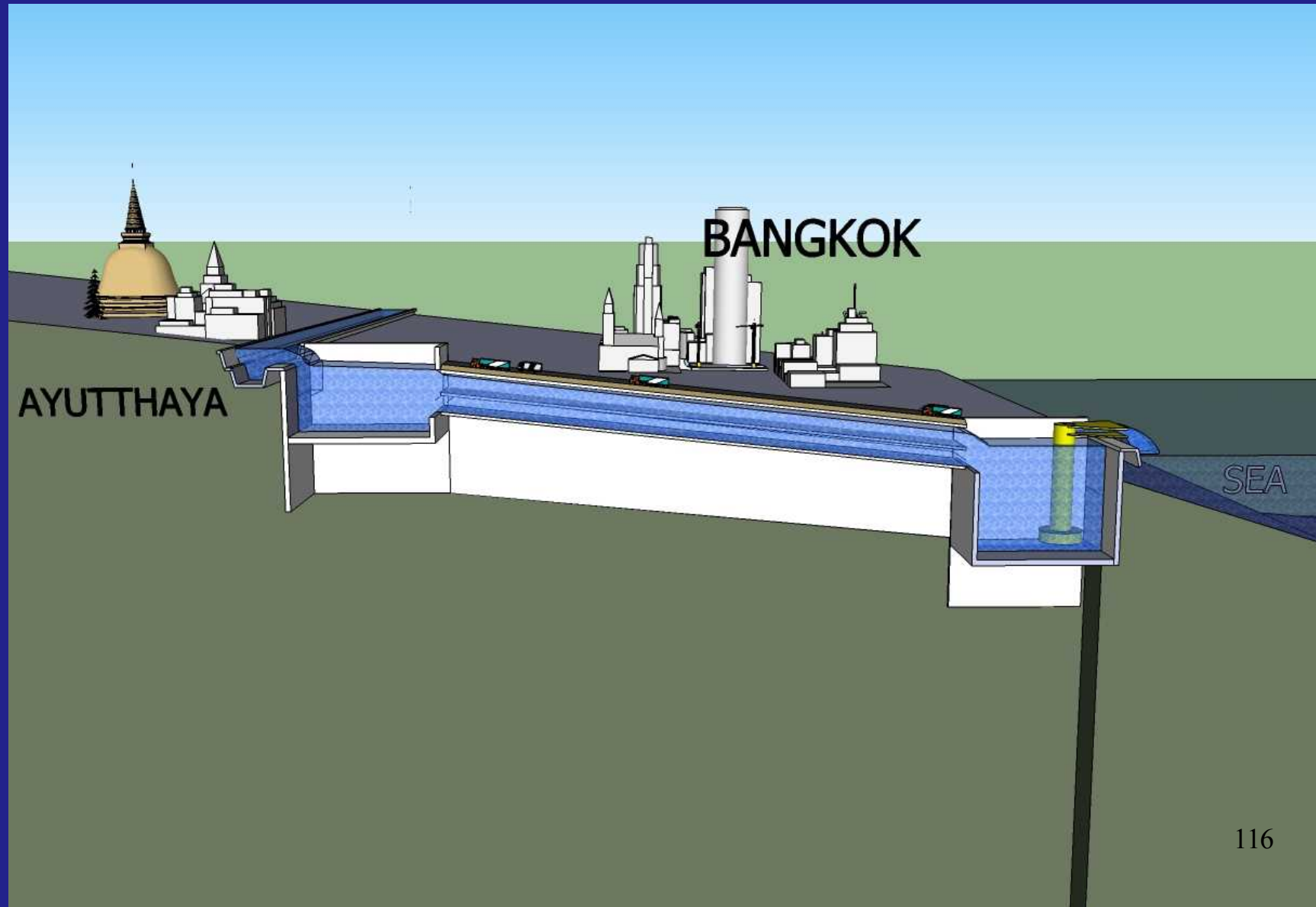
Moderate Flood situation

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

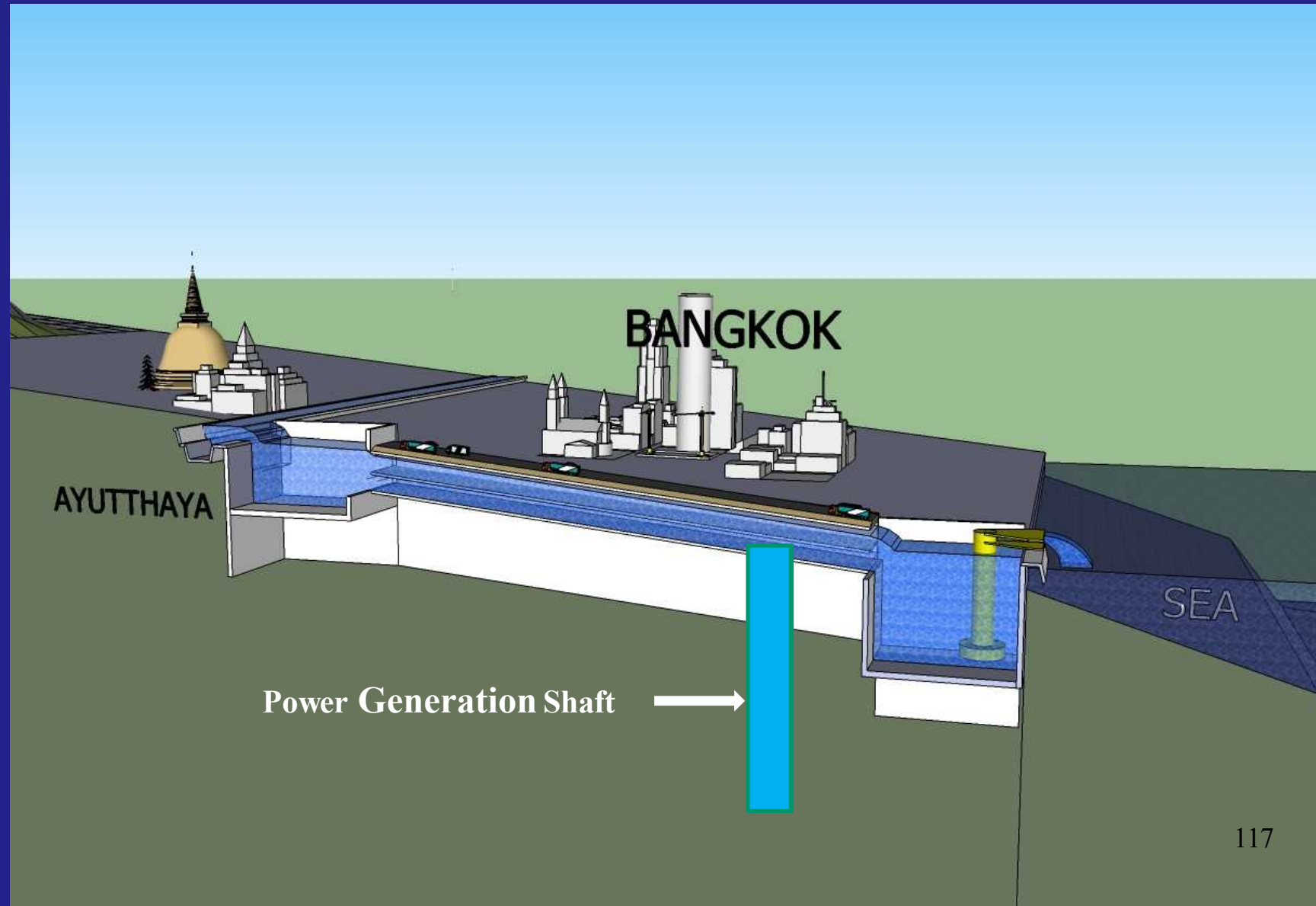


Major Flood situation

(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 m³/s, 129,600,000 m³/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

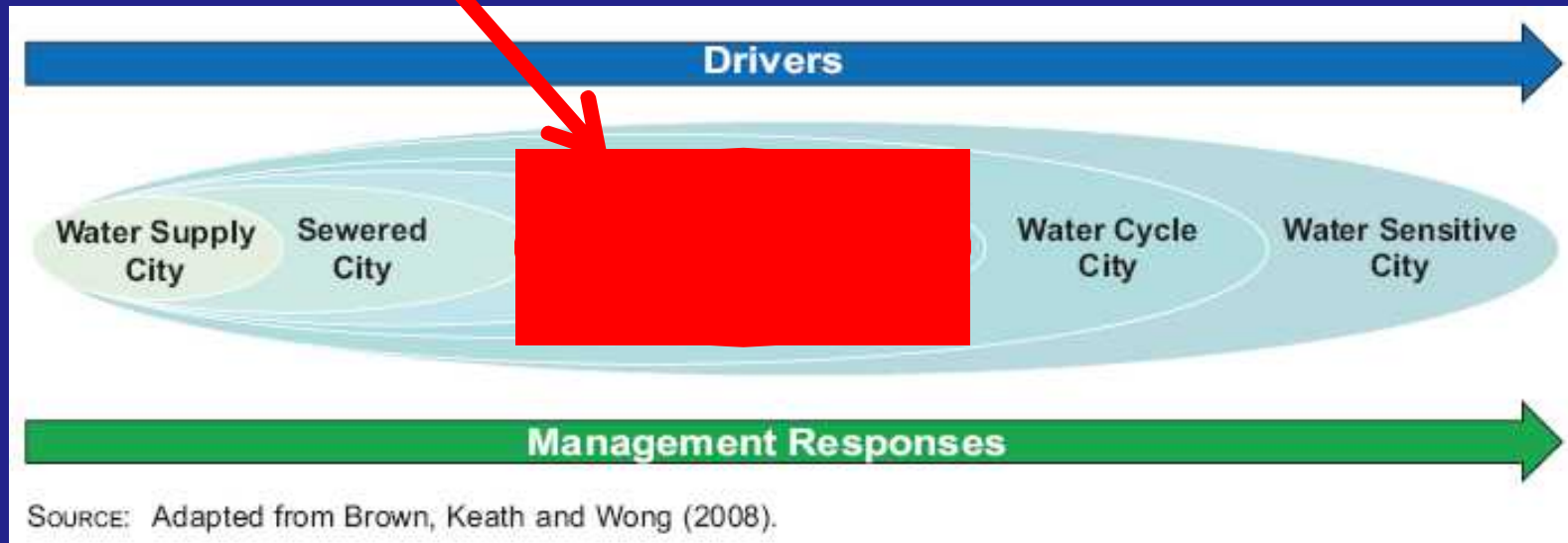
Minimum land appropriation is required – practical for existing land use in Bangkok and nearby provinces

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