Building Global Partnership for Global Challenges

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CRITICAL INFRASTRUCTURE IN BENGAWAN SOLO RIVER

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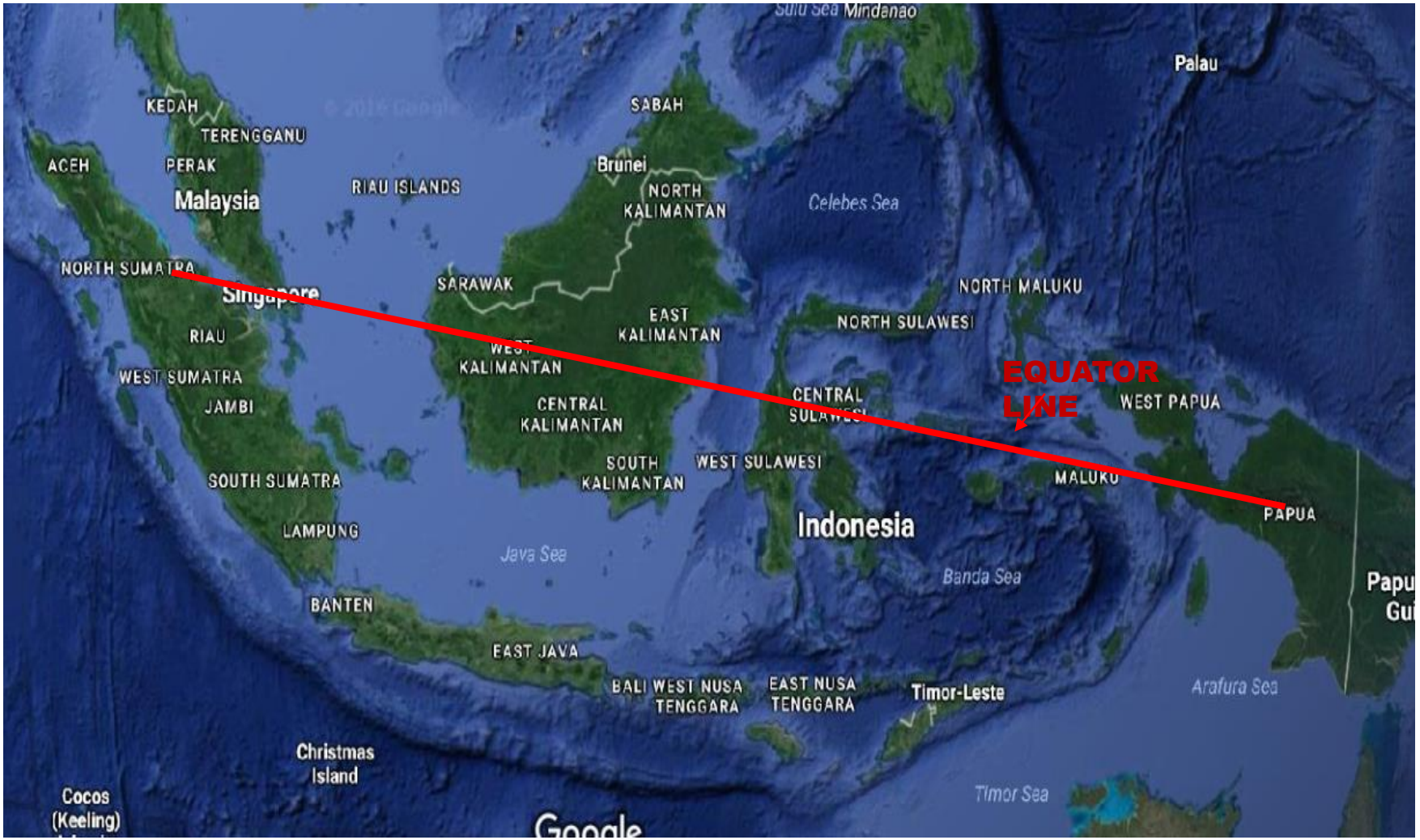
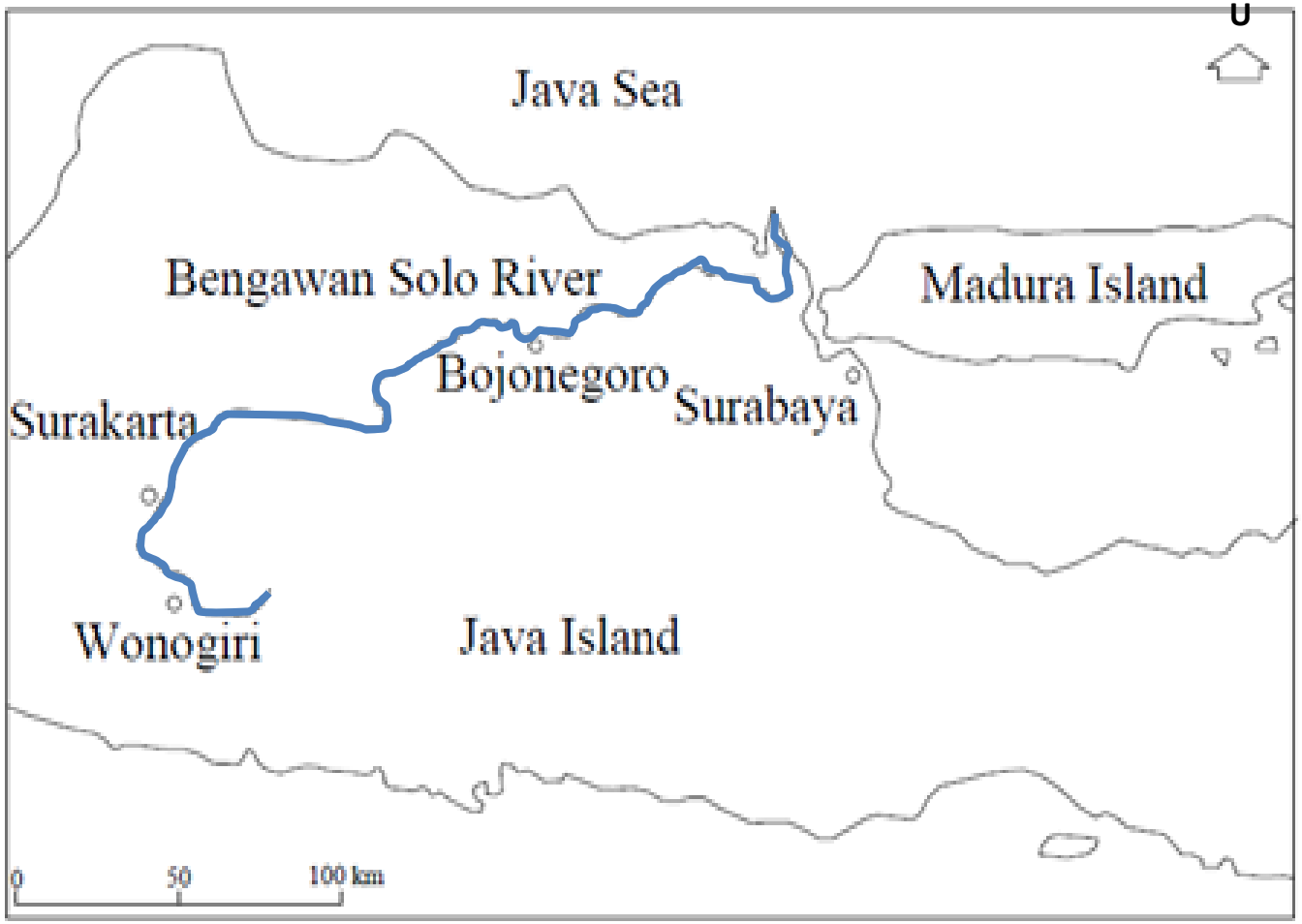
INDONESIA

- >5 million km²
- >13000 islands
- > 1100 tribes
- > 700 local languages

INDONESIA


Sulu Sea
Mindanao
Palau
KEDAH
TERENGGANU
ACEH
PERAK
Malaysia
RIAU ISLANDS
SABAH
Brunei
NORTH KALIMANTAN
Celebes Sea
NORTH SUMATRA
Singapore
SARAWAK
NORTH MALUKU
EAST KALIMANTAN
NORTH SULAWESI
RIAU
WEST KALIMANTAN
EQUATOR LINE
WEST SUMATRA
JAMBI
CENTRAL KALIMANTAN
CENTRAL SULAWESI
WEST PAPUA
SOUTH KALIMANTAN
WEST SULAWESI
SOUTH SUMATRA
MALUKU
PAPUA
LAMPUNG
Indonesia
Java Sea
Banda Sea
BANTEN
EAST JAVA
BALI
WEST NUSA TENGGARA
EAST NUSA TENGGARA
Timor-Leste
Arafura Sea
Christmas Island
Cocos (Keeling)
Timor Sea
Google

Bengawan Solo River



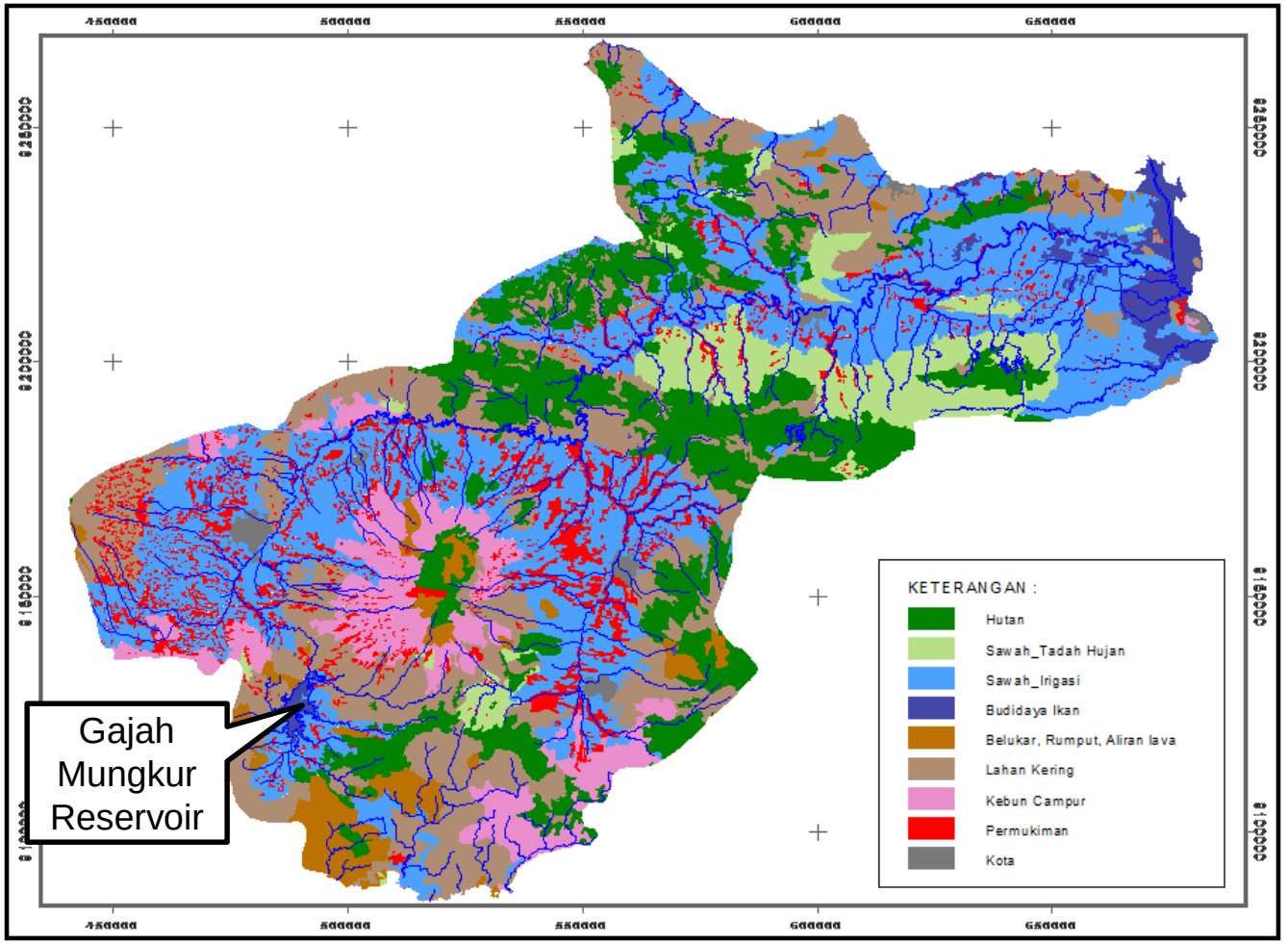
- Bengawan Solo River:
  - Catchment area: 1.70 million ha
  - River length: 600 km
  - Average river width: 150 m
  - River water current: min 0.30 m/sec & max 1.75 m/sec.

BENGAWAN SOLO RIVER OVERVIEW

- Main features:
  - 1.7 millions ha of watershed coverage area.
  - Water availability for irrigation system and fresh water supply.

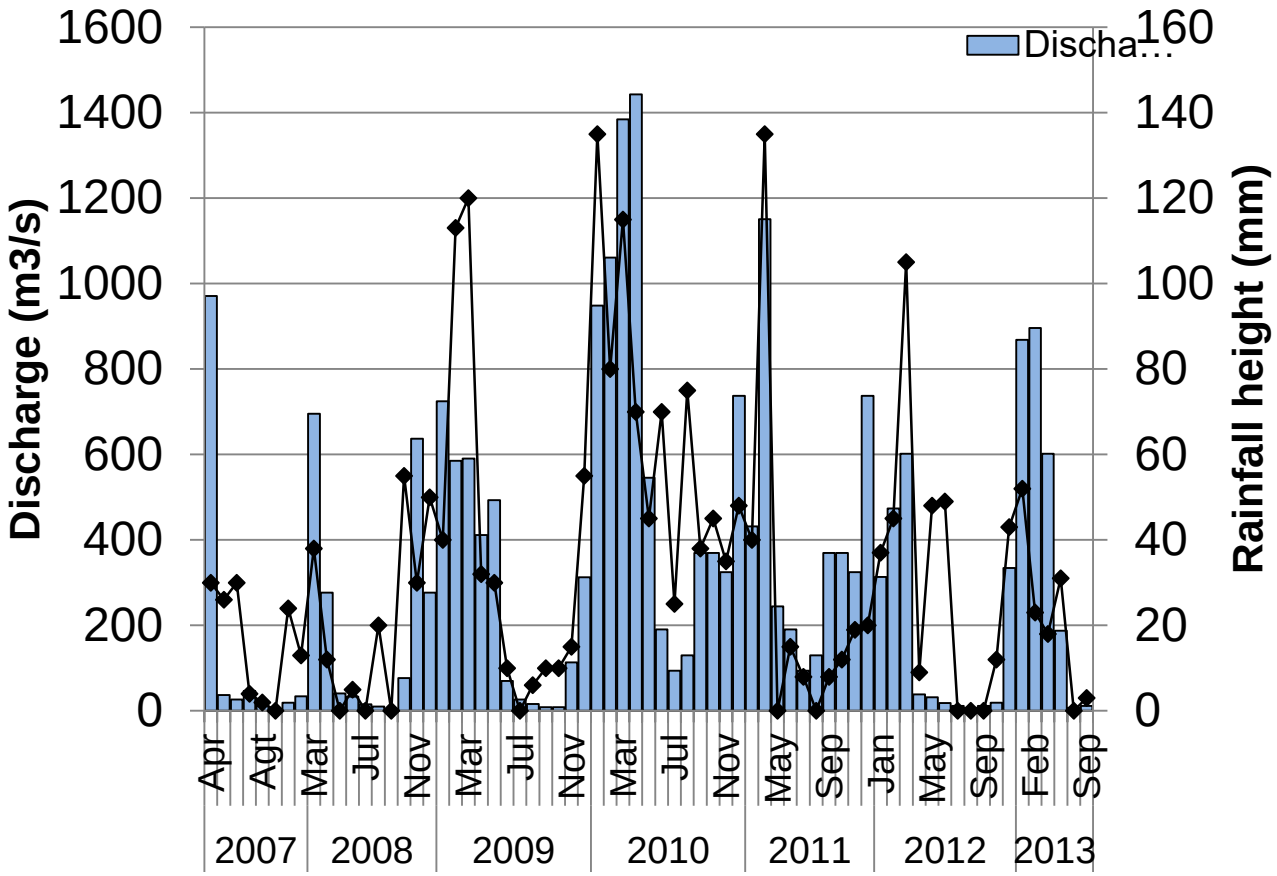
- Problems:
  - Critical lands
  - Sedimentation in the reservoir and the river body
  - Floods
  - Failure of river embankment
  - Stability of bridge foundation
  - Illegal sand mining
  - Inhabitants in the flooding area

LAND USE CONDITIONS



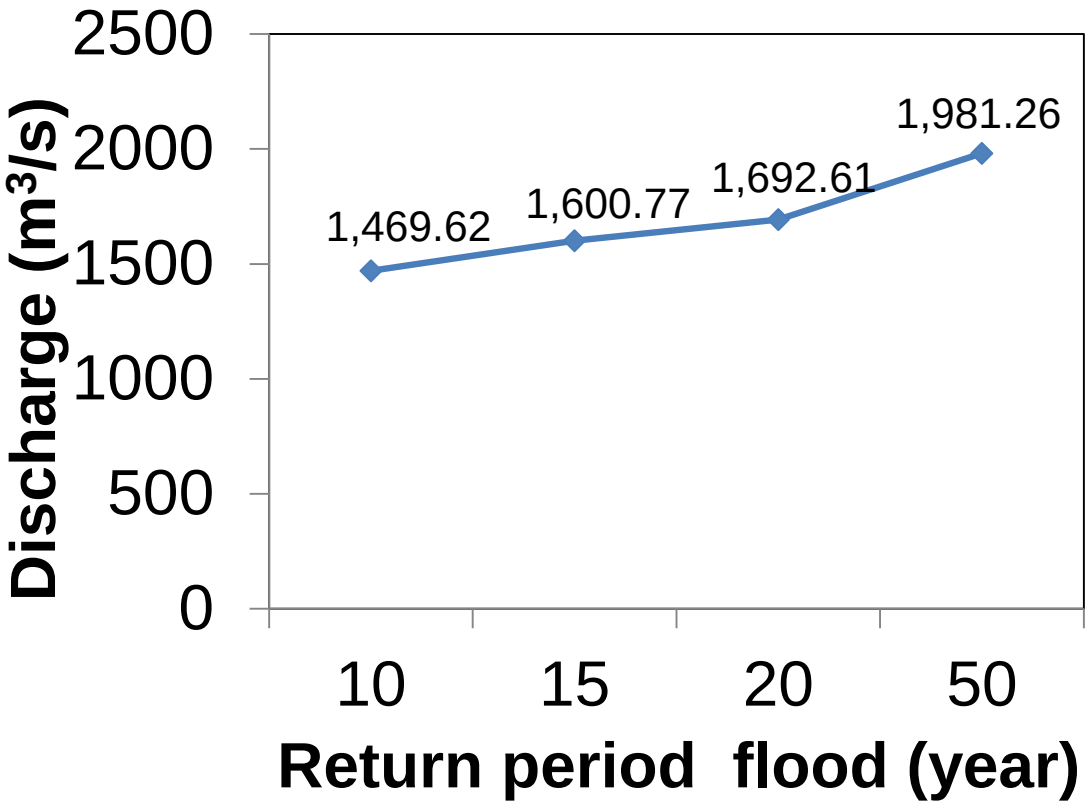
- The conservation zones (forests and green zone) are only 24% out of total area → land erosion risk

Hydrological condition of Bengawan Solo River

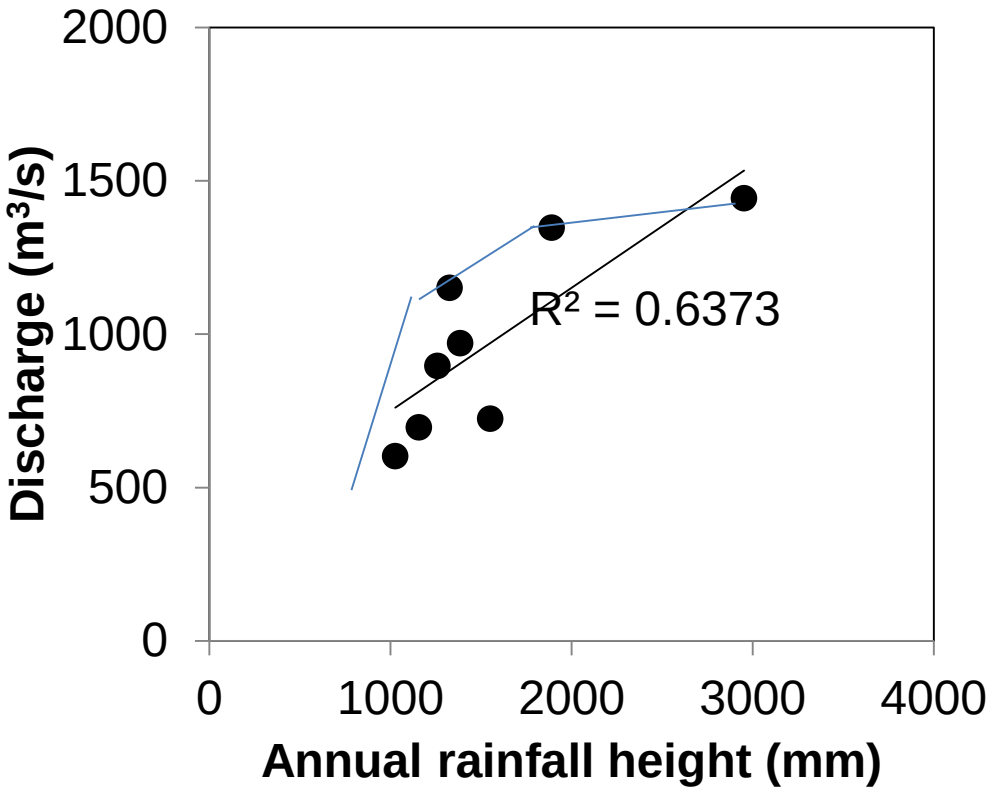


- The maximum flow discharge between 2007 – 2013 is **1442.509** m^3/s.
- The maximum annual rainfall: **2951** mm/year.

Bengawan Solo River return period flood



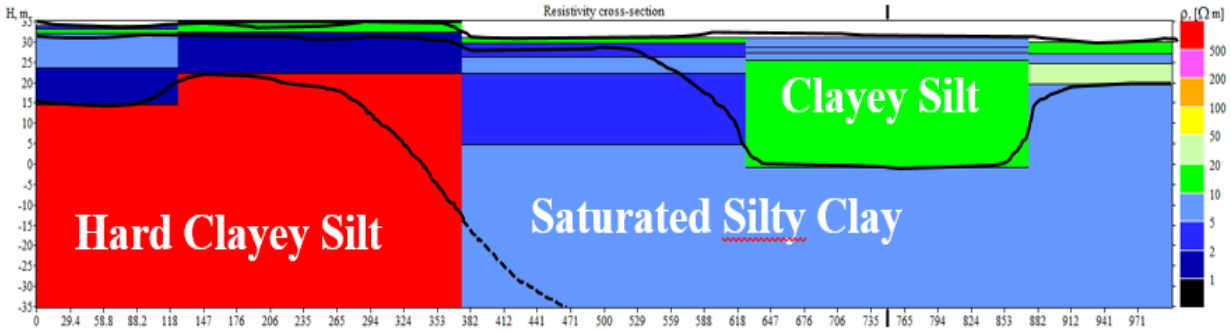
Climate changing effect on Bengawan Solo River



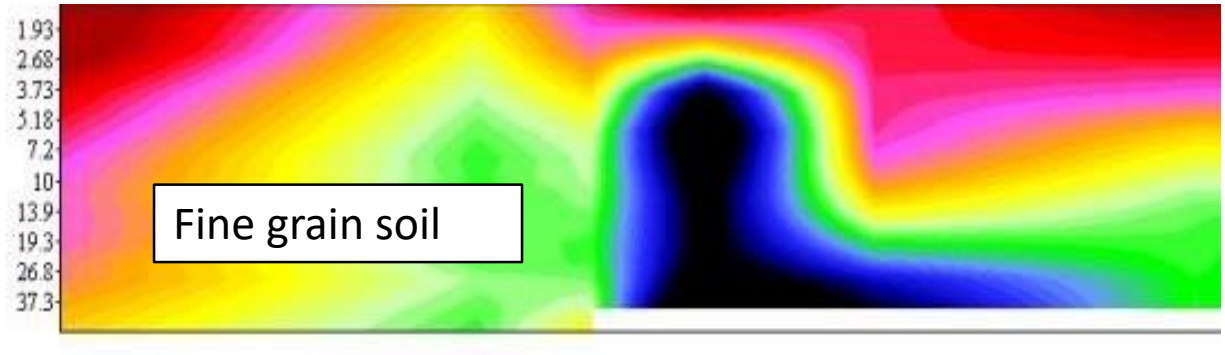
- **The increment of rainfall height indicates climate change impact in Bengawan Solo River.**
- **The graphic shows the correlation between rainfall and discharge on Bengawan Solo River from 2007 to 2014.**
- **It can be seen that the flood is increases as rainfall height incremental during 2007 and 2014.**

GEOPHYSICAL INVESTIGATION (river embankment)

Soil resistivity at downstream area



Soil resistivity at estuary area



Soil properties	Unit	Down-stream	Estuary
Specific gravity, G_s	-	2.6	2.45
Plasticity Index, PI	%	10	25
Dry density, γ_d	kN/m^3	12	11
Undrained cohesion, C_u	kN/m^2	7	15

- Downstream area is dominated by silty and sandy soil, whilst estuary area is dominated by clayey soil.
- It is due to coarse grain firstly deposits in the down-stream area.
- The soil specific gravity and soil plasticity value proves the soil composition at down stream and estuary area.

GEOTECHNICAL INVESTIGATION (river embankment)

No.	Depth	Soil description
1.	0.00 m – 4.00 m	Clay
2.	4.00 m – 5.50 m	Silty and Sandy clay
3.	5.50 m – 7.50 m	Clay
4.	7.50 m – 9.50 m	Silty and Sandy clay
5.	9.50 m – 28.00 m	Clay
6.	28.00 m – 30.00 m	Silty clay

- River embankment soil condition (sub-surface)
  - Clayey soil stratified at upper sub-surface layer
  - Silty clay soil stratified at bottom sub-surface layer

BATHYMETRY

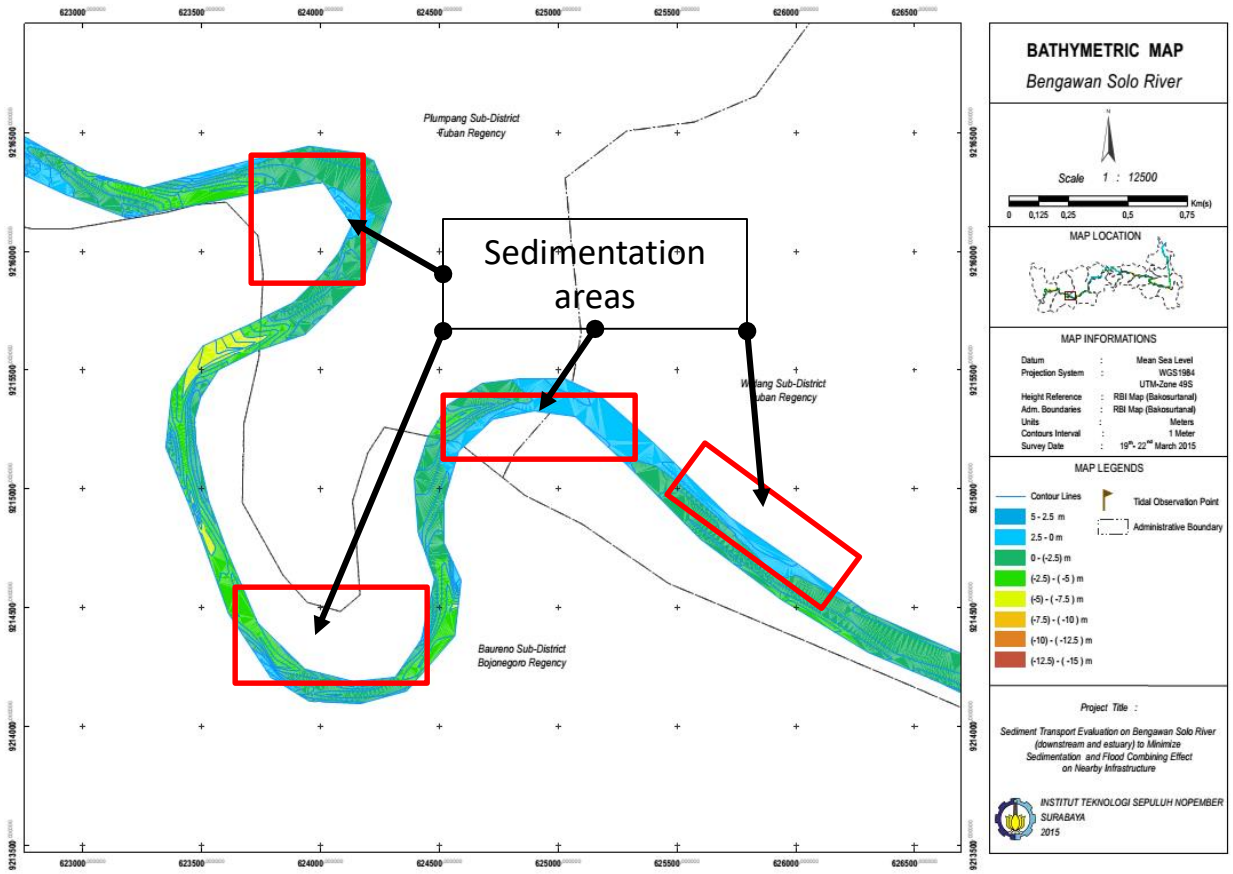
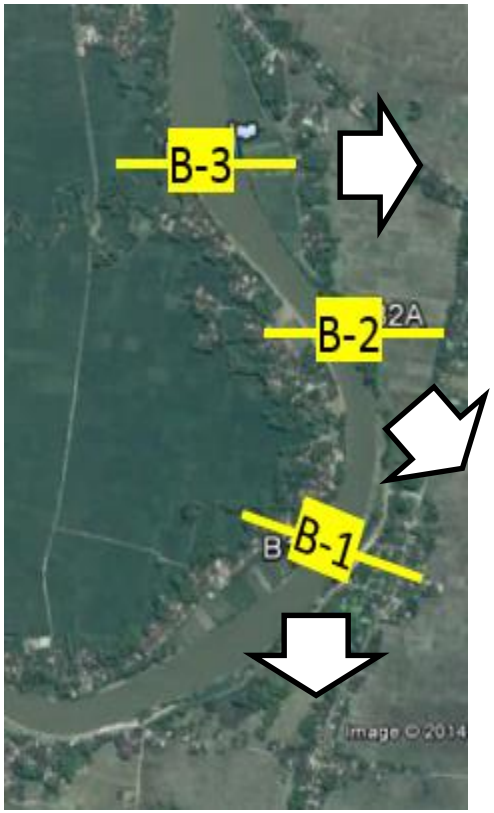
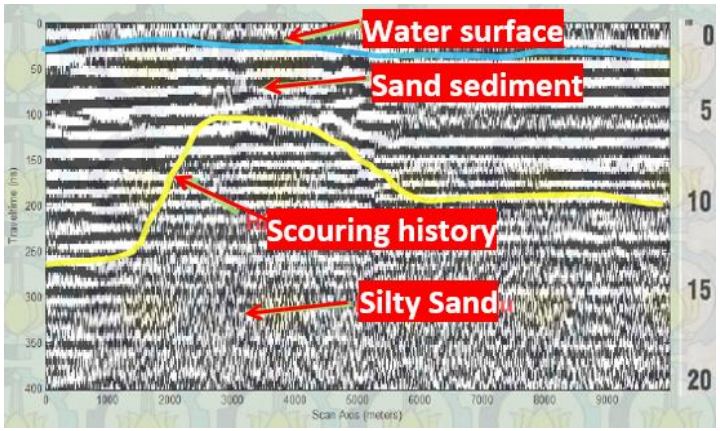


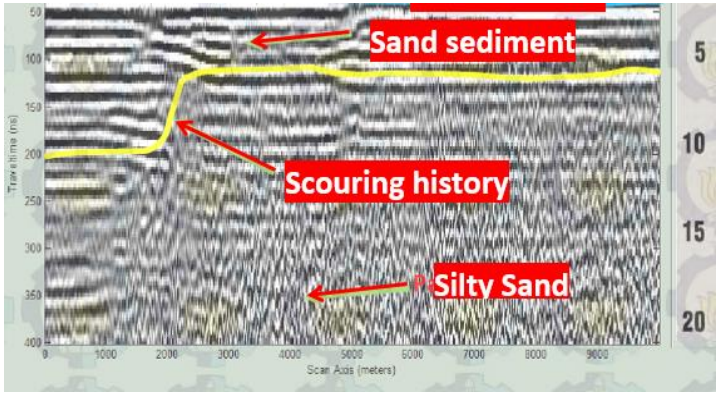
Figure. River bathymetry result

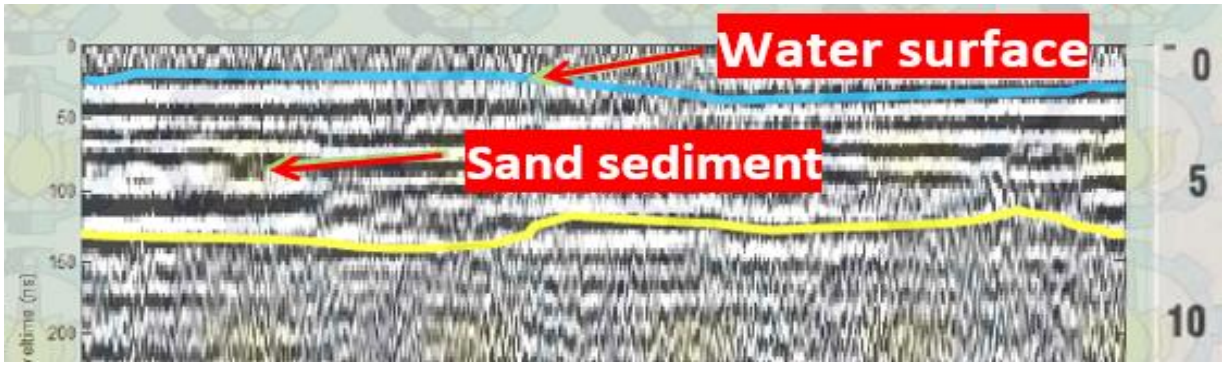
The riverbed levels are varied along river stream indicating the sediment transport occurred frequently.

GEORADAR INVESTIGATION (river embankment)









- River bed profile soil condition (from Geo-radar test)
  - B-2 and B-3 has high impact scouring river profile than B-1
  - Meandering area reduced river current, but high pressure of sedimented water led river profile scouring

Bengawan Solo
Kedung Arum Kec. Kanor - Bojonegoro

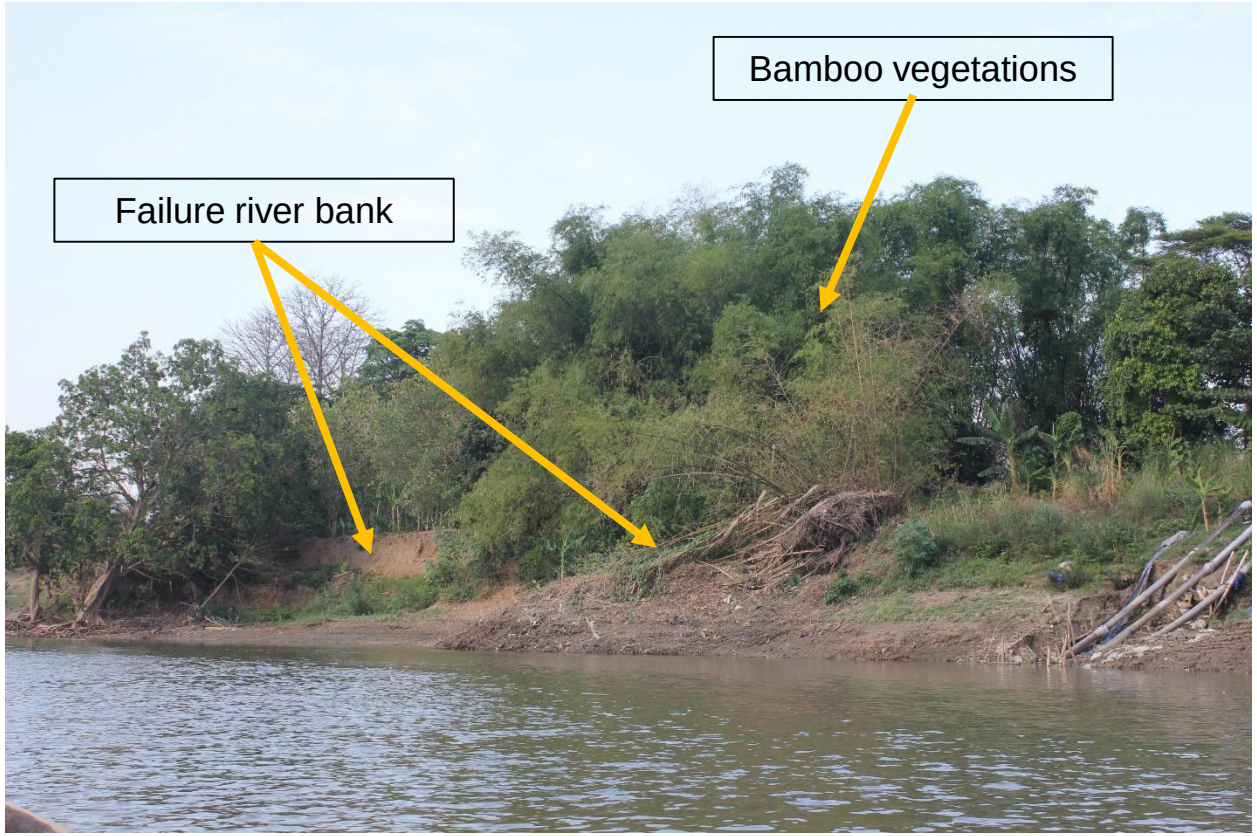
Bengawan Solo
Kedung Harjo Kec. Widang - Tuban

Bengawan Solo
Kedung Harjo Kec. Widang - Tuban

Bengawan Solo
Kedung Harjo Kec. Widang - Tuban

Bengawan Solo
Kedung Arum Kec. Kanor - Bojonegoro

River bank vegetation and slope failure in Bengawan Solo River



Embankment failure at Bamboo Vegetation Area

Embankment failure at Acacia Vegetation Area

- Uprooted Bamboo and other vegetation were stacked on the tree as flood outcomes in Bengawan Solo River, 2014

- Massive dumped bamboo in the bridge pier, 2016 (Source: Timlo.net)

BENGAWAN SOLO RIVER OVERVIEW

Main features:

- It stated in the Indonesian National Code (SNI) that river with 2000 – 5000 m^3/s of periodic flood should have 1.20 m in minimum of free board otherwise the overtopping flow gives an extra force to the embankment structure.

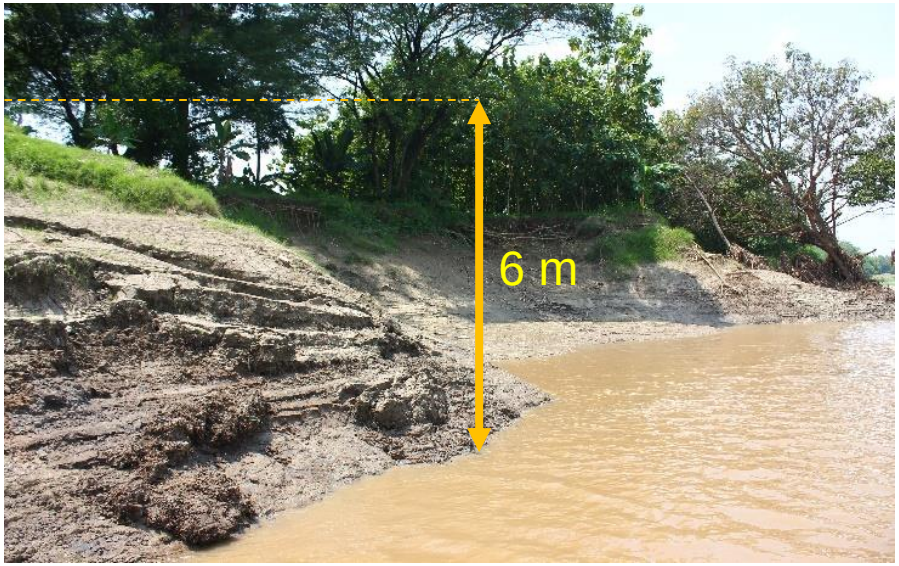
BENGAWAN SOLO RIVER OVERVIEW

Main features:

- Failure embankment which located in flood plain Bengawan Solo River was occurred in Banjarejo Village, Bojonegoro remaining 4 m space between river and residence house.
- According to the Minister of Public Work and Public Housing Code No. 28/PRT/M/2015 Chapter 6(2) as concerns river and reservoir flood plain border, it is stated for primary river should be 100 meters of right and left sides of river in minimum.

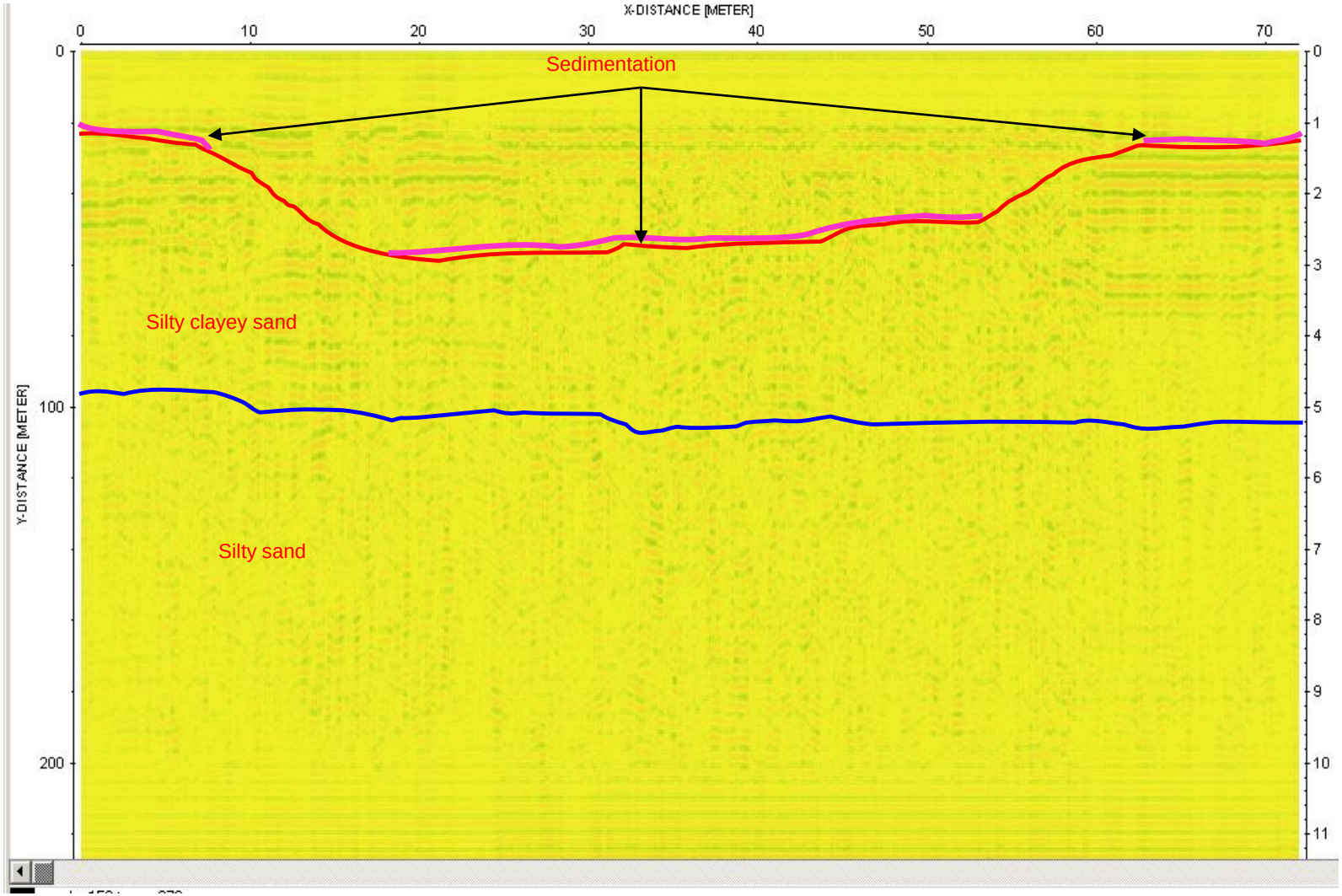
Analysis of River Embankment Failure

Embankment toe failure after flood in Bengawan Solo River, 2014

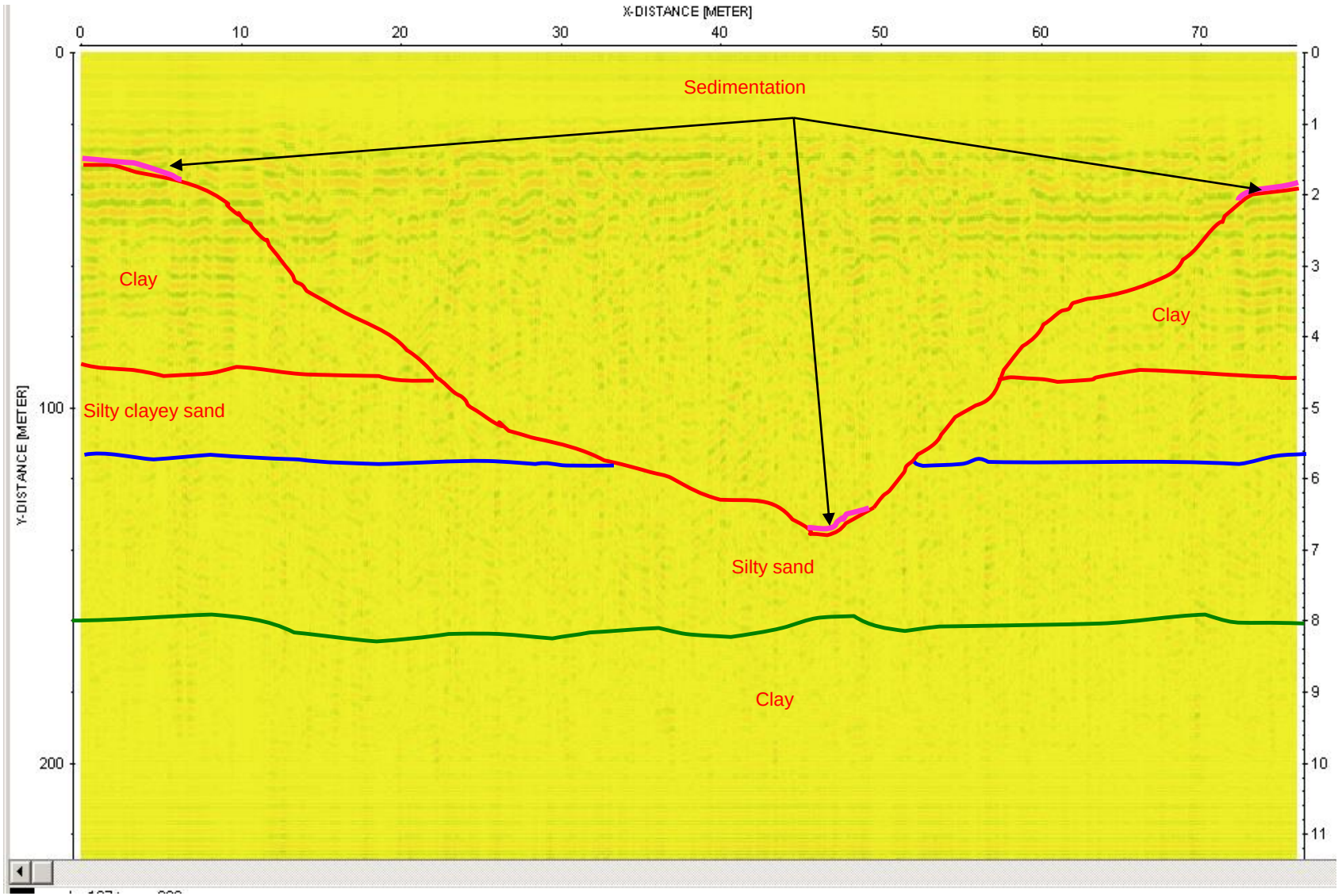


Manmade embankment failure of Bengawan Solo River in Lamongan District, 2017 (Source: citratv.co.id)

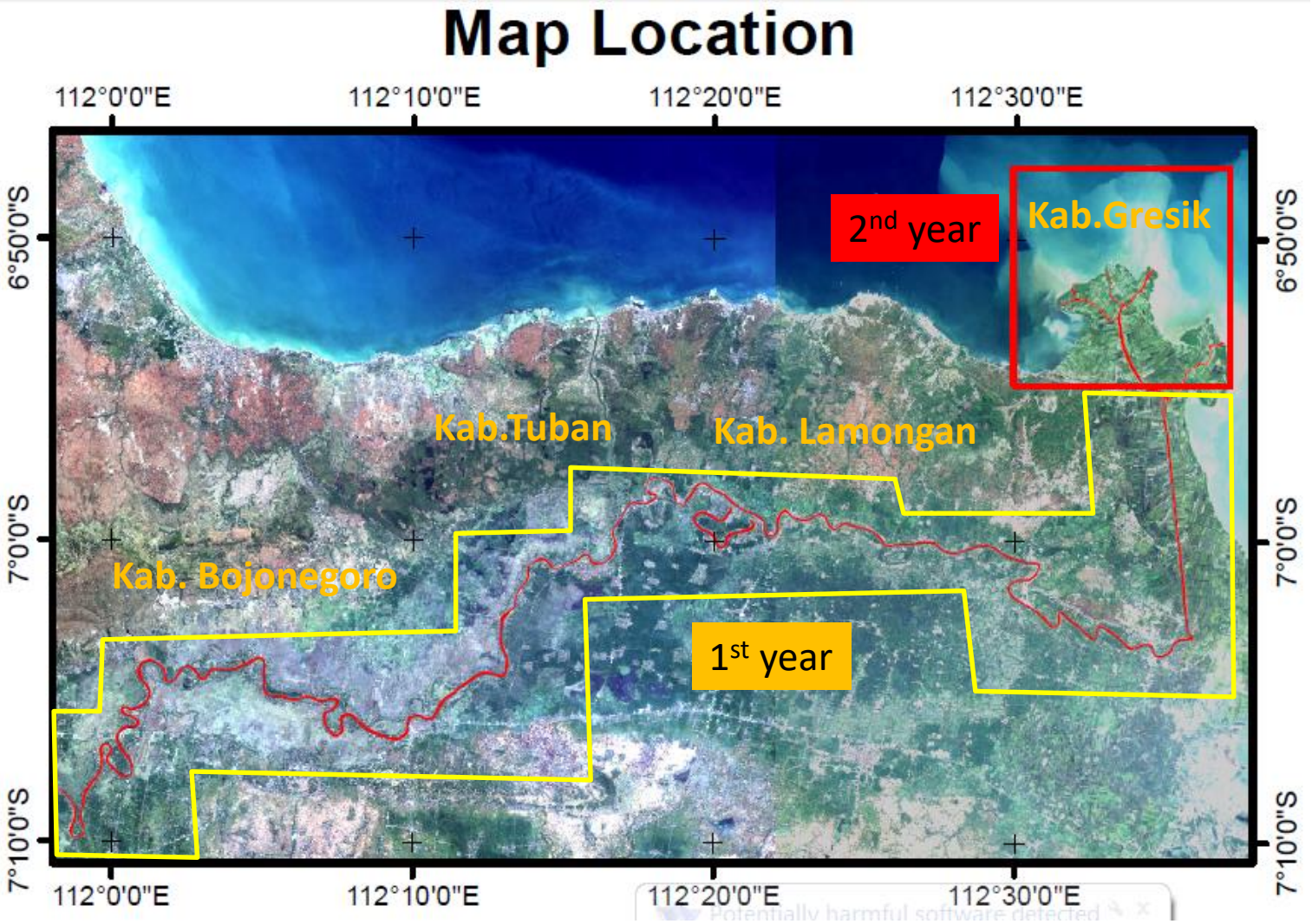
Normal River Cross Section



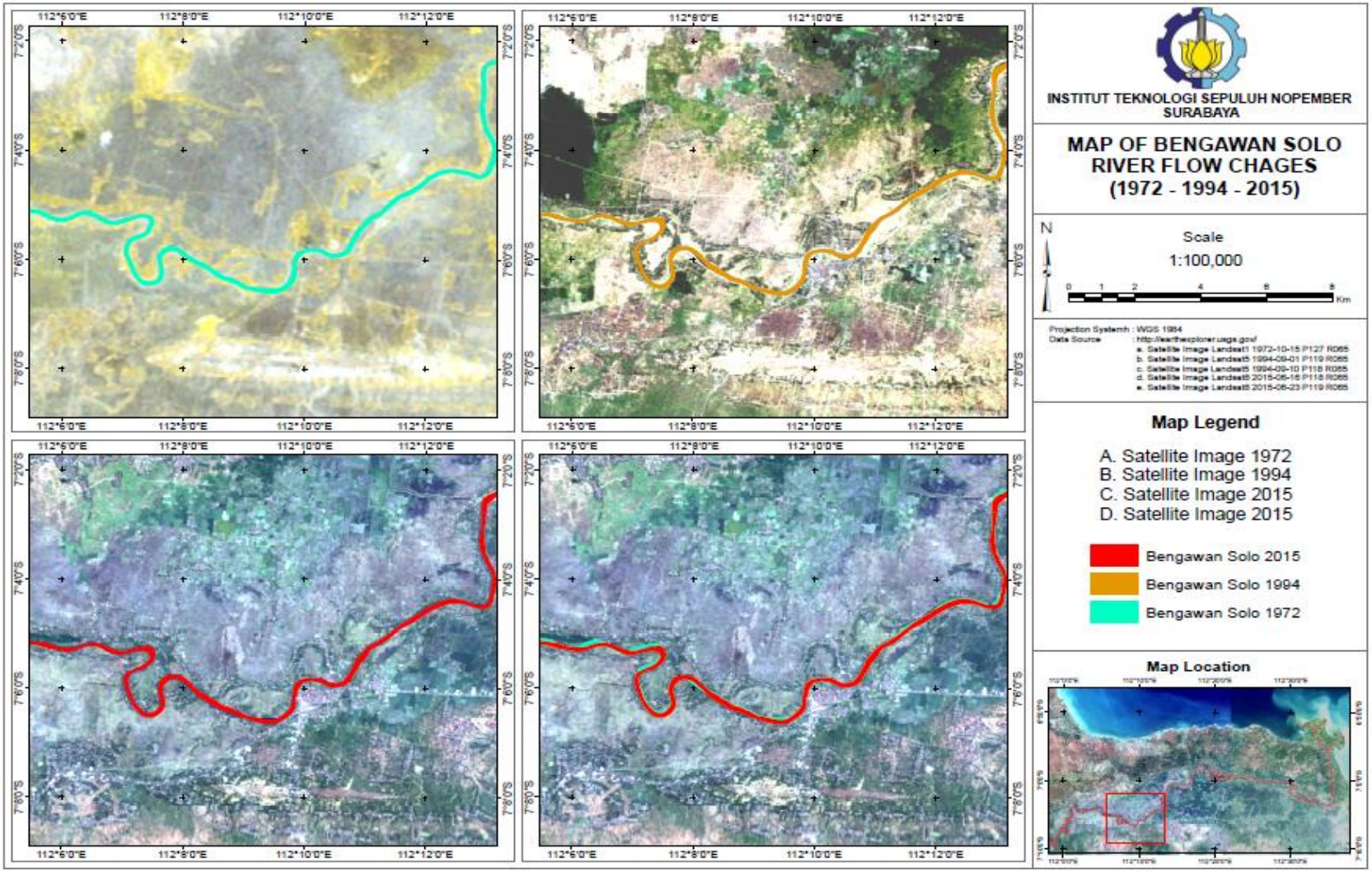
River Cross Section – Illegal Sand Mining



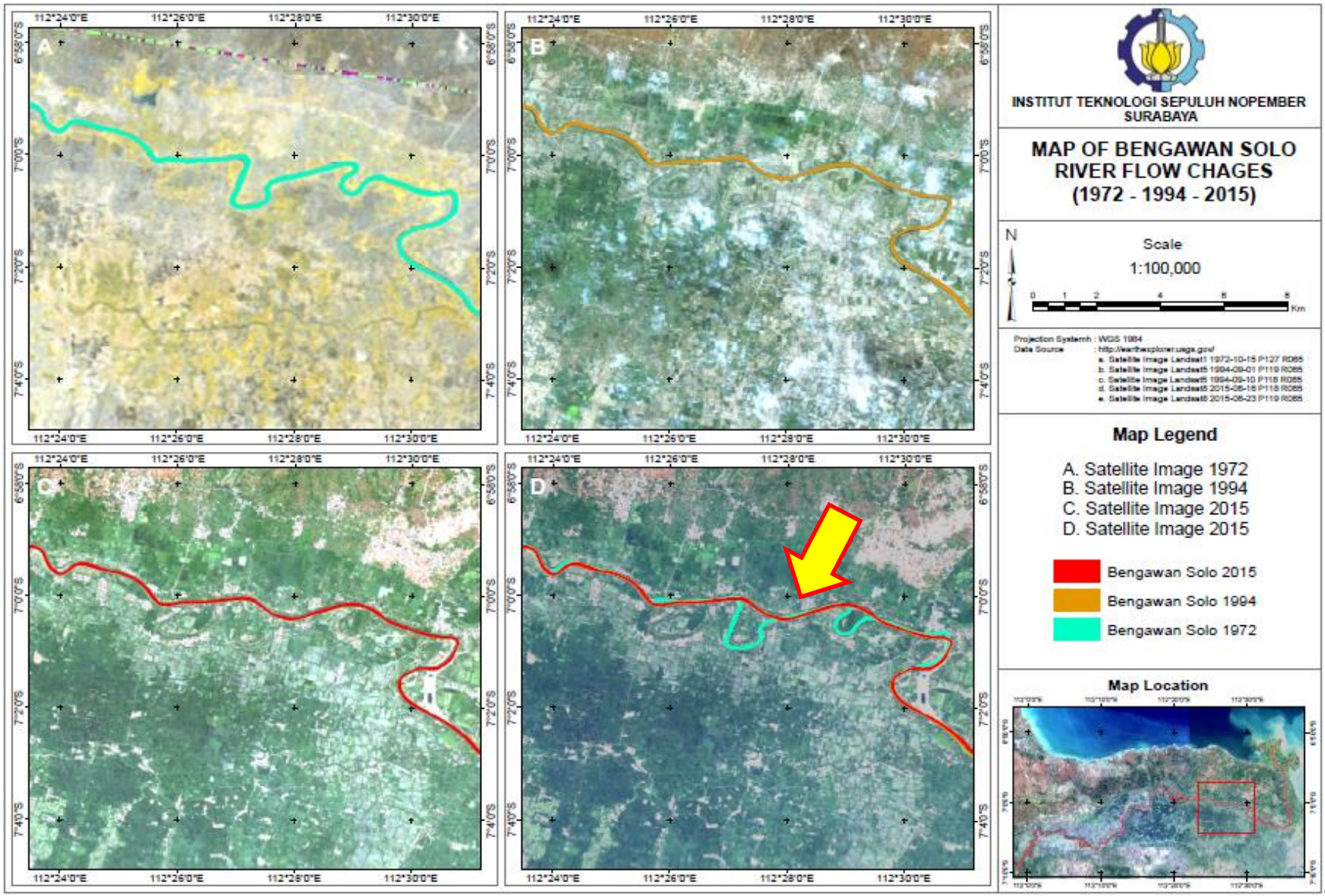
LOCATION STUDY



Bengawan Solo River (1972 – 2015)



BENGAWAN SOLO RIVER (1972 - 2015)



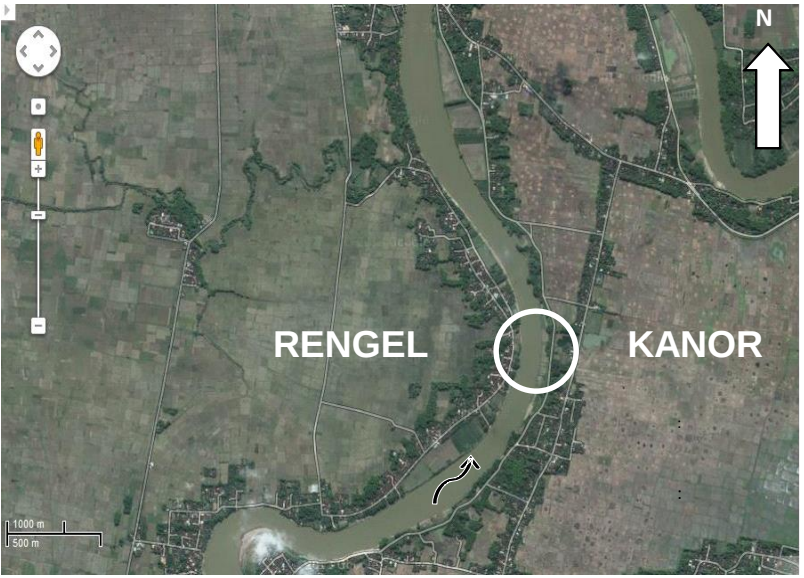
BED SEDIMENT THICKNESS

According to the sediment rate, the bed sediment thickness can be estimated.

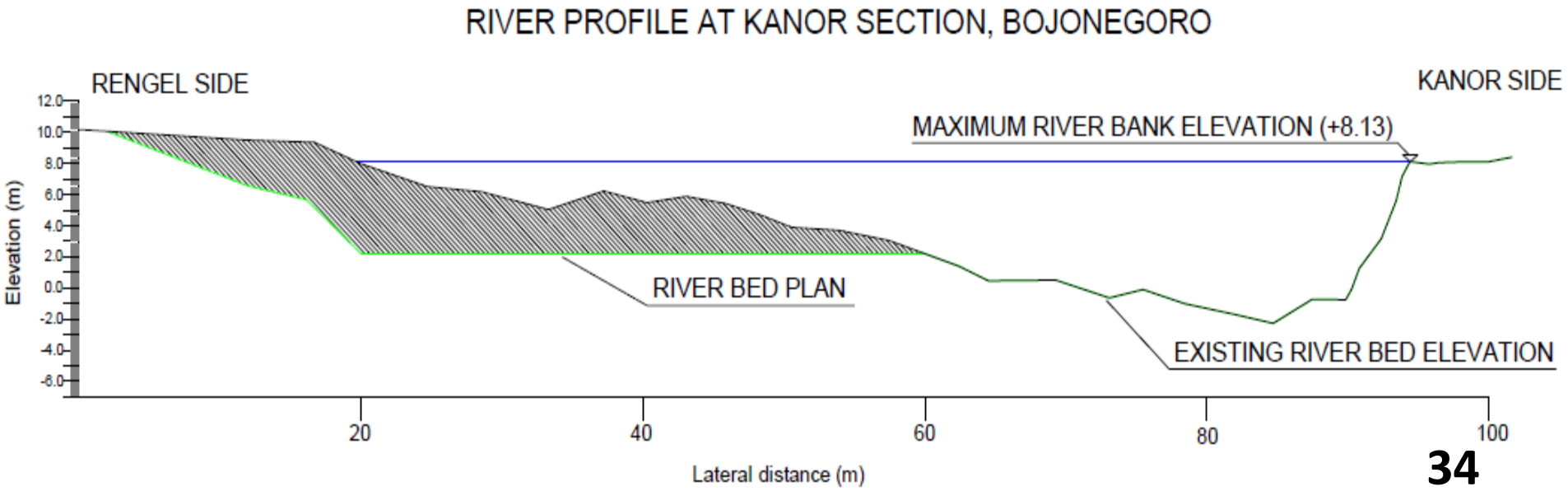
- Sampling point to estuary range: 100000 m
- Average river width: 80 m
- Average sediment thickness:

  (841.866 m^3/year)/(100000 m x 80 m) = **0.105 m/year**

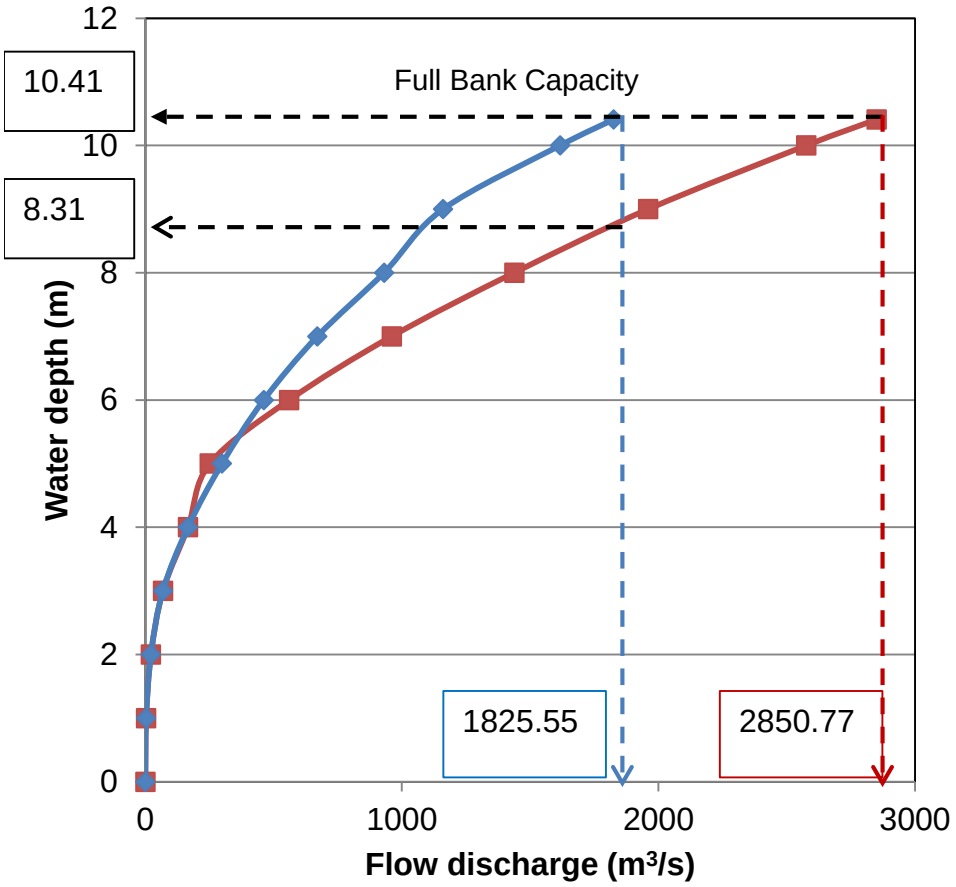
RIVER CHANNEL CONDITIONS



- River bed erosion occurred at Kanor side due to high flow velocity.
- Sediment deposition exist around inner bend at Rengel side developed by low flow velocity.
- Excessive flood is frequently happened in this section.



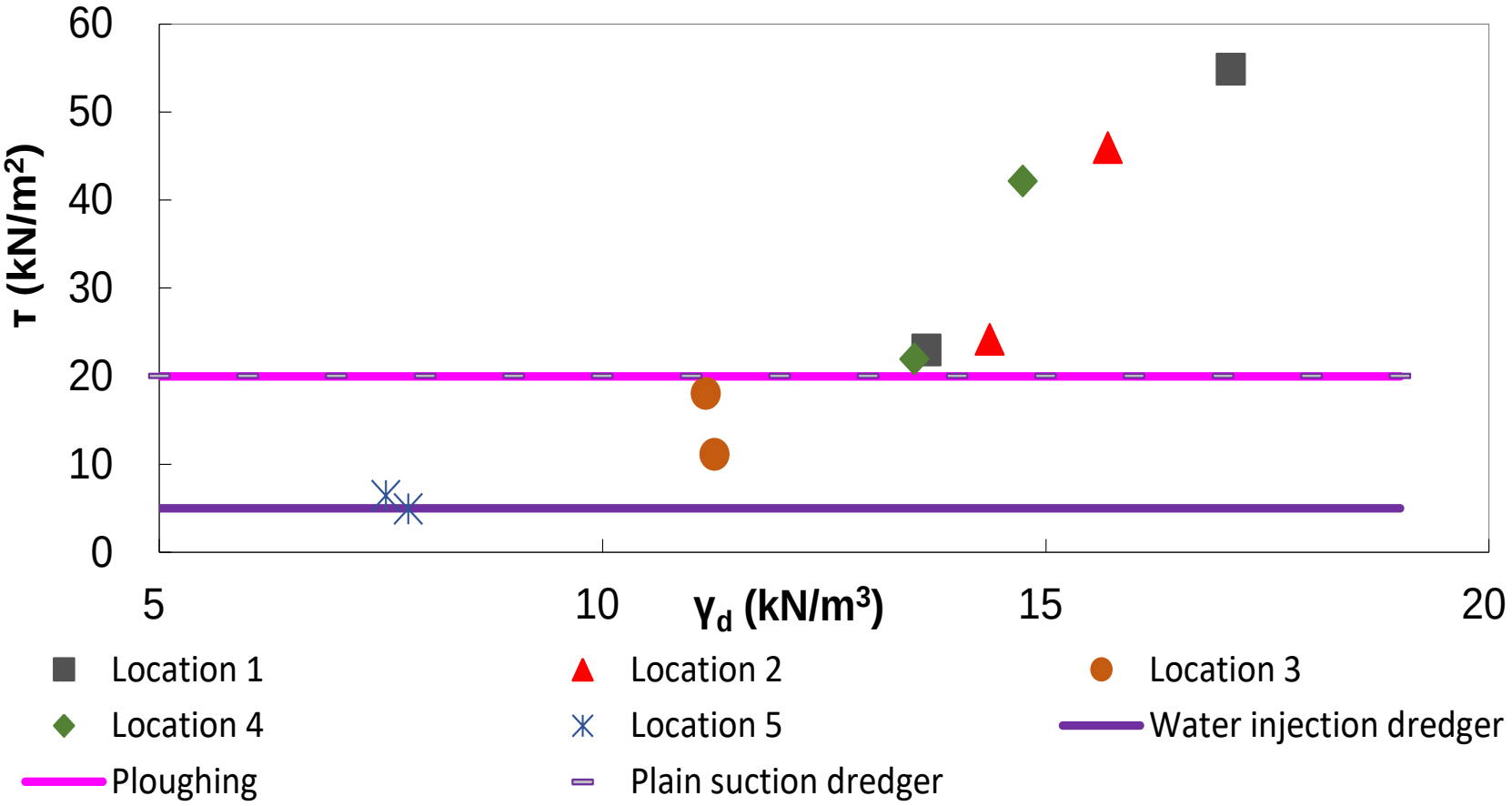
EVALUATION - RIVER CHANNEL CAPACITY ANALYSIS



Rating curve of Bengawan Solo River, Kanor section

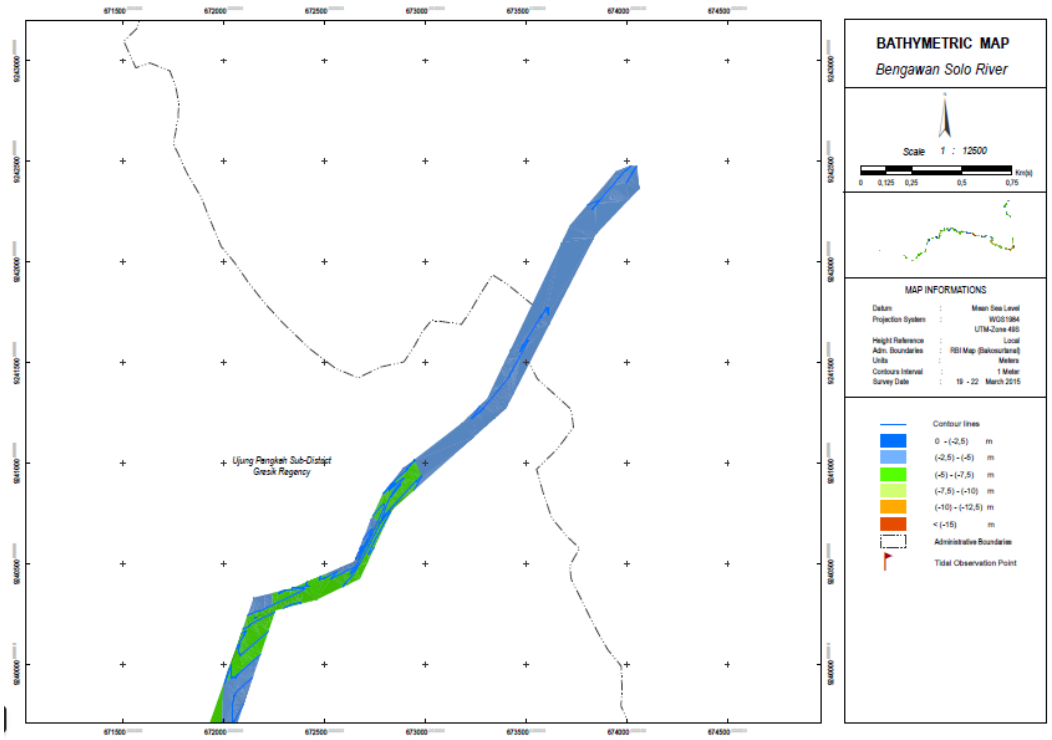
- In existing condition, the over topping flow occurred when the flow discharge reach 1825.55 m^3/s.
- By excavating 2- 3 m of sediment material will increase channel capacity up to 2850.77 m^3/s or 56% bigger than existing condition.

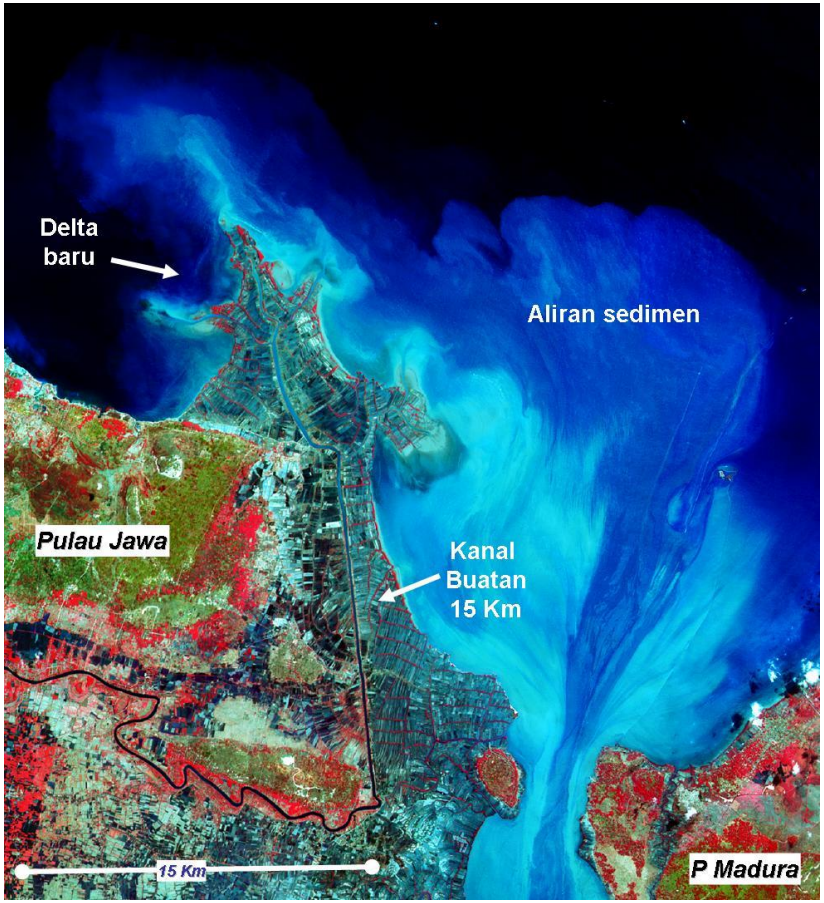
EVALUATION - SEDIMENT MAINTENANCE PROPOSED METHOD



Most of the sediment able to be dredged by using grab dredger.

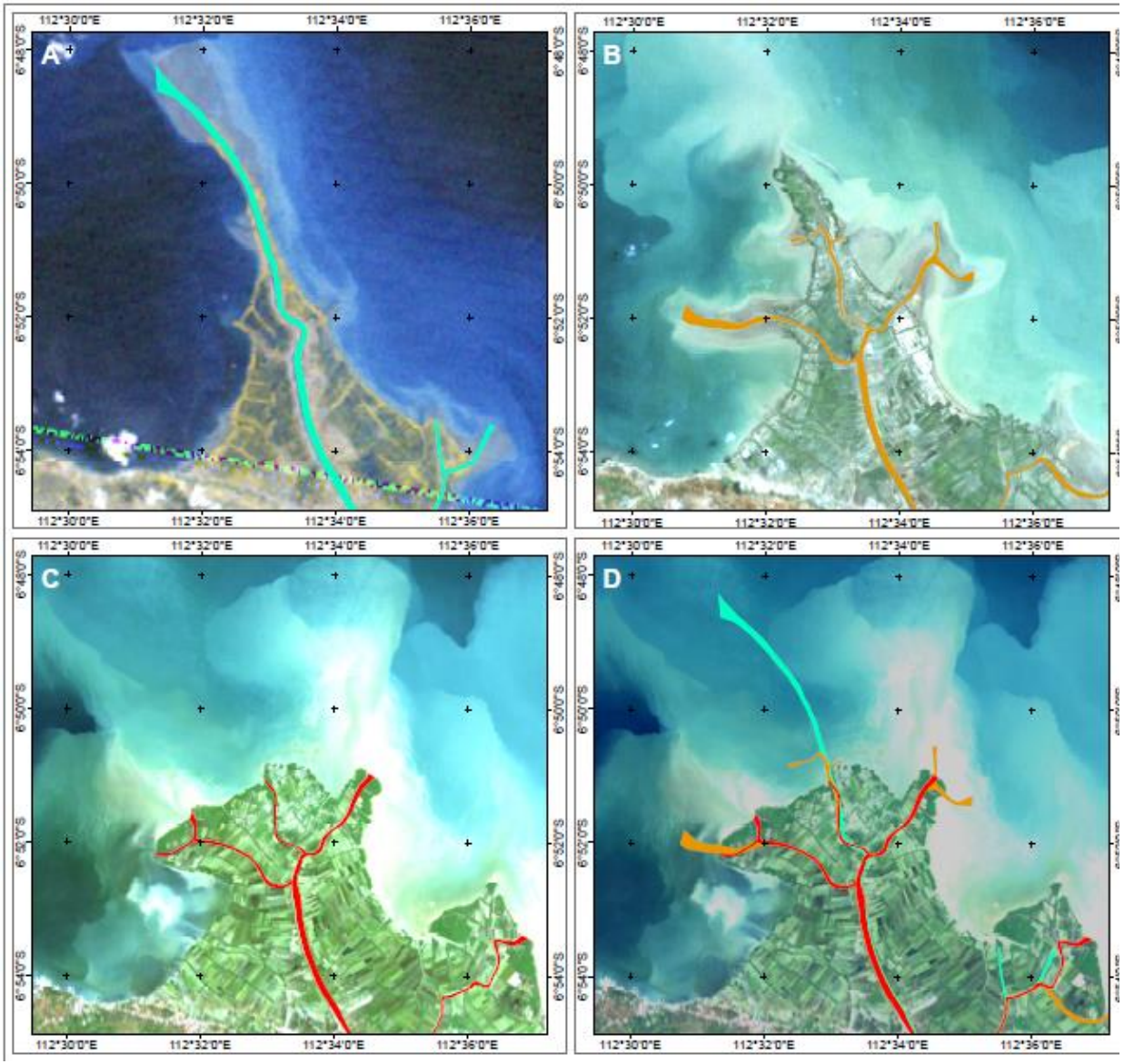
EVALUATION - DEPOSITION DEPTH CHANGING AT ESTUARY





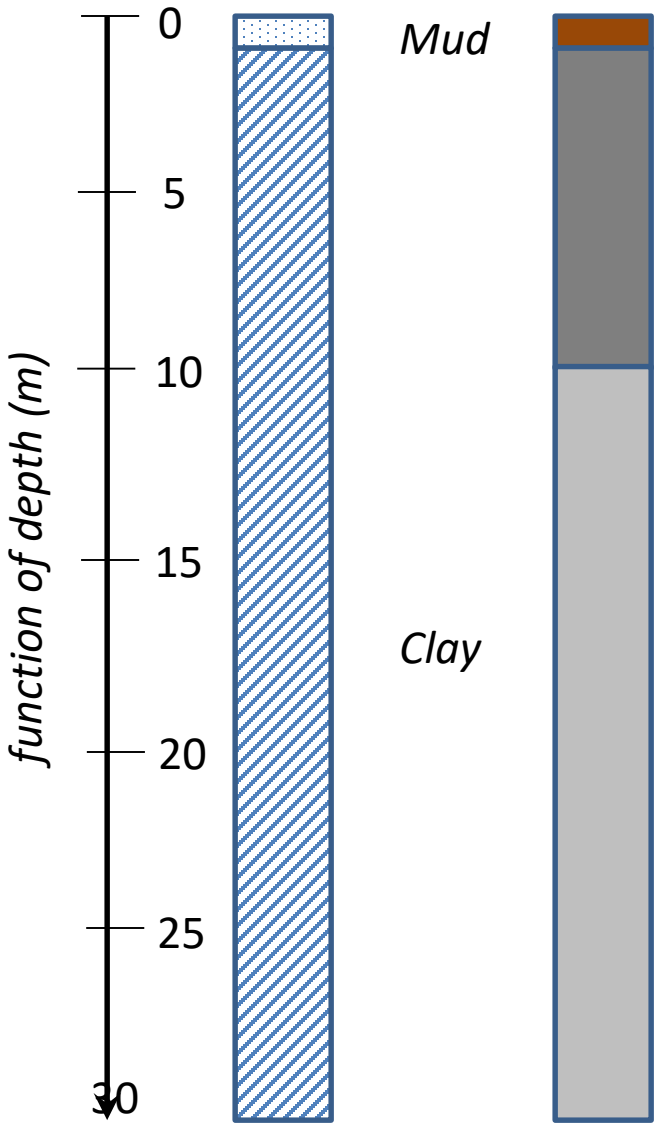
- Bed elevation in increasing near the shore at estuary area
- Sediment deposition was ended in the shore as the final of river path

SEDIMENT EFFECTS ON THE ESTUARY



- Sediment quantities investigation in Bengawan Solo River-Bojonegoro:
  - Dry season: 50 mg/L
  - Rainy season: 1700 mg/L
- Sediment rate: 841.866 m^3/year (1st year result).
- Average longitudinal growth in estuary around 70 m per year (Hoekstra et al, 1989).

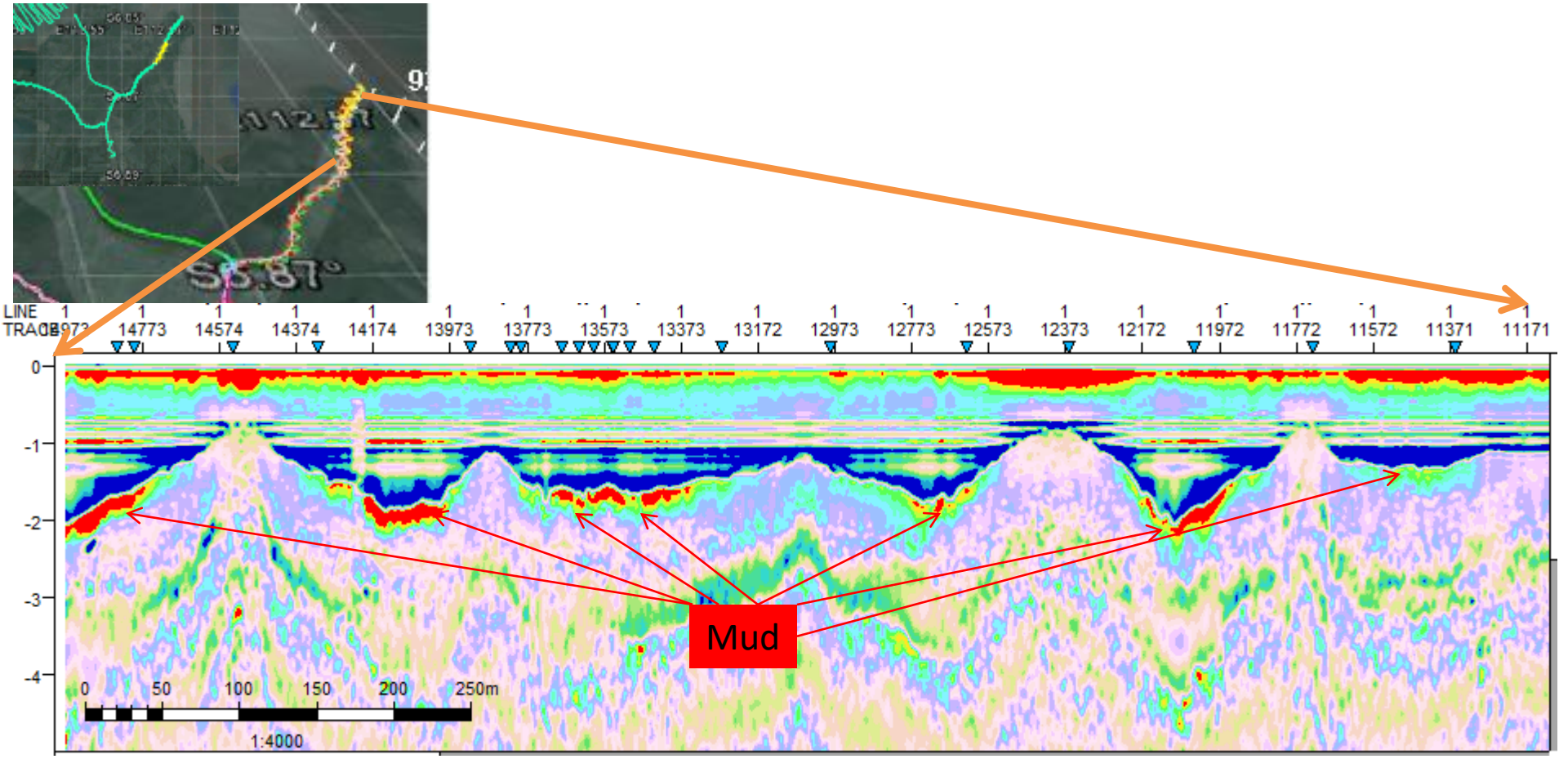
EVALUATION - SOIL BORE LOG AT SHORE IN ESTUARY



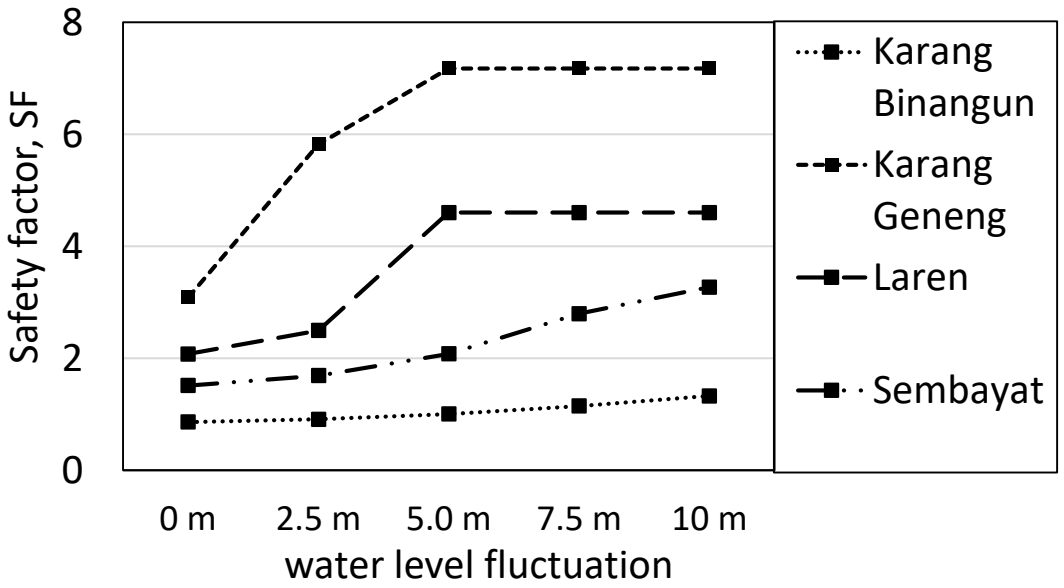
- All of the soil below shore is very soft soil with having N_{SPT} 0
- Sediment material at shore is dominated by fine grain material
- The soil colour describes the age of sedimentation process

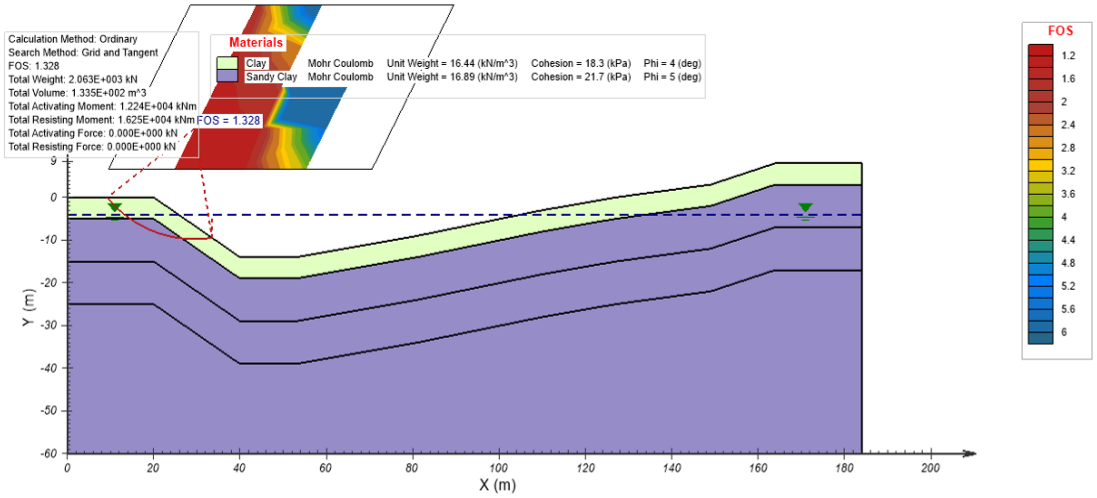
-1 m -5 m -15 m -30 m

EVALUATION - DEPOSITION DEPTH CHANGING AT ESTUARY (SUB BOTTOM PROFILE MEASUREMENT)



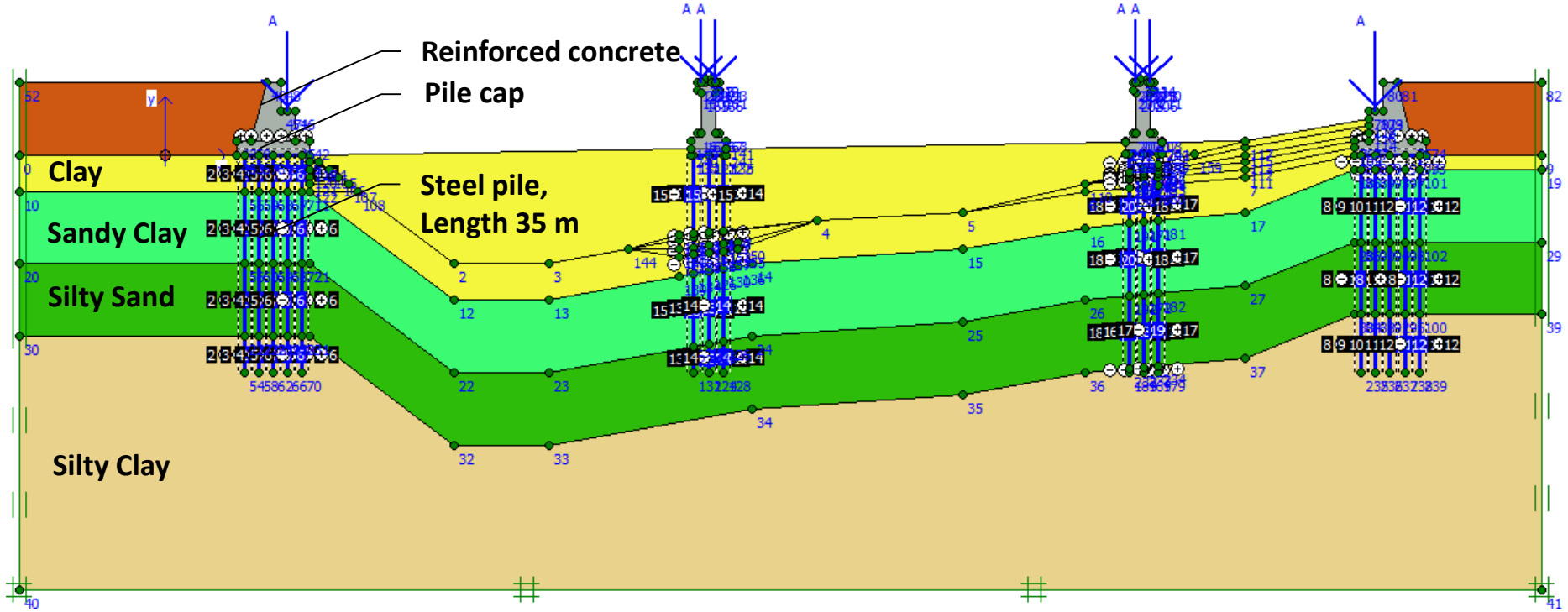
WATER FLUCTUATION EFFECT ON RIVER EMBANKMENT STABILITY



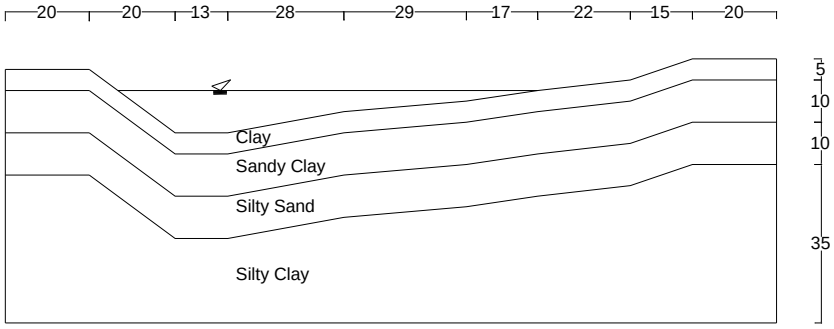


- Karang Binangun was the most critical condition (SF < 1.5) due to water level change
- Karang Geneng was the stable structure (SF > 1.5) since possessing flatter slope
- Considering the unsaturated condition beyond water level, the embankment stability should be re-analyzed.

BRIDGE FOUNDATION (NEARBY INFRASTRUCTURE)

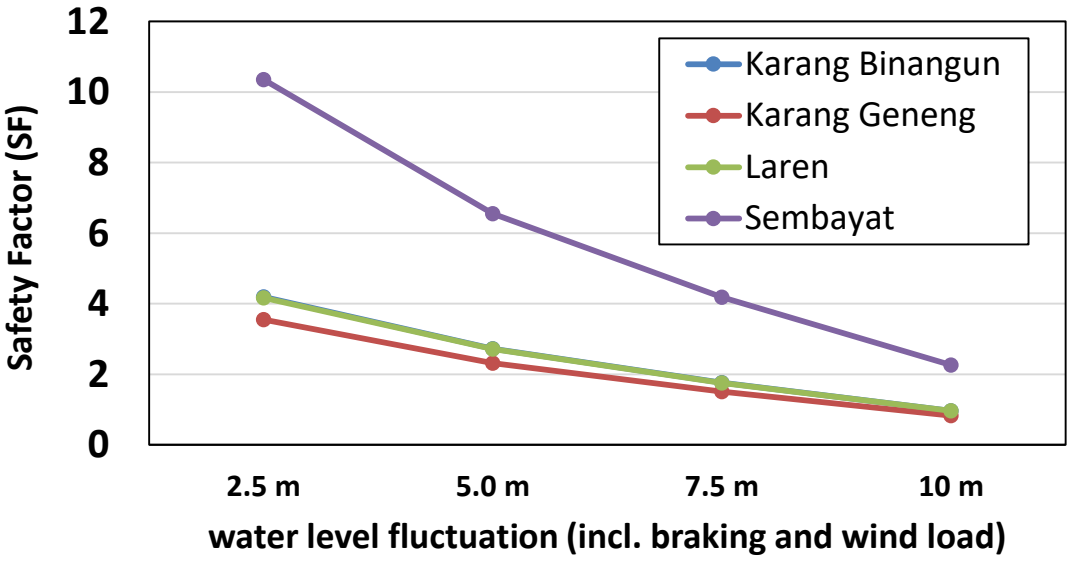


KARANG BINANGUN



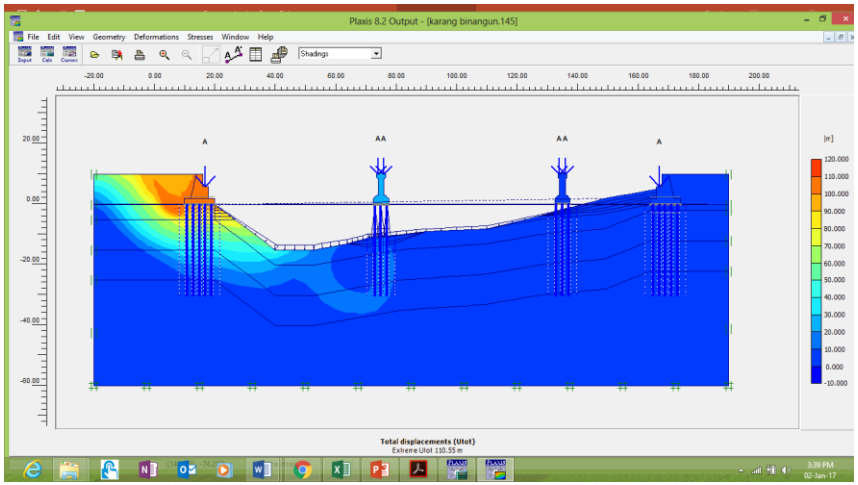
No.	Depth (from surface)	N_{SPT} (blows/feet)	Soil Type	Unit weight (kN/m^3)	Cohesion (kPa)	Internal angle friction (°)
1	0.00 - 5.00 m	8	Clay	16.44	18.3	4
2	5.00 - 15.00 m	10	Sandy Clay	16.89	21.7	5
3	15.00 - 25.00 m	26	Silty Sand	14.96	1	27
4	25.00 - 60.00 m	39	Silty Clay	20.00	50	37.8

SEDIMENT DEPOSITION EFFECT DUE TO WATER FLUCTUATION ON FOUNDATION STABILITY



- Load of sediment and water flow increases due to water level
- Foundation stability was influenced by additional load from sediment and water
- Karang Binangun, Karang Geneng and Laren bridges are vulnerable to water level fluctuation below 5 m
- Sembayat was the most stable structure since no impact area existed on the foundation

SCOURING EFFECT DUE TO WATER FLUCTUATION ON OVERALL BRIDGE STABILITY



- Karang Binangun was the most critical condition due to water level change
- The slope is tend to be collapsed due to water level change

Location	Initial	Remark	Scoured 1 m	Remark	Scoured 2 m	Remark	Scoured 3 m	Remark
Karang Binangun	1.119	< 1.5	1.118	< 1.5	1.115	< 1.5	1.111	< 1.5
Karang Geneng	1.808	> 1.5	1.791	> 1.5	1.741	> 1.5	1.730	> 1.5
Laren	1.781	> 1.5	1.783	> 1.5	1.779	> 1.5	1.779	> 1.5
Sembayat	1.644	> 1.5	1.618	> 1.5	1.615	> 1.5	1.611	> 1.5

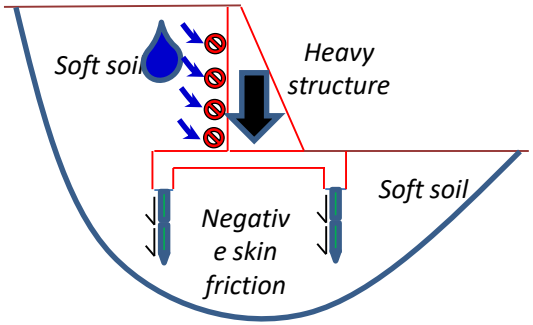
EVALUATION - RECENT OFFICIAL CODE ABOUT RIVER EMBANKMENT DESIGN

Name : Perencanaan Teknis Tanggul pada Sungai Lahar
Book of : Pedoman Konstruksi dan Bangunan
Number : Pd T-16-2004-A
Issued by : Departemen Permukiman dan Prasarana Wilayah
Remark : Keputusan Menteri Permukiman dan Prasarana Wilayah
Nomor = 360/KPTS/M/2004
Tanggal = 1 Oktober 2004

Content	Proposed modification
Slope protection uses rock or concrete.	Due to heavy material, slope has also to be equipped by **supporting reinforcement**
Necessary materials for river embankment are non-cohesive soil; rock or concrete; plant based material; and grass.	**Light-weight material** might be used in the river embankment that mostly consists of very soft soil.
Working loads are self weight; water force; sediment force; flowing impact.	River water level fluctuation should be taken into account due to **unsaturated soil** issue.

EVALUATION - RECENT PROTECTION – B SOLO RIVER

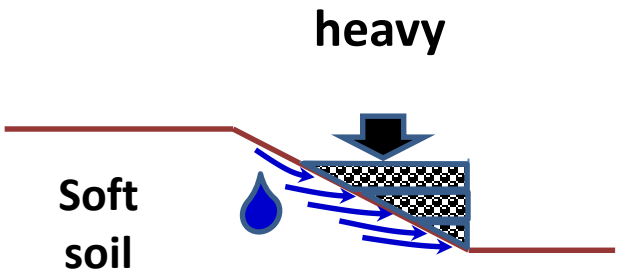
Retaining wall

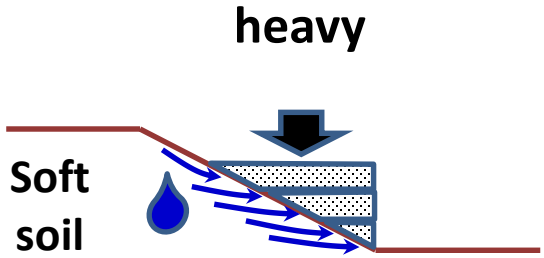


- Heavy structure since constructed by reinforced-concrete and rock material
- Pile bearing capacity is equal to 1/3 of self-weight of the wall structure
- Piles are laid on the soft soil which has low strength and high compressibility
- Water is difficult to find the way out (soil piping is possible)
- Fill behind the wall affects soil settlement which inducing negative skin friction to the piles
- Soil settlement is continued until the end of consolidation process

EVALUATION - RECENT PROTECTION – B SOLO RIVER

Gabion and sand-bags for slope protection





- Water is flowing into the protection without barriers
- Protections are laid on the soft soil which has low strength and high compressibility
- Heavy structure since constructed by rock and sand materials
- Soft soil settlement is completed in the following hundred years

EVALUATION - PREVIOUS RESEARCH - CONCEPT

- **Used tire** is industrial waste which tend to increase over the years.
- As much as **11 million tonnes** of tire-soil waste per year in Indonesia
- **70 % of tire waste** is utilized into the environment in US, meanwhile 30 % is wasted in containment yard (Garga and O'Shaughnessy, 2000)

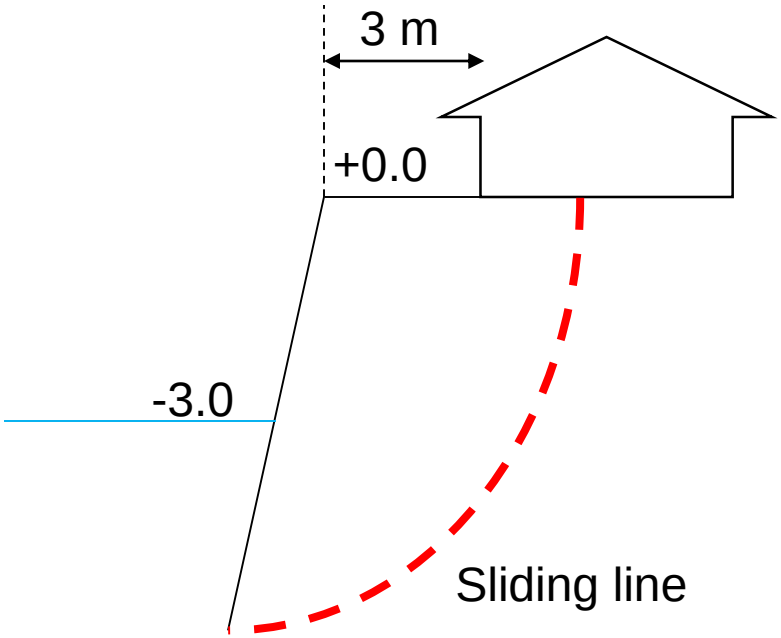
- **Light** river embankment protection system as an alternative
- **Anchorage application** is proposed as reinforcement of the entire protection system

EVALUATION - PREVIOUS RESEARCH - NUMERICAL MODEL

Slope Type	Water level	Safety factor
Natural	Low	1.342
	Medium	1.714
	High	0.105
Vertically arrangement of Tire-soil	Low	5.521
	Medium	9.243
	High	3.017
Horizontally arrangement of Tire-soil	Low	7.166
	Medium	13.185
	High	25.967

- Water level fluctuation induces **change** of safety factor
- Tire-soil reinforcement **increases** the safety factor of slope stability
- **Horizontal** arrangement of tire-soil has **higher** safety factor than vertical arrangement.

Analysis of River Embankment Failure



Embankment sliding of Bengawan Solo River next to public housing in Banjarejo Village, Bojonegoro, 2016 (Source: beritajatim.com)

Effect of external condition

Load distance	Safety factor, SF
3 m	0.96
10 m	1.024
20 m	1.028

Water level	Safety factor, SF
± 0 m	1.028
+ 5 m	1.209
+ 10 m	2.213

Rapid draw down	Safety factor, SF
From +10 m to +5 m	1.190
From +10 m to ± 0 m	1.002

- Conclusion:
  - Regulation of the distance of residential area is required to be applied
  - Slope stability is varied due to water level fluctuation
  - Phenomenon of rapid draw down decreases the river embankment stability

FUTURE WORK

- River morphology changing modeling induced by erosion and deposition processes.
- Mapping of sediment distribution on the dam by Sub Bottom Profile investigation
- Analysis of excessive sedimentation that lead to the decreased of reservoir capacity
- An advanced analysis of dam stability due to accumulated sedimentation
- Proposed of effective operational and maintenance activities towards sustainability of dam performance.

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Thank you