Quantification of Sediment Yield and Potential Sources of Erosion/Deposition in the Upper Citarum Basin, Indonesia Using A Distributed Rainfall-Runoff-Sediment Model

Apip

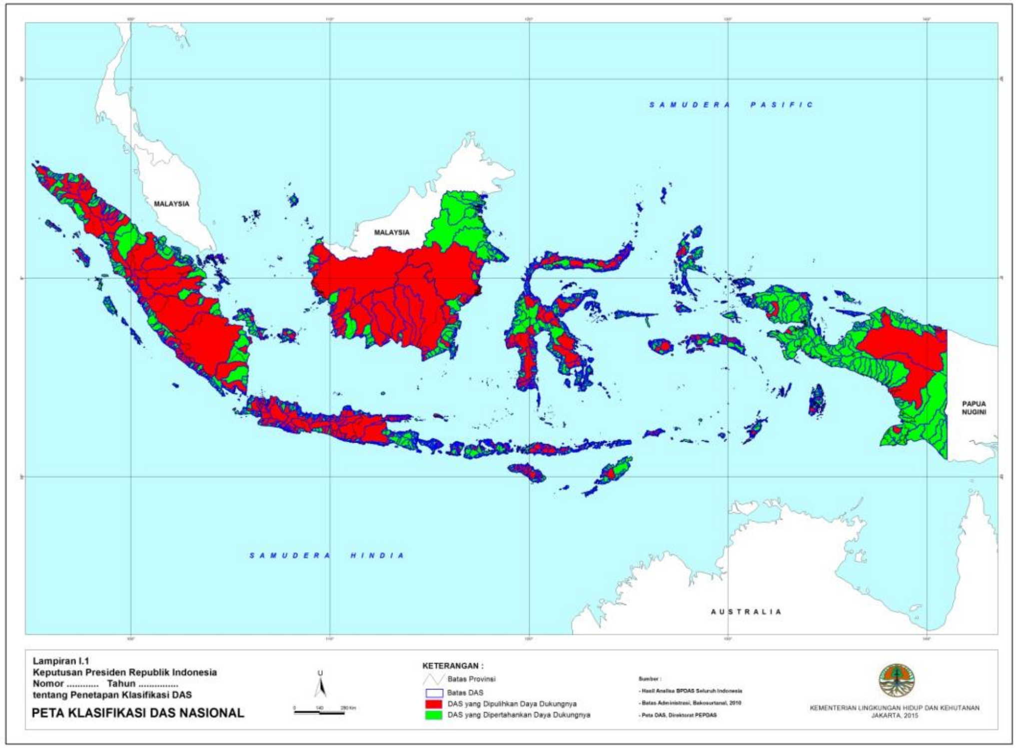
Research Center for Limnology, Indonesian Institute of Sciences (LIPI)

International Training Workshop on Integrated Sediment Management In River Basin

November 5-10, 2018, Ziyu Hotel, Beijing, China

River Basin Condition

Number of watersheds in Indonesia : 17.088 watersheds/ DAS (SK Menhut NO.511/Menhut-V/2011)



NATIONAL MID TERM DEVELOPMENT PLAN 2014-2019

108 watersheds **have Integrated Watershed Management Plan/ IWMP** (Rencana Pengelolaan DAS Terpadu/RPDAST)

108 RPDAST/IWMP → 15 priority watersheds /Daerah Aliran Sungai (DAS) will be restored

1) DAS Citarum
2) DAS Ciliwung
3) DAS Serayu
4) DAS Solo
5) DAS Brantas
6) DAS Cisadane
7) DAS Kapuas
8) DAS Siak
9) DAS Musi
10) DAS Asahan Toba
11) DAS Jeneberang
12) DAS Saddang
13) DAS Moyo
14) DAS Way Sekampung
15) DAS Limboto

Leading Sector : Ministry of Environment and Forestry

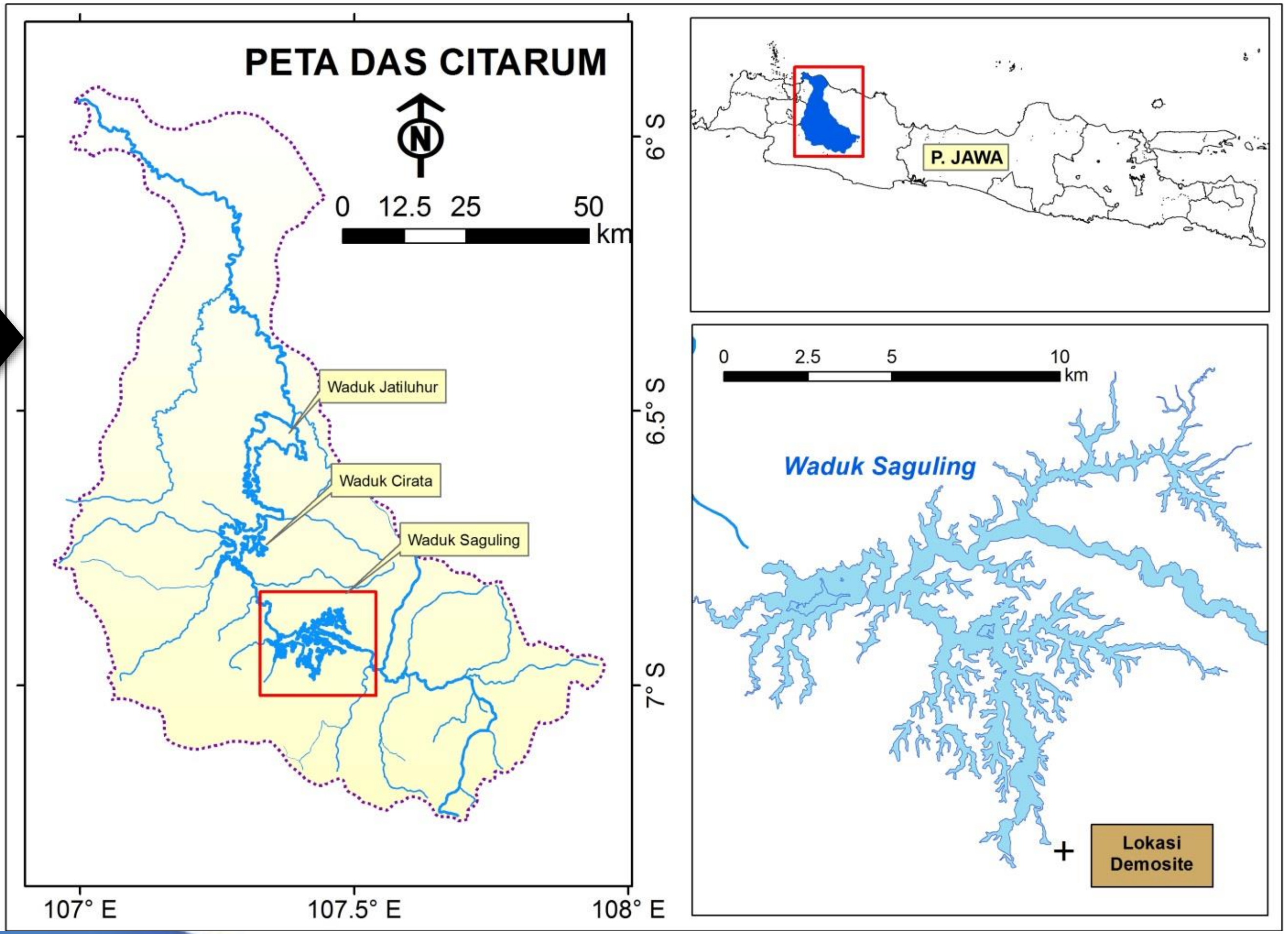
Leading Sector : Ministry ofPublic Works & Housing

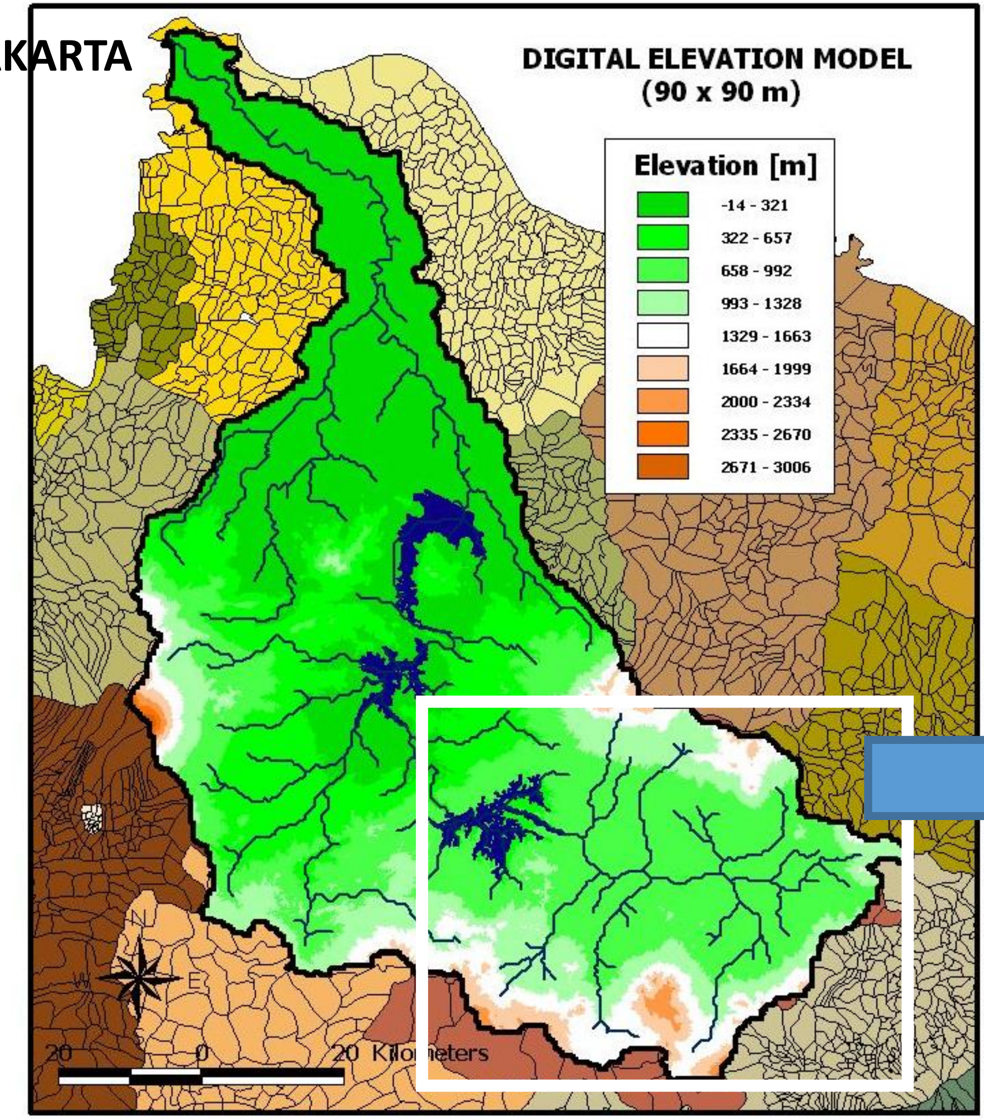
NATIONAL MID TERM DEVELOPMENT PLAN 2015-2019: WATER SECURITY

Priority Project: Erosion & Sediment Control at the Watersheds & Reservoirs/Dams

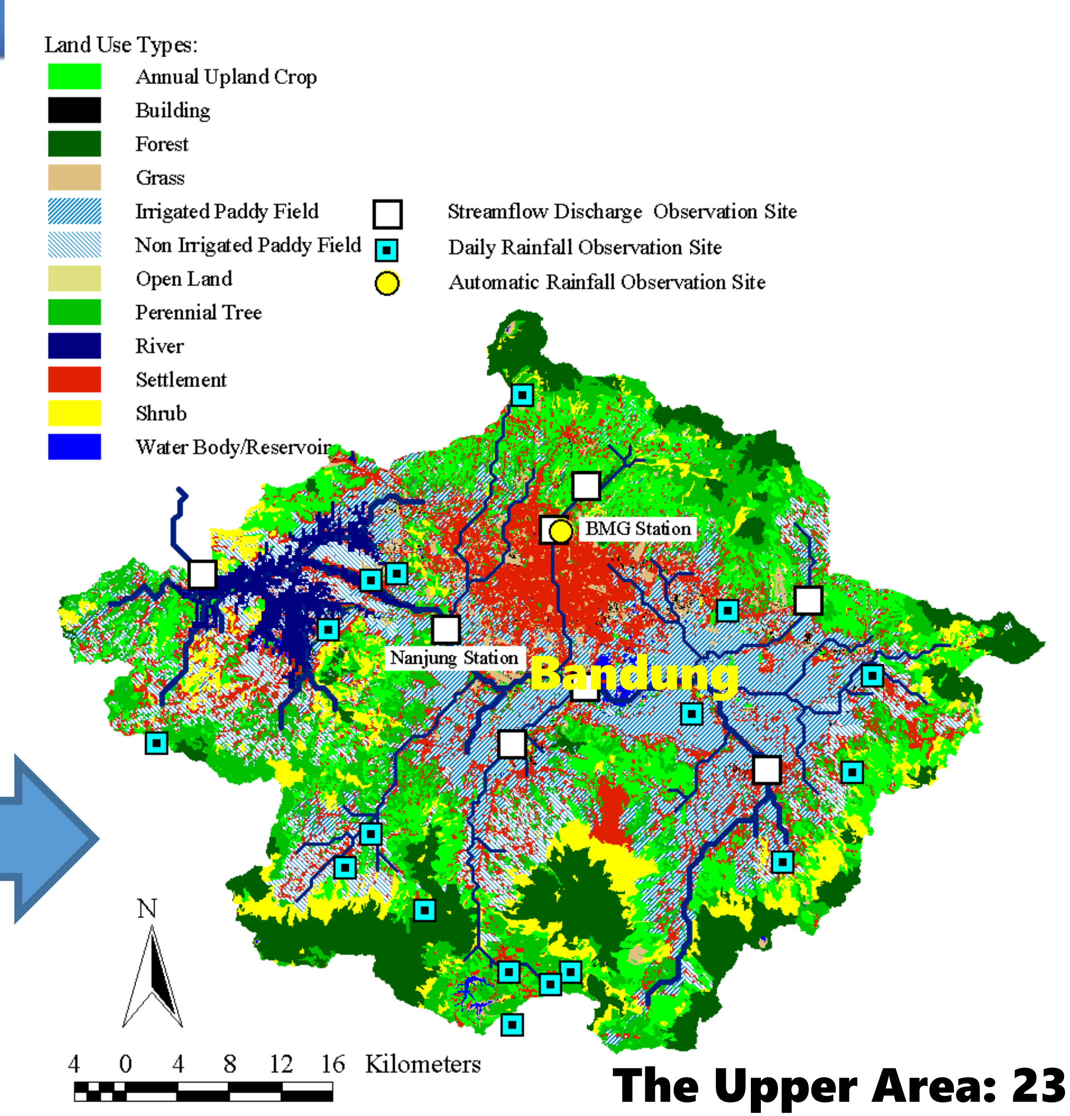
Citarum River Basin Restoration Program (2017 - 2024)

CITARUM RIVER BASIN





Total Area: 7295.86 km²

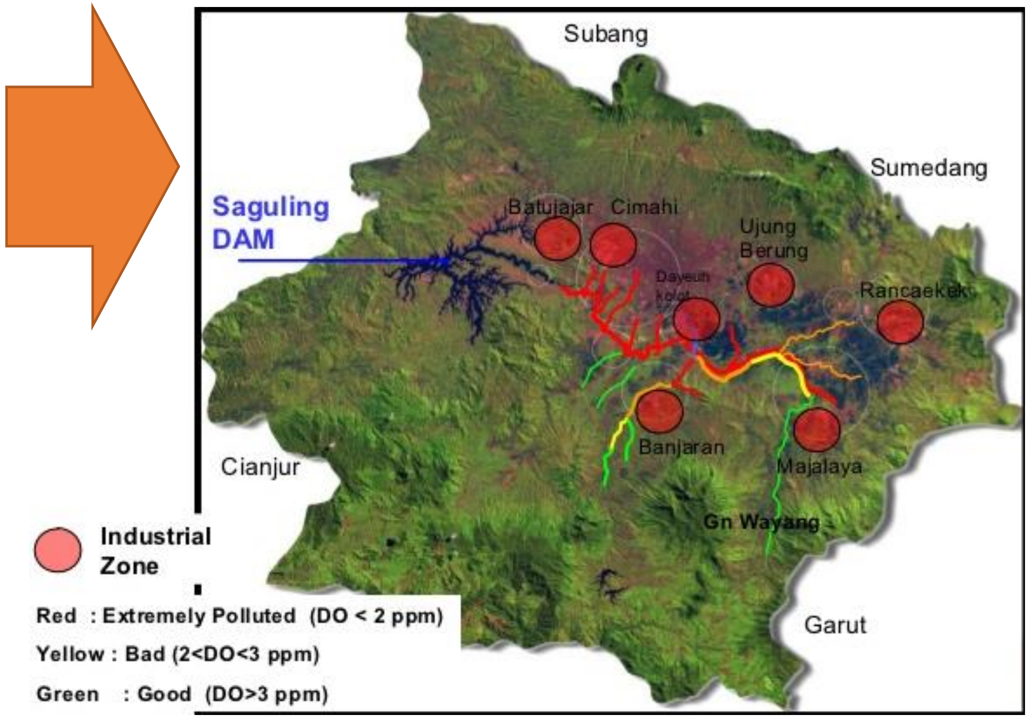


The Upper Area: 2329.86 km²

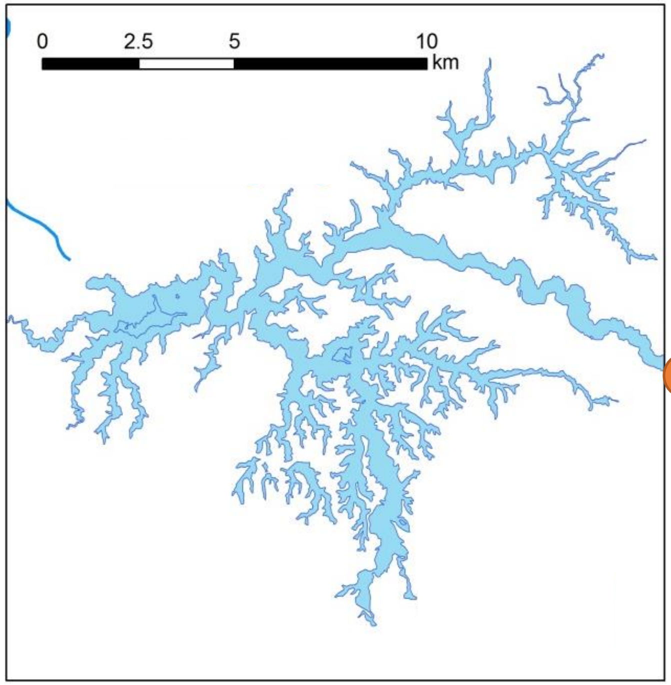
FORESTRY AREA:

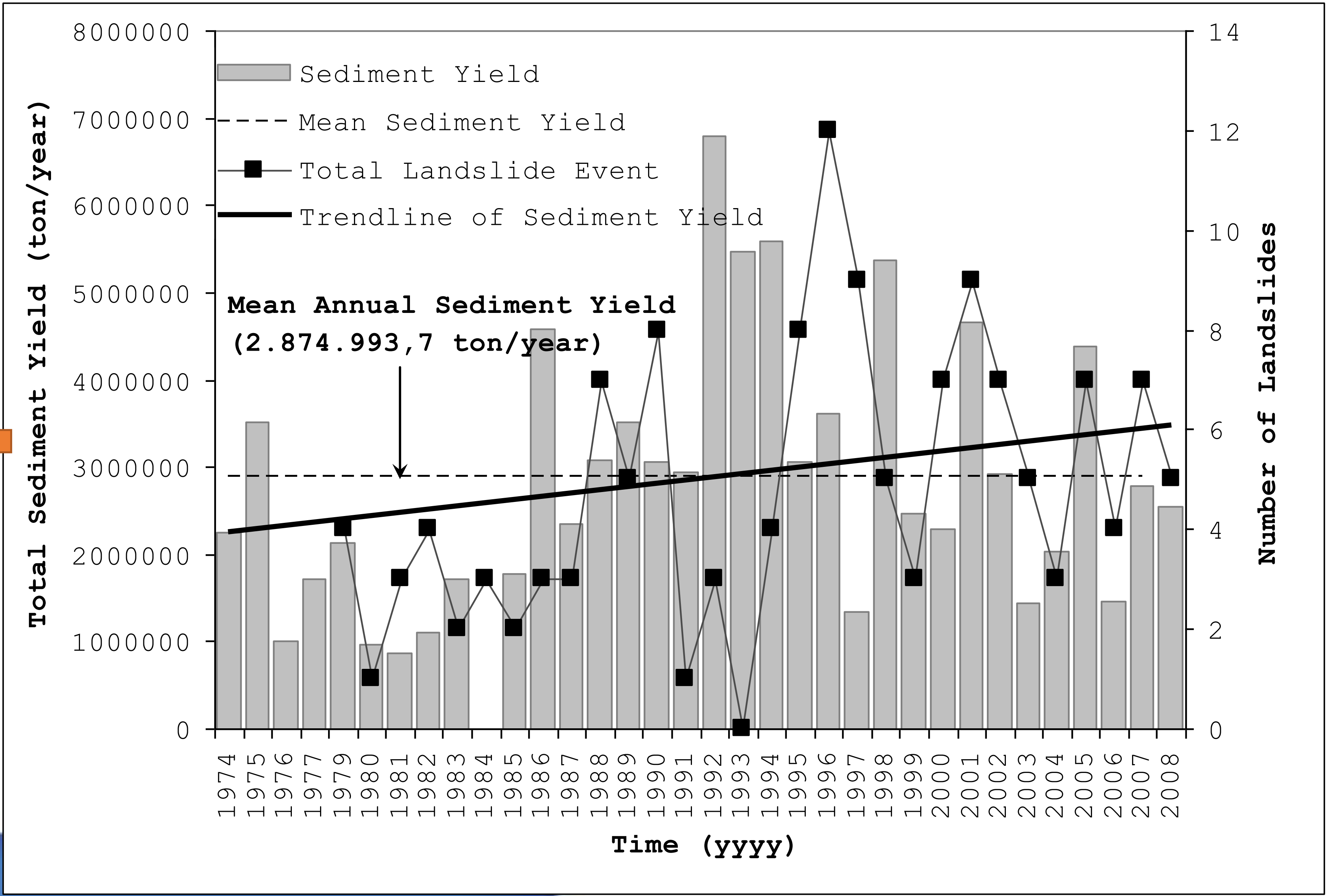
1993	→	27 %
2003	→	14 %

Climate Change & Anthoropogenic Activity

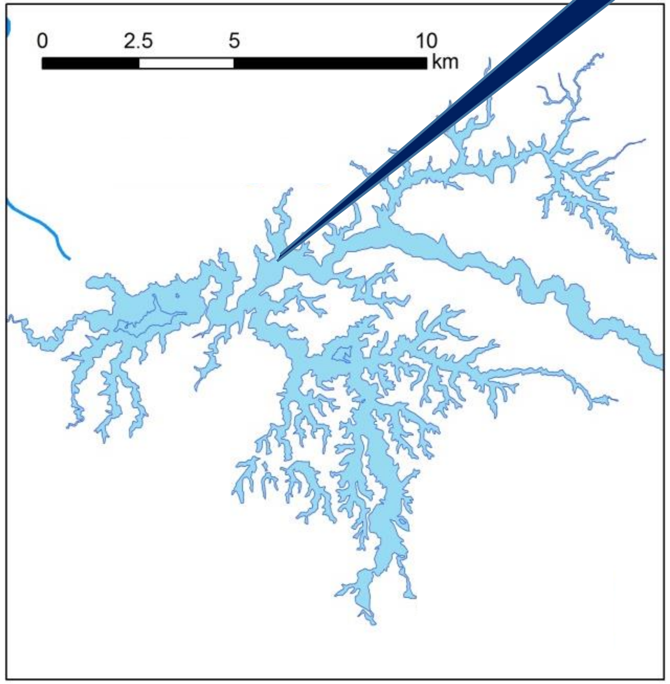


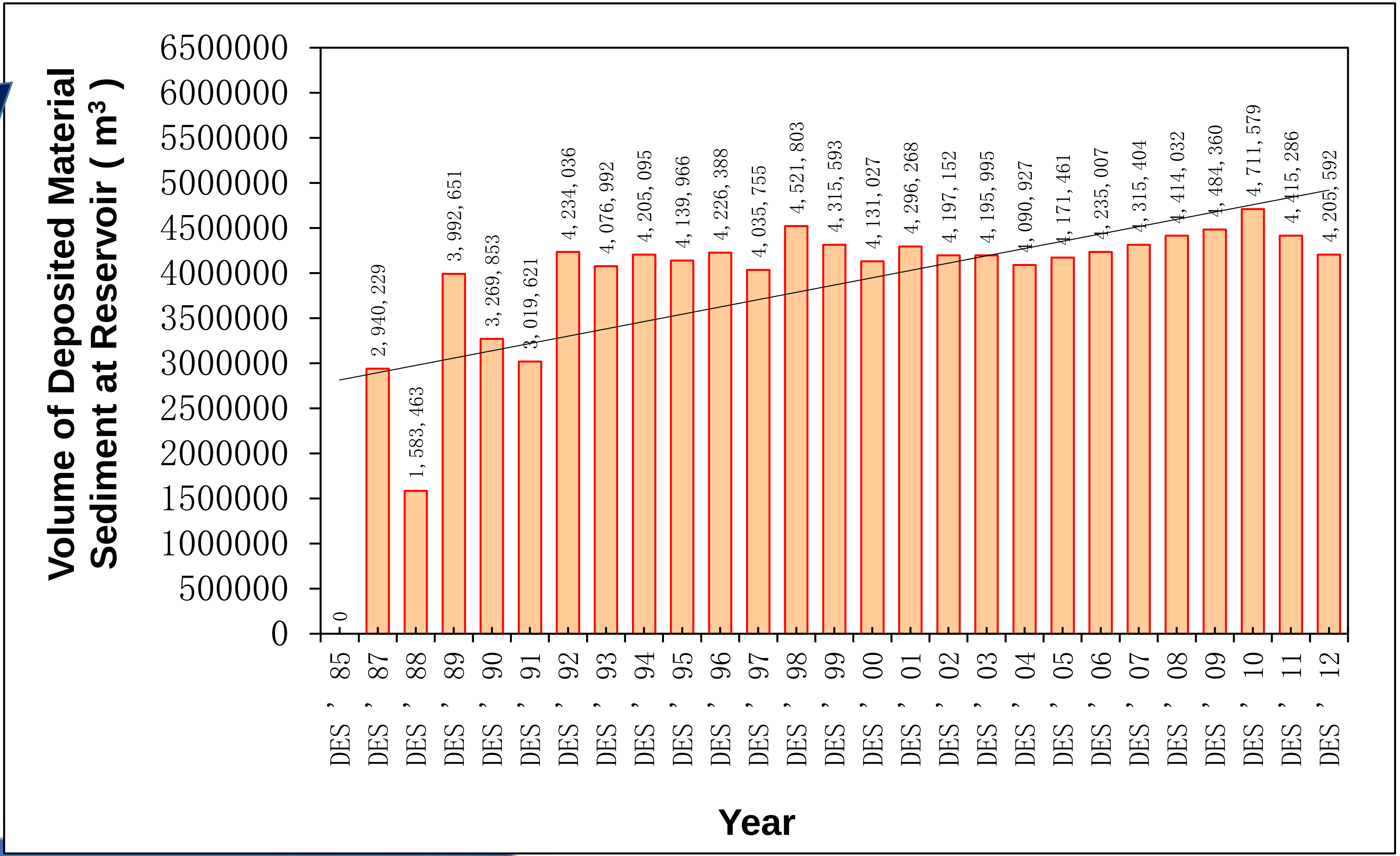
Total Amount & Increasing Trend of Annual Sediment Load into Main Inlet Saguling Dam (1974 - 2008) and Landslide Occurrence (1978 - 2008) at the Upper Citarum River basin





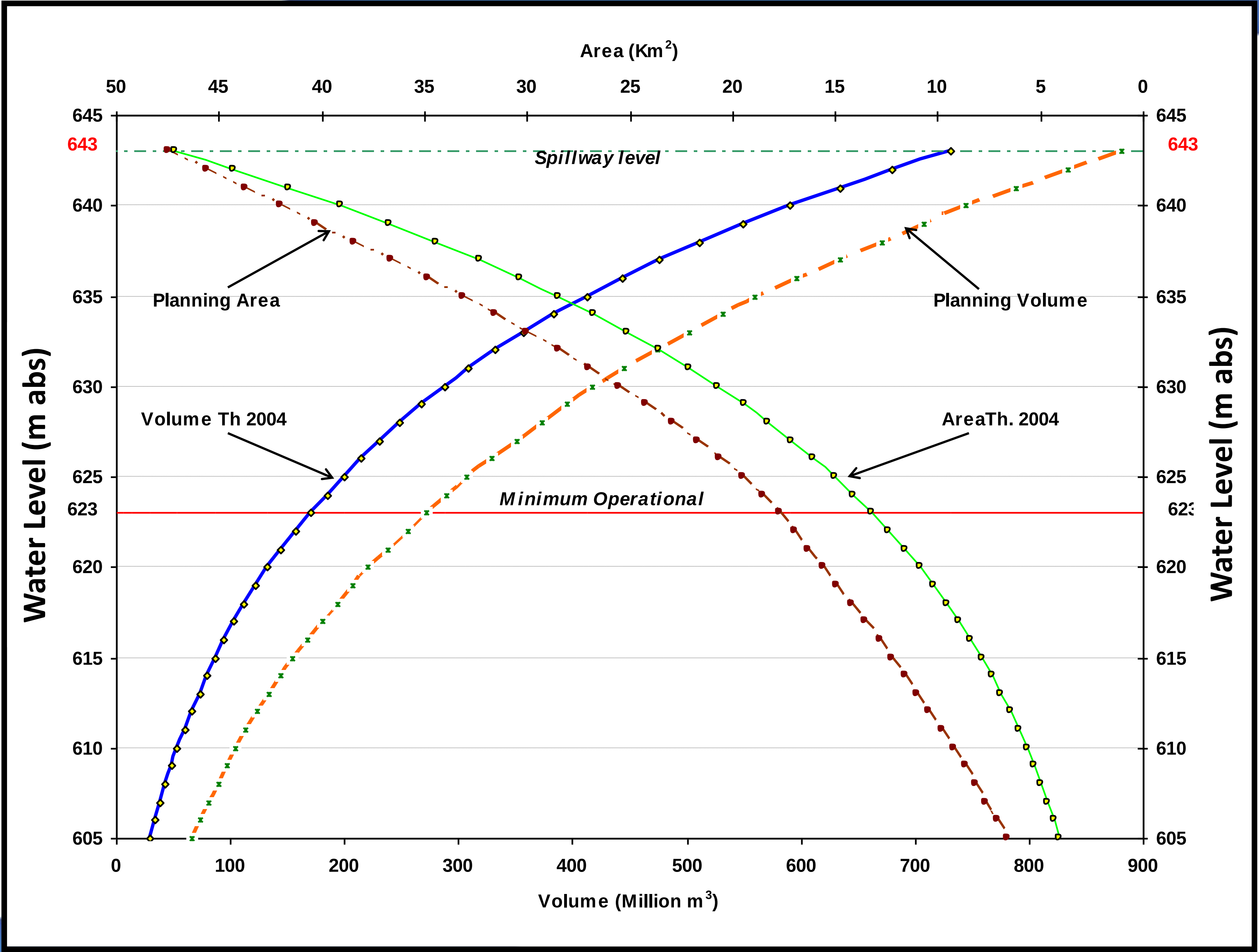
Total Amount & Increasing Trend of the Deposited Material Sediment Volume in Saguling Dam (1985 - 2012)





Saguling Dam Condition

Saguling Dam Condition



Ministry of Environment & Forestry

LIPI

Ministry of Public Works and Housing

1. **Contribute to the Citarum River Basin Restoration Program (2017 - 2024)** in Terms of Overlandflow (Runoff), Erosion and Sediment Transportion Controls

2. To reduce the impact of land-use and climate changes in the Upper Citarum River basin which have caused the increasing sedimentation rate along the river and the reducing the lifetime and storage capacity of the Saguling Dam

Development a Tool (Modeling System) for Design Strategy of Erosion and Sediment Control Plan

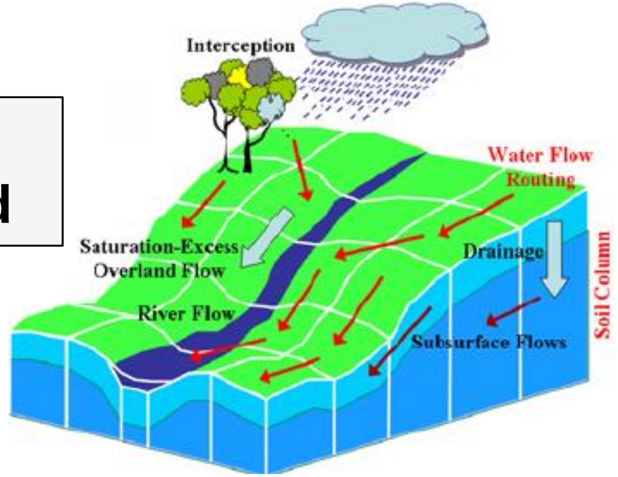
Prediction

Process Understanding

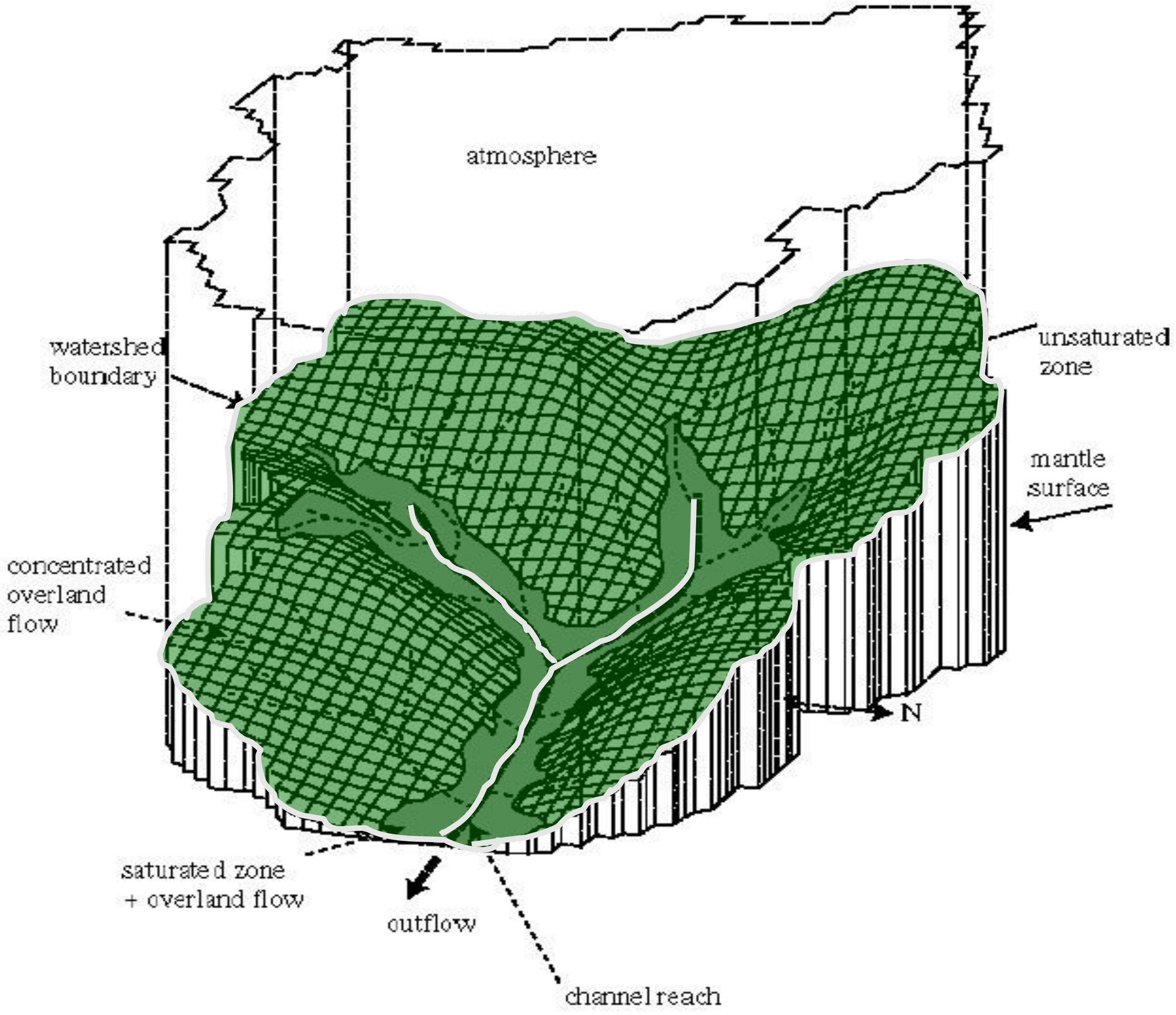
Scenario-based Management (Planning)

Model Type?

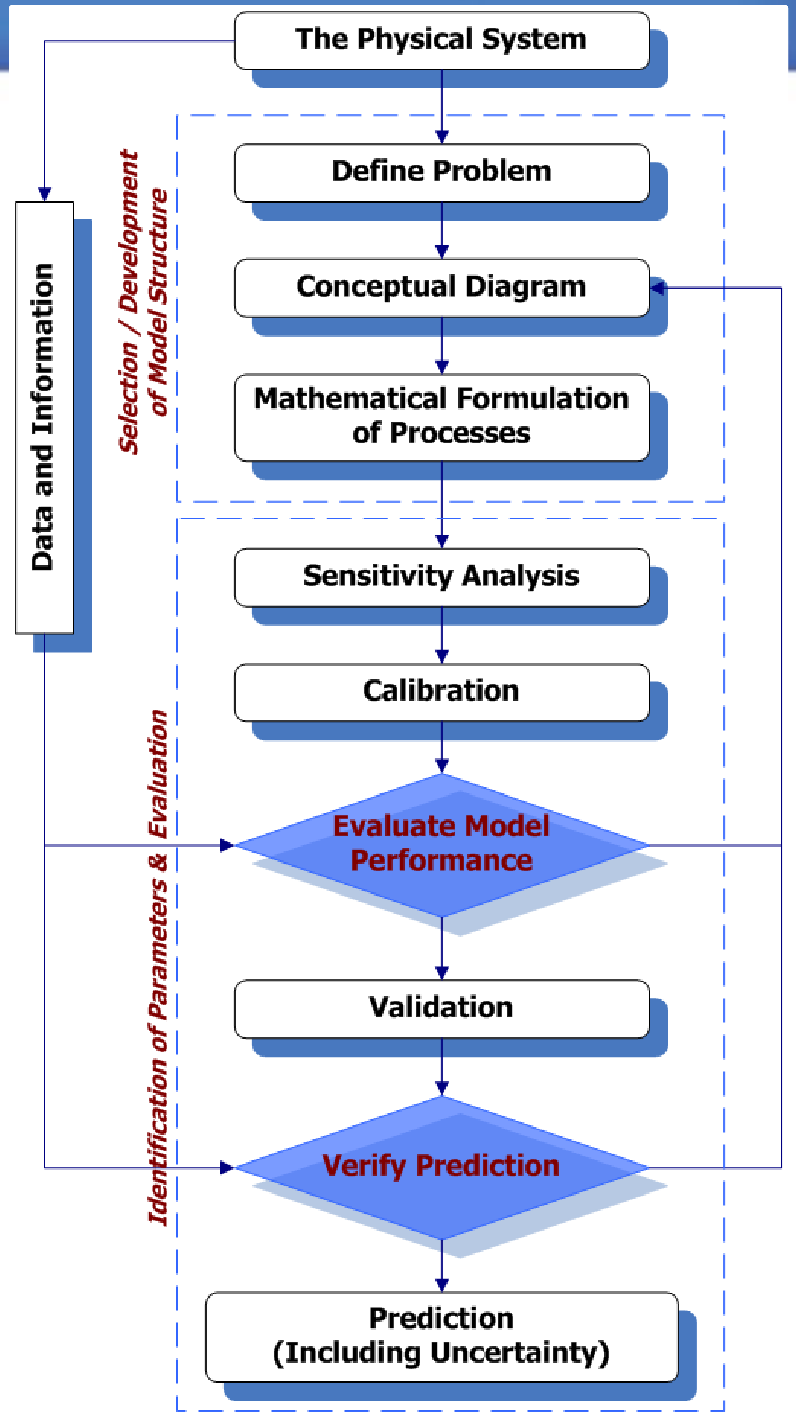
Distributed + Process-based



PHYSICALLY-BASED DISTRIBUTED MODEL



MODELING PROCEDURE



Sediment Discharge Model

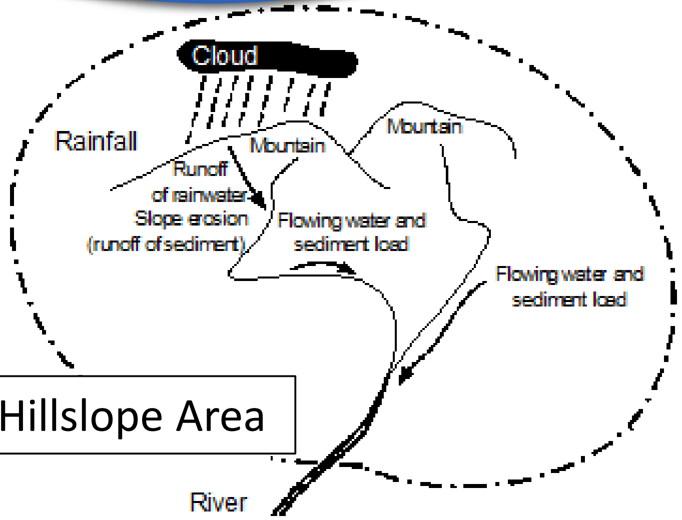
River Sediment Dyanamic Model

Seashore Sediment Dynamic Model

Upper Citarum River Basin

Sources:
1. Soil Erosion;
2. Shallow Landslide

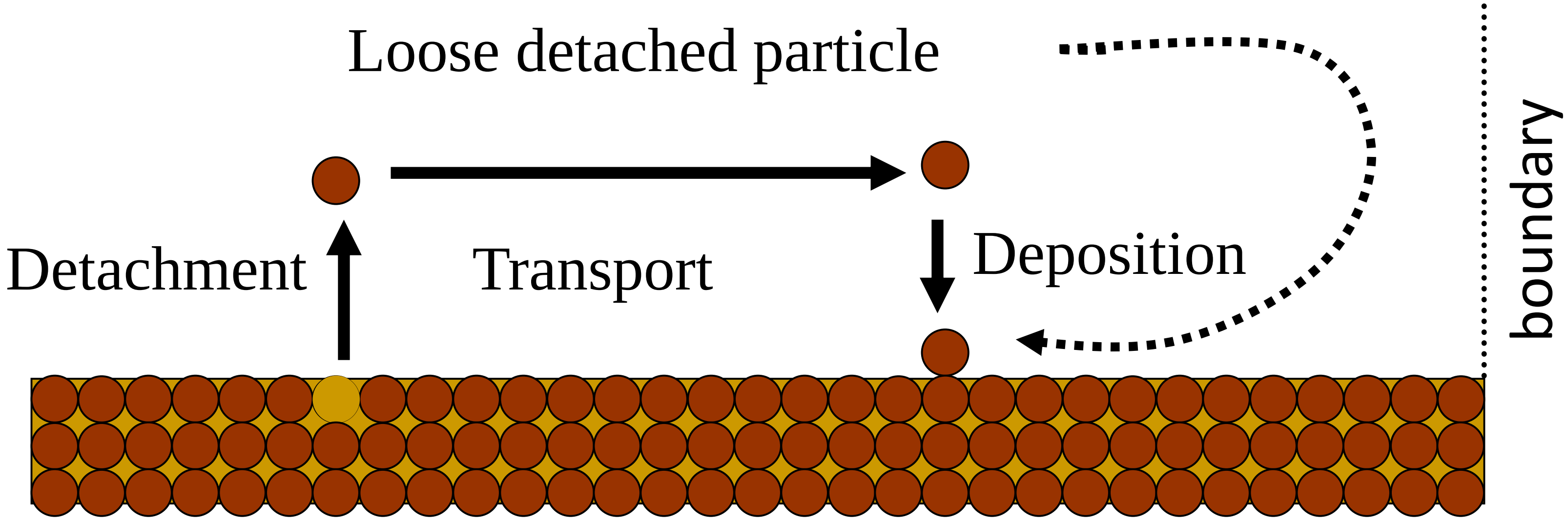
1-D PHYSICALLY-BASED DISTRIBUTED RAINFALL-RUNOFF-SEDIMENT MODEL



Upper Citarum River Area

MODEL COMPONENT:

1. **Soil Erosion & Transportation Process**: Erosion and transportation occurs when particles are **detached** from the surface of the soil matrix and **transported** across some boundary

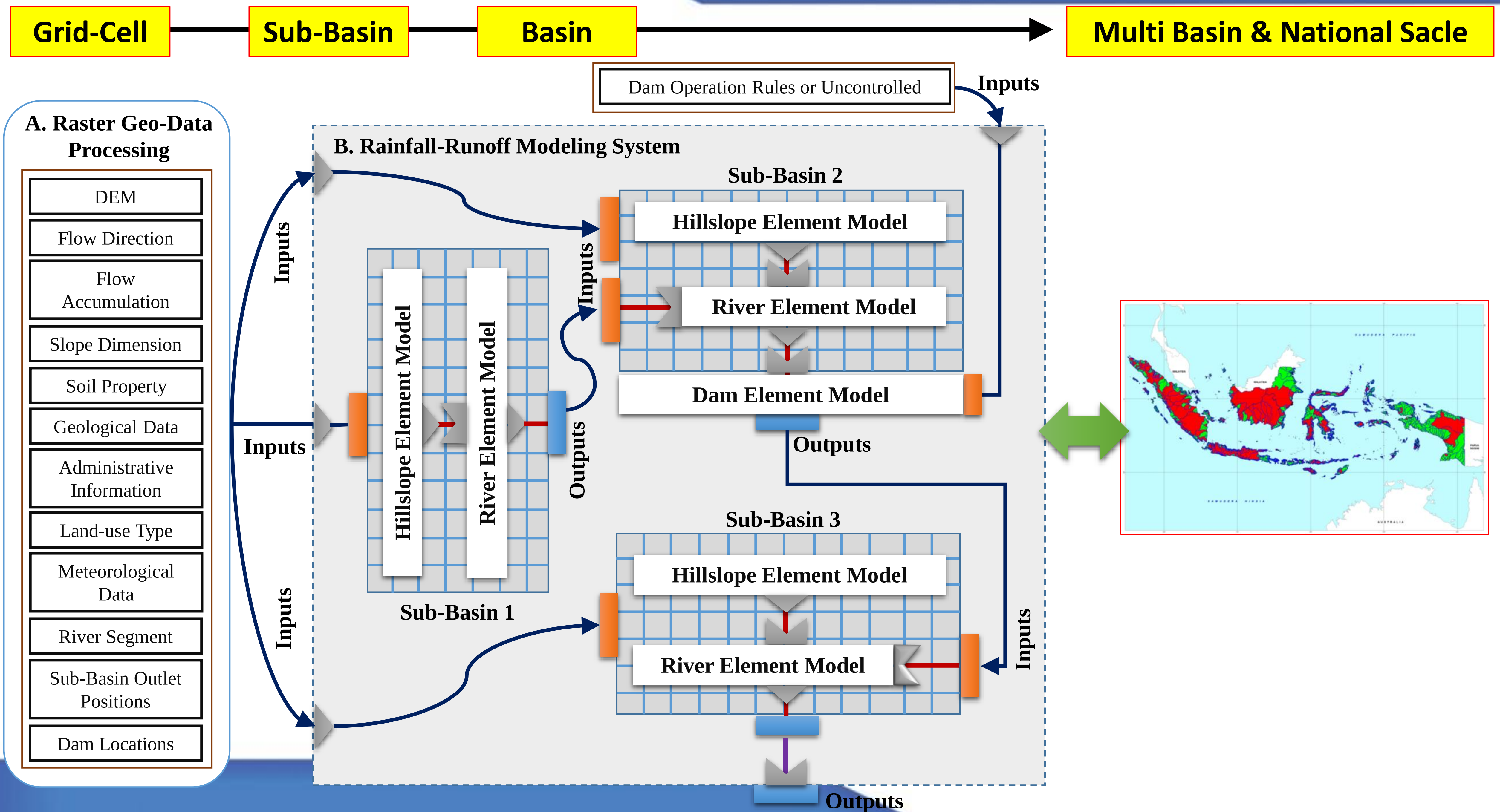


Sediment Transportation Capacity (TC) of surface flow at a particular grid:

Erosion : TC > Sed. Concentration of Inflow (upper grid)
Deposit : TC < Sed. Concentration of Inflow (upper grid)

2. **Dam Operation Rule & Erosion-Sediment Control Function (**
3. **Runoff Generation & Shallow Landlisde**

Scale of Model Application



Sub Surface & Surface Flow & Runoff Generation

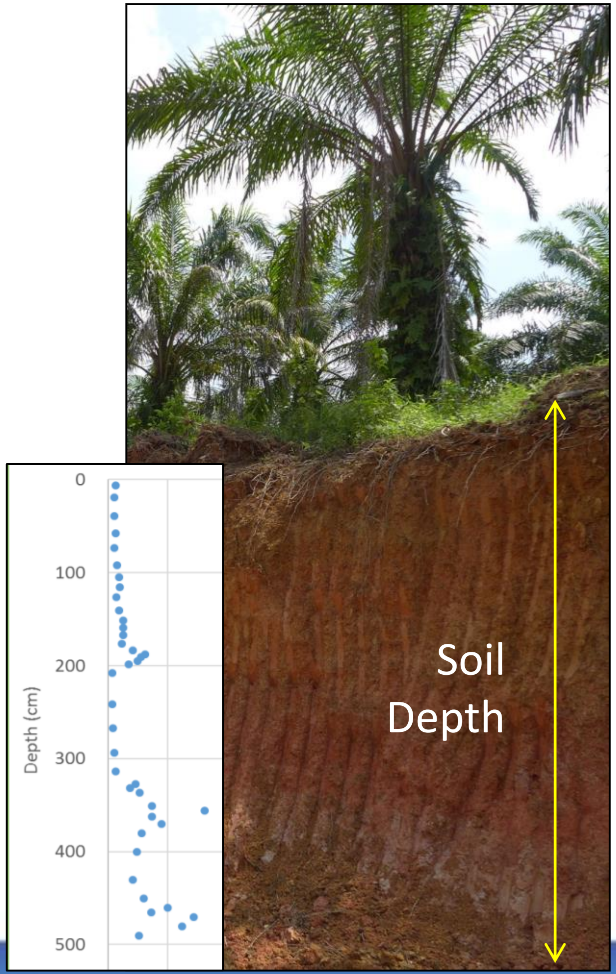
Cont. Eq.:

$$\frac{\partial H(X,t)}{\partial t} + \frac{1}{B(X)}\frac{\partial}{\partial X}\{B(X)Q(x,t)\} = r_e(X,t)\cos\theta,\ 0 \le X \le L$$

Routing Process 1-D Kinematic Wave

Momentum Eq.:

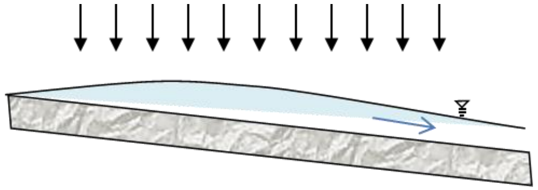
$$Q(X,t) = \alpha H(X,t)^m$$

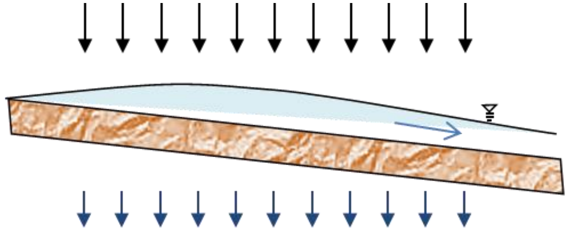


Three Conditions of Surface / Subsurface Flow (H-Q):

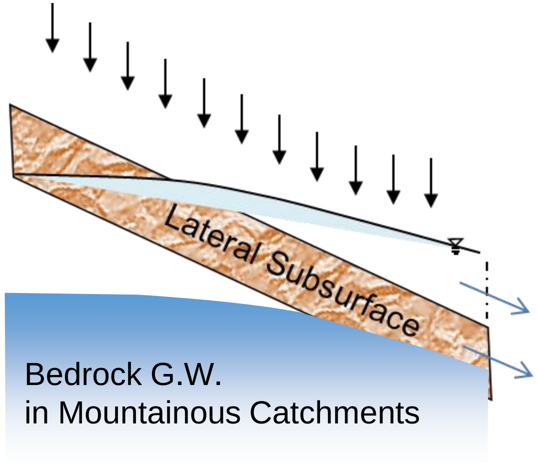
Surface / subsurface flow conditions

- (A) Only overland flow (no infiltration loss, no subsurface flow)
- (B) Vertical infiltration + Infiltration excess overland flow
- (C) Saturated subsurface + Saturation excess overland flow

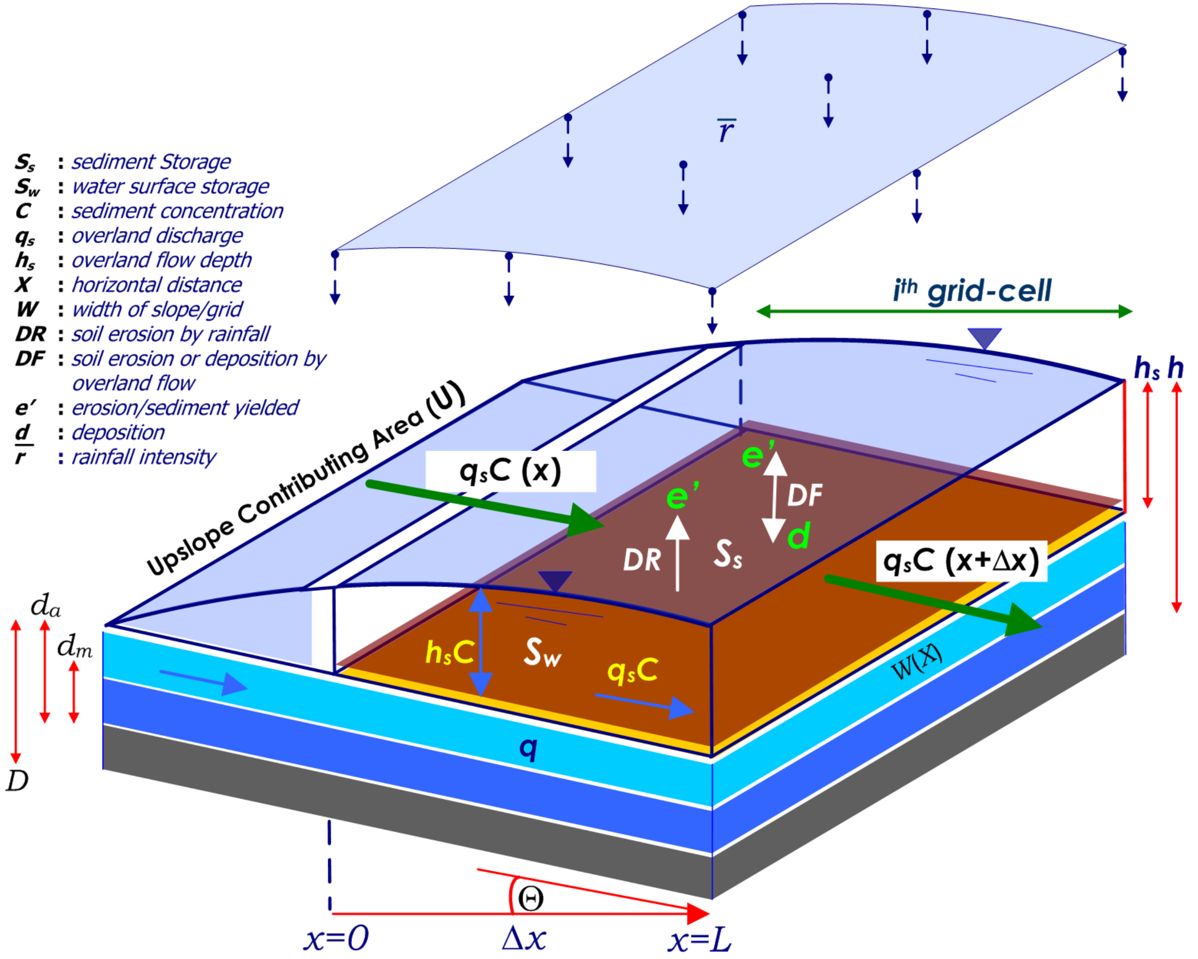




Infiltration : Green Ampt Model



Soil Erosion/Deposition & Sediment Transport Processes



Continuity Equation for Runoff-Sediment:

$$\boxed{\frac{\partial(h_s c)}{\partial t} + \frac{\partial(q_s c)}{\partial x} = e(x,t)}$$

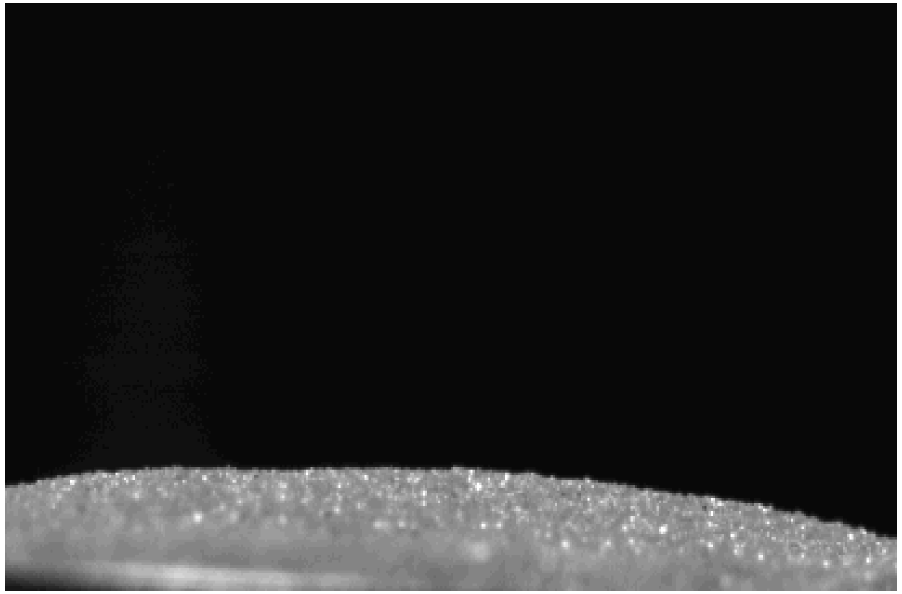
$$e(x,t) = DR + DF$$

Soil Detachment by Raindrop *(DR)*

Soil Detachment by Overland Flow *(DF)*

Empiracal models were selected: First, the models retain a strong physical base, but easy to understand and require few parameters.

Soil Detachment by Raindrop *(DR)*



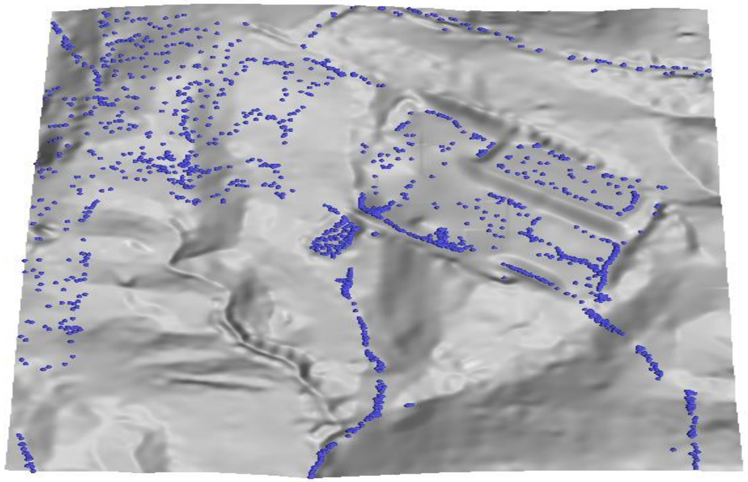
$$DR_i = k\ KE\ e^{-b*h_{si}} = k\ 56.48\ r_i\ e^{-b*h_{si}}$$

k is the soil detachability (kg/J); *KE* is the total kinetic energy of the net rainfall (J/m2); h_s is the overland flow depth; and *b* is an exponent to be tuned

- **Rainfall Intensity** predicted from raindrop size distribution has very strong linear correlation (**0.98**) with **impact energy work** which calculated by integrating the raindrop energy per unit area per unit time.

Dampening soil detachment rate by overland flow

Soil Detachment by Overland Flow *(DF)*



[Morgan *et al*., 1998]:

$$DF_i = \alpha\,(TC_i / 1000 - C_i)\,h_{s_i}$$

TC is the transport capacity of overland flow; α is the detachment/deposition efficiency factor shows a soil erodibility parameter, *C* is the sediment concentration

Concept of Transport Capacity and Unit Stream Power [Yang, 1996] :

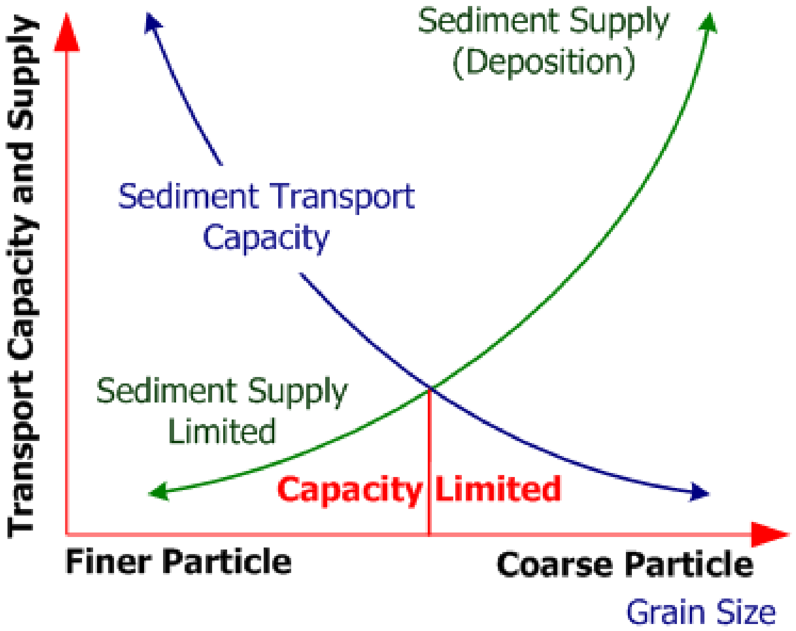
$$\boxed{TC = \log C_t = I + J\log((vi - v_{critical}\, i)/\omega)}$$

in which:

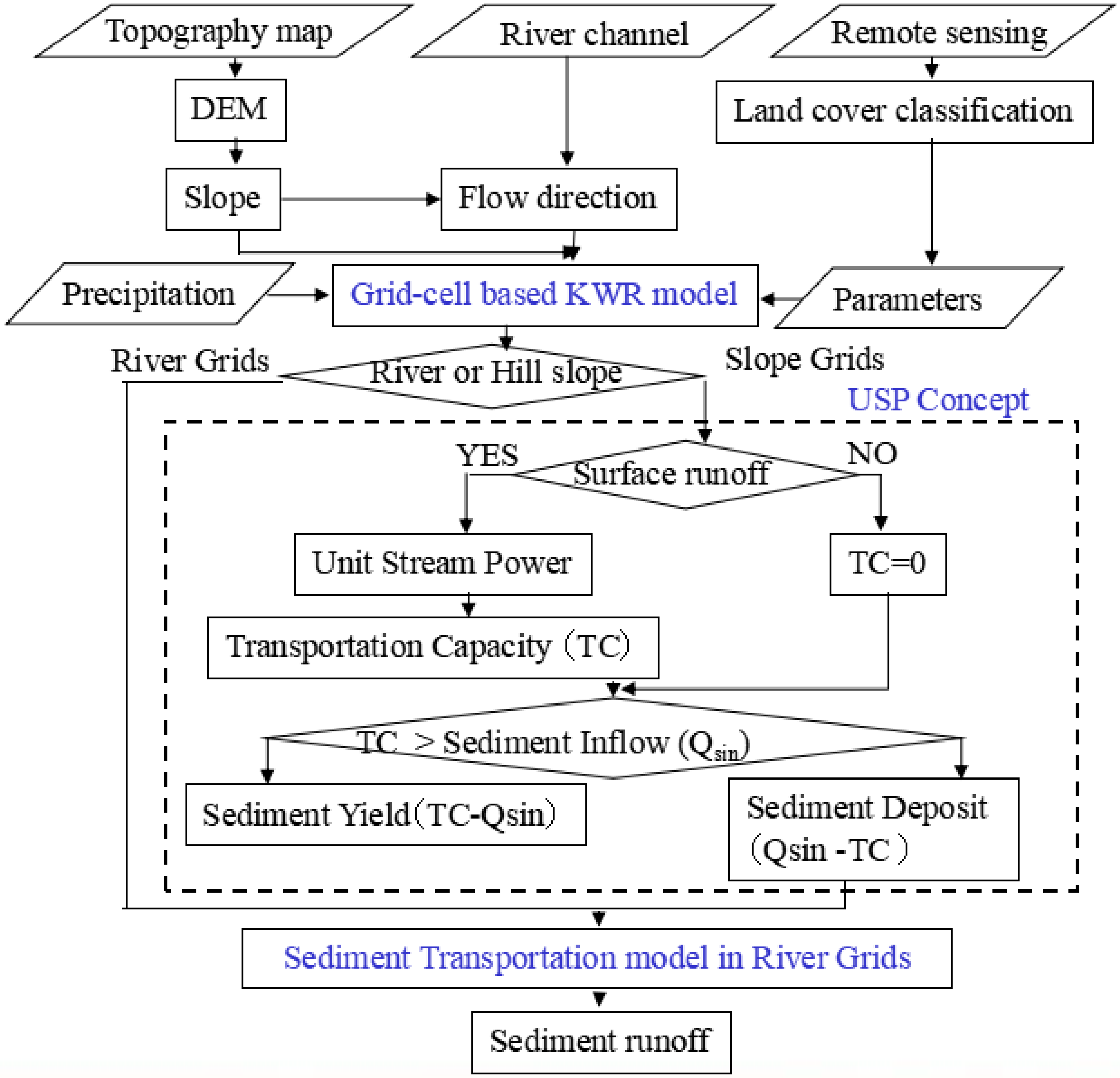
$$I = 5.435 - 0.286\log(\omega D_{50}/NU) - 0.457\log(U^*/\omega)$$

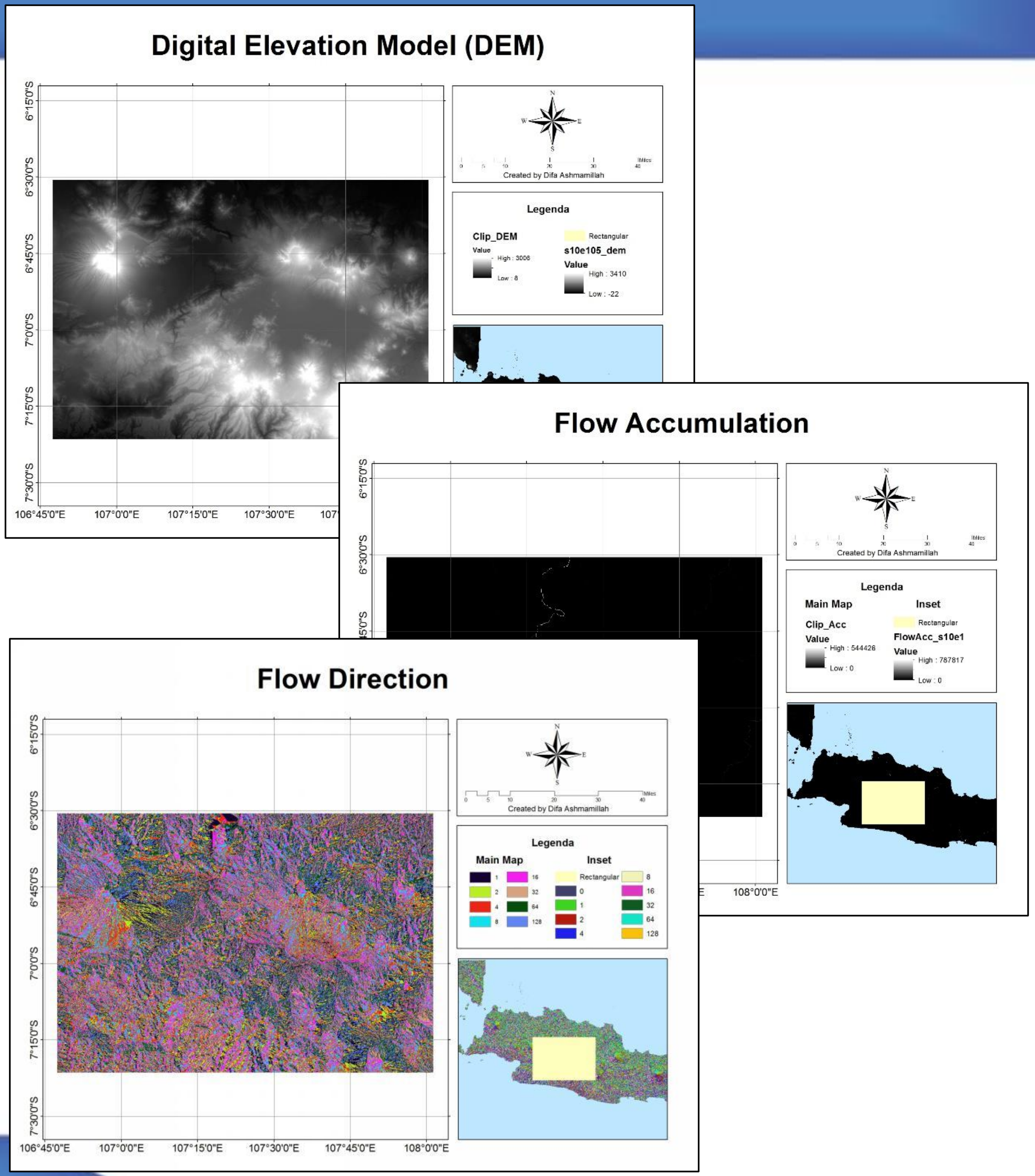
$$J = 1.799 - 0.409\log(\omega D_{50}/NU) - 0.314\log(U^*/\omega)$$

$$\omega = \sqrt{\frac{2}{3} + \frac{36}{\left(\frac{\rho_s}{\rho_w} - 1\right) g \left(\frac{D_{50}}{1000}\right)^{2/NU}}} - \sqrt{\frac{36}{\left(\frac{\rho_s}{\rho_w} - 1\right) g \left(\frac{D_{50}}{1000}\right)^{2/NU}}}$$



Rainfall-Runoff-Sediment Model Main Structure





Approach

Demosite/Plot Scale

Field monitoring of runoff, erosion and sediment transport processes

Groundwater, soil moisture, stream water level, soil depths, soil properties, rainfall

Runoff, erosion and sediment transportation controls

River Basin Scale (Upper Area)

Rainfall-Runoff-Sediment Process Modeling

Updating the model for tropical river basins

Assessment of erosion and sediment control function in response to environmental changes (climate & landuse)

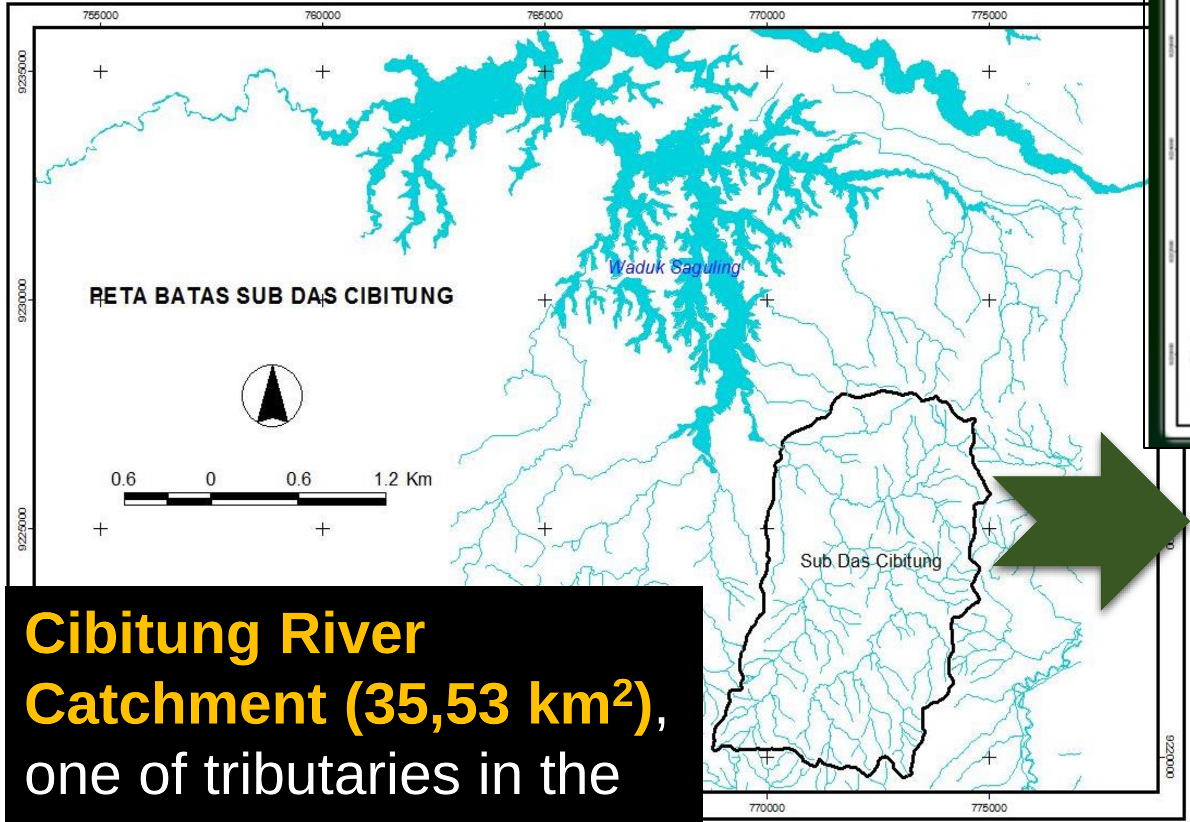
Regional/global Scale

Climate change projections by MRI-AGCM

Regional downscaling with NHRCM

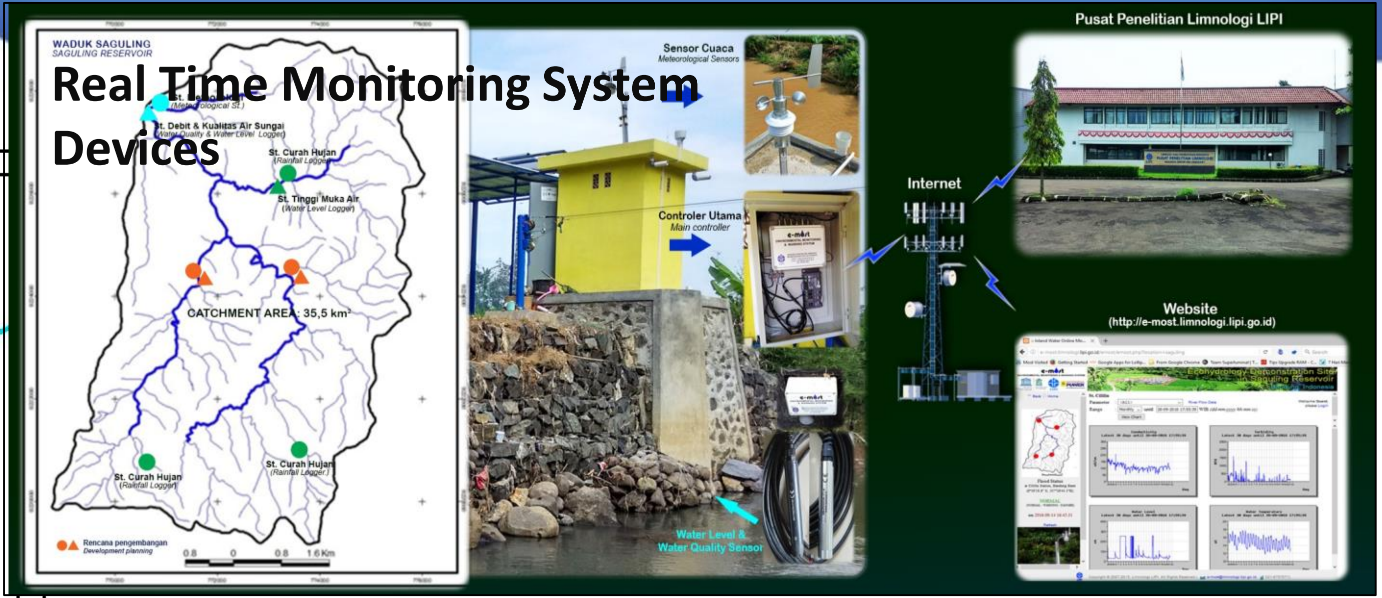
Utilizing GSMaP reanalysis rainfall product

Demosite/Plot Scale

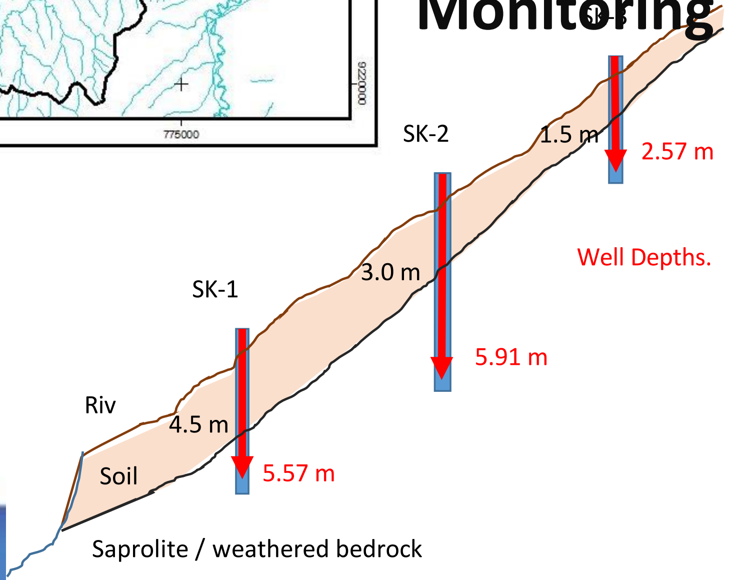


Cibitung River Catchment (35,53 km²), one of tributaries in the Upper Citarum River basin with the Saguling Dam as the outlet point was decided **as a demosite/plot scale location**

Real Time Monitoring System Devices

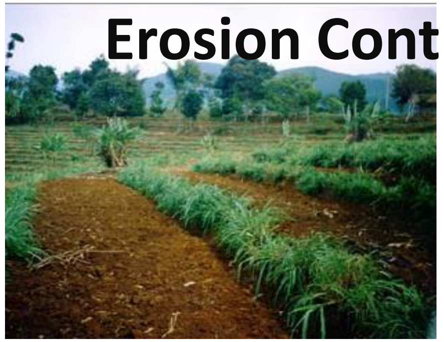


Runoff Generation Monitoring



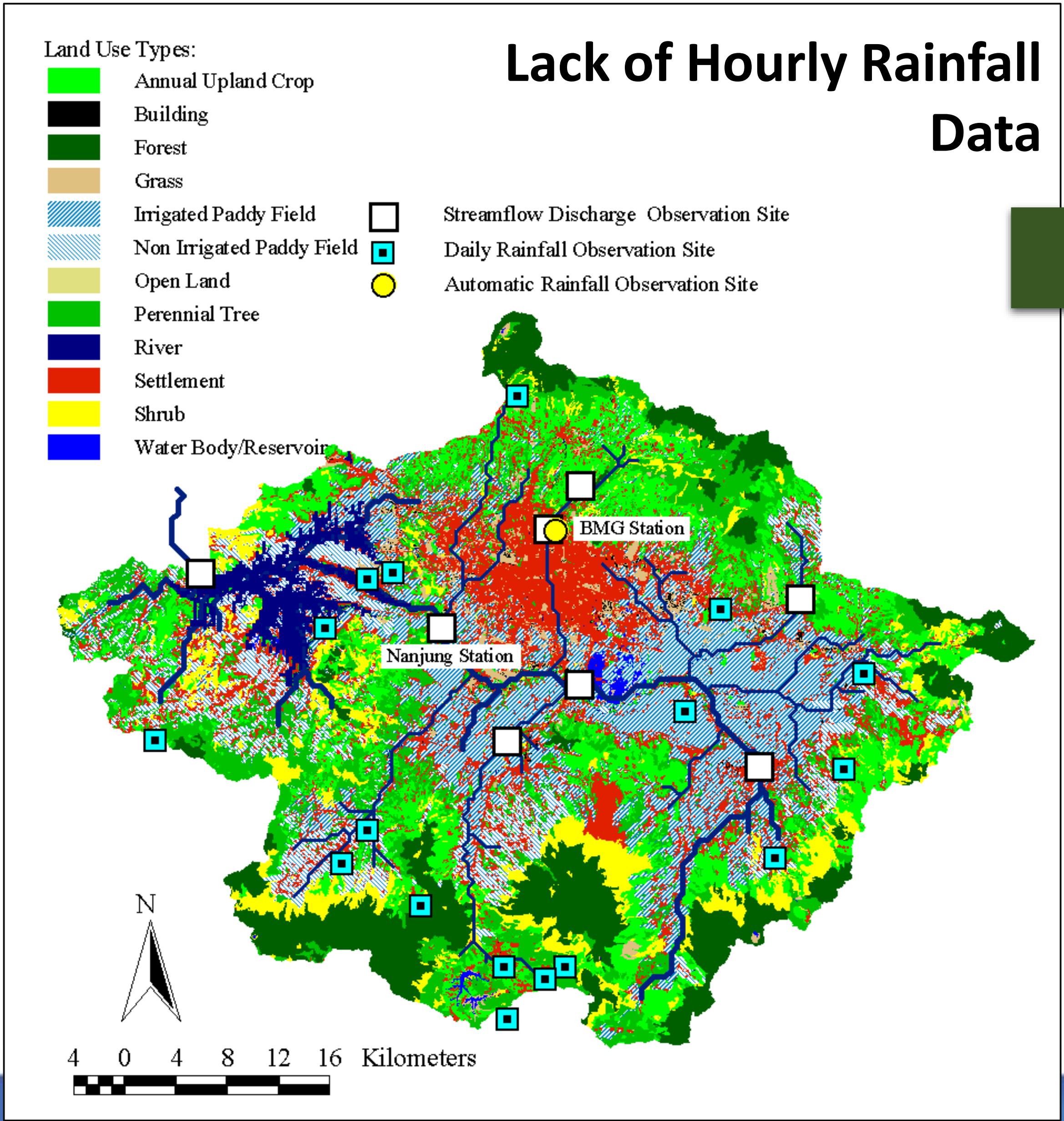
Phytotechnology Ponds

Erosion Control & Monitoring

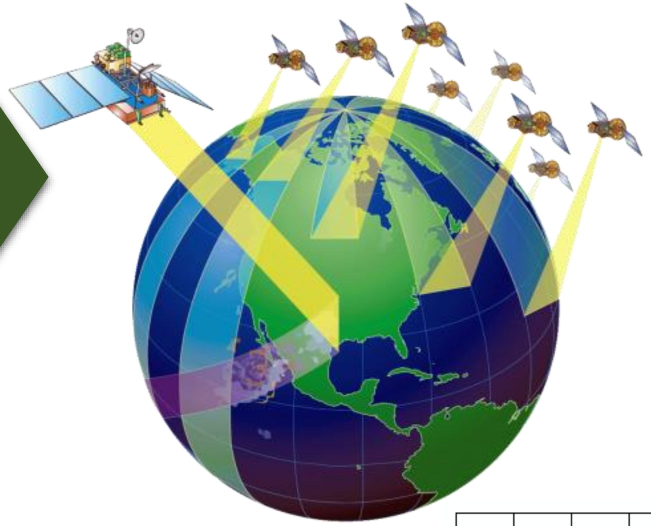


Basin/Global Scale

Lack of Hourly Rainfall Data



Recent Advances in Satellite-based Precipitation Observation Technology and Increasing Availability of Its Product In High-resolution are Providing Opportunities to be used at the poorly gauging river basins

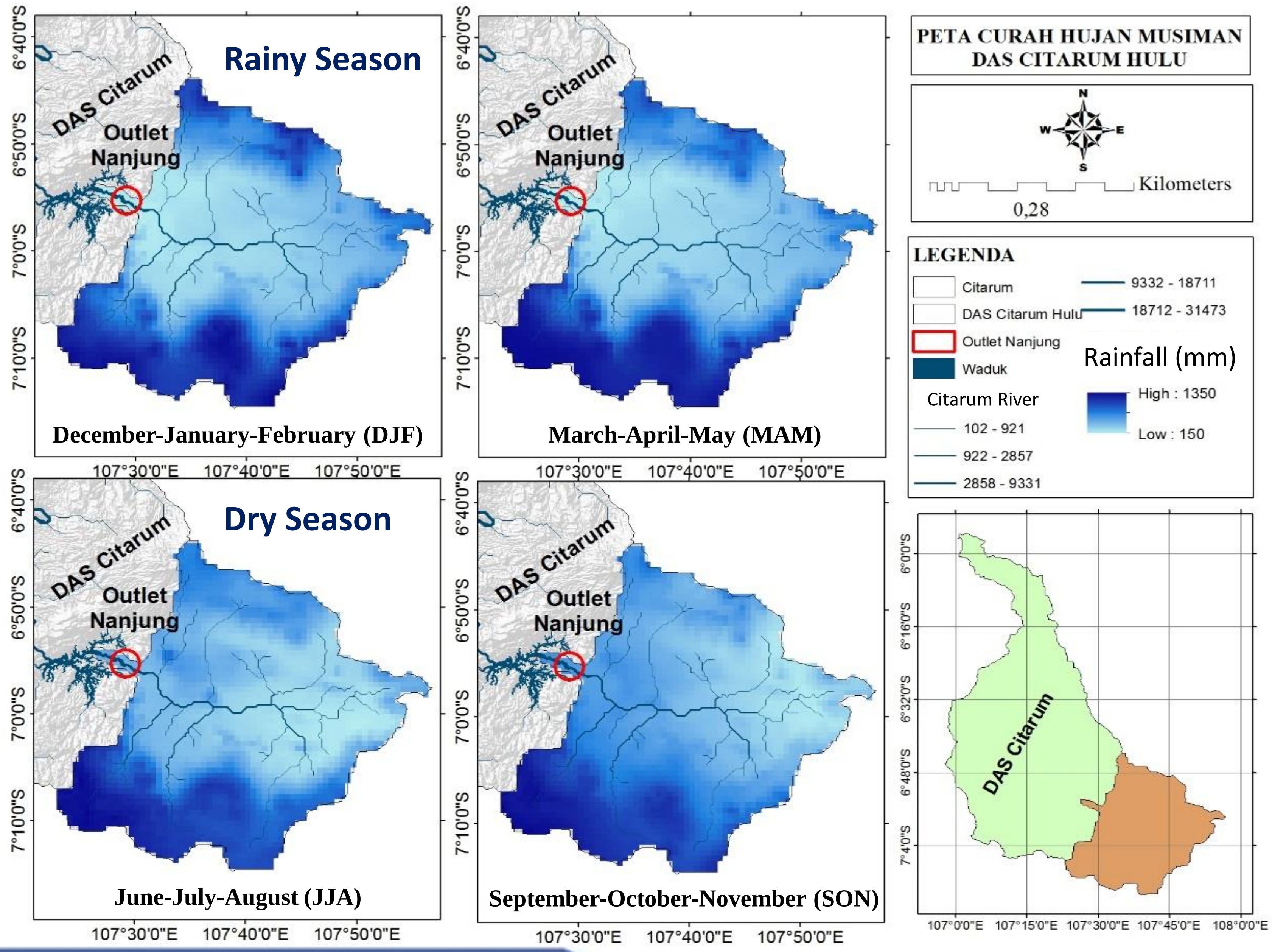


Global Satellite Mapping on Precipitation (GSMaP) Reanalysis Product (Hourly)

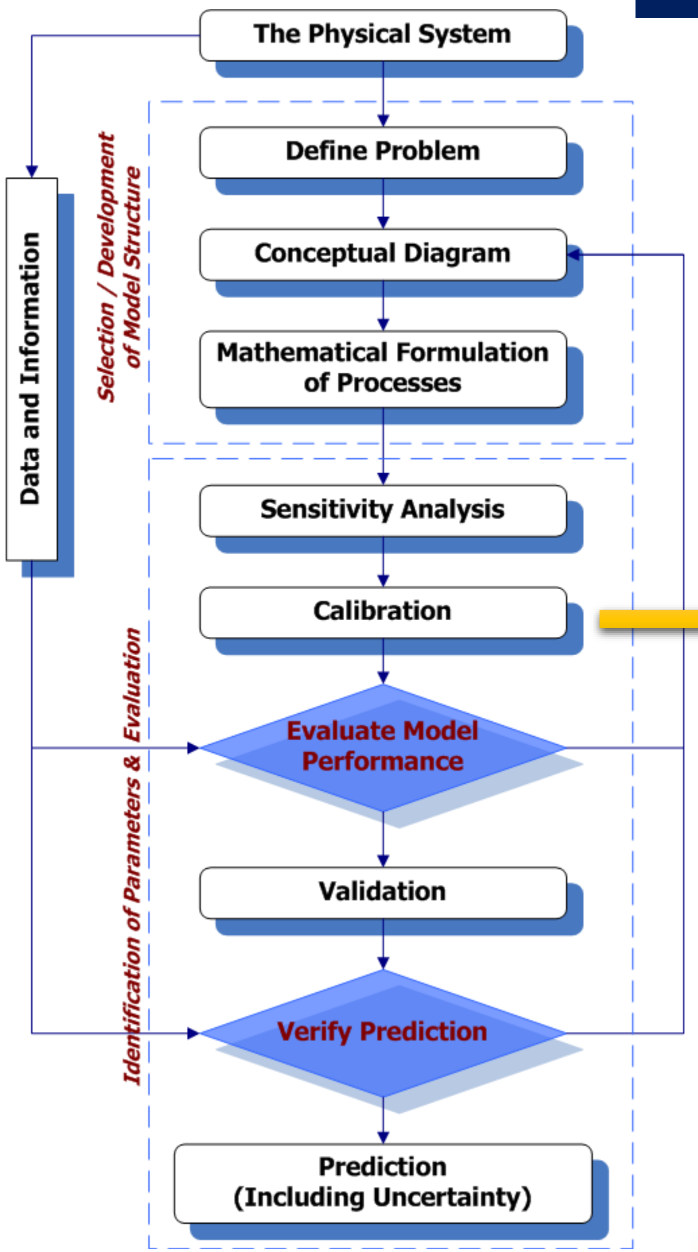
GSMaP Grid Nodes for the Upper Citarum River Basin (154 Grids)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
15	16	17	18	19	20	21	22	23	24	25	26	27	28
29	30	31	32	33	34	35	36	37	38	39	40	41	42
43	44	45	46	47	48	49	50	51	52	53	54	55	56
57	58	59	60	61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80	81	82	83	84
85	86	87	88	89	90	91	92	93	94	95	96	97	98
99	100	101	102	103	104	105	106	107	108	109	110	111	112
113	114	115	116	117	118	119	120	121	122	123	124	125	126
127	128	129	130	131	132	133	134	135	136	137	138	139	140
141	142	143	144	145	146	147	148	149	150	151	152	153	154

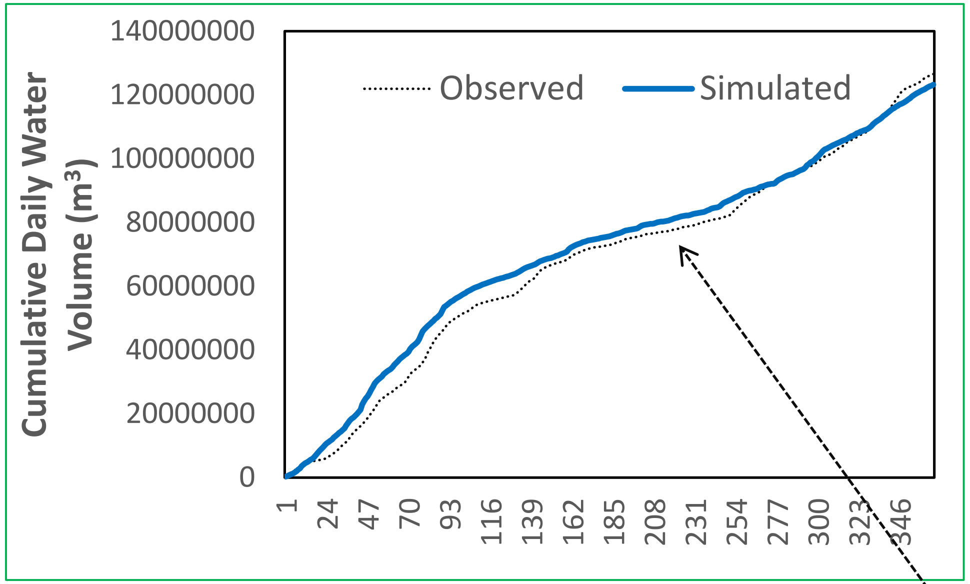
Distribution of Mean Seasonal Rainfall Distribution in the Upper Citarum Basin from GSMaP Data (2003 - 2017)



Comparison of Model Results and Observations in 2010 using GSMaP Rainfall Data

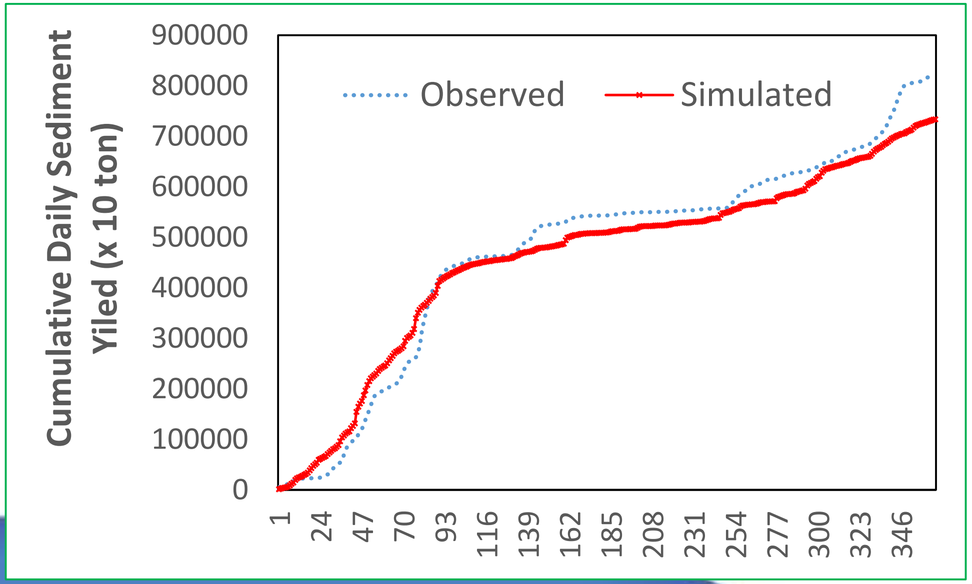


Water Yield

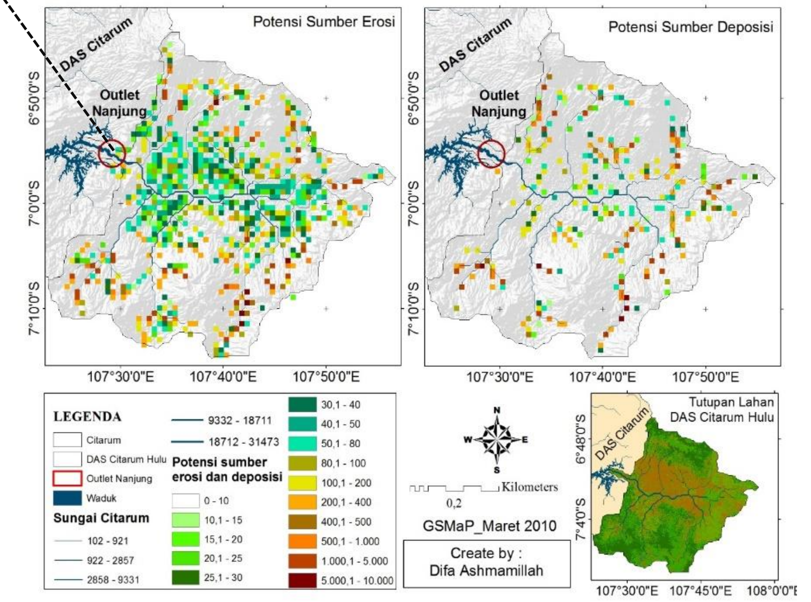


Range of Relative Error: 1-10%

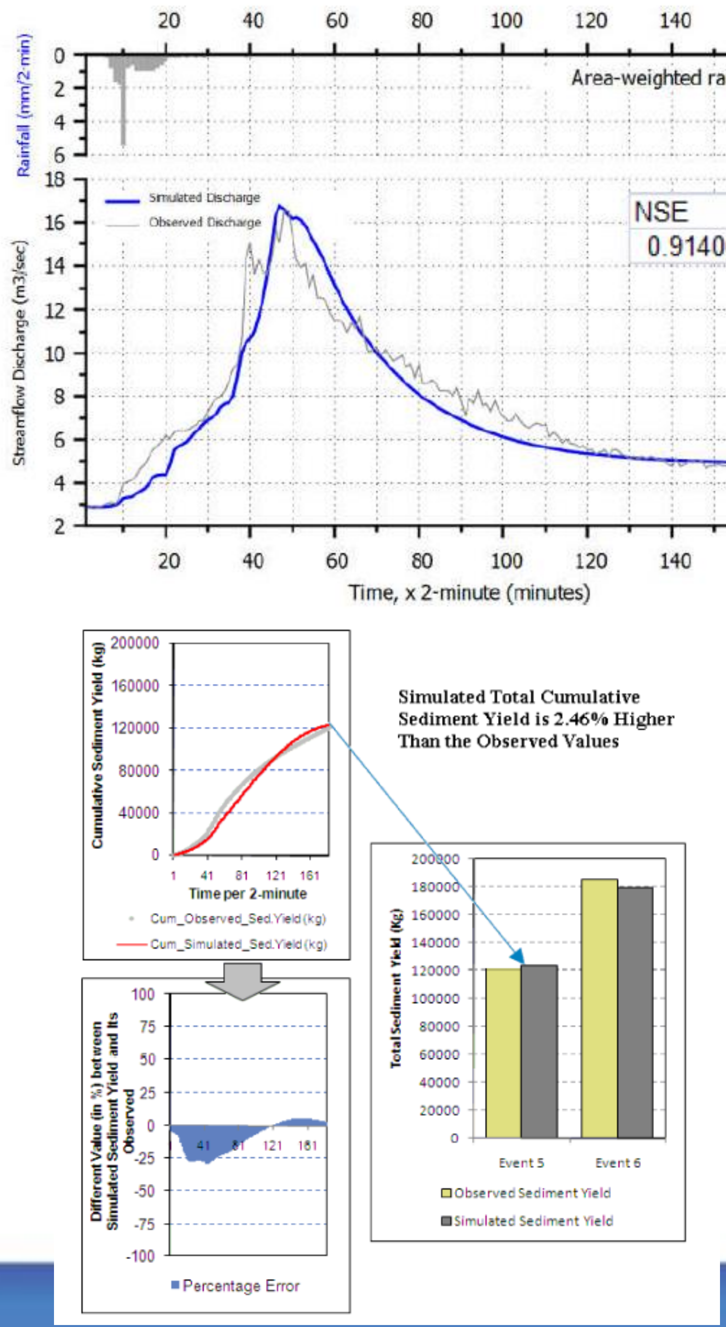
Sediment Yield



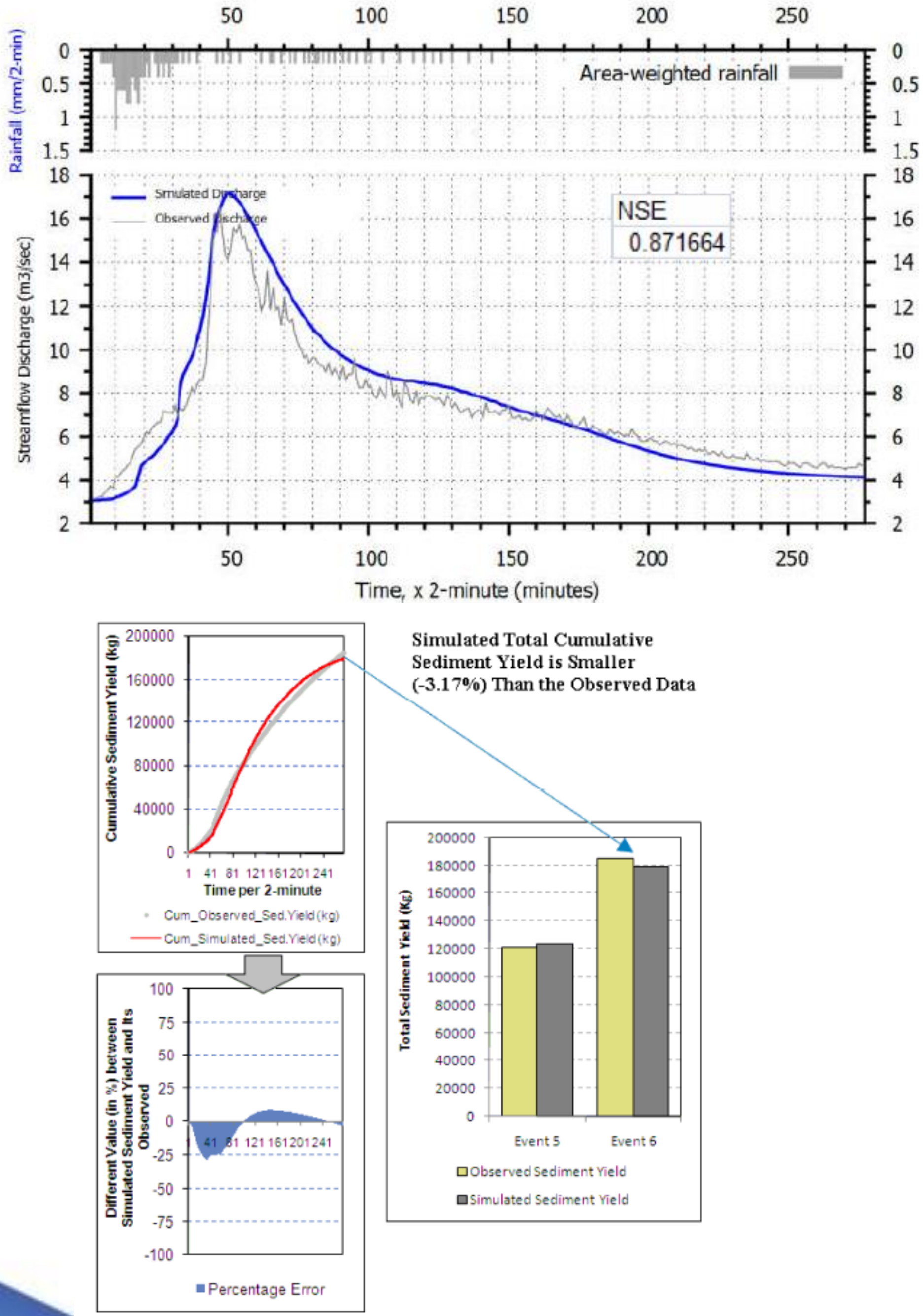
Potential Source



Comparison of Model Results and Observations During Flood Event in 2014 using Observed Hourly Rainfall Data



Range of Relative Error: 1-5%



DAM Control Element Model

Basic equation of dam's flood & sediment control rules are based on stage (H)-storage (V) and stage (H)-release (Q) relationships, operation rules, and trapping efficiency for sediment information.

Routing Process:

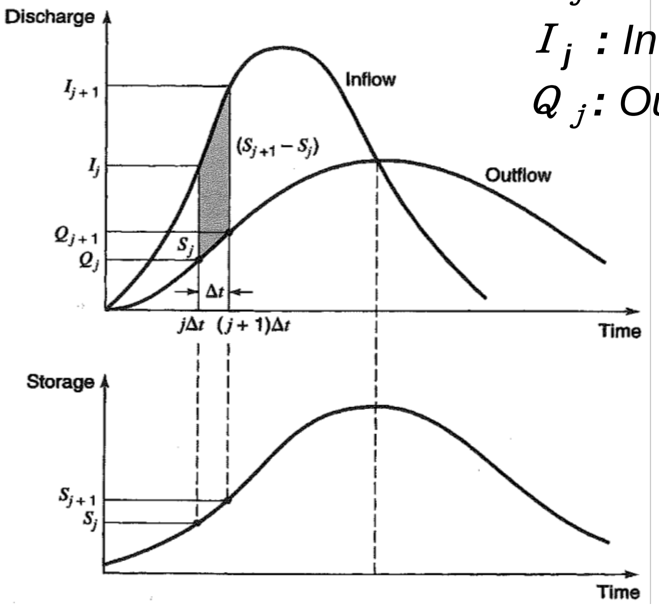
$$S_{j+1} - S_j = \frac{I_j + I_{j+1}}{2}\Delta t - \frac{Q_j + Q_{j+1}}{2}\Delta t$$

Minimum Data Necessary

S_j: Water Volume (V)

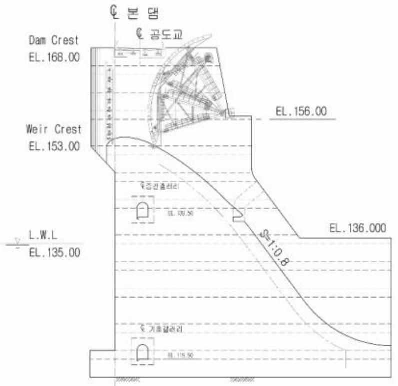
I_j : Inflow Discharge (Qi)

Q_j: Outflow Discharge (Qo)



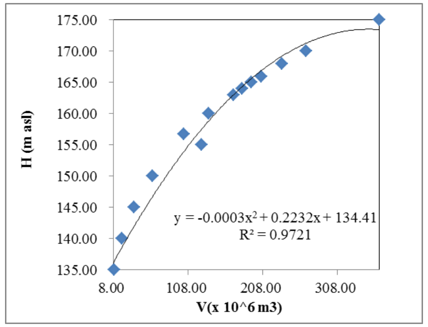
(Larry W. Mays :Water Resources Engineering)

Dam and Its Hydraulic Structures Dimension



Stage (H) - Storage (V) Relationship

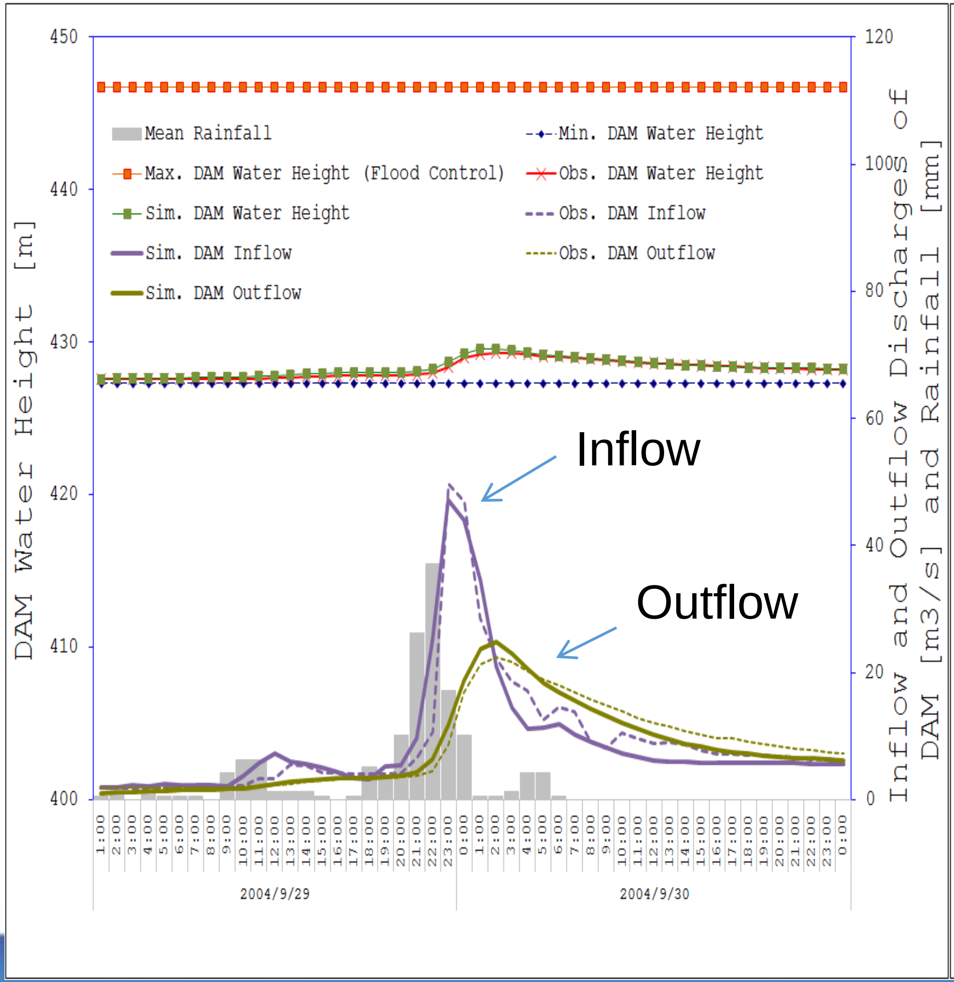
Stage (H) - Release (Q & Qs) Relationship



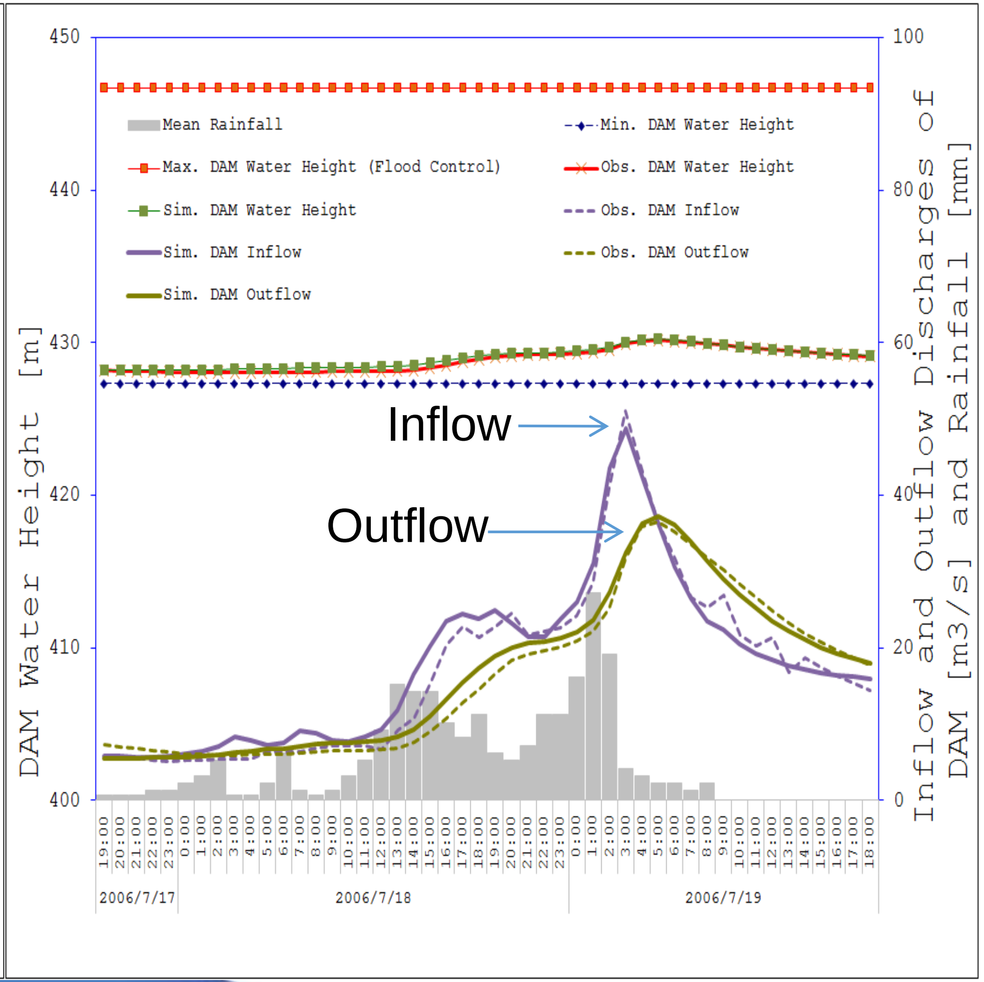
Operation Rules

Model Performance for Dam Function
(Case Study Anegawa Dam)

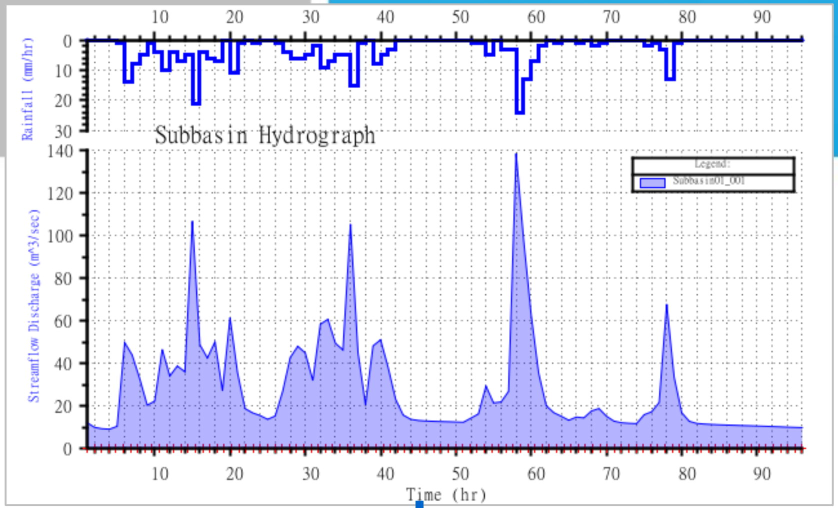
EVENT 1



EVENT 2



Rainfall-Runoff -Sediment Model Application

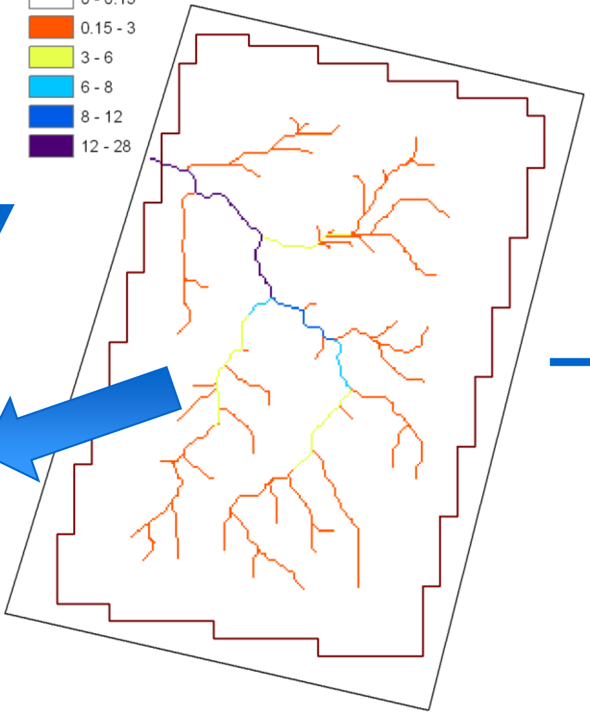


Identification of Priority Locations, Selection & Technical Design of Ecotechnology/Bio-Engineering

River Discharge (m3/s)

Debit Aliran (m3/det)

- 0 - 0.15
- 0.15 - 3
- 3 - 6
- 6 - 8
- 8 - 12
- 12 - 28

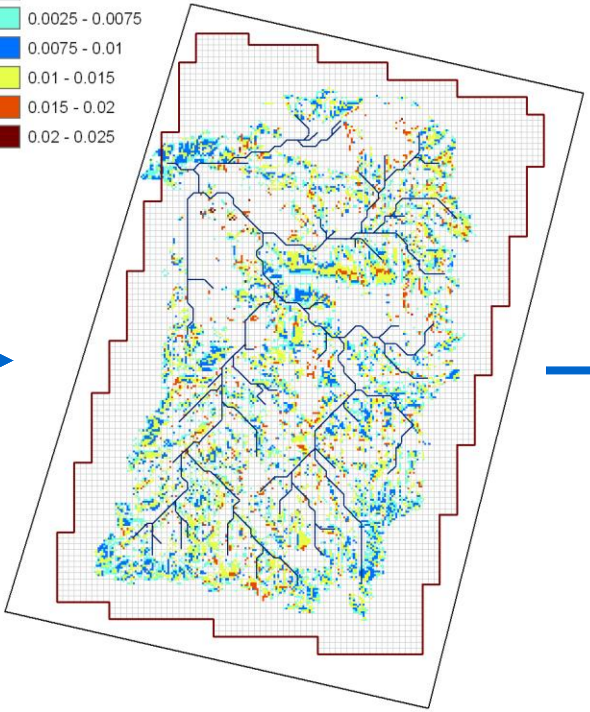


Flow Regimes

Total Eroded Soil (m3)

Total Erosi (m3)

- 0 - 0.0025
- 0.0025 - 0.0075
- 0.0075 - 0.01
- 0.01 - 0.015
- 0.015 - 0.02
- 0.02 - 0.025

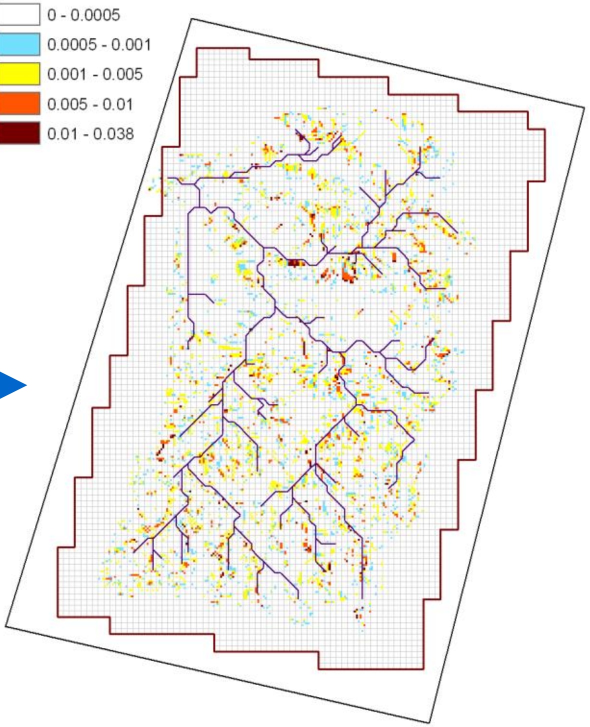


Erosion Hotspots

Total Deposited Soil (m3)

Total Deposisi (m3)

- 0 - 0.0005
- 0.0005 - 0.001
- 0.001 - 0.005
- 0.005 - 0.01
- 0.01 - 0.038



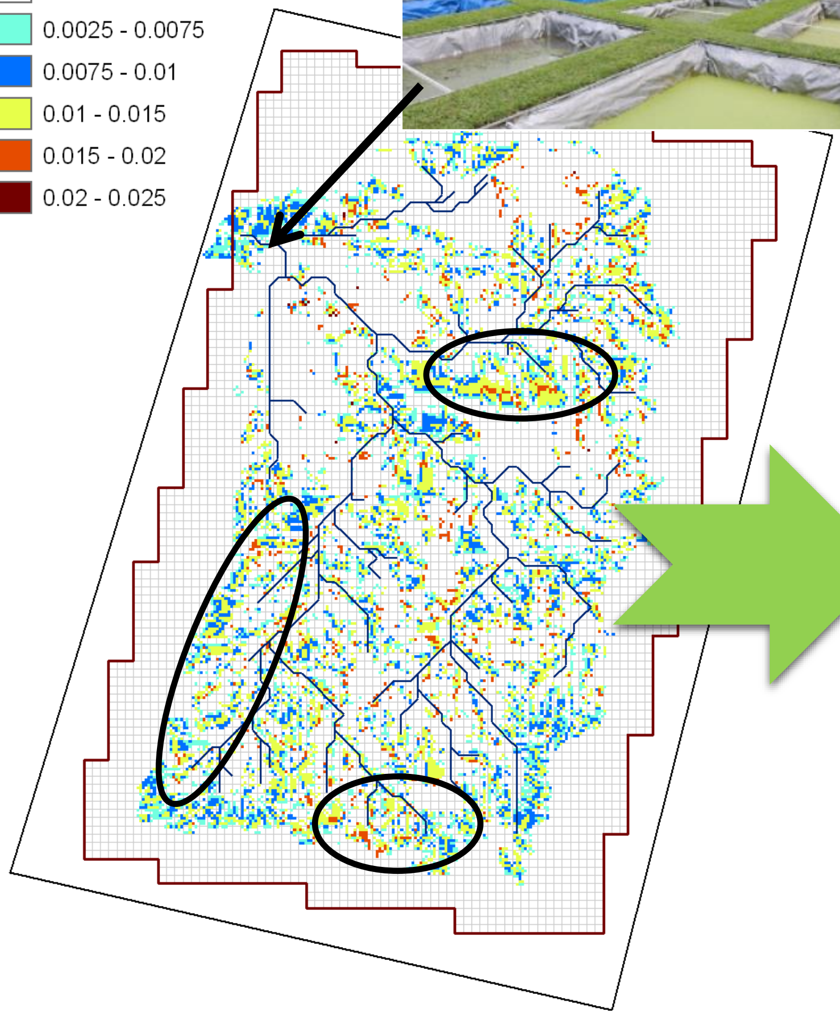
Deposition Hotspots

Richness of Microzoobenthos

Ecohydrology-Based Control Measures for Controlling Soil Erosion & Trapping Sediment

Total Eroded Soil (m3)

0 - 0.0025
0.0025 - 0.0075
0.0075 - 0.01
0.01 - 0.015
0.015 - 0.02
0.02 - 0.025



Erosion Hotspots

Alley Cropping (*Budidaya Sistem Lorong*) with Akar Wangi (Vitiveria zizanioides (L,)

“Rorak” Farming System

Terrace Farming System

Control Function:

Efficiency Value

⬇

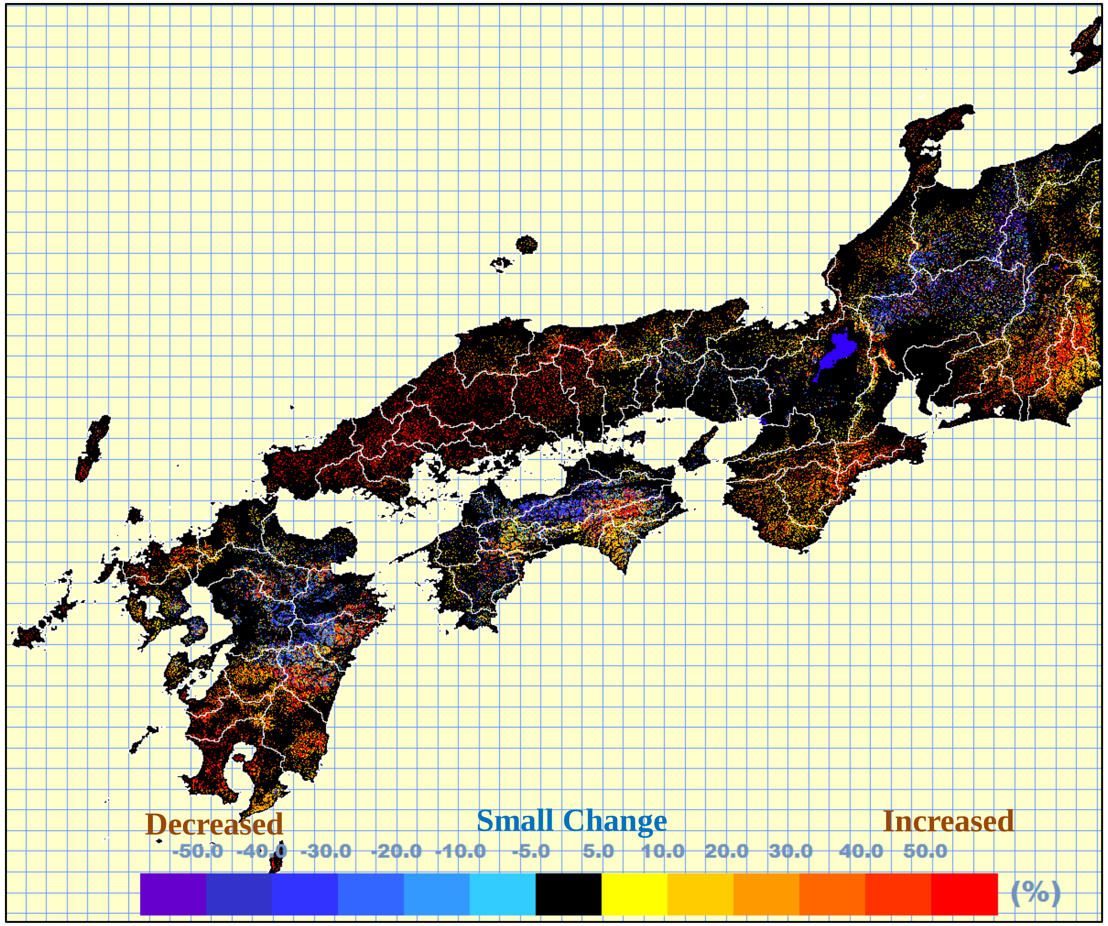
Empirical Equation

⬇

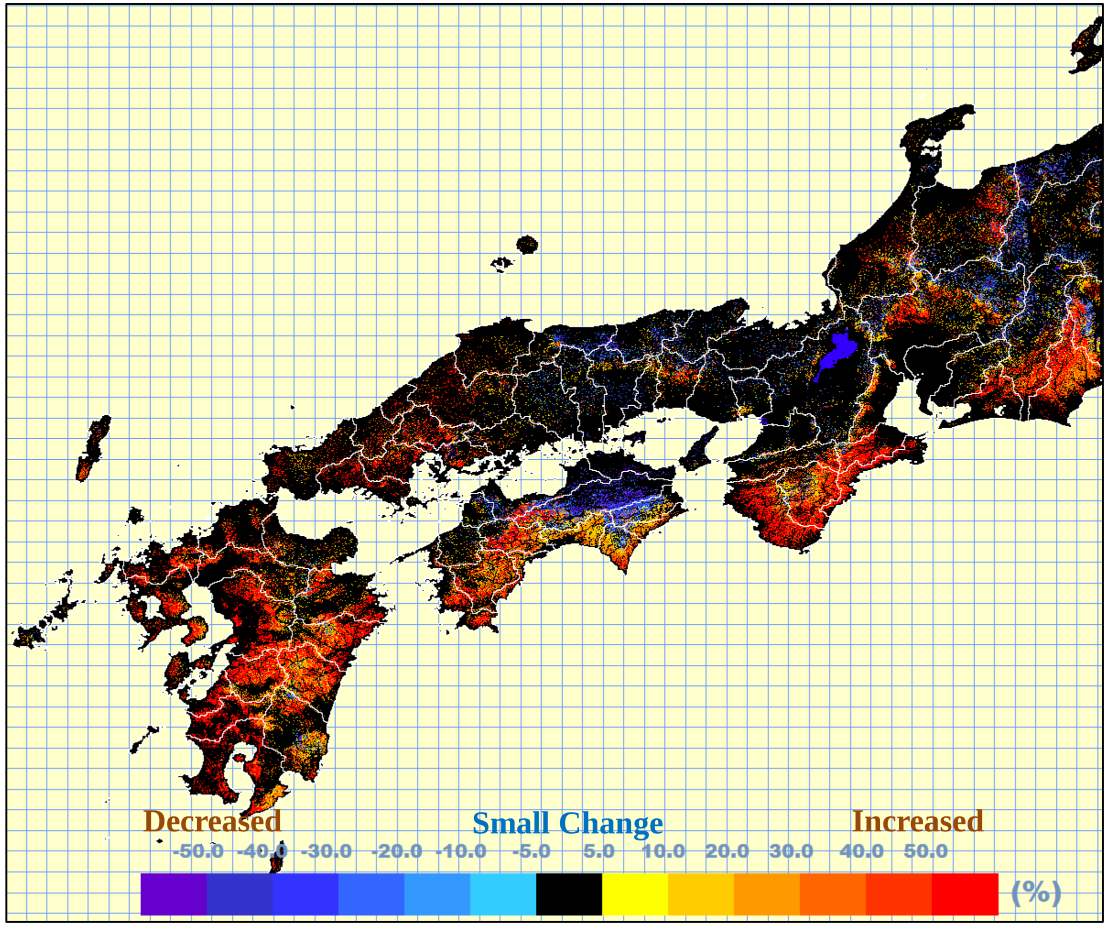
Physical Model

Percentage Change on the Average of Total Erosion (May to Oct) in Comparison to the Present Condition

Using GCM3.2 20-km



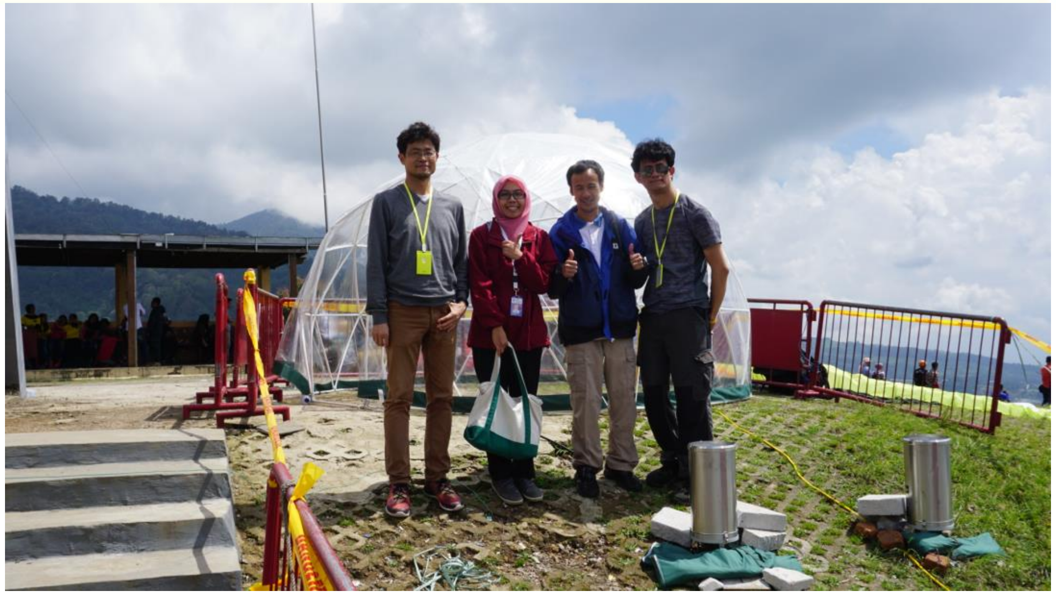
Using RCM 5-km



Apip et al, 2013

THANK YOU

UTM & USM Malaysia



K-Water & KOICA Korea

Durham Univ., UK

Kyoto Univ

Embung Sontoi, NTT, Indonesia

Water Resources

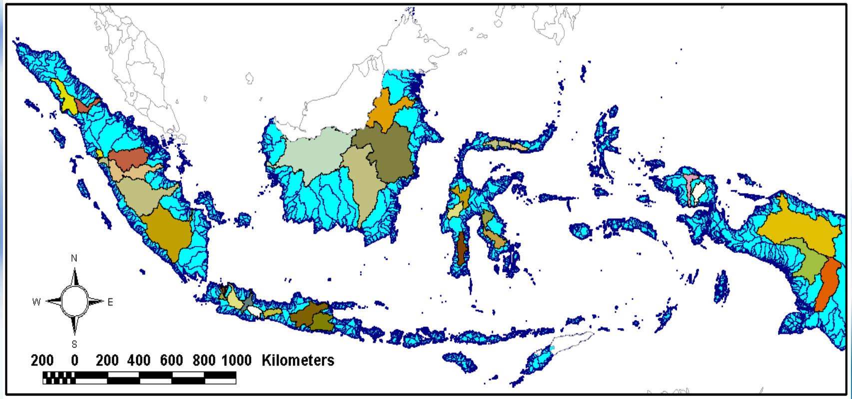



13.85 million ha: rivers, lakes and reservoirs

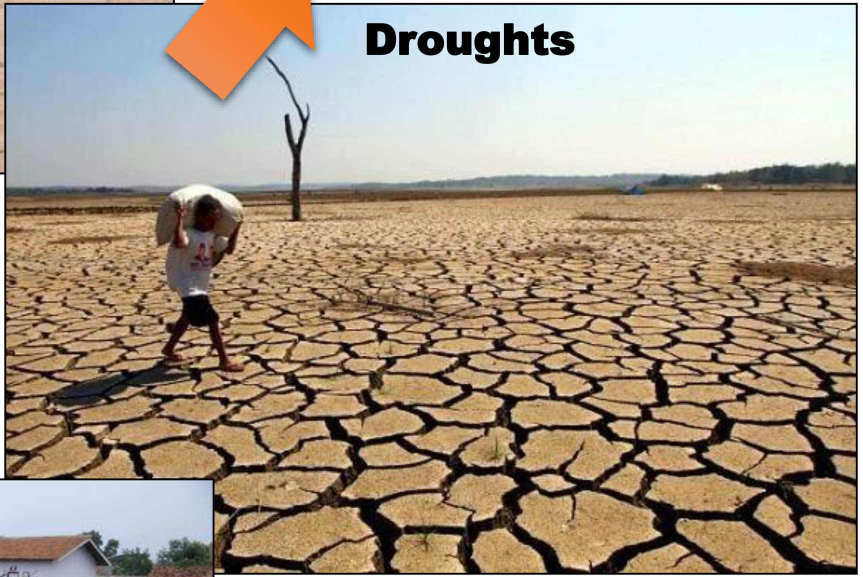
- 12.0 million ha river and flood plain
- 1.8 million ha natural lakes
- 0.05 million ha reservoirs

5,590 large rivers with 65,017 branch rivers

- Total length of river 94,573 Km
- Watersed area 1,512,466 Km2



Water Resources

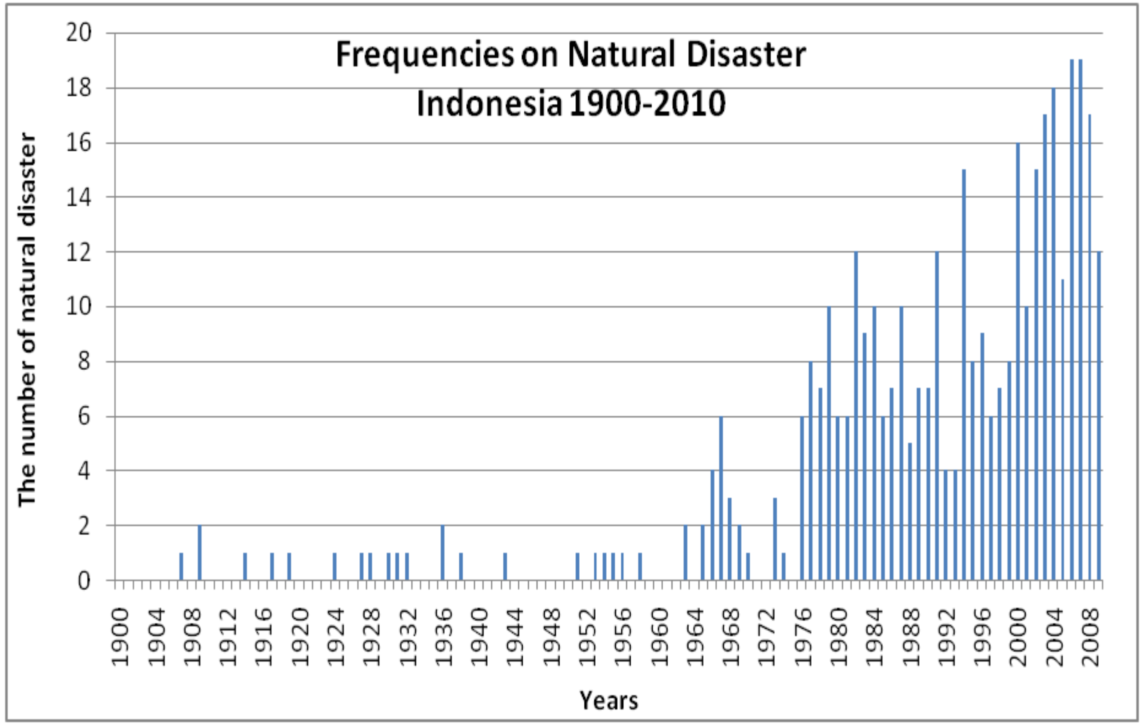


Problems: **Extremely surplus & deficit, Decreasing inland waters ecosystem services**

Disaster exists if there is a risk/damage

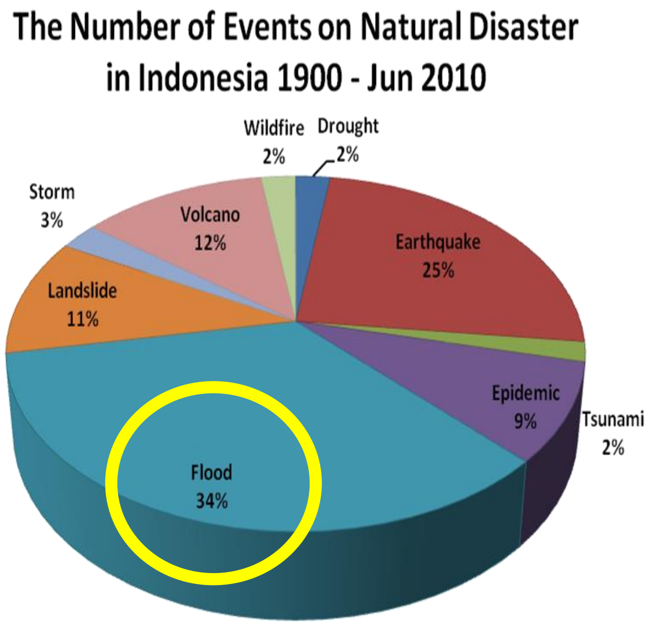
1. *Rapid Onset Type Disasters (flood, drought)*
2. *Slow Onset Type Disasters (environmental problems)*

Total Event



Multi Disasters - Multi Hazard - Multi Risk

Dominant Type



Source: BNPB (National Agency for Disaster Management), 2010

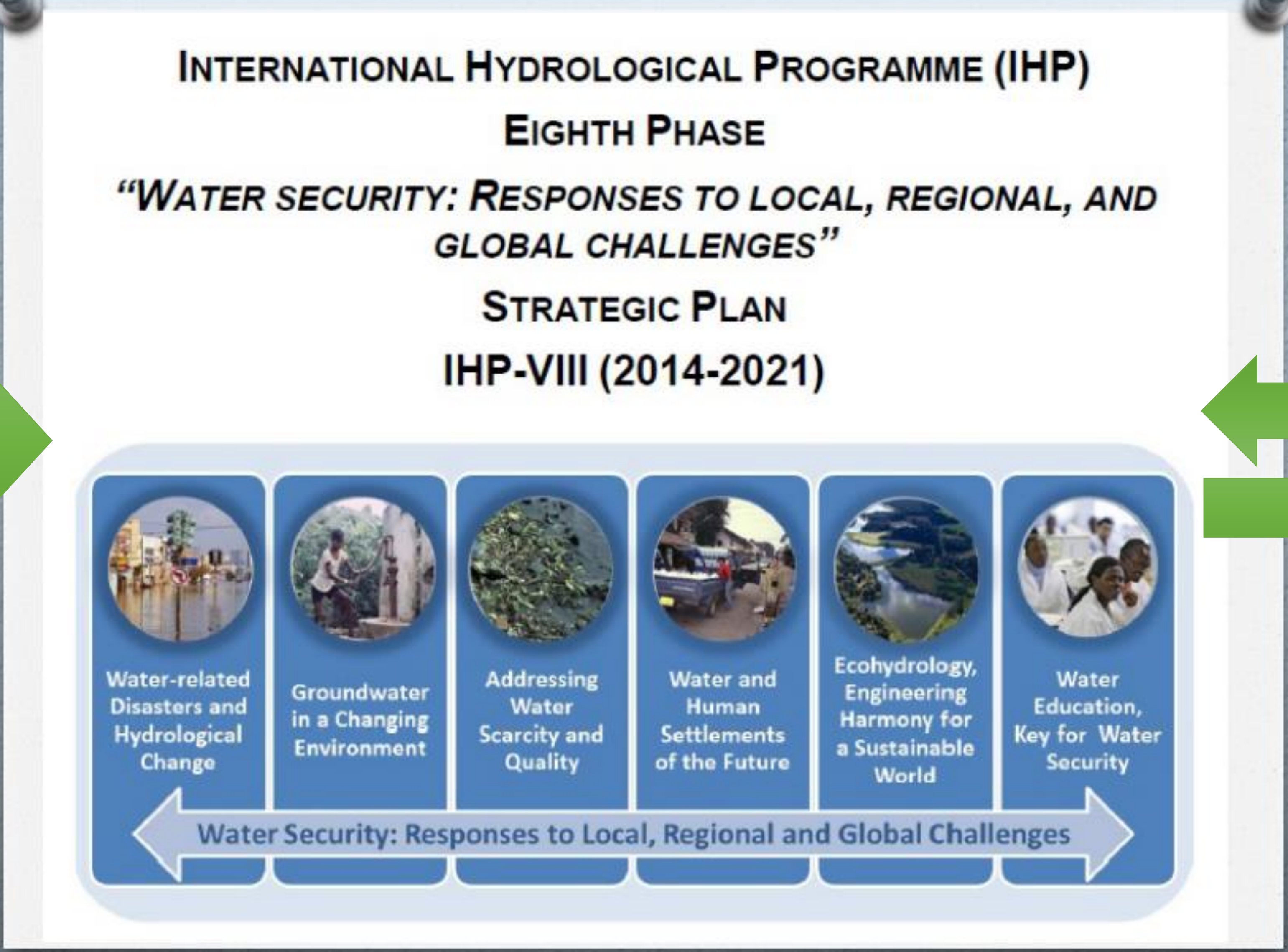

Lake Rawa Pening, Central Java

NATIONAL WATER RESOURCES MANAGEMENT POLICY

National Development Planning Agency, Indonesia

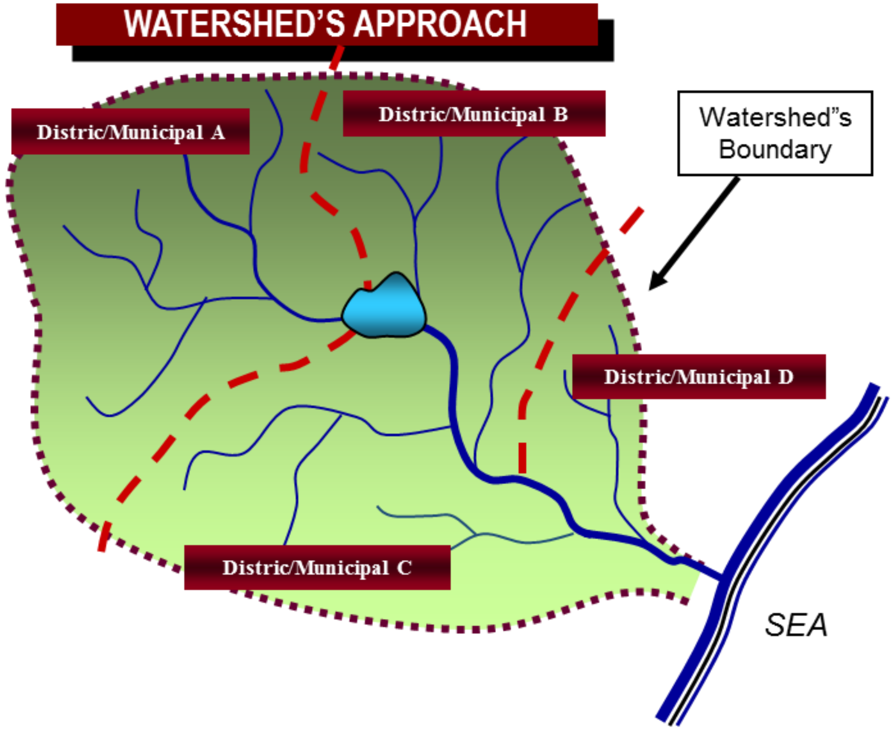
UNESCO International Hydrological Programme

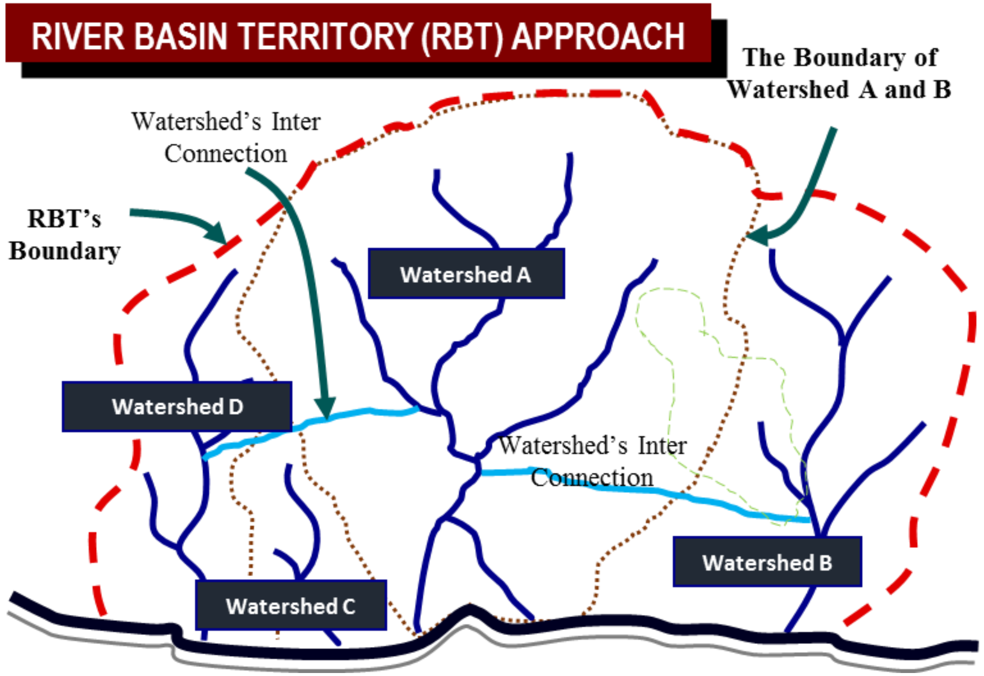
WATER SECURITY: ASIA-PACIFIC REGION & GLOBAL



NATIONAL MID TERM DEVELOPMENT PLAN 2015-2019: WATER SECURITY

WATER RESOURCES (includes Sediment) MANAGEMENT APPROACHES





An integral part of the river and the river branches → **to store the water that originated from the rainfall into the body (lands) of watershed as a natural reservoir**

An integrated **water resources management** area in one or more watersheds and/or small islands

Leading Sector : Ministry of Environment and Forestry

a. Ecosystem Perspective: Ecological Engineering

Leading Sector : Ministry of Public Works and Housing

b. Infrastructure Perspective: Civil Engineering

1) RIVER BASIN TERRITORY APPROACH

NO	CONDITION OF RIVER BASIN TERRITORY (WS)	TOTAL BASED ON PERMEN PUPR 4/PRT/M/2015
1	Cross Country WS	5
2	Cross Province WS	31
3	National Strategic WS	28
4	Cross City/Regency WS	52
5	City/Regency WS	12
	Total	128

Source : Ministerial Decree of Public Works and Housing No. 04/PRT/M/2015

Leading Sector : Ministry of Public Works and Housing

KEMENTERIAN PEKERJAAN UMUM DAN PERUMAHAN RAKYAT
REPUBLIK INDONESIA