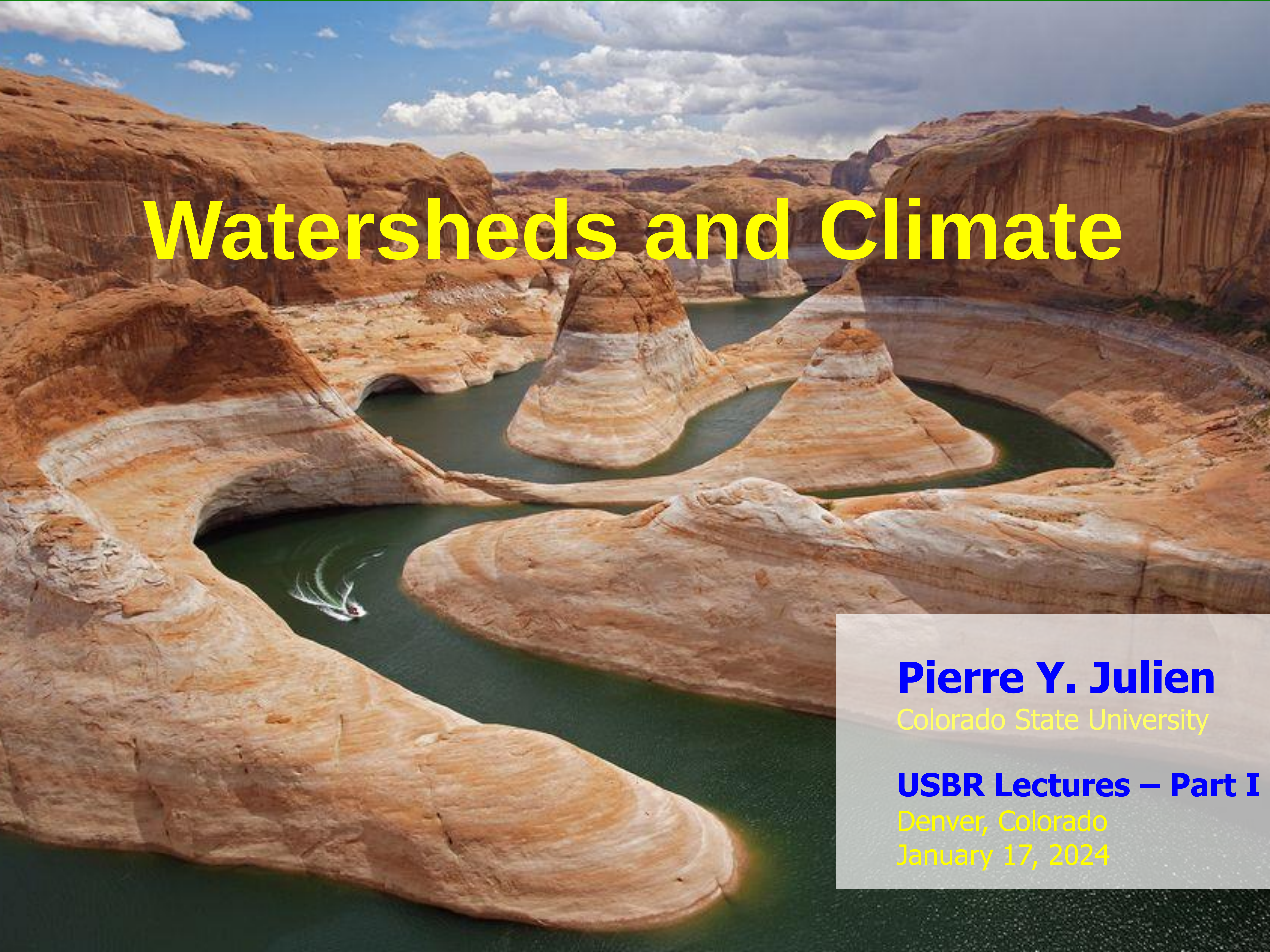
Welcome to this Short Course

USBR Short Course

Four 2-hour lectures by Pierre Julien

1. **Watersheds and Climate**
2. **Sedimentation Engineering**
3. **Rivers and Dams**
4. **River Environment**

Approx. 75 slides per lecture + Q&A



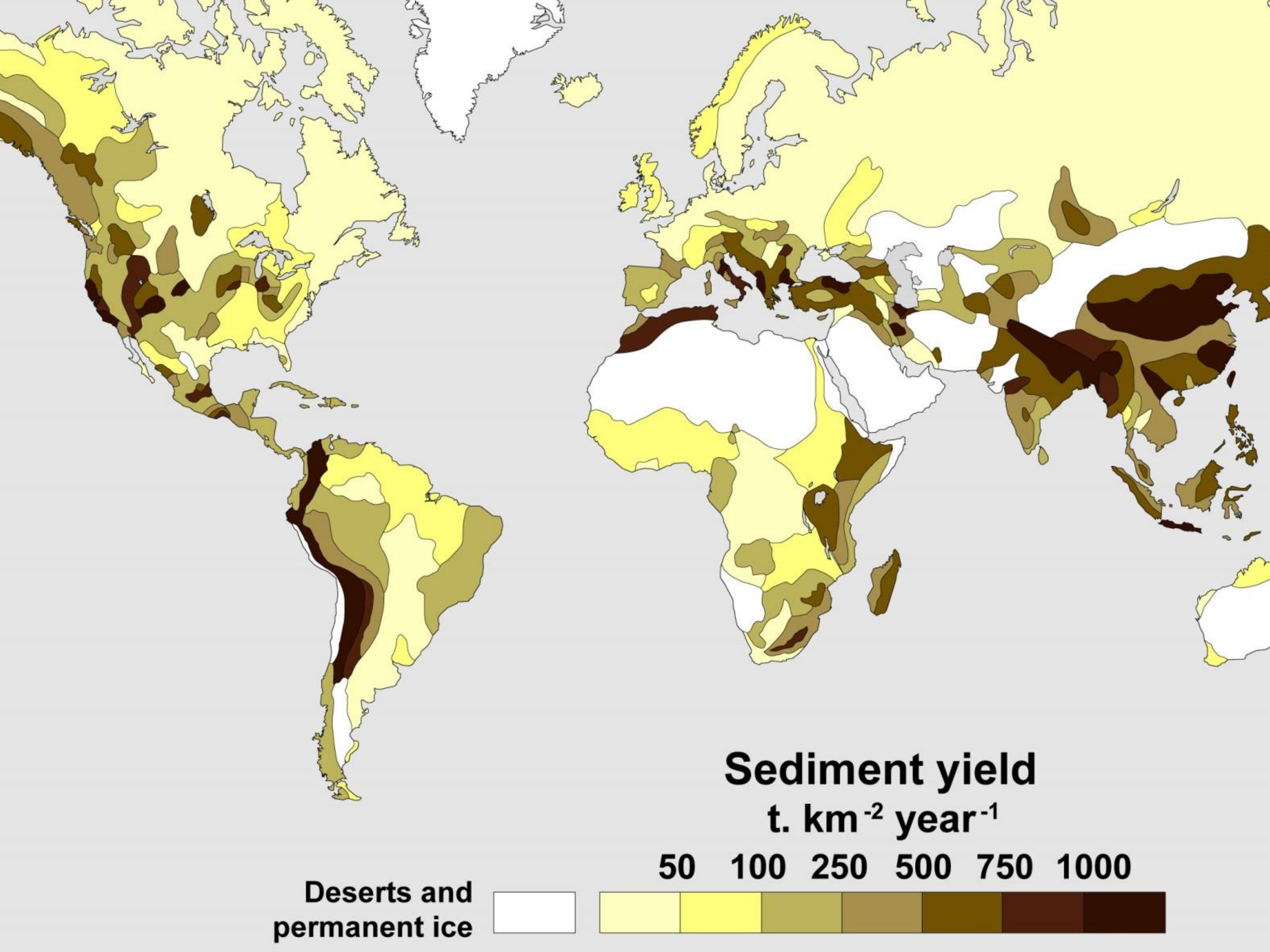
Watersheds and Climate

Pierre Y. Julien
Colorado State University

USBR Lectures – Part I
Denver, Colorado
January 17, 2024

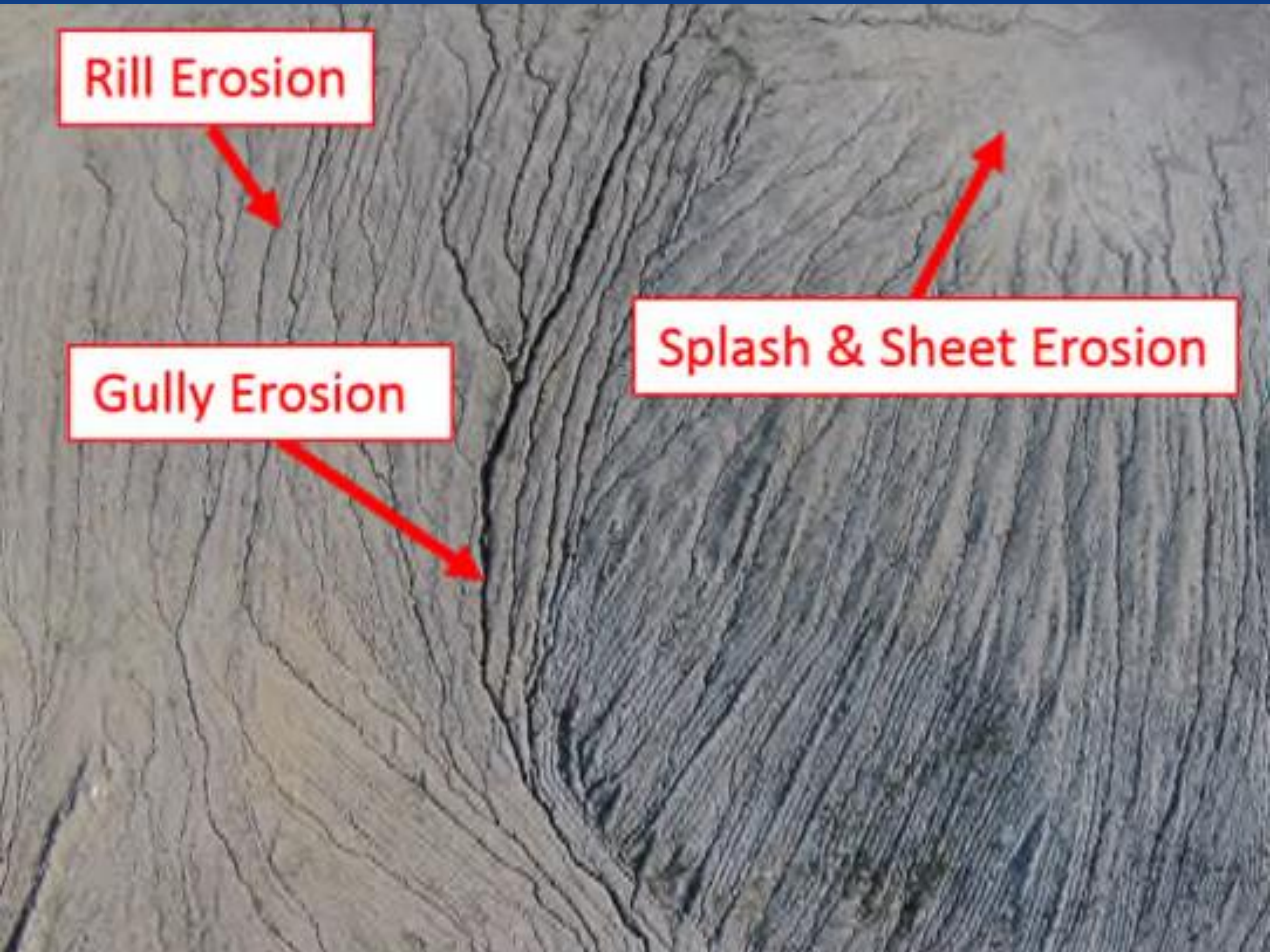
Watersheds and Climate

1. Sediment Sources and Yield
2. Dynamic Watershed Modeling
3. Flashflood Case Study
4. Climate Change Perspective


Sediment yield
t. km^{-2} year^{-1}
50 100 250 500 750 1000
Deserts and
permanent ice

Sediment Sources



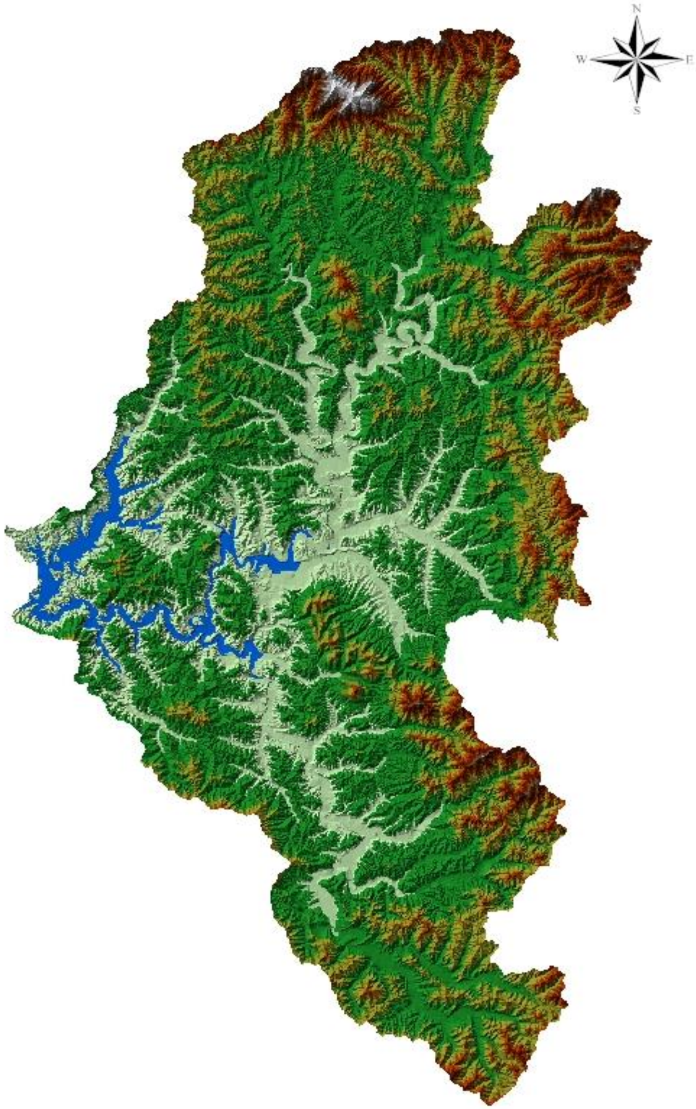
Rill Erosion
Gully Erosion
Splash & Sheet Erosion

Revised Universal Soil-Loss Equation (RUSLE)

$$E = R\ K\ L\ S\ C\ P$$

- E: mean annual soil loss
- R : rainfall erosivity
- K : soil erodibility
- L : slope length
- S : slope steepness
- C : cropping management
- P : conservation practice

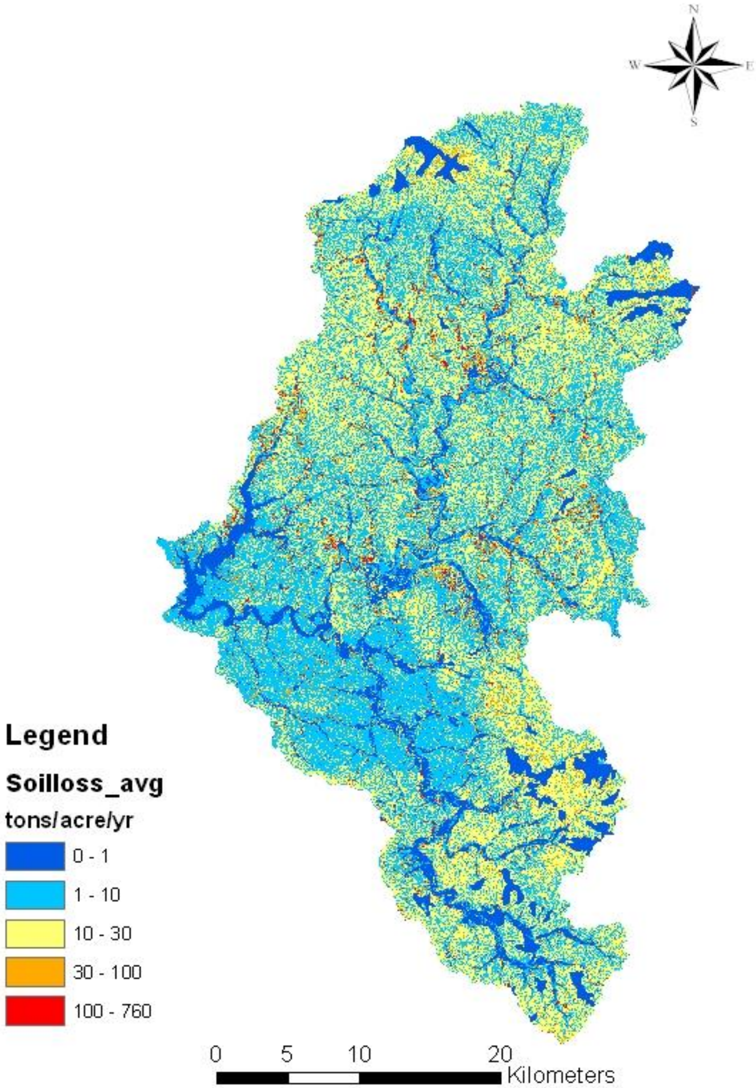
Example, Imha Watershed, South Korea



- **Watershed area: 1,361 km^2**
- **Channel length: 96 km**
- **Average watershed slope: 40%**
- **Fast and high peak runoff characteristics**
- **30m x 30m resolution**

From Hyeonsik Kim and Julien (2006)

Results: Annual Average Soil Loss Map



- Drainage area A = 1361 km^2
- **Annual average soil loss:**

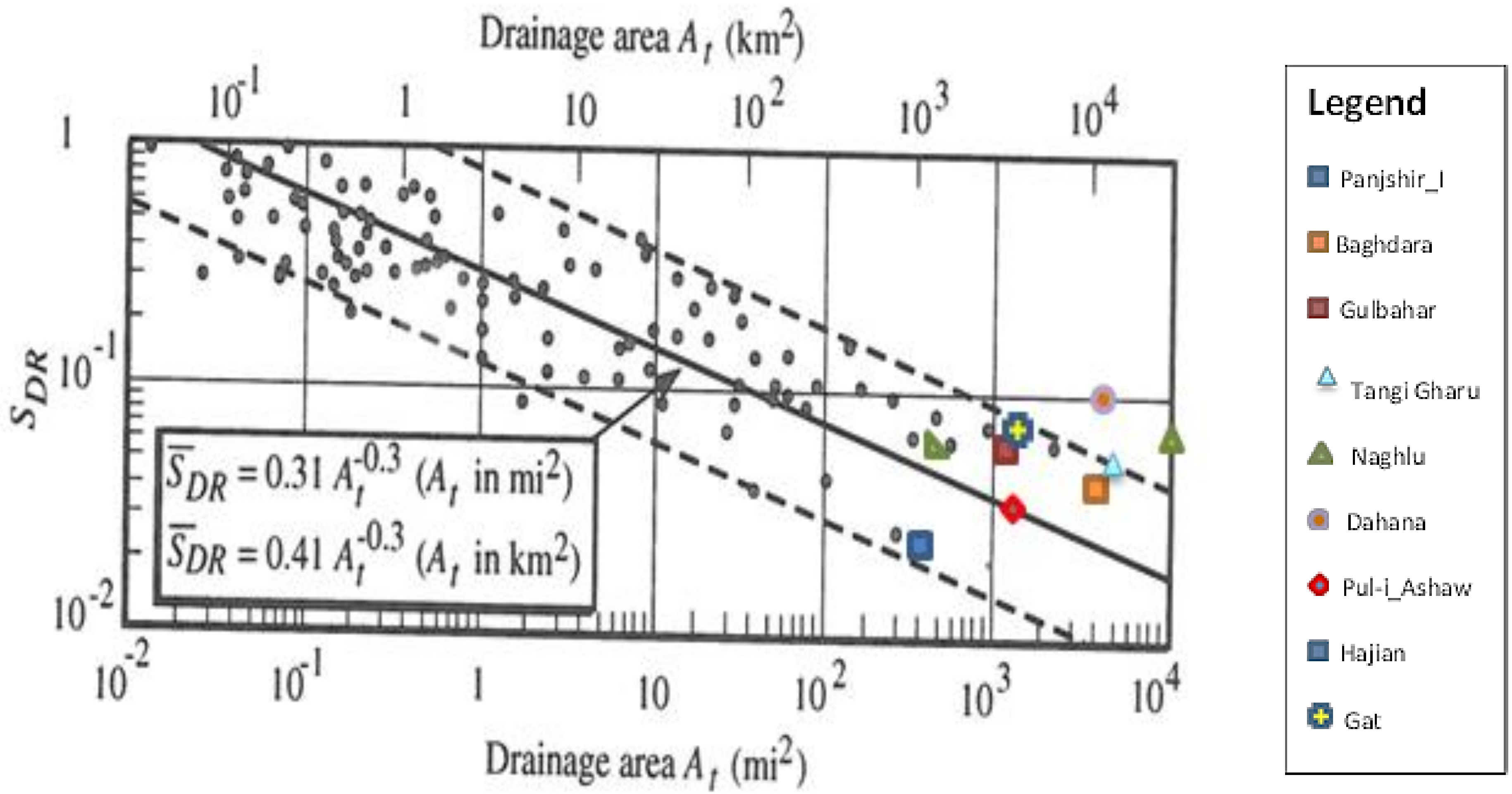
  E =4.7 x 10^6 tons/year

  E/A = 3,450 tons/km^2/year
- **Sediment Delivery Ratio**:

  $\boldsymbol{SDR \cong 0.41\ A^{-0.3} \cong 0.047}$
- **Yield** = E x *SDR* ≅ **220, 000** tons/year
- **Specific degradation**
- Y/A ≅ 0.047x3450 ≅ **162** tons/km^2/year

From Hyeonsik Kim and Julien (2006)

Sediment Delivery Ratio (SDR)

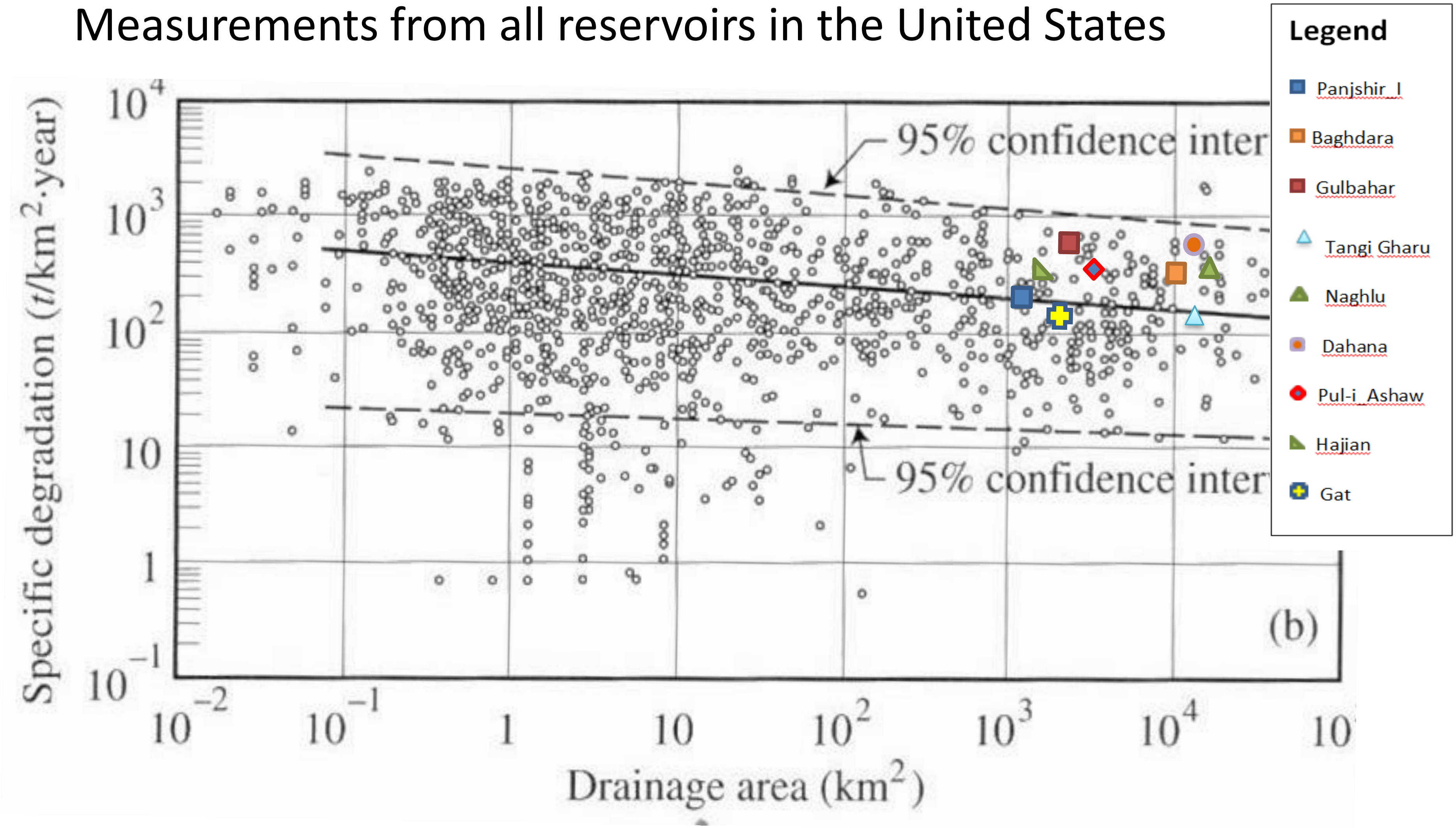


Sediment Yield...

- Kane and Julien, IJSR (2007)

Afghanistan, Sahaar (2013)

Measurements from all reservoirs in the United States



Watersheds and Climate

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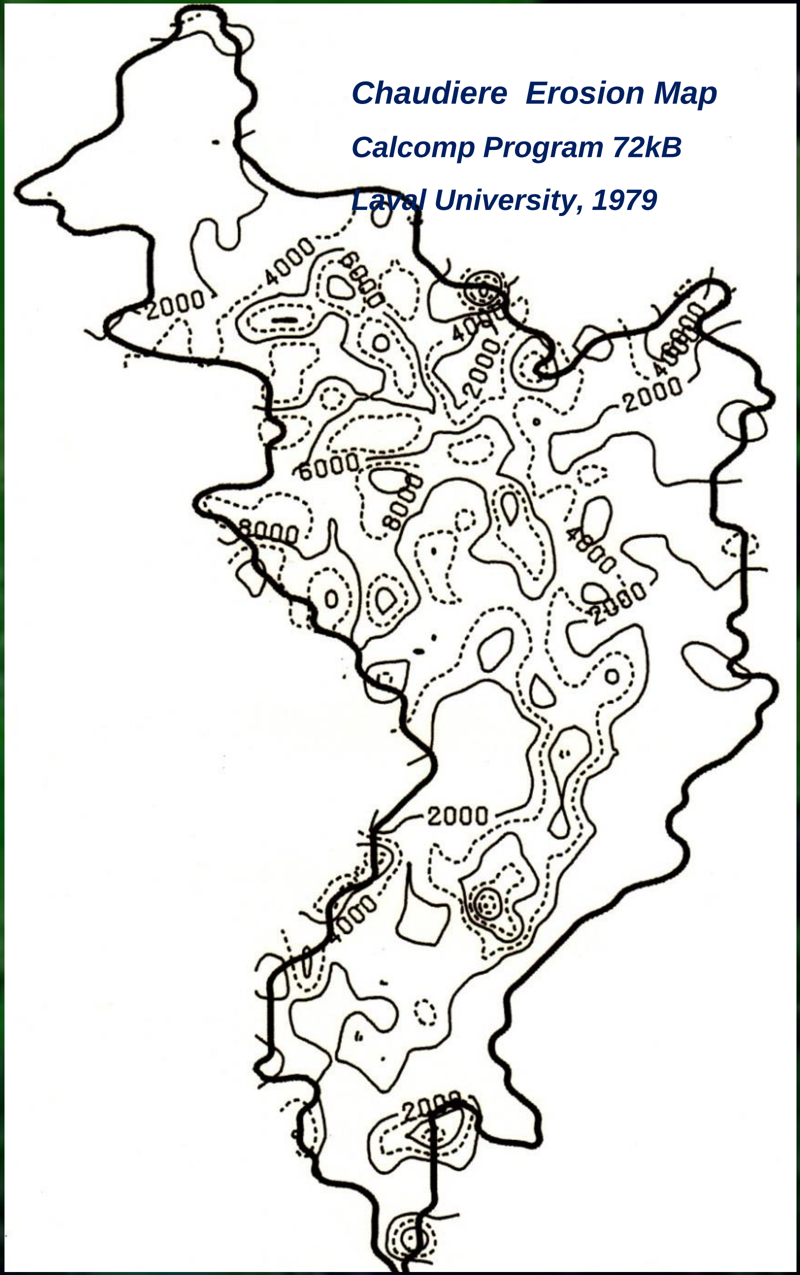
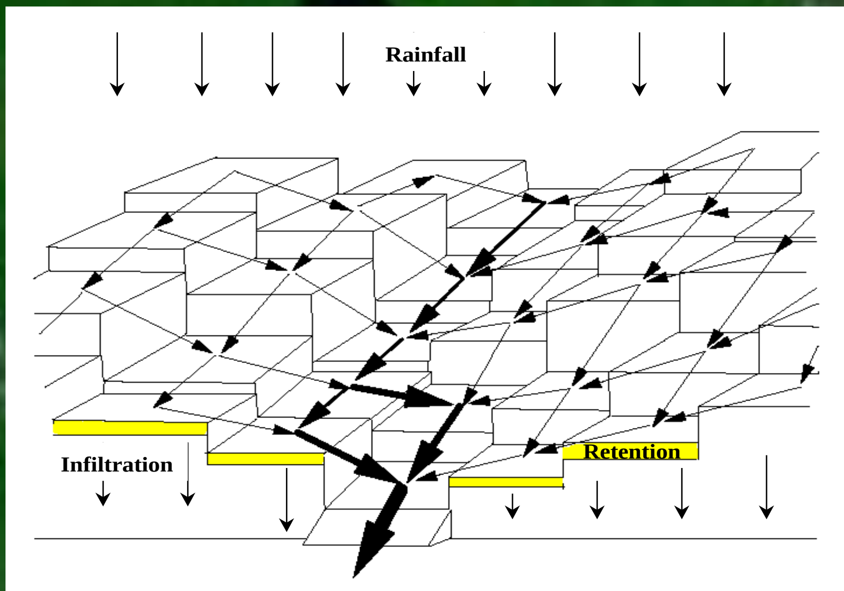


From Julien, MS thesis, 1979



CASC2D- Julien et al. (1995)

Jerry Richardson, PhD ‘89
Bahram Saghafian, PhD ‘92
Fred Ogden, PhD ‘92
William Doe III, PhD ‘92
Don May, PhD ‘93
Darcy Molnar, PhD ‘97

CASC2D-SED – Johnson et al. (2000)

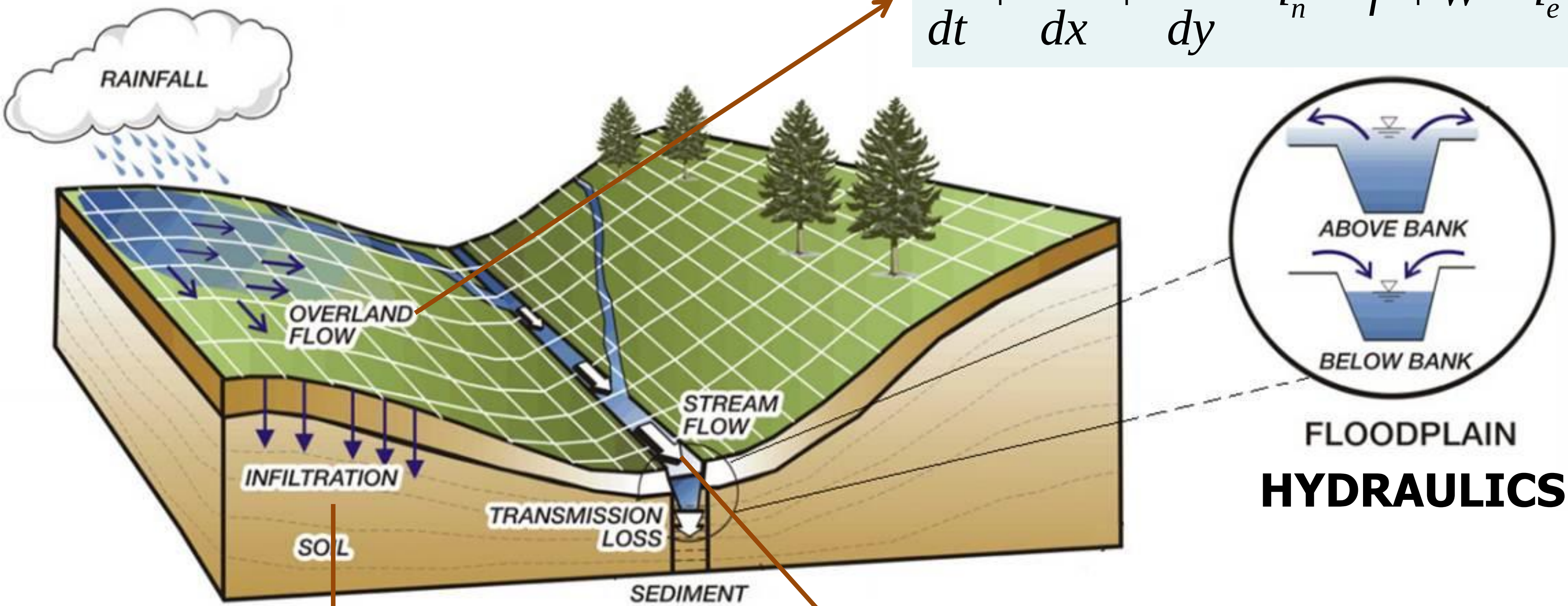
Billy Johnson, PhD ‘97
Jeff Jorgeson, PhD ’99
Amit Sharma, PhD ‘00
Rosalia Rojas, PhD ‘02

Aug. 9, 2005: Before Katrina

TREX: Two-dimensional Runoff Erosion and eXport

HYDROLOGY

$$\frac{\partial h}{dt}+\frac{\partial q_x}{dx}+\frac{\partial q_y}{dy}=i_n-f+\dot{W}=i_e$$



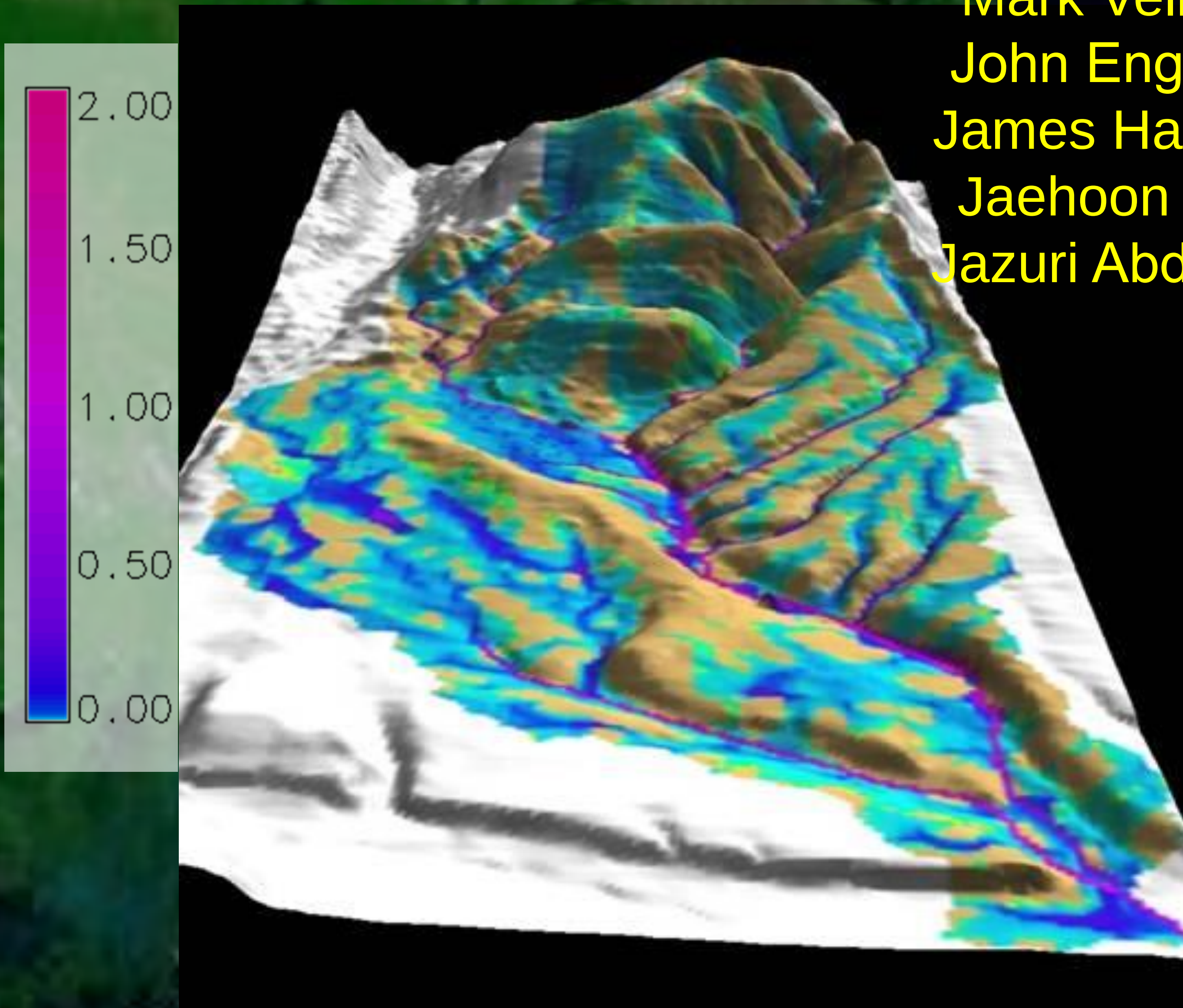
HYDRAULICS

$$f=K_h\left(1+\frac{H_c\left(1-S_e\right)\theta_e}{F}\right)$$

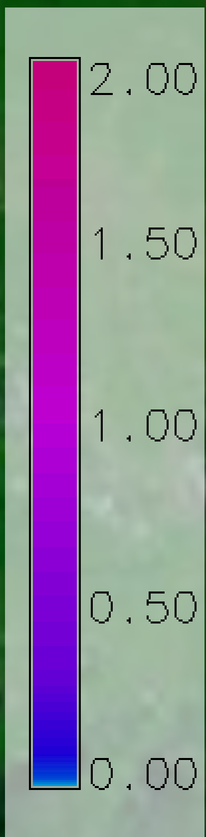
$$\frac{\partial A}{dt}+\frac{\partial Q}{dx}=q_l+\hat{W}$$

TREX Model

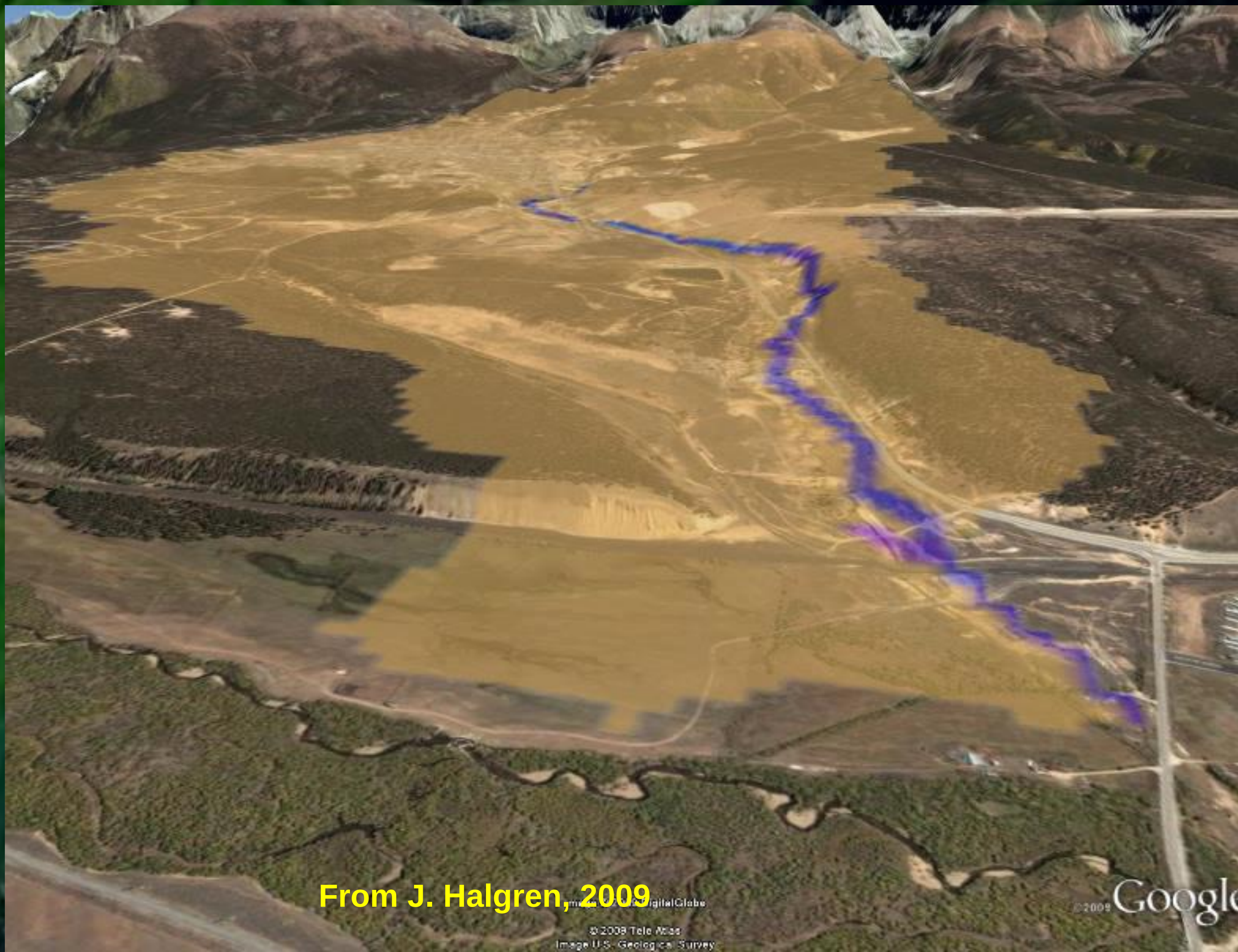
Mark Velleux, Ph.D. ‘05
John England, Ph.D. ‘06
James Halgren, Ph.D. ‘12
Jaehoon Kim, Ph.D. ‘12
Jazuri Abdullah, Ph.D. ‘13



CSU Watershed Model TREX



Surface Water Depth [ft]



From J. Halgren, 2009

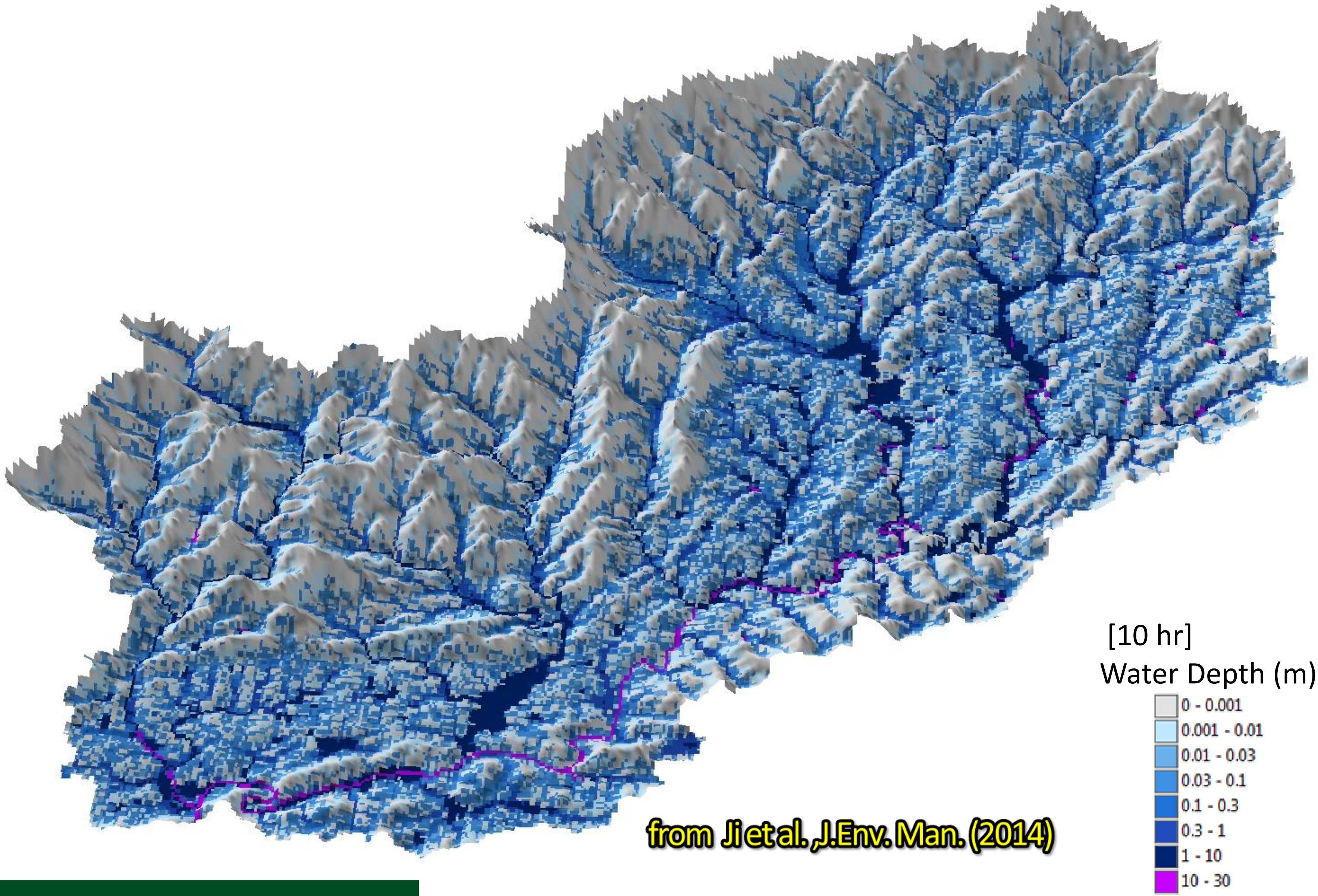
Runoff and TSS Visualization at Naesung Stream, South Korea

(TREX Simulation from Dr. Mark Velleux, HDR HydroQual, NJ)

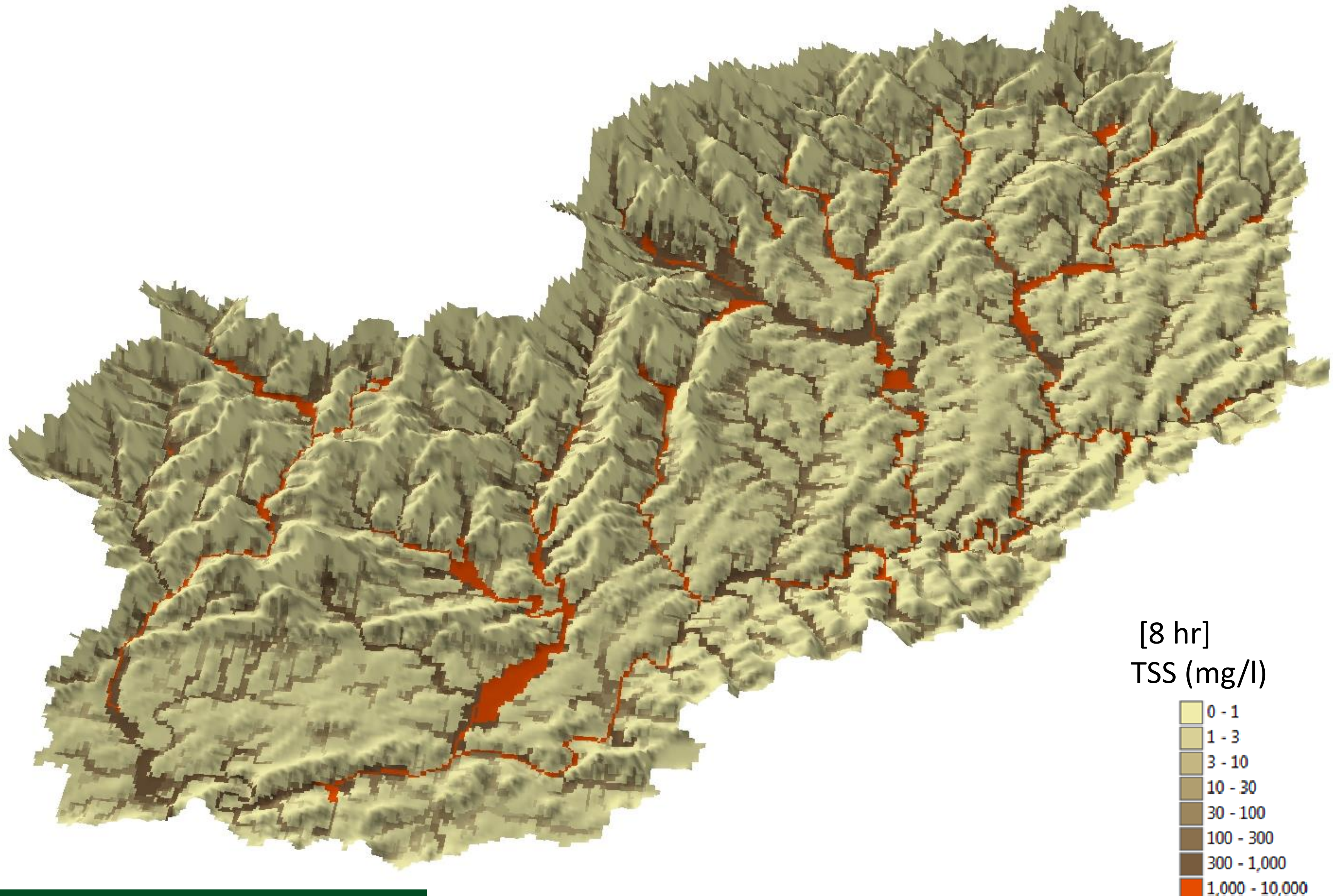
Jaehoon Kim and Pierre Y. Julien

Department of Civil and Environmental Engineering
Colorado State University

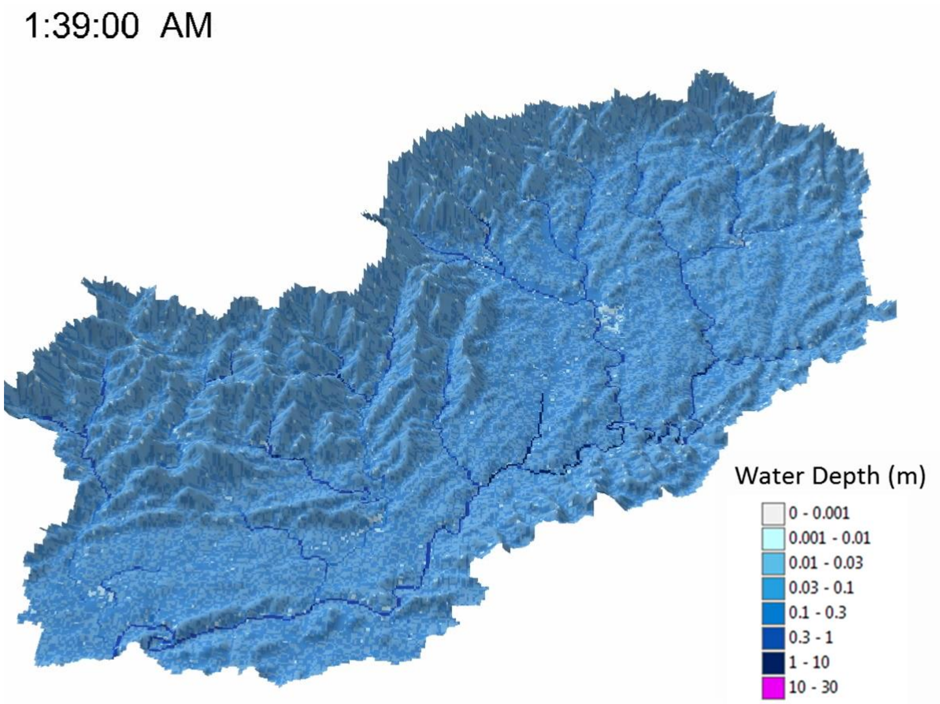
Water Depth

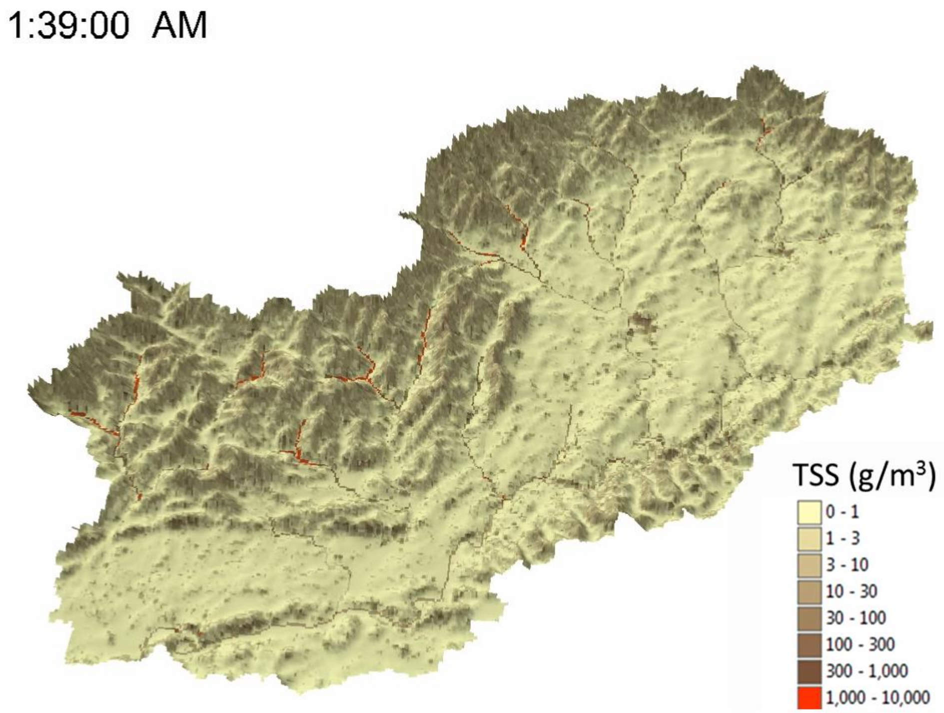

[10 hr]
Water Depth (m)
0 - 0.001
0.001 - 0.01
0.01 - 0.03
0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 10
10 - 30
from Ji et al. ,J.Env. Man. (2014)

Total Suspended Solids

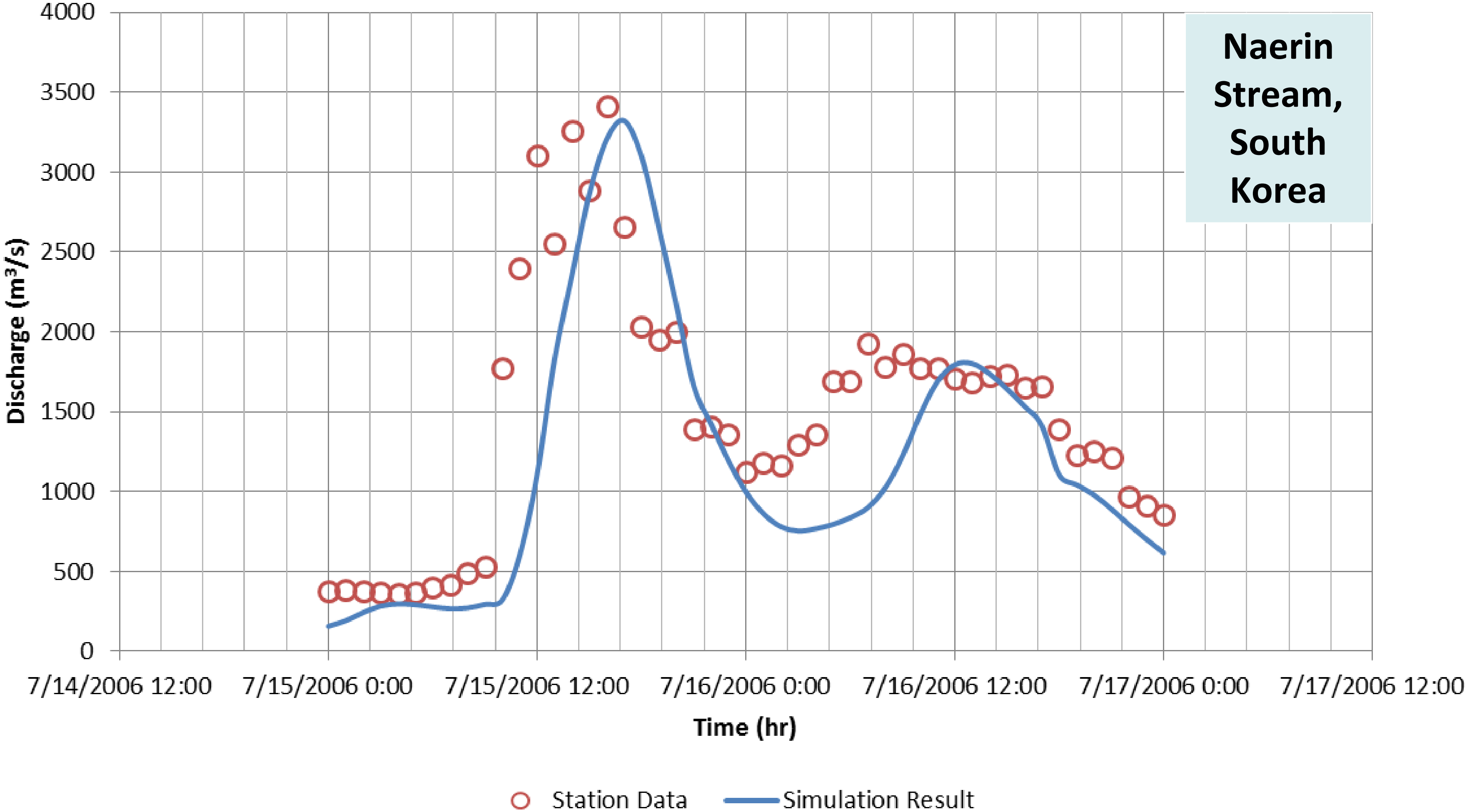


Runoff and TSS Visualization at Naesung Stream





Example of TREX Calibration



Watersheds and Climate

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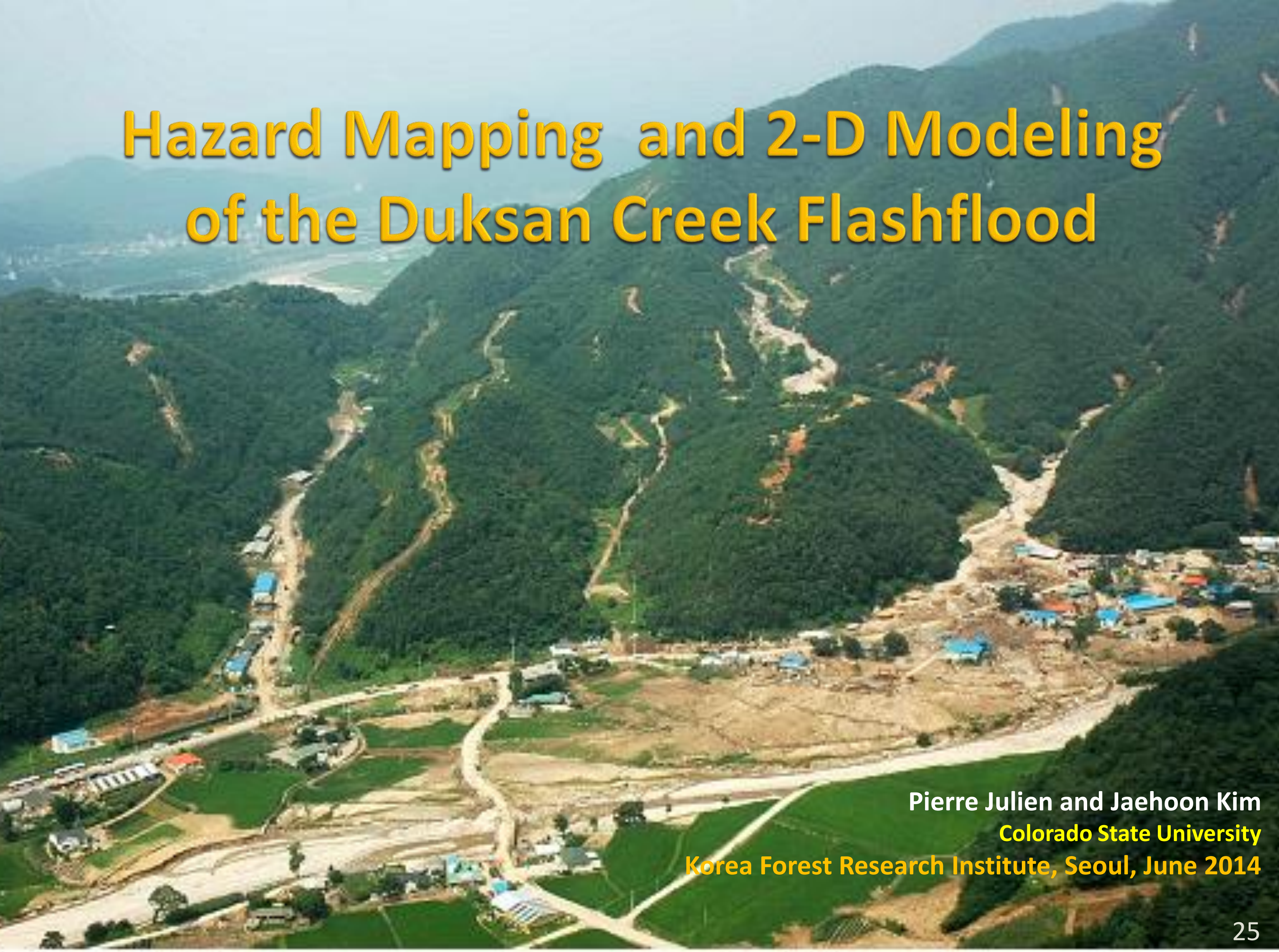
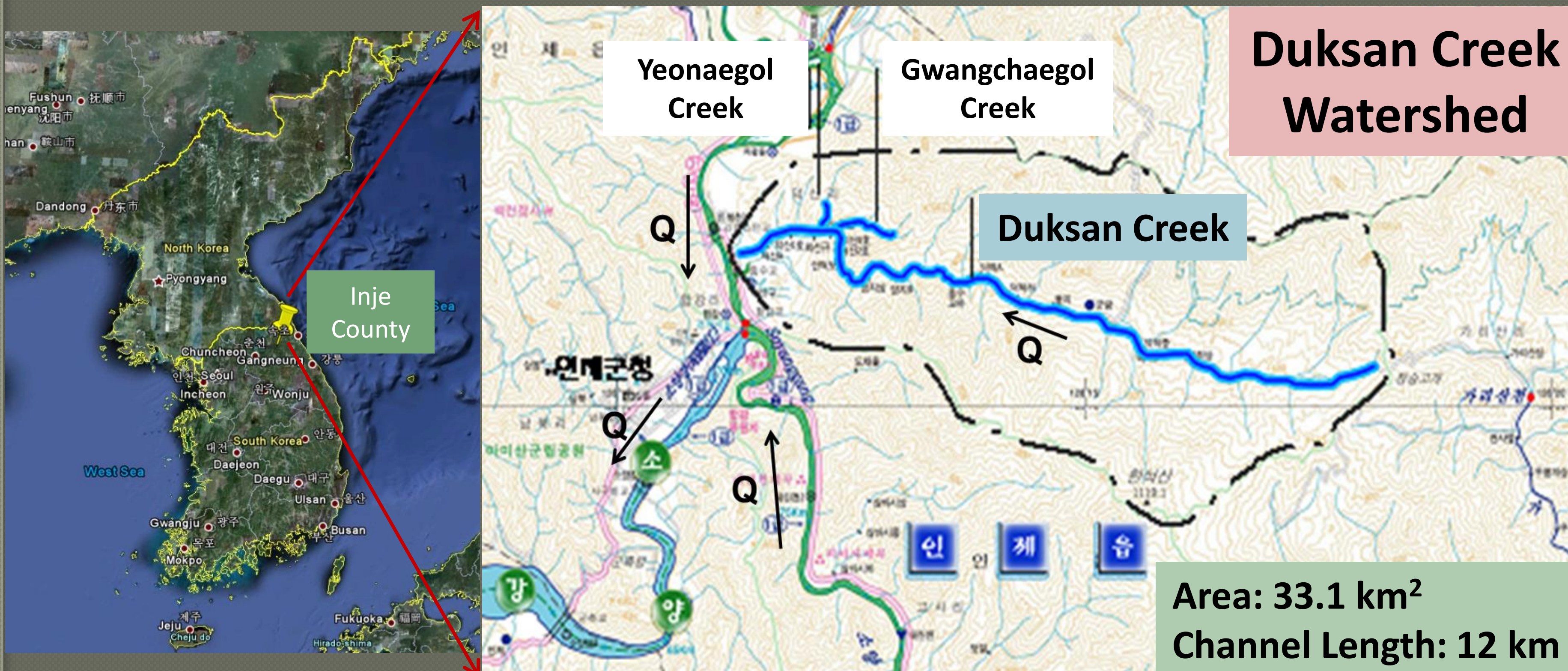
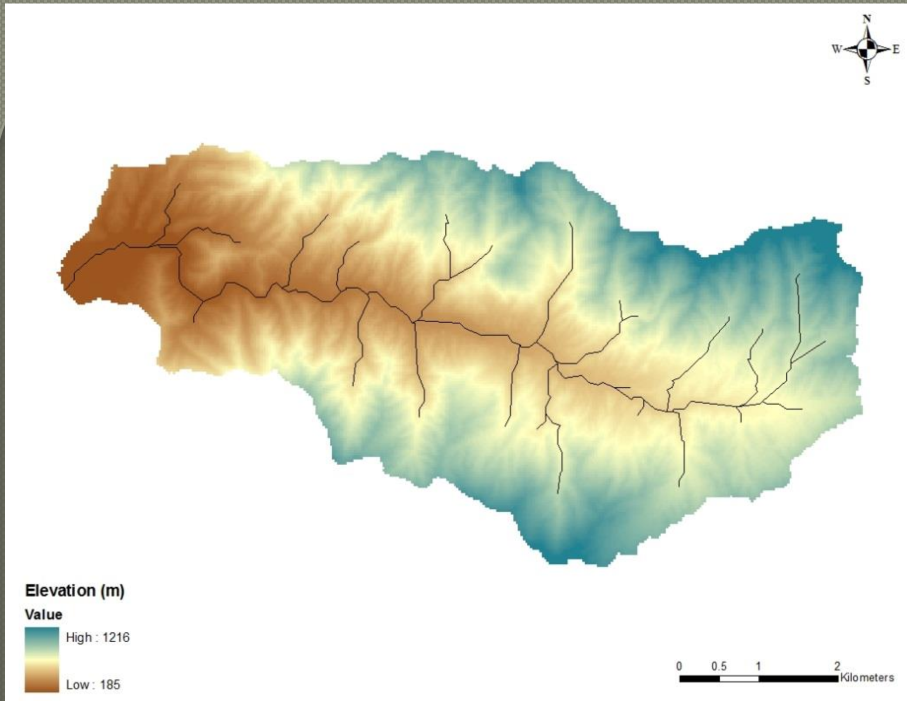
Hazard Mapping and 2-D Modeling of the Duksan Creek Flashflood

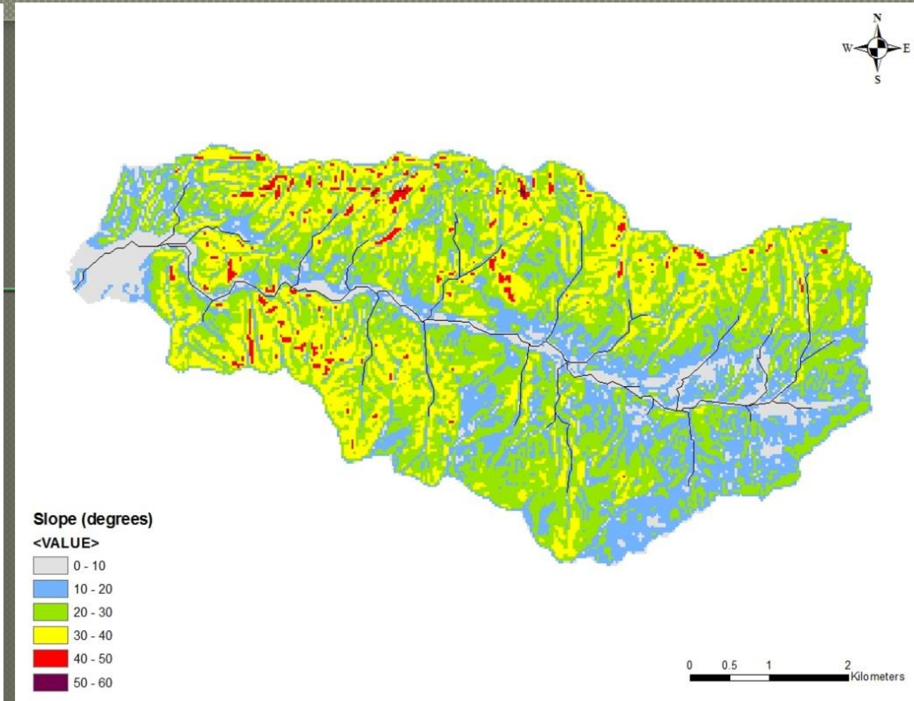


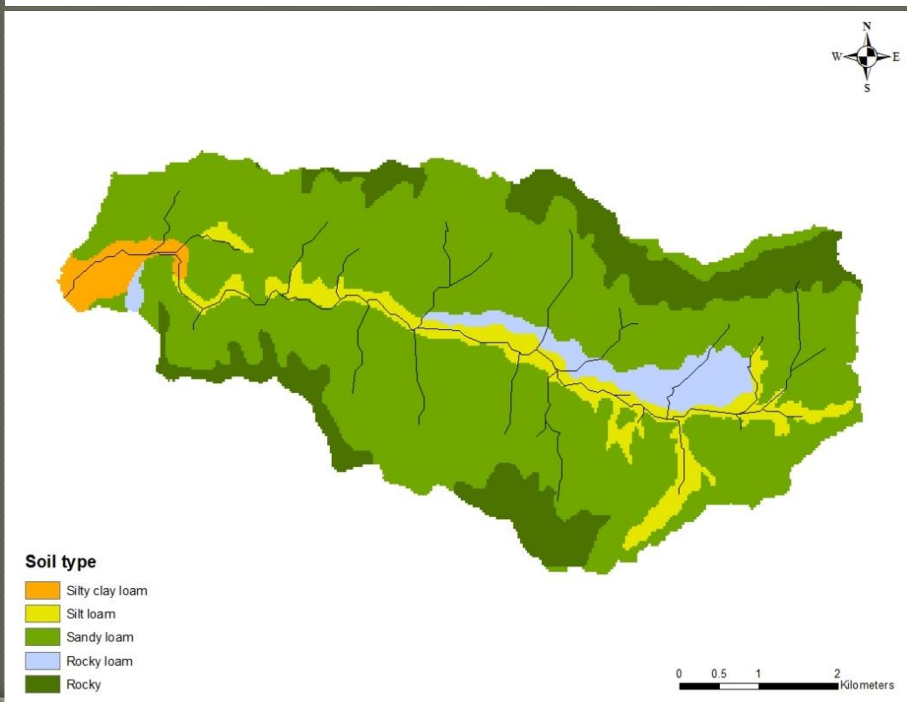
Pierre Julien and Jaehoon Kim
Colorado State University
Korea Forest Research Institute, Seoul, June 2014

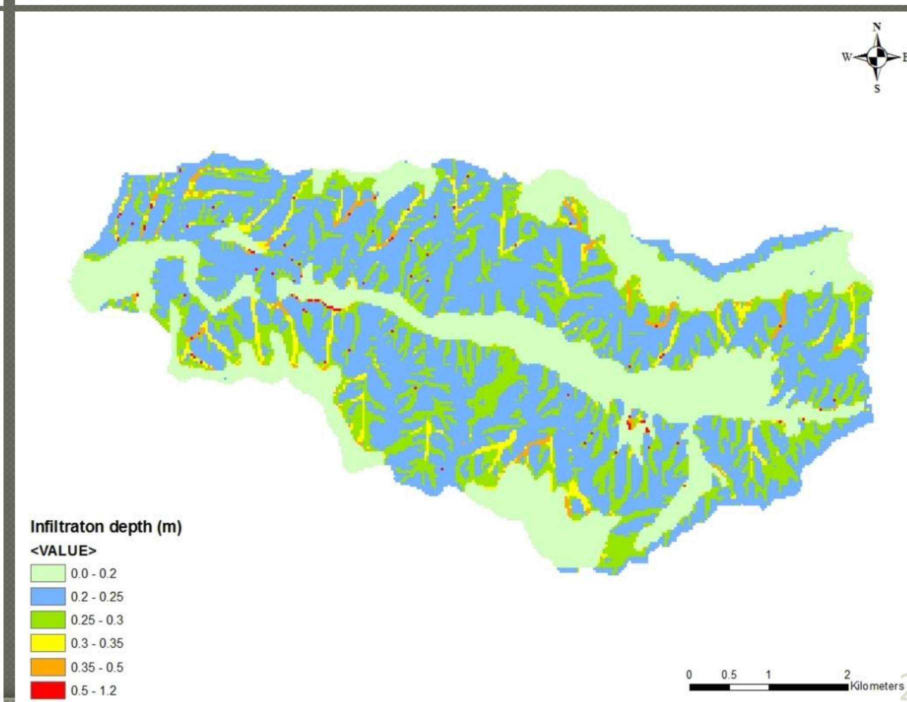
Site Description



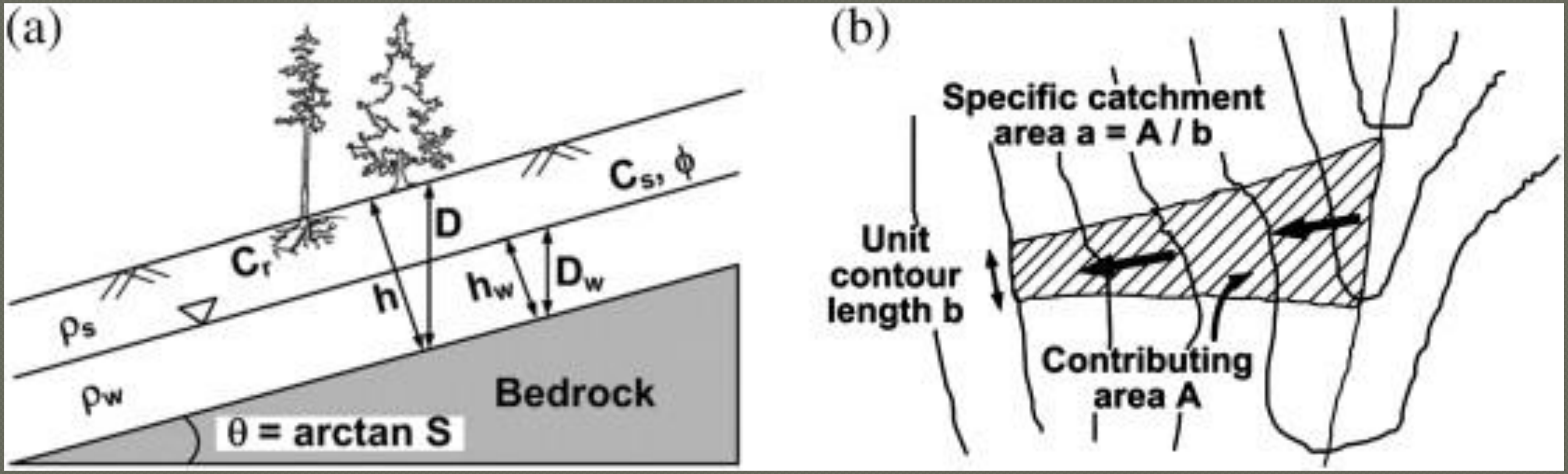

N
W
E
S
Elevation (m)
Value
High : 1216
Low : 185
0 0.5 1 2
Kilometers


N
W
E
S
Slope (degrees)
<VALUE>
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
0 0.5 1 2
Kilometers


N
W
E
S
Soil type
Silty clay loam
Silt loam
Sandy loam
Rocky loam
Rocky
0 0.5 1 2
Kilometers


N
W
E
S
Infiltraton depth (m)
<VALUE>
0.0 - 0.2
0.2 - 0.25
0.25 - 0.3
0.3 - 0.35
0.35 - 0.5
0.5 - 1.2
0 0.5 1 2
Kilometers

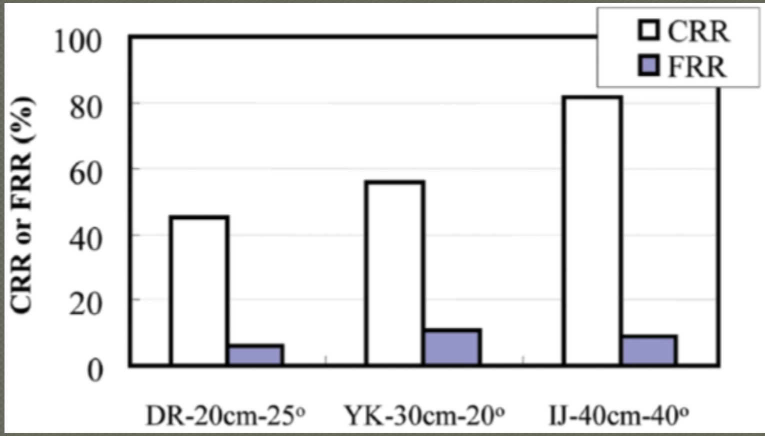
SINMAP

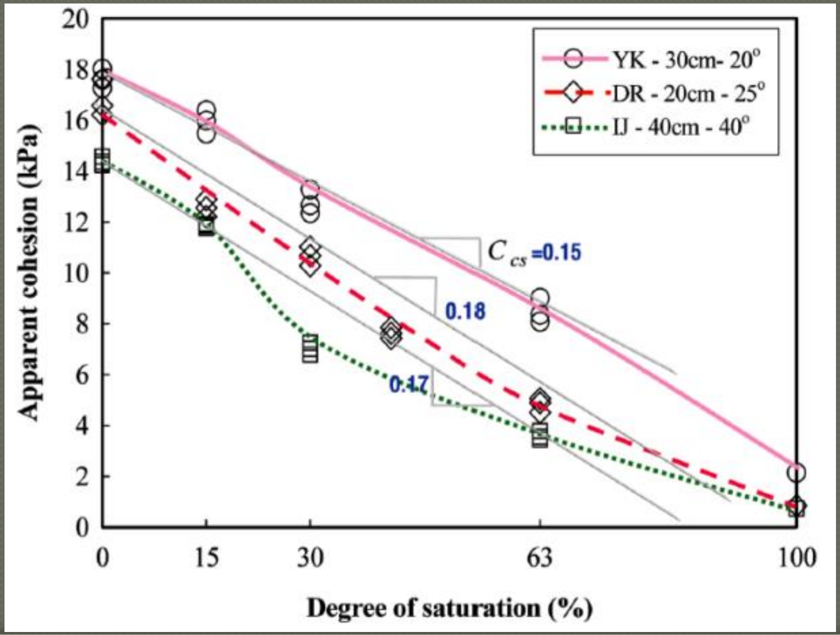


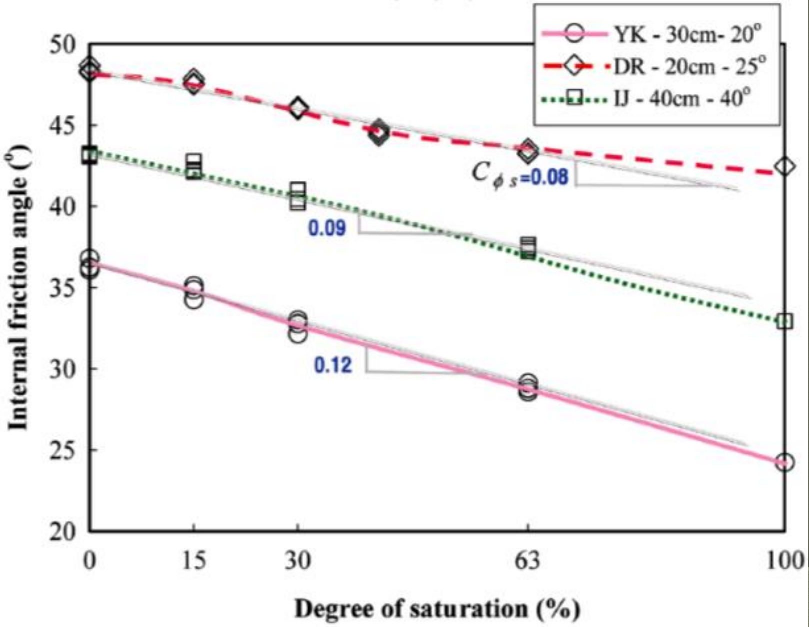
$$FS = \frac{C_r + C_s + \cos^2\theta\left[\rho_s\, g\left(D - D_W\right) + \left(\rho_s\, g - \rho_W\, g\right) D_W\right]\tan\phi}{D\,\rho_s\, g\sin\theta\cos\theta}$$

$$SI = FS\min = \frac{C + \cos\theta\left[1 - \min\left(\frac{R}{T}\frac{a}{\sin\theta}, 1\right) r\right]\tan\phi}{\sin\theta}$$

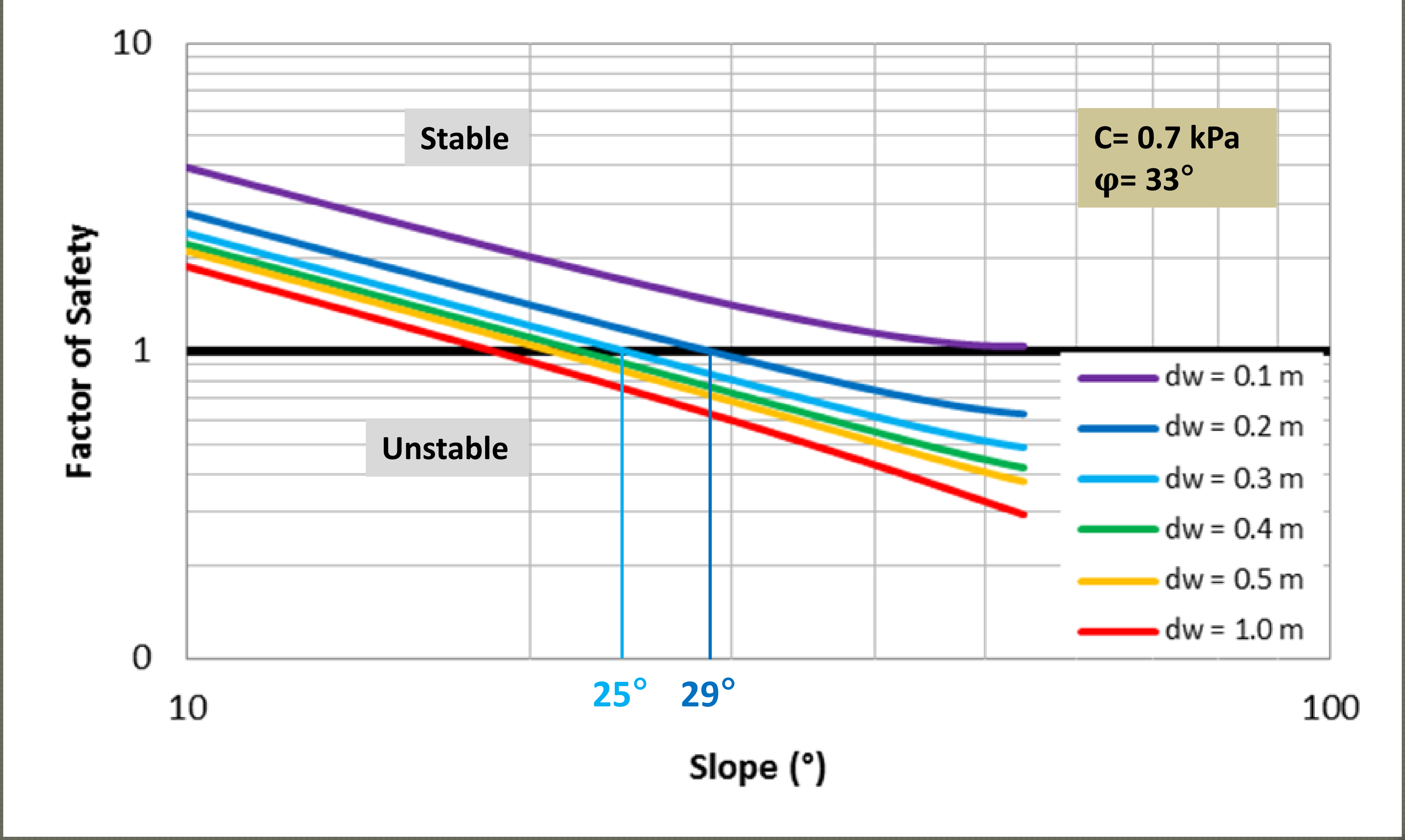
Soil cohesion and Friction angle



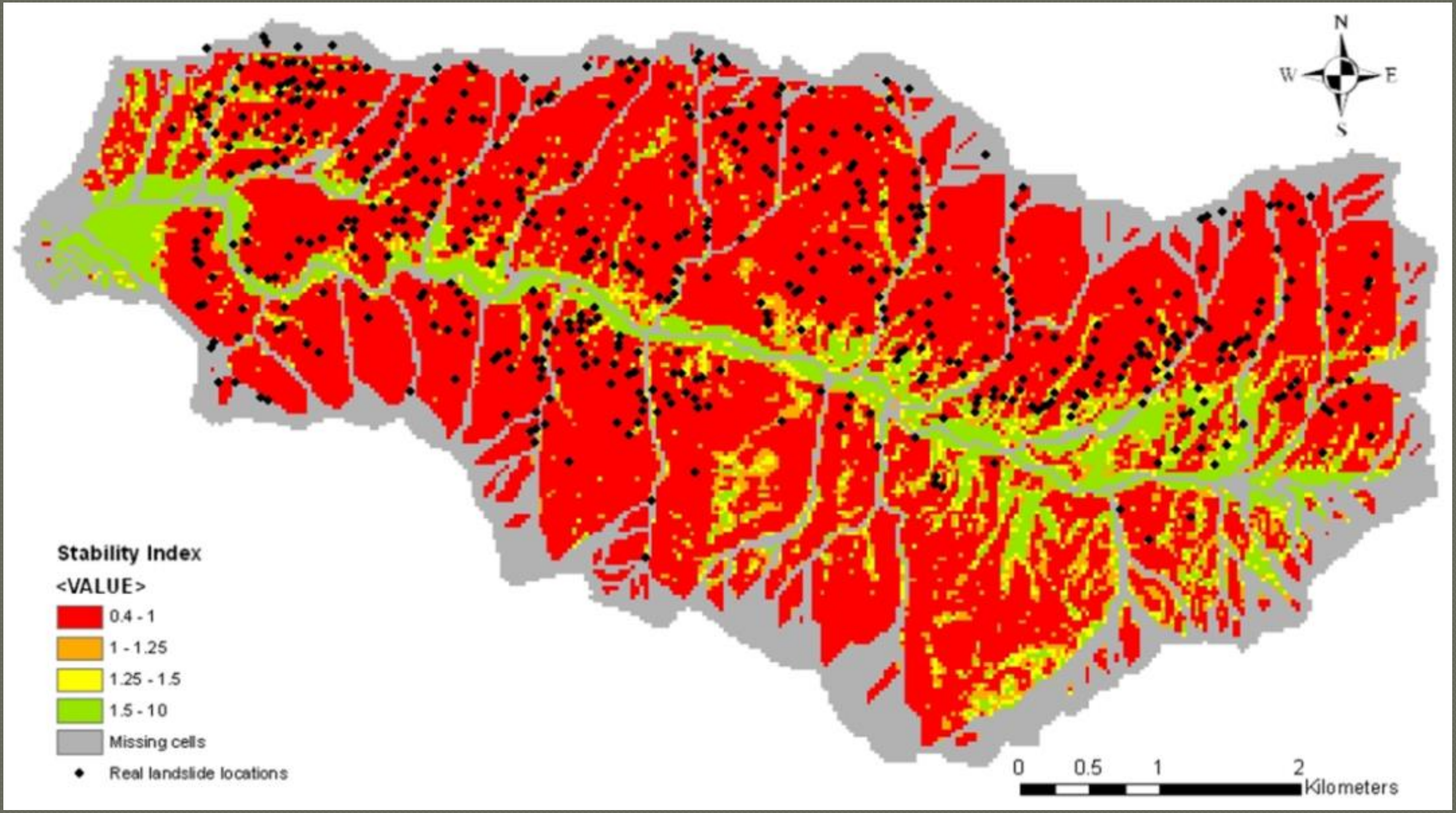




Critical Slope Analysis

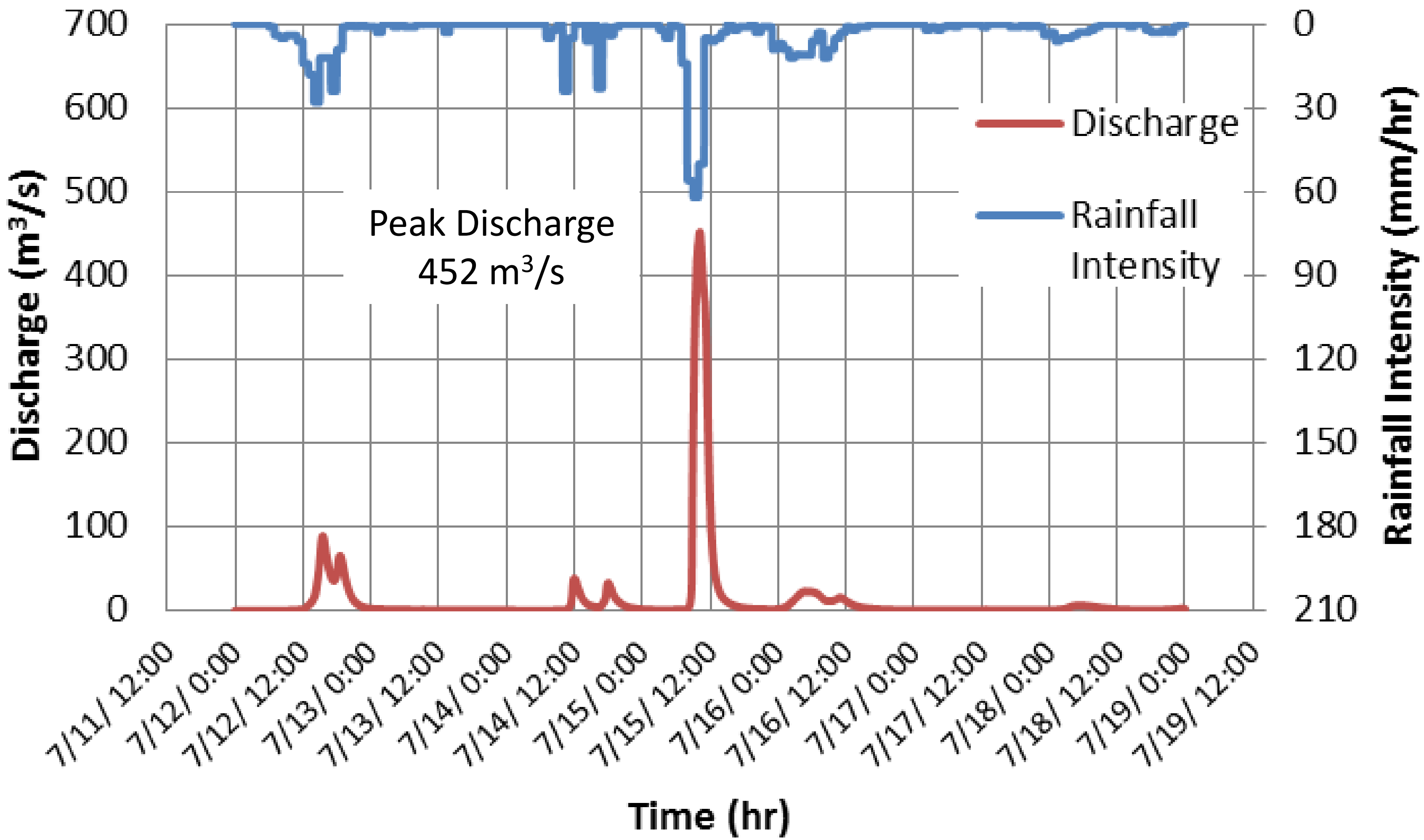


SINMAP result

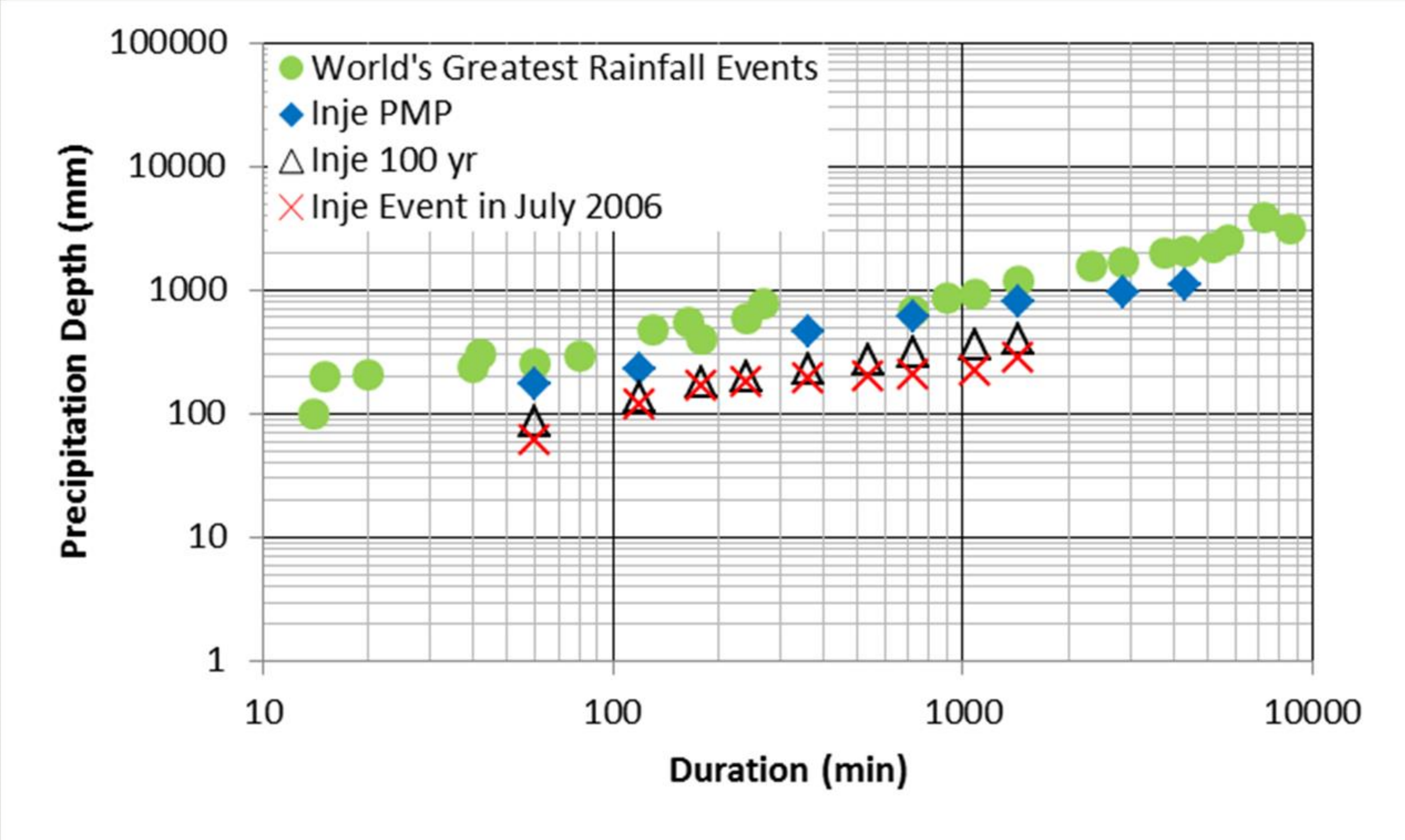


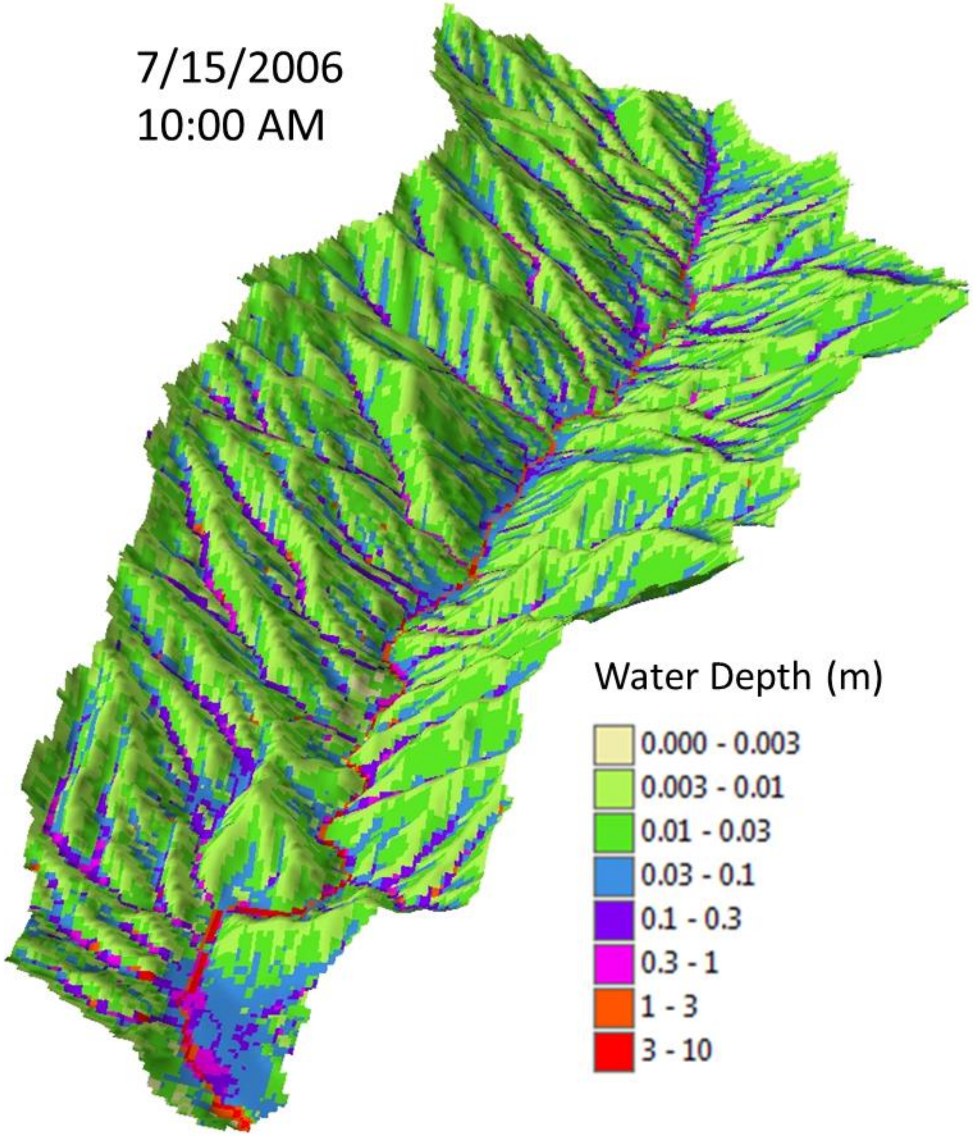
Duksan Creek

Hydrograph in the Duksan Creeek



Extreme Event on July 15, 2006




7/15/2006
10:00 AM
Water Depth (m)
0.000 - 0.003
0.003 - 0.01
0.01 - 0.03
0.03 - 0.1
0.1 - 0.3
0.3 - 1
1 - 3
3 - 10

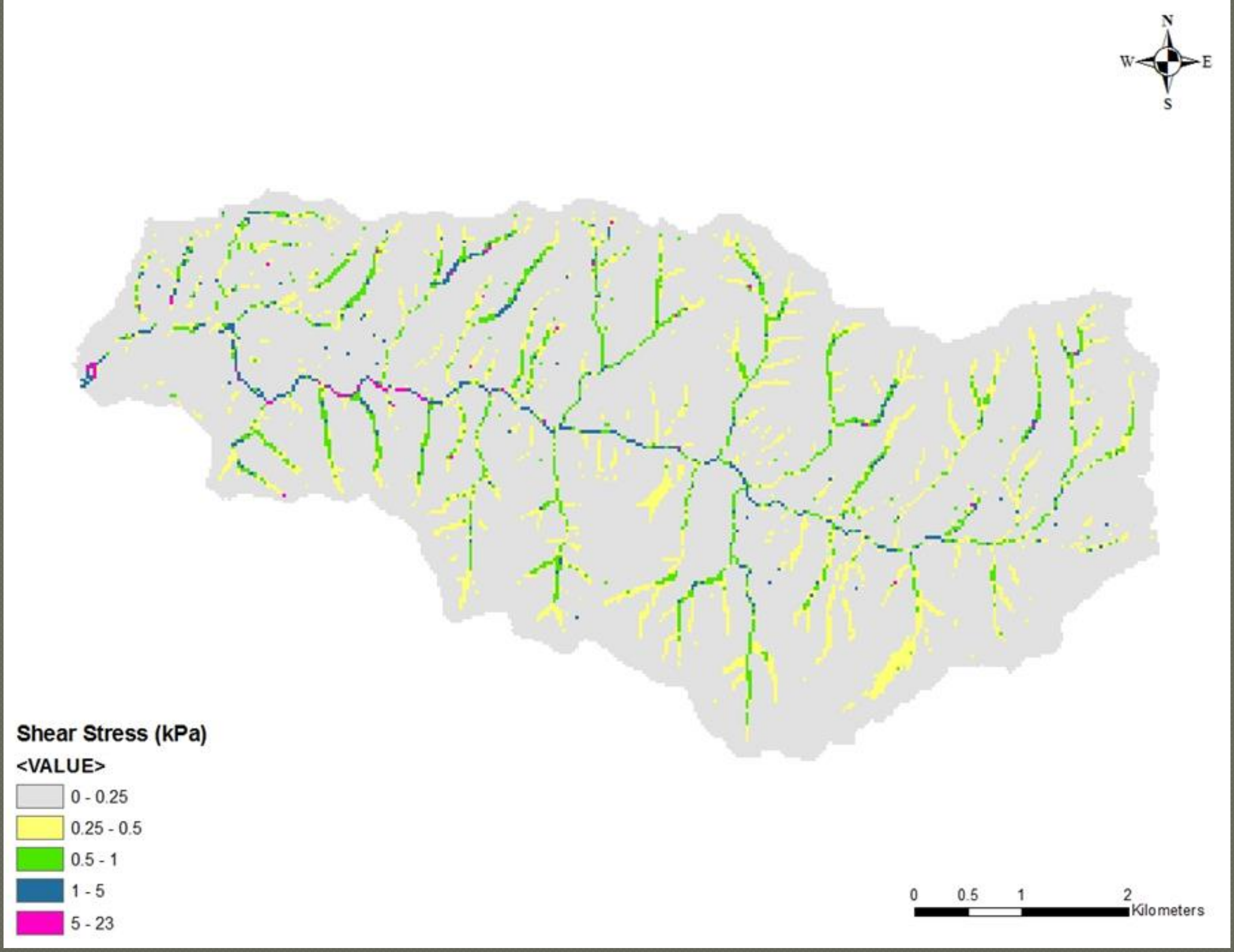
TREX Modeling

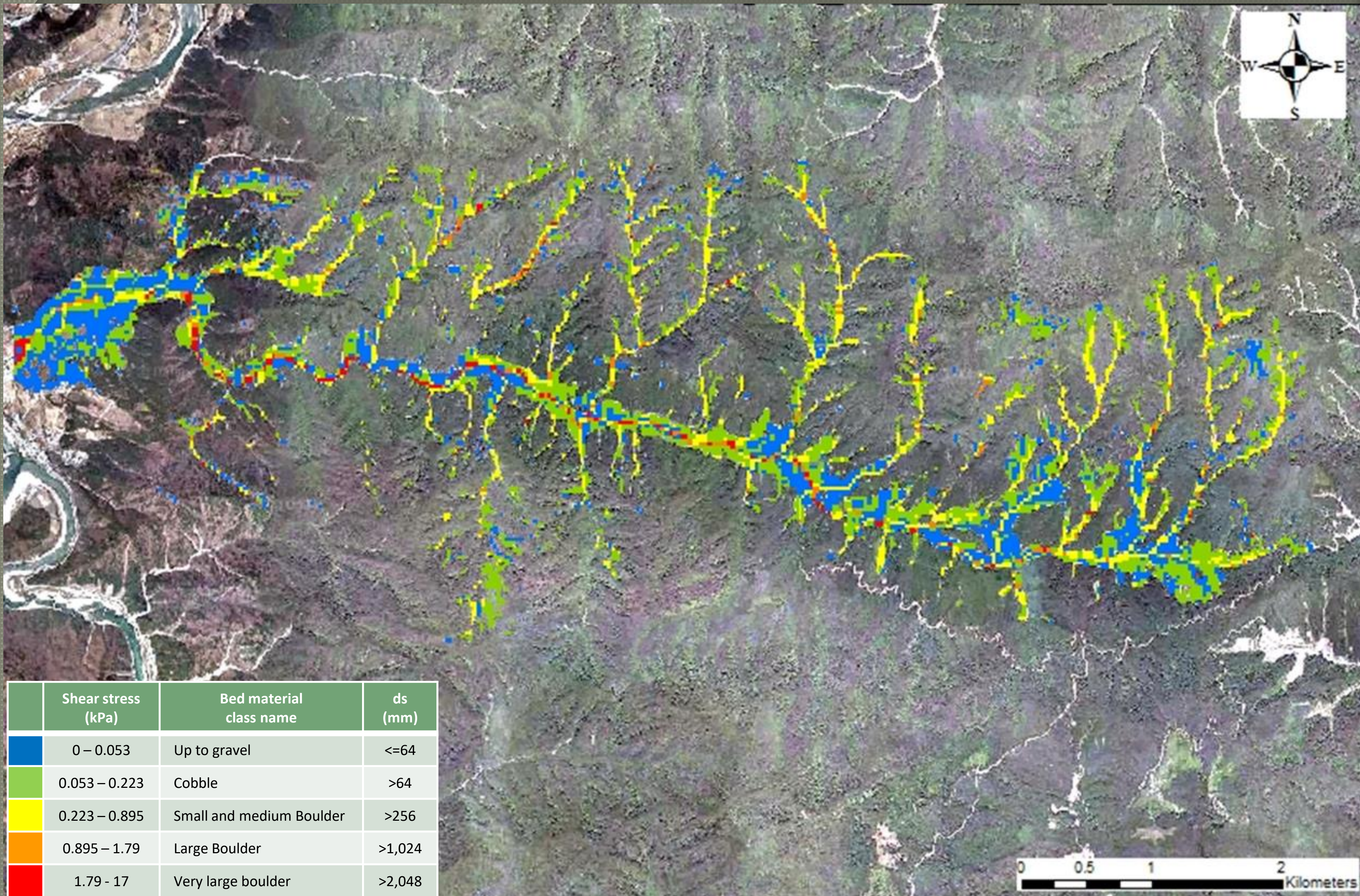
7/15/2006 8:00:00 AM

Water Depth (m)

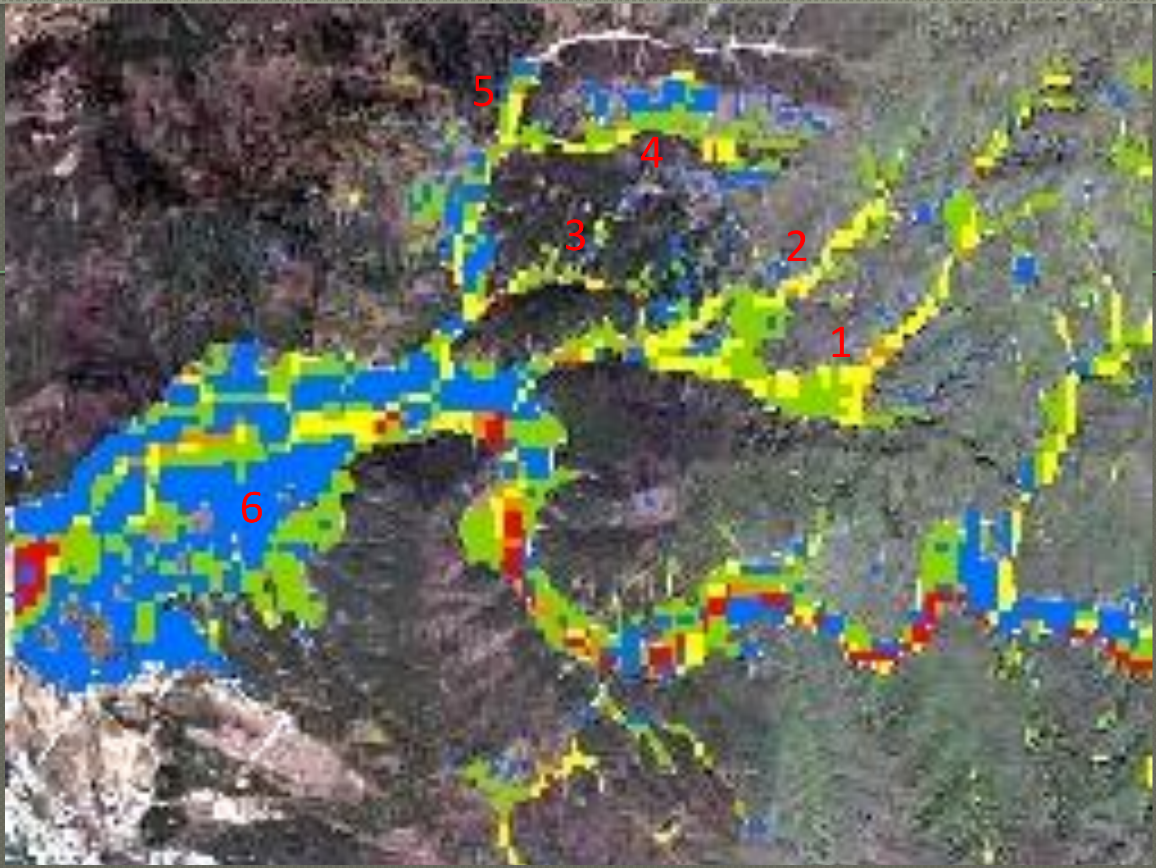
- 0.000 - 0.003
- 0.003 - 0.01
- 0.01 - 0.03
- 0.03 - 0.1
- 0.1 - 0.3
- 0.3 - 1
- 1 - 3
- 3 - 10

Shear Stress



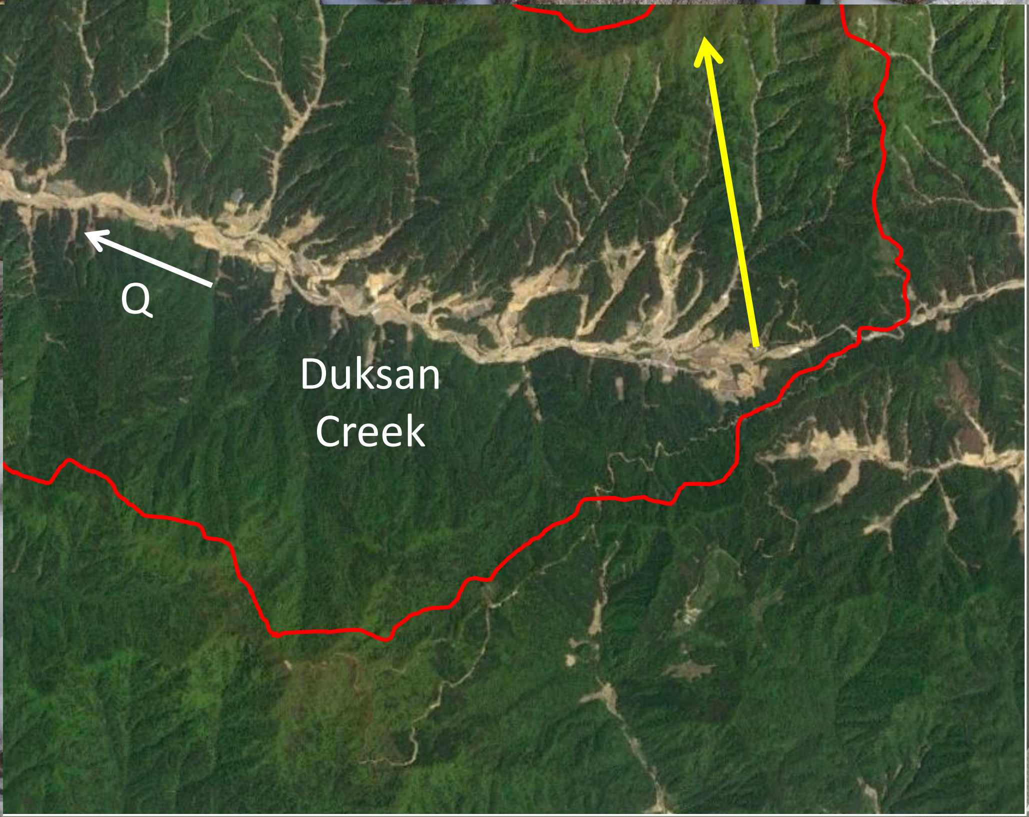


	Shear stress (kPa)	Bed material class name	ds (mm)
(blue)	0 – 0.053	Up to gravel	<=64
(light green)	0.053 – 0.223	Cobble	>64
(yellow)	0.223 – 0.895	Small and medium Boulder	>256
(orange)	0.895 – 1.79	Large Boulder	>1,024
(red)	1.79 - 17	Very large boulder	>2,048


5
4
3
2
1
6


1
2
4
3
5
6

Compar



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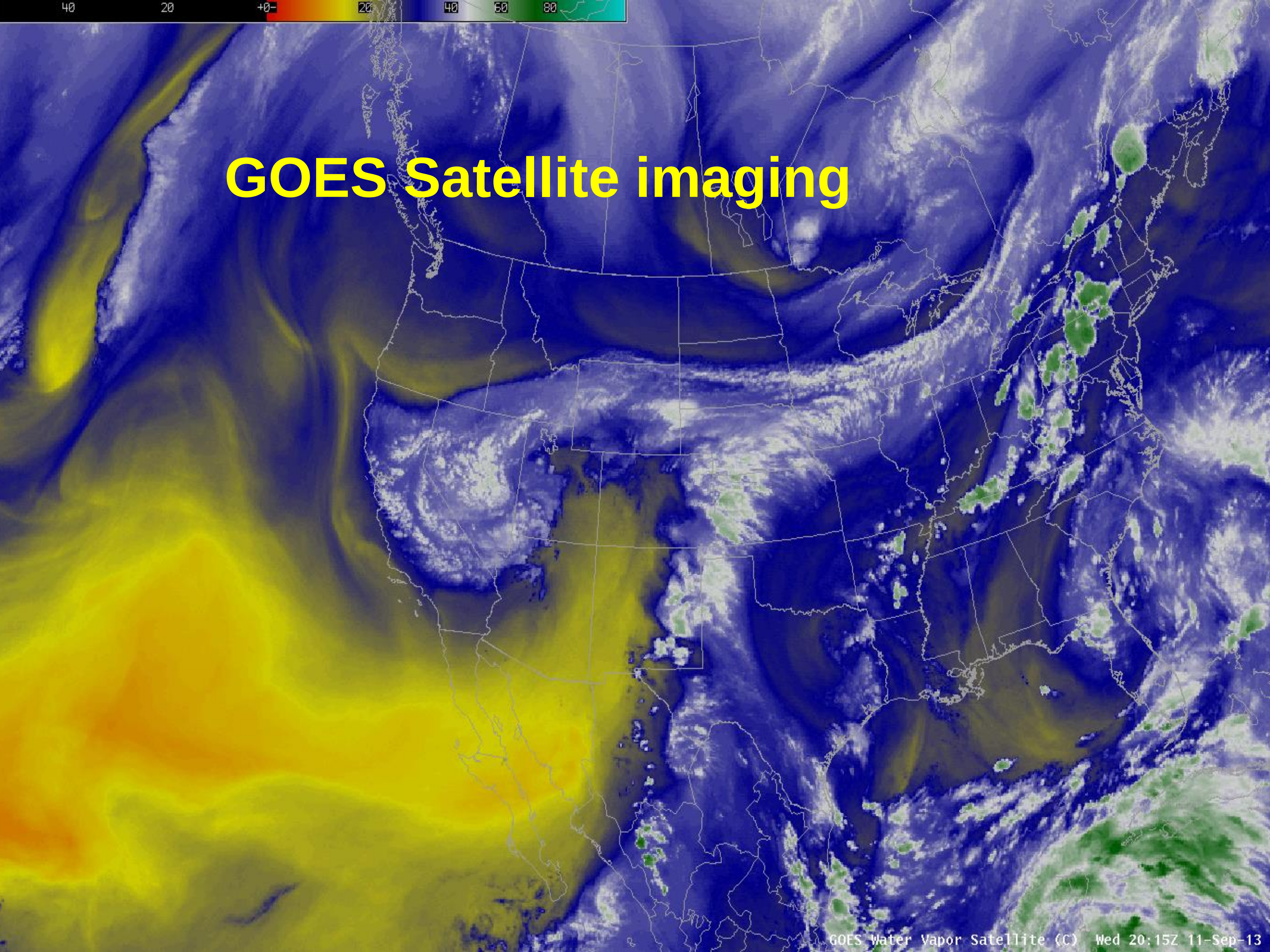
GOES Satellite imaging



Climate Change Perspective

1. Snowmelt and thunderstorms


1917
Athabasca Glacier, Jasper National Park Canada in 1917 and 2005. Wheeler Survey photo (above) © 2005 Gary Braasch
2005
Athabasca Glacier
Jasper National Park, Canada

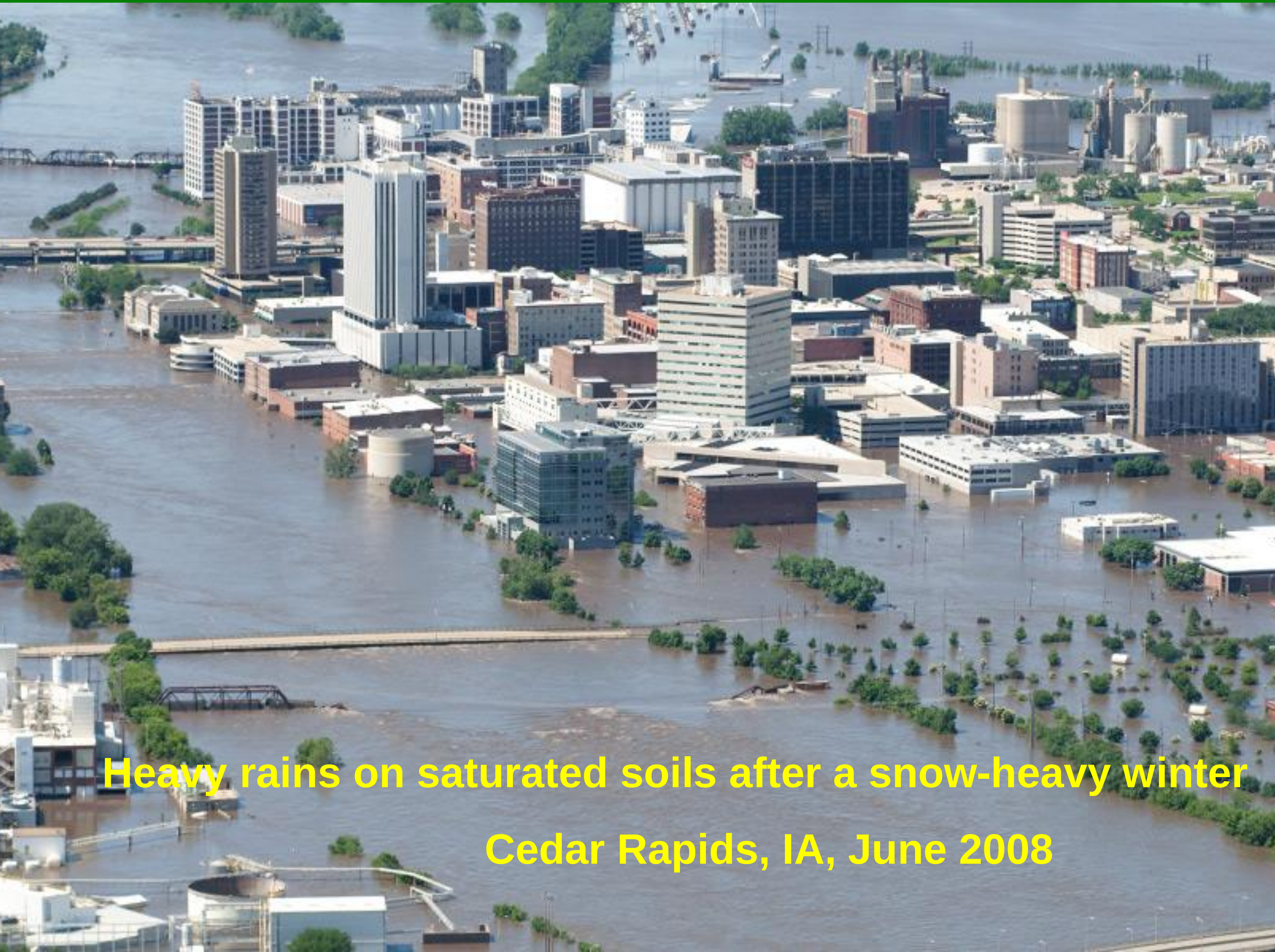
Rainfall vs Snowmelt

Flooding from rapid widespread snowmelt

'integral'

Flooding from intense local thunderstorms

'differential'


Heavy rains on saturated soils after a snow-heavy winter
Cedar Rapids, IA, June 2008


Cedar Rapids, IA, June 2008

Climate Change Perspective

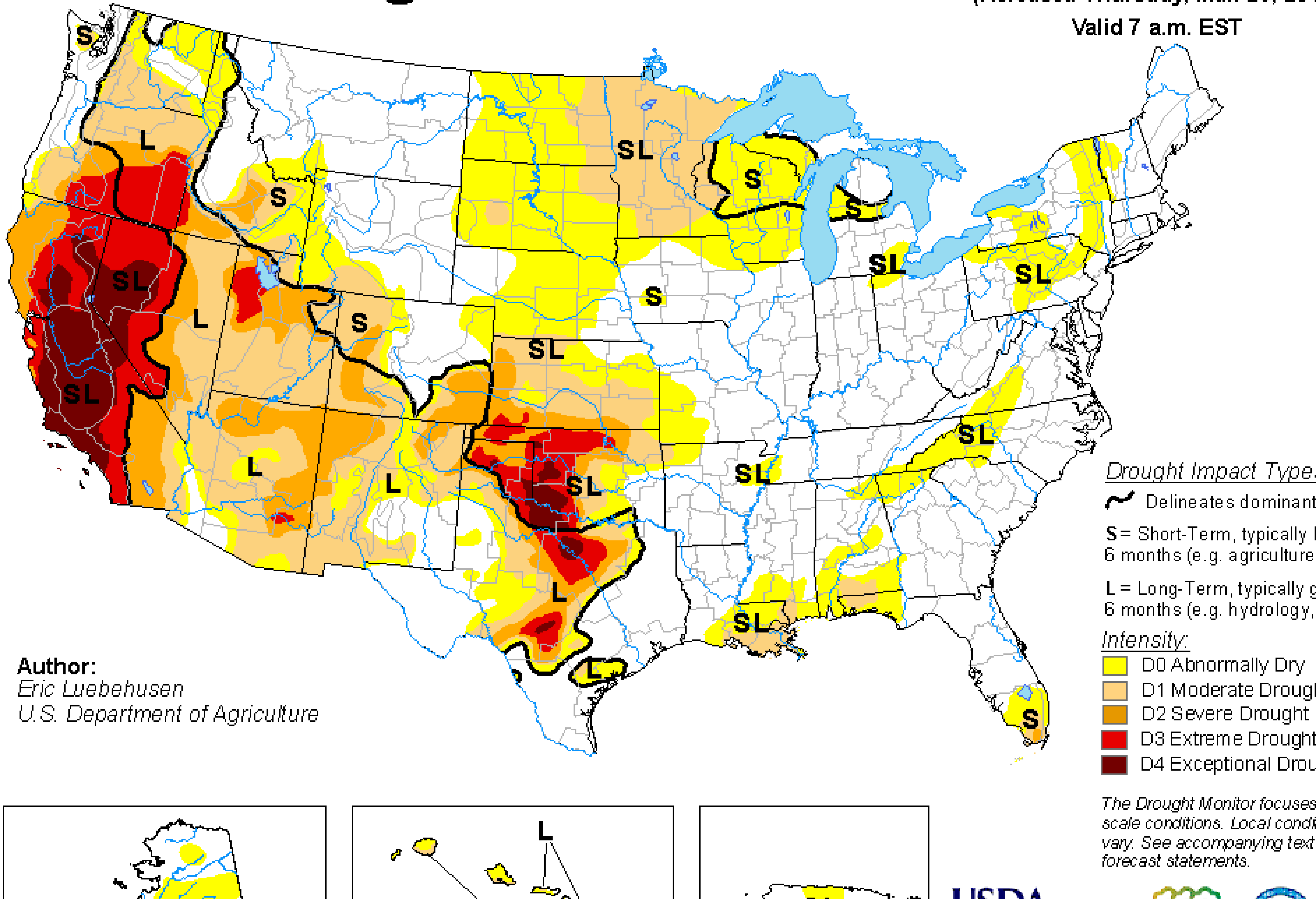
1. Snowmelt and thunderstorms
2. Extended droughts

U.S. Drought Monitor

March 24, 2015

(Released Thursday, Mar. 26, 20

Valid 7 a.m. EST



California Imposes First Mandatory Water Restrictions to Deal With Drought

PHILLIPS, Calif. — Gov. Jerry Brown on Wednesday ordered mandatory water use reductions for the first time in California's history, saying the state's four-year drought had reached near-crisis proportions after a winter of record-low snowfalls.

Oroville Lake, April 2015


Pine beetle and the Colorado Forest

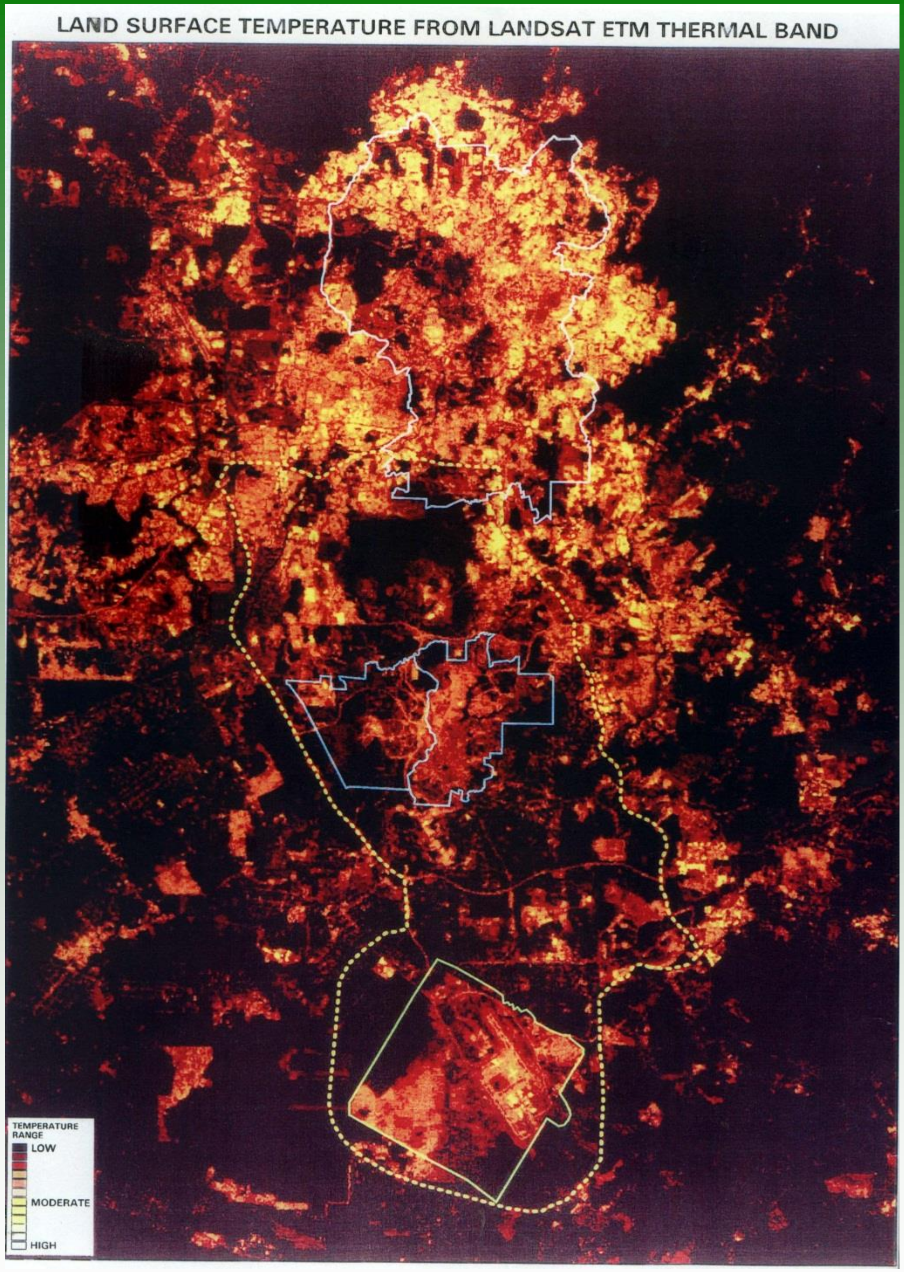

Waldo Fire
Colorado June 2012

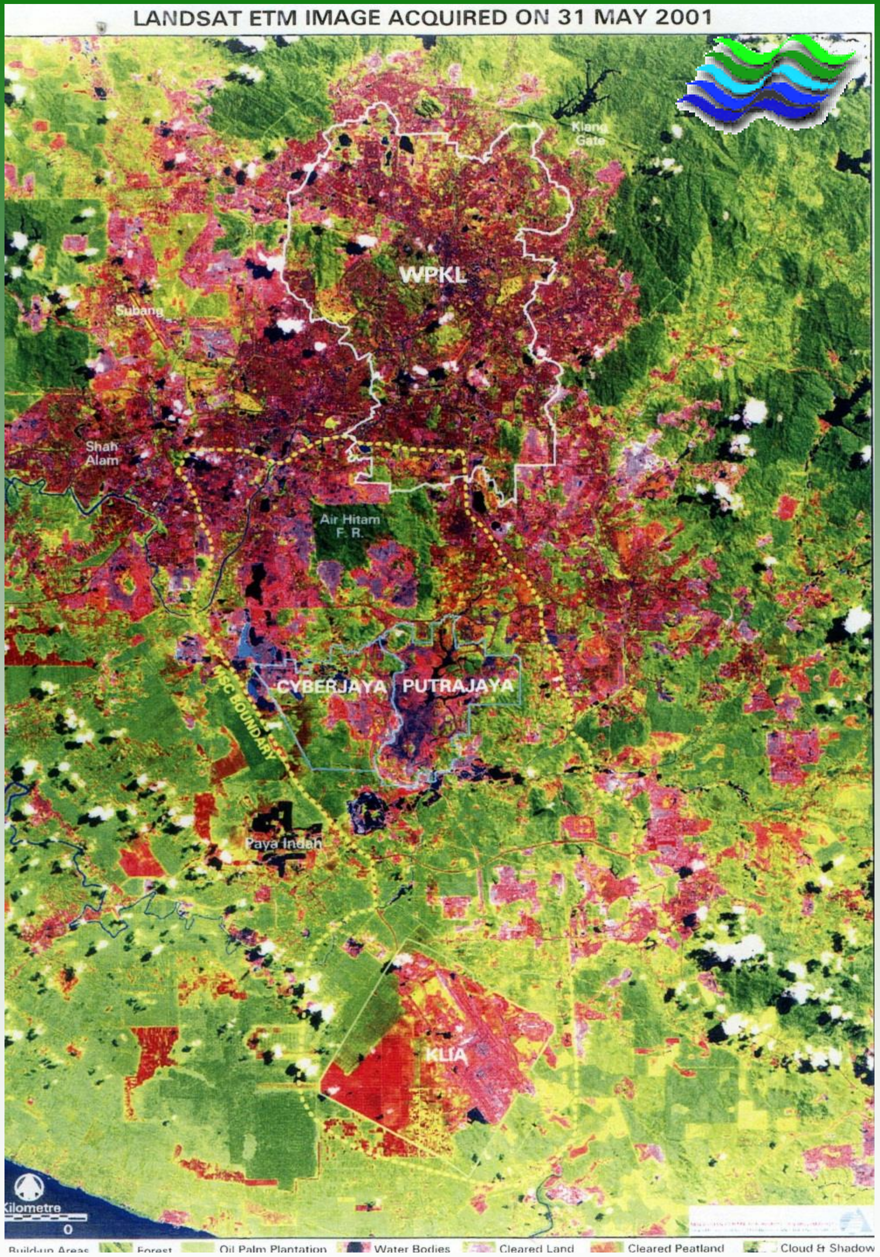

Waldo Fire
Colorado June 2012

Climate Change Perspective

1. Snowmelt and thunderstorms
2. Extended droughts
3. Heat Island

Urbanization and Heat Island
Kuala Lumpur, Malaysia



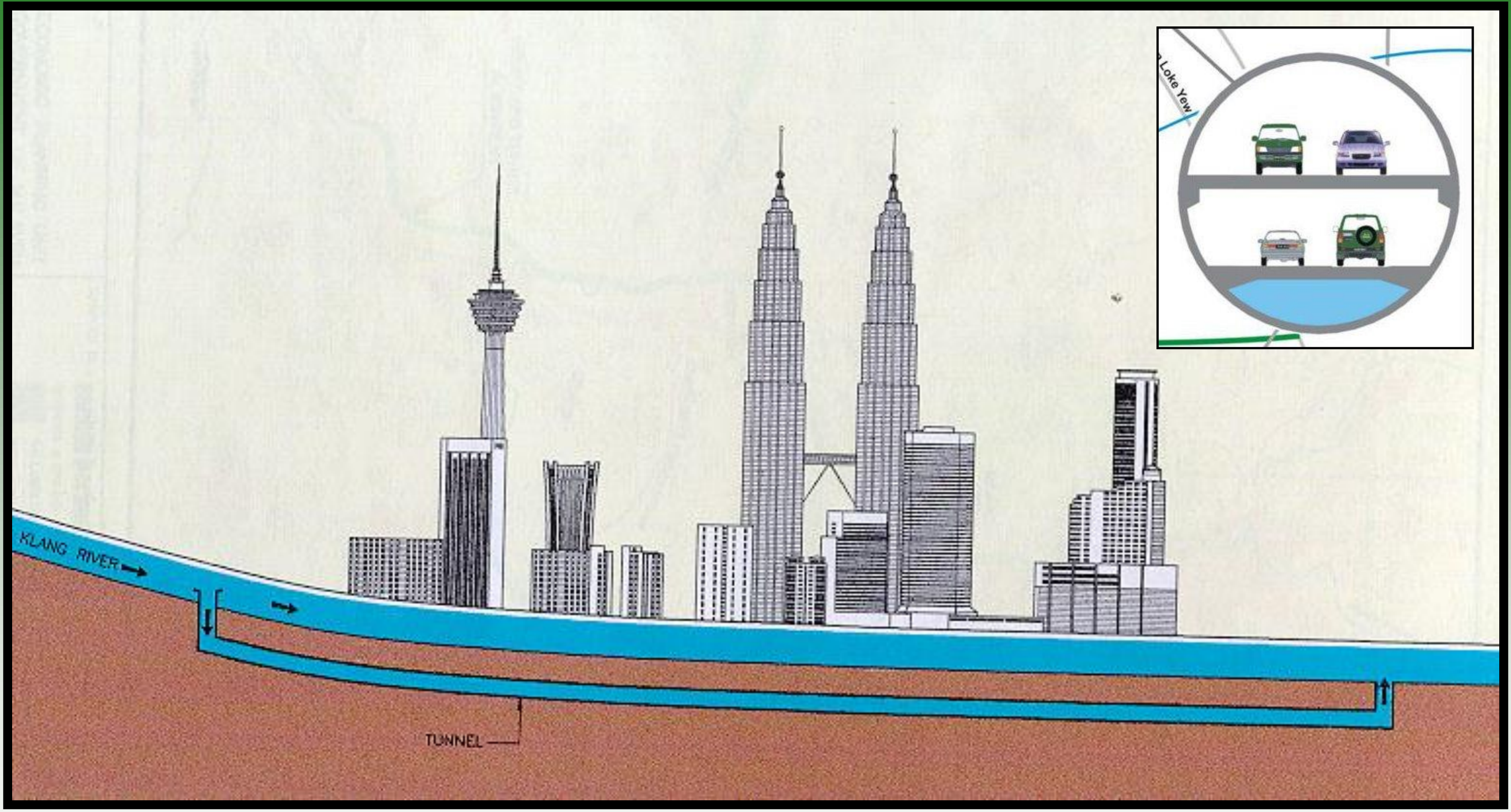


Satellite image of Kuala Lumpur

Jalan Dang Wangi Pada 10 Jun 2003


JABATAN PENGAIRAN DAN SALIRAN
WATER QUANTITY CONTROL
Flash Floods
Damage in Klang Valley RM 50 M /yr

SMART TUNNEL



SCHEMATIC DIAGRAM OF A FLOOD TUNNEL UNDER KLANG RIVER

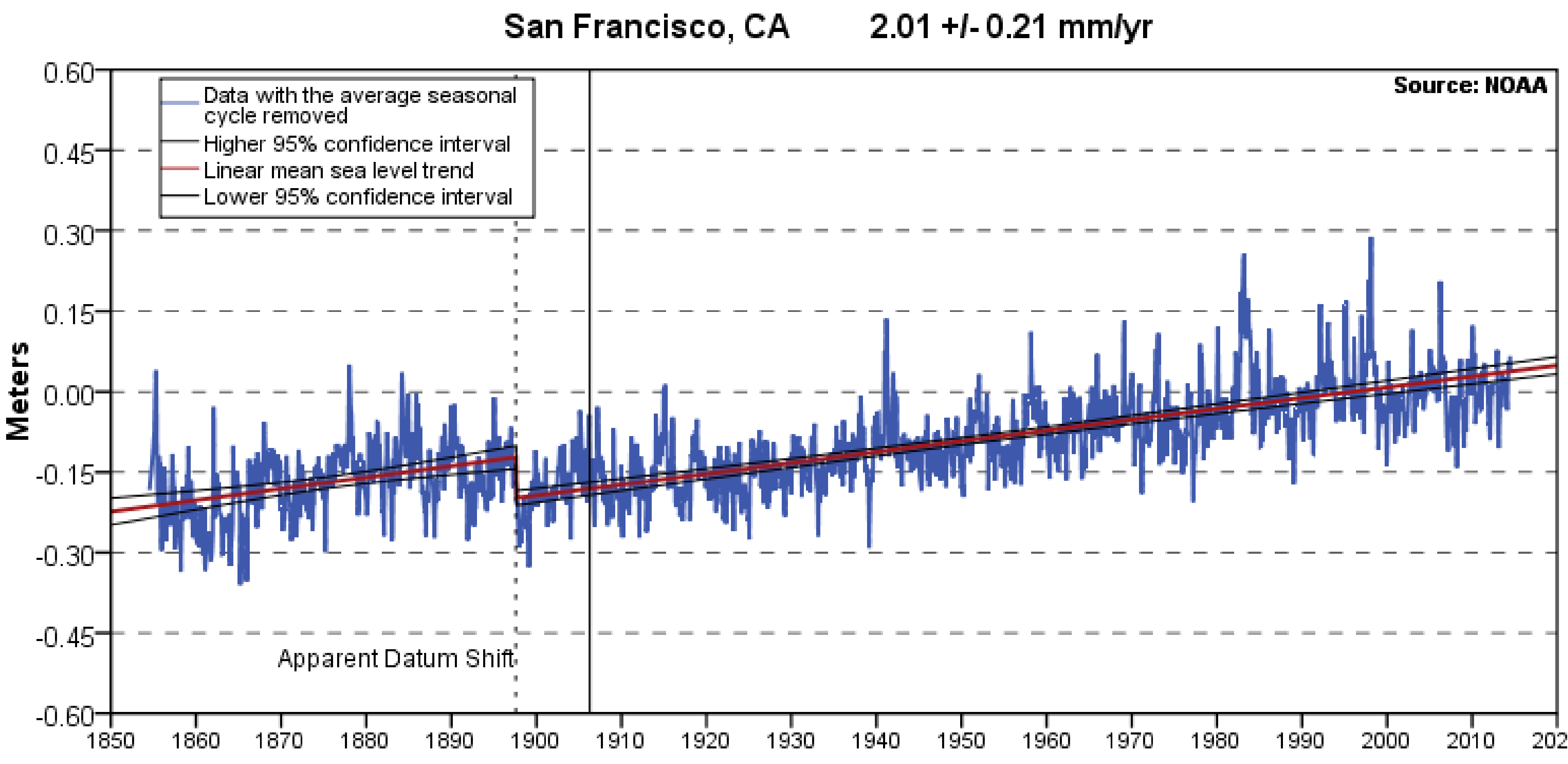
TBM No.1 – SOUTH DRIVE

Tunnel Boring Machine break-through, June 2005

Climate Change Perspective

1. Snowmelt and thunderstorms
2. Extended droughts
3. Heat Island
4. Sea level rise and temperature

Mean Sea Level Trend
9414290 San Francisco, California



rs/year with a 95% confidence interval of +/- 0.21 mm/yr based on monthly mean sea level data from 1897 to 2006 whi
100 years.

From P. O'Brien, USACE

Sea Level Trends

East Coast | West Coast | Gulf Coast | Alaska | Hawaii | Global

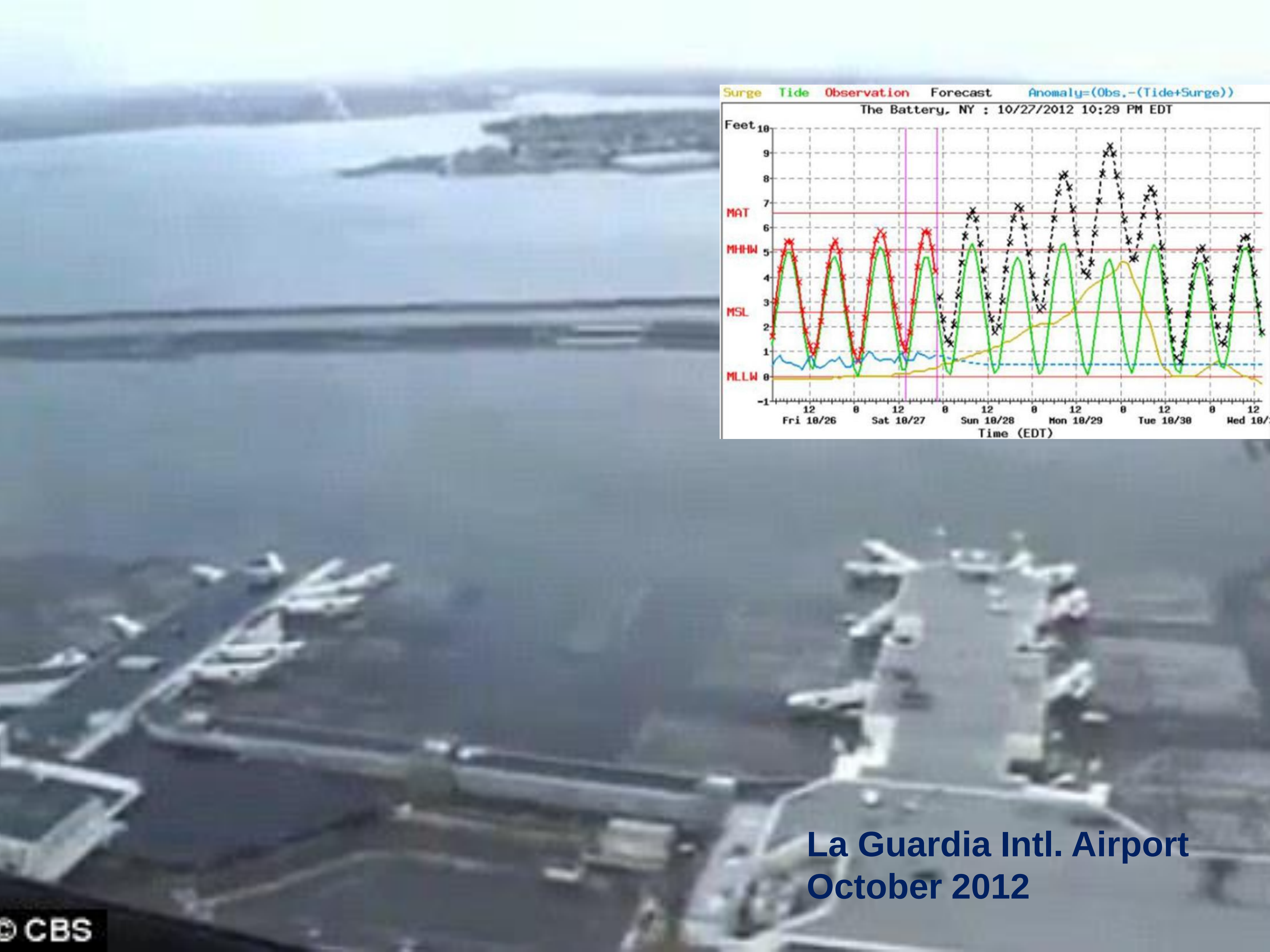
View in Google Earth

The map above illustrates regional trends in sea level, with arrows representing the direction and magnitude of change. Click on an arrow to access additional information about that station.

Sea Level Trends

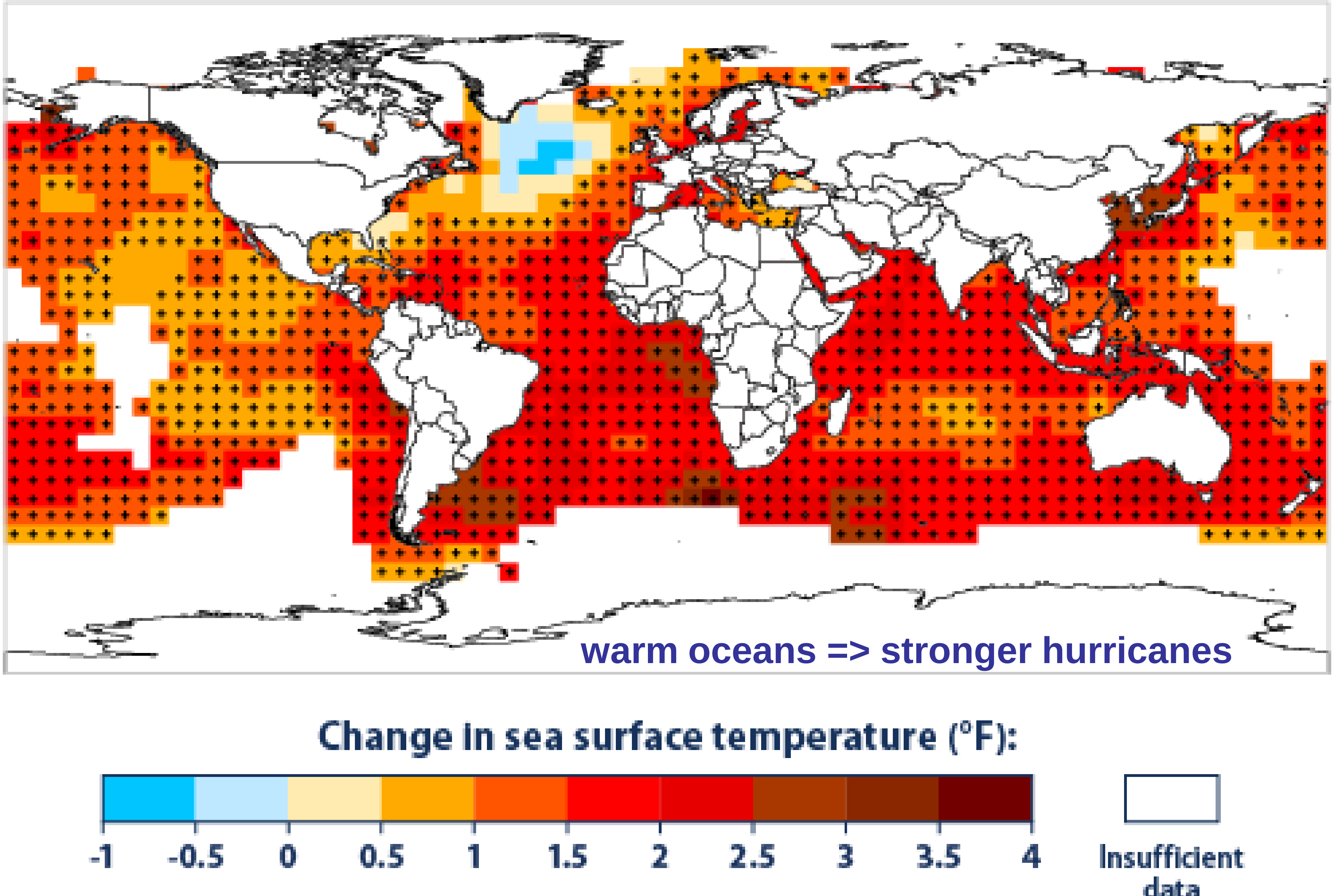
mm/yr (feet/century)

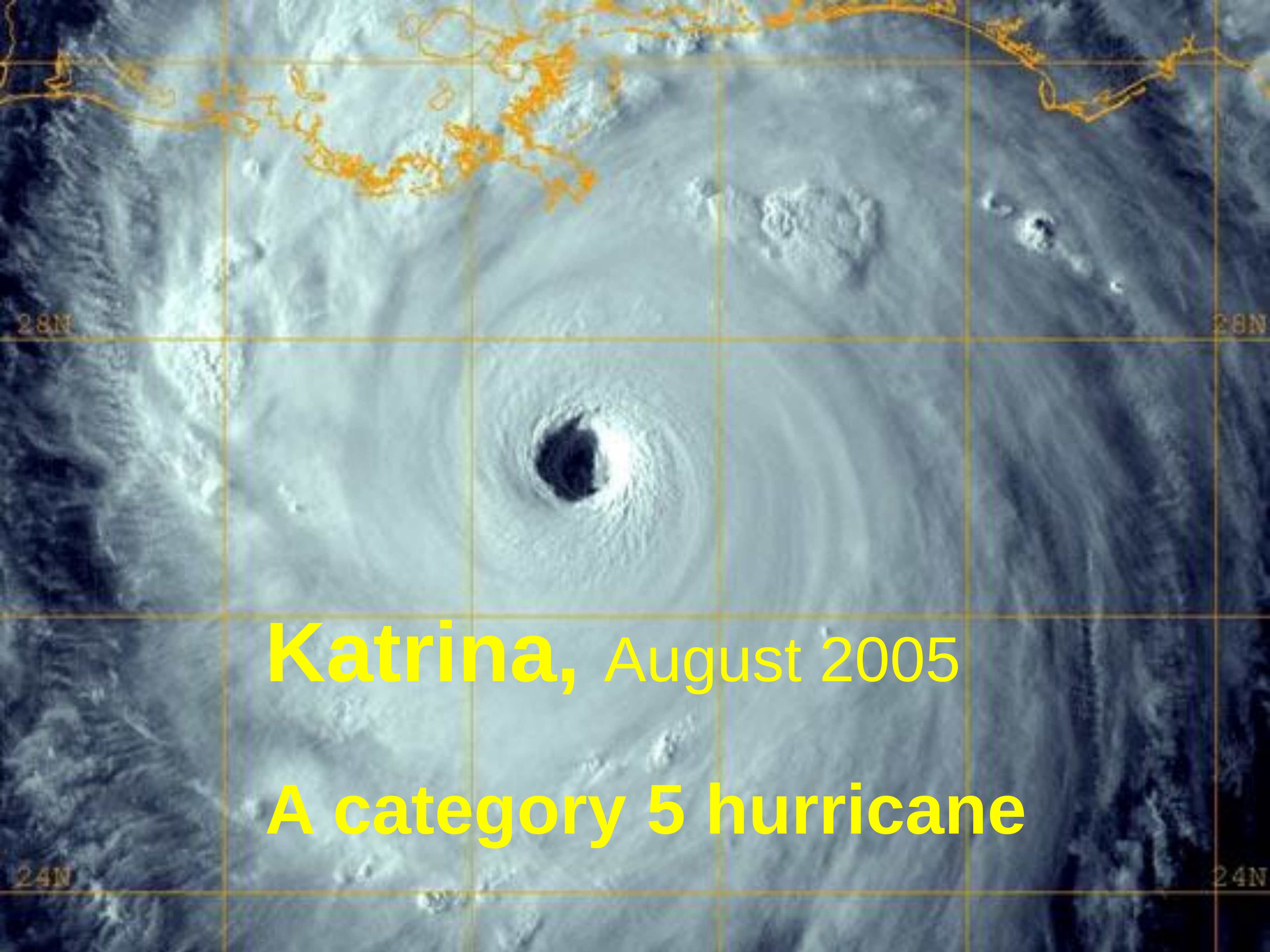
15 to 21 (5 to 7)	6 to 9 (2 to 3)	-3 to 0 (-1 to 0)	-12 to -9 (-4 to -3)
12 to 15 (4 to 5)	3 to 6 (1 to 2)	-6 to -3 (-2 to -1)	-15 to -12 (-5 to -4)
9 to 12 (3 to 4)	0 to 3 (0 to 1)	-9 to -6 (-3 to -2)	-18 to -15 (-6 to -5)



La Guardia Intl. Airport
October 2012

Figure 2. Change in Sea Surface Temperature, 1901–2012





Katrina, August 2005

A category 5 hurricane

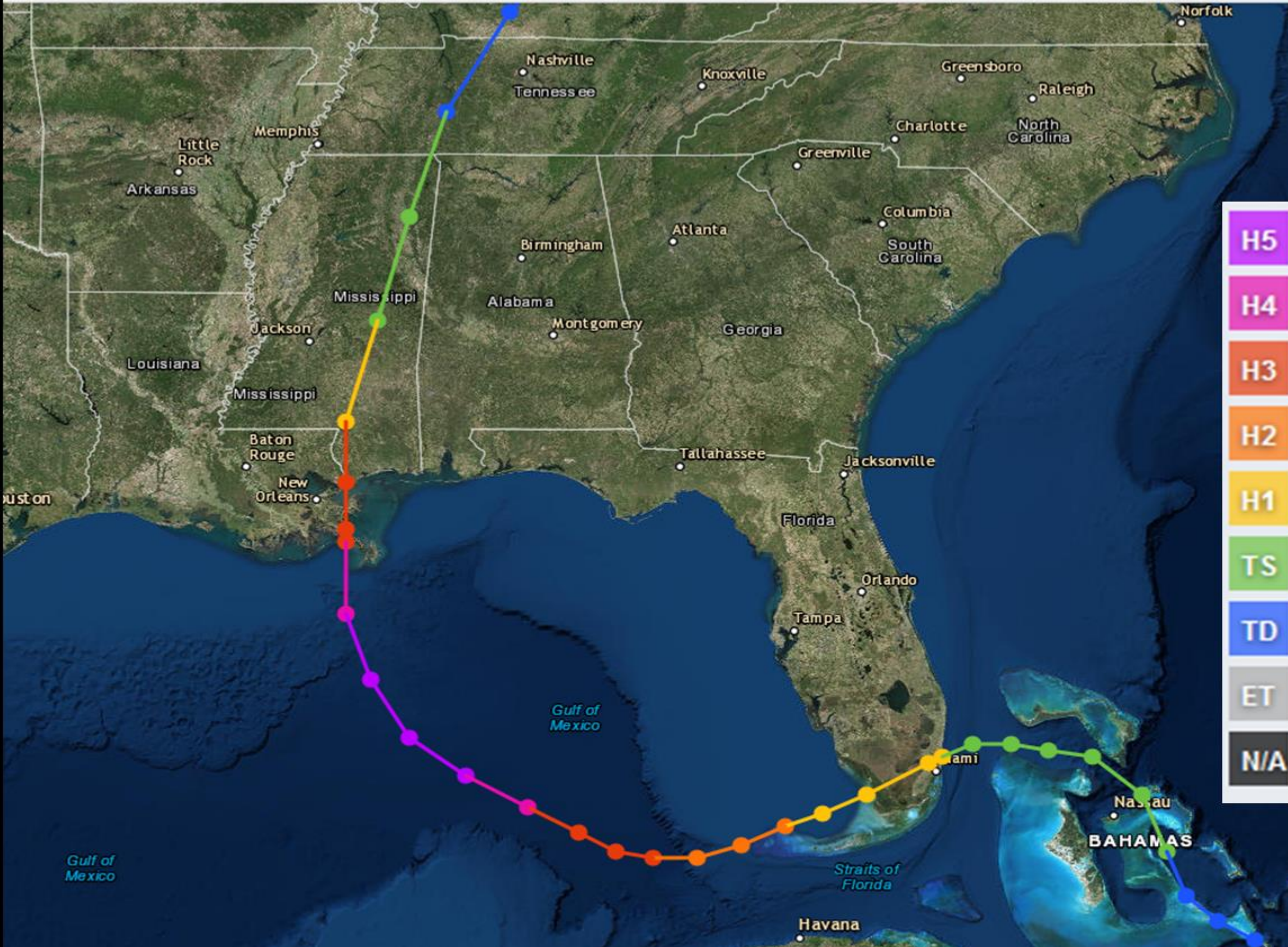

New Orleans in August 2005
after Hurricane Katrina
Damage $108 billions

Climate Change Perspective

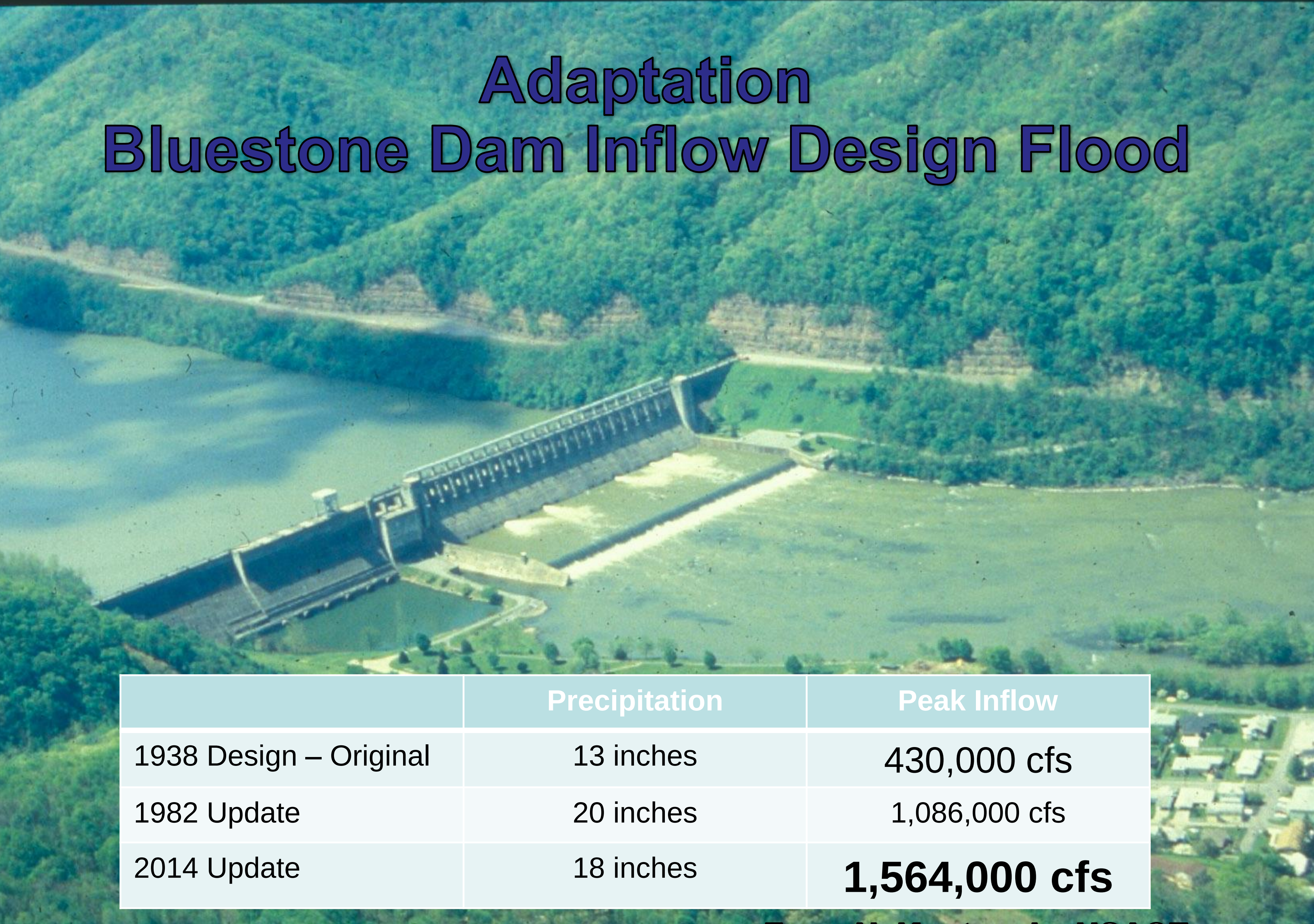
1. Snowmelt and thunderstorms
2. Extended droughts
3. Heat Island
4. Sea level rise and temperature
5. Can anything be done?


Lake Borgne Surge Barrier, New Orleans, LA
Is $1.1 billion … too much or not enough?

Historical Hurricane Tracks



Adaptation
Bluestone Dam Inflow Design Flood



	Precipitation	Peak Inflow
1938 Design – Original	13 inches	430,000 cfs
1982 Update	20 inches	1,086,000 cfs
2014 Update	18 inches	**1,564,000 cfs**

From N. Koutsunis, USACE

Structural Measures at a Glance

GENERAL COASTAL RISK REDUCTION PERFORMANCE FACTORS:
STORM SURGE AND WAVE HEIGHT/PERIOD, WATER LEVEL

Levees

Benefits/Processes

Surge and Wave attenuation and/or dissipation

Reduce Flooding

Risk Reduction for vulnerable areas

Performance Factors

Levee height, crest width, and slope

Wave height and period

Water level

Storm Surge Barriers

Benefits/Processes

Surge and Wave attenuation

Reduced Salinity Intrusion

Performance Factors

Barrier height

Wave height

Wave period

Water level

Seawalls and Revetments

Benefits/Processes

Reduce flooding

Reduce wave overtopping

Shoreline stabilization behind structure

Performance Factors

Wave height

Wave period

Water level

Scour protection

Groins

Benefits/Processes

Shoreline stabilization

Performance Factors

Groin length, height, orientation, permeability and spacing

Depth at seaward end

Wave height

Water level

Longshore transportation rates and distribution

Detached Breakwaters

Benefits/Processes

Shoreline stabilization behind structure

Wave attenuation

Performance Factors

Breakwater height and width.

Breakwater permeability, proximity to shoreline, orientation and spacing

From K. White, USACE, ETL 1100-2-1 https://corpsclimate.us


Hang on!
Are we reacting fast enough?
photo J. Obeysekera and J. Salas


But wait, some still ask:
Hm … is this climate thing for real?
Galveston Texas, Sept. 14, 2008
after Hurricane Ike

Summary and Conclusions

1. Runoff and Sediment Yield

Erosion mapping locates problem source areas

2. Dynamic Modeling

Dynamic models like TREX can simulate extreme floods

3. Flashflood Case Study

Models quantify flow parameters during extreme events

4. Climate Change

More widespread flooding from snowmelt and more extreme localized thunderstorms

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