Webinar: Tropical Engineering for Sustainable Well Being

Fakultas Teknik Universitas Mulawarman, Indonesia, 2020

Various Techniques for Measuring Streambank and Upland Erosions

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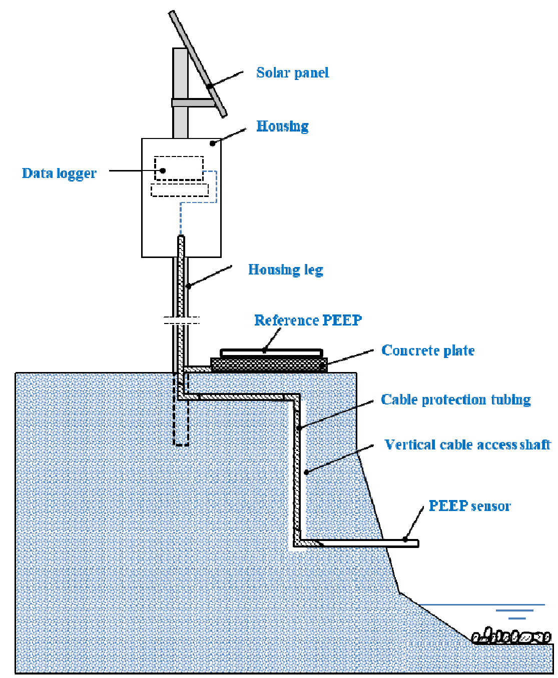


Alur Sungai Karangmumus dari Bandara A.P. Pranoto hingga Muara

Ruas Bandara – Waduk Lempake = 11 km

Ruas Waduk Lempake – Muara = 17,28 km

Benanga/ Lempake Reservoir

Multi Purpose:
- ✓Irigation
- ✓Drinking water supply (Q= 100 l/s)
- ✓Flood control
- ✓Recreation

Waduk Lempake di Ruas Tengah Sungai Karangmumus

Kondisi Awal (Tahun 1978)

Luas genangan waduk = 159 ha

Kedalaman genangan rata-rata = 1,5 m

Kapasitas tampung waduk = 2,39 juta m^3

Fungsi waduk = irigasi sawah 350 ha

Kondisi Tahun 2015

Luas genangan waduk = 110 ha

Kedalaman genangan rata-rata = 0,52 m

Kapasitas tampung waduk = 567.000 m^3

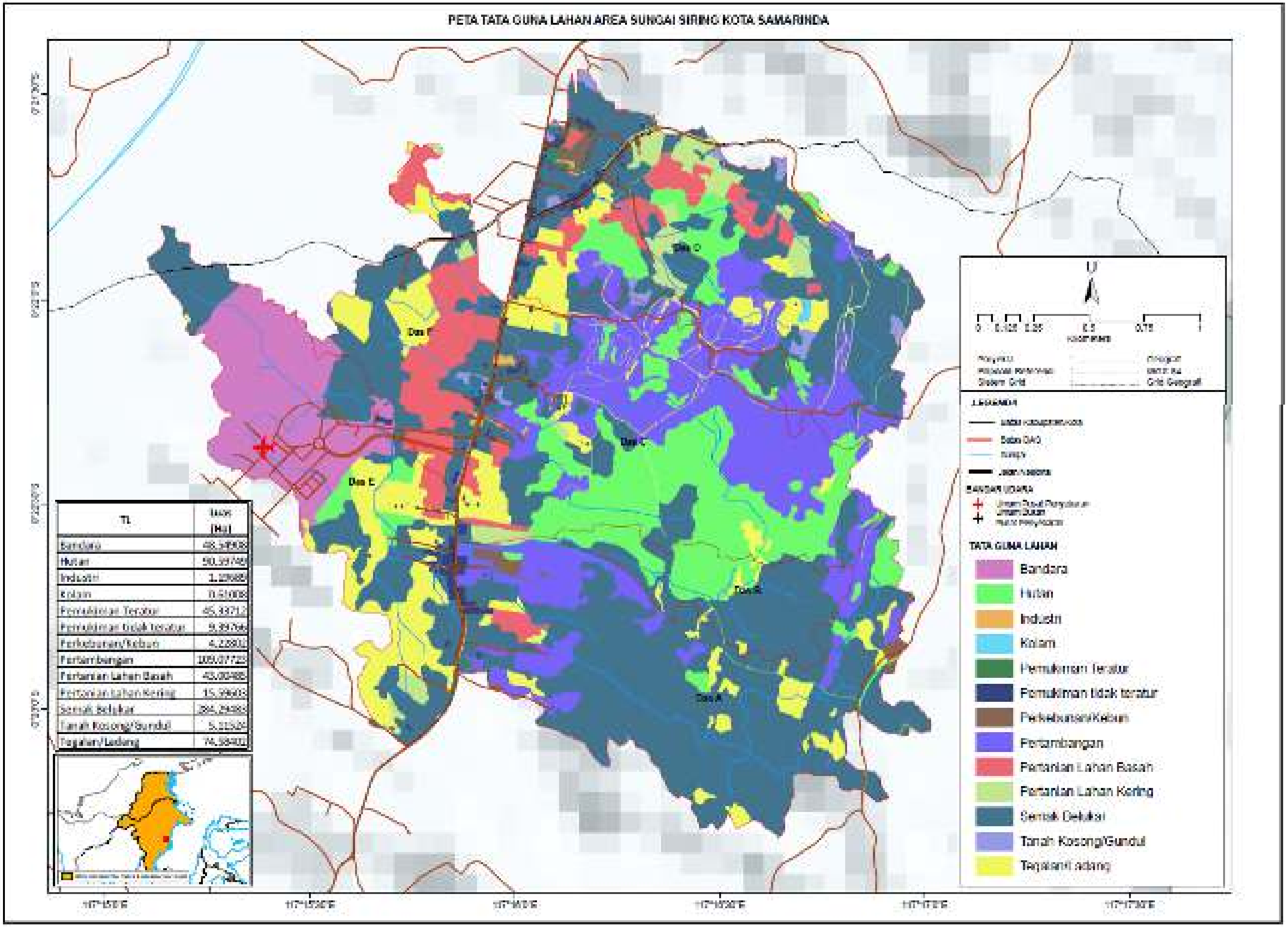
Fungsi waduk = irigasi sawah 350 ha, PDAM 100 l/det, objek wisata

Laju sedimentasi waduk = 49.270 m^3/tahun

Penyusutan kapasitas tampung waduk = 2,1% per tahun (rata-rata dunia 1%, Zarfl, C. dan Lucia, A. (2018): "The connectivity between soil erosion and sediment entrapment in reservoirs." *Current Opinion in Environmental Science & Health,* 2018, doi: 10.1016/j.coesh.2018.05.001.

Pembukaan lahan di hulu Sungai Karangmumus sangat masif

Kegiatan tambang batubara mendominasi pembukaan lahan di hulu Sungai Karangmumus



TL	Luas (Ha)
Bandara	48.54908
Hutan	50.59748
Industri	1.29688
Kolam	0.61008
Pemukiman Teratur	45.33712
Pemukiman tidak teratur	9.39766
Perkebunan/Kebun	4.22802
Pertambangan	109.07723
Pertanian Lahan Basah	43.00488
Pertanian Lahan Kering	15.99603
Semak Belukar	284.29083
Tanah Kosong/Gundul	5.31524
Tegalan/Ladang	74.98402

Pegerukan (dredging) Waduk Lempake

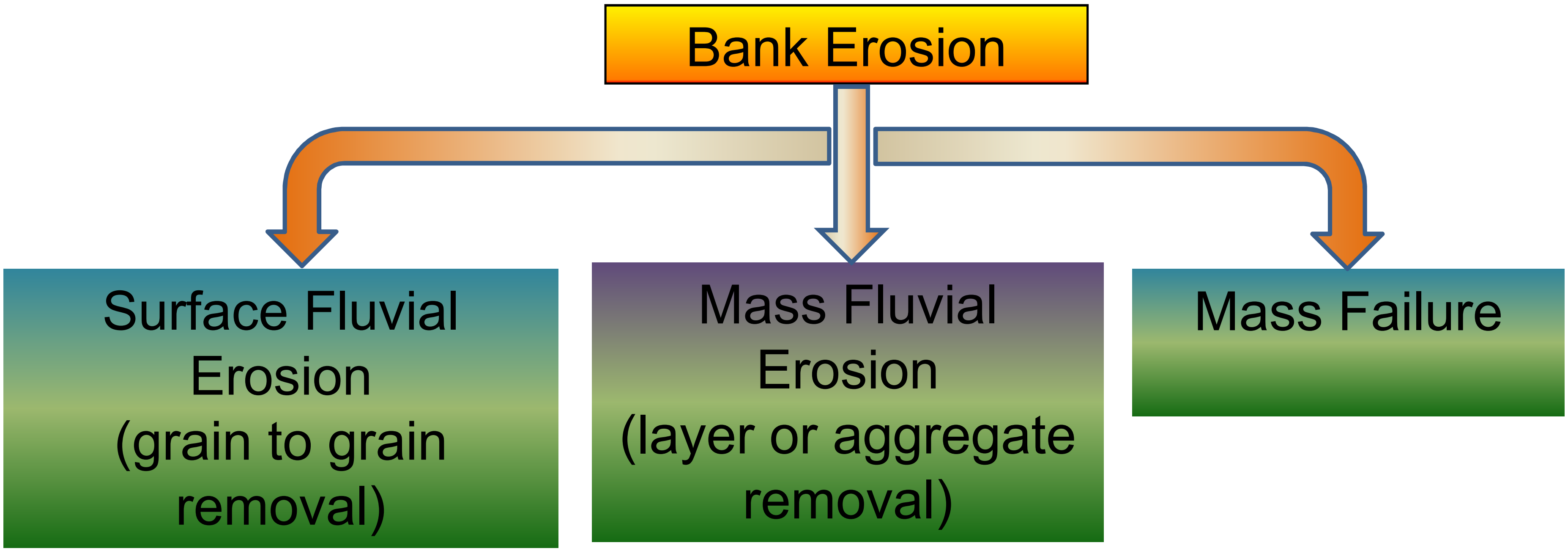
Untuk mengembalikan kapasitas tampung Waduk Benanga diperlukan biaya pengerukan Rp. 60 Milliar atau $ 4,28 Juta.

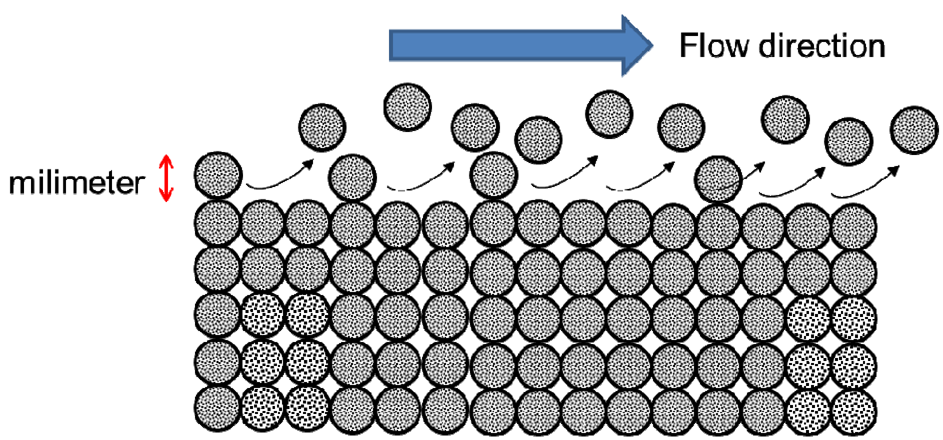
Erosi tebing sungai Karangmumus di ruas Lempake (middle stream)

Bank erosion recorded at middle reach of Clear Creek, IA.

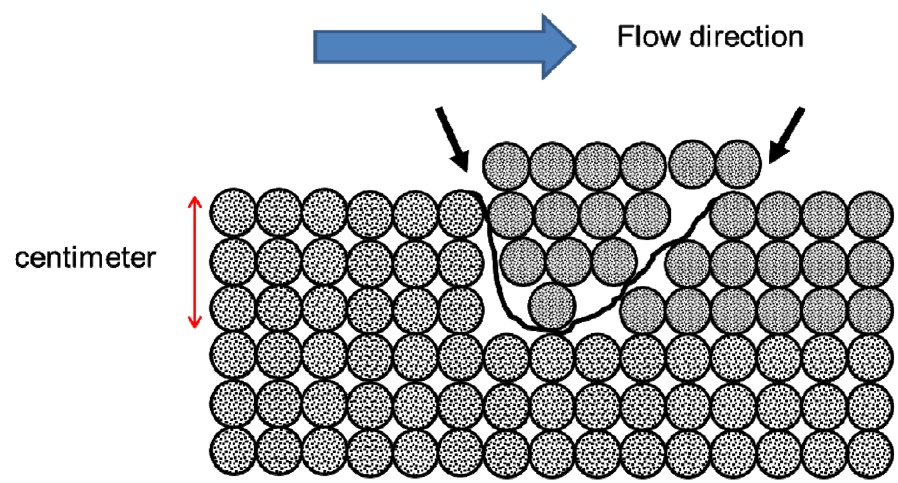
Pengerukan sungai akan menjadi kegiatan rutin di hilir Karangmumus

Different Modes of Bank Erosions





Surface fluvial erosion

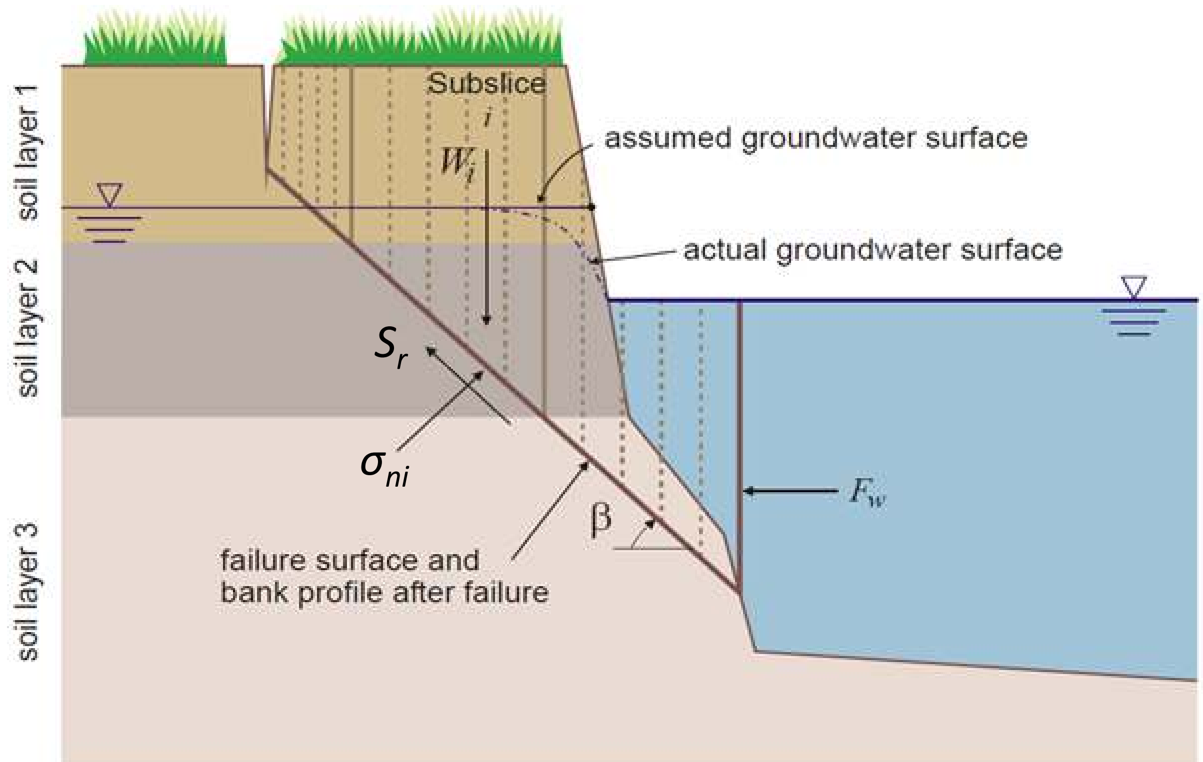


Mass fluvial erosion

Mass failure occurred in Karangmumus stream bank at Lempake

Mass Failure

The en masse collapse of a soil block is determined by the relationship between driving and resisting forces:

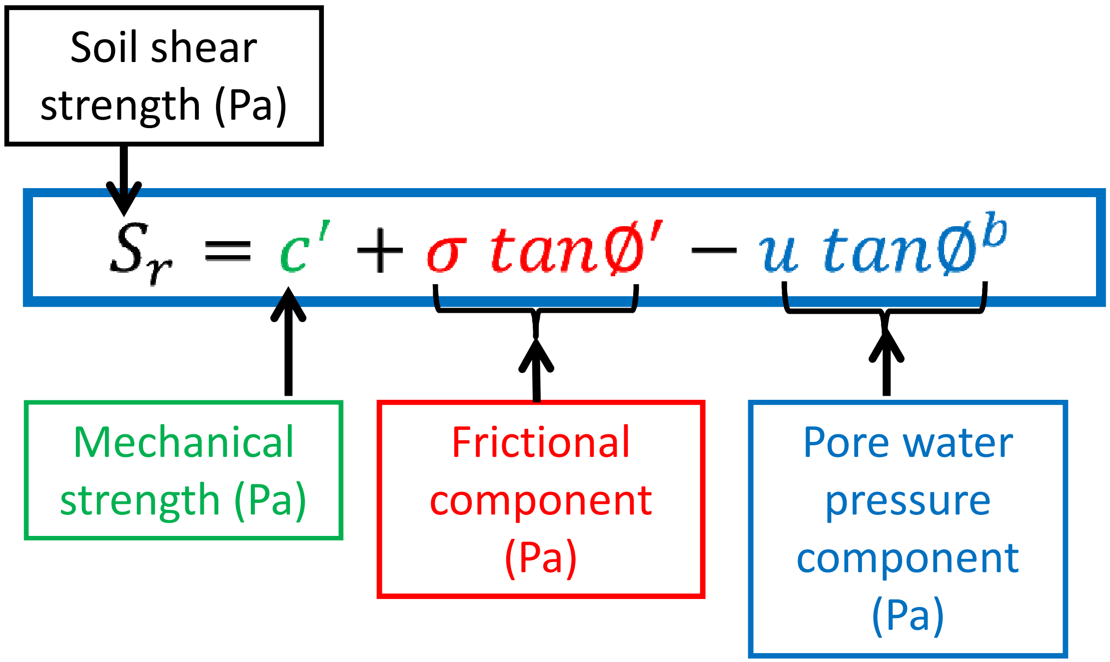


Driving forces: Soil bulk weight, *W*

Resisting forces:

- ✓ Root
- ✓ Soil shear strength, S_r
- ✓ Temporary confining pressure of the stream water, F_w

According to the Mohr-Coulomb theory, the shearing strength of a soil block, , is dependent on the internal friction angle, , and mechanical strength, . The soil shear strength, , is written as follows:



$$S_r = c' + \sigma \tan\emptyset' - u \tan\emptyset^b$$

Where:

c' = mechanical strength (Pa)

σ = normal stress produced by the weight of the soil block (Pa)

$\emptyset'$ = internal friction angle (degrees)

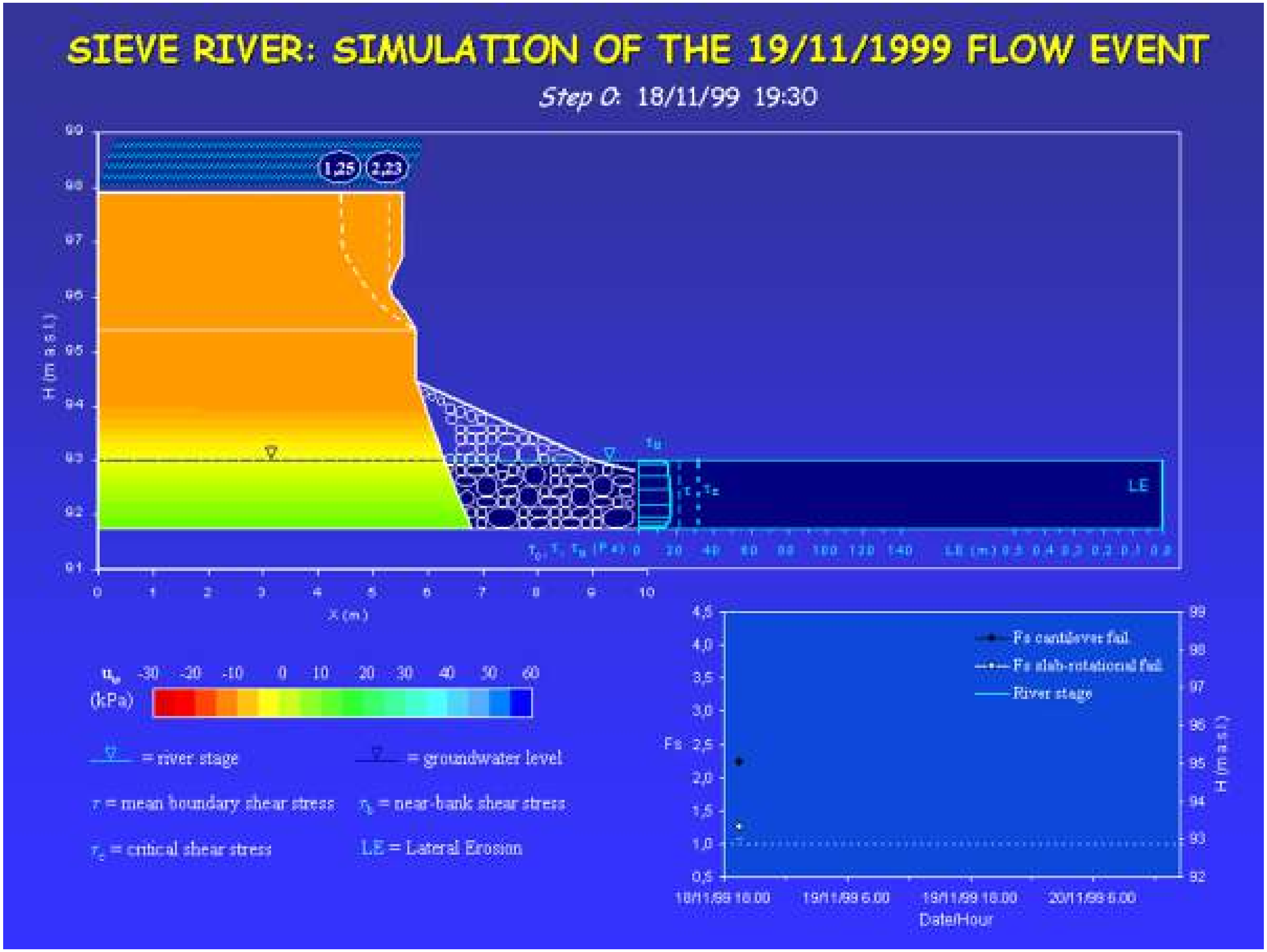
u = soil pore water pressure (Pa)

$\emptyset^b$ = matric suction angle (degrees)

How important processes are fluvial erosion?

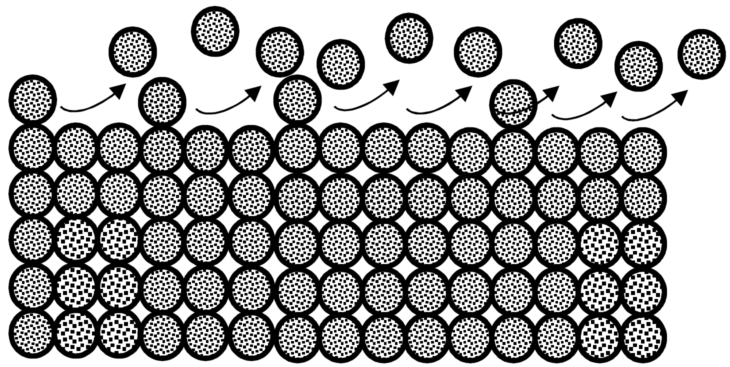
Fluvial erosion can be precursors to mass failure by eroding the basal layer of the bank (bank toe undercutting). Not considering fluvial erosion in bank stability analysis will lead to underestimation of mass failure.

Bank retreat is a product of a combination of fluvial erosion and mass failure.



Source : Massimo Rinaldi

The rate of surface fluvial erosion, E_{sf}, in kg/m^2/s can be determined by an excess shear stress formula:



$$E_{sf} = M_{sf}\left(\frac{\tau_w}{\tau_{c,sf}} - 1\right)^m$$

Rate of erosion (kg/m^2/s)

Erodibility coefficient for surface fluvial erosion (kg/m^2/s)

Near bank or side wall shear stress (Pa)

m = 1 for consolidated and aged, cohesive soils.

Critical shear stress for surface fluvial erosional (Pa)

Surface fluvial erosion

The rate of mass fluvial erosion, E_{mf}, in kg/m^2/s can be determined by an excess shear stress formula:

Erodibility coefficient for mass fluvial erosion (kg/m^2/s)

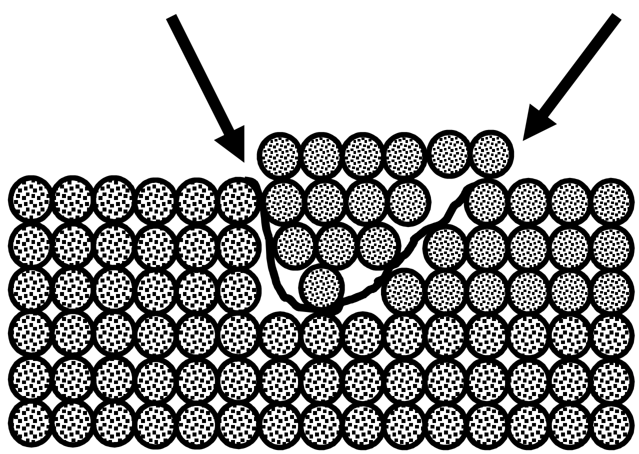
Near bank or side wall shear stress (Pa)

m = 1 for consolidated and aged, cohesive soils.

Rate of mass erosion (kg/m^2/s)

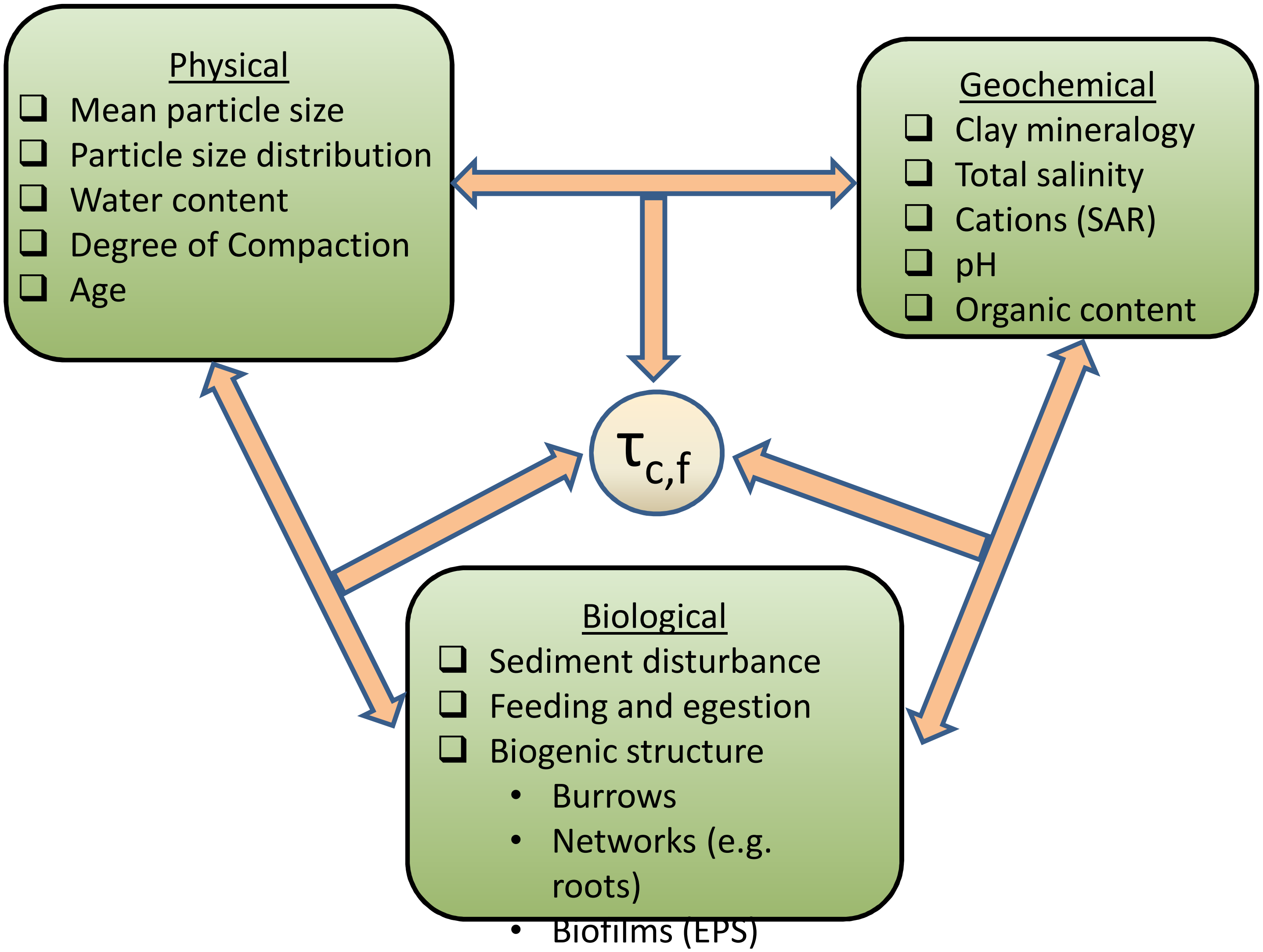
$$E_{mf} = M_{mf}\left(\frac{\tau_w}{\tau_{c,mf}} - 1\right)^m$$

Critical shear stress for mass fluvial erosional (Pa)



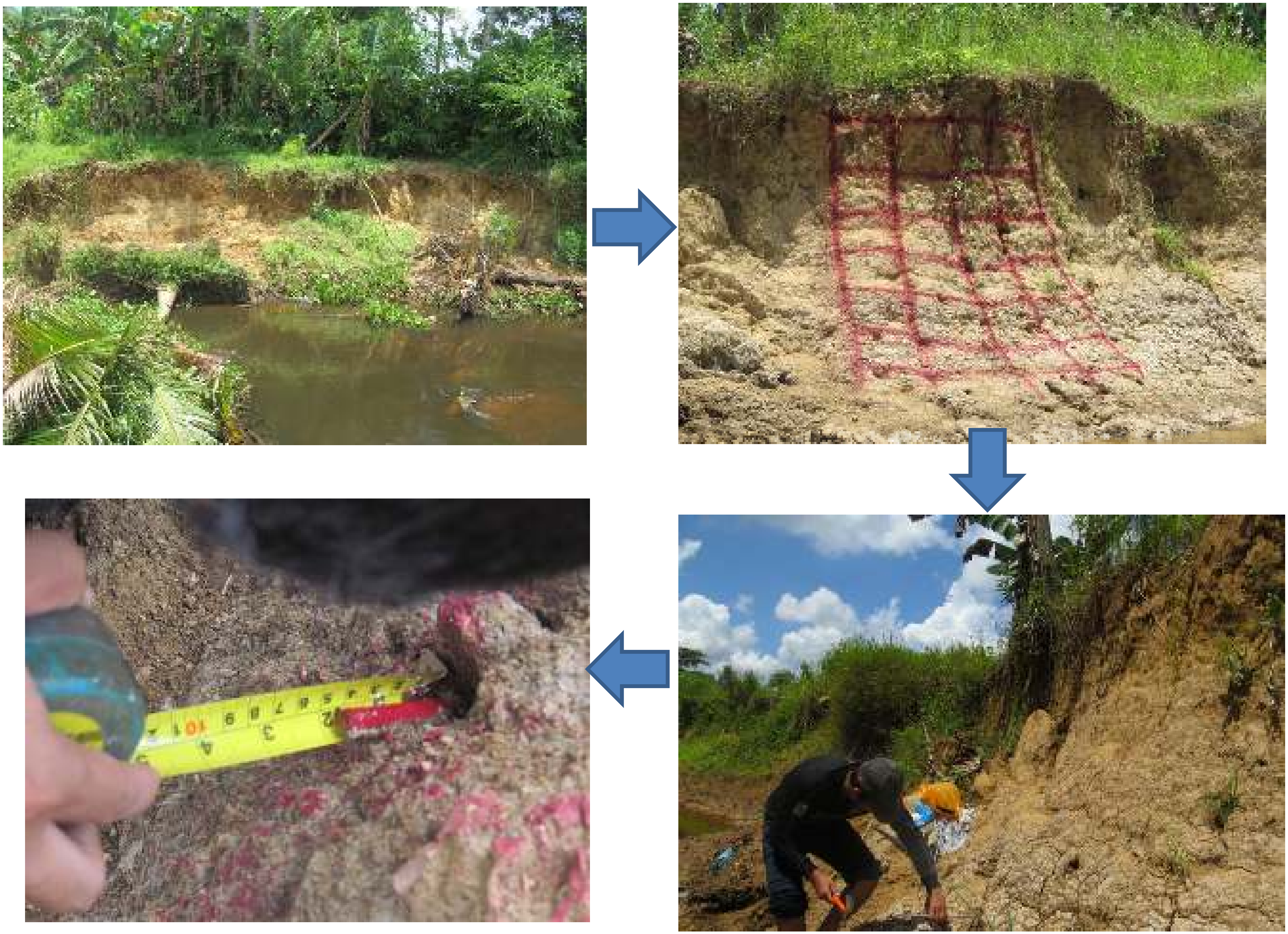
Mass fluvial erosion

Fluvial erosional strength, $\tau_{c,f}$, is the product of inter-particle forces of attraction or repulsion, including electrostatic, van der Waals, hydration, and biological forces.

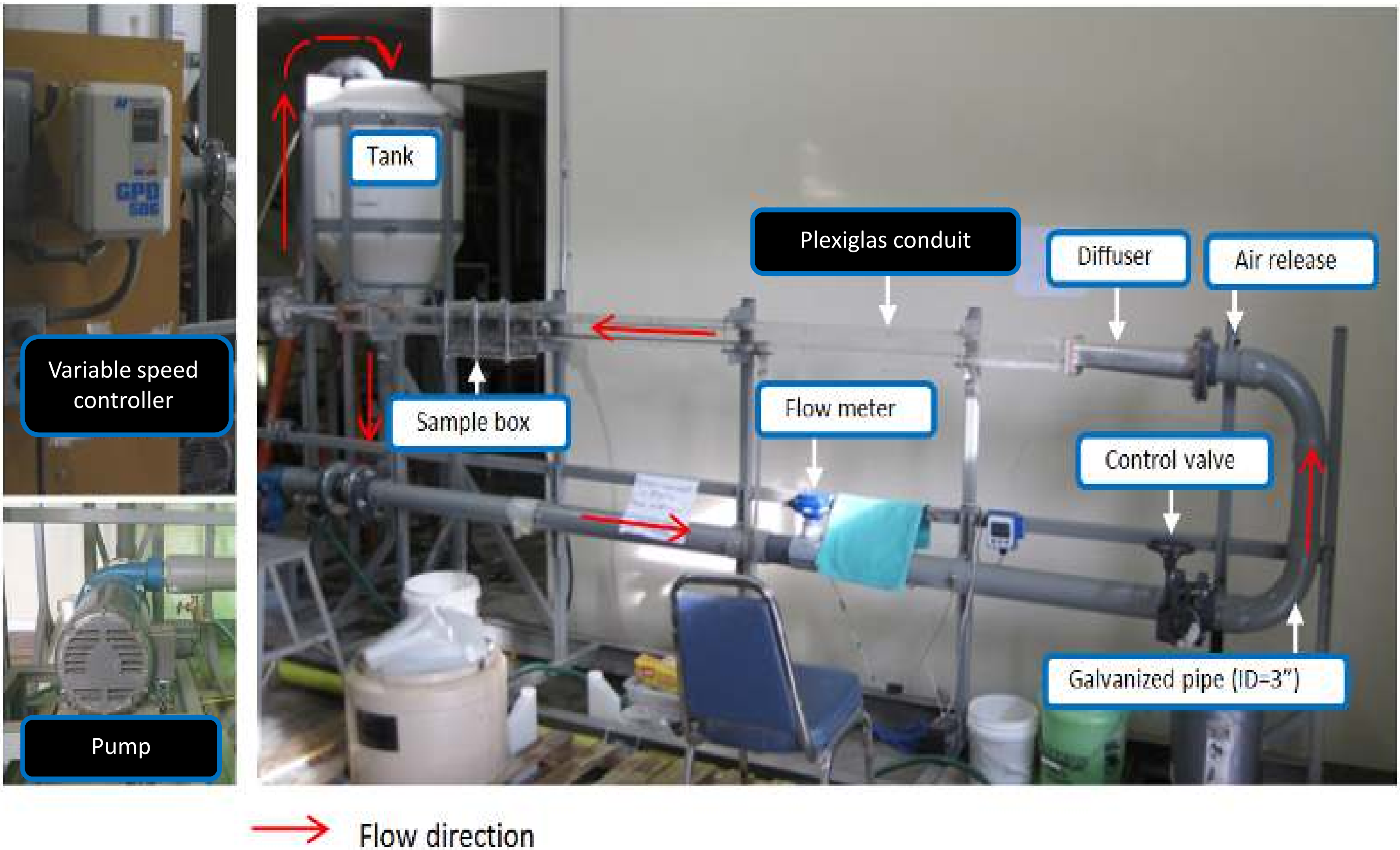


Conceptual model of the soil properties and mechanisms affecting fluvial erosional strength of bank soils (Grabowski, 2011).

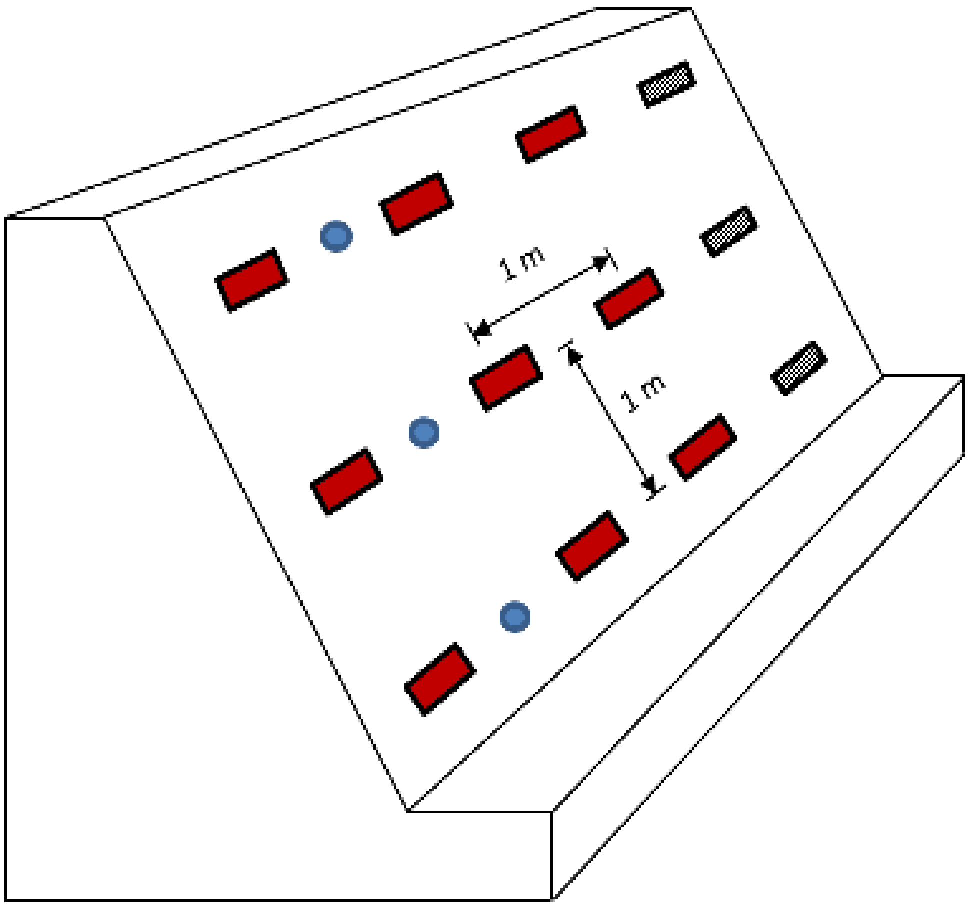
Erosion Pin was used to measure bank retreat directly on the field.



Flume Technique for Estimating Critical Shear Stress for Surface Fluvial Erosion



Soil sample extractions for laboratory analysis



Samples (L=35 cm, W=20 cm, H=15 cm) for conduit flume tests

Samples (L=35 cm, W=20 cm, H=15 cm) for gamma attenuation tests

Shelby tube samples (L 40 cm, D 7.62 cm) for index property and direct shear tests

Soil sample extraction

Soil sampling procedure for conduit flume and gamma attenuation tests.

A Soil block (35 cm x 20 cm x 15 cm) was cut from the bank.

The bottom side was cut using a wire saw.

A box was used to store the soil block.

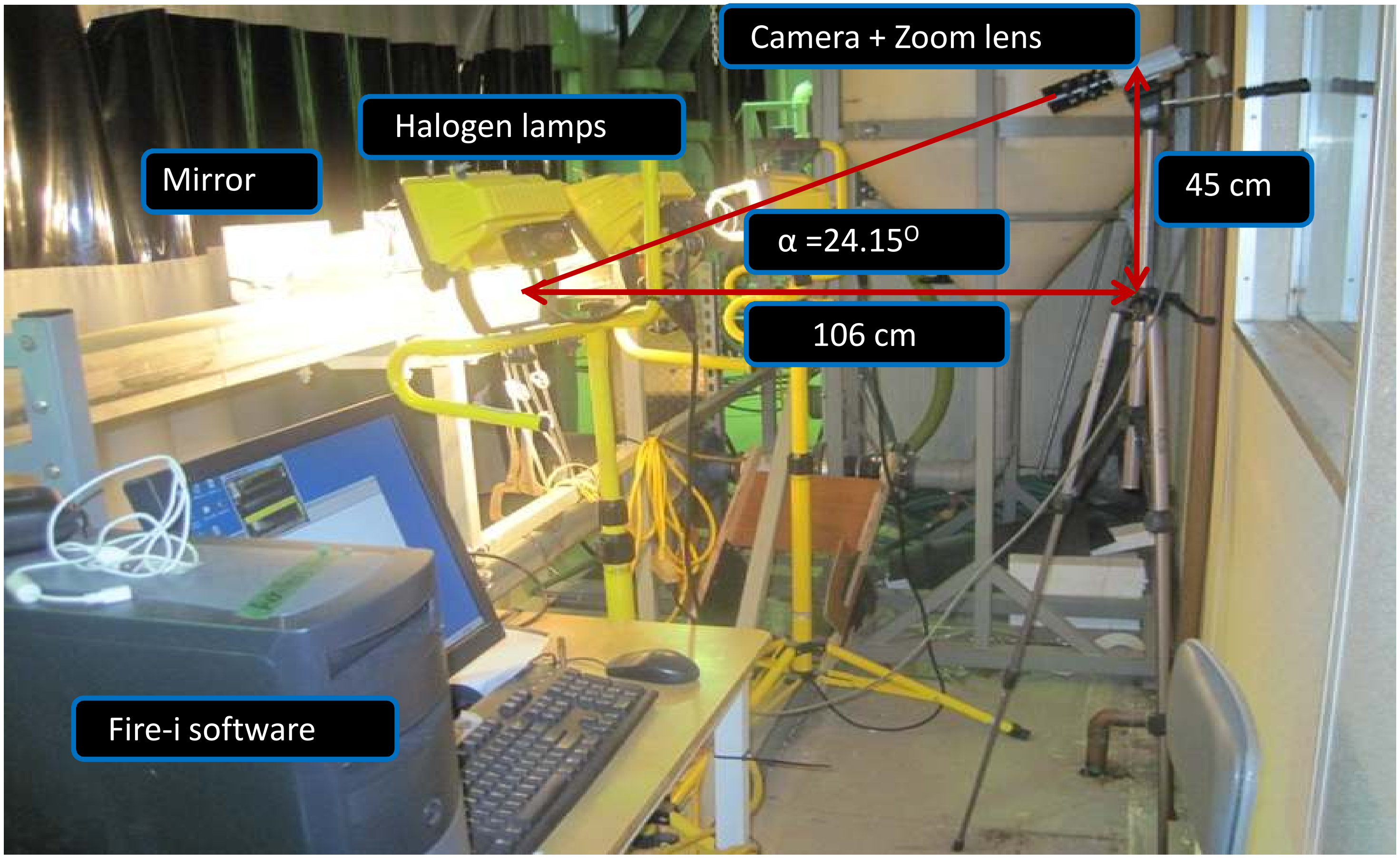
The soil block was placed in the box using a long bladed knife.

The soil block was covered with plastic sheet and stored in a box.

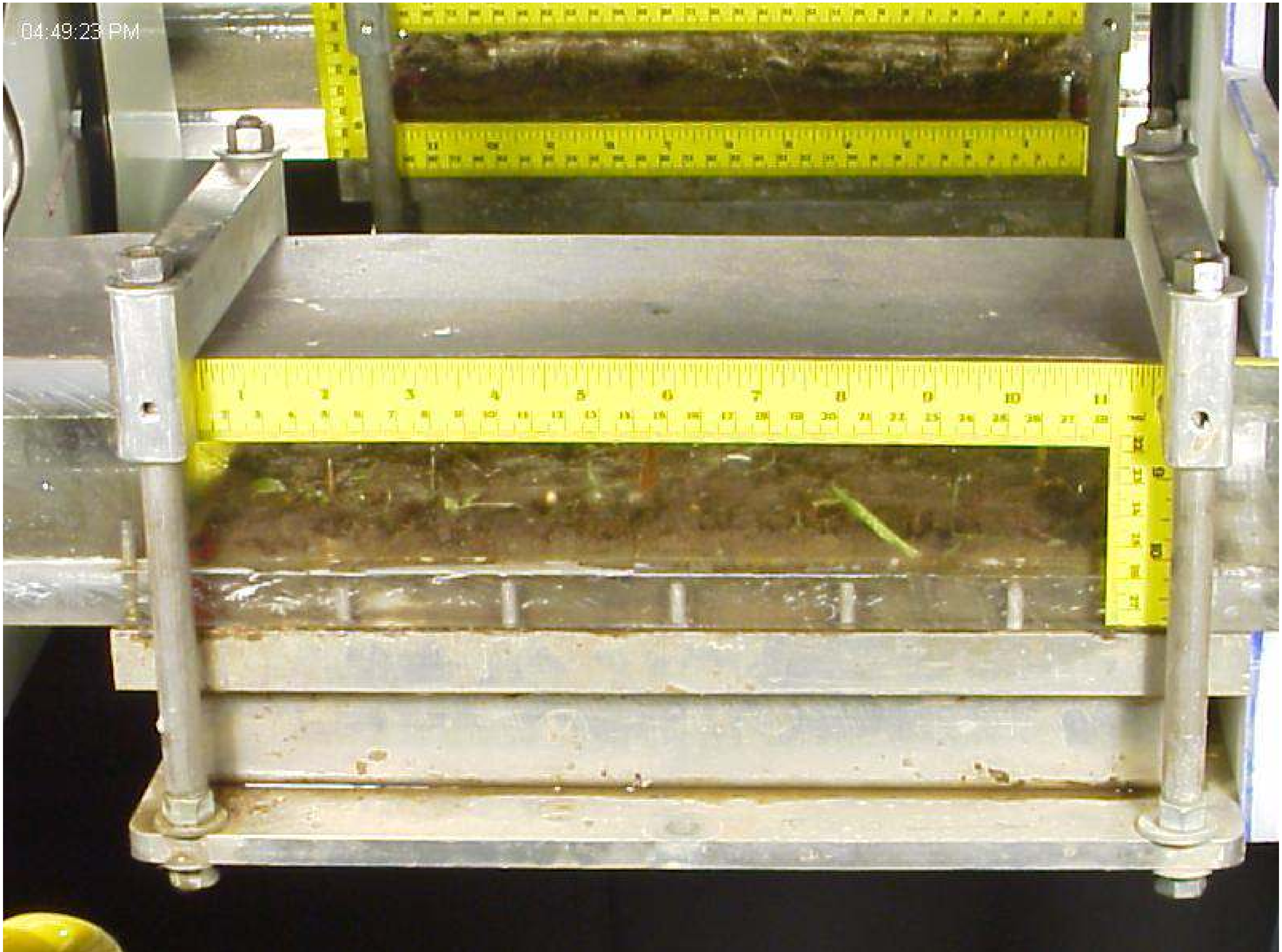
The soil block was wrapped with cheese cloth and waxed.

Flume Test Preparation: Soil Sample Preparation

Imaging Technique



- The imaging technique was used to capture the reduction of soil due to erosion in the high temporal resolution.
- The camera resolution is 1024 x 768 pixels.
- The camera, zoom lens, and the mirror are adjusted to capture both sides of the sample with good resolution.
- Fire-i software was used to control the camera for video capturing and frame grabbing properties.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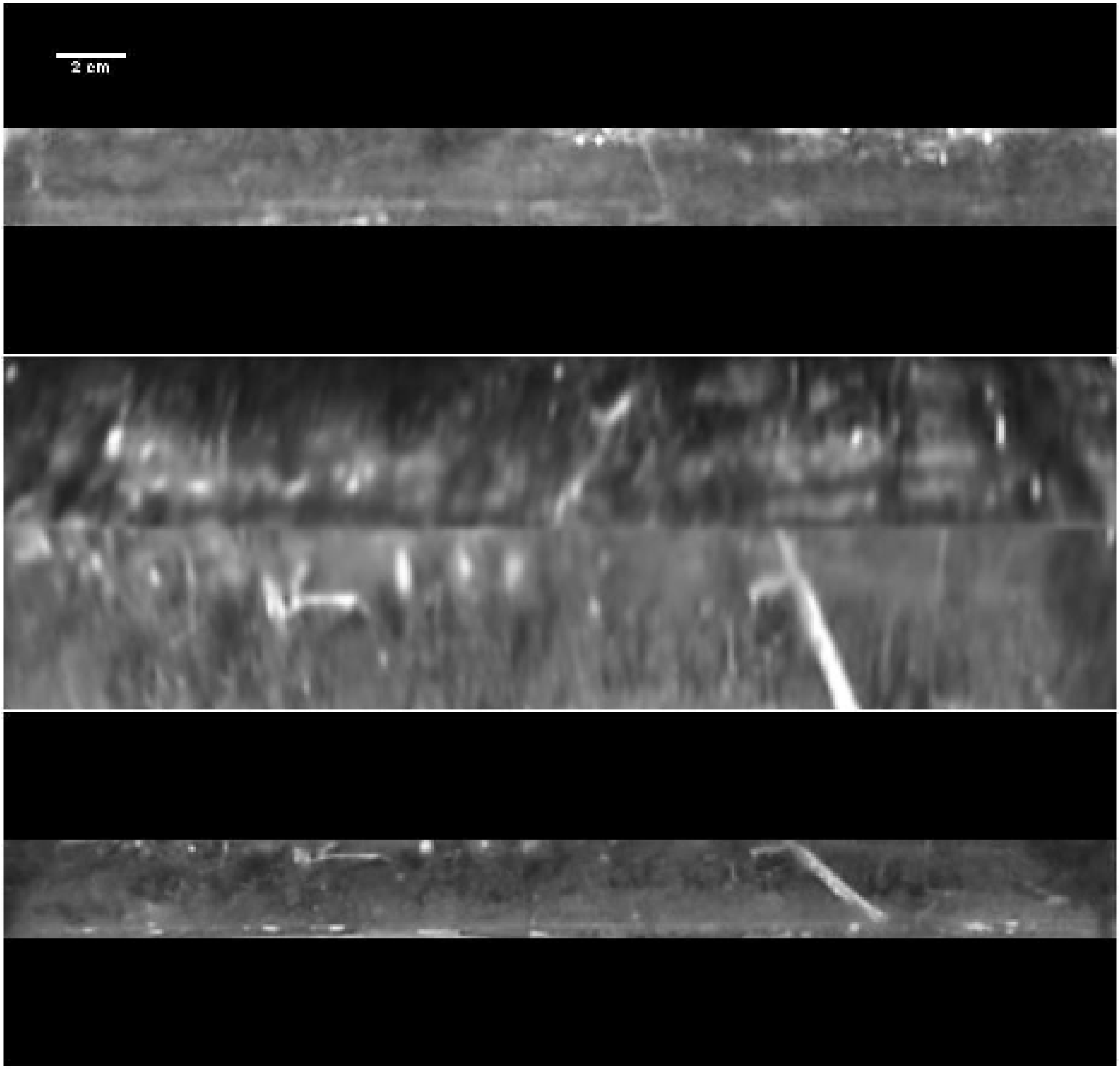
Fluvial erosion process recorded in a flume



Imaging Technique

- Image sequences (Δt = 2 minutes) showing the reduction of soil area due to erosion:

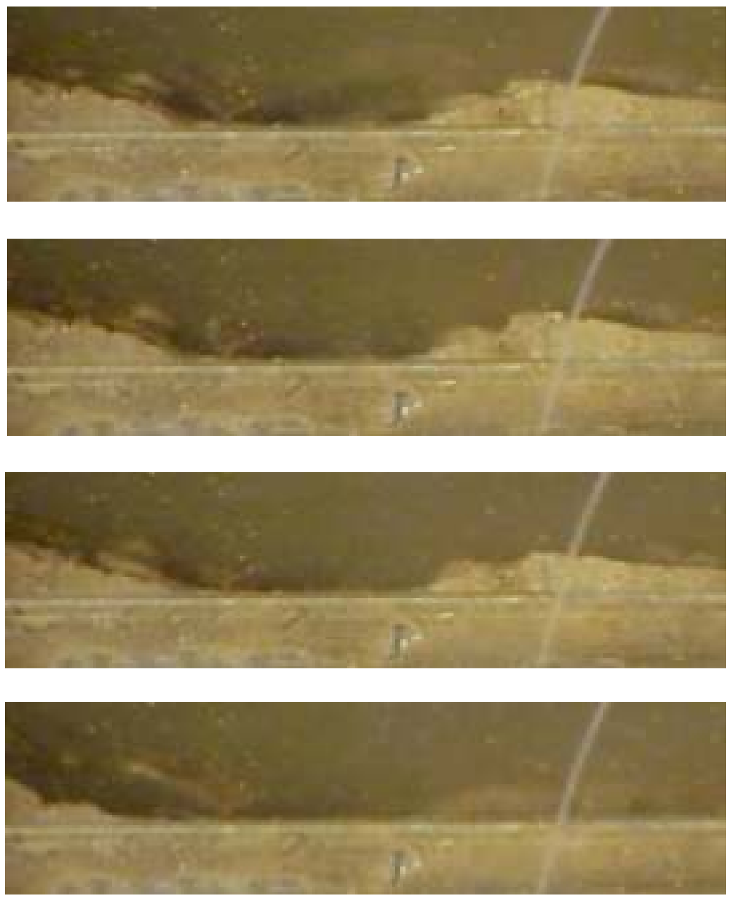
Original Frames Captured by the Camera

1

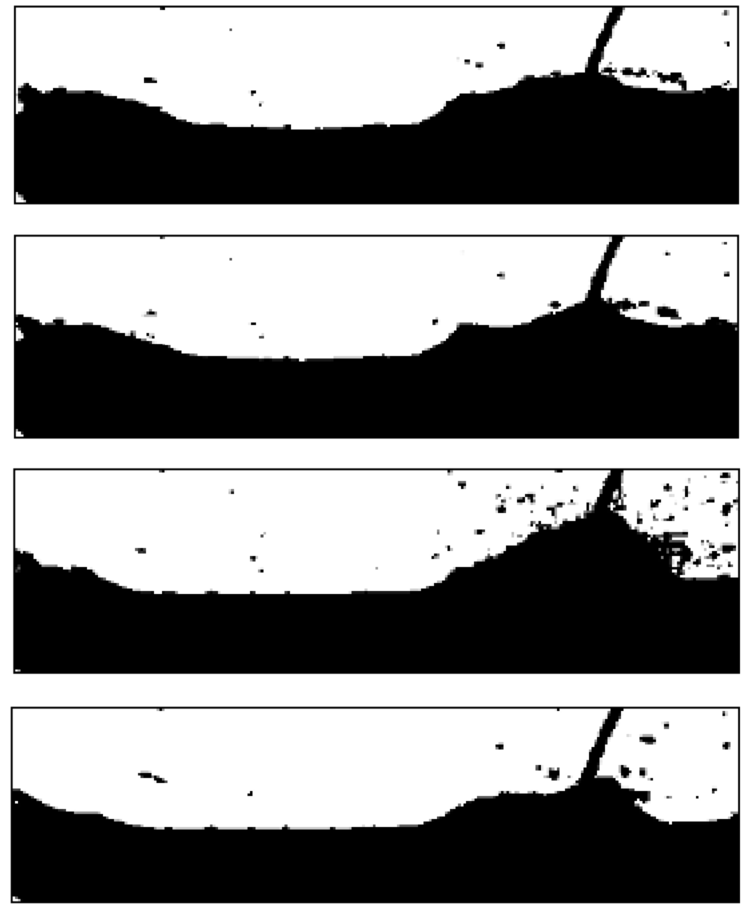
2

3

4



Binary Images

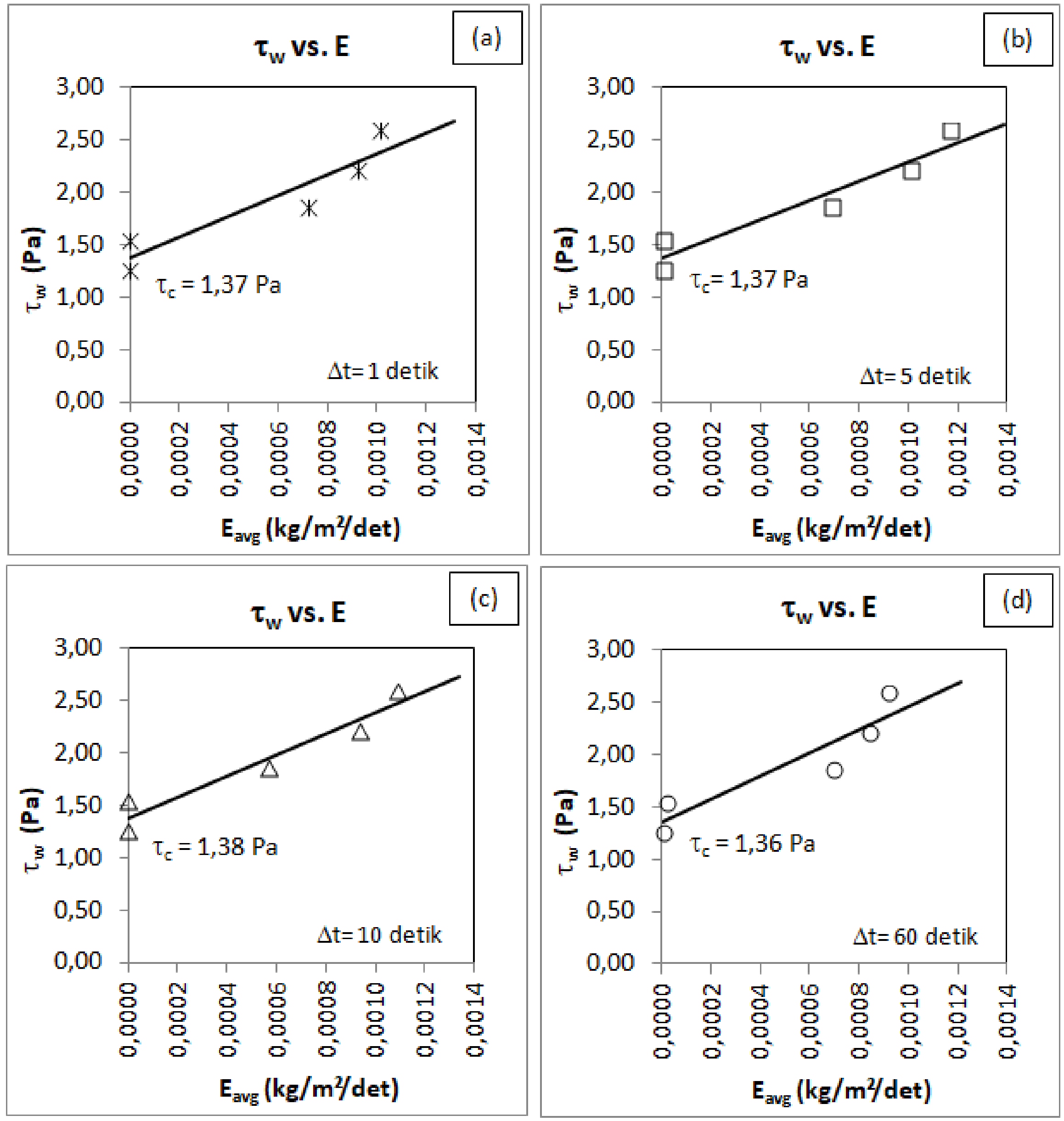


[redacted]

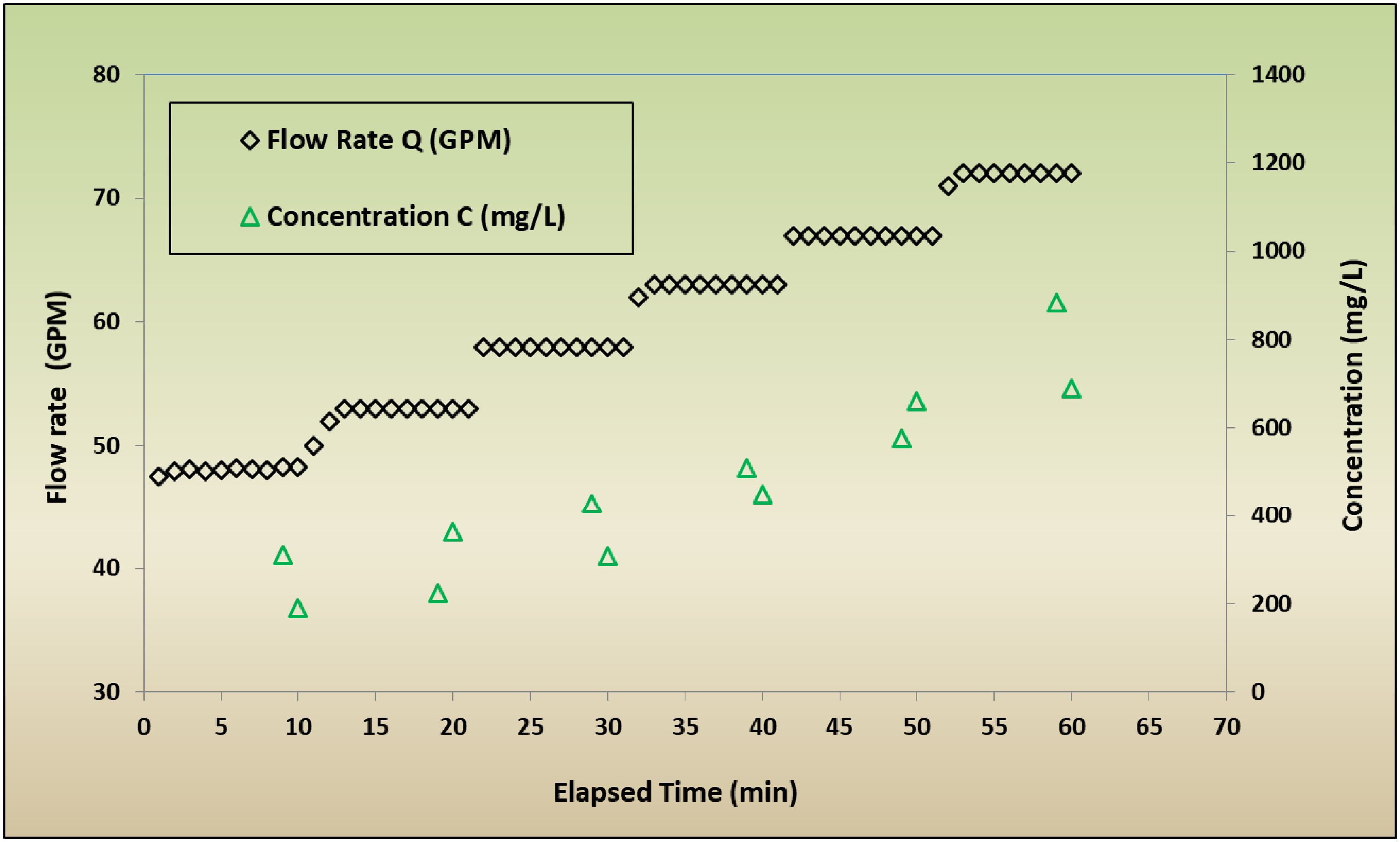
$$\tau = \frac{\rho U^2}{8} f$$

$$E_{(n)} = \frac{A_{(n)} - A_{(n-1)}}{L * \Delta t} \rho_s$$

Contoh grafik hubungan antara τ_w vs. E_{avg} hasil experimen saluran konduit erosi untuk satu sampel tanah. Laju erosi E_{avg} diperoleh dari analisa frame gambar berurutan dengan interval: (a) $\Delta t = 1$ detik, (b) $\Delta t = 5$ detik, (c) $\Delta t = 10$ detik, dan (d) $\Delta t = 60$ detik. Tegangan gesek kritis atau kuat gesek erosif tanah τ_c *adalah nilai tegangan gesek pada* $E_{avg} = 0$.



A typical result of conduit flume test



$$E = \frac{\Delta C * Q}{A}$$

$$\tau = \frac{\rho U^2}{8} f$$

The $\tau_{c,sf}$ and M_{sf} are determined graphically based on conduit flume test result.

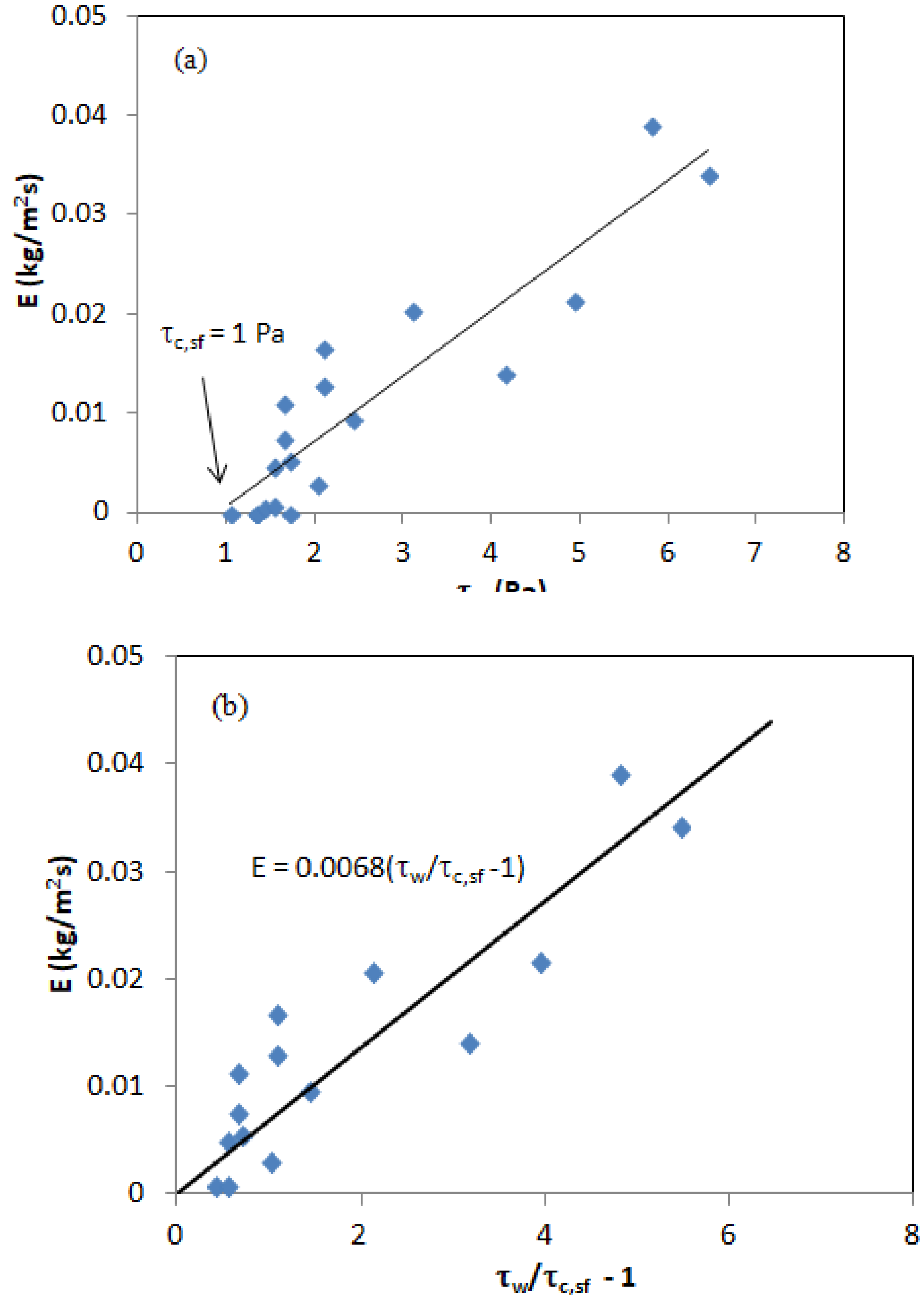


Photo Electronic Erosion Pin (PEEP) was used to measure mass fluvial erosion directly on the field.

Description	Photo-resistant PEEP
Manufacturer	Rickly Hydrological Co.
Tube length (cm)	55
Total sensor length (cm)	59
Active length (cm)	21.45
Tube external diameter (cm)	1.8
Number of cells in series	13
Number of reference cells	0
Number of thermistors	0
Spacing between neighboring cells (cm)	1.65
Reference cell output(mV)	0 - 1
Cell series output (mV)	0 - 1

Ideal size for measuring mass erosion that cause bank retreat in the order of centimeters.

PEEP set-up

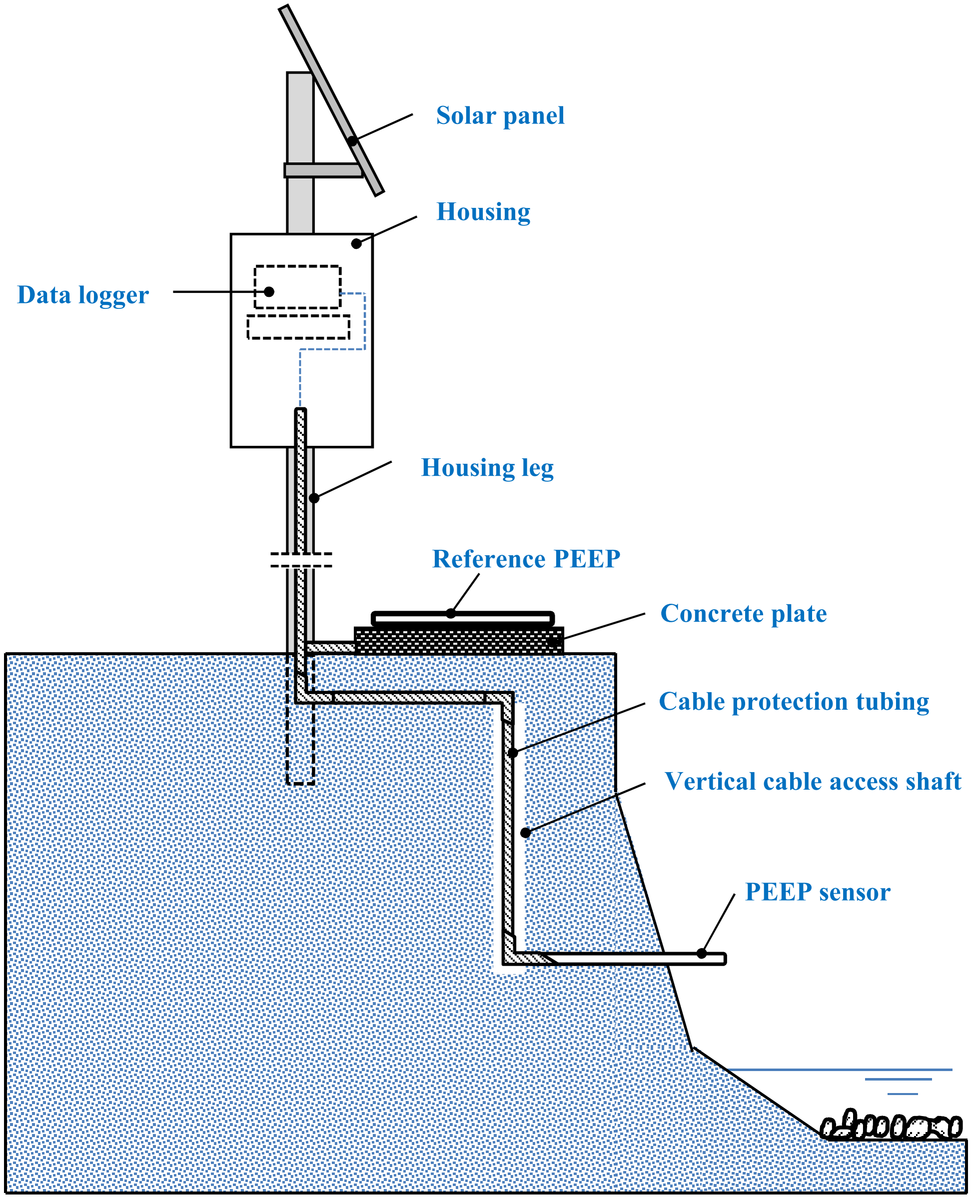
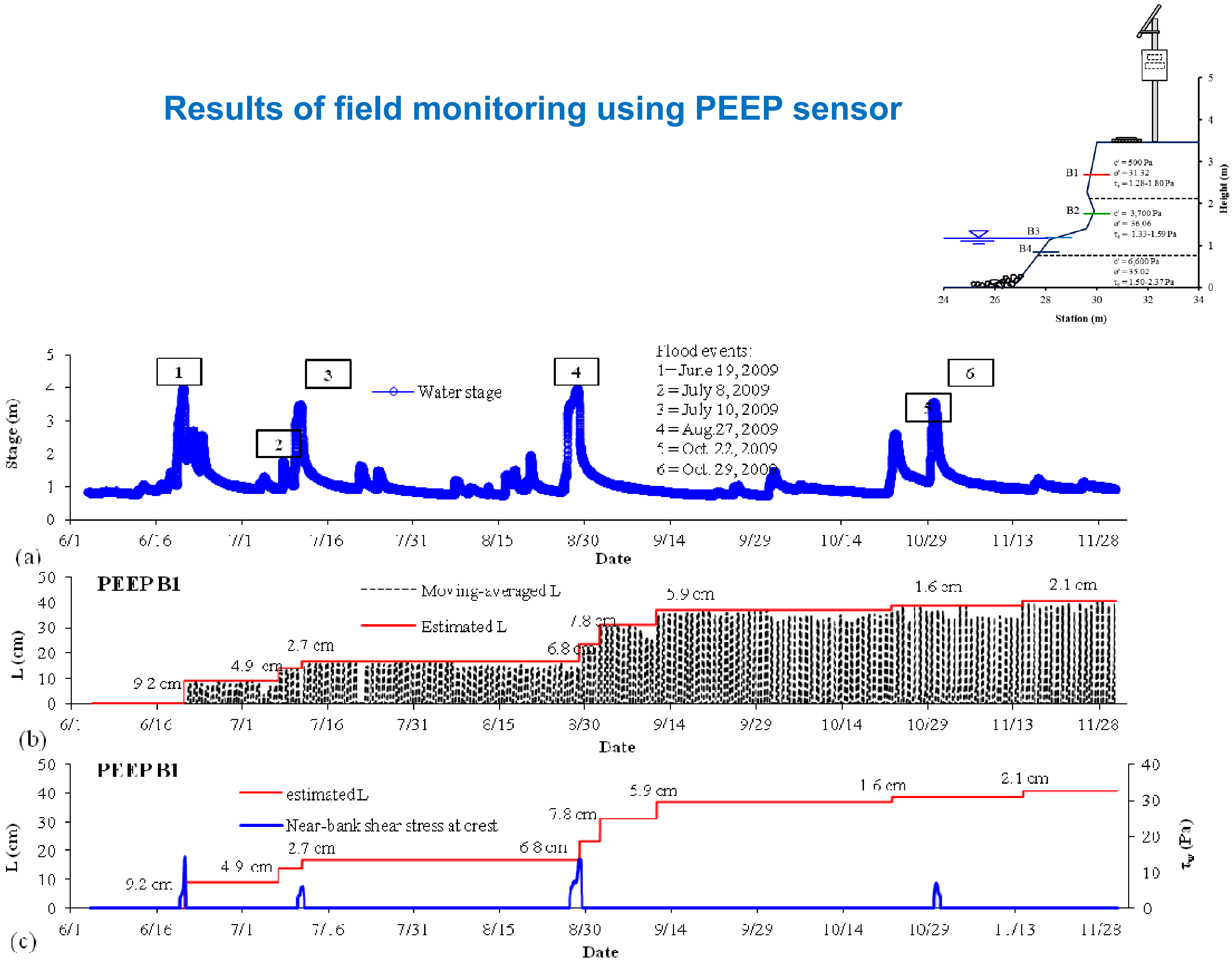


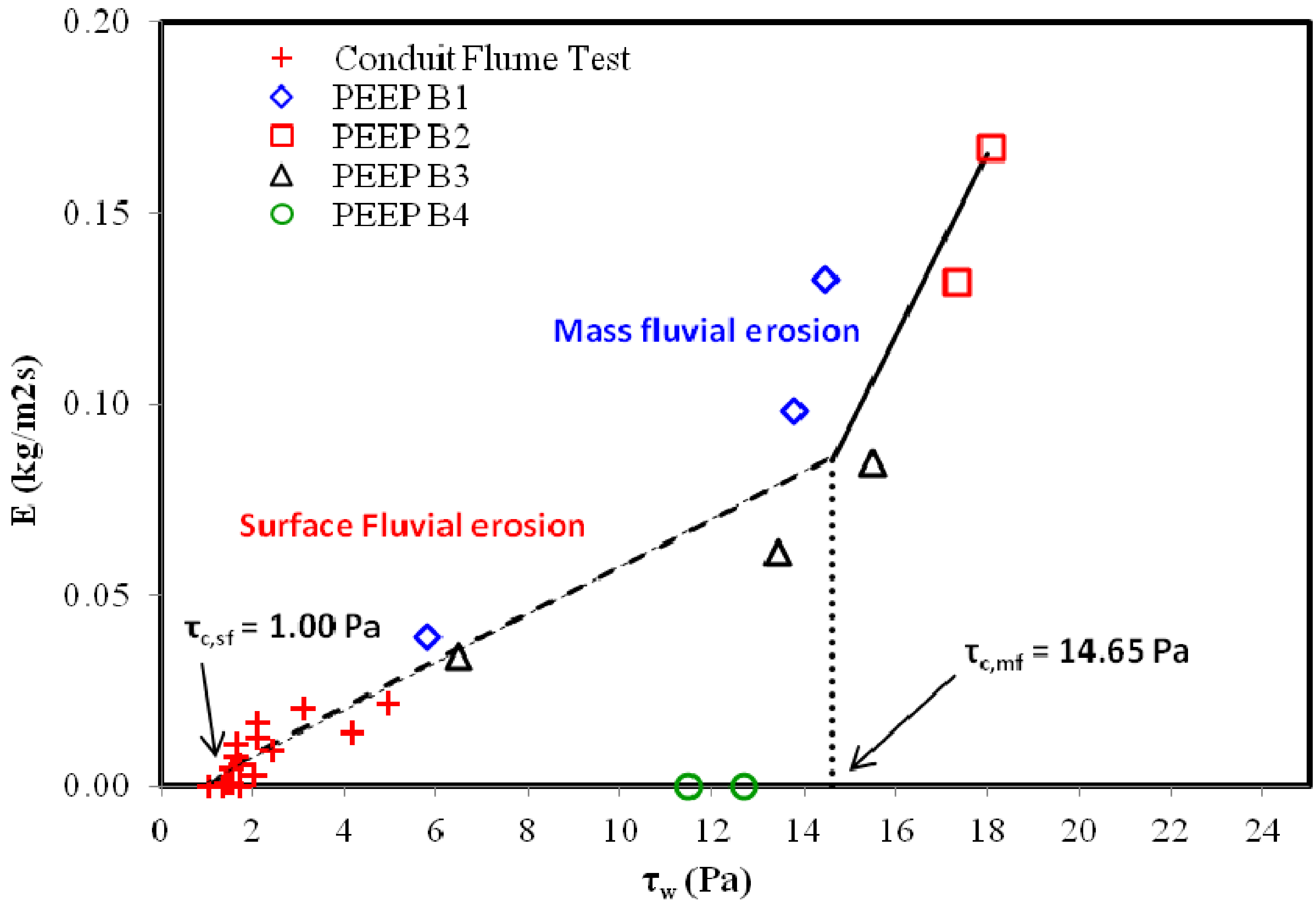
Photo resistant PEEP

PEEP exposure length

Results of field monitoring using PEEP sensor



Surface and mass fluvial erosion regimes.



More details can be refered in:

Papanicolaou, A.N., Wilson C.G., Tsakiris, A.G., **Sutarto, T.E**., Bertrand, F., Rinaldi, M., Dey, S., Langendoen, E., 2017. "Understanding mass fluvial erosion along a bank profile: Using PEEP technology for quantifying retreat lengths and identifying the event timing". *Earth Surface Processes and Landform 42(11):1717-1732*. Doi: 10.1002/esp.4138. http://onlinelibrary.wiley.com/doi/10.1002/esp.4138/full

Tommy E. Sutarto, 2015. "A Combined Flume-Imaging Technique for Measuring Fluvial Erosion of Cohesive Stream Bank Soils". *Procedia Engineering*. Volume 125, 2015, Pages 368–375.doi:10.1016/j.proeng.2015.11.087. http://www.sciencedirect.com/science/article/pii/S1877705815034049

Tommy E. Sutarto, 2015. "Application of Large Scale Particle Image Velocimetry (LSPIV) to Identify Flow Pattern in a Channel". *Procedia Engineering*. Volume 125, 2015, Pages 213–219. doi:10.1016/j.proeng.2015.11.031 http://www.sciencedirect.com/science/article/pii/S1877705815033482

Sutarto, **T.E**., Papanicolaou, A.N., Wilson, C.G., Langendoen, E.J. 2014. "Stability analysis of semicohesive streambanks with CONCEPTS: Coupling field and laboratory investigations to quantify the onset of fluvial erosion and mass failure". *Journal of Hydraulic Engineering*. Volume 140(9), 2014. Doi:10.1061/(ASCE)HY.1943-7900.0000899. http://ascelibrary.org/doi/10.1061/%28ASCE%29HY.1943-7900.0000899

Tommy Ekamitra Sutarto, 2019. "Teknik Sensor Cahaya untuk Menentukan Laju Erosi Tebing Sungai". *Matrix* 9(1), 13-18. Doi: http://dx.doi.org/10.31940/matrix.v9i1.1259. http://ojs.pnb.ac.id/index.php/matrix/article/view/1259

Tommy Ekamitra Sutarto."Tinjauan Ringkas Berbagai Teknik Terkini untuk Menentukan Kuat Gesek Erosif Tanah". *Jurnal Poli-Teknologi* 18(1). Doi: http://dx.doi.org/10.32722/pt.Vol18.No.1.2019.pp. http://jurnal.pnj.ac.id/index.php/politeknologi/article/view/1291

Thank you