Sediment Mechanics

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River Mechanics and Sediment Transport
Lima Peru – January 2016

Objectives

Brief overview of examples and techniques:

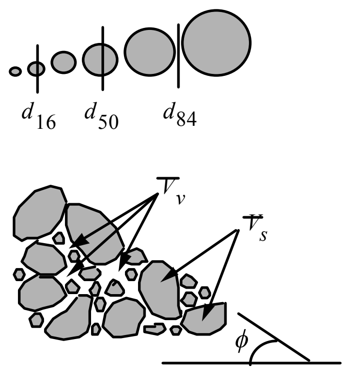
1. Fall Velocity;
2. Turbulent Velocity Profiles;
3. Incipient Motion;
4. Bedforms.

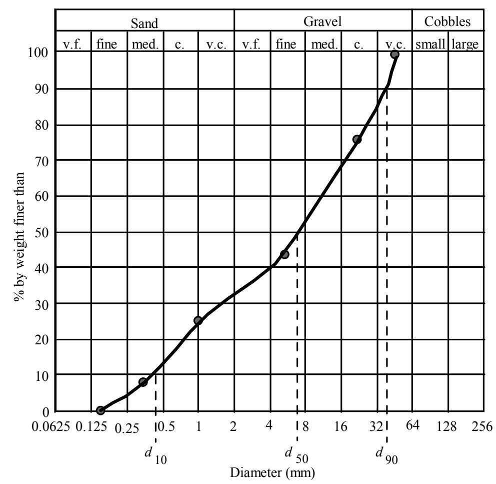
1. Fall Velocity

				Openings Per Inch		Class
Millimeters		Microns	Inches	Tyler	U.S. Standard	
4000-2000	—	—	160-80	—	—	Very large boulders
2000-1000	—	—	80-40	—	—	Large boulders
1000-500	—	—	40-20	—	—	Medium boulders
500-250	—	—	20-10	—	—	Small boulders
250-130	—	—	10-5	—	—	Large cobbles
130-64	—	—	5-2.5	—	—	Small cobbles
64-32	—	—	2.5-1.3	—	—	Very coarse gravel
32-16	—	—	1.3-0.6	—	—	Coarse gravel
16-8	—	—	0.6-0.3	2 1/2	—	Medium gravel
8-4	—	—	0.3-0.16	5	5	Fine gravel
4-2	—	—	0.16-0.08	9	10	Very fine gravel
2-1	2.00-1.00	2000-1000	—	16	18	Very coarse sand
1-1/2	1.00-0.50	1000-500	—	32	35	Coarse sand
1/2-1/4	0.50-0.25	500-250	—	60	60	Medium sand
1/4-1/8	0.25-0.125	250-125	—	115	120	Fine sand
1/8-1/16	01.25-0.062	125-62	—	250	230	Very fine sand
1/16-1/32	0.062-0.031	62-31	—			Coarse silt

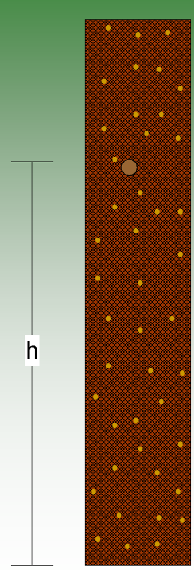
64-32	—	—	2.5-1.3	—	—	Very coarse gravel
32-16	—	—	1.3-0.6	—	—	Coarse gravel
16-8	—	—	0.6-0.3	2 1/2	—	Medium gravel
8-4	—	—	0.3-0.16	5	5	Fine gravel
4-2	—	—	0.16-0.08	9	10	Very fine gravel
2-1	2.00-1.00	2000-1000	—	16	18	Very coarse sand
1-1/2	1.00-0.50	1000-500	—	32	35	Coarse sand
1/2-1/4	0.50-0.25	500-250	—	60	60	Medium sand
1/4-1/8	0.25-0.125	250-125	—	115	120	Fine sand
1/8-1/16	01.25-0.062	125-62	—	250	230	Very fine sand
1/16-1/32	0.062-0.031	62-31	—			Coarse silt
1/32-1/64	0.031-0.016	31-16	—			Medium silt
1/64-1/128	0.016-0.008	16-8	—			Fine silt
1/128-1/256	0.008-0.004	8-4	—			Very fine silt
1/256-1/512	0.004-0.0020	4-2	—			Coarse clay
1/512-1/1024	0.0020-0.0010	2-1	—			Medium clay
1/1024-1/2048	0.0010-0.0005	1-0.5	—			Fine clay
1/2048-1/4096	0.0005-0.0002	0.5-0.24	—			Very fine clay

Los Corales





Fall Velocity



$$\omega = \frac{g\left(G-1\right)d_s^2}{18\nu} \qquad \textit{Stokes Law} \rightarrow \textit{valid for silts \& clays}$$

$$\omega = \sqrt{\frac{4}{3}\frac{g\left(G-1\right)d_s}{C_D}} \qquad \textit{valid for gravels, cobbles \& boulders}$$

$$\omega = \frac{8\nu_m}{d_s}\left[\left(1+\frac{d_*^3}{72}\right)^{0.5} - 1\right]$$

dimensionless particle diameter

$$d_* = d_s\left[\frac{\left(G-1\right)g}{\nu_m^2}\right]^{\frac{1}{3}}$$

[redacted]

Visual Accumulation Tube method VAT

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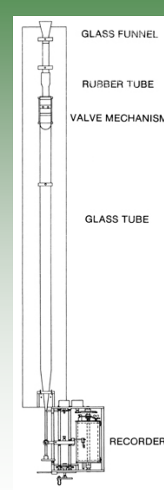
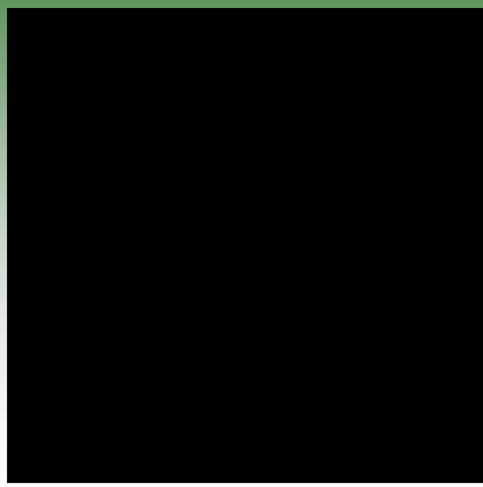
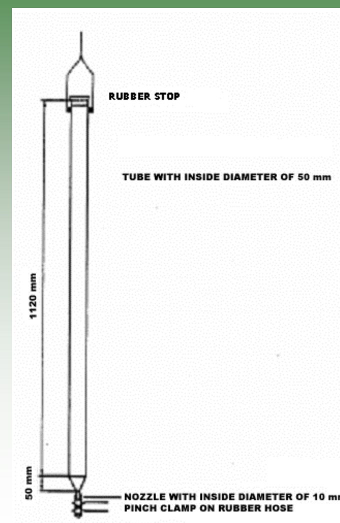
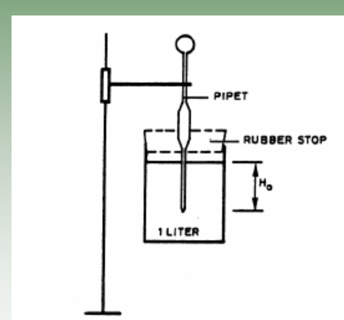


Bottom Withdrawal Tube method BWT

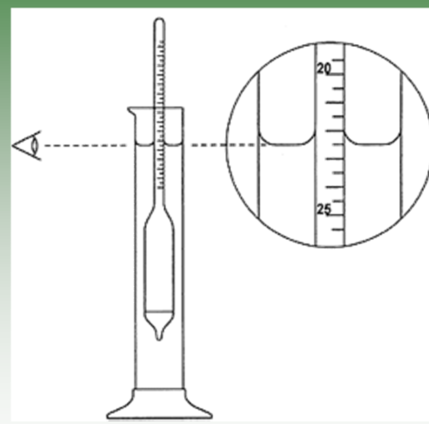




Pipette Method



Hydrometer Method



Example - Fall Velocity

$$d_* = d_s \left[\frac{(G-1)g}{v_m^2} \right]^{\frac{1}{3}}$$

$$d_* = 0.001182m \left[\frac{(2.65-1)9.81 \, {}^{m}\!/\!_{s^2}}{\left(1.14 * 10^{-6} \, {}^{m^2}\!/\!_{s}\right)^2} \right]^{\frac{1}{3}}$$

$$d_* = 27.4$$

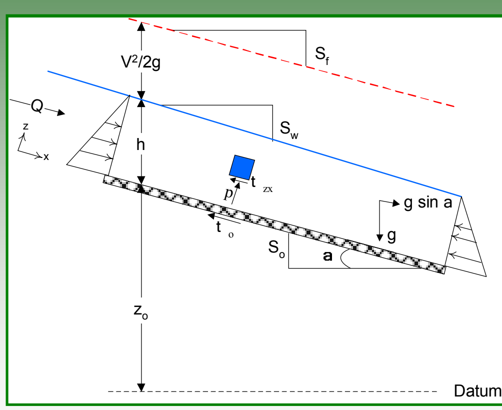
$$\omega = \frac{8 v_m}{d_s} \left[\left(1 + \frac{d_*^3}{72} \right)^{0.5} - 1 \right]$$

$$\omega = \frac{8 * 1.14 * 10^{-6} \, {}^{m^2}\!/\!_{s}}{0.001182m} \left[\left(1 + \frac{27.4^3}{72} \right)^{0.5} - 1 \right]$$

$$\omega = 0.123 \, {}^{m}\!/\!_{s}$$

2. Turbulent Velocity Profiles

Open Channel Flow



$$\int_p^0 dp = \rho \int_z^h -g\,dz$$

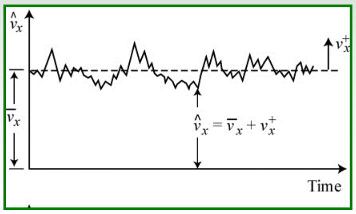
$$p = \rho g (h - z)$$

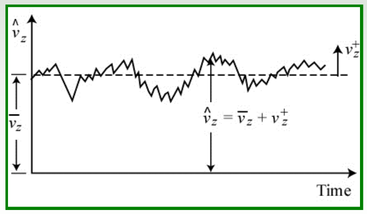
$$\tau_{zx} = \rho g (h - z) S_f$$

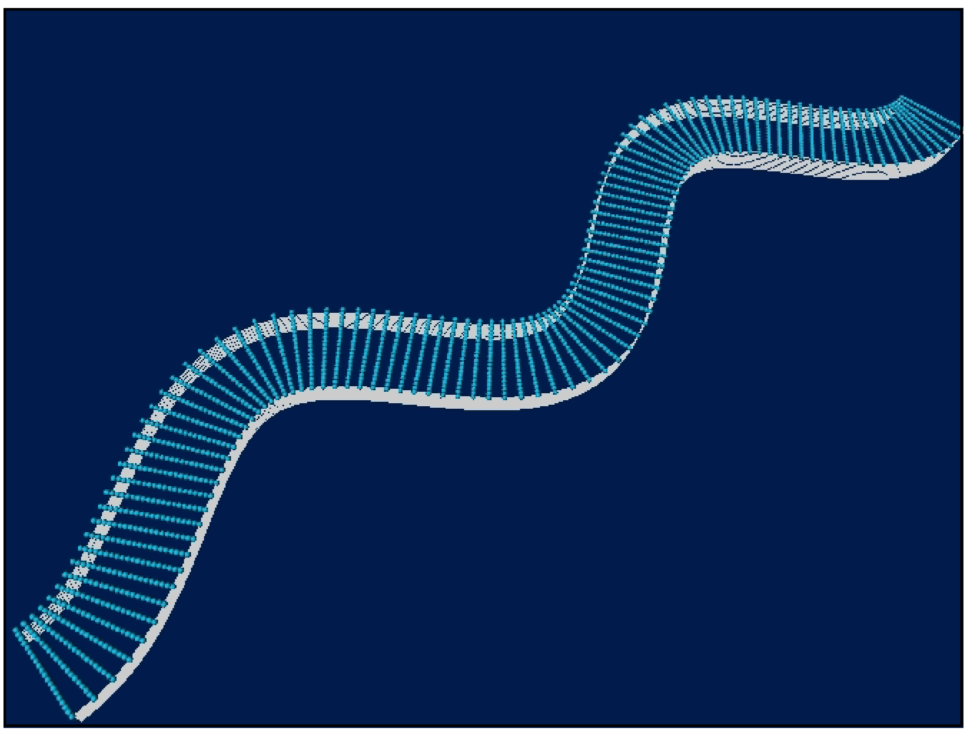
$$\tau_o = \rho g h S_f$$

$$u_* = \sqrt{\frac{\tau_o}{\rho}} = \sqrt{g h S_f}$$

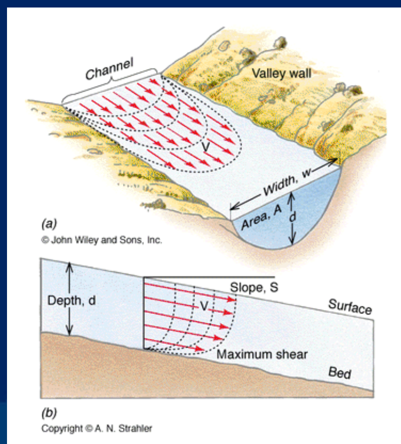
Turbulent Flow Equations

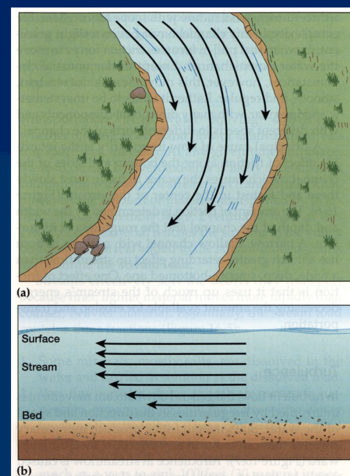






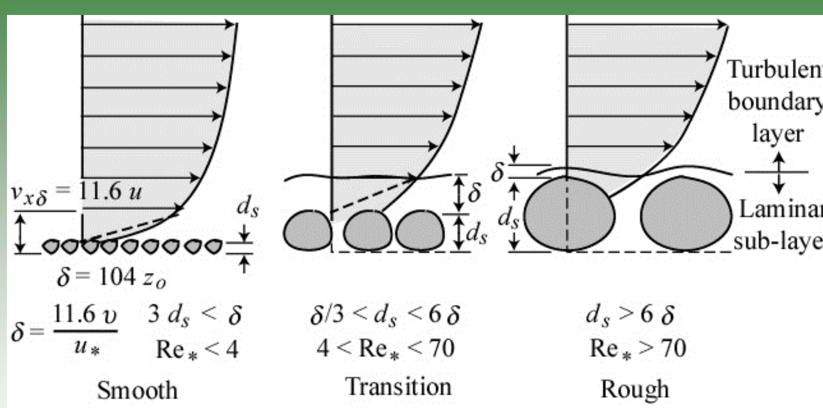
Logarithmic Velocity Profile





$$\frac{v_x}{u_*} = \frac{1}{\kappa} \ln \frac{z}{z_o}$$

Logarithmic Velocity Profile



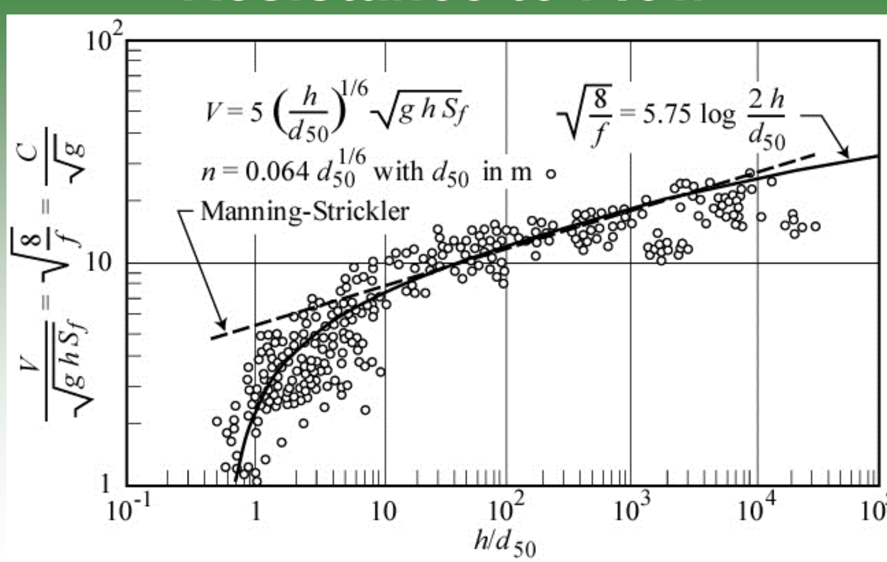
$$v = \frac{u_*}{\kappa} ln\left(9.05 \frac{z\, u_*}{v}\right)$$

$$v = \frac{u_*}{\kappa} ln\left(30.2 \frac{z\chi}{k_s}\right)$$

$$v = \frac{u_*}{\kappa} ln\left(30.2 \frac{z}{k_s}\right)$$

Depth Average Velocity

Resistance to Flow



Saint-Venant Equation

Bed Slope

$$S_o = -\frac{\partial z_o}{\partial x}$$

Free Surface Slope

$$S_w = -\frac{\partial (z_o + h)}{\partial x} = S_o - \frac{\partial h}{\partial x}$$

Energy Slope

$$S_f = -\frac{\partial \left(z_o + h + V^2 / 2g \right)}{\partial x} = S_o - \frac{\partial h}{\partial x} - \frac{V \partial V}{g \partial x}$$

Unsteady Flow Saint − Venant Equation

$$S_f = S_o - \frac{\partial h}{\partial x} - \frac{V \partial V}{g \partial x} - \frac{\partial V}{g \partial t}$$

Example – Rhine River

[redacted]

[redacted]

Depth	Velocity		Depth	Velocity
m	m/s		m	m/s
0.3	0.74		2.2	1.63
0.3	0.81		3.5	1.92
0.3	0.72		4	1.85
0.4	0.47		4.1	1.86
0.5	0.84		5.3	1.99
0.8	1.22		6	1.98
0.9	1.34		7.3	2.08
1.2	1.38		8	2.04
1.3	1.47		9	1.9

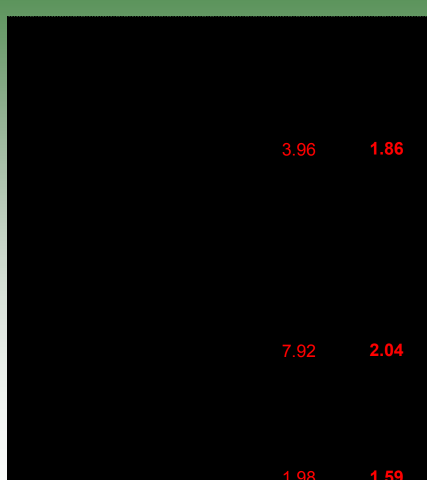
[redacted]

Example - Shear Velocity

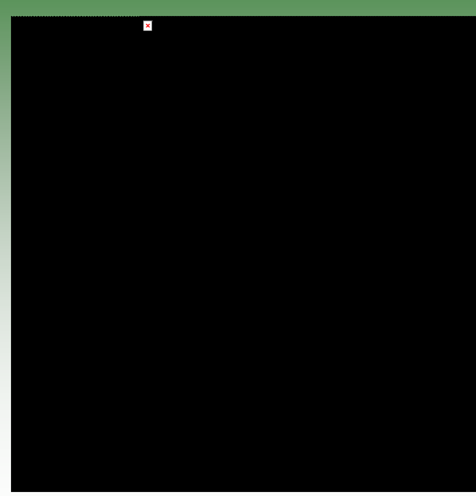
$$u_* = \sqrt{ghS_f} = \sqrt{9.81\frac{m}{s^2} * 9.9m * 0.0001312}$$

$$u_* = 0.113\frac{m}{s}$$

Example - Mean Velocity

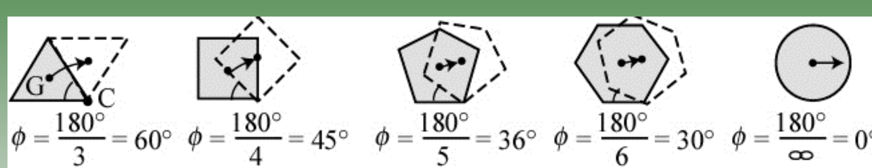


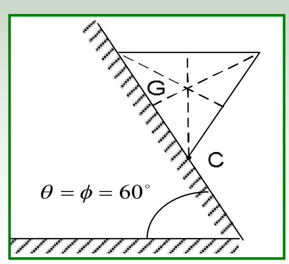
s	2.2	1.63



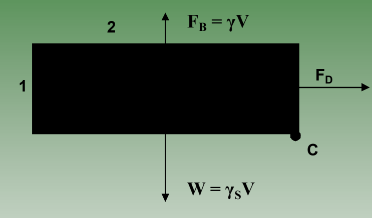
3. Incipient Motion

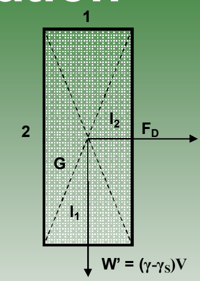
Angle of Repose
Effects of Angularity

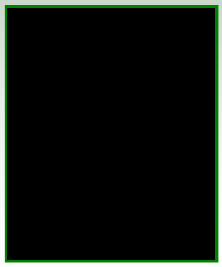


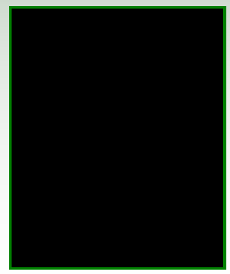


Angle of Repose
Particle Orientation

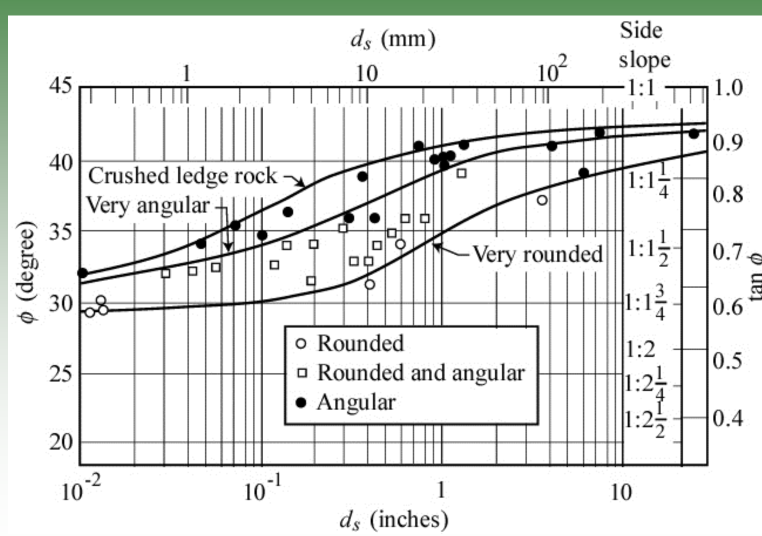




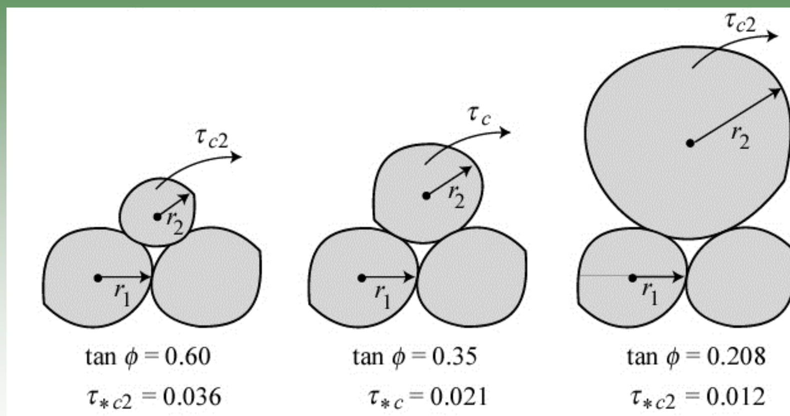




Angle of Repose
Granular Material



Angle of Repose
Boundary and Particle Size



Los Corales

Incipient Motion

Shields Parameter

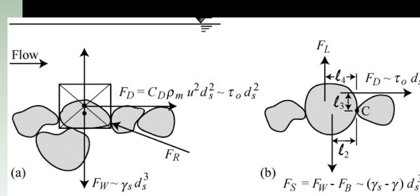
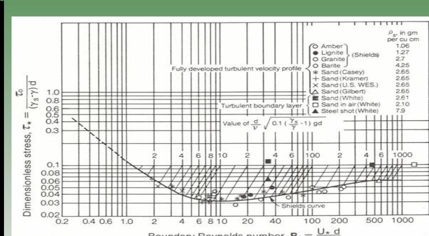


Figure 7.6. Force diagram under steady uniform flow



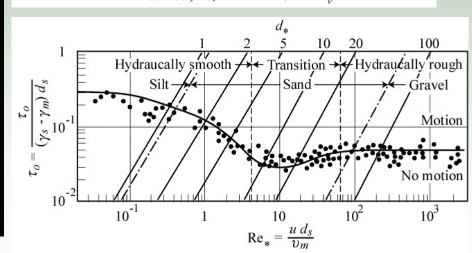
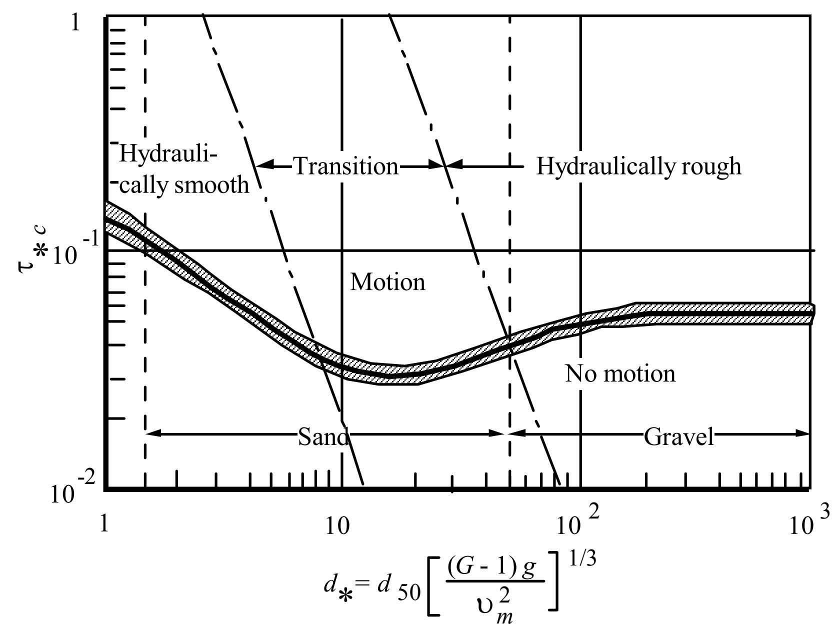


Figure 7.7. Shields diagram for granular material



Beginning of Motion

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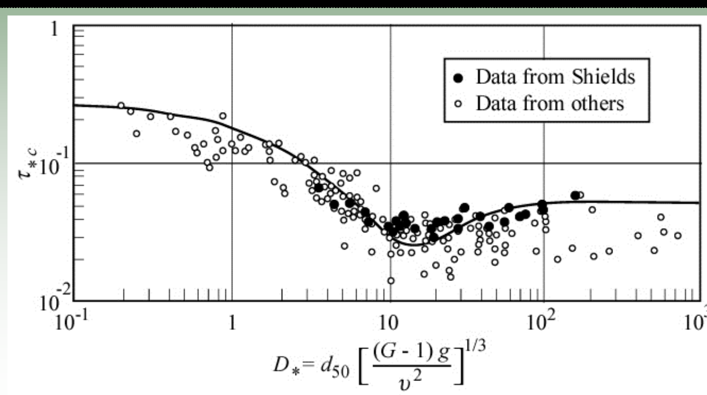


Figure 7.8. Modified Shields diagram

Calculating Critical Shear Stress

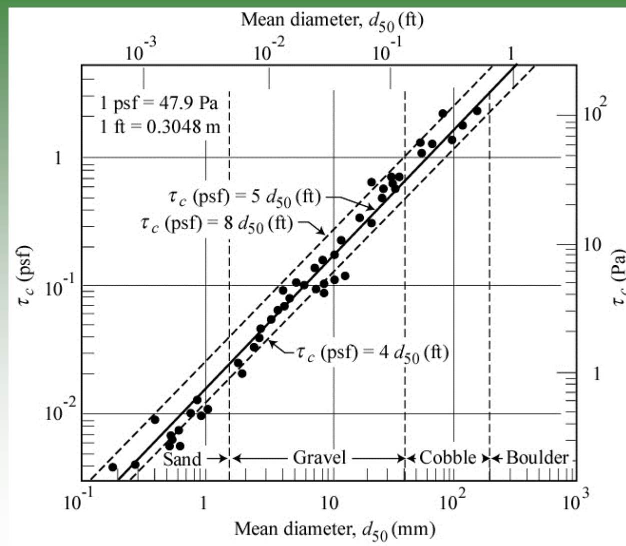
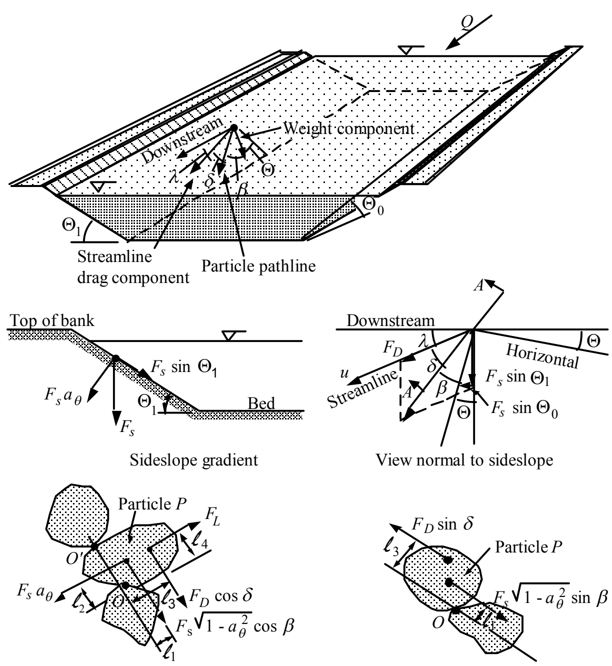
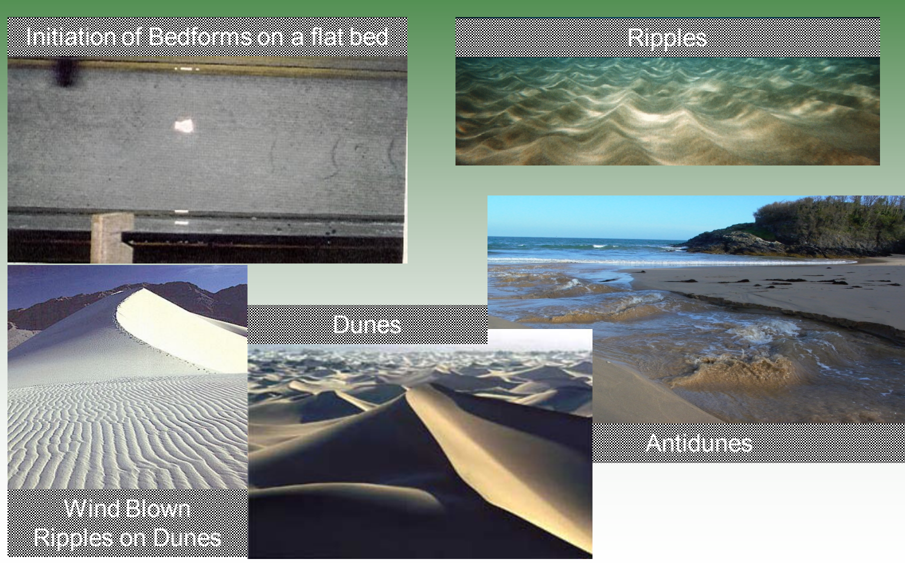


Figure 7.9. Critical shear stress on a horizontal surface



4. Bedforms

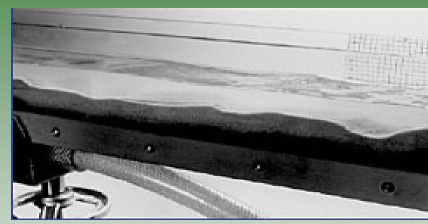
What are bedform?



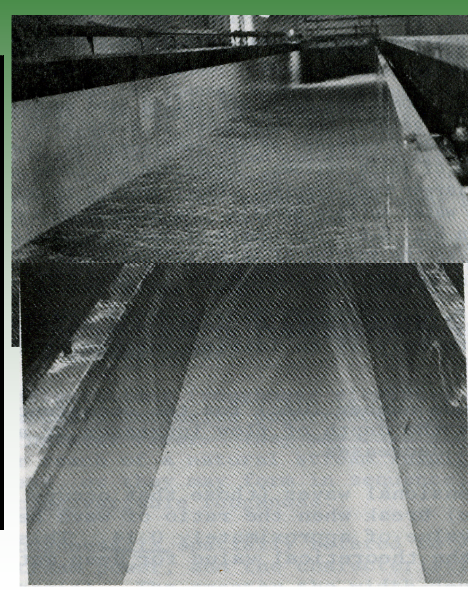
Lower Regime - Ripples

Lower Regime - Dunes

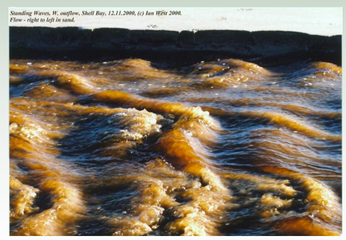
Transition - Washed Out Dunes



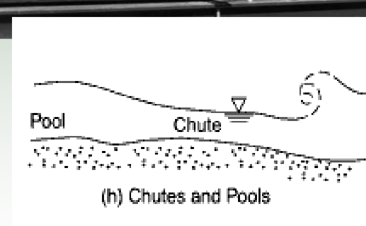
Upper Regime - Plane Bed



Upper Regime – Antidunes



Upper Regime – Chutes and Pools



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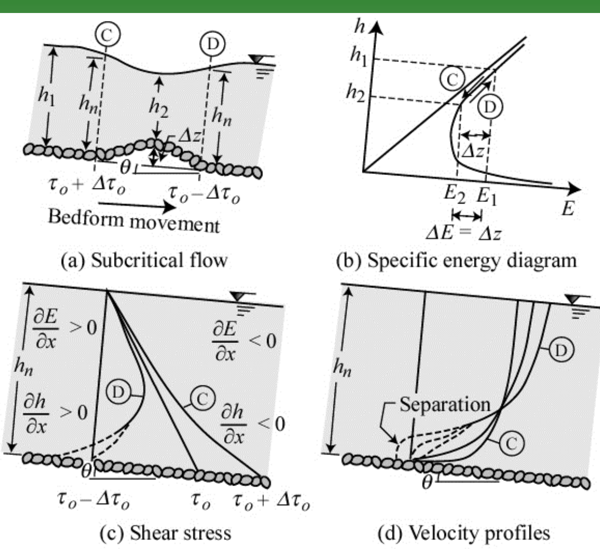
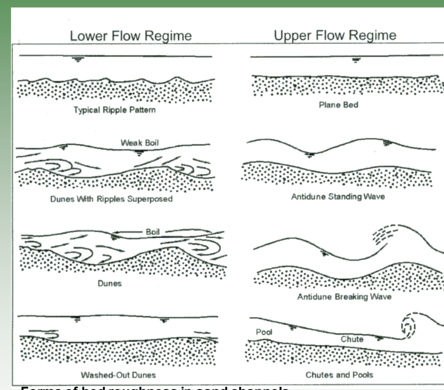


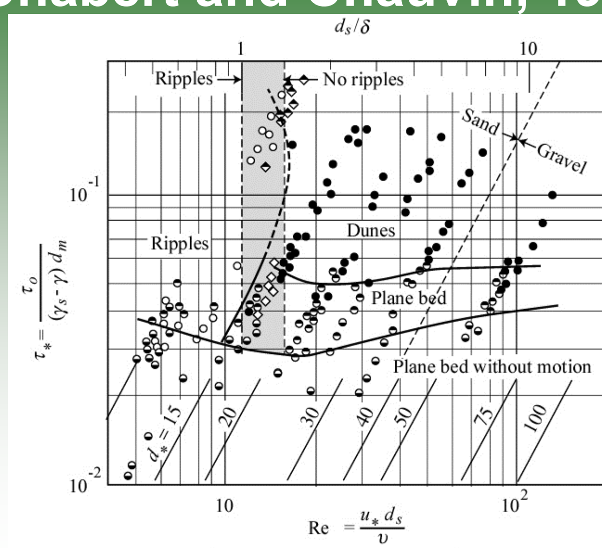
Figure 8.2 - Steady nonuniform subcritical flow in alluvial channels

Bedform Classification

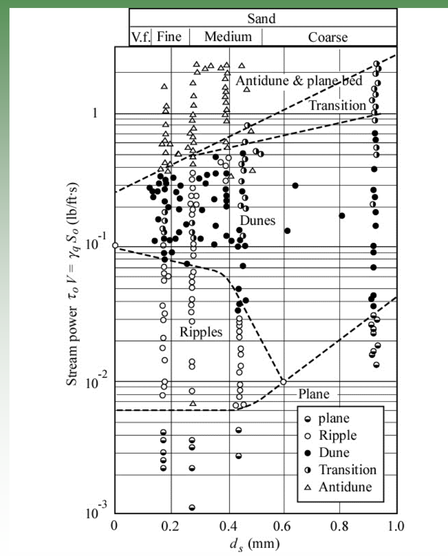


Forms of bed roughness in sand channels (Simons and Richardson 1963, 1966)

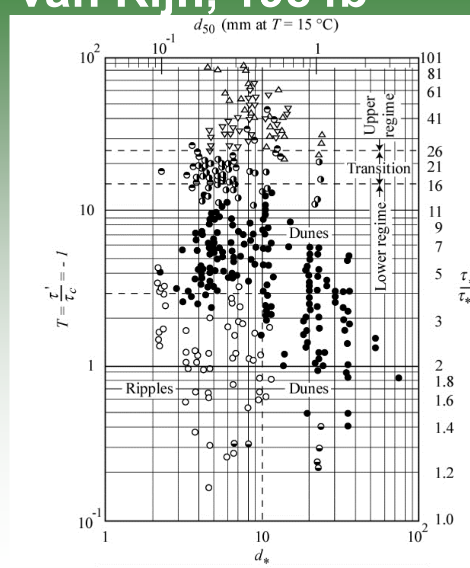
Based on the Shields Number Chabert and Chauvin, 1963



Based on Stream Power
Simons and Richardson, 1963, 1966



Based on Transport-Stage Parameter
van Rijn, 1984b



Laboratory Bedform Geometry from van Rijn, 1984

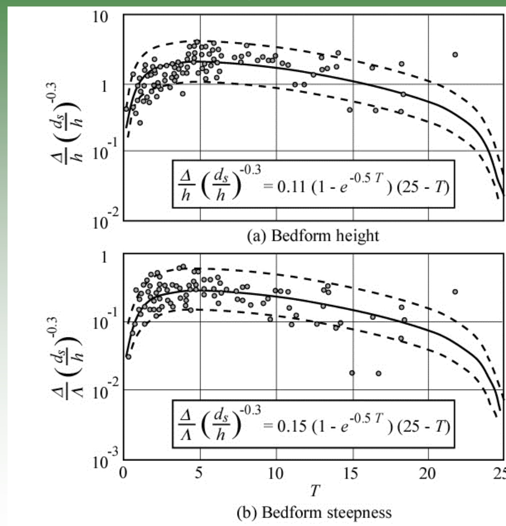


Figure 8.11. Bedform height and steepness (after van Rijn,1984b)

Bedform Profiles

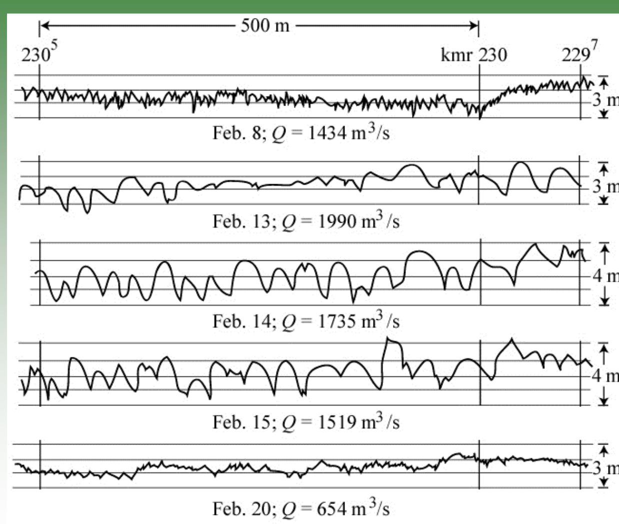


Figure 8.15. Dunes of the Bergsche Maas during the 1984 flood of the meuse River (kmr denotes river kilometer; after Adriaanse, 1986)

Dune Height from Large Rivers

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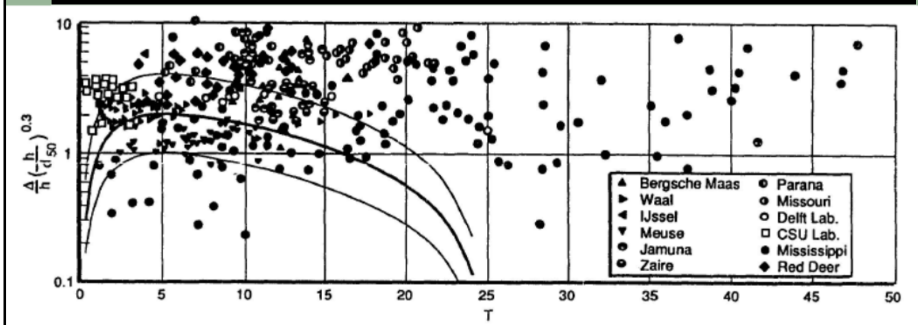

FIG. 6. van Rijn's Bed-Form Height Predictor with Large River Data

Dune Steepness from Large Rivers

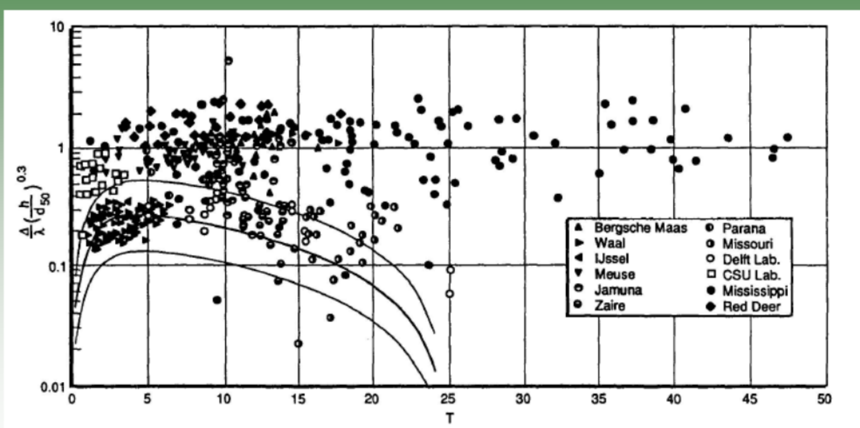

FIG. 7. van Rijn's Bed-Form Steepness Predictor with Large River Data

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Resistance to Flow

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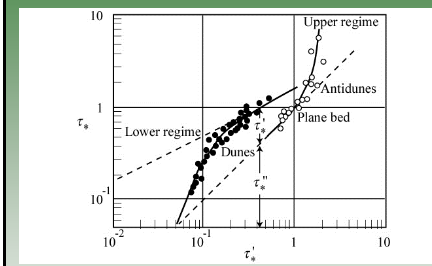
$$\tau_* = \tau_*' + \tau_*''$$

Engelund's Resistance Method



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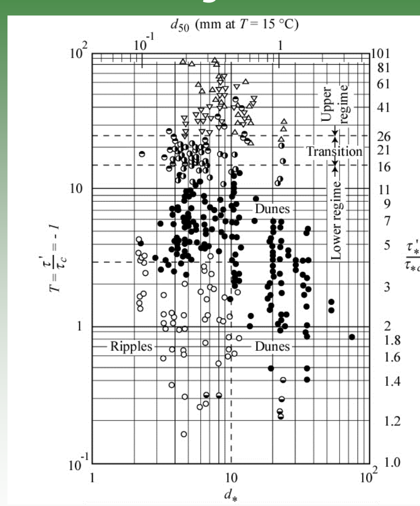
van Rijn's Resistance Method



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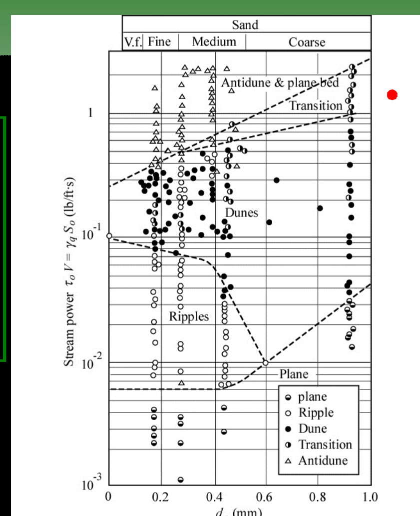
Example - Rhine River

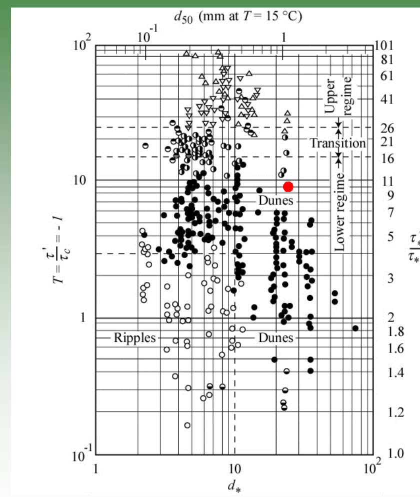
Example – Bedform Predictor



Simons and Richardson's method predicts washed-out dunes

Example - van Rijn

[redacted]



Based on result the expected bed forms are DUNES. In the field, dunes 0.9 m high and 20 m long were observed.

Example - Determine τ_*'

[redacted]

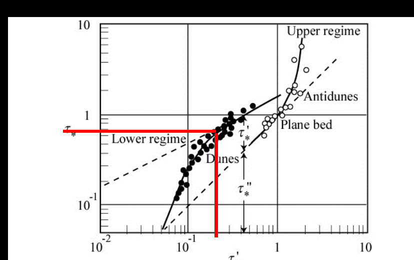
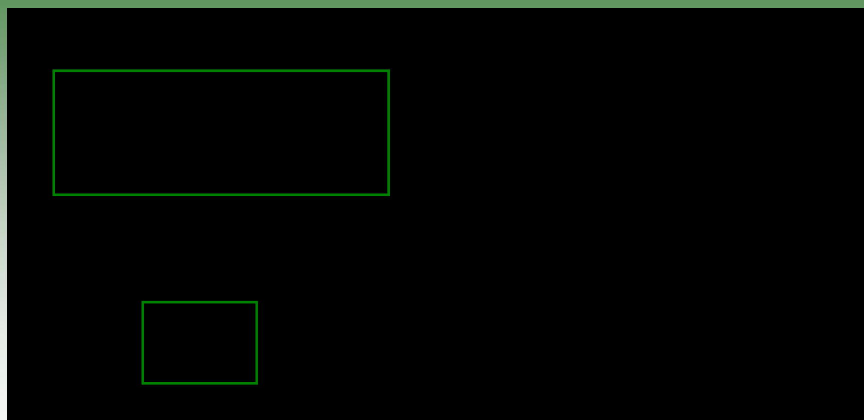


Figure 8.12. Total versus grain resistance (after Engelund and Hansen, 1967)

[redacted]

Example – Dune Height and Length



In the field, the dunes are measured to be 0.9 m high and 20 m long were observed.

Rhine River Flood 1998

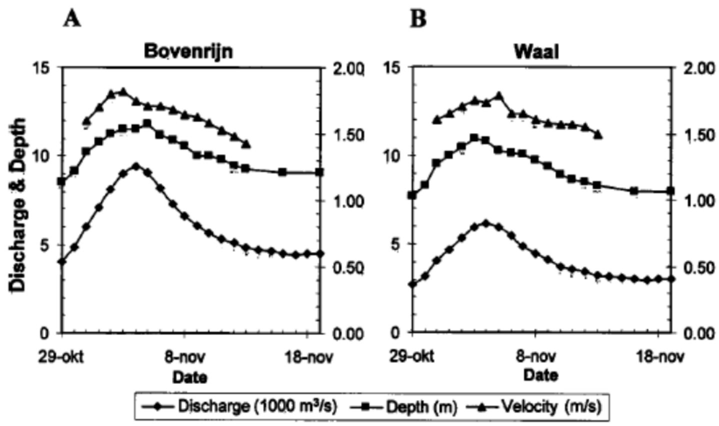
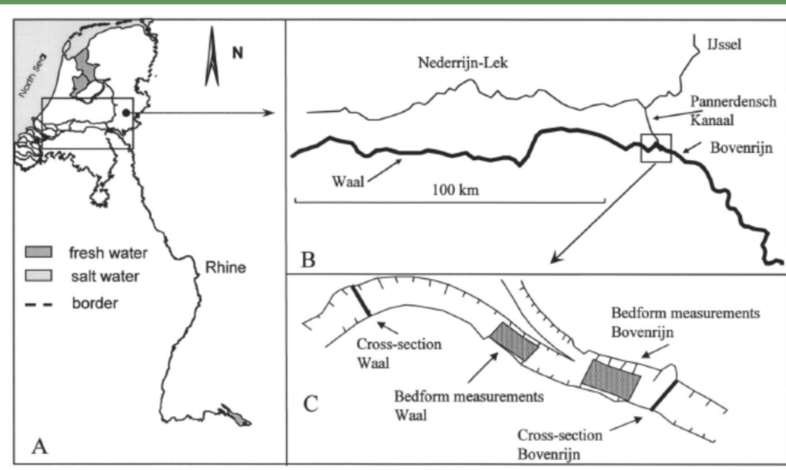


Fig. 2. Flood discharge, flow depth, and velocity: (a) Bovenrijn and (b) Waal

Study Area of the Rhine River



Field Surveys on the Rhine River

Bedform Profiles

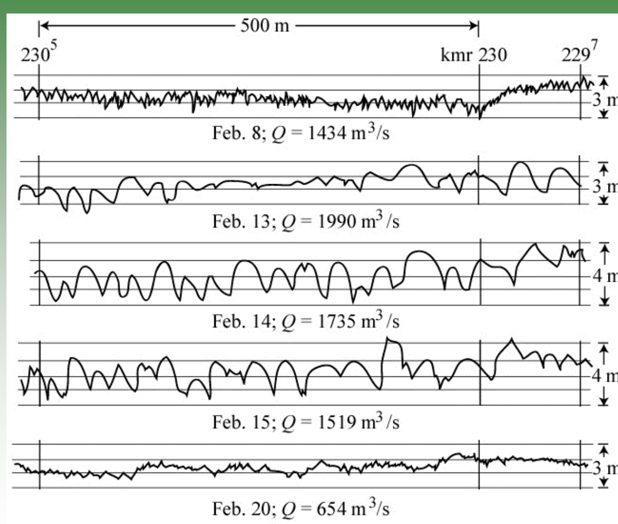


Figure 8.15. Dunes of the Bergsche Maas during the 1984 flood of the meuse River (kmr denotes river kilometer; after Adriaanse, 1986)

Dune Height during the Flood

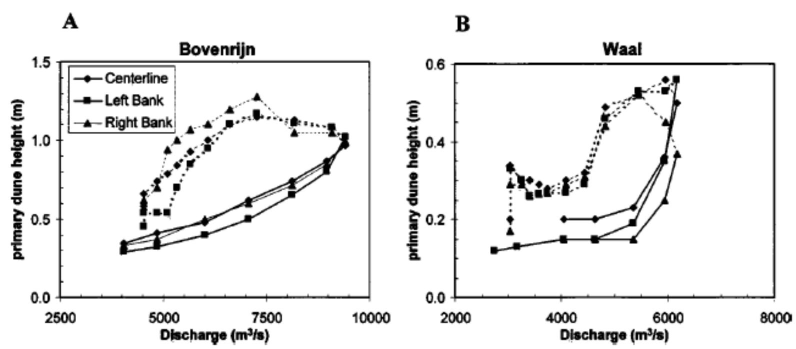


Fig. 3. Primary dune height versus discharge: (a) Bovenrijn and (b) Waal (dashed lines represent falling stage)

Manning n during the Flood

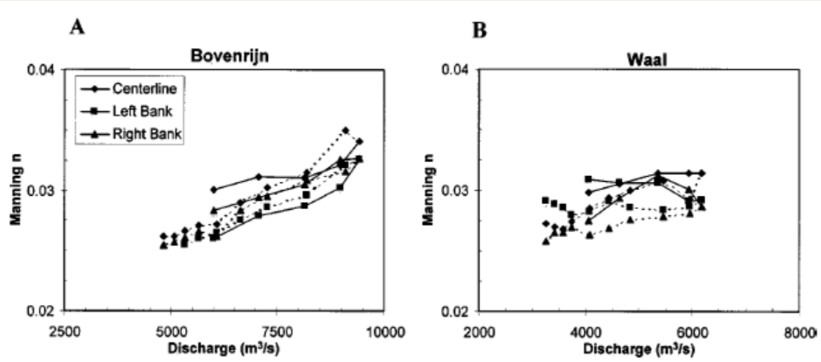
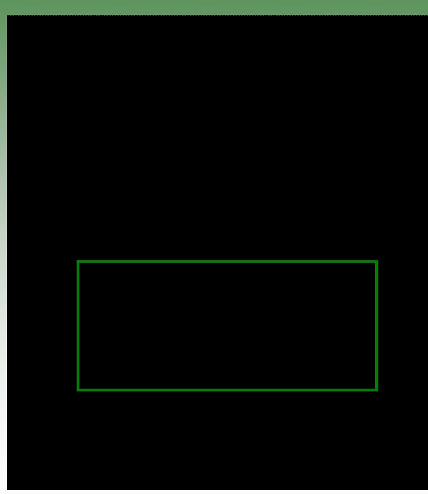
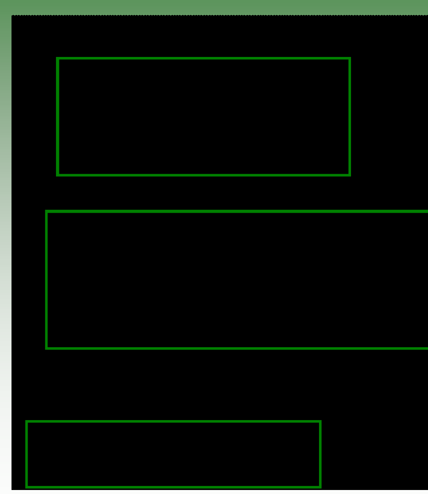


Fig. 6. Manning *n* versus discharge: (a) Bovenrijn and (b) Waal (dashed lines correspond to falling stage)

Example Amazon River

Calculate
Depth and Velocity





Simons and Richardson

[redacted]

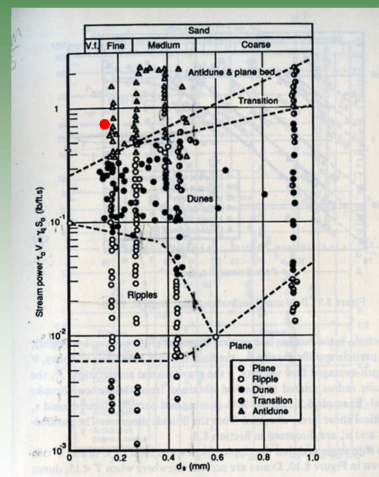
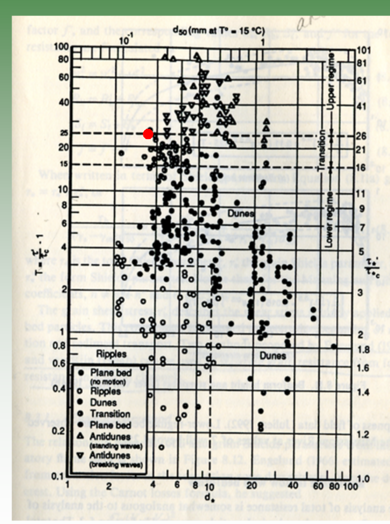


Figure 8.8. Bedform classification (after Simons and Richardson, 1963, 1966)

van Rijn

[redacted]




ACKNOWLEDGMENTS
Dr. Seema Shah Fairbanks, CSU-Pomona
Dr. Junke Guo, CSU and UNO
Dr. Daryl B. Simons, CSU and SLA
Dr. H. W. Shen, CSU and CU Berkeley
Dr. Gerrit Klaassen, Delft Hydraulics
Dr. Kristin Bunte, CSU
Un Ji, KICT, South Korea
Hwayoung Kim, K-Water, South Korea
... so many others ...


Muchas
Gracias!
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