Sediment Budget and Hydrology

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Acknowledgments

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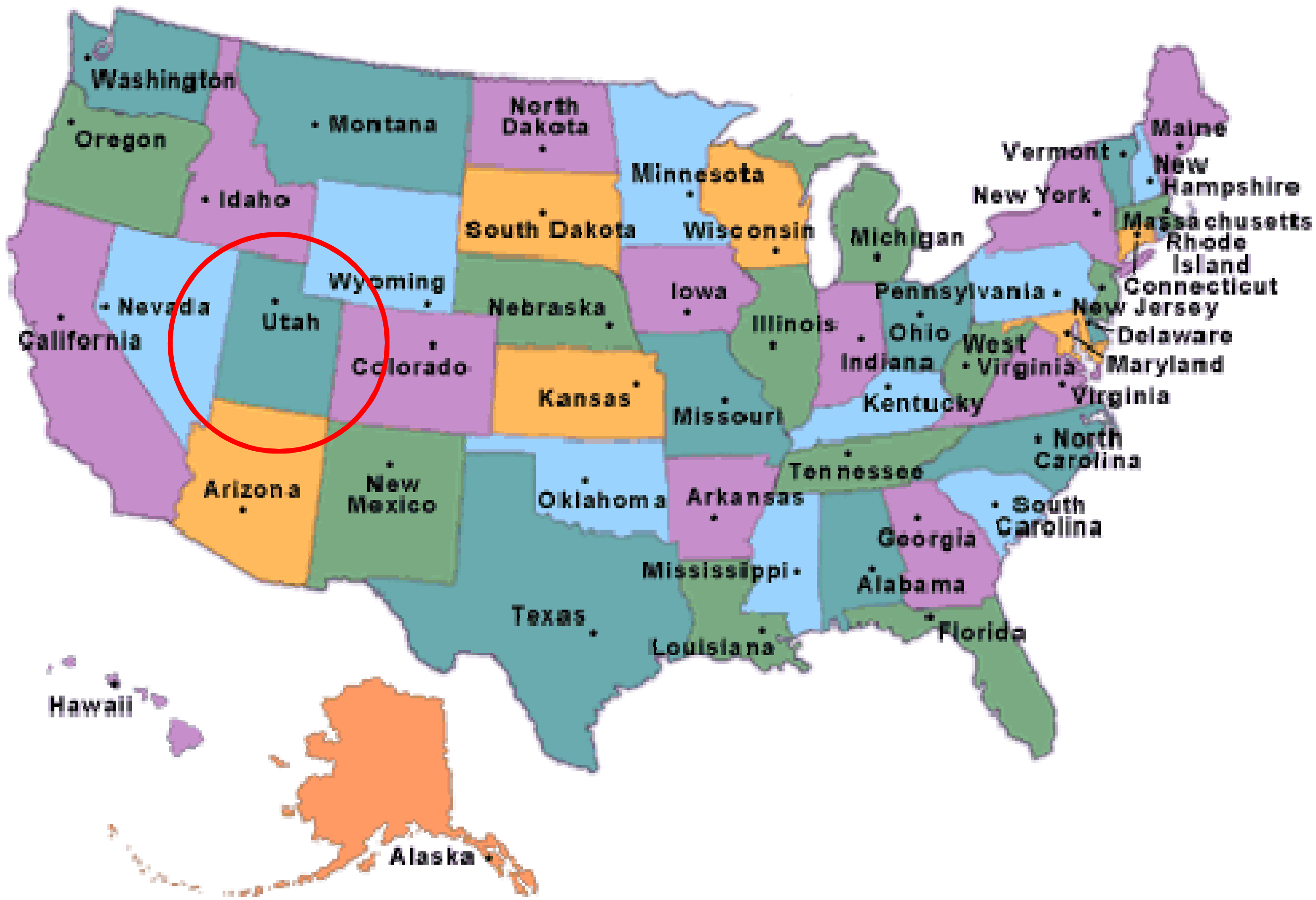
- Manfred Spreafico, Chairman
  - International Sediment Initiative
  - ISI
- Des Walling – the REAL content expert
- Jos Brils: Energy and Passion!

Provo, Utah



http://i.infopls.com/images/states_imgmap.gif

Units in this Section

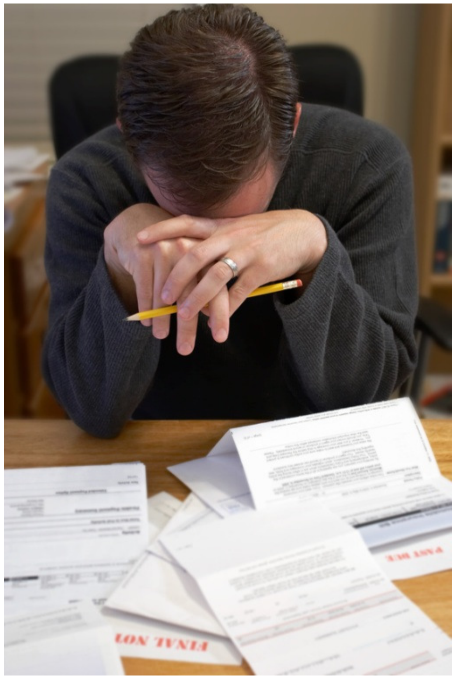
1. Introduction
2. Overview of soil loss and erosion
3. Components of the sediment budget
4. Estimating or measuring each component
5. Land use impacts on sediment budget
6. River transport of sediments
7. Measuring transported sediments
8. Making the sediment budget
9. Measuring streamflow discharge rates

Objective

- Help you learn specific steps you can take to calculate a sediment budget for watersheds in your country, or for a river at a national boundary

1. Introduction

- What is a sediment budget?
- Budgets have
  - Inflows (income)
  - Outflows (payments)
  - Storage (savings or unpaid bills)
- We will apply this to sediment
  - Consider sediment mass
  - Mass has units of
    - Metric tons (tonnes)
    - kg



Conservation of Mass Equation

- $0 = \frac{\partial}{\partial t} \iiint \rho d\forall + \iint \vec{V} \cdot \vec{n}\, dA$

Where

t= time

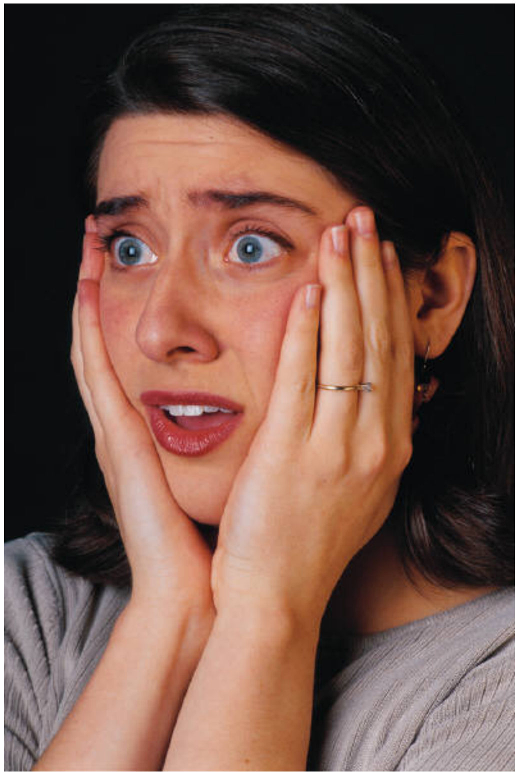
ρ = density

$\forall$ = volume

$\vec{V}$ = velocity vector

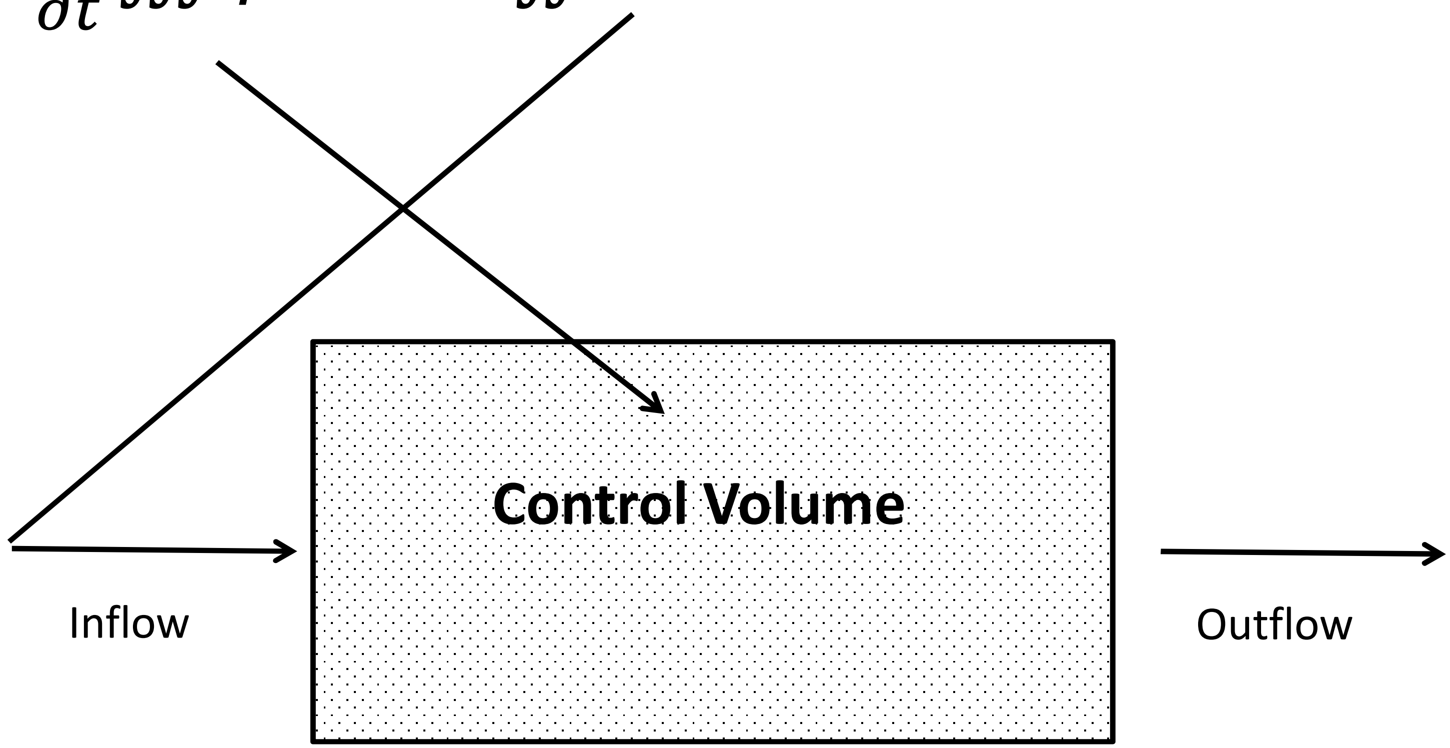
$\vec{n}$ = unit normal vector

A = area



Meaning of Equation

- $0 = \frac{\partial}{\partial t}\iiint \rho d\forall + \iint \vec{V} \cdot \vec{n}\, dA$

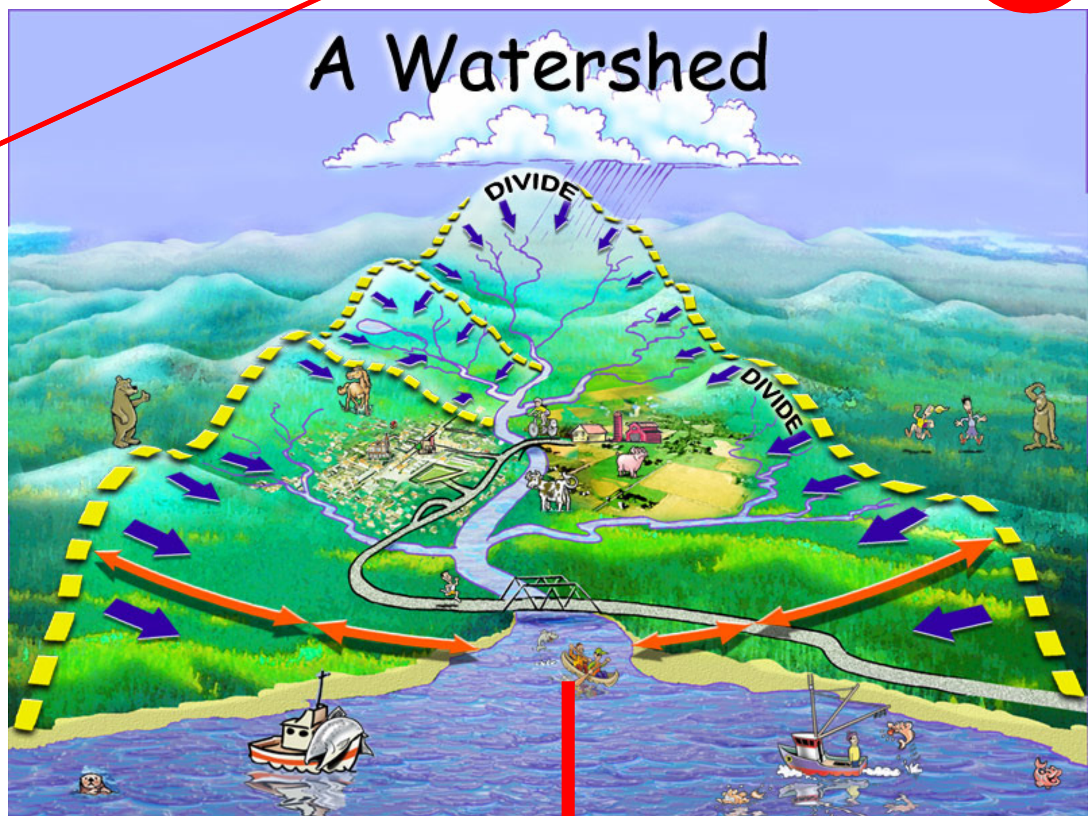


- 0 = change of sediment in C.V + Outflow - Inflow

Applied to a Watershed

0 = change of sediment in C.V + Outflow - Inflow

Negative: loss

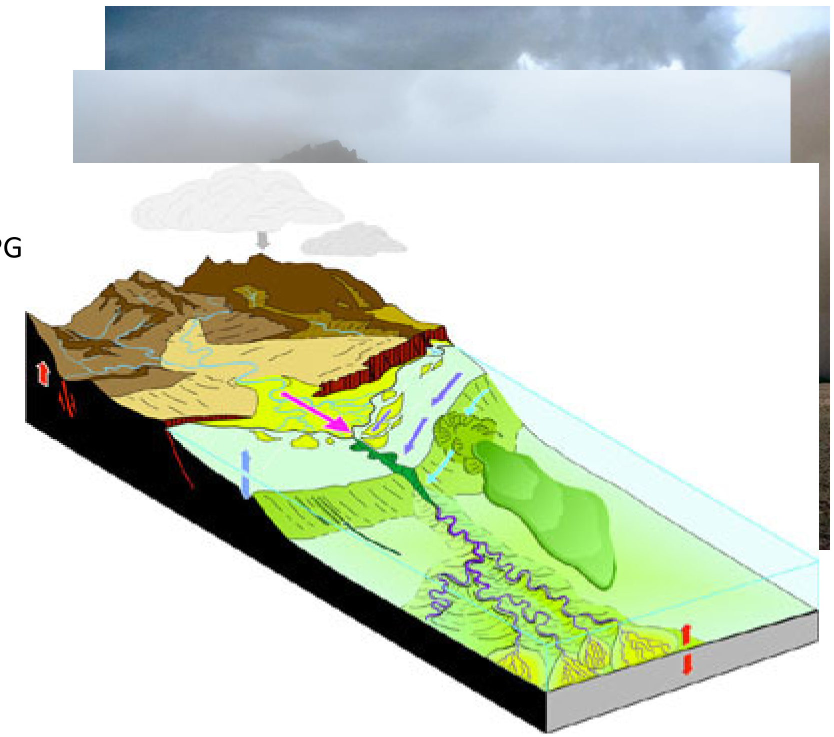


http://www.raritanbasin.org/Pictures/watershed.jpg

Sediment Outflow

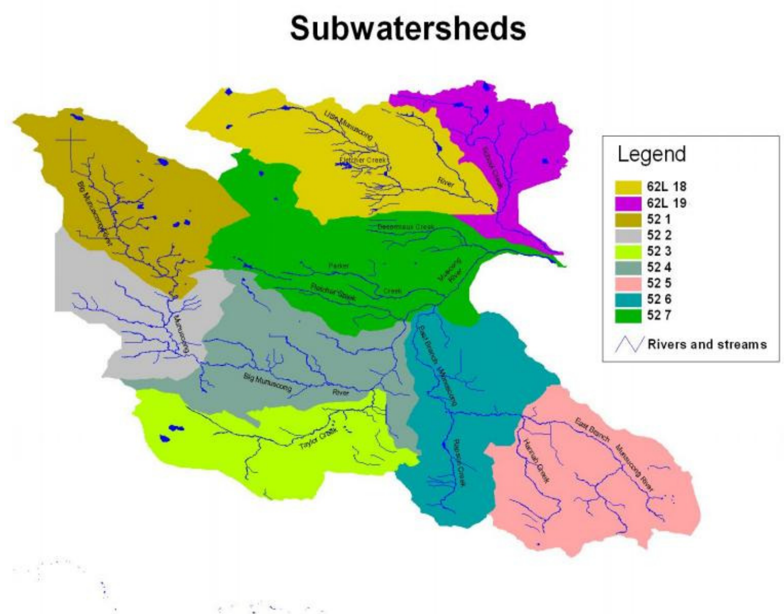
No Sediment Added?

- Considers watershed from divide to mouth
- POSSIBLE sources outside the 'control volume'
  - Dust deposition
    http://www.crh.noaa.gov/ddc/swaw/glddust.JPG
  - Ash deposition
    http://www.thorvaldseyri.is/skrar/image/Frettir/oskubylur.JPG
  - Tectonic uplift
    http://www.conjugatemargins.com/images/Source_to_Sink.jpg



Applied to Subwatersheds

- Each colored area is its own watershed
- Now “0 = change of sediment in C.V + Outflow – Inflow” has changed
  – Outflow from upstream is equal to inflow to downstream
- What if each colored area were a country?



http://www.munuscongwatershed.org/media/pages/subwatersheds_1.jpg

2. Overview of Soil Loss and Erosion

- It all begins with soil in the watershed
- *Processes* (budget later)
    1. rainfall splash
    2. freeze/thaw
    3. overland flow
    4. landslides
    5. mechanical movement

These 3 combined for soil erosion budget

Rainfall Splash

- Rainfall detaches soil
- Function of
  - Soil strength
  - Rainfall intensity
    - Location on planet
    - Time of year
    - What other factors?

http://www.falw.vu/~trendy/splash.jpg

Freeze/Thaw

- Expansion upon freezing
- Can "cryoturbate" soil
- Makes more susceptible to erosion
- Can be a significant factor

http://farm5.staticflickr.com/4150/5084482442_1974452967.jpg

Overland Flow

- “Rill” can be plowed over
- “Gully” cannot be plowed over
- Not restricted to agricultural lands

http://soilerosion.net/image/hillslope_rills.jpg

http://www.teara.govt.nz/files/p19790pc.jpg

Landslide Input

- Can be massive
- Function of
  - Geology
  - Land use history
  - Precipitation

http://eusoils.jrc.ec.europa.eu/library/themes/Landslides/images/EC.jpg

Mechanical Movement

- Mechanical push into stream
- Often done during
  - Mining
  - Logging
  - Other watershed disturbance

http://upload.wikimedia.org/wikipedia/commons/d/dc/Mining_Debris_in_Cwm_Nant_Iago_-_geograph.org.uk_-_300633.jpg

3. Components of the Sediment Budget

1. Dust deposition/scour
2. Soil erosion: combine
    1. Rainfall detachment
    2. Freeze/thaw
    3. Overland flow
3. Landslides
4. Mechanical Movement
5. Streambank erosion
6. Reservoirs associated with dams
7. Tributary input

Dust Deposition/Scour

- Deposition is input to watershed
- Scour and transport by air is loss from watershed
- Usually very long term process

http://4.bp.blogspot.com/_yoZVx644Jak/TE0IYfx3gtI/AAAAAAAAAEU/PspvyizArhQ/s1600/1.jpg

http://news.sciencemag.org/sciencenow/assets_c/2011/01/sn-tibet-thumb-800xauto-5105.jpg

Soil Erosion

- We've already reviewed *processes*
- Soil erosion budget includes
  - Rainfall detachment
  - Freeze/thaw
  - Overland flow
- Important: Erosion vs. Delivery
  - *Erosion*: loss of soil from its *Delivery*: that portion of soil loss that is delivered to a stream or river
- Sediment delivery ratio (SDR): delivered/eroded
- SDR primarily a function of watershed size

Soil Erosion and SDR

- A LOT of soil is stored in the watershed!
- Where?
  - Floodplains
  - Flatter areas
- Careful when calculating budget

Drainage Area (Square Miles)	Sediment Delivery Ratio
0.5	0.33
1.0	0.30
5.0	0.22
10.0	0.18
50.0	0.12
100.0	0.10
200.00	0.08

Stewart, B. A., D. A. Woolhiser, J. H. Caro, and M. H. Frere. 1975. Estimating Potential Erosion. In Control Of Water Pollution From Cropland. Vol 1, 7-25. U. S. Environmental Protection Agency Report No EPA-600/2-75-026a or USDA Report No ARS-H-5-1. Washington, DC.

Landslides and Mechanical Movement

- Part of erosion and soil loss, but
- Separate budget items because processes are fundamentally different

Streambank Erosion

http://www.cws.bse.vt.edu/images/sized/images/uploads/Pic_2_-_streambank_erosion-440x230.jpg

http://www.crwr.utexas.edu/gis/gishydro03/Classroom/trmproj/Lancaster/AustinErosion_files/image002.jpg

Streambank Erosion

- 37% of the total load in River Ouse, Yorkshire, UK
- 50% in Midwestern streams, USA
- 78% in the Gowrie Creek, Australia
- 80% in the loess area of Midwest USA
- Up to 92% in Gelbaek stream, Denmark
- From Yong Lai, U.S. Bureau of Reclamation who has sources for each example

Reservoirs Associated with Dams

- Reservoirs are *sinks* within a watershed
- Sediment stored in reservoir
- May or may not be released
- Matilija Dam, CA
  - Being removed
  - *Sink* becomes a *source*

http://www.usbr.gov/pmts/sediment/projects/Matilija/images/ReservoirDelta.png

Tributary Input

- Confluence of Ohio River and Mississippi Rivers, USA
- One carries more sediment than the other

http://media-3.web.britannica.com/eb-media/80/3080-004-CCCE5015.jpg

4. Estimating or Measuring Each Component: Summary

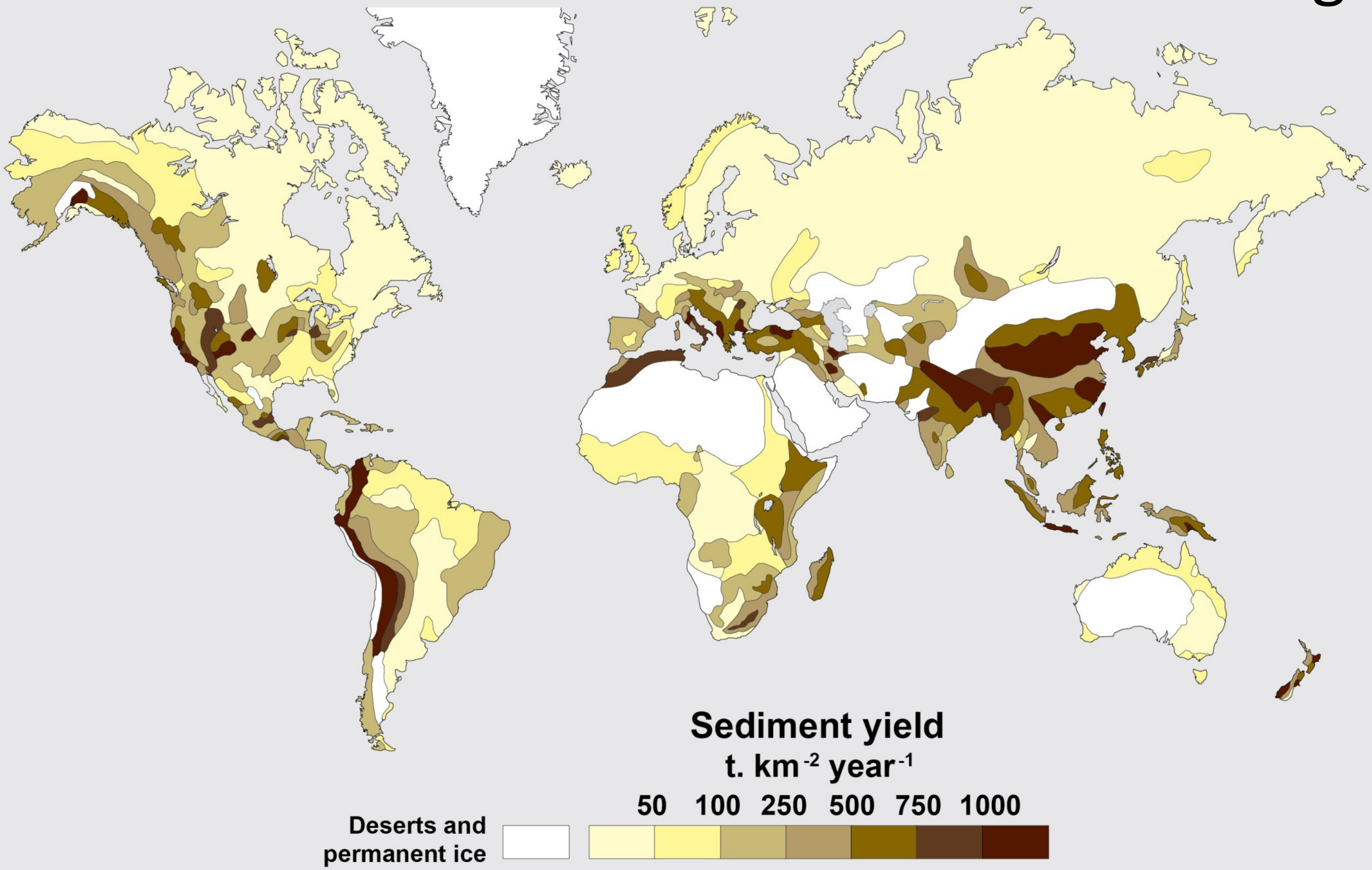
Component	How Estimated/Measured
Dust deposition/scour	Floodplain excavation; anecdotal evidence
Soil erosion	Several components: section 2 for components
Streambank erosion	Field surveys and aerial mapping
Landslides	Aerial photography and survey
Mechanical movement	Field survey
Reservoir sedimentation	Reservoir sediment surveys
Tributary input	Riverine measures of sediment transport

Estimating/Measuring Dust

- Time scale: centuries or more
- Floodplain excavation
- Stratigraphic analysis
- Example: London,England

http://getfile6.posterous.com/getfile/files.posterous.com/temp-2012-05-08/AHJxgJgscsHIeIlyGHoiJmCEBfBxmFslcpxvHJzIzpqyrogEkHoBHggCrtHa/borehole3.jpg

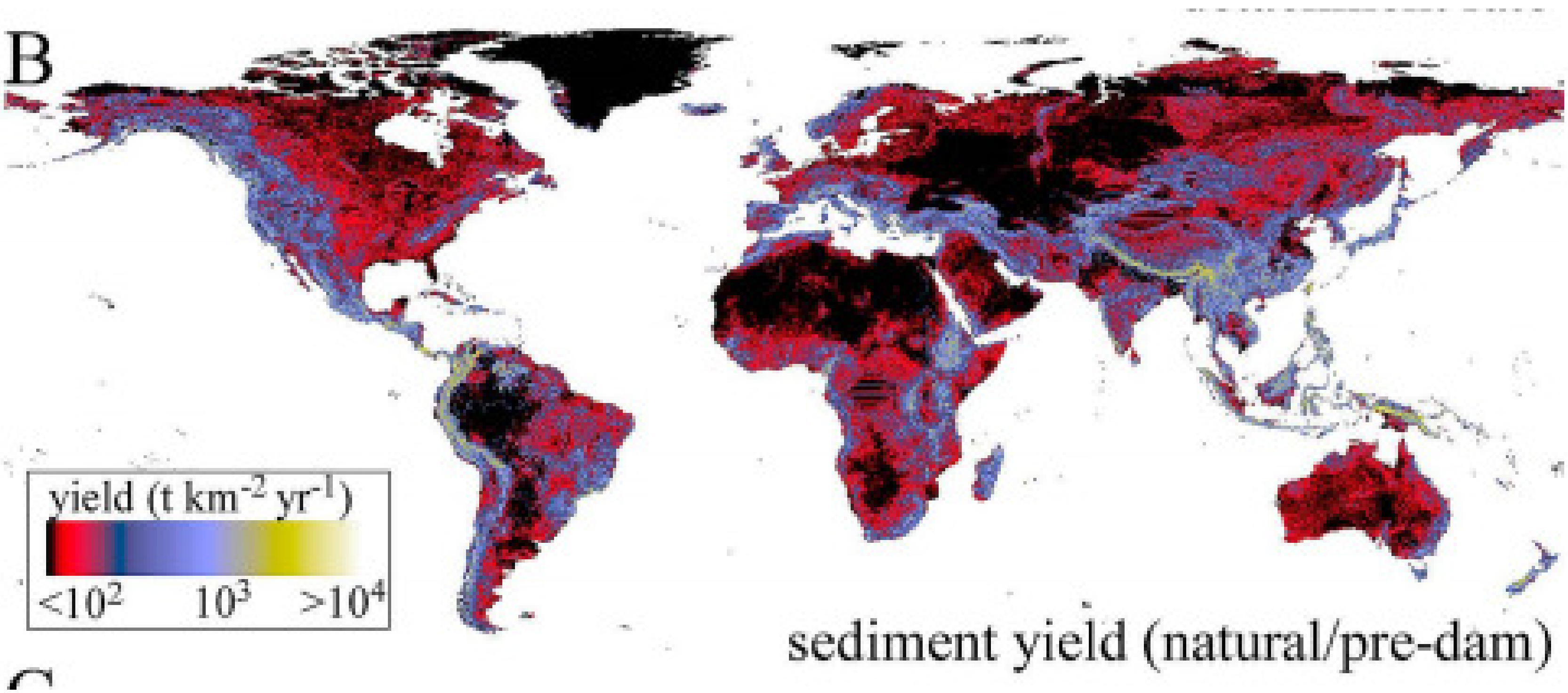
Observed at a Global Scale: from Des Walling



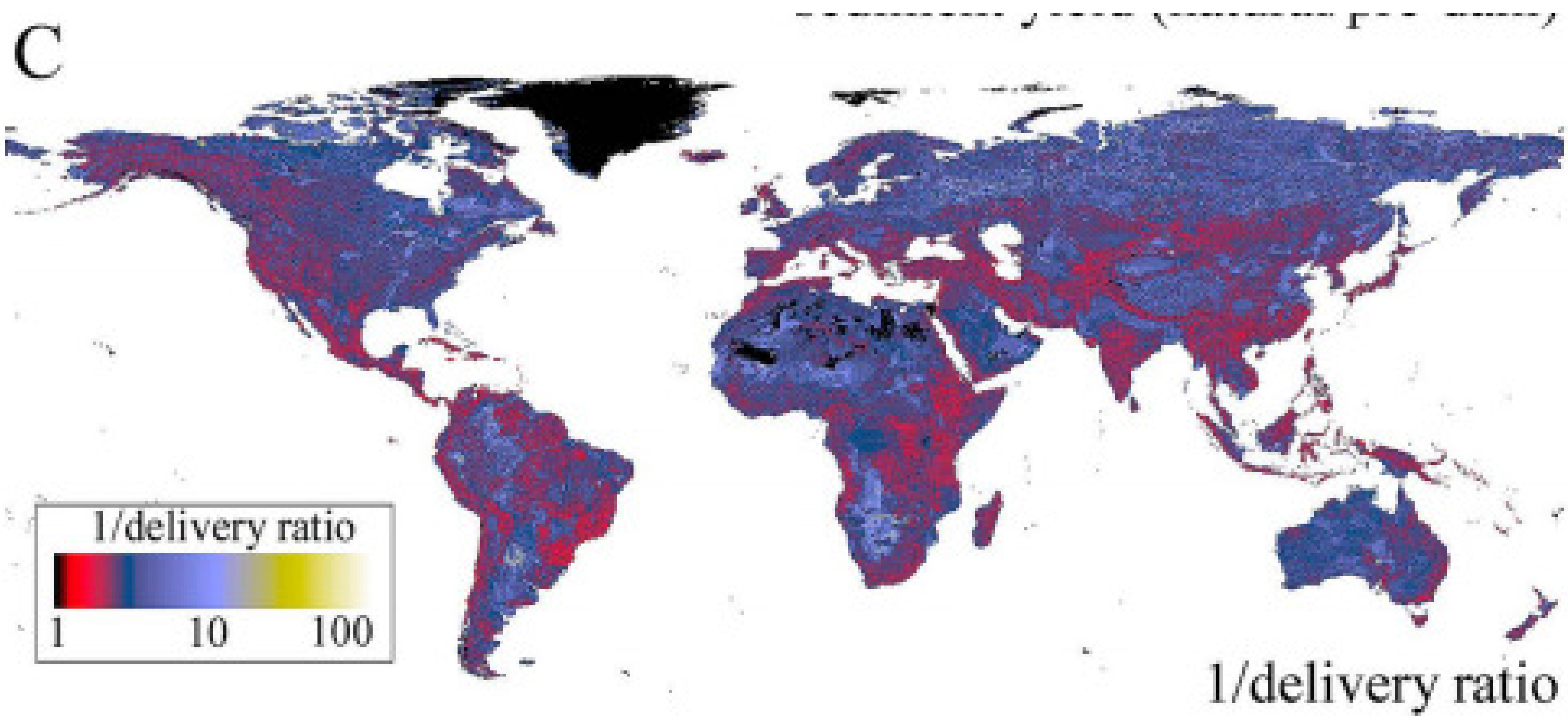
Predicted at a Global Scale

- Jon Pelletier, 2012. A spatially distributed model for the long-term suspended sediment discharge and delivery ratio of drainage basins. Journal of Geophysical Research 117.
- Pixel-by-pixel computer modeling using GIS tools at a very large scale
- Predicts the kind of charts that Walling produced from observed data

Modeled Sediment Yield



1/(sediment delivery ratio)



Estimating/Measuring Soil Erosion – Local Scale

- Does not include landslides or mechanical movement
- Simplest: nails in a board
- Harder: measure from plots

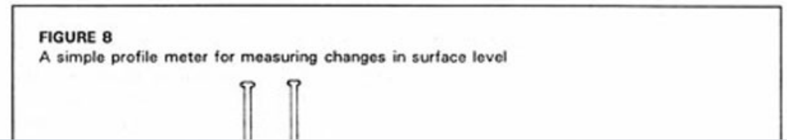


FIGURE 8
A simple profile meter for measuring changes in surface level

http://www.marketplace.org/sites/default/files/styles/slide-show-2-column-530x396/public/SRI.jpg

Estimating Soil Erosion

- Based upon many plot experiments
- Universal Soil Loss Equation (USLE)
- $A = RKLSCP$ where

  A = soil loss, tons/acre

  R = rainfall erosivity index

  K = soil erodibility index

  LS = hillslope length-slope factor

  C = cropping management factor

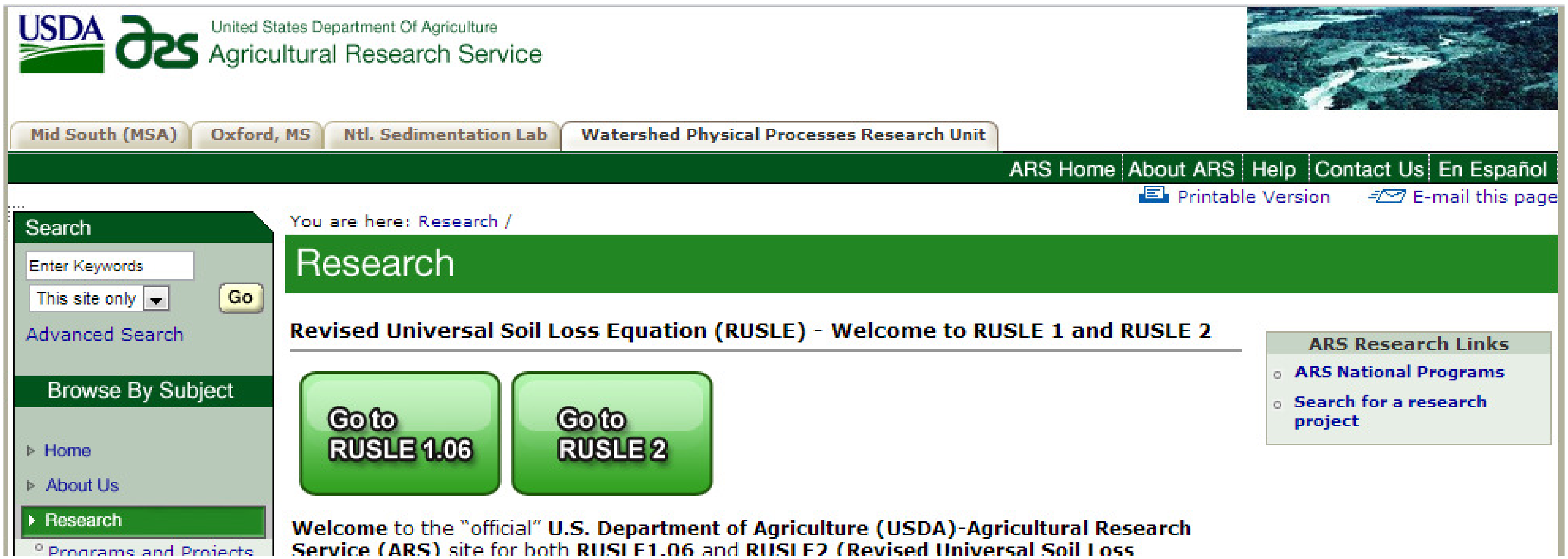
  P = erosion-control factor

USLE

- Published 1965
- Much information available
- Figures, charts, tables for each parameter
- Most common method for estimating *soil loss*
- Does NOT predict *delivery*
- US Department of Agriculture now advocates the use of RUSLE2

RUSLE2

- http://www.ars.usda.gov/Research/docs.htm?docid=5971



- Computer-assisted software and documentation

RUSLE2, continued

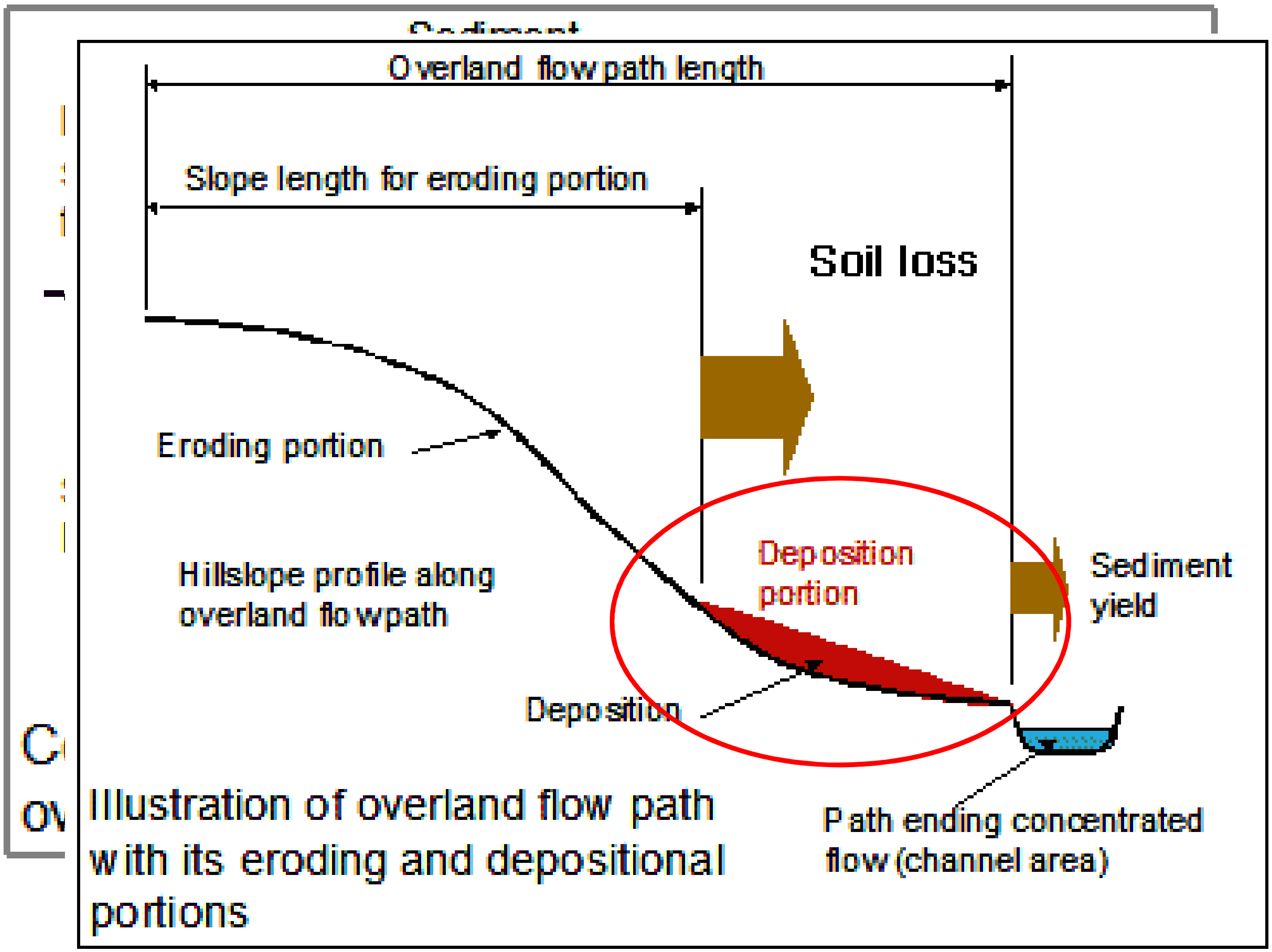
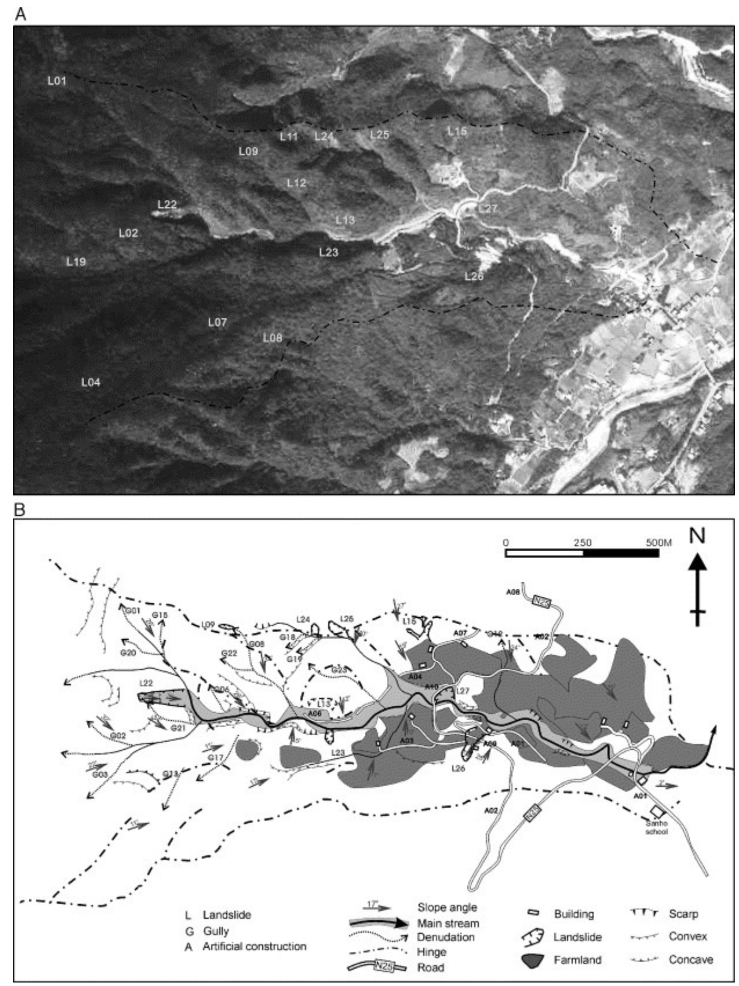


Illustration of overland flow path with its eroding and depositional portions

Landslide

- Aerial photography
- Somewhat random
- Estimate volume by
  - Map measurements
  - Ground survey



http://ars.els-cdn.com/content/image/1-s2.0-S0169555X06000067-gr6.jpg

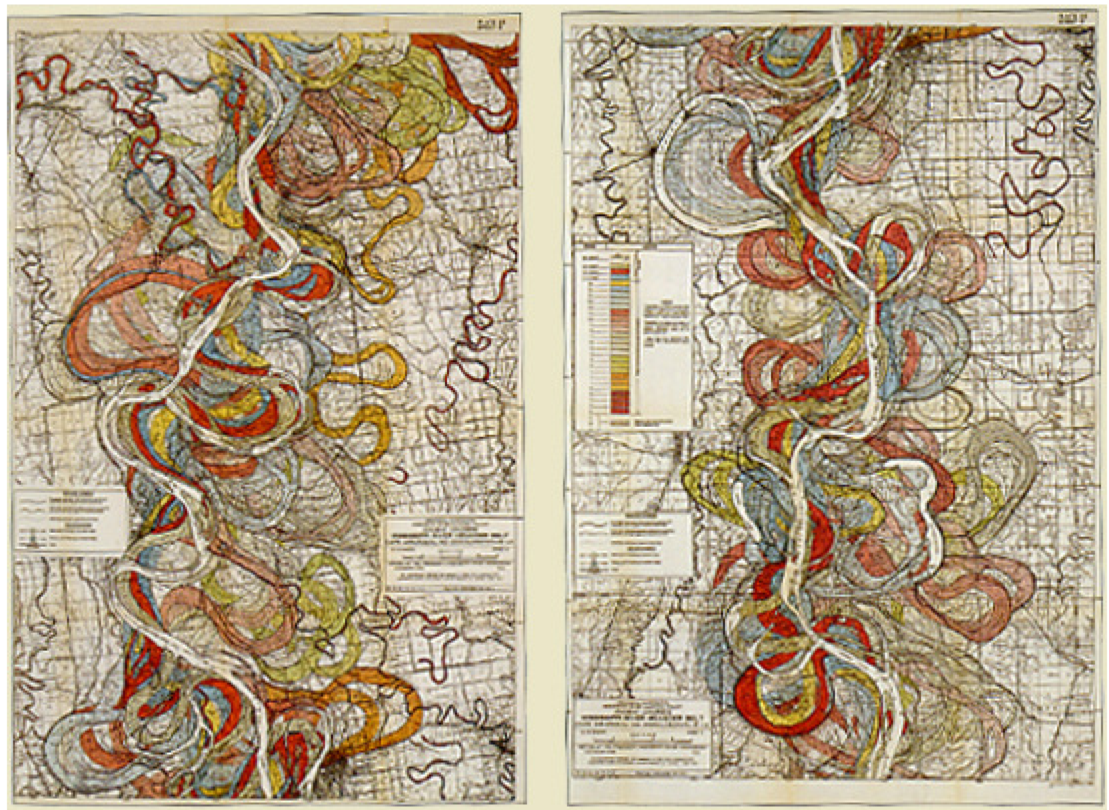
Estimating/Measuring Mechanical Movement

- Field-based survey
- Usually required as part of a restoration or reclamation plan
- Meet required performance criteria

http://www.eoearth.org/files/123401_123500/123460/250px-Surface_mine_reclamation.jpg

Estimating/Measuring Streambank Erosion

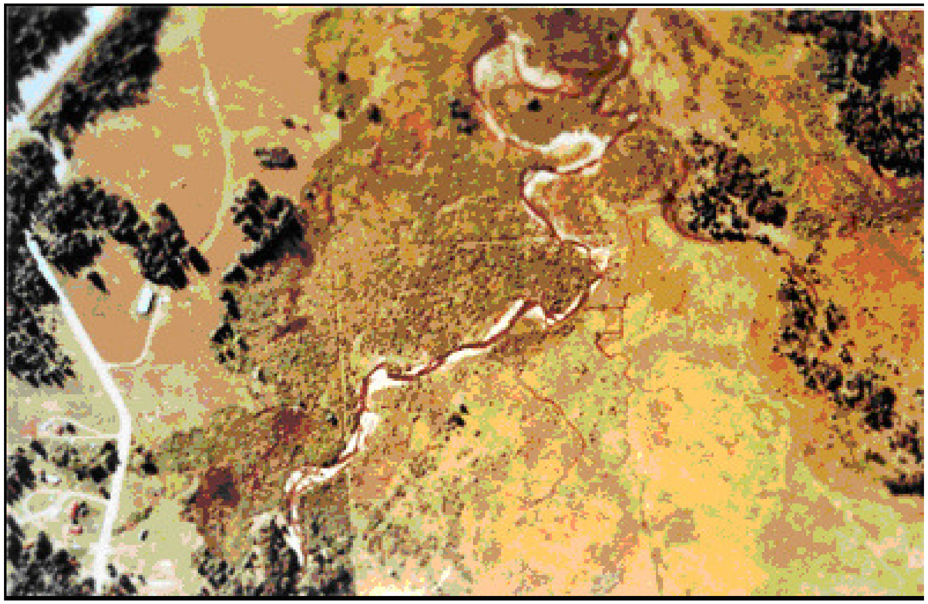
- Historical maps for meander belts
- Mississippi River



http://www.jenbervin.com/images/mississippi/meanderbeltmap.jpg

Estimating/Measuring Streambank Erosion

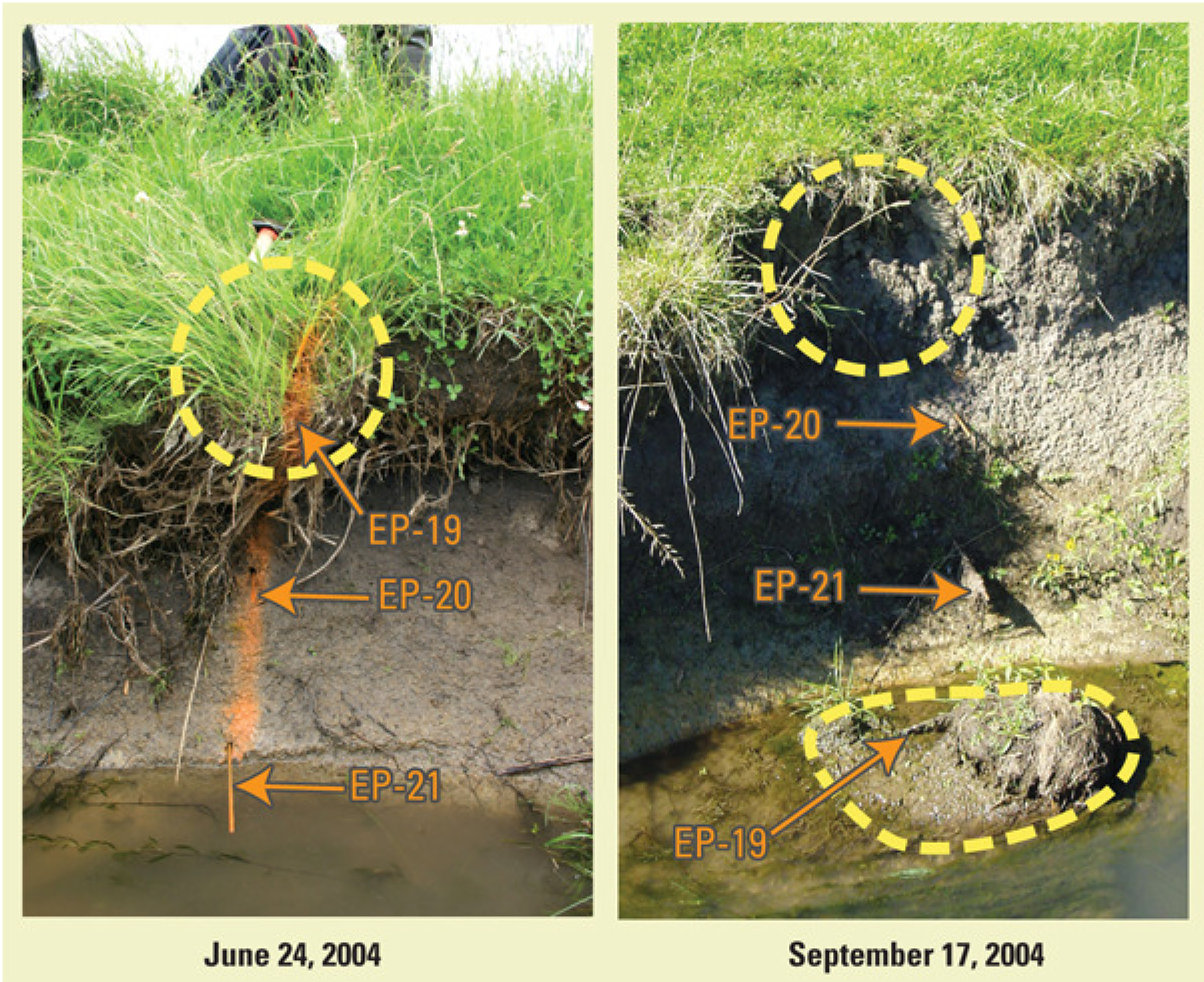
- Aerial photography for more recent bank failure
  - Good for reconnaissance
- Can field survey for more accurate data



http://water.epa.gov/scitech/datait/tools/warsss/images/fig30.jpg

Estimating/Measuring Streambank

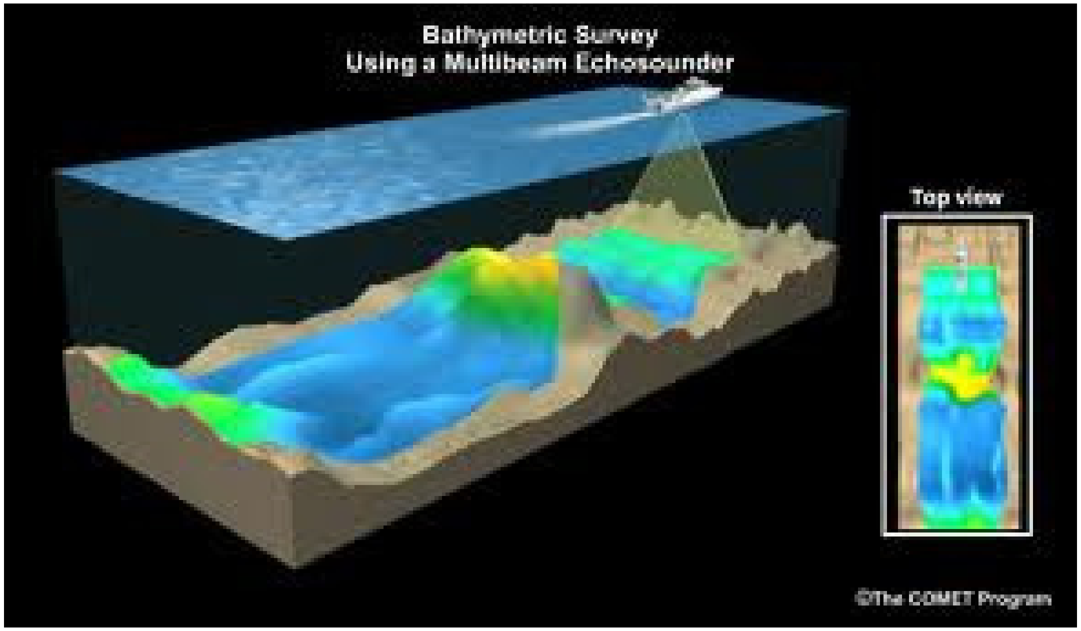
- Erosion Pins
- Easily used
- Monitor
  - ➢Floods
  - ➢Annually
  - ➢Seasonally



http://pubs.usgs.gov/fs/2005/3134/images/fig07_left.jpg

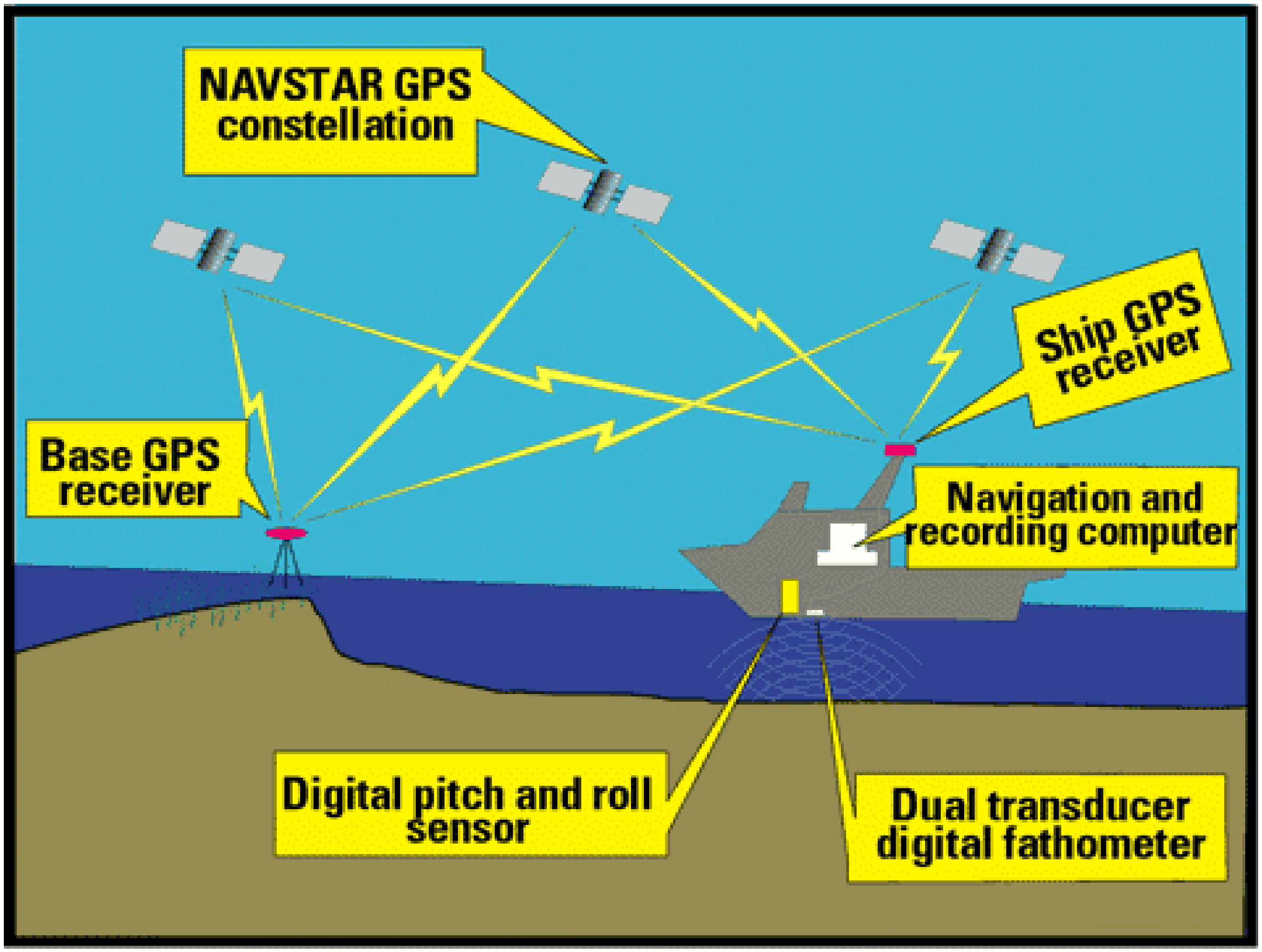
Estimating/Measuring Reservoir Sedimentation

- Need initial survey
  - Topo map before construction
  - Bathymetric soon after closure
- Subsequent surveys
  - Best: multibeam echosounder - $80,000
  - Good: single beam echosounder: $25,00



http://t0.gstatic.com/images?q=tbn:ANd9GcRUS3O8Fi9iX11K8VZibZ9Sdyu8QrpJ8ByLFfWy2vn8cUKxEege8UolJga6

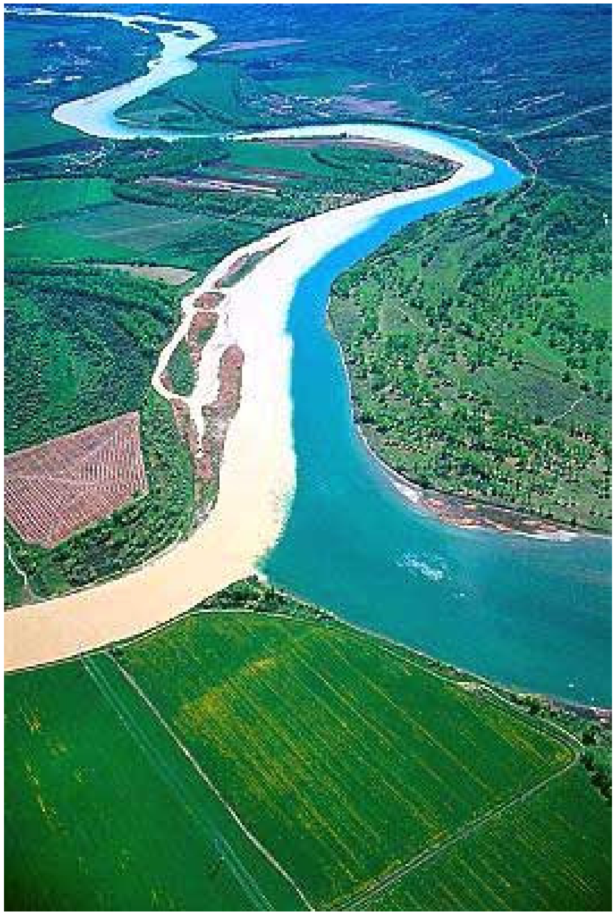
Elements of Modern Surveys



http://sofia.usgs.gov/publications/ofr/00-347/images/survey.gif

Estimating/Measuring Tributary Input

- Milk River, Montana
- You may want to trace where sediment is coming from
- Go upstream looking at tributaries
- Measure tributary input
- See item 7



http://www.airphotona.com/stockimg/images/00066.jpg

5. Land Use Impacts on Sediment Budget

- Deforestation
- Well-known impacts
- Exposure to rainfall splash
- Loss of soil strength

http://www.dr1.com/blogs/uploads/environment_deforestation.jpg

Urbanization

- Often clear land for entire subdivisions
- Increase in
  - Runoff
  - Erosion
- Can impact an entire region/country or countries

http://passel.unl.edu/Image/siteImages/UrbanRillErosion-NRCS-LG.jpg

Agriculture

- Centuries-old problem
- Cultivating perpendicular to contours
- Add water
- And…increase erosion!

http://static.howstuffworks.com/gif/irrigation-soil-erosion.jpg

Other Land Use Impacts

- You name them!

…And NO land use impact?

Moderate Precip = High Erosion

http://2.bp.blogspot.com/-F0rei5azSEs/Tvtd1ltJ6rI/AAAAAAAAA-w/1tUU8KGzdOc/s1600/Lesotho+Landscape.JPG

Soil Loss

Low Precip = Low Erosion

High Precip = Low Erosion

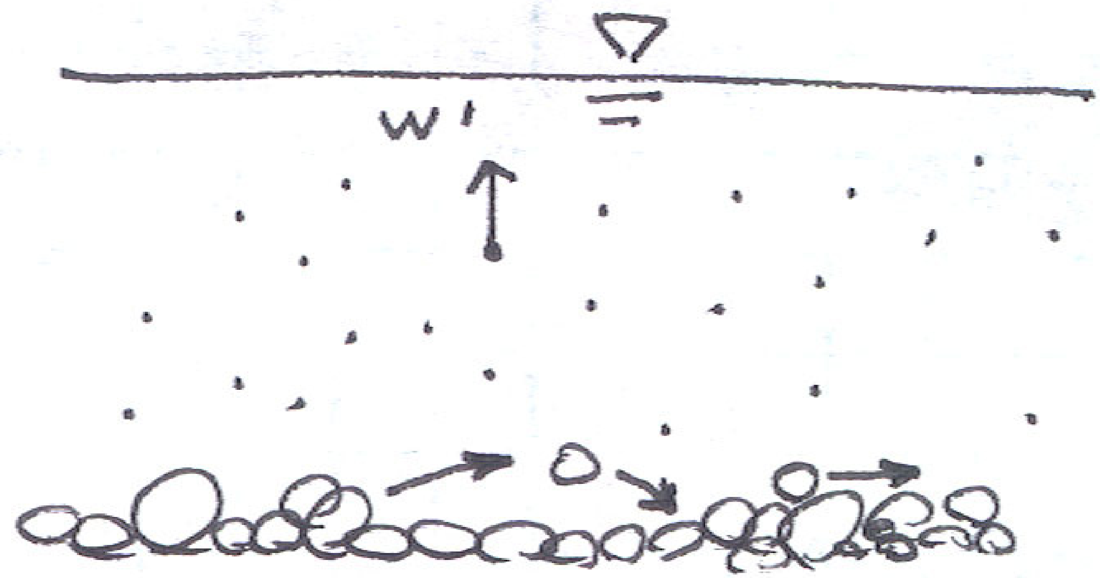
http://farm2.static.flickr.com/1299/556137713_ef65e479e2.jpg

http://www.isavo.com/pic409/jungle2.jpg

Mean Annual Precipitation

6. River Transport of Sediments

- Bedload
  - Along streambed
- Suspended Load
  - In water column
  - Can deposit
- Washload
  - Very fine
  - Does not deposit



Bedload

- Requires high Q
- VERY nonlinear
- Einstein's challenge
- Can be between 5 and 80% of total sediment load
- Low end = gravel
- High end = sand

http://gallery.usgs.gov/video/water/2010/jul/bedload_transport_kootenai_river_2.jpg

Suspended Load

- New Zealand
- Glacial outwash
- Grey is suspended load
- Can see previous bedload

http://www.swisseduc.ch/glaciers/new_zealand/fox_glacier/icons/17_river_turbulent.jpg

Wash Load

- Very fine material
- Colors water
- Deposits only
  - In reservoirs
  - On floodplains
- *Colorado* River

http://therockyriver.com/wp-content/uploads/2012/08/ColoradoRiverSedimentLoadMonsoonHugeFishKill.png

7. Measuring Transported Sediments

- Suspended Load
  - DH-48
  - Hand-held
  - Only small rivers
- Manual procedure
  - Very expensive

http://www.envcoglobal.com/files/MO-HyS-DH-48-L.jpg

Larger Rivers

- Deployed from bridges
- Still expensive

http://www.envcoglobal.com/files/MO-HyS-D49-L.jpg

http://mi.water.usgs.gov/splan5/sp09500/images/sus.sam.jpg

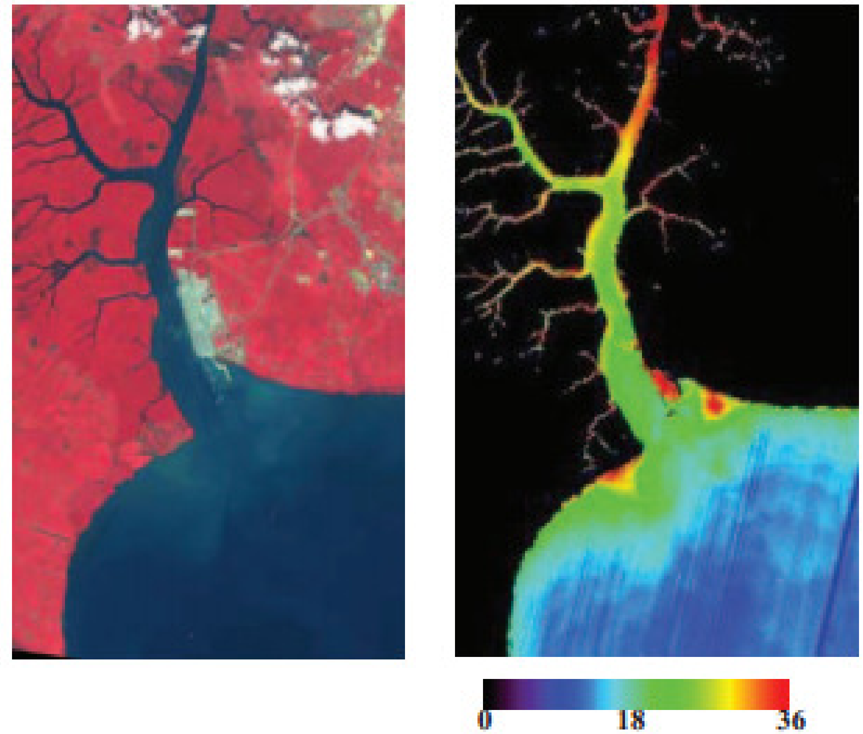
Emerging Suspended Load Methods

- Continuous recording turbidity meter
  - Mounted on bottom of stream
  - Light shines upward
  - Records turbidity
- Related to suspended load concentration
  - Occasional water samples collected for calibration

http://ga.water.usgs.gov/edu/pictures/TurbiditySond.jpg

Emerging Suspended Load Methods

- Satellite imagery
- Coloration indicates suspended load
- Need some calibration
- Very useful and emerging technology

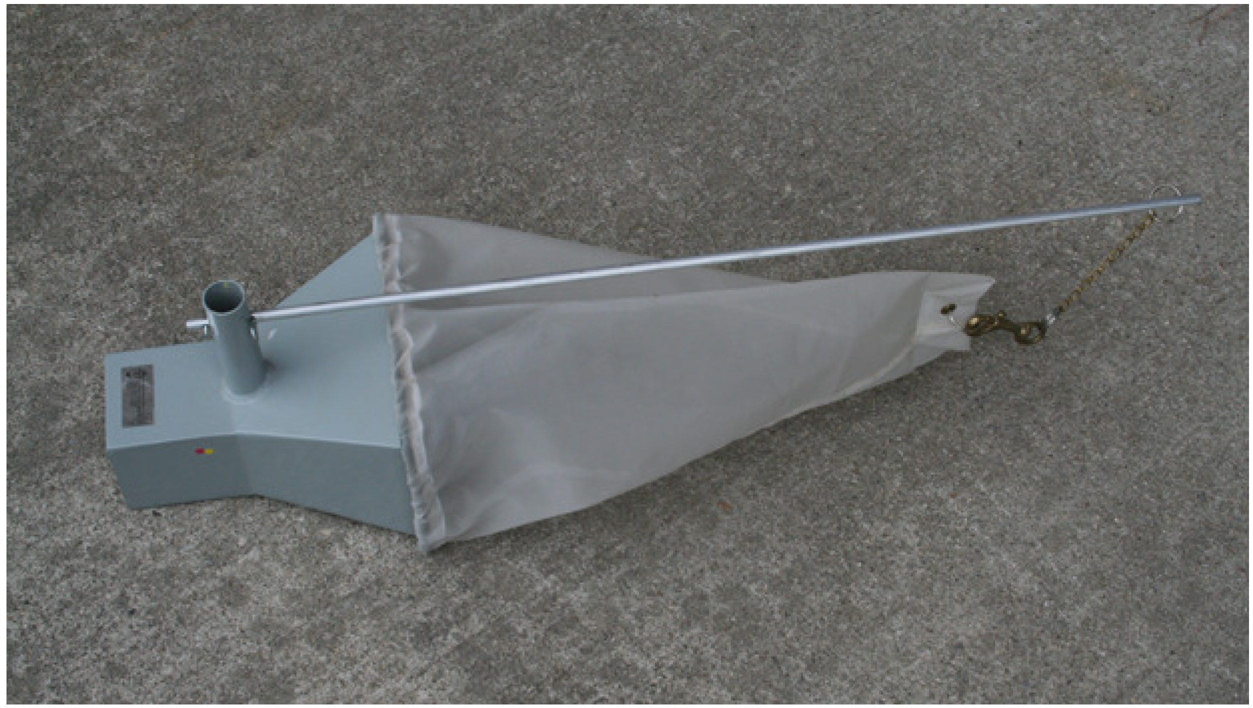


Coastal Singapore: infrared (left) and turbidity (right)

Soo Chin Liew. Monitoring turbidity and suspended sediment concentration of coastal and inland waters using satellite data. Geoscience and Remote Sensing Symposium, 2009 IEEE International. Pages 11-837 to II-839

Bedload Sediment Measurements

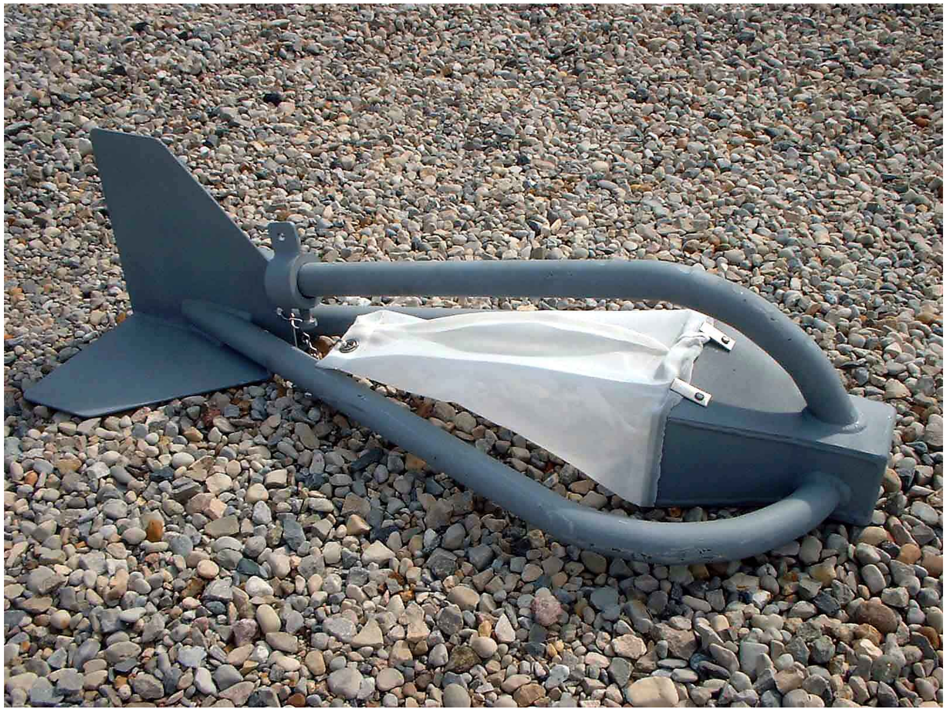
- Hand-held method
  - Small streams
  - Labor intensive
  - Dangerous
- Helley-Smith



http://www.halltechaquatic.com/wp-content/themes/halltechaquatic/images/cat1/bedloadsampler621.jpg

Larger Rivers

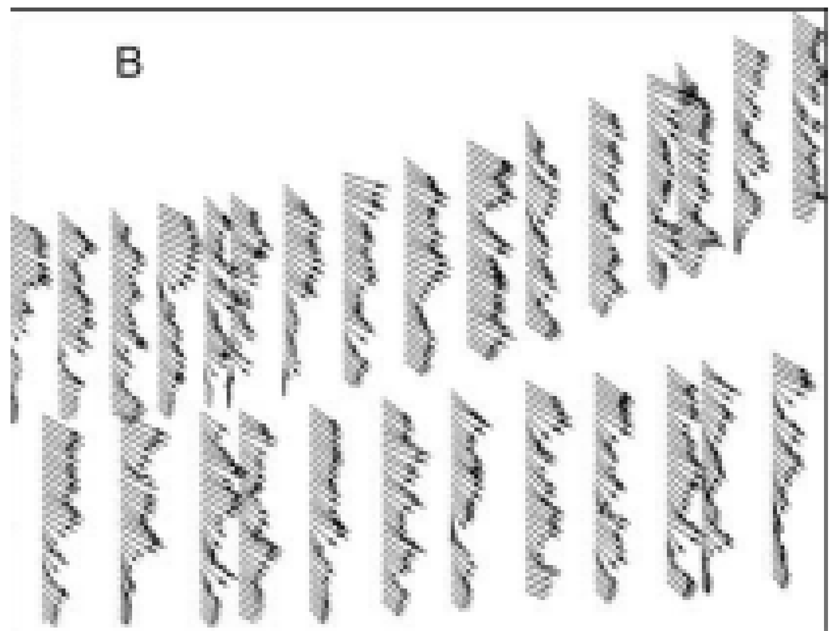
- Heavier Helley-Smith!
- Deployed from bridge
- Still expensive



http://www.rickly.com/ss/images/HELLEY.JPG

Emerging Bedload Methods

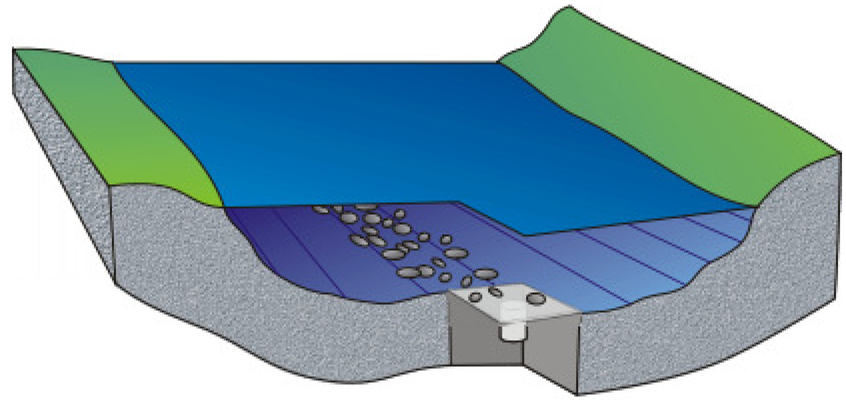
- Sandy streams: ADCP
  - Measures water velocity
  - Tracks bottom sediments
- Can estimate velocity of bedforms



Dinehart, R.L. and J.R. Burau. 2005. Repeated surveys by acoustic Doppler current profiler for flow and sediment dynamics in a tidal river. Journal of Hydrology pp. 1-21.

Other Bedload Methods

- Impact
  - Strikes plate
  - Sound ~ transport



Moen, Knut M., Jim Bogen, John F. Zuta, Premus K. Ade, and Kim Esbensen. 2010. Bedload measurement in rivers using passive acoustic sensors. USGS Scientific Investigations Report 2010-5091

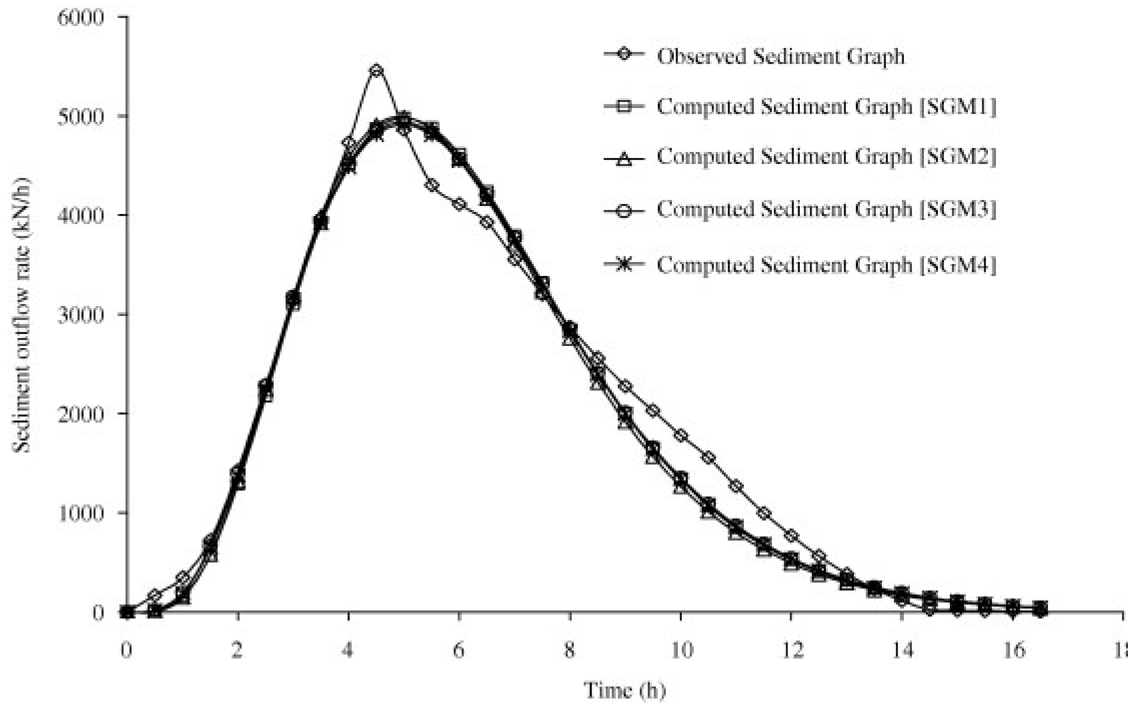
- Painted rocks, magnetic rocks

8. Making the Sediment Budget

- Two approaches
  - Add up components
  - Simulate components with computer models
- First approach
  - $Sediment\ Yield = \sum All\ of\ the\ components$
  - Usually simply measured as riverine transport
  - Individual budget items allow you to focus on those particular items

2^{nd} Approach: Computer Modeling

- Use measure data to calibrate a computer model
- Use the model to predict impacts of changes



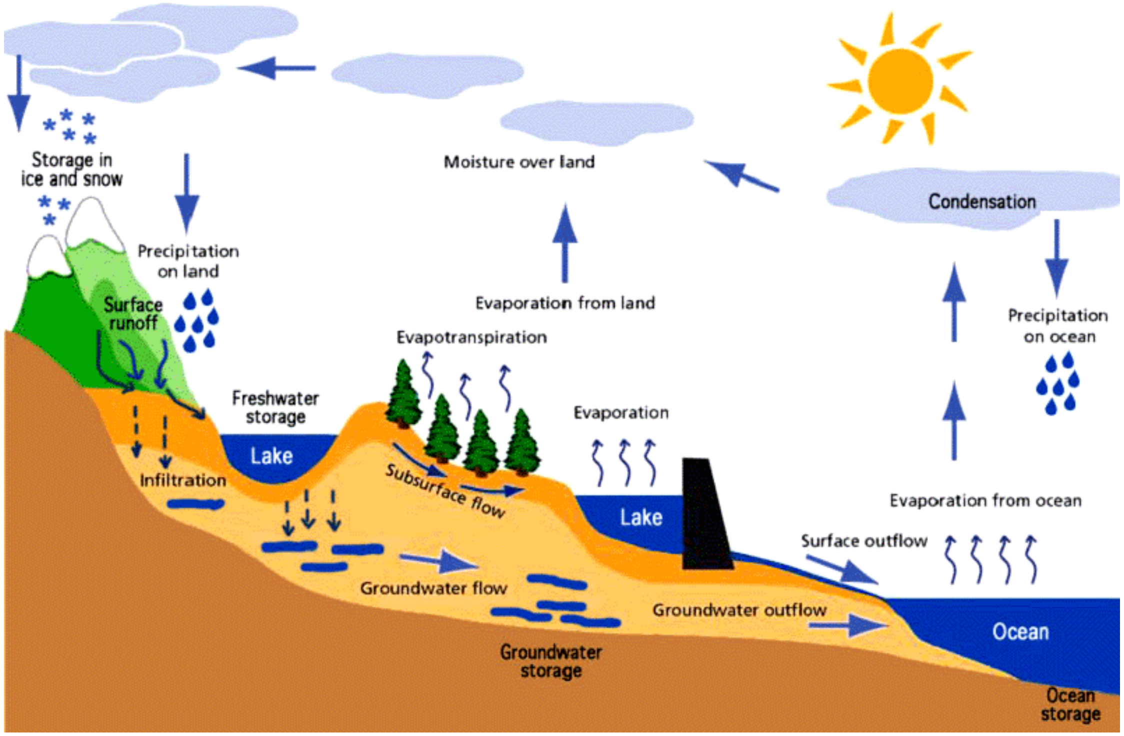
http://ars.els-cdn.com/content/image/1-s2.0-S0022169407006737-gr4.jpg

Computer Models

Model	Reference	Comments
RUSLE2: Revised Universal Soil Loss Equation	http://fargo.nserl.purdue.edu/	Upland watersheds
AGNPS: Agricultural Non-Point Source Pollution Model	Google "AGNPS"	Upland watersheds
MIKE SHE	http://www.crwr.utexas.edu/gis/gishyd98/dhi/mikeshe/Mshemain.htm	Comprehensive rainfall/runoff model
GSSHA: Gridded Surface-Subsurface Hydrologic Analysis	http://chl.erdc.usace.army.mil/gssha	2-D rainfall/runoff/erosion

Hydrology

- We'll not talk about each component
- Focus: discharge rates
- MIKE SHE and GSSHA simulate all components



http://geofreekz.wordpress.com/the-hydrosphere/

9. Measuring Streamflow Discharge Rates

- Why focus on measuring streamflow discharge rates?
- Sediment yield = sediment concentration x water discharge
  - Example: (3,000 mg/l) x (1 million l/s) = 1 billion mg/s = 1 million kg/s = 1,000 metric tons/s

Smaller Streams

- USA: Price meter
- Used since 1880s
- Deploy by
  - Wading
  - From bridge
- Most common method for 100 years

http://www.envcoglobal.com/files/imagecache/product_page_image/MO-D622RG-L.jpg

Smaller Streams

- Online video training
- http://wwwrcamnl.wr.usgs.gov/sws/SWTraining/WRIR004036/Index.html

http://fishwild.vt.edu/afs/fisheries_techniques/Chapter4/Estimation%20of%20stream%20velocity%20using%20a%20Price%20AA%20flow%20meter%20f.JPG

Medium to Large Rivers: Modern Method

- Acoustic Doppler Current Profiler (ADCP)
- 0.8 m-long ‘boat’
- Dragged across river or drone
- Acoustic signals use Doppler effect to measure velocity

The StreamPro's transducer can be towed from different points onboard the platform, or can be removed and hand held in the water for applications such as under ice flow measurements.

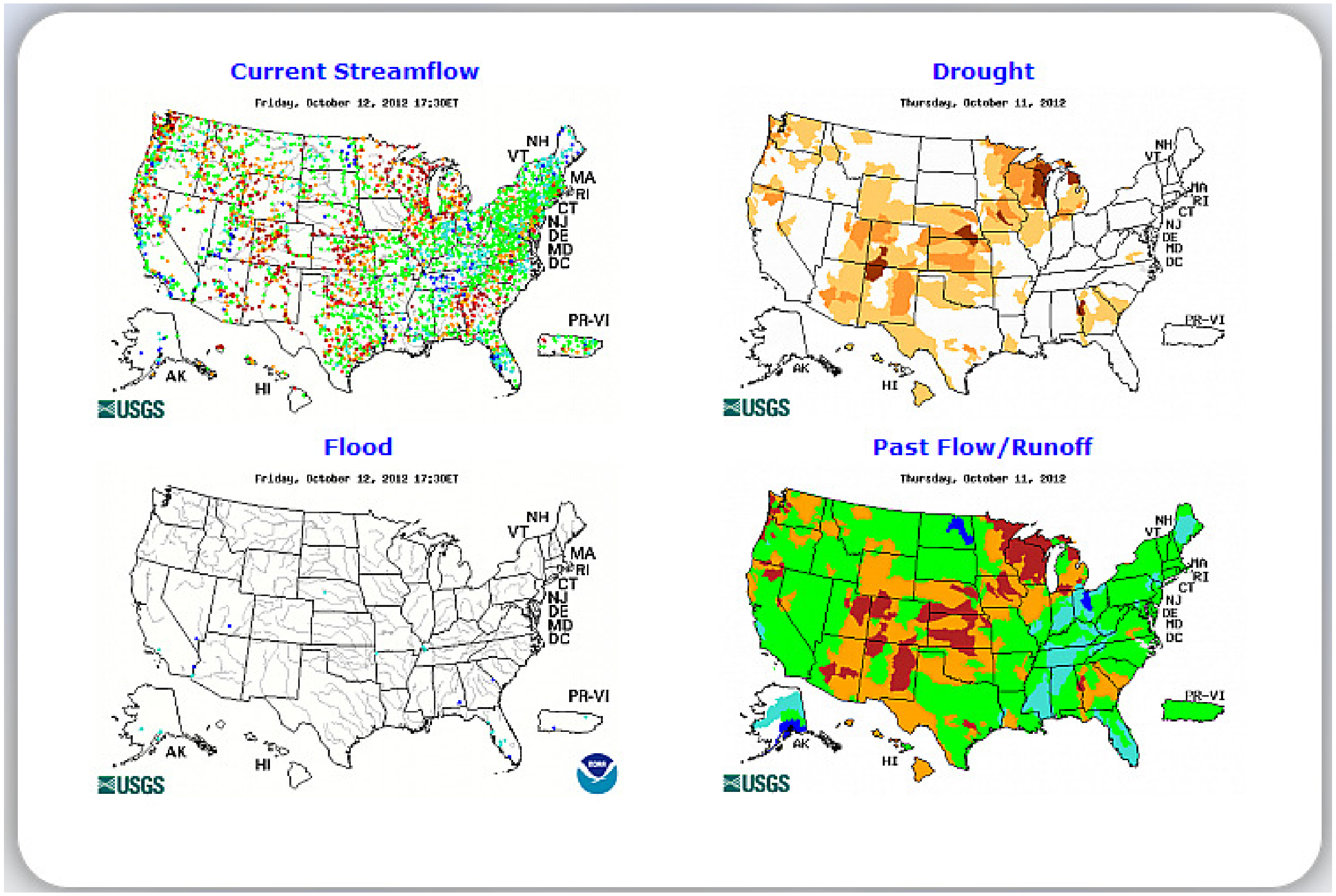
http://t0.gstatic.com/images?q=tbn:ANd9GcTg3xFgJXmSZ4ZhO4yMt_ngu3e9ru0T3zPOwOuOj5iXDVxG44IDdw

ADCP Methods

- 4 sensors: 1 for depth, 1 each for velocity in x, y, and z directions
- Integrates meassurements instantly
- Gives detail about discharge distribution

http://www.eoearth.org/files/110701_110800/110736/310px-Adcp_600.jpg

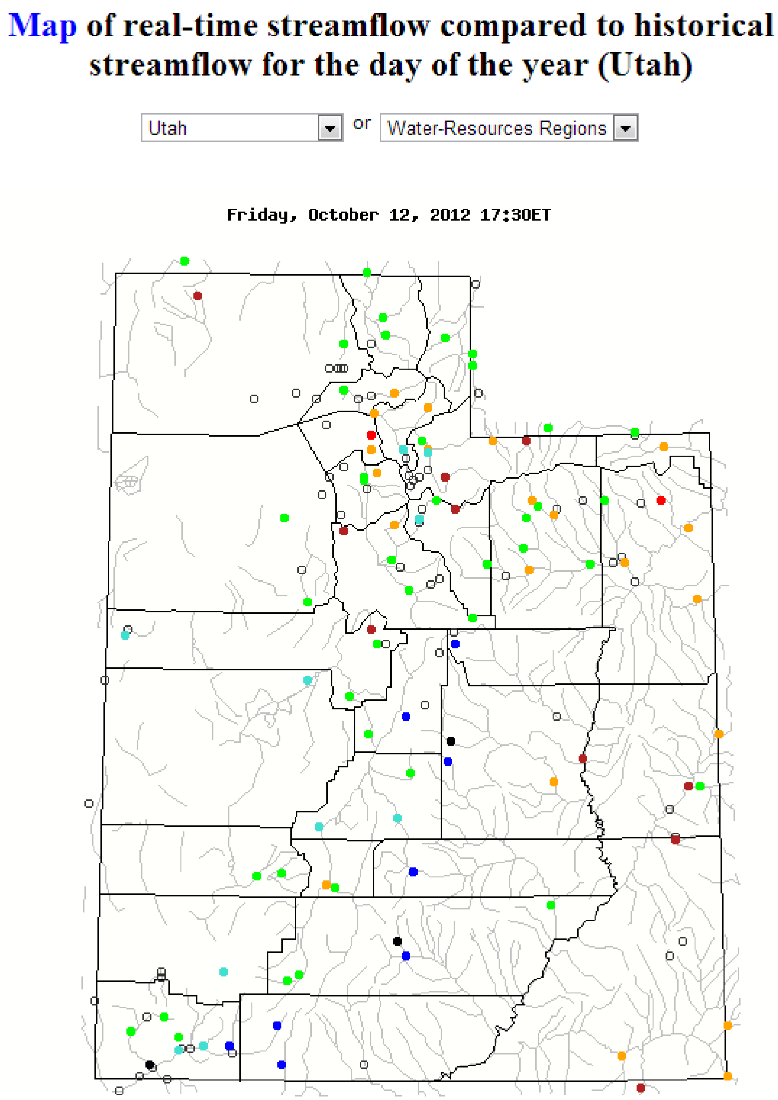
Accessing Records: U.S. Geological Survey (USGS)



http://waterwatch.usgs.gov/

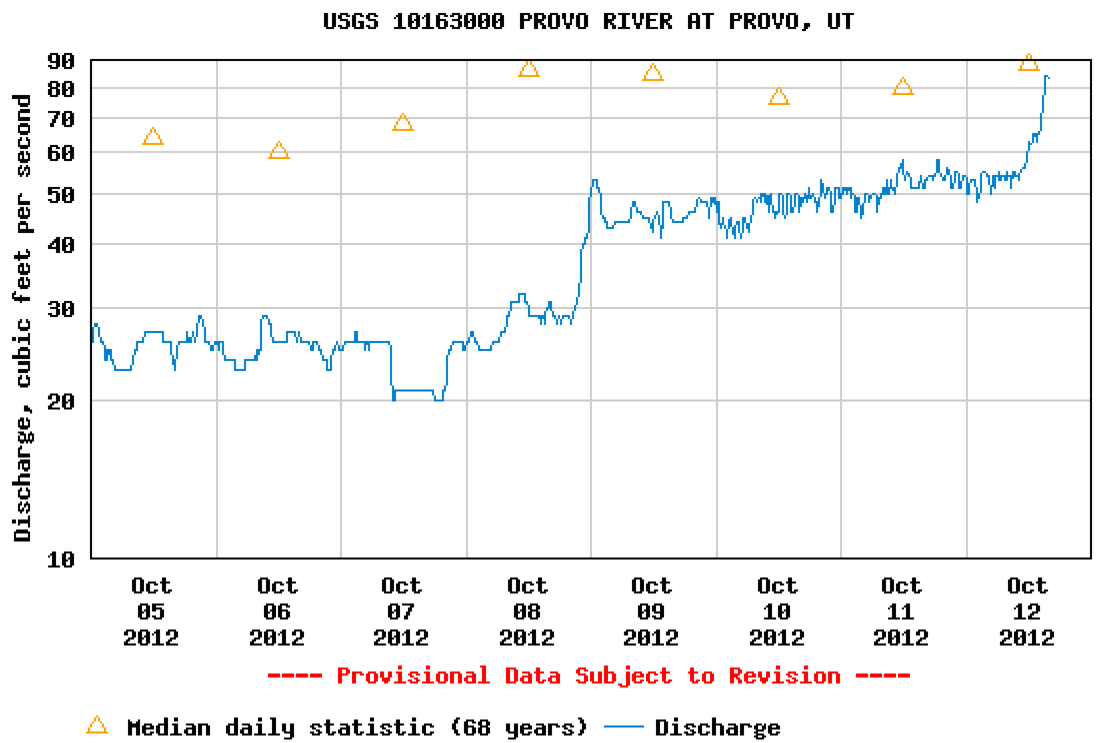
State-Scale View

- Shows all current stream gages
  - Continuous
  - Crest stage only
  - Water quality including suspended sediment!
- Each location icon is clickable



Provo River, Provo, Utah

- Plots for one week
- All axes can be changed
- Updated frequenty each day
- State of art



Summary

- Sediment Budgets
  - Consider each component
  - What is dominant in your watershed/country?
  - Invest in data collection!!
- Riverine sediment concentration measurement
  - Collaborate across countries
  - Use consistent methods and training
  - All data put online in real time
- Stream discharge measurement is foundation
  - Add sediment measurements to the discharge net
  - Many other topics to discuss!

Thank you!