A Fulcrum Approach for Assessing Sediment Source-to-Sink Mass Balance Using Fluvial Paleohydrologic Data Extractable from Cores: An Assessment of Potential and Limitations Using the Cenomanian Bahariya Formation, Egypt*

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Search and Discovery Article #50993 (2014)**
Posted August 11, 2014

*Adapted from oral presentation given at 2014 AAPG Annual Convention and Exhibition, Houston, Texas, April 6-9, 2014

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Abstract

Source-to-sink interpretations of genetic equivalency between fluvial feeder systems and basin accumulations infer that the sediment supplied by the rivers is in mass balance with the sediment volume ultimately deposited. This relationship has value for modeling basin fill volumes over time steps and for related projecting of reservoir partitioning and potential. Executing an estimate of this mass-balance assumption is challenging in modern systems but even more difficult in deep-time stratigraphic settings where critical variables from the source and sink system are not preserved or preserved with large uncertainties. Available data sets from ancient systems are likewise often limited to a few localized boreholes. This article offers a method for estimating mass flux from the source area to the basin sink by calculation of paleohydrologic variables from a cross-section of channel-belts using data extractable from outcrop or core. We use the Cenomanian channels of the Bahariya Formation, Egypt to test this method.

Total sediment mass passing through a cross section of channels over a period of time should match with both the total sediment delivered to the channels from the source area and the total volume delivered through these channels to basin. This cross section would constitute a fulcrum across which source and sink sediment mass should balance. Flow transport equations are used to estimate bankfull discharge and sediment concentrations using methods illustrated in Van Rijn (1984) and Parker (2004). These concentrations are projected over longer durations to estimate total channel mass-through flux over basin time spans. These estimates can be tested against known basin accumulation volume and/or estimates of basin denudation. The required calculations can be made from paleohydrologic information routinely extracted from core and/or outcrop data sets by reconstruction of channel-belt architecture and sediment sampling. Calculations of mass flux from Bahariya channels that feed the equivalent fluvial/marine basin show these channels were capable of delivering twice the sediment actually preserved. This method is nascent in its development and limited by large uncertainties in averages and deviations in key parameters used in calculations,

particularly in the relationship between bankfull and annual-average discharge. At present, the method is accurate only within an order of magnitude.

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An Assessment of Potential and Limitations Using the Cenomanian Bahariya Formation, Egypt

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Journal of Sedimentary Research

April/May 2014

A FULCRUM APPROACH TO ASSESSING SOURCE-TO-SINK MASS BALANCE USING CHANNEL PALEOHYDROLOGIC PARAMATERS DERIVABLE FROM COMMON FLUVIAL DATA SETS

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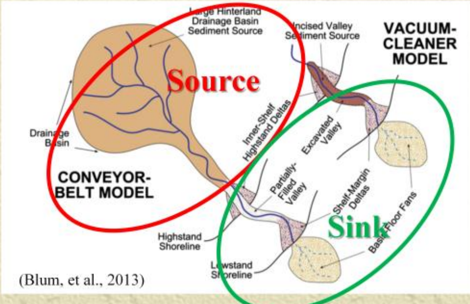
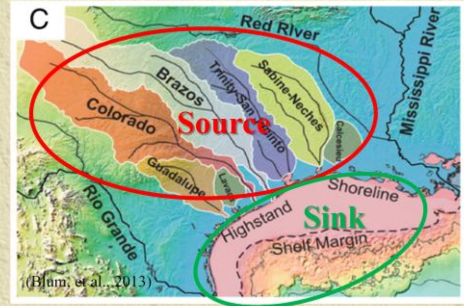
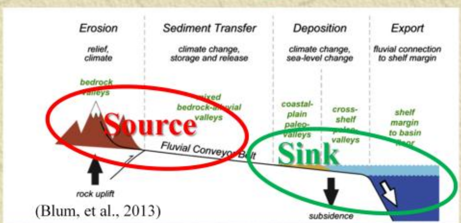
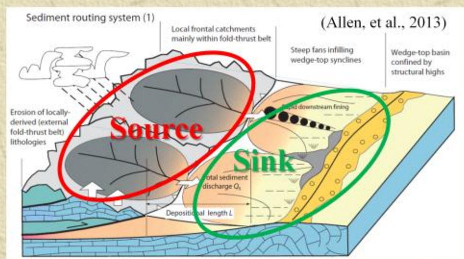
Source-to-Sink and Reservoir Volumes





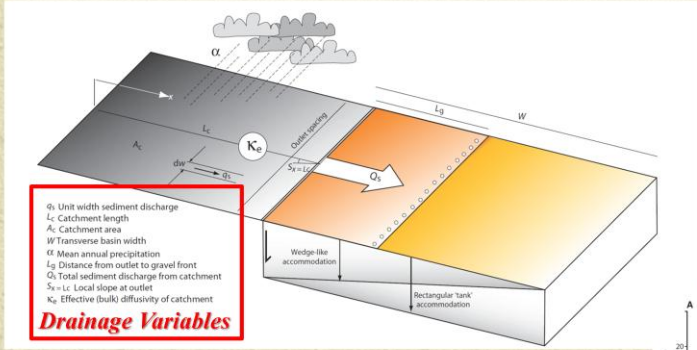


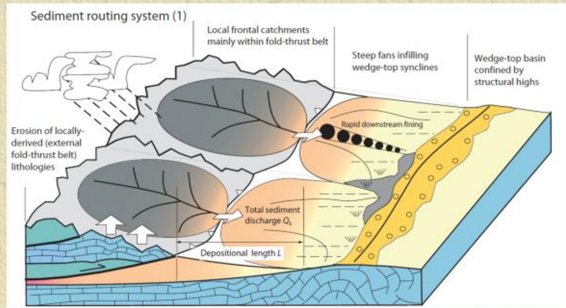


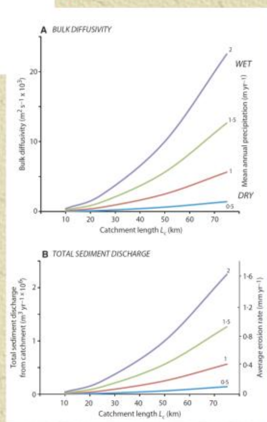
Source = Sediment Budget **Sink = Reservoir Potential**

Source-to-Sink Approaches

Catchment Approach

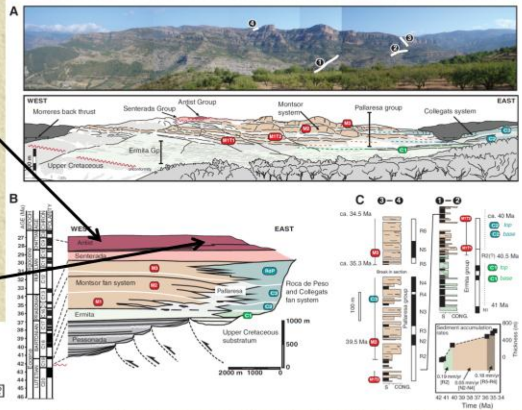


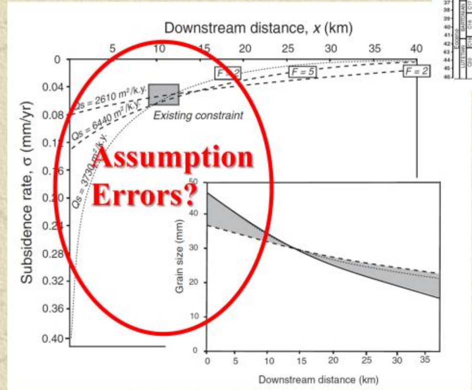




(Allen, et al., 2013)

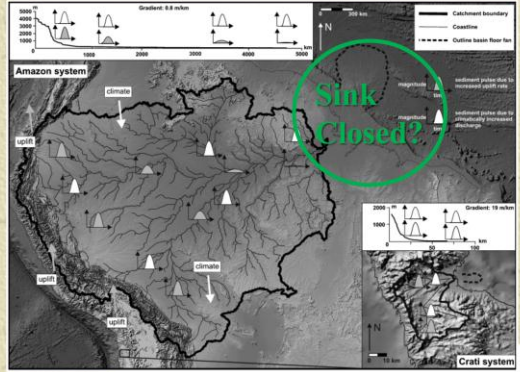
(Whittaker et al., 2011)





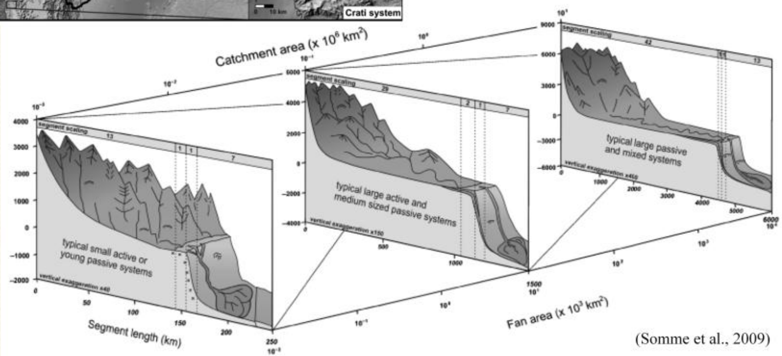
Source-to-Sink Approaches

Grain Sequestration



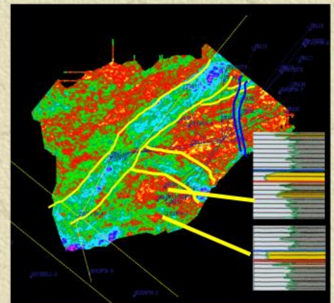
Source-to-Sink Approaches

Basin Volumes

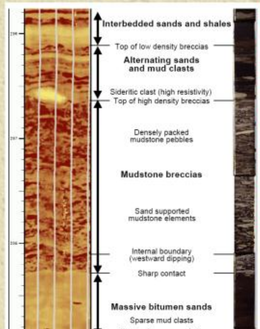


(Somme et al., 2009)

Typical Subsurface Data Sets



AEA limited to lower-order in Core and FMI and higher order in Wire-line and Seismic

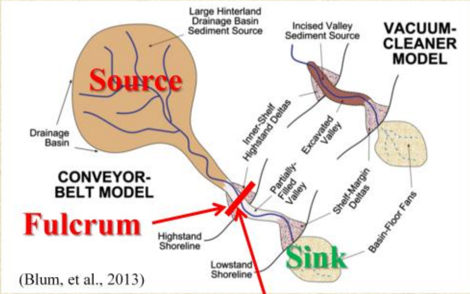


(Bal, et al.)

Scenes from the Triassic Mungaroo, NW Shelf Australia

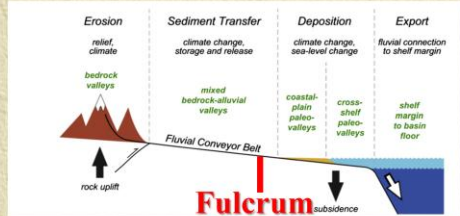
Scales
- **Bar/Channel**
- **Channel Belt**
- **Valley**

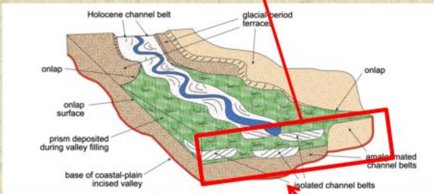
Source-to-Sink Approaches



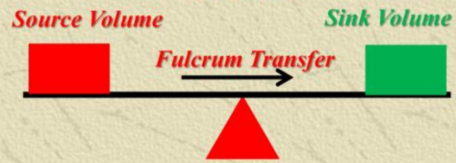
(Blum, et al., 2013)

Fulcrum Test



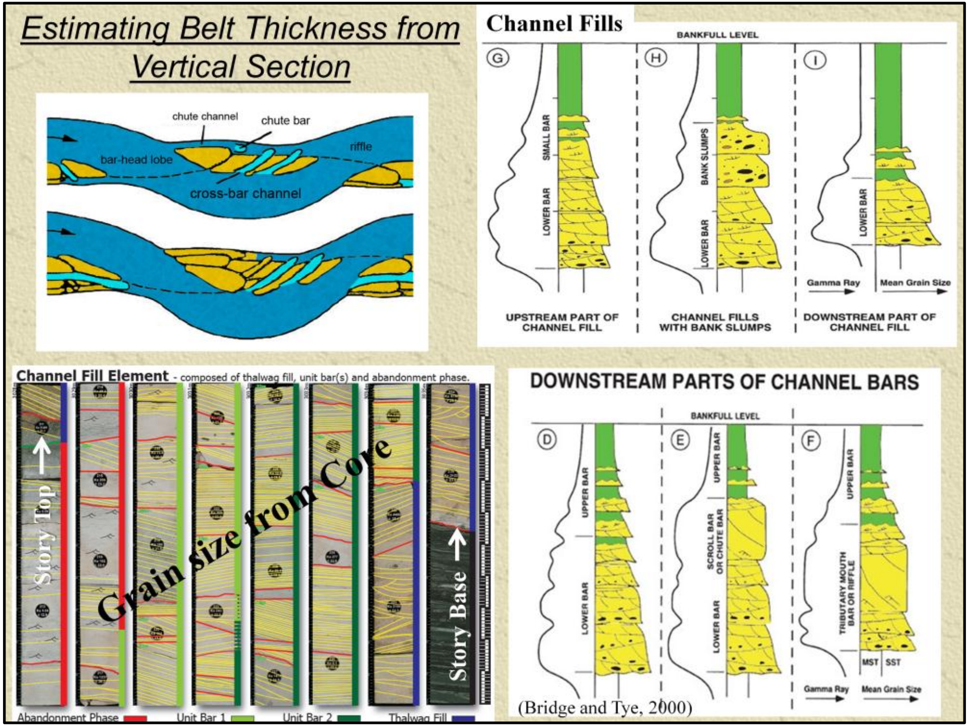


(Blum, et al., 2013)



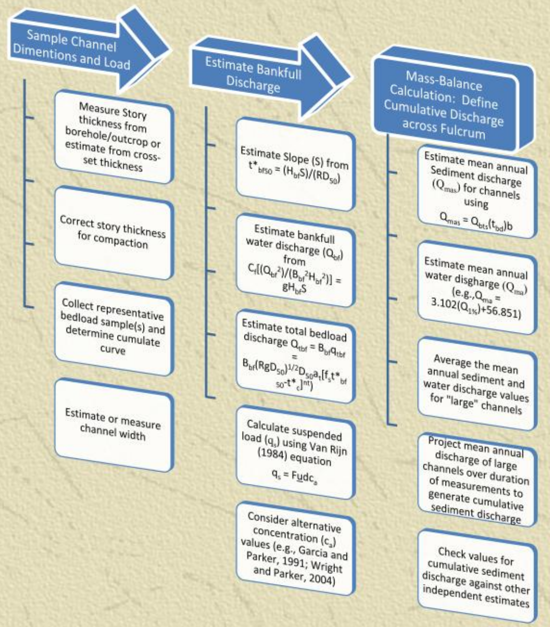
Data Requirements: Story Thickness and Grain size

Source Volume = Sink Volume = Fulcrum Transfer

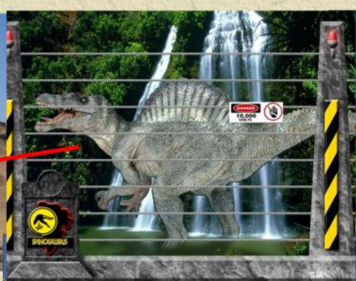


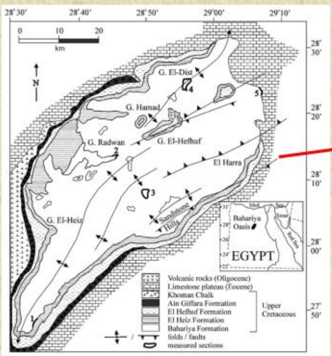
Presenter‟s notes: Recognition of channel belts in core and wire-line log is pivotal to AEA at the belt scale. Bridge and Tye define numerous sequences that are typical of sections encountered in channel belt penetrations. This slide offers a series of "mug shots" for channel belts.

A Fulcrum Test Workflow



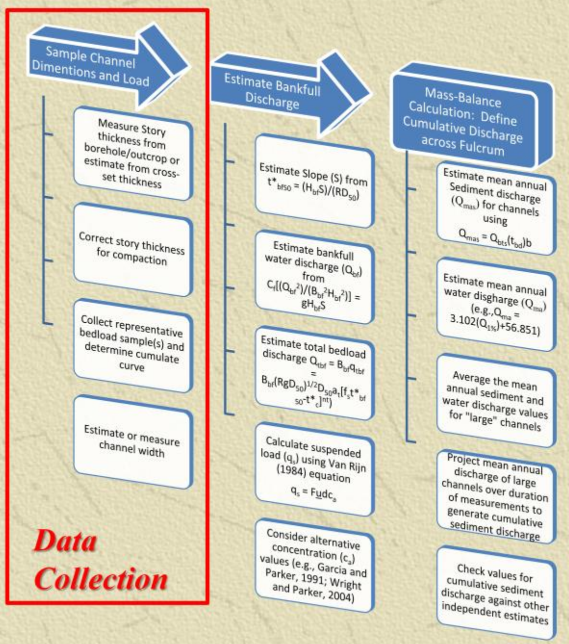
A Fulcrum Test Example

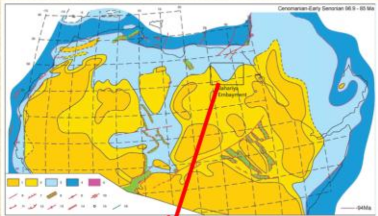


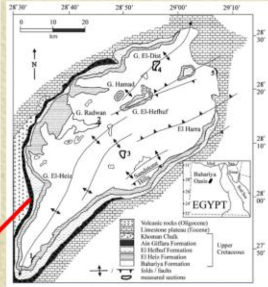


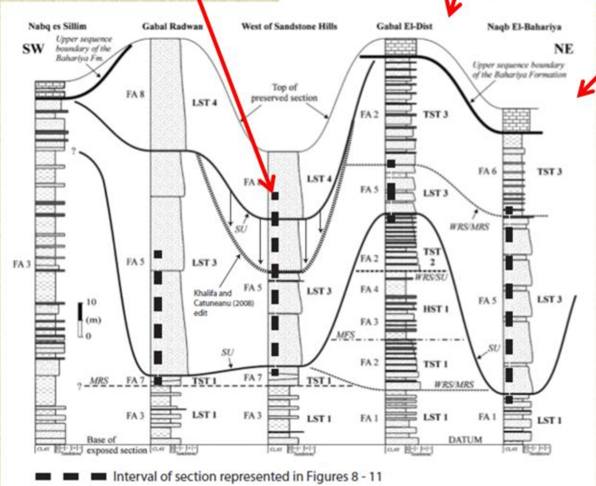
The Bahariya Fm

A Fulcrum Test Workflow







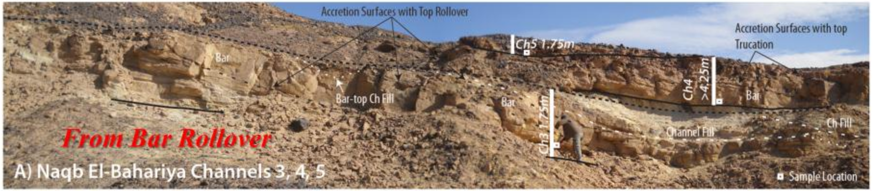


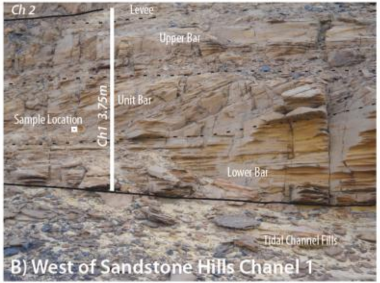
The Fulcrum

Bahariya Fm

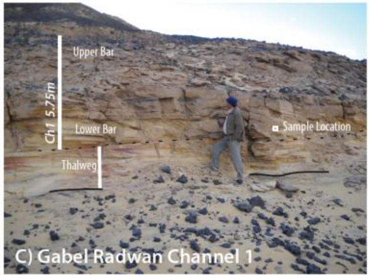
Channel Story Thickness and Bedload Sampling

Bahariya Fm



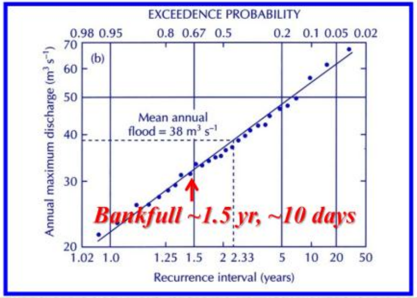


From Facies Succession



Channel Hydraulics

Flood Frequency and Bankfull Flow



B. Discharge calculation

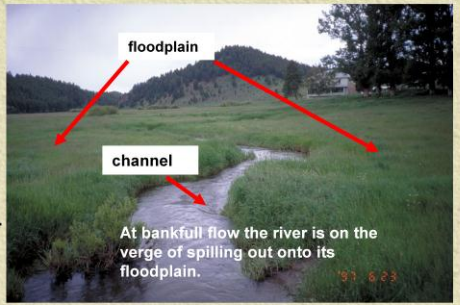
1. Q=VA

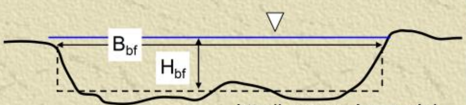
Where:

Q = Discharge (volume/time)

V = average flow velocity

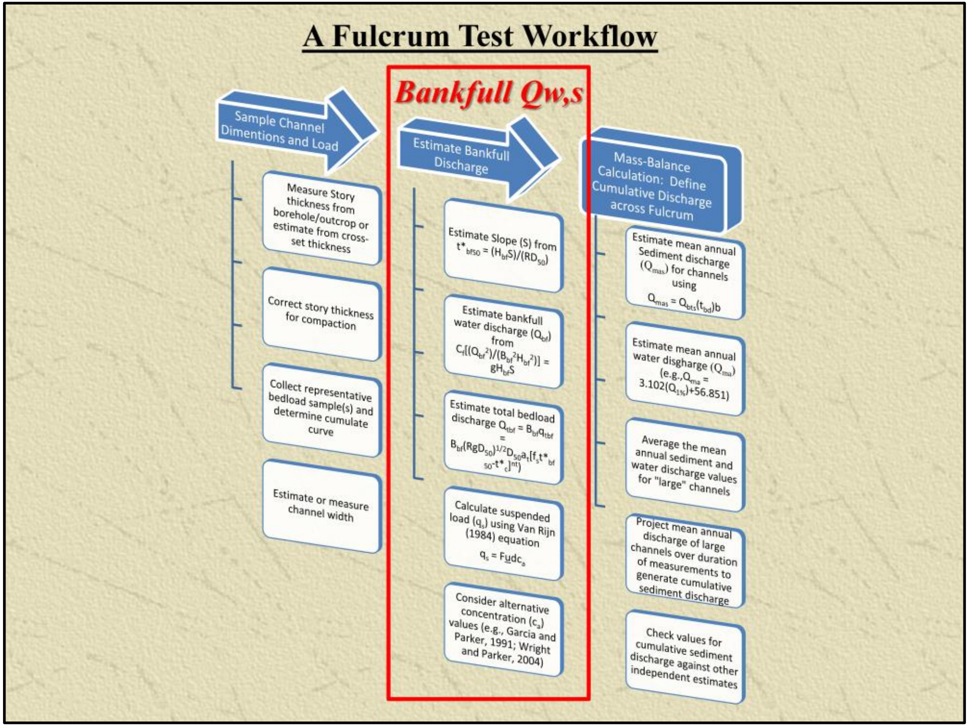
A= Channel Cross sectional area





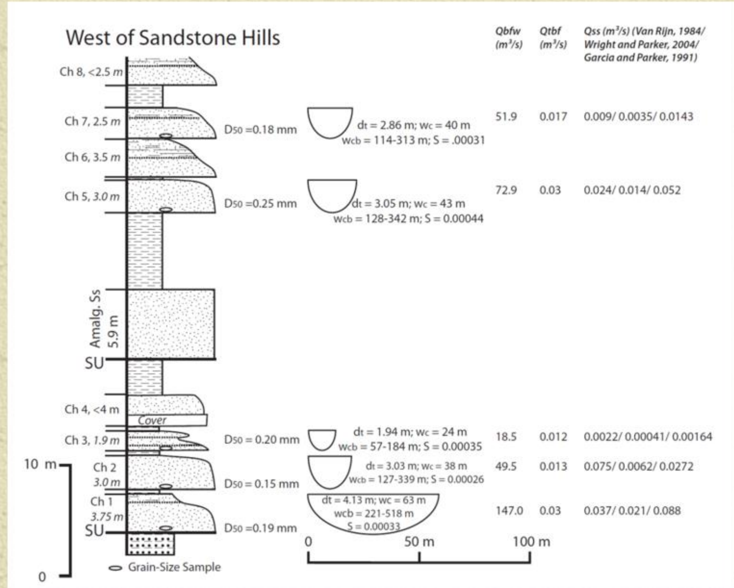
http://www.nced.umn.edu/

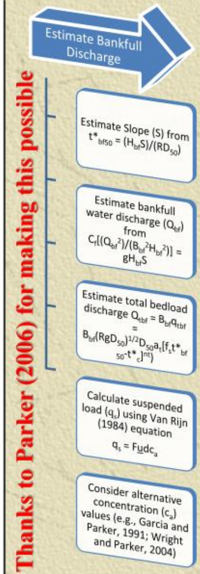
Presenter‟s notes: Not all sampling is random and many examples are known where a unique output is driven by some average/attractor. (example, Channel size converging toward alliance with mean annual flood)


A Fulcrum Test Workflow
Bankfull Qw,s
Sample Channel Dimentions and Load
Measure Story thickness from borehole/outcrop or estimate from cross-set thickness
Correct story thickness for compaction
Collect representative bedload sample(s) and determine cumulate curve
Estimate or measure channel width
Estimate Bankfull Discharge
Estimate Slope (S) from $t^*_{bf50} = (H_{bf}S)/(RD_{50})$
Estimate bankfull water discharge (Q_{bf}) from $C_f[(Q_{bf}^2)/(B_{bf}^2H_{bf}^2)] = gH_{bf}S$
Estimate total bedload discharge $Q_{tbf} = B_{bf}q_{tbf} = B_{bf}(RgD_{50})^{1/2}D_{50}a_t[f_st^*_{bf50}-t^*_c]^{nt})$
Calculate suspended load (q_s) using Van Rijn (1984) equation $q_s = F\underline{u}dc_a$
Consider alternative concentration (c_a) values (e.g., Garcia and Parker, 1991; Wright and Parker, 2004)
Mass-Balance Calculation: Define Cumulative Discharge across Fulcrum
Estimate mean annual Sediment discharge (Q_{mas}) for channels using $Q_{mas} = Q_{bts}(t_{bd})b$
Estimate mean annual water disgharge (Q_{ma}) (e.g.,Q_{ma} = $3.102(Q_{1\%})+56.851$)
Average the mean annual sediment and water discharge values for "large" channels
Project mean annual discharge of large channels over duration of measurements to generate cumulative sediment discharge
Check values for cumulative sediment discharge against other independent estimates

Calculating Bankfull Qw/Qs

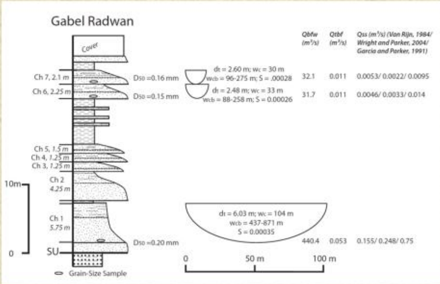
Bahariya Fm

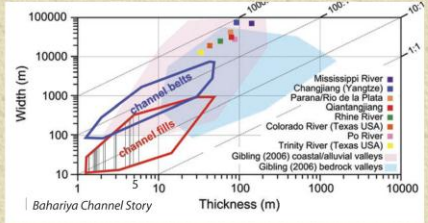


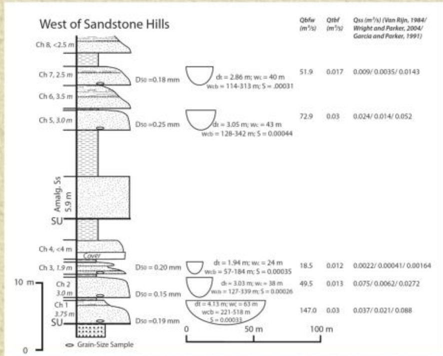


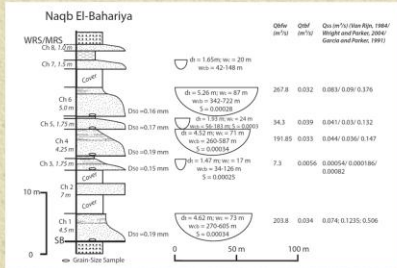
Calculating Bankfull Qw/Qs

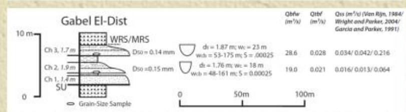
Bahariya Fm





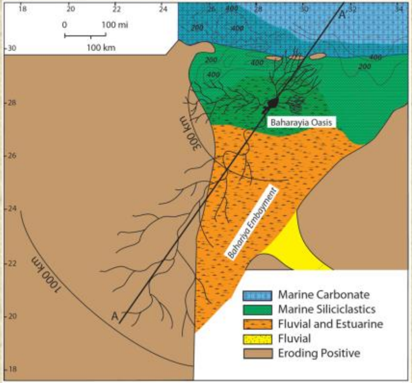


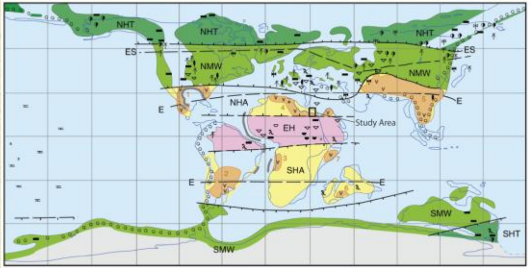




Calculating Bankfull Qw/Qs

Largest Channels/Bahariya Fm





Drainage Area (after Davidson and North, 2009)

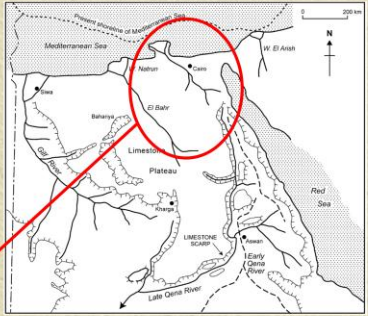
Channel Section and Number	Average Bankfull Depth (d_m) (m)	Suspended load (m^3/sec) (range)	Bed load (m^3/sec)	Water Discharge (m^3/sec)	Drainage area (km^2)/ discharge (m^3/sec) /drainage length (km) (semi-arid)*	Drainage area (km^2)/discharge (m^3/sec)/drainage length (km) (semi-arid-humid)*
Naqb 1	2.31	0.074 – 0.506	0.034	203.8	30786/508/691	5215/340/238
Naqb 4	2.26	0.036 – 0.147	0.033	191.85	28950/485/665	4987/327/232
Naqb 6	2.63	0.09 – 0.376	0.032	267.8	52082/761/947	7644/472/299
Gab. R 1	3.02	0.155 – 0.75	0.053	440.4	97350/1232/1378	12047/698/393
Average	2.55	0.089 – 0.445	0.038	276	52292/747/920	7473/459/291

Calculating Bankfull Qw/Qs

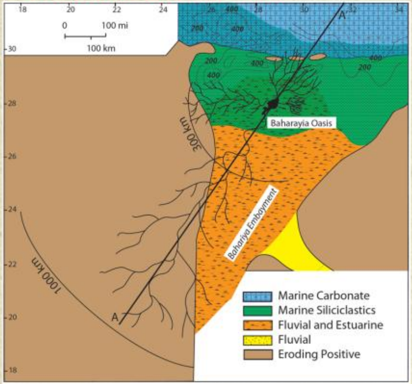
Bahariya Fm

Evolution of the Nile

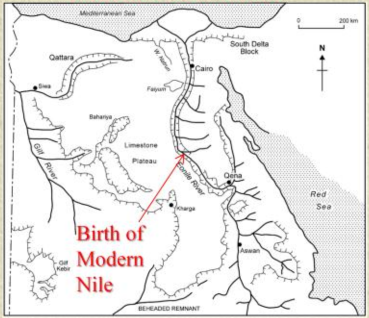
Paleocene-to-Middle Miocene



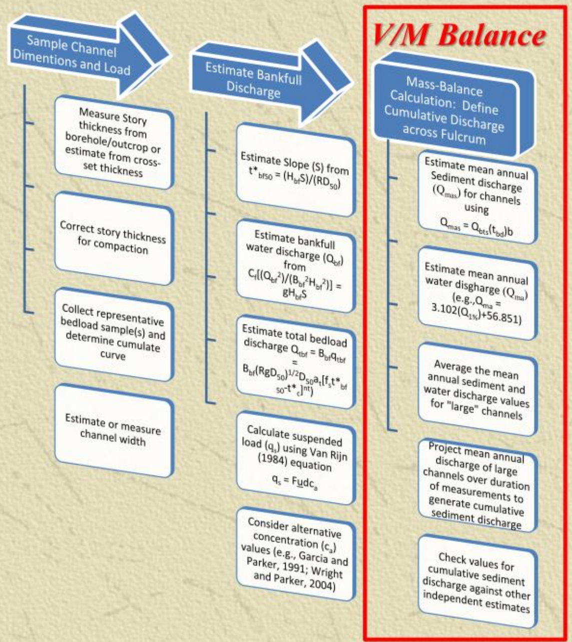
Cretaceous (Cenomanian)



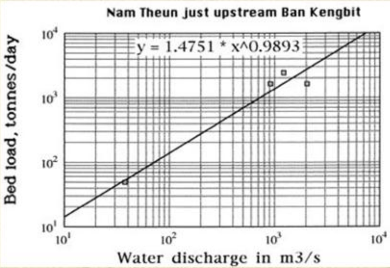
Miocene (Messinian)

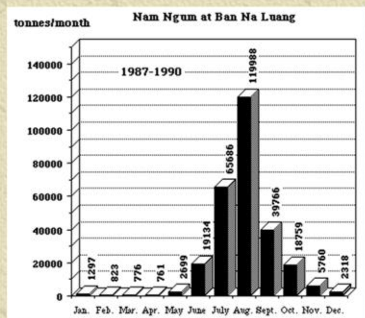


A Fulcrum Test Workflow



Converting Bankfull to Annual Qs





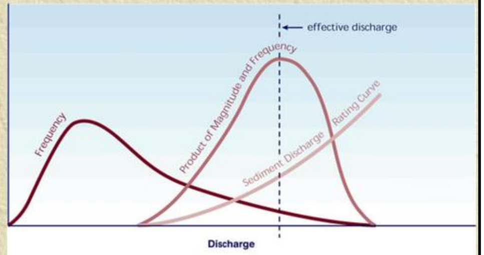
Estimate mean annual Sediment discharge (Q_{mas}) for channels using

$$Q_{mas} = Q_{bts}(t_{bd})b$$

Q_{bts} = *Bankfull sediment discharge*

t_{bd} = *Average annual bankfull duration*

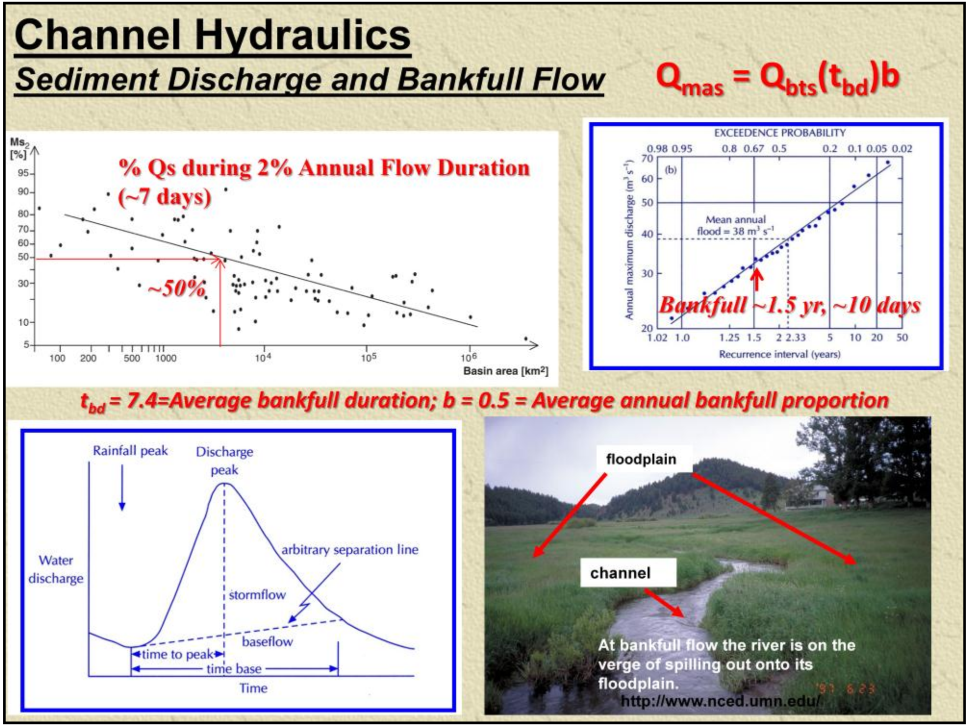
b = Average annual bankfull proportion



From Wolman and Miller, 1960.

Fig. 7.5 – Effective discharge determination from sediment rating and flow duration curves. In Stream Corridor Restoration: Principles, Processes, and Practices, 10/98. Interagency Stream Restoration Working Group (FISRWG)(15 Federal agencies of the US).

http://home.swipnet.se/valter/Ri3.htm



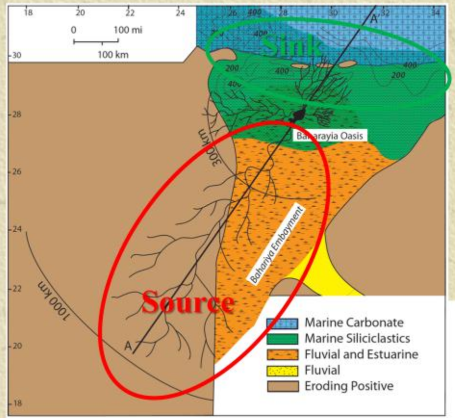
Presenter‟s notes: Not all sampling is random and many examples are known where a unique output is driven by some average/attractor. (example, Channel size converging toward alliance with mean annual flood)

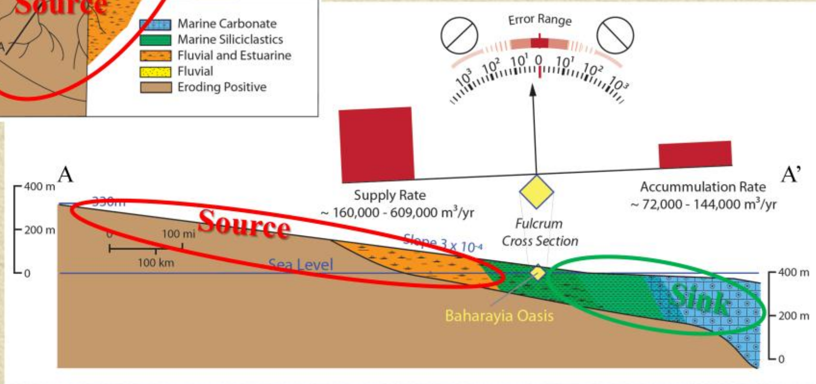
Qs Volume Balance

Bahariya Fm

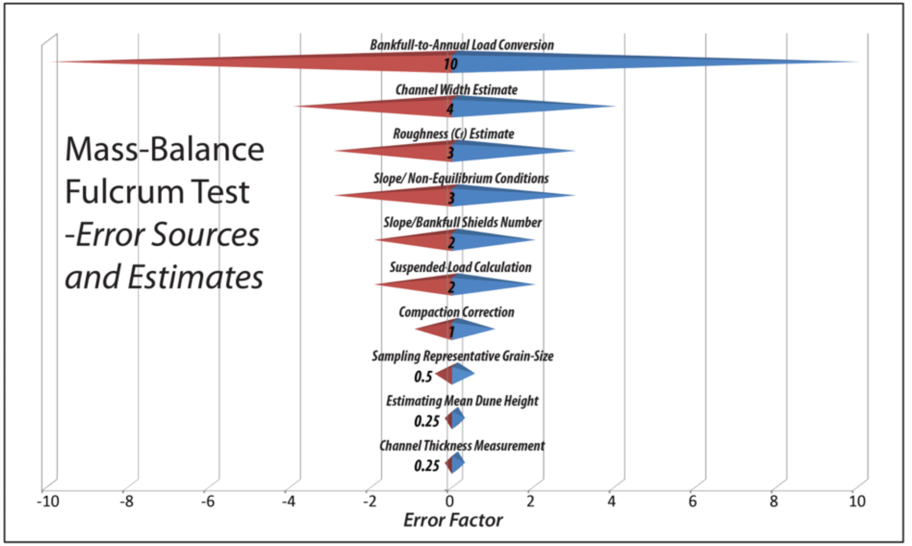
The Sink Leaks?

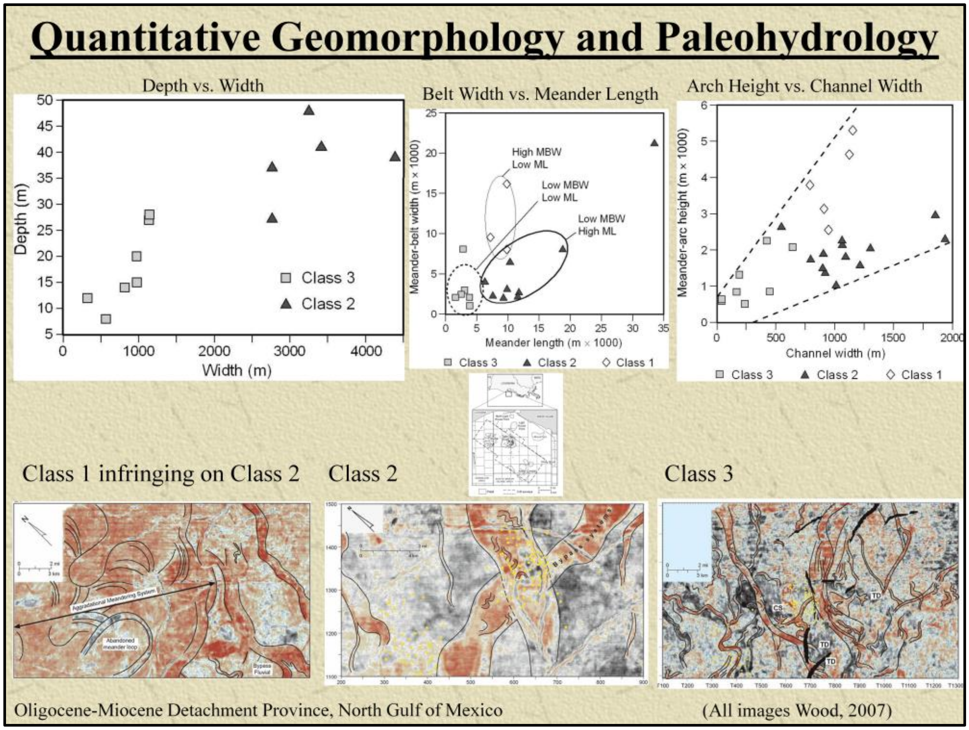
Sediment Supply Rate 3x Accumulation Rate from Preserved Sediment





Error Sources
Volume/Mass Balance





Presenter‟s notes: Once we have distinguished channels and bars, we can start using quantitative geomophology techniques to estimate fluvial characteristics such as discharge, sediment supply, etc.

It is possible to determine flow characteristic of ancient fluvial systems.

The area of study was in the northern Gulf of Mexico (Vermillion Island and South Marsh Island) shelf study area, 902 square kilometers of 3D seismic data and well logs was analyzed. A method called quantitative seismic geomorphology (QSG) is used to analyze landforms image in seismic 3-D for the purposes of understanding history, process and fill architecture of basins and fluvial systems. Three specific fluvial-incision classes were examined and were found to show their own unique sinuosity, channel widths, meander lengths and meander-belt widths. These characteristics were capable of showing relationships of shale versus sand present in channel fills.

The top loft graph is a Width-to-depth plot of Class 3 and Class 2 systems. Class 3 systems, distributaries, and creeks show shallower depths and narrower widths than Class 2, bypass systems.

Top Middle Figure: When meander belt width was plotted versus meander belt length, Class 1 systems had a high MBW and high ML indicating relatively low discharge and thus carrying only suspended load.

Class 2 systems had low MBW and low ML and thus lower discharge due to its size but able to carry a mixed load.

Class 3 Systems and a low MBW, but a high ML meaning a high discharge carrying bedload.

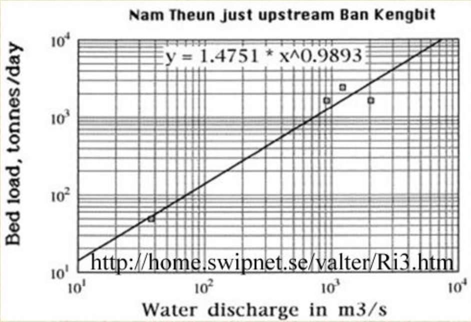
The top right graph is a cross plot of meander-arc height versus channel width. The widening „„envelope"""as the channel widths and meander-arc heights increase indicates the increasing uncertainty of predicting the actual channel-body sizes as systems become larger. However, the previously defined classes fall into distinct morphometric provinces that allow their differentiation.

Classification of the channels systems is based on a range of sinuosity since sinuosity alone is not used to characterize these systems. Class 2 system sinuosity ranges from a low 1 to 1.4 which is a bedload carrying channel. Class 3 sinuosity system sinuosity ranges from 1.4 to 2 making them mixed load channels. Class 1 system sinuosity ranges from 2.0 and above making them suspended load channels.

Class 1 Systems are large, aggradational fluvial systems with large meander-belt width, high sinuosities and large meander-arc heights. They are transportive and depositional, forming extensive flood plains, with large abandoned oxbow lakes. They have the highest sinuosity and are easily and easily differentiated from the relatively straight Class 2 Systems. These systems were not evaluated for sand quality.

Class 2 Systems are interpreted as bypass fluvial valleys, showing significantly lower sinuosity and well defined edges within the study area and small meander-arc heights. They show significant incision and are often filled with many individual channel types are dominantly filled with a sandy lithology. They are extremely thick, 20 to 50 m, and have good sand volumes generally with 26% to 32% porosity.

Class 3 Systems are made of up a wide variety of architectural element in the fluvial-deltaic coastal-plain system including distributary channels, tidal creeks and interdistributary drainages. They form narrow meander belts with highly sinuous and often crenulated channels and are sometimes nearly anastomosing. The make up the range between Class 1 and 2 systems. Channel fills generally average around 12 m thick with good sand percentages with 24% to 29% porosity.



Estimate mean annual Sediment discharge (Q_{mas}) for channels using

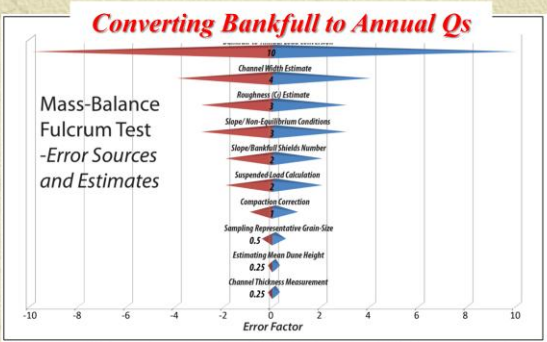
$$Q_{mas} = Q_{bts}(t_{bd})b$$

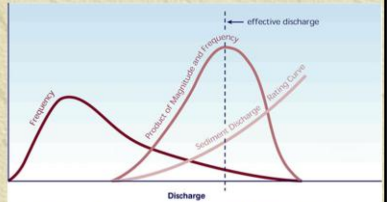
Q_{bts} = Bankfull sediment discharge

t_{bd} = Average annual bankfull duration

b = Average annual bankfull proportion

Error Sources Volume/Mass Balance





From Wolman and Miller, 1960.

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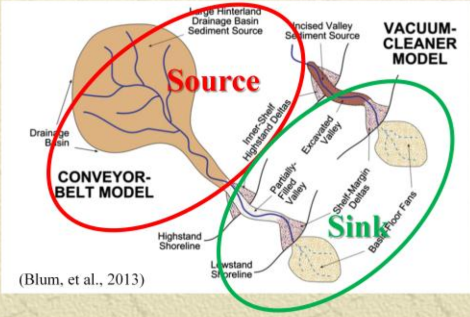
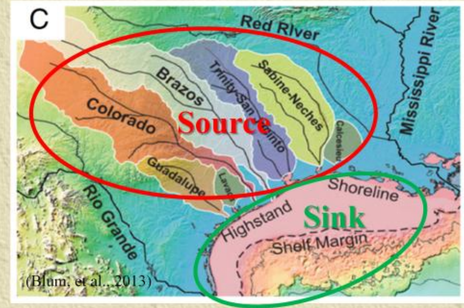
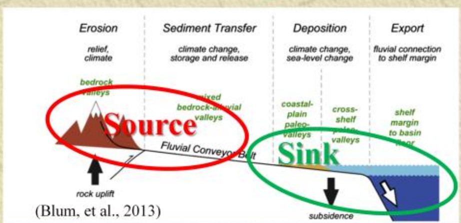
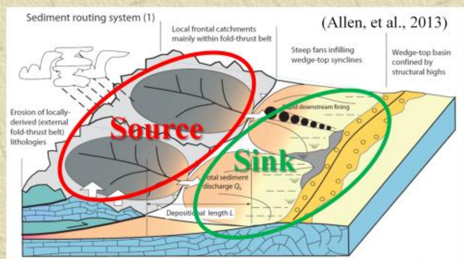
Error from Multiple Channels

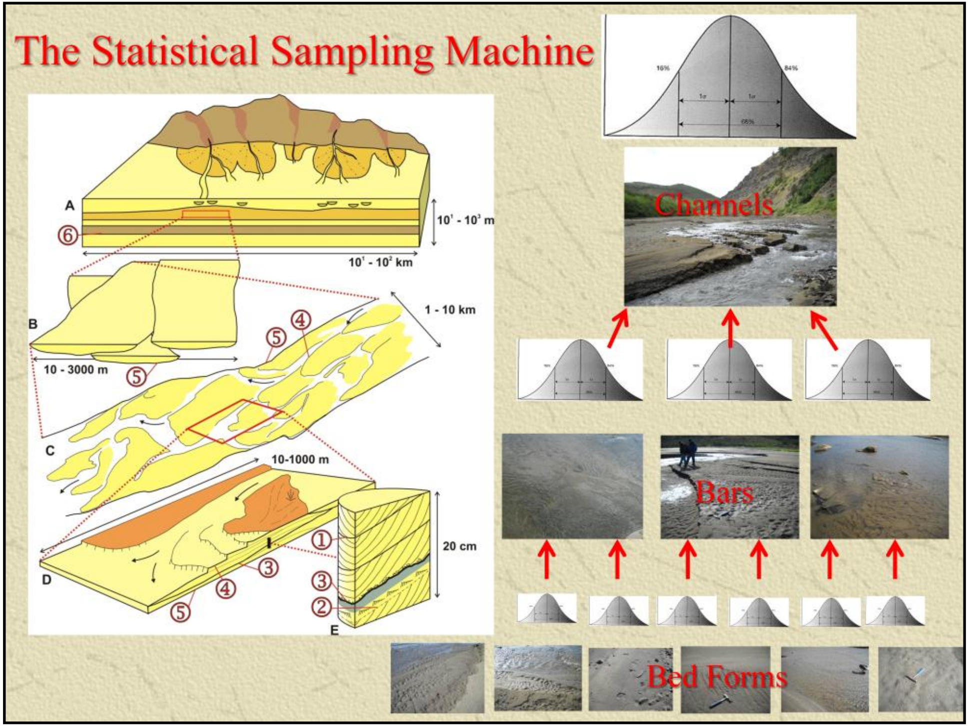




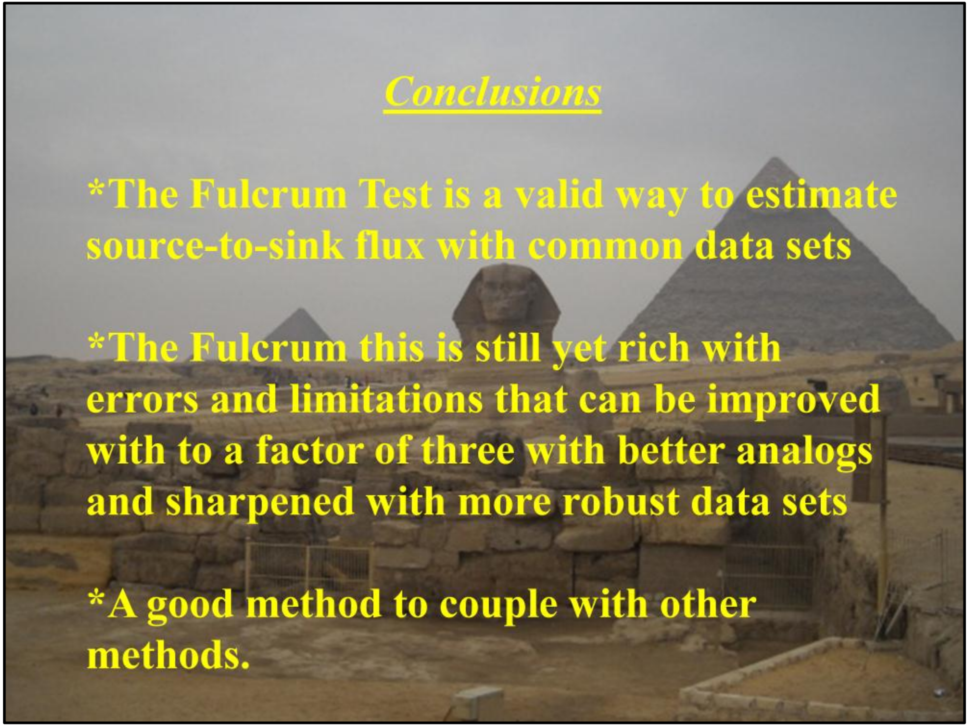




How Many Channels?



Presenter"s notes: Since sampling builds toward larger elements, which serve as the sample population for larger elements, the shredder concept means that signals preserve at order = Tx+1, or at the order that best coincides with the duration of the actually change. No sense in looking for the signal where the duration of the process is substantially different that the duration of the signal.



Conclusions

*The Fulcrum Test is a valid way to estimate source-to-sink flux with common data sets

*The Fulcrum this is still yet rich with errors and limitations that can be improved with to a factor of three with better analogs and sharpened with more robust data sets

*A good method to couple with other methods.