Challenges of Quantifying Bedmaterial Particle-size Distributions in Gravel-bed Streams

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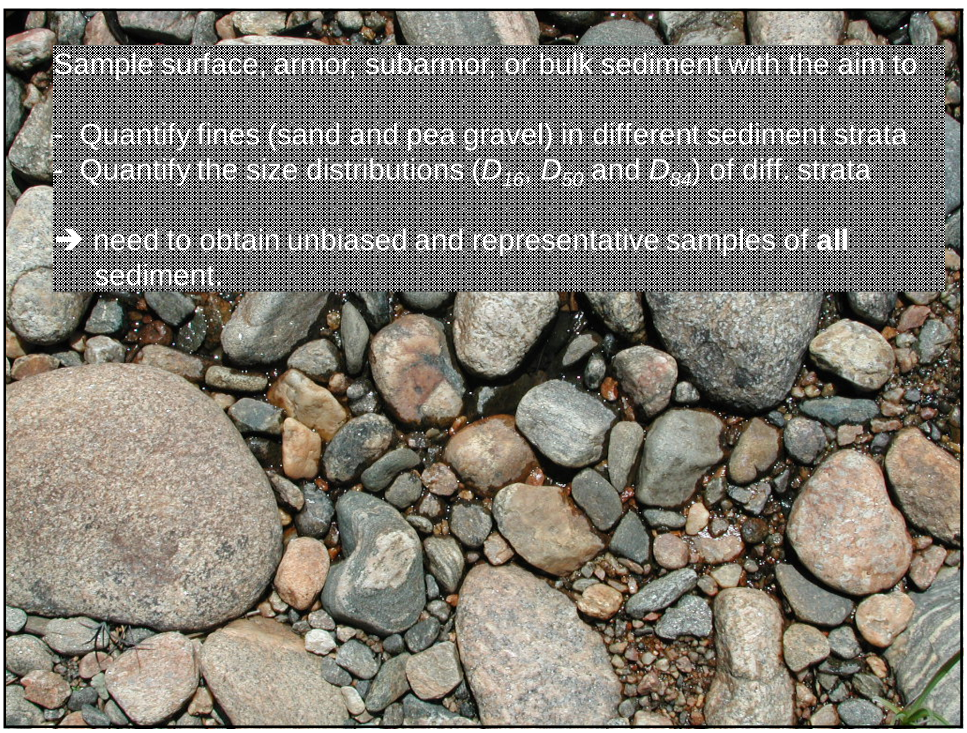
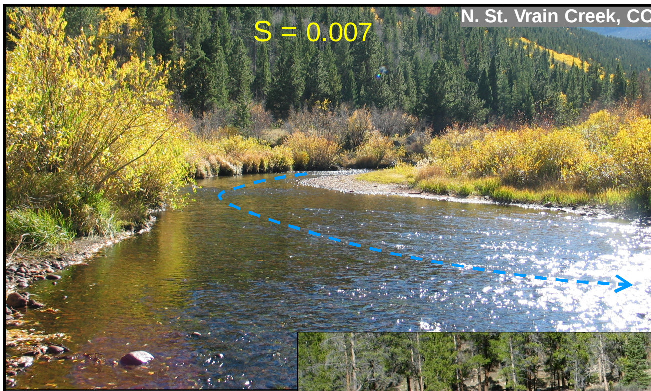
Challenges of bed material sampling are accuracy and comparability—both are affected by:

- Spatial variability of bed surface fines
- Vertical stratification of bedmaterial fines

Different field methods for quantifying fines
- surface pebble count
- surface grid counts
- volumetric samples



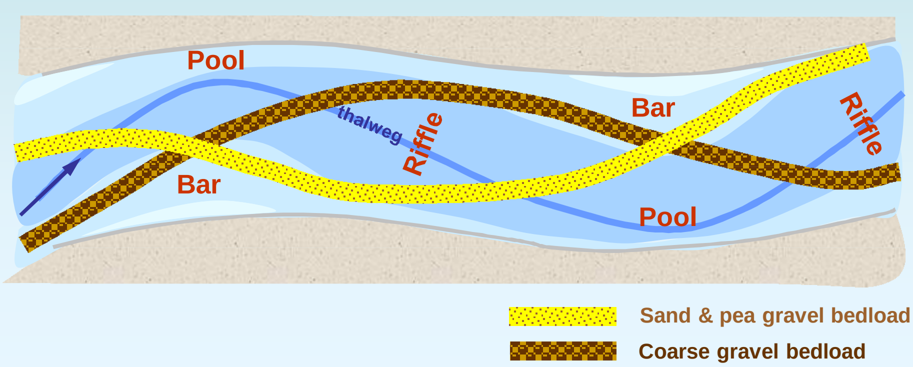


Pool-riffle morphology

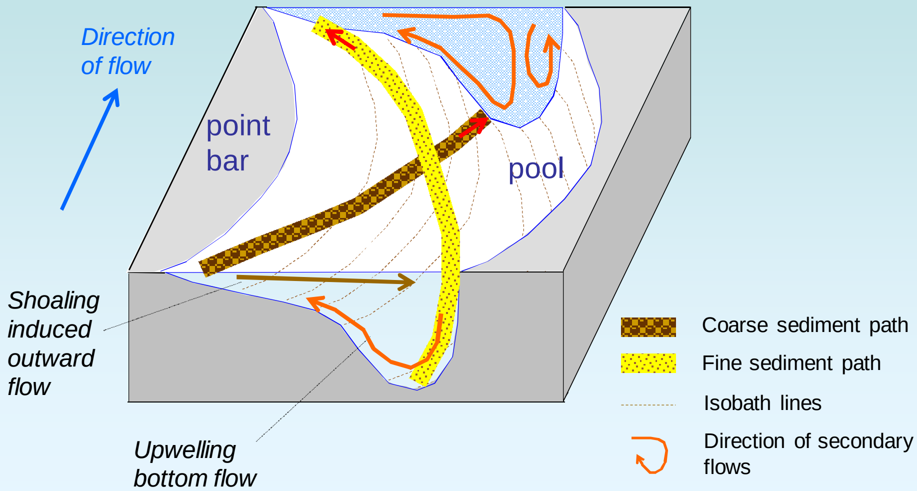
Water and sediment interact to form a channel with alternating pools and riffles. Point bars may be present on alternate sides of the channel.

Transport paths of coarse gravel bedload and fines in pool-riffle section

Over a reach, secondary helical flows transport coarse and fine sediments downstream along specific, meandering paths that differ from the thalweg.

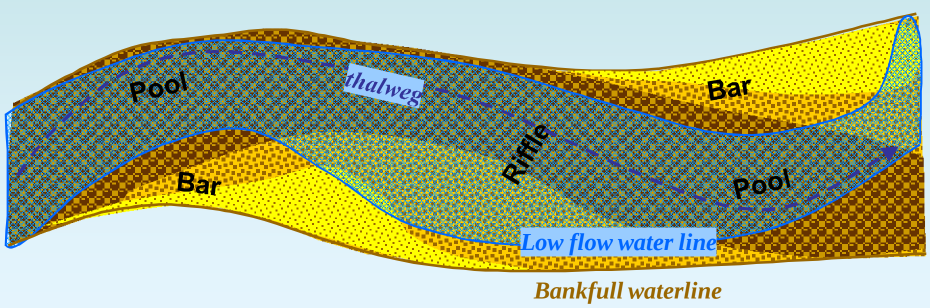


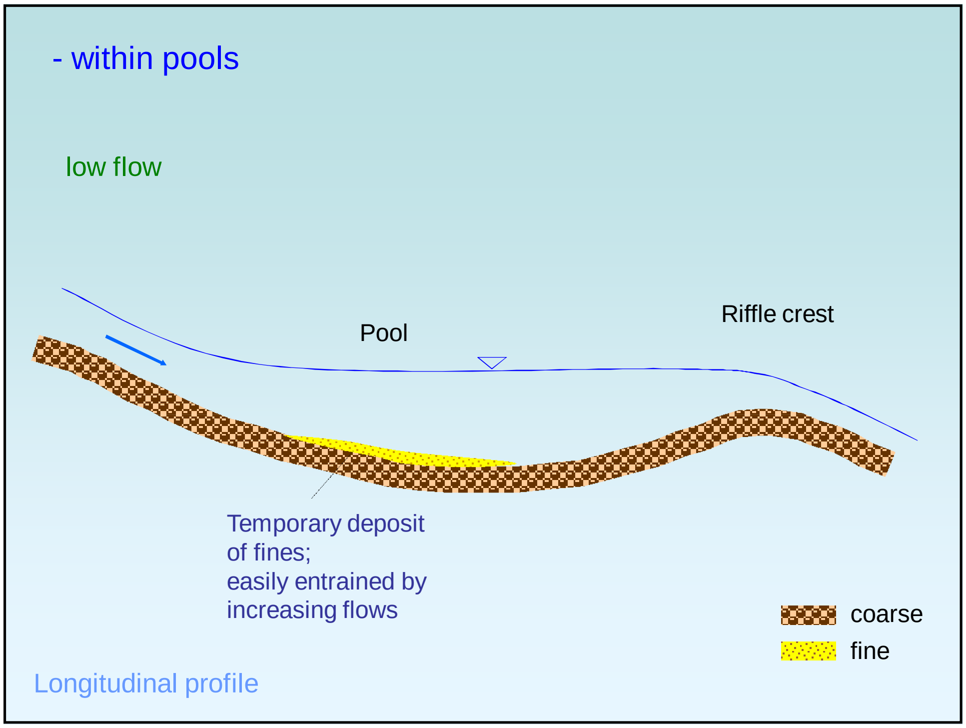
Secondary flows move fines from the deep streambed portions to shallower ones, specifically to the downstream end of gravel-bars and towards the banks (after Dietrich and Smith 1984)

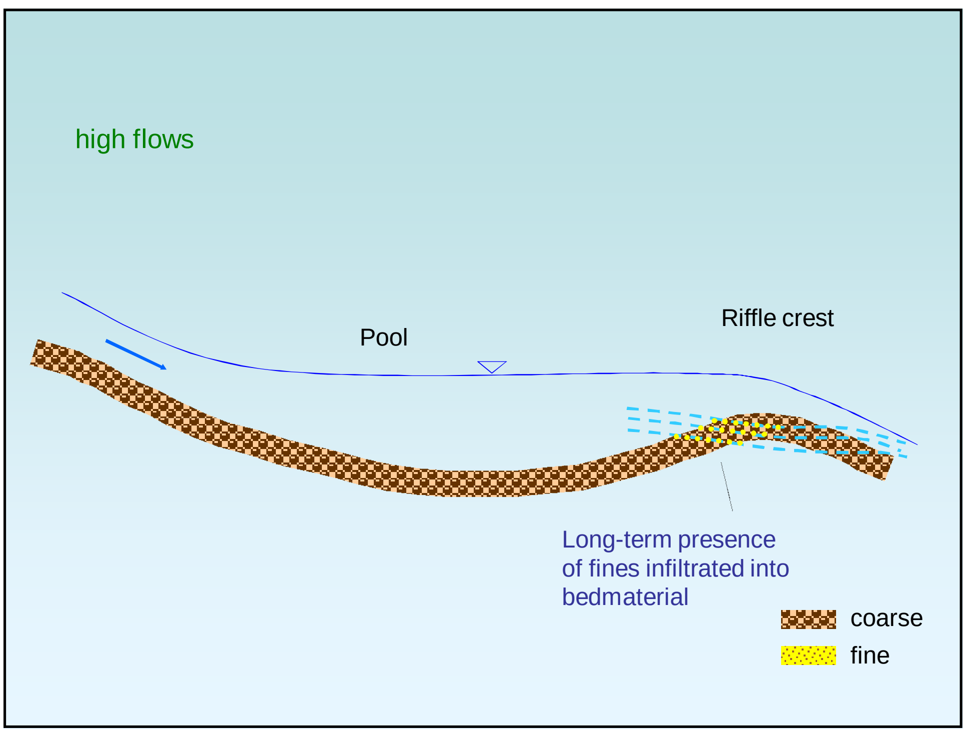


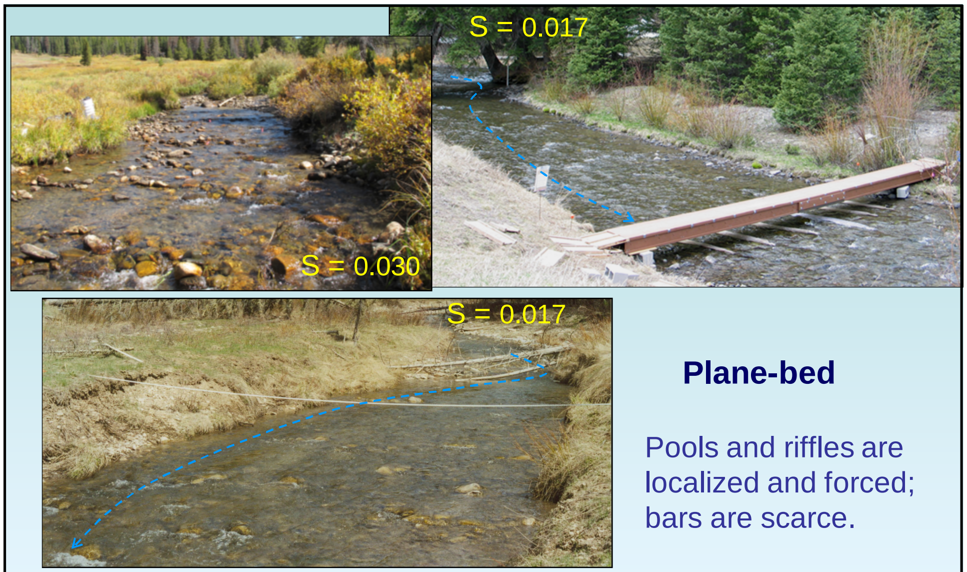
➔ **predictable patterns in spatial variability of fine and coarse particles**

- **on bars:** downstream and bankward fining
- **on riffles** (close to bars): a fine and a coarse side




- within pools
low flow
Pool
Riffle crest
Temporary deposit
of fines;
easily entrained by
increasing flows
coarse
fine
Longitudinal profile


high flows
Pool
Riffle crest
Long-term presence
of fines infiltrated into
bedmaterial
coarse
fine



Plane-bed

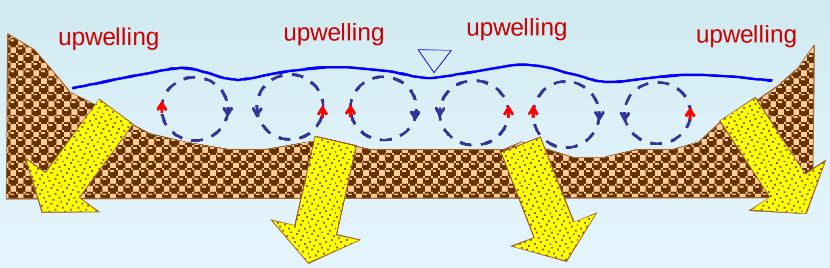
Pools and riffles are localized and forced; bars are scarce.

If the thalweg has a meandering course, spatial variability of fines may follow that in pool-riffle streams, but at a less intense level because the morphological features are much less developed.

If the thalweg is poorly defined or not meandering, …

Multiple cells of secondary flow

may develop and transport fines along streaks and along banks

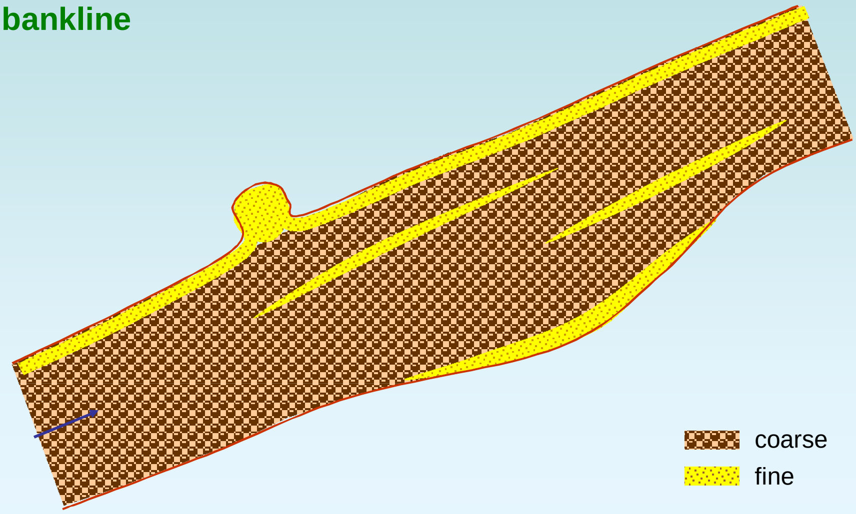


Temporary streaks of fines

side view

In locations with low flow velocity or upwelling flow

Along the banks or in bays in the bankline



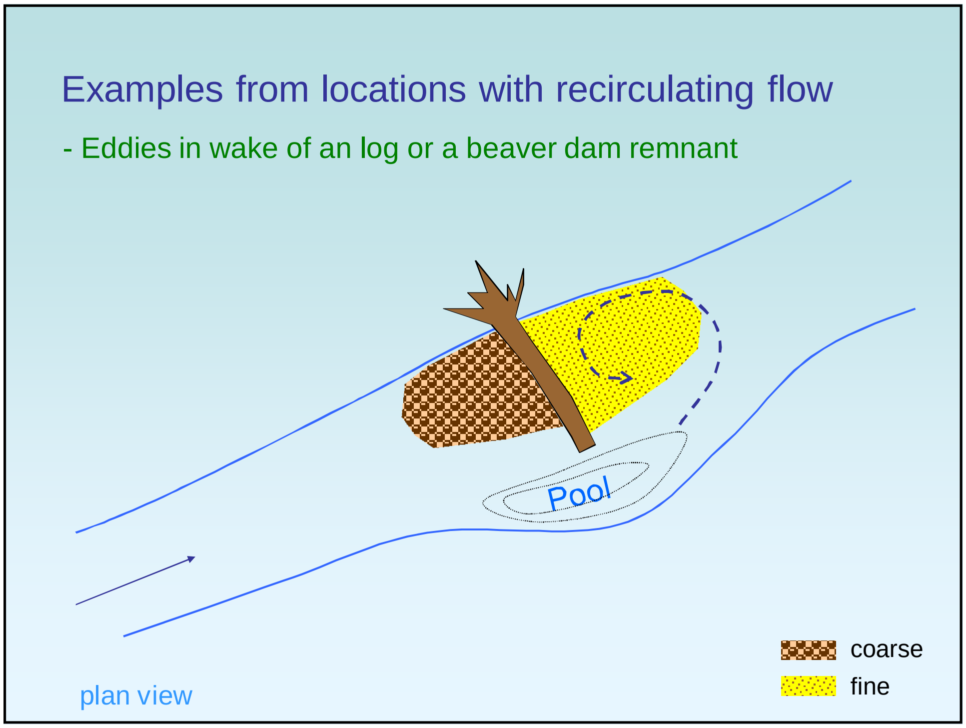
Plan view

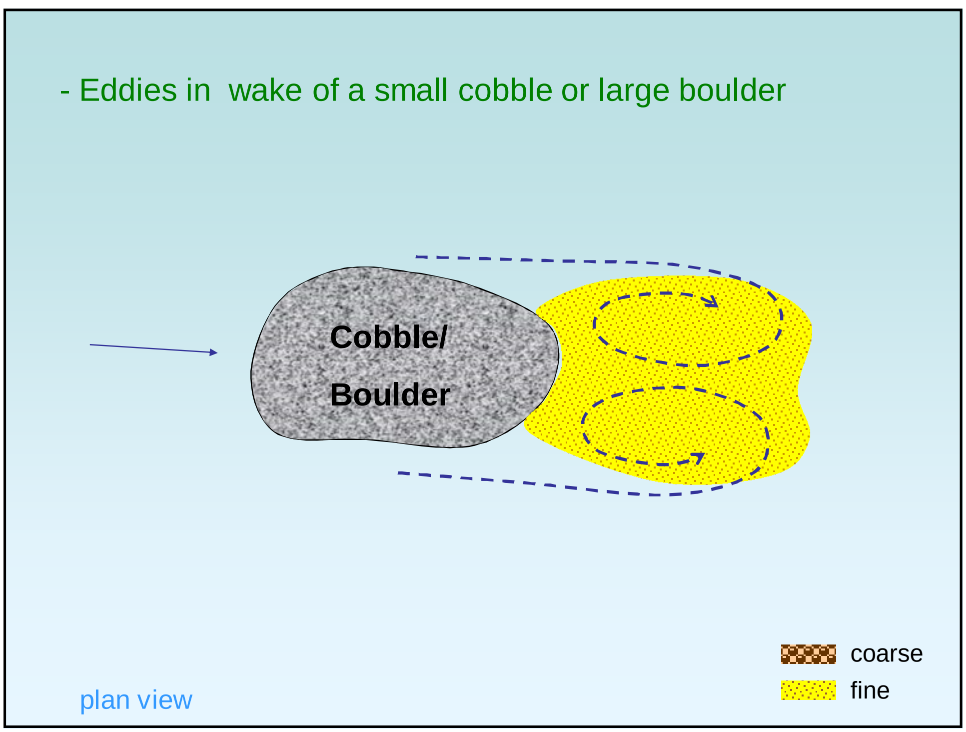
Locally “forced” channel morphology

The underlying morphology (pool-riffle, plane-bed) is highly influenced by non-mobile objects:

- Large woody debris
- Isolated large rocks
- Beaver dams
- Sharp bends

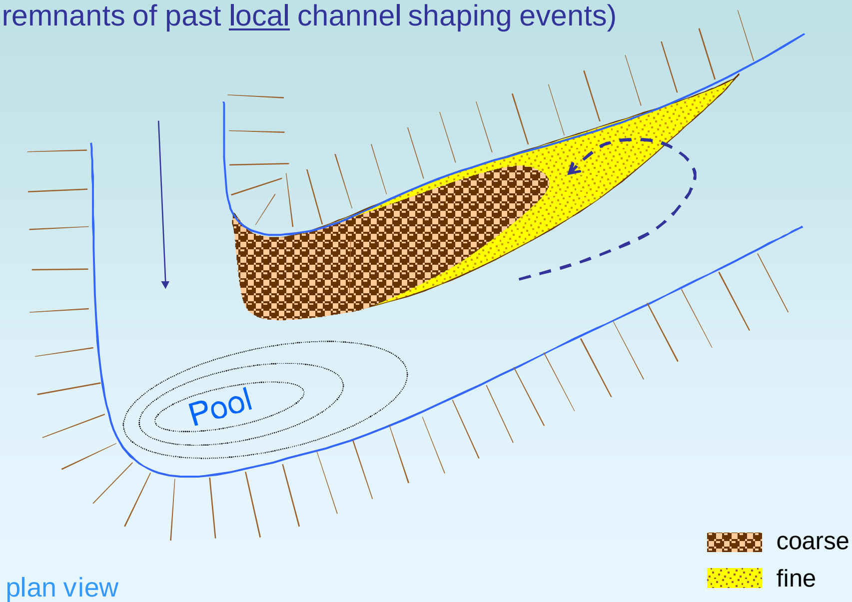
➔ Local hydraulics near individual features control deposition of fines and cause random longitudinal variability


Examples from locations with recirculating flow
- Eddies in wake of an log or a beaver dam remnant
Pool
coarse
fine
plan view

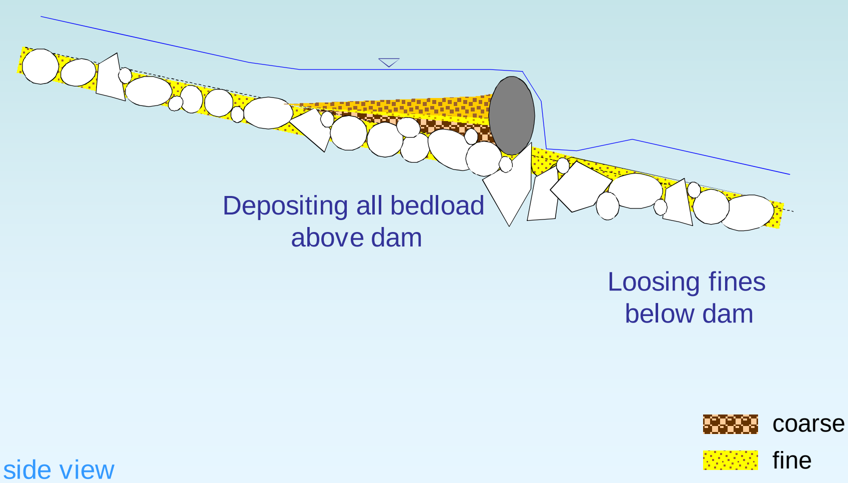

- Eddies in wake of a small cobble or large boulder
Cobble/
Boulder
coarse
fine
plan view

- Bar in sharp bend

remnants of past <u>local</u> channel shaping events)



- around dams from LWD and beavers



➔ There are predictable patterns of spatial variability of fine and coarse sediment in channel beds. Locations with high proportions of fines can be inferred from

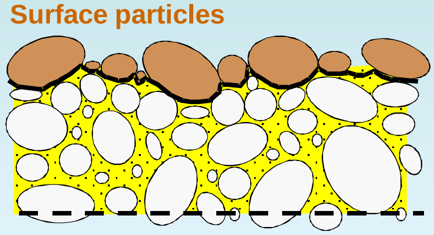
- general fluvial geomorphology
  - travel path of coarse and fine bedload (downbar and lateral fining;
  - temporary pool-bottom fines at low flows; temporary streaks)
  - fines infiltrated into the pool exit bed
- isolated channel features
  - bankline bays, backwaters
  - stoss and wake deposits behind isolated rocks or features protruding laterally into flow,
  - retained in log- or beaver dams

➔ **Sampling of fines that aims to be accurate and comparable cannot ignore the patterns of spatial variability of bedmaterial particle sizes**

Surface particles can ONLY be sampled using surface sampling methods:

- Pebble counts
- Grid counts
- Areal samples

Surface particles

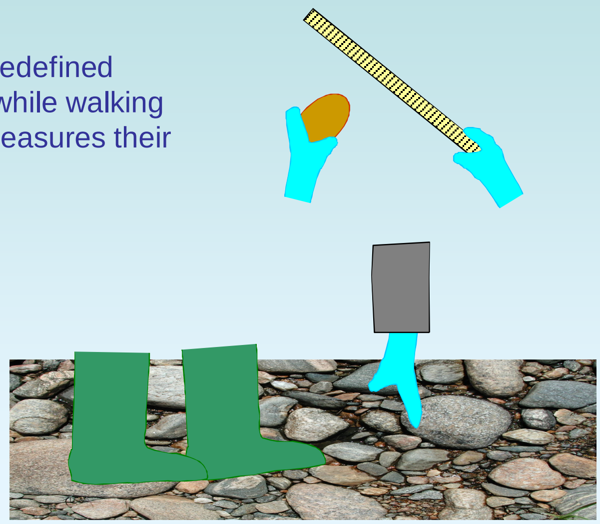


Subsurface layer

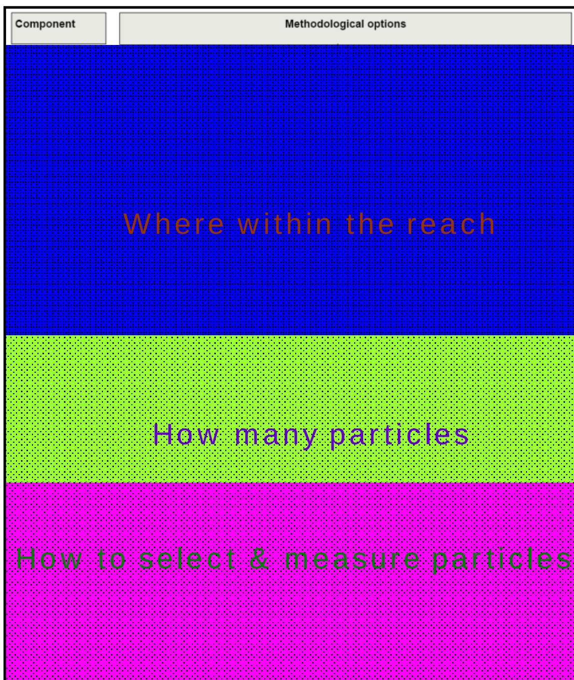
Armored deposit typical of 3rd order coarse gravel-bed streams

Most general definition of **Pebble count**

Operator picks up predefined number of particles while walking along the bed and measures their sizes.



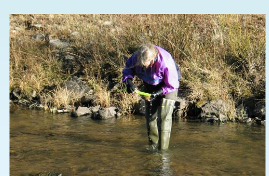
Countless pebble count variations



(Bunte et al., JAWRA 2009)

EMAP PIBO SFT

e.g.: **S**ampling **F**rame, **T**emplate, Trans. along w_{bf}, (**SFT**) (Bunte et al. '09)



e.g., Tip of the boot, Ruler, Heel-to-toe walk (Wolman 1954)

Different results!

Pebble counts are notorious for biases among protocols and observers

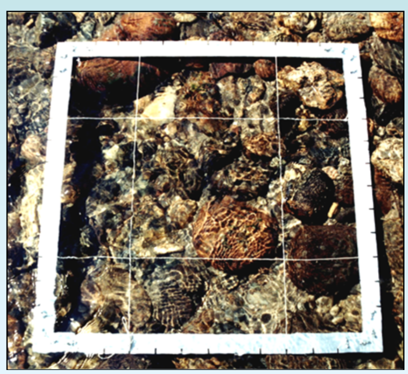
To increase pebble-count accuracy and usefulness:

- Carefully decide where within the reach to sample (depends on spatial variability of particle sizes and sampling goal)
- Avoid bias when picking up particles
- Avoid bias when measuring particle size
- Record pebble count data to retain spatial information
- Sample enough particles for statistical rigor

SFT procedure

- Visually selects particles under grid points (typ. spaced 0.3 m) spanned across a **S**ampling **F**rame to avoid observer bias in particle selection

0.6 m x 0.6 m Sampling Frame



- Advantage over heel-to toe sampling

If the bed is not clearly visible, grid intersections (close to the bed) serve to guide the finger to the particle to be selected. There is a bias against hidden fines. Use plexiglass viewer to improve visibility.

SFT uses a 0.5 ϕ template to make particle size measurements in pebble counts **accurate, unbiased, and reproducible**

- particle sizes span 3-4 orders of magnitude

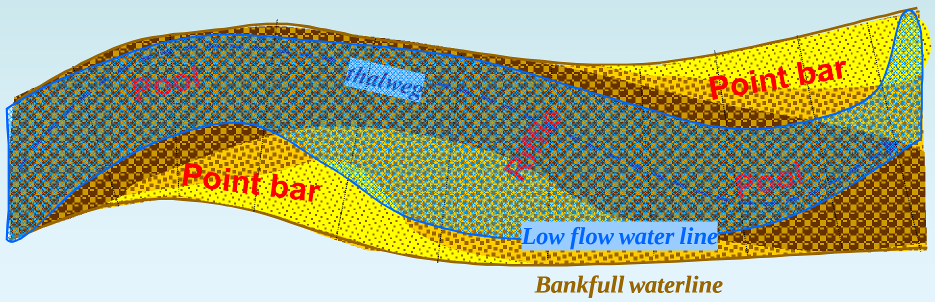
  → opening sizes that progress in log-scale and correspond to log-based Wentworth scale (not to arithmetically scaled ruler)

Template in 0.5 phi increments

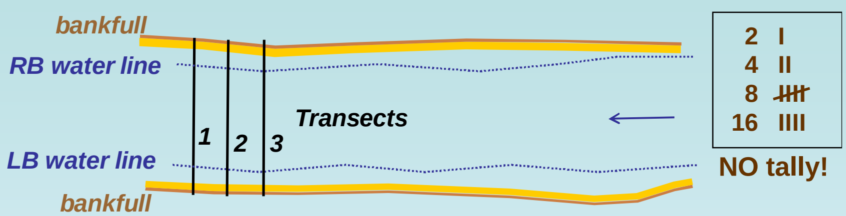
- Comparable to sieve analysis obtained using square-hole lab sieves

SFT typically samples along transects, covers the spatial variability, and characterizes it

- **from bankfull to bankfull**



SFT records pebble count data sequentially to retain spatial information

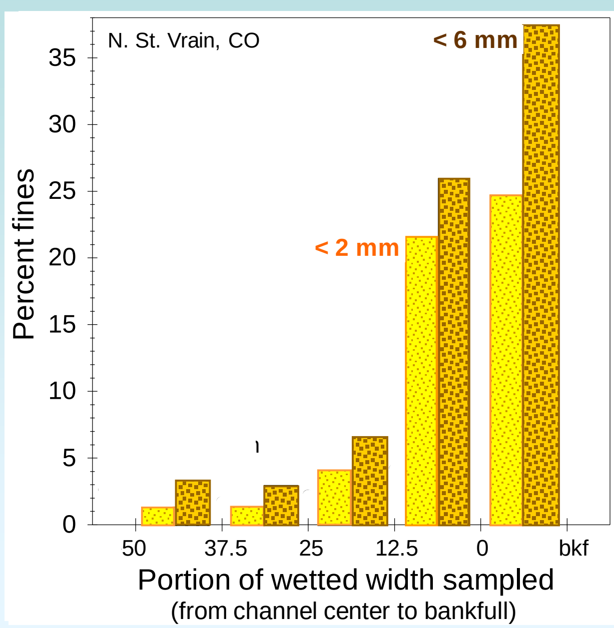


Transect number:	*1*	*2*	*3*
Dist. upstr. from ref. loc.	*0*	*5*	*10* ...
Left Bank, bankfull	*5.6*	*<2*	*8*
	16	*8*	*5.6*
	32 **WL**	*22.6*	*45* **WL**
	45	*64* **WL**	*90*
	⋮ riffle	⋮	⋮ pool
	90	*45* **WL**	*32*
	16	*11.3*	*8*
	22.6	*16* bar	*11.3*
WL = waterline	*4* **WL**	*5.6*	*4* **WL**
			2
Right Bank, bankfull	*2*	*<2*	*5.6*

	C	D	E	F	G	H	I	J	K	L	M	N	O	P	
1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	x-sect. #
2	0	16	32	48	64	80	96	112	128	144	160	176	192	208	Dist. from ptc 1 (m)
3	45	1.4	1.4	1.4	180	64	64	90	90	22	1.4	16	8	22	
4	2.8	8	1.4	1.4	90	64	90	2	90	1.4	90	45	22	45	
5	1.4	22	1.4	1.4	90	64	16	45	22	128	64	22	11	45	
6	1.4	32	1.4	64	90	128	32	16	90	90	64	45	45	45	
7	2	64	16	64	128	32	64	45	90	45	128	45	22	90	
8	32	22	22	90	128	64	90	128	128	180	64	90	22	11	
9	45	64	64	64	45	64	64.0	90	128	32	64	128	22	64	
10	45	64	64	45	2	64	32	90	45	180	45	45	45	64	
11	22	22	64	32	64	45	90	32	64	64	16	64	22	90	
12	32	45	64	64	64	90	128	128	45	64	32	45	64	45	
13	2.8	22	22	128	32	16	45	32	32	45	64	32	32	32	
14	2.8	45	90	128	32	64	32	64	90	90	90	32	64	64	
15	45	45	64	180	64	90	22	45	32	90	22	45	64	64	
16	45	45	32	90	64	64	64	90	64	90	64	180	45	4	
17	22	64	90	45	45	45	22	1.4	32	90	64	64	45	45	
18	32	64	64	90	64	32	128	90	64	64	90	45	45	1.4	
19	22	90	90	45	90	32	90	32	45	64	32	180	45	45	
20	22	64	64	64	32	90	90	90	45	32	45	32	45	1.4	
21	8	90	22	32	32	32	32	64	2.8	64	64	64	22	2	
22	11	45	32	45	2.8	32	64	64	4	90	64	64	45	128	
23	64	64	45	32	45	32	22	45	45	128	11	64	32	64	
24	32	90	90	64	22	64	45	22	32	32	90	45	64	45	
25	64	45	45	64	45	45	64	32	90	45	5.6	90	32	32	
26	22	45	128	32	22	45	64	32	45	32	22	22	32	45	
27	90	64	45	45	16	45	45	45	64	64	22	32	5.6	22	
28	32	45	90	45	22	32	64	45	32	32	8	16	32	2.8	
29	45	64	90	45	45	64	64	16	45	64	45	32	5.6	2	
30	16	45	64	32	45	22	22	16	32	32	8	2.8	32	2.8	
31	64	64	64	45	32	64	8	11	45	8	32	16	22	11	
32	45	45	32	45	1.4	45	22	8	45	16	2	45	2	1.4	
33	5.6	32	45	45	11	45	32	11	45	11	5.6	5.6	2.8	8	
34	32	64	32	8	5.6	45	45	8	22	32	2.8	8	2	2.8	
35	90	4	45	32	22	45	22		32	32	1.4	22	4	5.6	
36	45	5.6	90	45	5.6	64	22			16	35	22	64	32	
37	5.6	32	45	45	22	45				64		32	5.6	1.4	
38	11	45	32	16	5.6	64				16		11	1.4	45	
39	16	32	22	32	11	32				11		2.8	1.4	45	
40	32	16	64	16		22				22		1.4	1.4	45	
41	32	32	5.6	1.4		1.4				1.4		1.4		32	
42	64	32	1.4	4		32						1.4		22	
43	5.6	16	1.4	45		16								64	
44	45	1.4	1.4	11		2.8								2.8	
45	22	1.4		11		4								64	
46	1.4			1.4		1.4								45	
47	32					1.4								2	
48	32					1.4								32	
49	22													8	
50	1.4													16	
51	1.4													32	
52	1.4													45	

exp. bar
subm.bar
riffle/run
pool
backwater
bank sed.

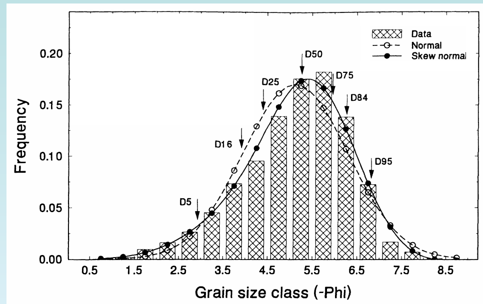
Analyzing data in lateral increments ↳ Bankward fining trend



Sample size and accuracy from bootstrap approach

(Rice and Church 1996; no underlying distribution type assumed)

Based on results from the Mamquam River:



Conversion ϕ to *D:*
$\phi_i = -\log_2(D_i)$
$= -3.322 \log(D_i)$

$D_i = 2^{-\phi i}$

Absolute error in ± ϕ-units (95% confidence level) for percentile estimates, **s = 1.17** ϕ,

Sample size	D_5	D_{16}	D_{25}	D_{50}	D_{75}	D_{84}	D_{95}
50	0.89	0.61	0.52	0.37	0.33	0.35	0.44
100	0.62	0.40	0.36	0.26	0.23	0.25	0.30
400	**0.30**	**0.21**	**0.19**	**0.12**	**0.11**	**0.11**	**0.12**
1000	0.19	0.13	0.12	0.07	0.07	0.06	0.07

To speed up field time:

Three-person pebble counts, 2 pers. sampling, one recording

Grid sampling

General meaning:
Measuring particle sizes under a predetermined number of grid points (any scale)

Special meaning:
- pebble count spatially focused under small area of interest
- Visually determining the % surface fines under grid points and evaluating their spatial variability within geomorphological or habitat units

How to?
Count the number of fine particles < 2 or < 6 mm under 50 grid intersections spaced by 2 inch (5 cm)

(e.g., 4 out of 50 points = 8%)

- Mind ratio of grid size of D_{max}

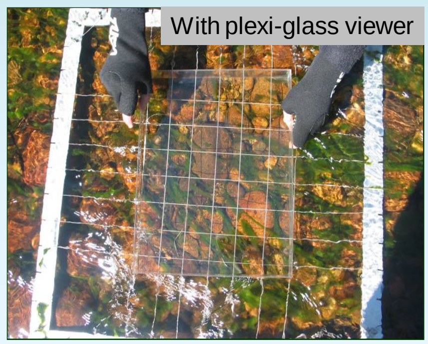
7 by 7 grid (+1), 5 cm spacing

Gallo et al. (2005)

MT DEQ (2009)

Plexiglass viewer

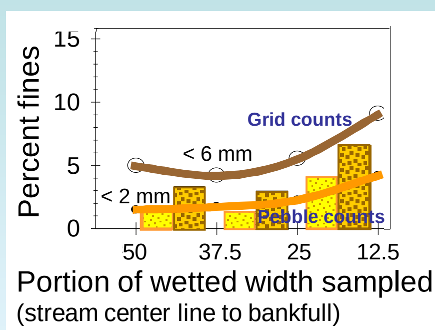
Its use is vital to improve the visibility of the bed

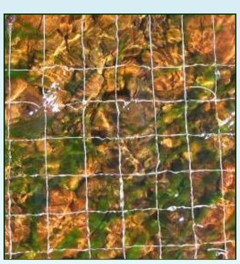


Comparison of grid count- vs. pebble count fines

When sampled over the same pool tail area, grid counts identify more fines than pebble counts

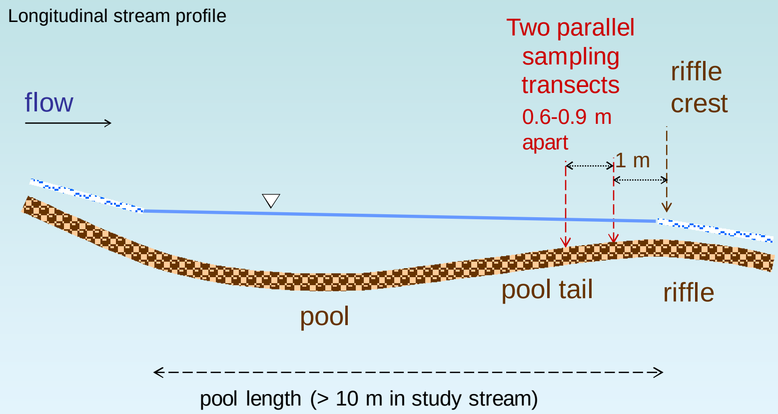
→ focus on fines
→ plexiglass viewer
helps identify fines



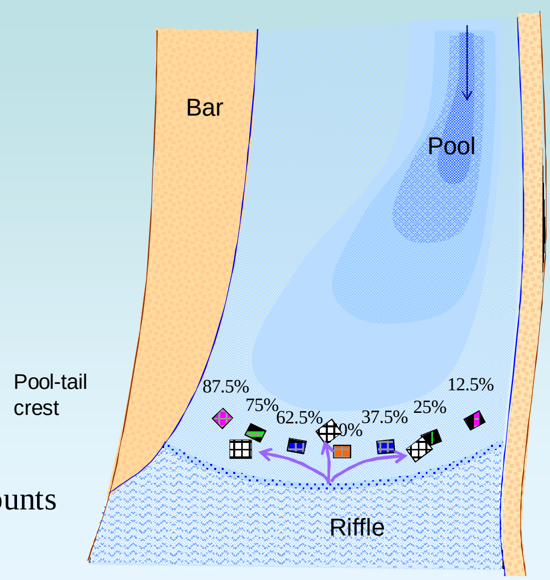


Grid counts better suites for quantifying fines, if…

Grid counts useful for quantifying surface fines within rel. small areas (e.g., benthic habitat evaluation in pool-tail areas)



Effects of different sampling locations on sampled % fines

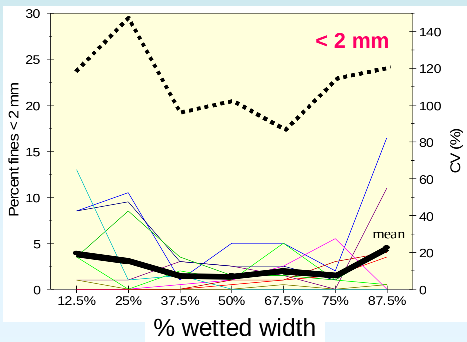


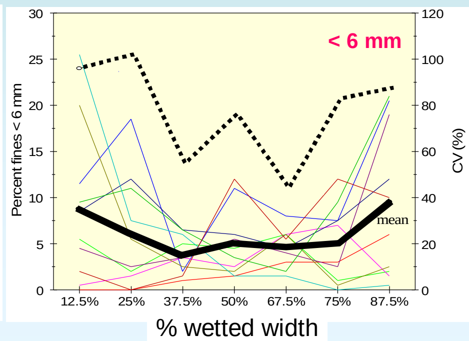
Grid tosses

Systematic grid counts

Lateral variability of fines (N. St. Vrain, averaged over 10 study pools)

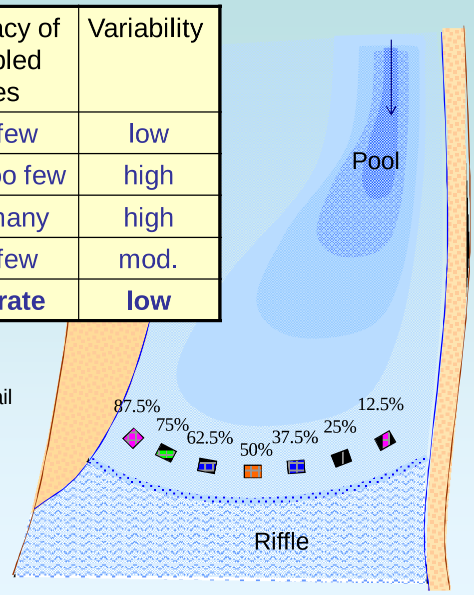
- Abundance (stat. sign.) of fines near banks at 12.5 and 87.5% w_{wet}
  - ~ 3 x more fines than at 50% w_{wet}
  - ~ 2 x more fines than at 25 and 75% w_{wet}
- CV %: higher near banks
  - % fines least variable near center
  - % fines most variable near banks





Differences among grid-count protocols

Sampling locations (% of wetted width)	Accuracy of sampled fines	Variability
37.5, 50, 62.5 **(center)**	Too few	low
25, 50, 75 **(lat. distrib.)**	Sltly. too few	high
12.5, 50, 87.5 **(grid toss)**	Too many	high
25, 37.5, 50, 62.5, 75	Too few	mod.
All 7 locs. (12.5 - 87.5)	**accurate**	**low**



➔ Poor comparability among protocols with small differences in sampling location

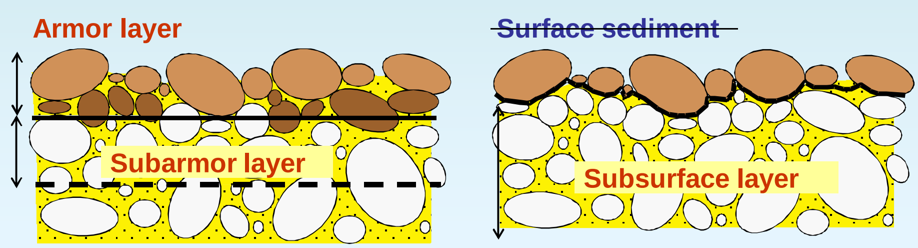
(Bunte et al., JAWRA 2012)

Collecting a predefined sample volume or mass from within a homogeneous area:

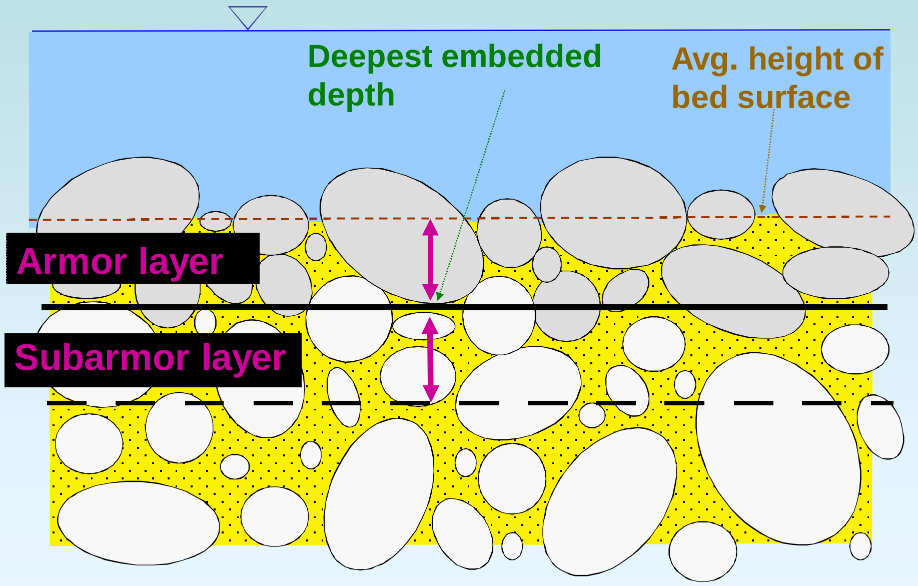
Volumetric sampling

Layers to be collected volumetrically

Layer/strata	Thickness of sampled layer
Armor layer	→ critical (≈ max. embedded depth)
subarmor	less important (1 or 2 D_{max} or D_{95})
subsurface	
unstratified bulk	

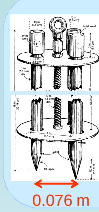


How thick are armor and subarmor layers?

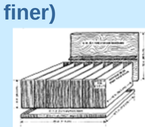


Different methods for collection of volumetric samples

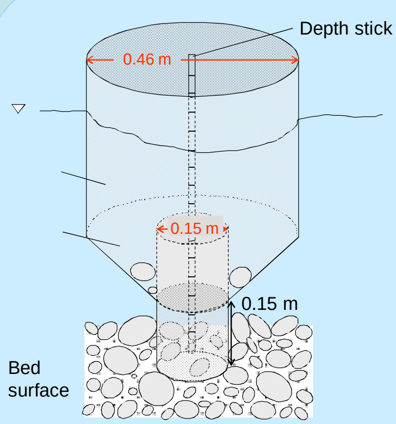
Shovel (med. gravel or finer)
- Loss of fines
- No stratification
- quick



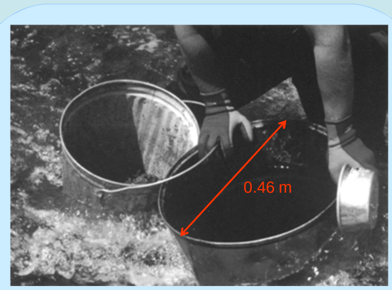
Tri-tube freeze core sampler (coarse gravel and finer)
(Platts et al. 1983)



- Fines retained
- some stratification
- small sample volume



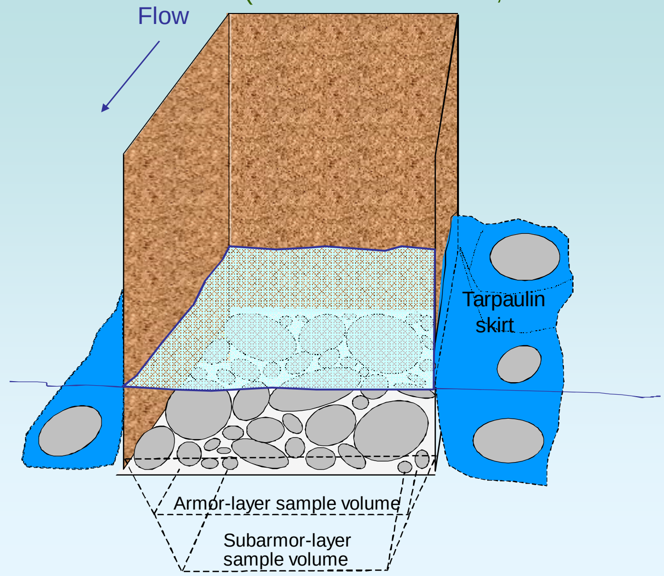
McNeil sampler (med. Gravel or finer)
(McNeil and Ahnell 1964)
- Fines retained
- No stratification
- small sample vol.



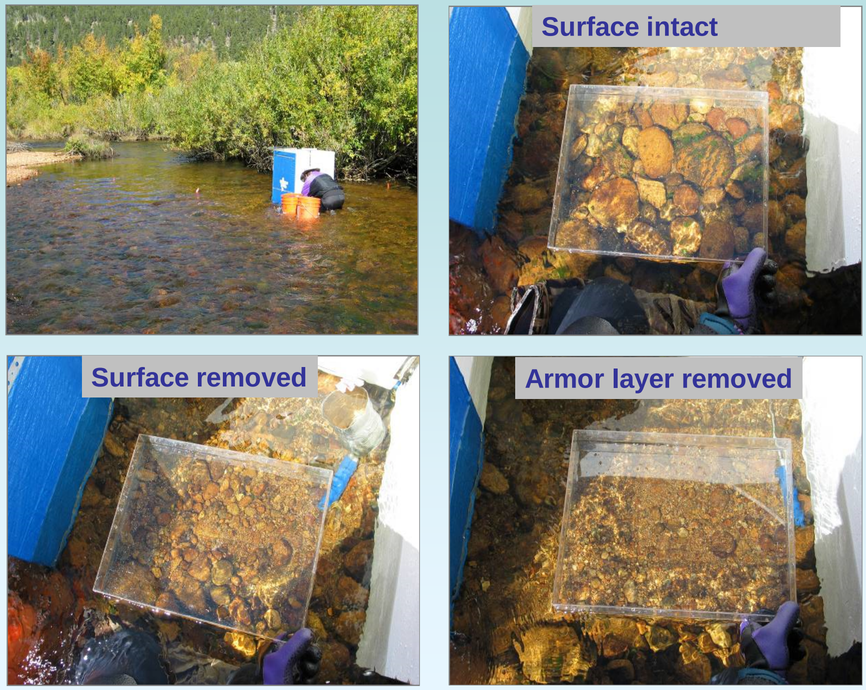
Barrel sampler (cobbles and finer)
(Hogan et al. 1995; Milhous et al. 1995)
- fines retained
- some stratification
- mod. large sample volume
- laborious

Three-sided plywood shield

(Winema Natl. Forest, Klamath Falls, OR)



3-sided plywood shield, opening facing downstream

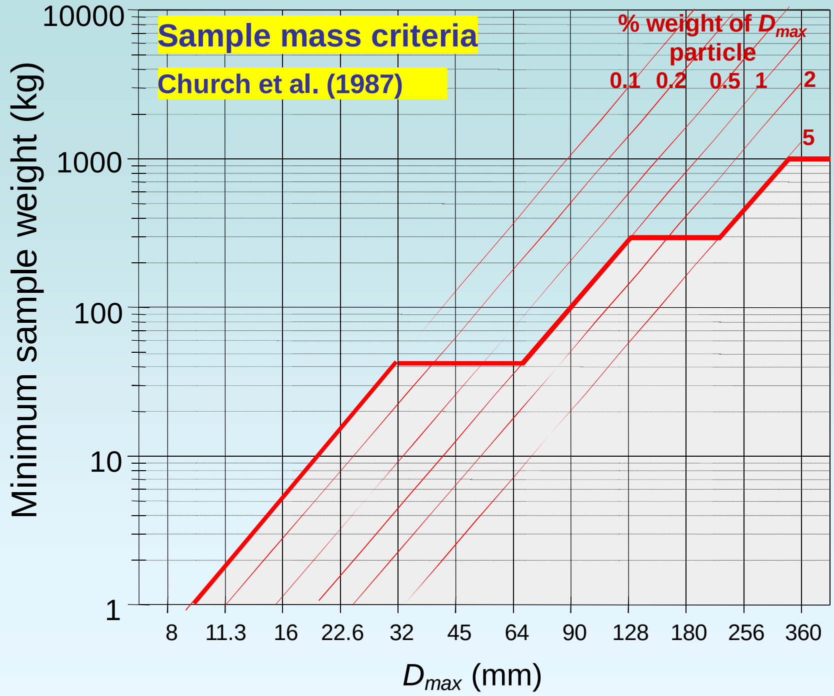


Sediment samples from individual strata

Surface + armor w/o surface = armor

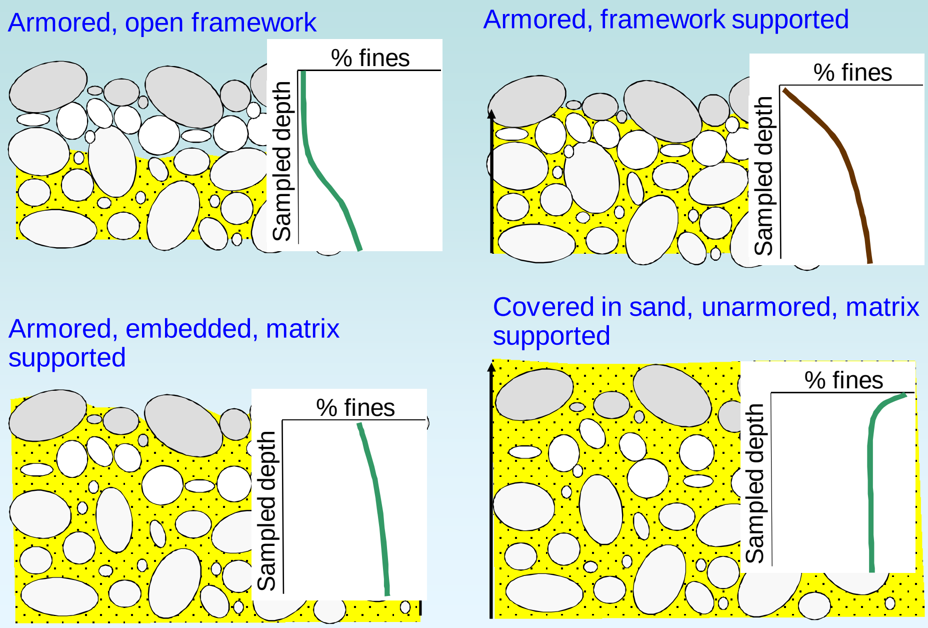
Armor w/o surface + subarmor = subsurface

- Volume of sediment sampled per locations depends on thickness of sampled layer
- Take several samples from within one habitat (or sedimentary) unit to arrive at required sample mass
- Analyze samples individually, composite mathematically (info on variability)

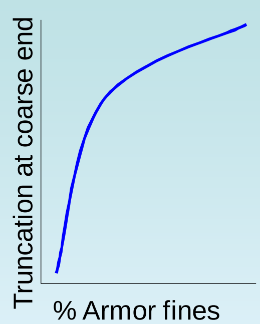


Field sieving and weighing

Change of % fines with increasing sampling depth—variable

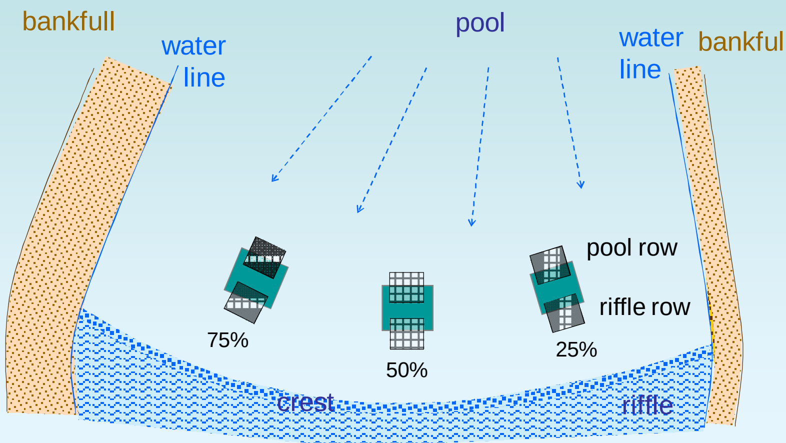


- Effects of truncation the sample at the coarse end

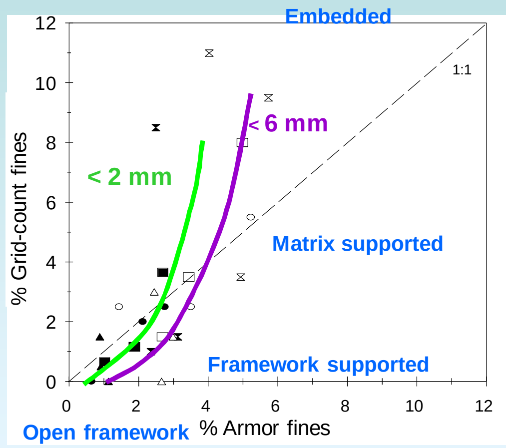


- Truncation enriches fines in the remaining sample
- Effects on comparability?

Grid count fines and armor fines: different or same?



For fixed sampling depth and truncation (e.g., at 64 mm), grid- and armor fines increase at different rates depending on how the bedmaterial is stratified



➔ Grid-count and armor fines are not generally comparable

Spatial sampling strategies for channel monitoring of:

Change in watershed delivery of fines

- Sample where fines are preferentially deposited
  - Monitor specific reach deposits (bar tails, wakes, bank lines) (disadvantage: amount of fines or size of deposit depends on timing and flow)
- Sample to integrate over spatial variability of fines within the reach
  - Systematically cover the high-flow channel, recording all sampling locations to characterize spatial variability within the reach
  - Low flows may relocate fines, but not remove them

Change in benthic habitat

- Sample at specific habitat locations (e.g., pool tail area within w_{wet})
  - Characterize spatial variability within pool-tail areas (e.g., bankward fining, fines along streaks, proximity to riffle crest)
  - Sample numerous pool-tail areas
  - Characterize the vertical variability

Take-home messages for bedmaterial sampling

Sampling method affects sampling results.

Sampling results differ **among** methods (pebble counts, grid counts, and volumetric samples), and **within** methods depending on the **exact** ways with which each method is carried out.

Spatial variability affects sampling results.

Patterns of spatial variability of surface fines are explainable by channel morphology, transport paths, and effects of isolated objects (e.g., LWD, log- or beaver dams, large rocks). Sampling procedures need to take that into account, e.g., by characterizing spatial variability.

Bedmaterial is vertically stratified.

Sampling depth of volumetric armor samples matters. Use a plywood shield to **see** the vertical stratification. In downward-fining sediment (common), sampling deeper strata causes finer particle-size distributions and more fines in the sample. Note different trends on beds embedded in fines.

Volumetric samples on coarse beds need to be large.

Samples sufficiently large to characterize the coarse part of the distribution are required even for quantification of fines; Absence or presence of one large rock affects the percent fines, esp. in small samples. Also, truncation at the coarse end increases the percent fines for the remaining distribution.

Bedmaterial sampling is not easy.

The field operator (or one of the crew) must be experienced; Spatial diversity requires expert decisions all the time. "Cookbook" protocols not suitable to cover channel complexity.

Bedmaterial sampling is labor intensive.

Accurate bedmaterial sampling on coarse gravel/cobble beds requires large samples sizes (400+ particle pebble counts; 50-100 grid counts; several 100 kg of volumetric samples), hence bedmaterial sampling is labor intensive and costly.

Happy sampling!

Sampling strategies for bed material sampling

Understanding how different streams work

- study specific
- important for setting the background awareness

Monitoring change in delivery of fines

- Sample where fines are preferentially deposited
  - Monitor specific reach deposits (bar tails, wakes, bank lines)
  - problem: amount of fines or size of deposit depends on timing and flow)
- Sample to integrate over spatial variability of fines within the reach
  - Systematically cover the high-flow channel, recording all sampling locations to characterize spatial variability within the reach
  - Low flows may relocate fines, but not remove them
  - Problem: how far onto the banks to sample? bankfull width and highflow width (last flood event) may not be easily to distinguish

Monitoring change in benthic habitat

- Sample at specific habitat locations (e.g., pool tail area within w_{wet}) at spec. time when fines pose a problem (smothering fry, entombment, decreasing rearing habitat,…)
  - Characterize spatial and vertical variability within habitat if area is large enough to understand what is going on loacally (e.g., bankward fining, fines along streaks, proximity to riffle crest) (understanding sediment dynamics in habitat area)
  - Extend sampling over a sufficient number of habitat locations
- Use results from monitoring for sediment delivery as indication of potential effects (fines on bars might get into habitat locations)

Collaboration:
Sedimentologists know the how to sample sediment and the general sediment dynamics, but not specific habitat concerns;
Fisheries biologists know when and where habitat is endangered. They need to know sediment dynamics within habitat locations and sample on the background of spatial/temporal variability of sediment dynamics and habitat needs

Gaps in our understanding of sediment science and management

Document, explain, and publish bedmaterial variability in a variety of different streams

Don't be lax about field methods—mind the details:

Examine field protocols. Avoid methodological and observer bias. Careful about combining or comparing results from different methods. Find the fine line between adhering to protocol and improvising when needed.

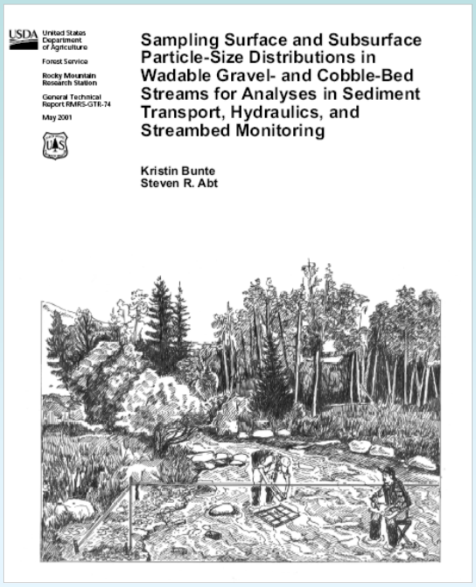
Be aware of spatial and vertical variability of bedmaterial:

Consider how to sample in its presence—document it.

Accept that bedmaterial sampling is neither easy nor cheap:

Send the most experienced—not the least experienced—people into the field; Extend field time and increase sample sizes!

http://www.fs.fed.us/rm/pubs/rmrs_gtr74.html


USDA United States Department of Agriculture

Forest Service

Rocky Mountain Research Station

General Technical Report RMRS-GTR-74

May 2001

Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring

Kristin Bunte
Steven R. Abt

Journal of the American Water Resources Association, 2009


JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

AMERICAN WATER RESOURCES ASSOCIATION

JAWRA

COMPARISON OF THREE PEBBLE COUNT PROTOCOLS (EMAP, PIBO, AND SFT) IN TWO MOUNTAIN GRAVEL-BED STREAMS[1]

Kristin Bunte, Steven R. Abt, John P. Potyondy, and Kurt W. Swingle[2]

ABSTRACT: Although the term "pebble count" is in widespread use, there is no standardized methodology used for the field application of this procedure. Each pebble count analysis is the product of several methodological choices, any of which are capable of influencing the final result. Because there are virtually countless variations on pebble count protocols, the question of how their results differ when applied to the same study reach is becoming increasingly important. This study compared three pebble count protocols: the reach-averaged Environmental Monitoring and Assessment Program (EMAP) protocol named after the EMAP developed by the Environmental Protection Agency, the habitat-unit specific U.S. Forest Service's PACFISH/INFISH Biological Opinion (PIBO) Effectiveness Monitoring Program protocol, and a data-intensive method developed by the authors named Sampling Frame and Template (SFT). When applied to the same study reaches, particle-size distributions varied among the three pebble count protocols because of differences in sample locations within a stream reach and along a transect, in particle selection, and particle-size determination. The EMAP protocol yielded considerably finer, and the PIBO protocol considerably coarser distributions than the SFT protocol in the pool-riffle study streams, suggesting that the data cannot be used interchangeably. Approximately half of the difference was due to sampling at different areas within the study reach (i.e., wetted width, riffles, and bankfull width) and at different locations within a transect. The other half was attributed to using different methods for particle selection from the bed, particle-size determination, and the use of wide, nonstandard size classes. Most of the differences in sampling outcomes could be eliminated by using simple field tools, by collecting a larger sample size, and by systematically sampling the entire bankfull channel and all geomorphic units within the reach.

(KEY TERMS: sediment; monitoring; fluvial processes; sampling technique; habitat evaluation; percent fines.)

Bunte, Kristin, Steven R. Abt, John P. Potyondy, and Kurt W. Swingle, 2009. Comparison of Three Pebble Count Protocols (EMAP, PIBO, and SFT) in Two Mountain Gravel-Bed Streams. *Journal of the American Water Resources Association* (JAWRA) 1-19. DOI: 10.1111/j.1752-1688.2009.00355.x

INTRODUCTION

Pebble counts are one of the most frequently used field methods to assess the size distribution of bed surface sediment in gravel-bed and cobble-bed streams. However, pebble counts exist in countless variations; more than 30 different procedures are used by the USDA Forest Service alone (Hilaire Bojonell, Hydrologist, USDA Forest Service, National Resources Information System, Corvallis, Oregon, personal communication, June 2008). In fact, nearly

[1]Paper No. JAWRA-08-0164-P of the *Journal of the American Water Resources Association* (JAWRA). Received August 29, 2008; accepted May 20, 2009. © 2009 American Water Resources Association. No claim to original U.S. government works. **Discussions are open until six months from print publication.**

[2]Respectively, Research Scientist (Bunte) and Professor (Abt), Engineering Research Center, Department of Civil Engineering, Colorado State University, 1320 Campus Delivery, Fort Collins, Colorado 80523; Program Manager/Hydrologist (Potyondy), Stream Systems Technology Center, Watershed, Fish, Wildlife, Air, & Rare Plants Staff, USDA Forest Service, Washington, D.C.; Environmental Scientist (Swingle), Boulder, Colorado (E-Mail/Bunte: kbunte@engr.colostate.edu).

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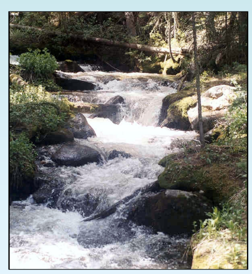
Spatial variability of bedmaterial fines in coarse gravel-bed streams depends on several factors:

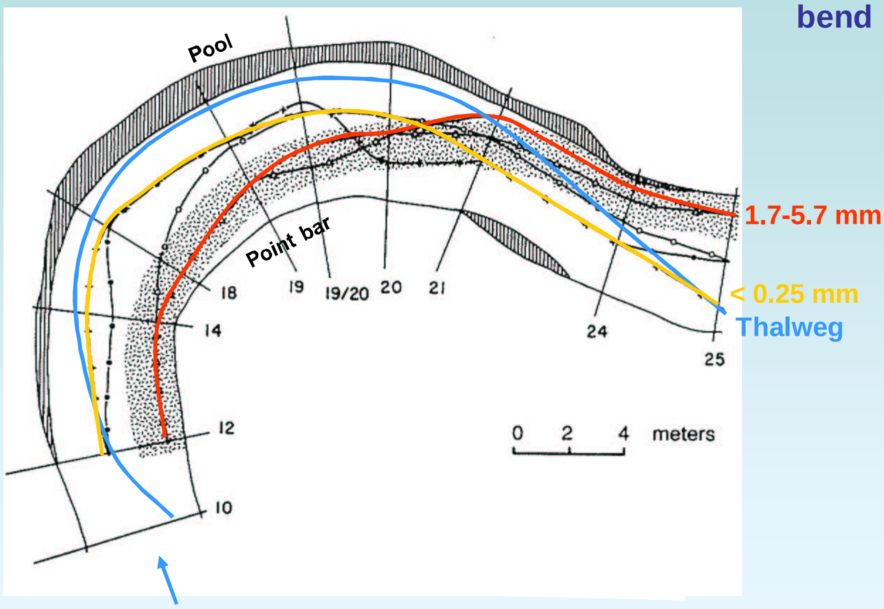
- Type of stream (pool-riffle, plane-bed, …)
- Amount of fine sediment delivered
- Flow at sampling time (low or mod.)

Generally, the steeper the stream, the less fine sediment is retained in the channel. In the highly turbulent flow of step-pool channels, much of the fines are moved in suspension. At low flow, pea gravel might deposit in sheltered locations.



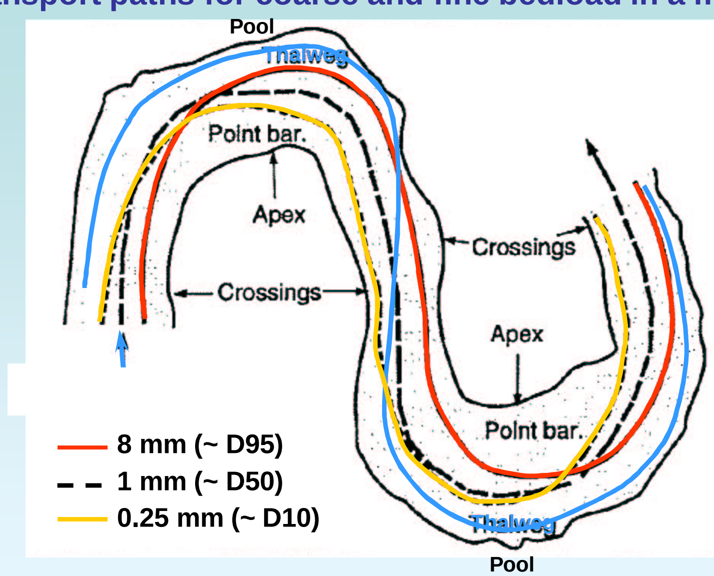
Lower gradient streams offer more chance for fine sediment to be deposited in the channel

Transport paths for coarse and fine bedload in a meander bend



From: Dietrich and Whiting (1989), slightly altered

Transport paths for coarse and fine bedload in a meander bend



From: Julien and Anthony (2002), slightly altered

Particle selection in heel-to-toe walks:

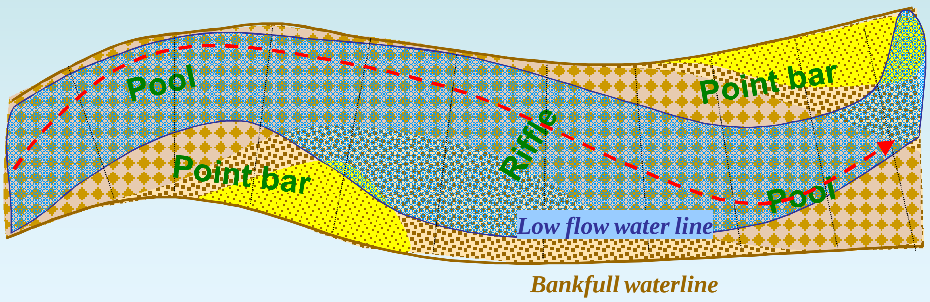
First particle touched at the tip of the boot eyes averted (Wolman 1954)

Heel-to-toe sampling versus sampling frame

	Heel-to-toe steps	Using a sampling frame
Step spacing:	1 - 2 paces (0.3 - 0.6 m), regardless of bed material size, (Counts large particles twice)	1-2 times the D_{max} particle size, in accordance with bedmaterial size (No double counting)
Particle selection	Blind touch at the tip of the boot (Favors mid-sized particles)	Visual correspondence with grid intersections in sampling frame (No favorite particle sizes)
Sampling path:	Along an imaginary line at operator's discretion (Favors easily wadeable areas, avoids pools, underbrush)	Evenly spaced along a transect, strictly predetermined (No sampling locations avoided)
Possibility for operator bias:		
- against fines	Higher	Lower
- against cobbles	Higher	Lower
Variability between:		
- samples	Higher	Lower
- operators	Higher	Lower

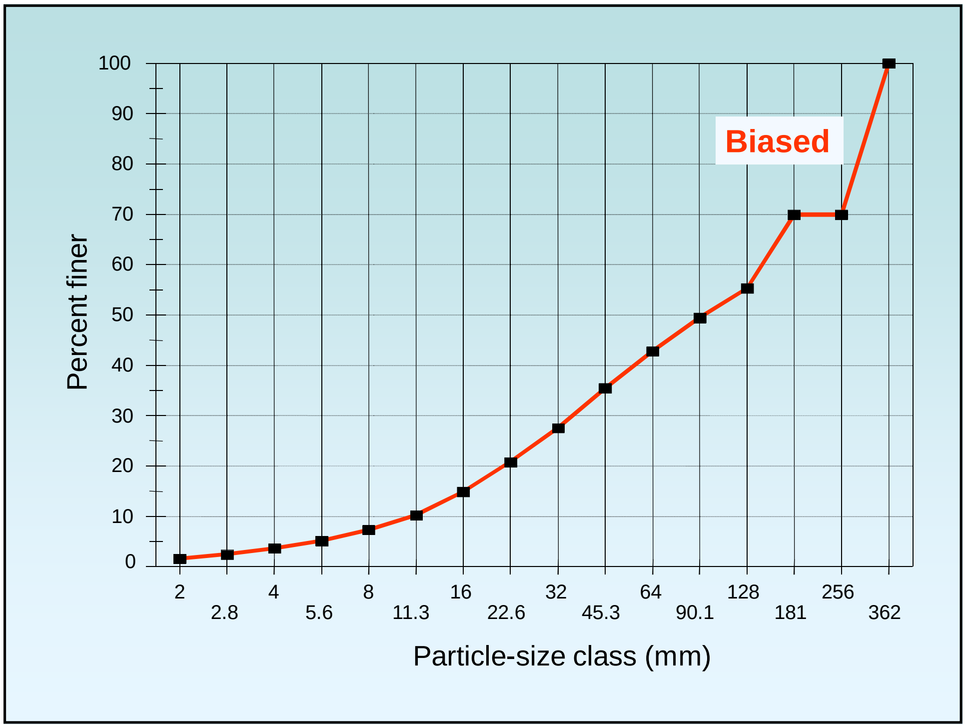
Spatially integrated sampling

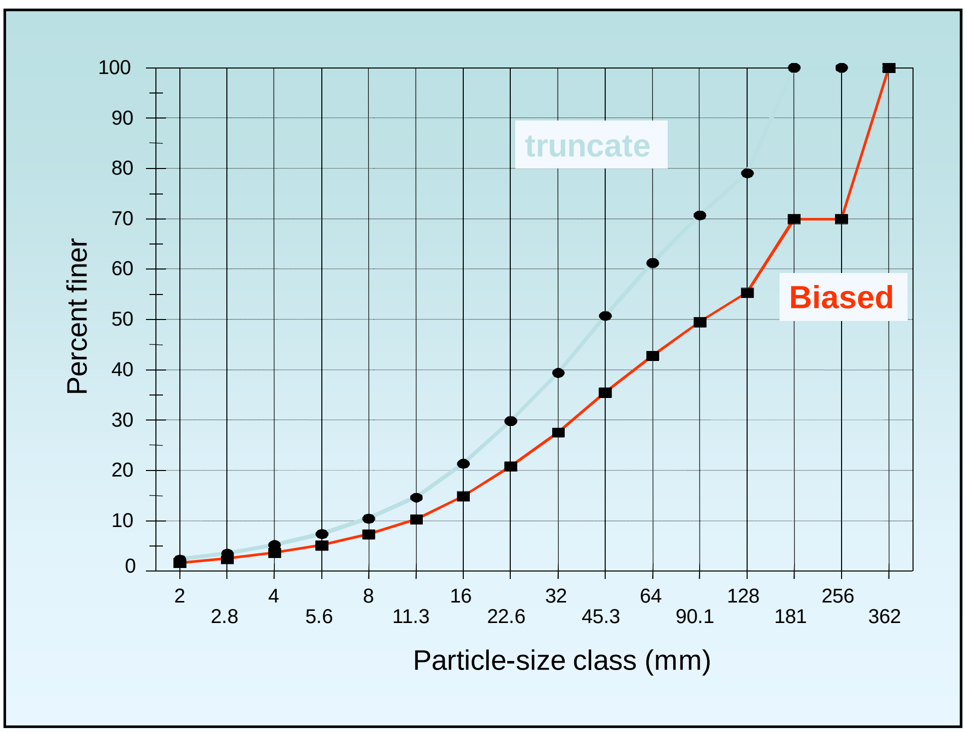
- **from bankfull to bankfull** (stream & watershed studies)
- within lowflow waterlines (flow resistance, spec. studies)




Surface intact


Surface removed


Biased
Percent finer
100
90
80
70
60
50
40
30
20
10
0
2
2.8
4
5.6
8
11.3
16
22.6
32
45.3
64
90.1
128
181
256
362
Particle-size class (mm)


truncate
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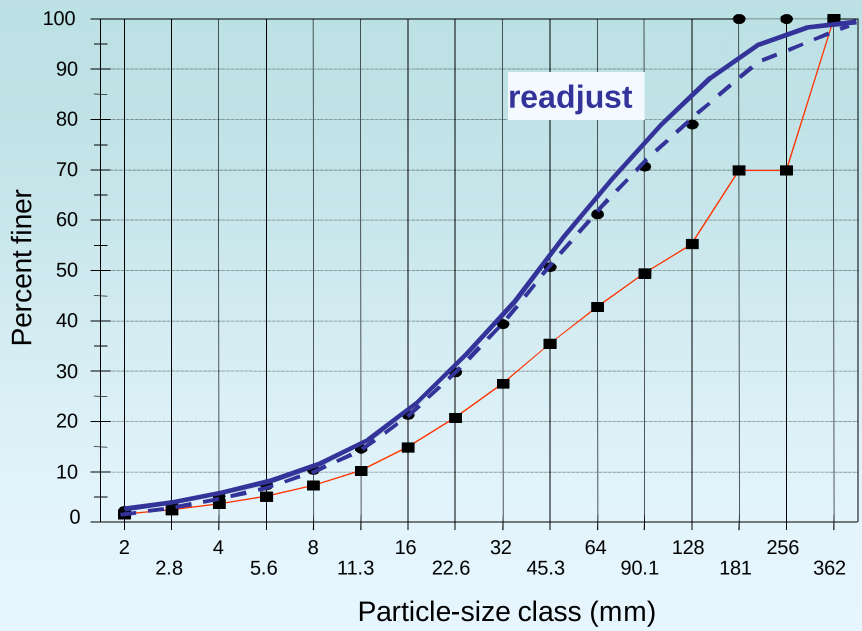
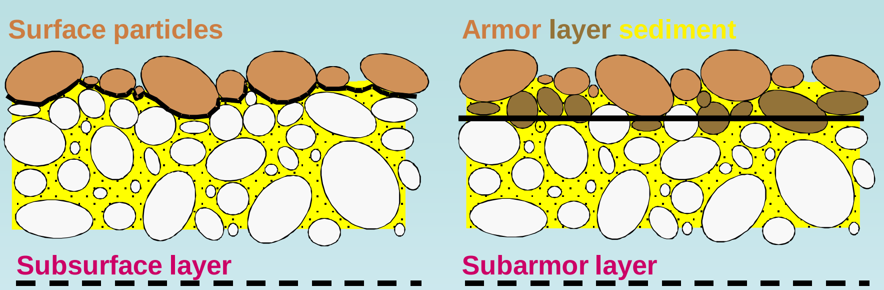
Particle-size class (mm)

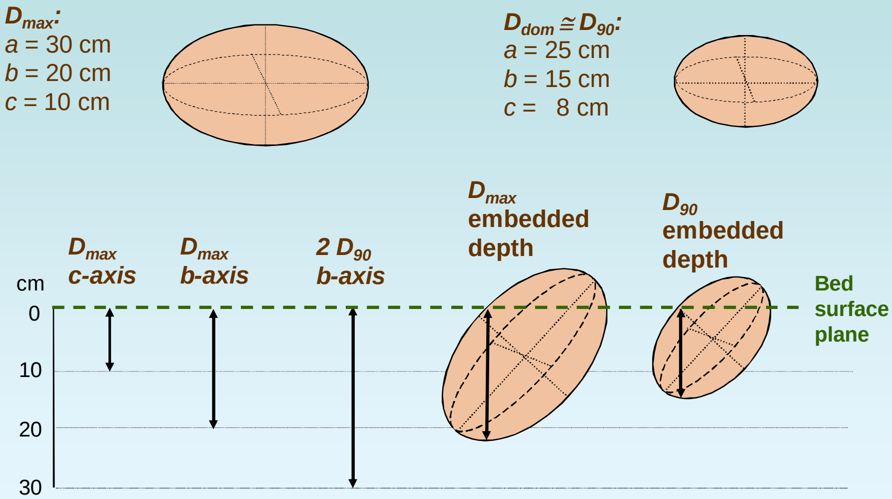




Sediment strata		**Sampling methods:**
Surface particles	→	surface methods
Armor layer sediment Subsurface subarmor Unstratified bulk sediment	}	*volumetric methods*

(problem: how much of a particle needs to be exposed to count as a surface particle?)

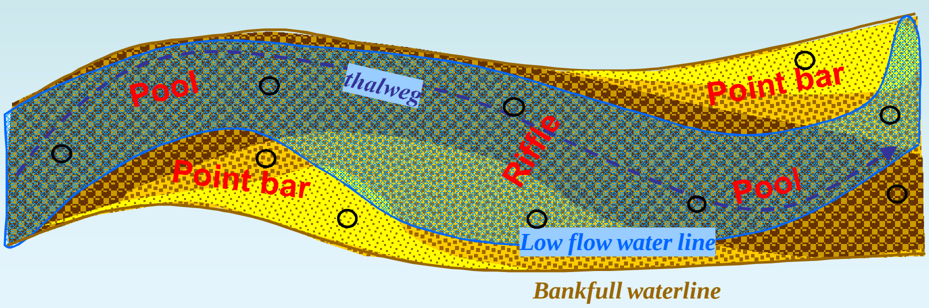
Estimators for armor layer depth



Variable definition of armor layer depth results in different size-distributions and makes comparisons between studies difficult.

Spatially stratified sampling

Covering each facies or habitat unit with sample points systematically or random



Possibility for spatial bias based on selected sampling site

Sample size for volumetric samples and mass-based particle-size analysis

- **empirical approach: based on D_{max}**

  (e.g., Church et al. 1987)

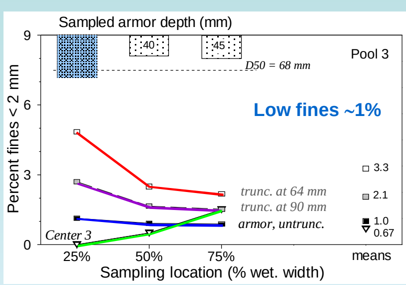
  If coarsest particles are of no interest, consider truncating samples at commonly occurring large particle size, e.g., 64 mm

- **analytical approach: based on distribution type**

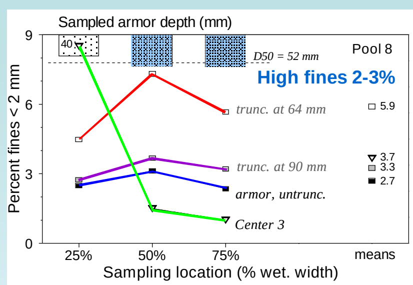
  σ and D_x

  (e.g., Ferguson and Paola 1997)

What affects armor fines and ratio of grid- to armor fines?



Grid fines less than armor fines

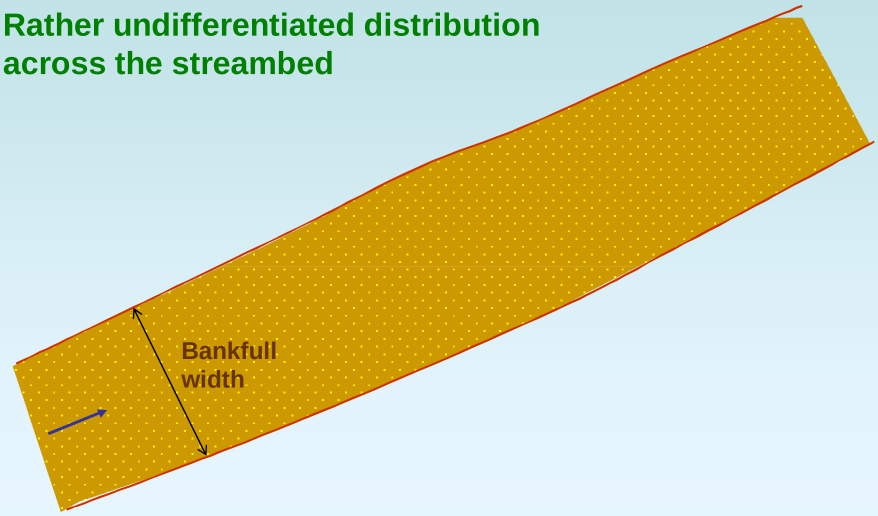


Grid fines more than armor fines

→ Truncation of armor sed. increases in % fines
→ More fines for deeper armor samples
→ Ratio grid fines to armor fines **not** constant
→ Grid fines more spatially variable than armor fines

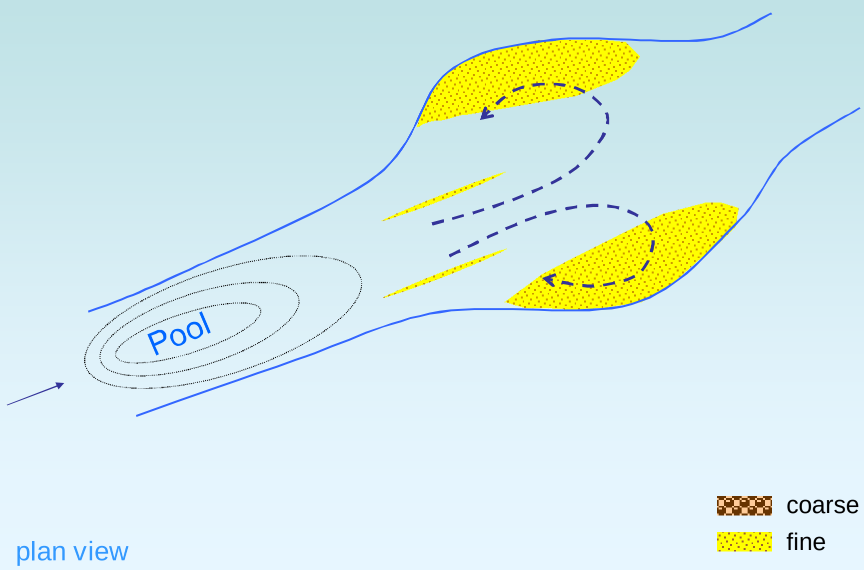
Very low supply of fines: No strongly favored location

Rather undifferentiated distribution across the streambed



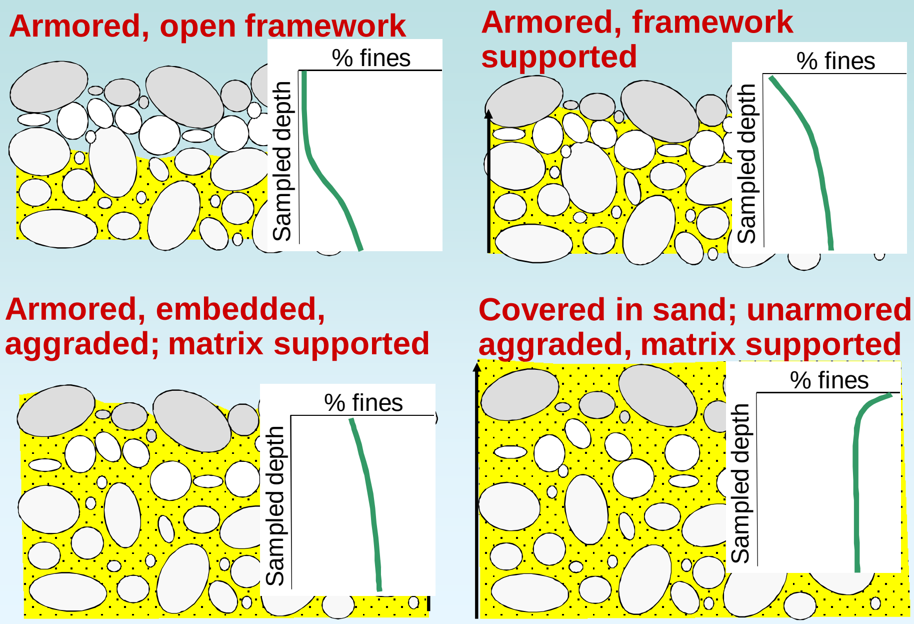
Plan view

Eddies in isolated pool exit



plan view

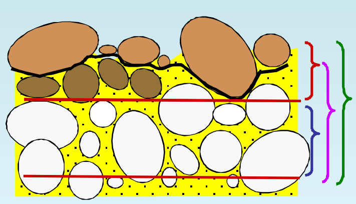
Increasing level and volume of subsurface fines



Various effects on sampled % armor fines:

(average over all N. St. Vrain samples)

- Sampling depth



Sampled strata	Fines < 2 mm	Fines < 6 mm
Armor layer	**2**	**4**
Subsurface	**16**	**28**
Subarmor	**18**	**32**
Bulk	**8**	**14**

% fines in volumetric samples increases with sampling depth…