WSDOT
Scour Workshop

Module 5
Sediment Sampling for Scour Analyses

May 31st, 2023

Robert Humphries

Geomorphologist, LEG.

HQ Development Division
WSDOT

Current Duties

- Chronic Environmental Deficiencies Program
- Fish Passage: design, management, and review Section
- Emergency Repair: design and construction

Background and Experience

- 14 years as a consulting geologist / engineering geologist / geomorphologist
- ~1.5 years at WSDOT

Education

- B.S. in Geology from UGA
- M.S. Applied Geosciences from SFSU

Personal Interests

- My family and friends
- Fly Fishing
- Camping
- Travel

Gabriel Taylor

Assistant State Engineering Geologist, LEG.

HQ State Geotechnical Office
WSDOT

Current Duties

- Landslide and Rockfall Response
- Unstable Slope Mitigation
- Earthwork/Widening Projects
- Geotechnical Fish Passage Scoping
- Scour Research!

Background and Experience

- 18 years at WSDOT
- Licensed Engineering Geologist since 2010
- AEG Nisqually past-Chair

Education

- B.S. Geology (WWU 2004)

Personal Interests

- Mountains (biking and climbing)
- Music (various stringed instruments)
- History & Astronomy
- Camping with friends and family

Overview: Sediment Sampling for Scour Analyses

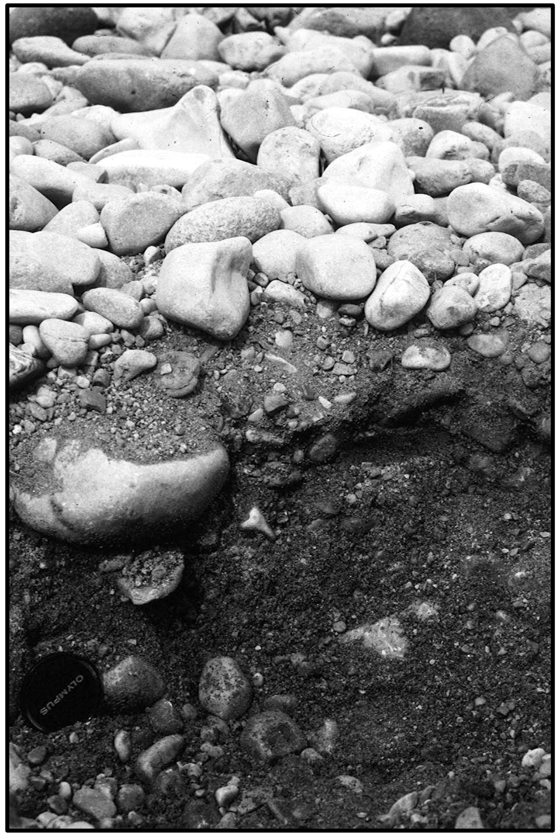
- Aligning Scour Analysis Methods with Scour Processes

- Bed Material Surface and Subsurface Sample for Scour Analysis
  - Geomorphology
  - Sampling Locations
  - Observations
  - Methods

- Subsurface Material Sampling Methods
  - Review of geotechnical boring logs, grainsize plots, index testing, etc.

"You must ask the question at the scale of the process."

~Dr. Church



Parker ebook

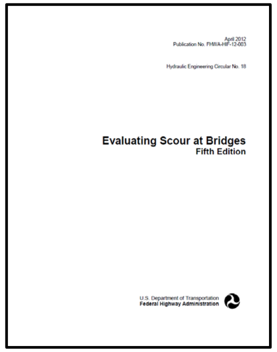
Aligning Scour Analysis Methods with Scour Processes

- **Total Scour Analysis**
  - Contraction Scour **(Module 7)**
  - Local Scour **(Module 8 and 9)**
  - Lateral Migration **(Module 6)**
    - Stream Instability
    - Geomorphic Assessment: Site, Reach, and Watershed
  - Long-Term Degradation **(Module 6)**
    - Stream Instability
    - Geomorphic Assessment: Site, Reach, and Watershed
- **Hydraulic Modeling**
- **Foundation Design**
- **Slope/Global Stability**
- **Stream Instability**
- **Geomorphic Assessment: Site, Reach, and Watershed**
- **Etc.**

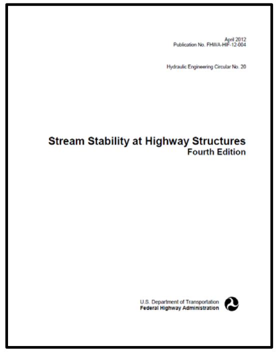
- **Data for Scour Analysis (Module 5)**
  - Bed Material Samples
    - Surface (Wolman Pebble Count)
    - Subsurface
  - Geotechnical Samples
    - Cohesionless
    - Cohesive
    - Rock

Aligning Scour Analysis Methods with Scour Processes

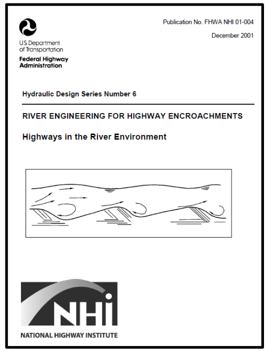
- **Total Scour Analysis**
  - Contraction Scour and Local Scour
    - (Live-Bed or Clear Water Scour)
  - Lateral Migration
  - Long-Term Degradation



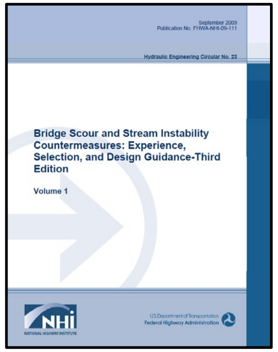
HEC 18



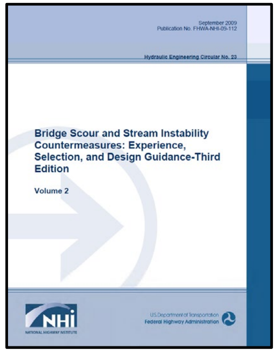
HEC 20



HDS 6

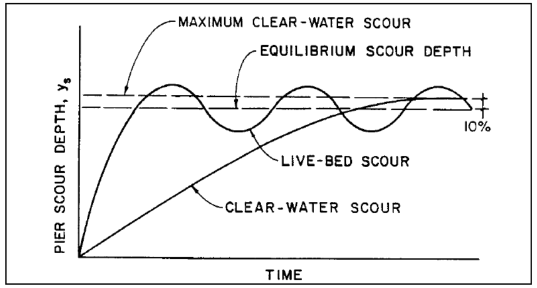


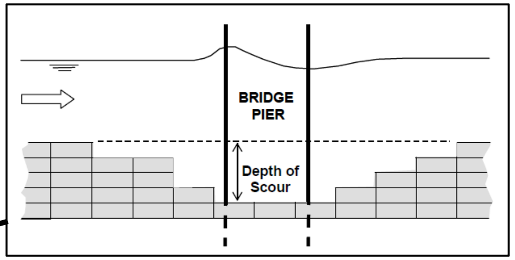
HEC 23 Vol. 1

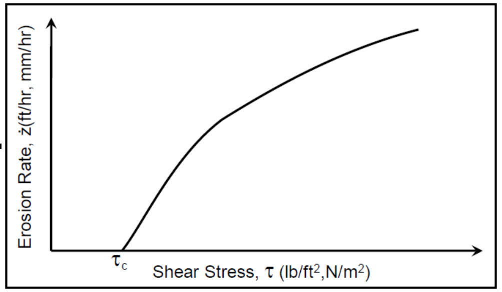


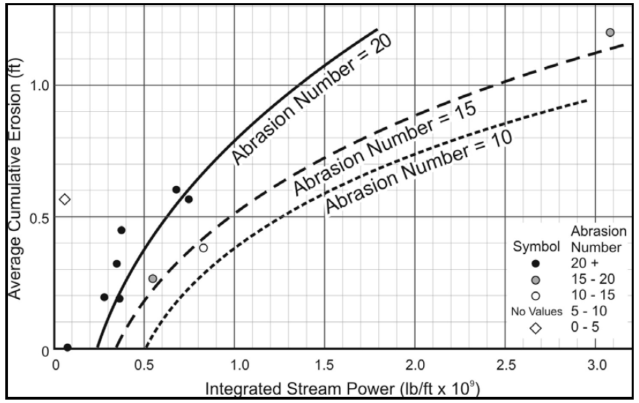
HEC 23 Vol. 2

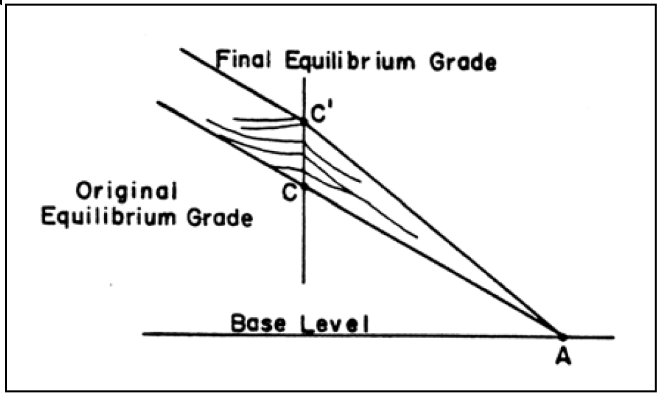
- **Scour Processes**
  - Sediment Transport
  - Block Dynamics
  - Corrasion (hydraulic scour)
  - Aggradation - Degradation
  - Abrasion (particle impact)



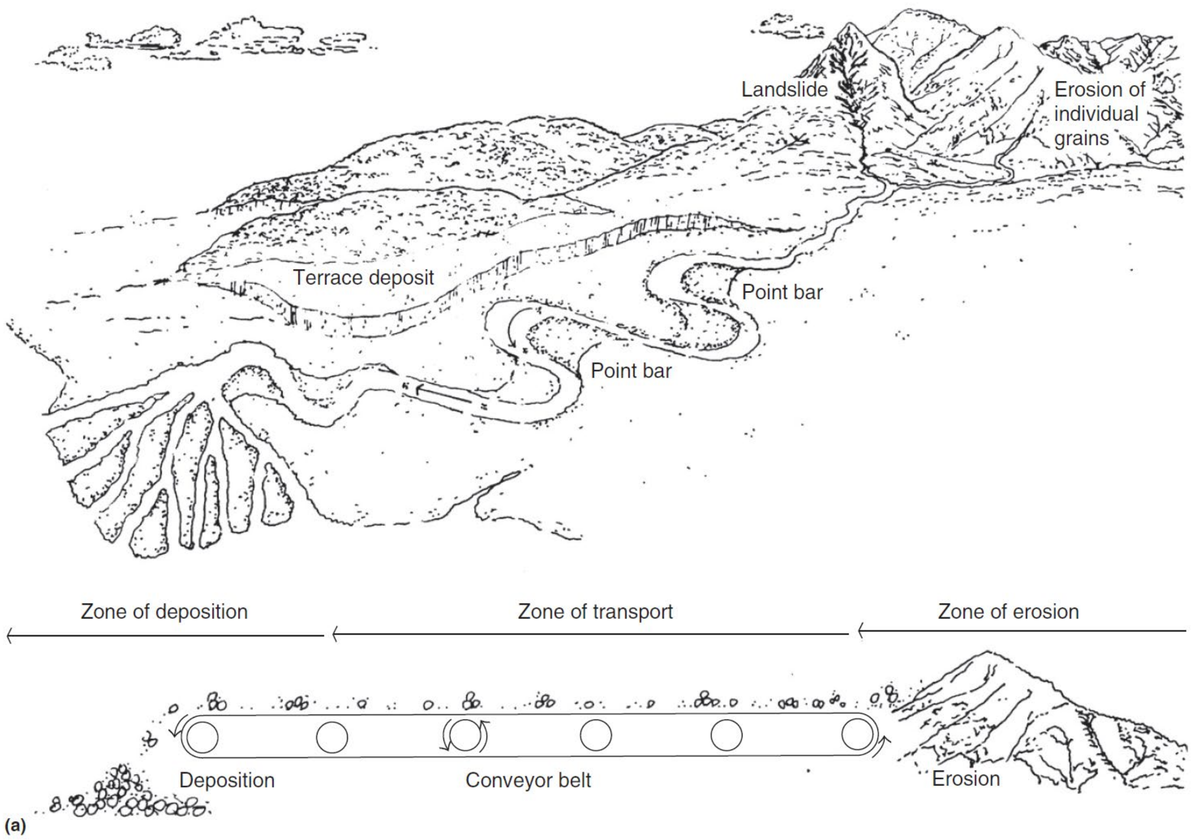






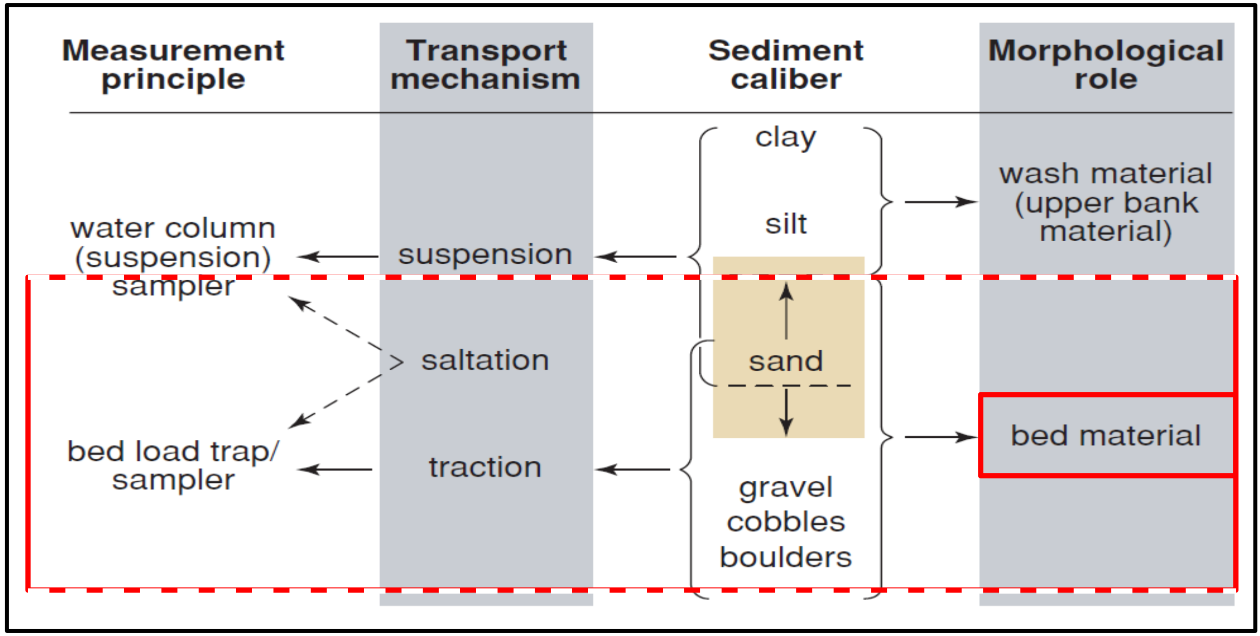


The Geomorphology of Sediment for Scour Analyses



Schuum 1997 and Kondolf 1994

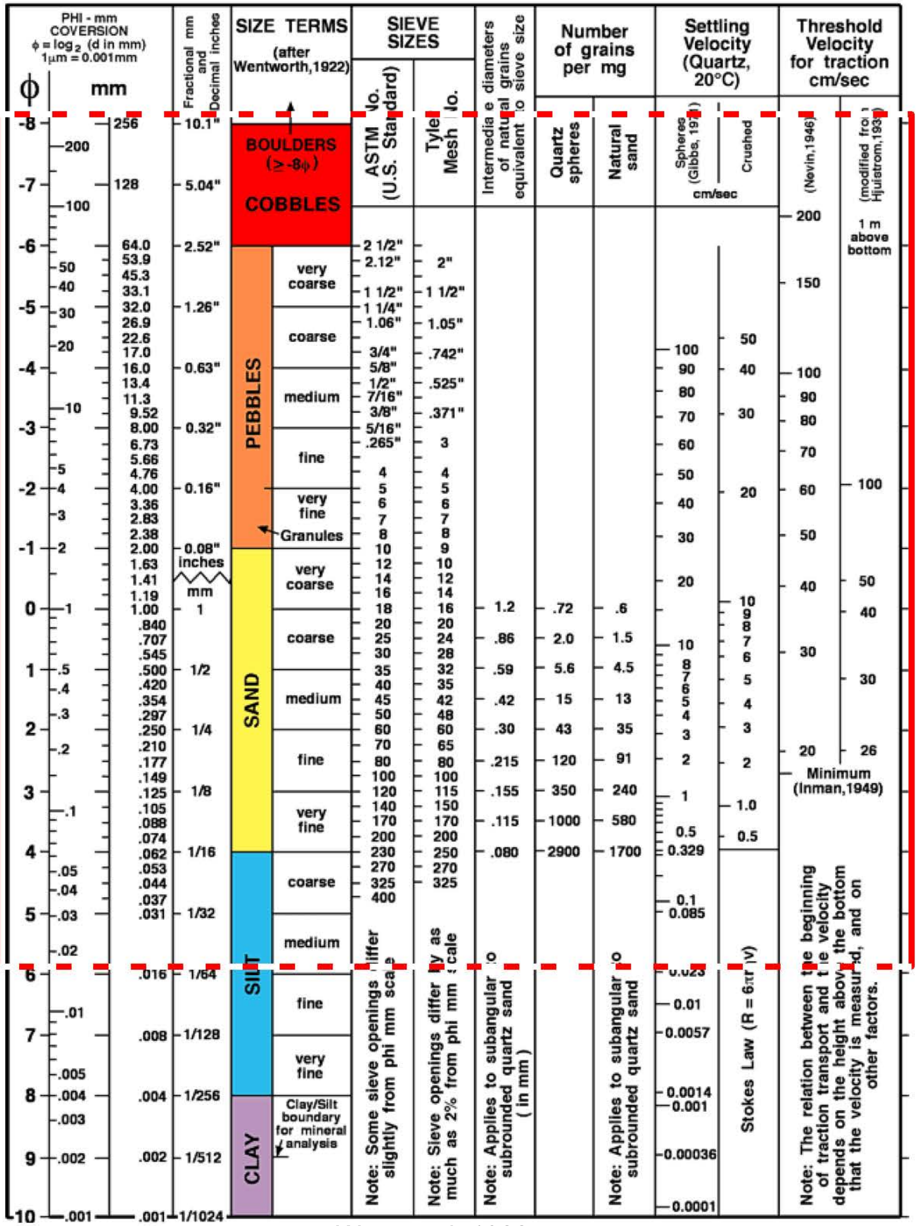
Fluvial Sediments



Church (2006)

Bed material: material that forms the bed and lower banks of the river and chiefly determines the morphology of the channel. In alluvial channels, it corresponds with the coarser part of the sediment load transported by the river, and it may move either as bedload or as intermittently suspended load.

Wentworth Grain Size Scale



Wentworth 1922

Table 2.1. Sediment Grade Scale.					
Size			Approximate Sieve Mesh Openings (per inch)		Class
Millimeters	Microns	Inches	Tyler	U.S. Standard	
4000-2000	---	180-160	---	---	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	2.5	---	Medium gravel
8-4	---	0.3-0.16	5	5	Fine gravel
4-2	---	0.16-0.08	9	10	Very fine gravel
2.00-1.00	2000-1000	---	16	18	Very coarse sand
1.00-0.50	1000-500	---	32	35	Coarse sand
0.50-0.25	500-250	---	60	60	Medium sand
0.25-0.125	250-125	---	115	120	Fine sand
0.125-0.062	125-62	---	250	230	Very fine sand
0.062-0.031	62-31	---	---	---	Coarse silt
0.031-0.016	31-16	---	---	---	Medium silt
0.016-0.008	16-8	---	---	---	Fine silt
0.008-0.004	8-4	---	---	---	Very fine silt
0.004-0.0020	4-2	---	---	---	Coarse clay
0.0020-0.0010	2-1	---	---	---	Medium clay
0.0010-0.0005	1-0.5	---	---	---	Fine clay
0.0005-0.0002	0.5-0.24	---	---	---	Very fine clay

HEC 20

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0.016-0.008	16-8	---	---	---	Fine silt
0.008-0.004	8-4	---	---	---	Very fine silt
0.004-0.0020	4-2	---	---	---	Coarse clay
0.0020-0.0010	2-1	---	---	---	Medium clay
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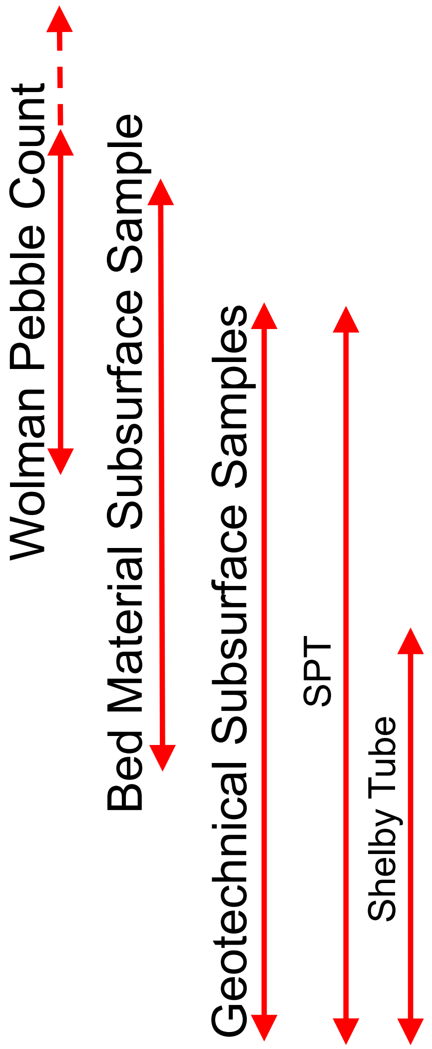
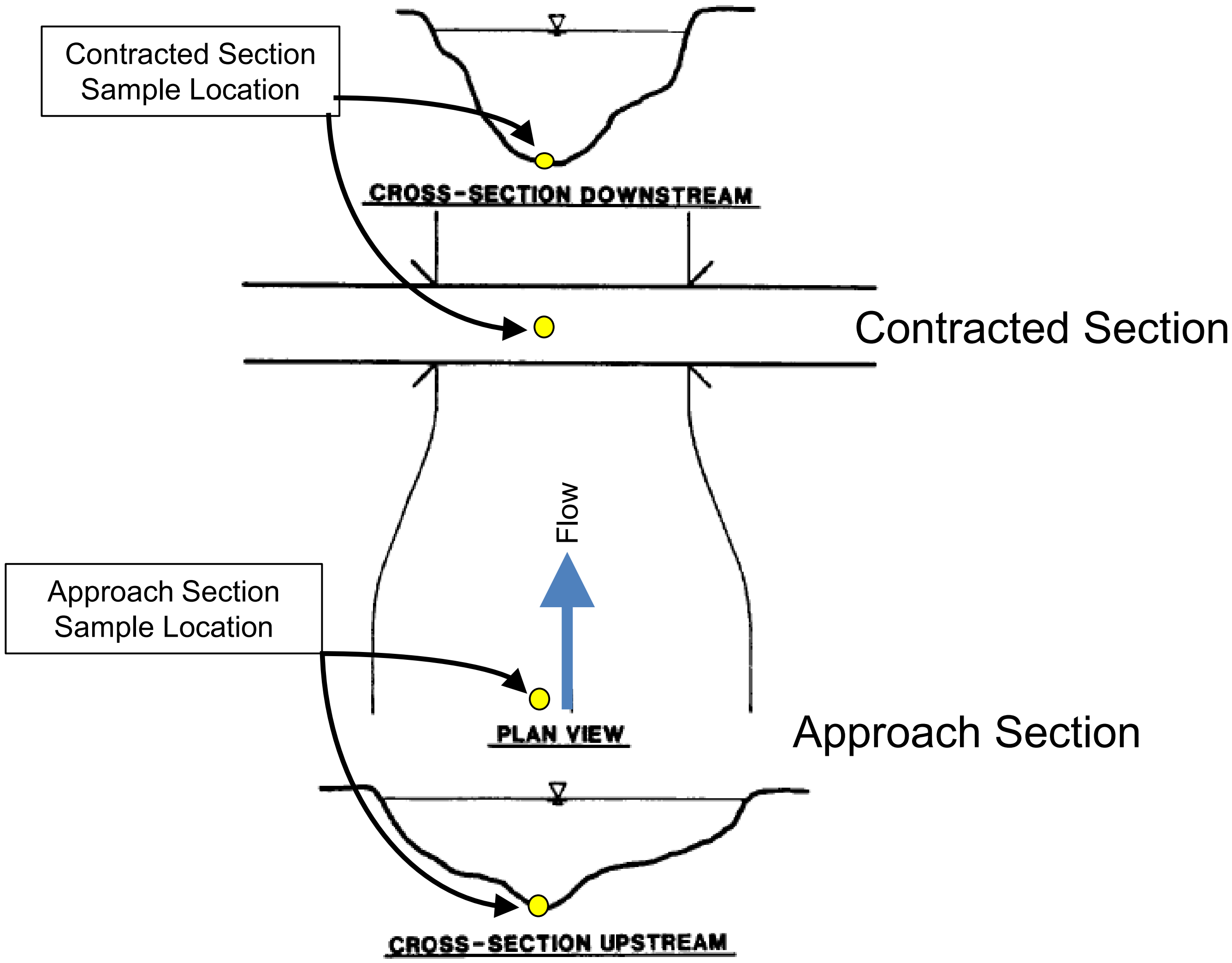
0.0005-0.0002	0.5-0.24	---	---	---	Very fine clay

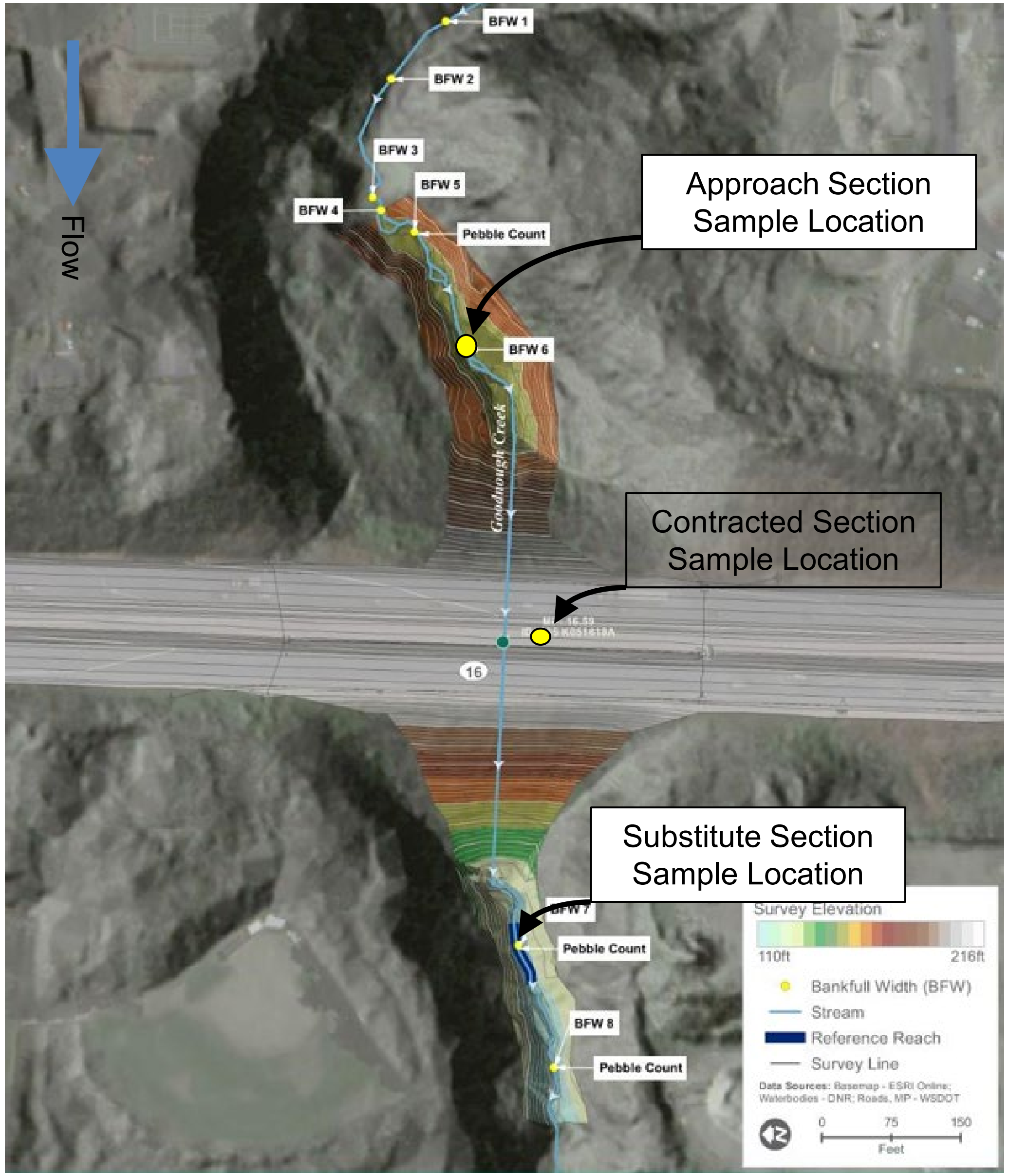


HEC 20

Sediment Sampling Locations for Erosion/Scour Analysis

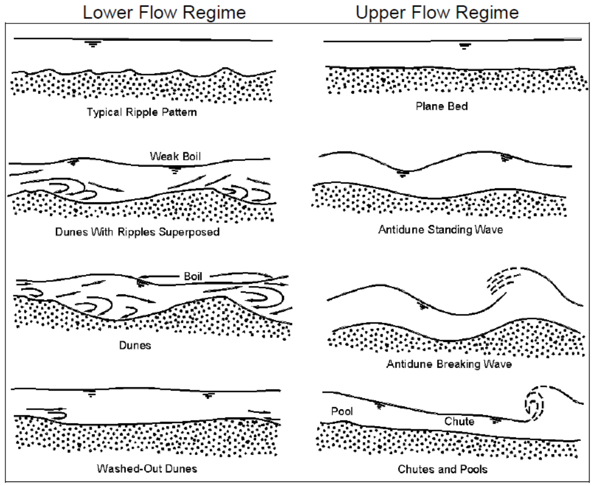


Adapted from HEC 18

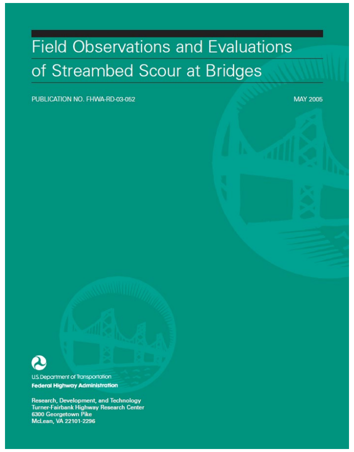


Mapping for Scour

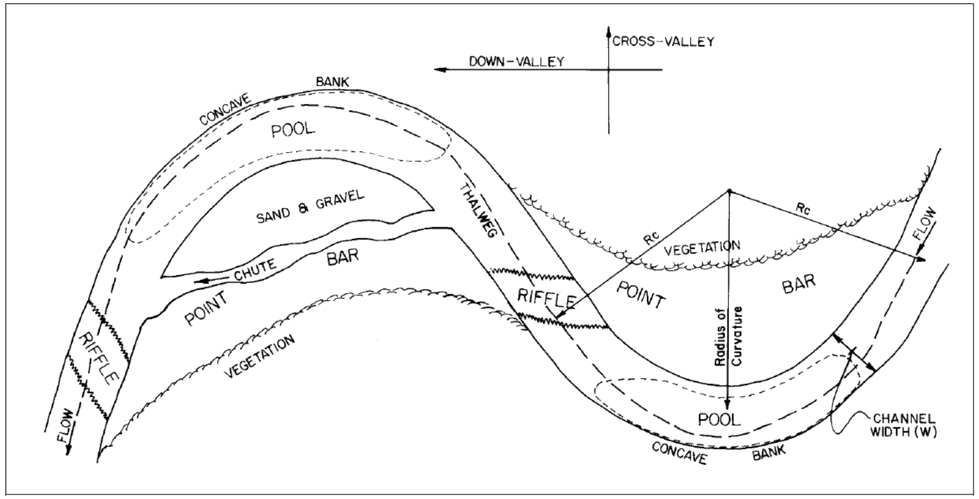
- Geomorphic Mapping for Scour Analysis
  - Geomorphic Units
  - Detailed observations at:
    - Approach Section
    - Contracted Section
  - Observations of
    - Bedrock Characteristics
    - Till, or other glacial sediments
    - Large Boulders
    - Bedforms
    - Channel Bends
    - Confluences
    - Slope Changes



Simons and Richardson 1963



FHWA 2005



HEC 20 (2012)

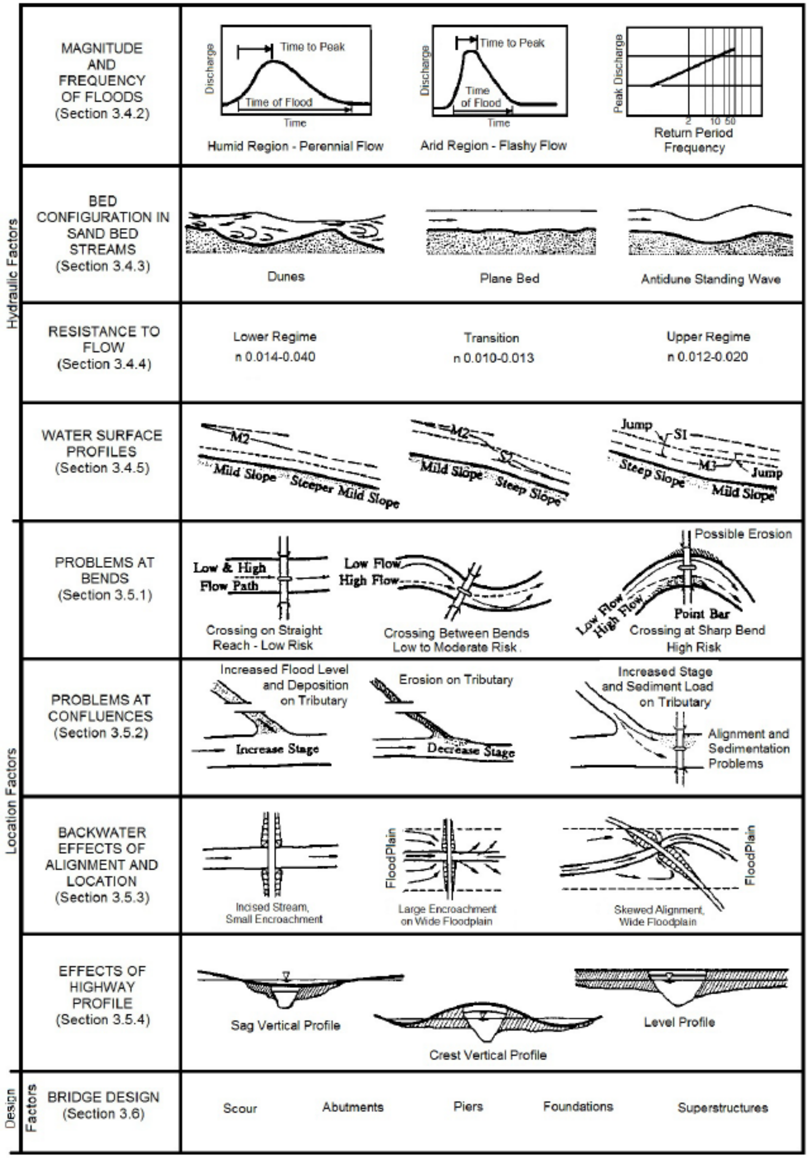


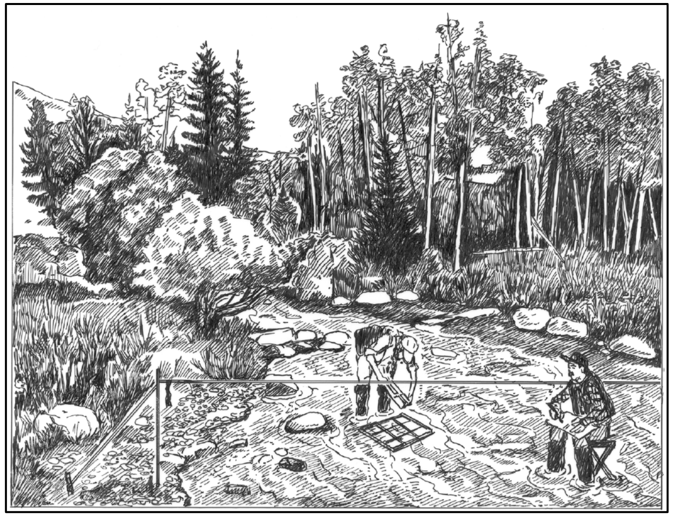
Figure 3.3. Hydraulic, location, and design factors that affect stream stability.

HEC 20 (2012)

Bed Material Sampling

Alluvial Sediment Sampling: Resources

- **WSDOT Resources**
  - **Hydrology and Hydraulics training website**:
    - https://wsdot.wa.gov/engineering-standards/project-management-training/training/hydraulics-hydrology-training
  - **2022 Fish Passage and Stream Restoration Design Training Module 8: Geomorphic Assessment for Stream Crossings** by Cygnia F. Rapp, LG. 2022
    - https://wsdot.wa.gov/publications/fulltext/Hydraulics/hhtraining/FishPassageTraining/8-Geomorphic-Assessment-of-Stream-Crossings.pdf



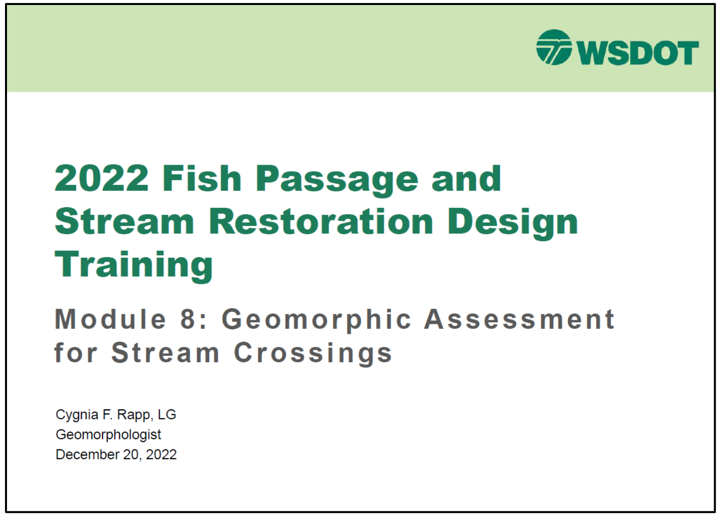
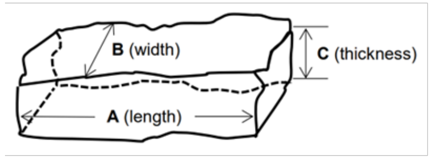


Image Source: Casey Kramer

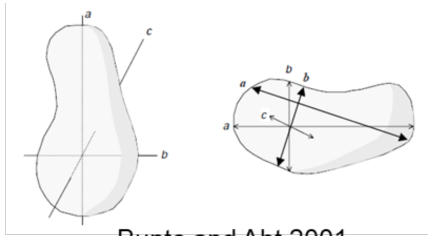
Surface Sediment Sampling: Grain Size Distribution of Clastic Sediment.

The Wolman Pebble Count

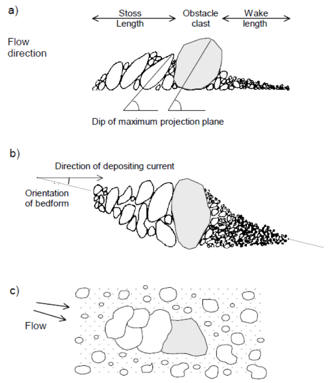
- Purpose: Measure and characterize the grain size distribution of the surface of fluvial sediment deposit in a geomorphically active river at approach and contracted sections.
  - Sample from single geomorphic unit, preferably coarser material near the center of the channel
  - Sample dry sediment.
- Particle selection must be random.
  - Tape method (preferred)
  - Grid method (use to stay within a single geomorphic unit)
  - Random-walk / Step-toe method (not recommended)
- Sampling Plan:
  - At least 110 particles should be measured per sample, and an additional measurement should be taken for each sand particle.
  - At least 2 grain size distribution samples should be collected for each section
- Measure the medial axis of each particle.
  - Not the longest axis, not the shortest, but the medial axis.
  - Gravelometer preferred measured medial axis.
  - Must include an estimate of the % of sand on bed
    - Visual estimate of % sand on bed conducted in the field.
    - Sand particles to be recorded as <2 mm in the particle count, but additional measurements must be added to the sample.
- Observe fabric or texture of surface gravel for:
  - Imbrication
  - Gravel clusters



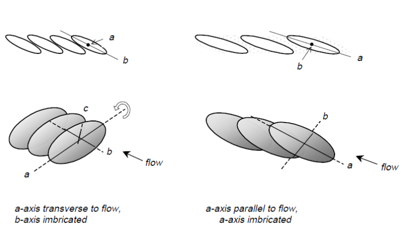
FHWA



Bunte and Abt 2001



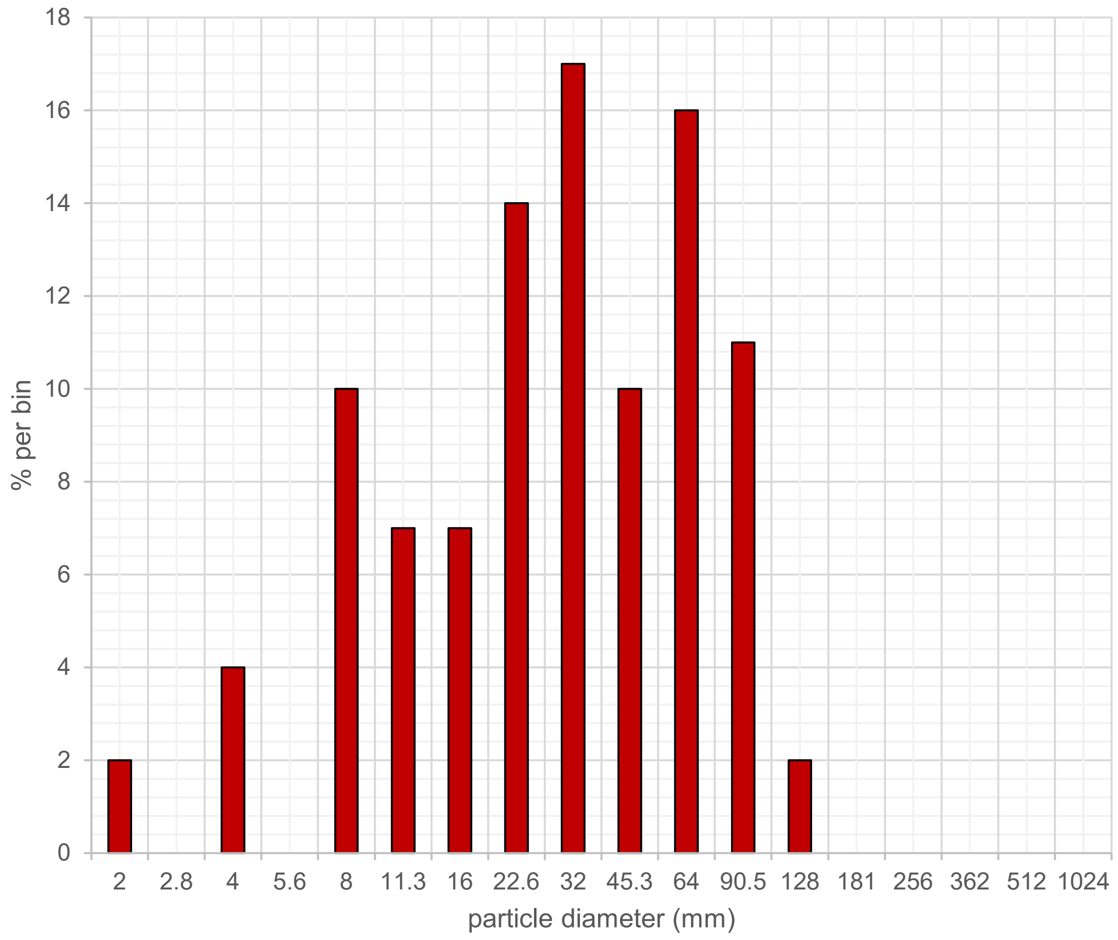
Bunte and Abt 2001



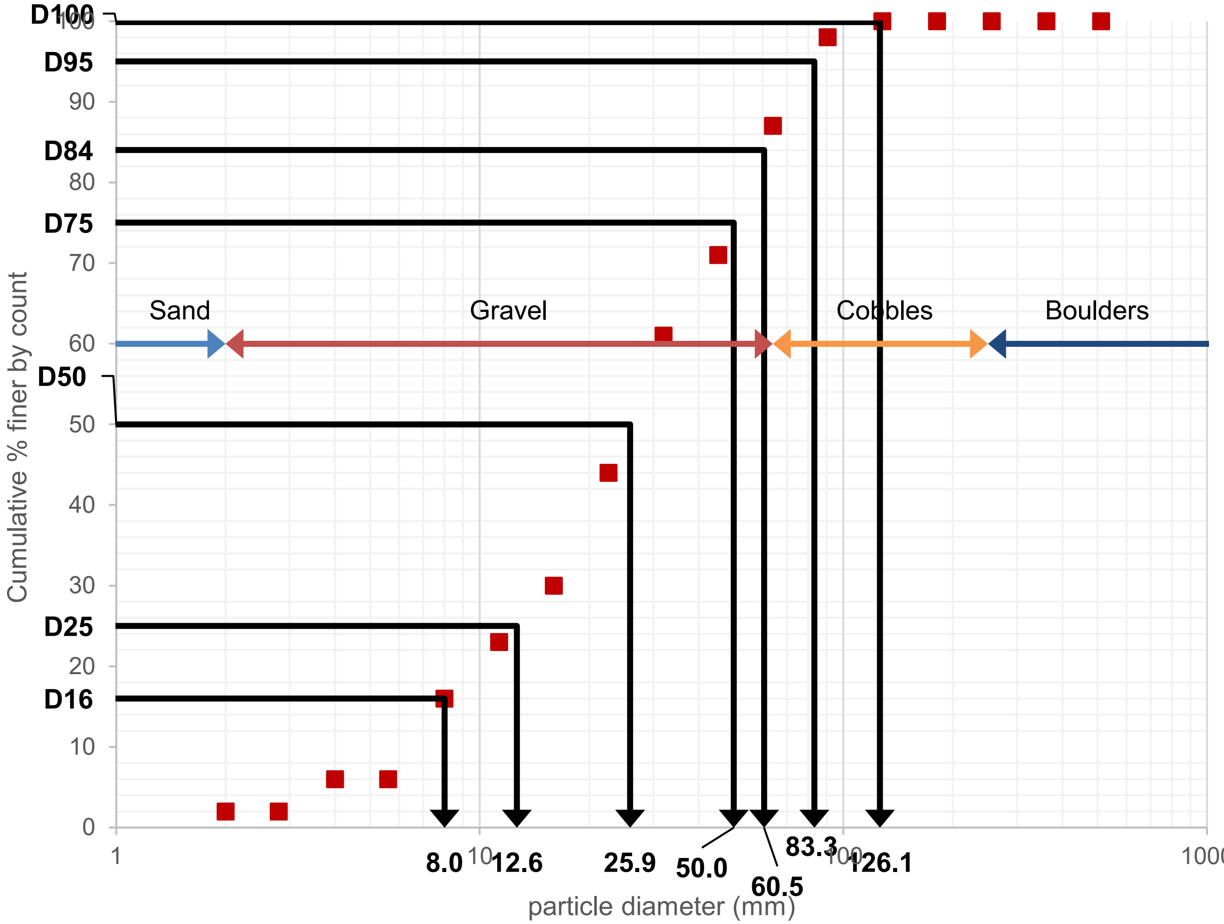
Bunte and Abt 2001

Grain Size Distributions

Probability Distribution Function (PDF)



Cumulatively Distribution Function (CDF)



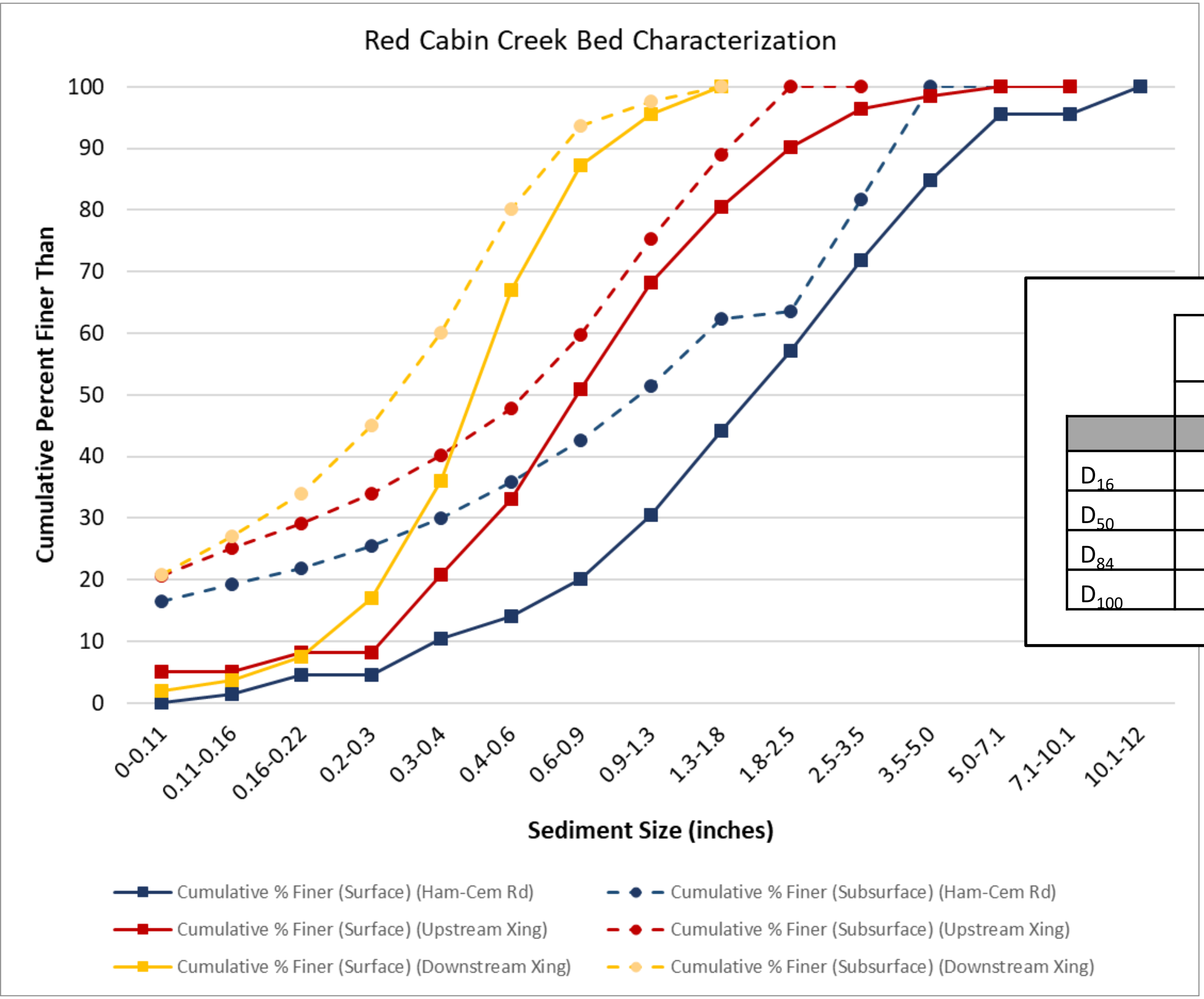
Sub-Surface Bed Material Sampling:
Grain Size Distribution of Clastic Sediment.
Bulk Sampling

- Appropriate method for sampling fluvial clastic sediment in subsurface alluvial deposits.
- Remove surface layer of sediment
  - Thickness of removed layer equal to the D100 of the surface material
- Sample Volume:
  - Note that statistical validity may require impractical sample volumes.

Nominal Maximum Particle Size	Sample Weight
2 in. (50 mm)	45 lbs. (20 kg)
¾ in. (19 mm)	15 lbs. (7 kg)
¼ in. (6.3 mm)	2 ½ lbs. (1 kg)



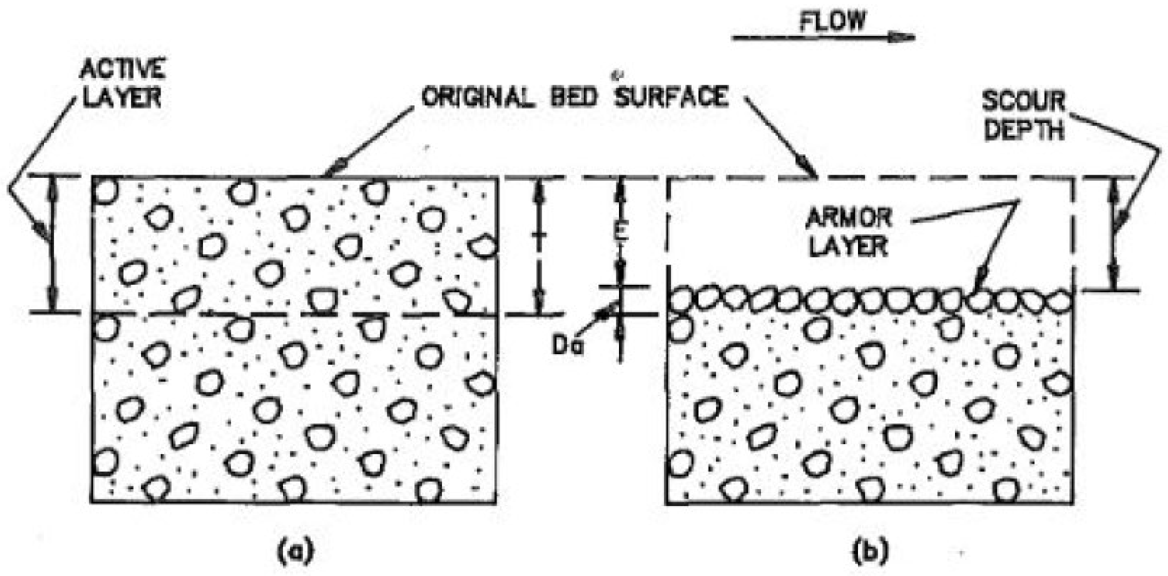

Grain Size Distributions



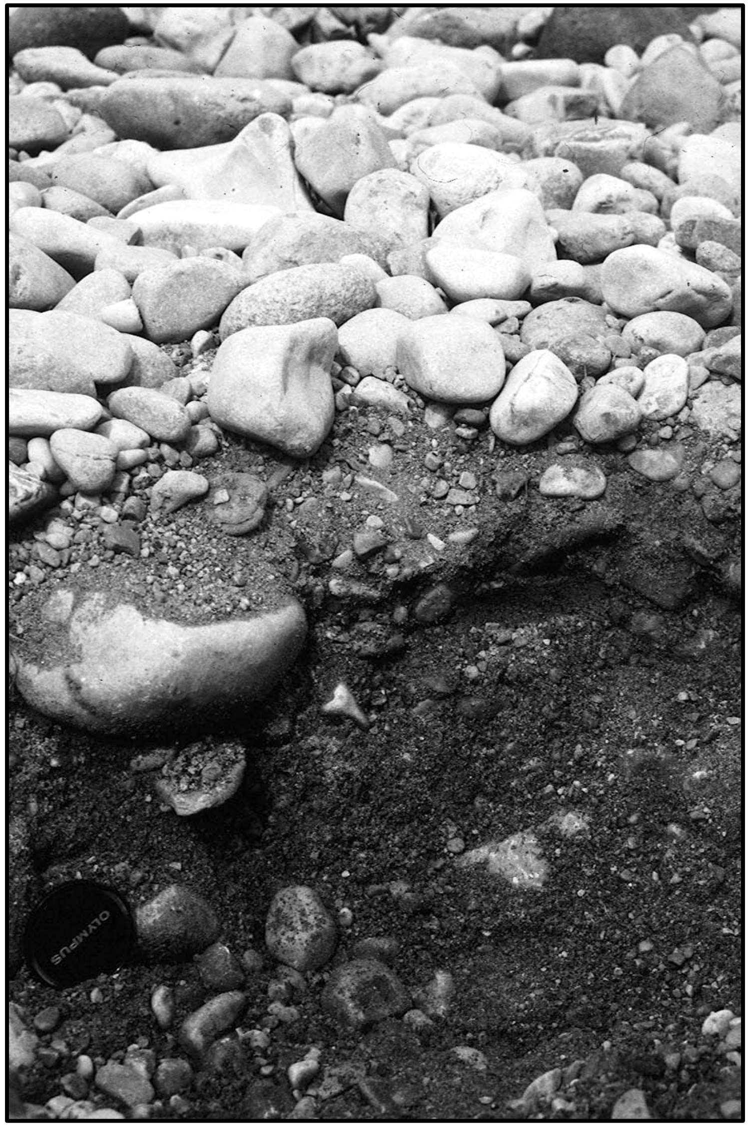
	Downstream of Hamilton Cemetery Rd		Upstream of SR 20		Downstream of SR 20	
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
	in	in	in	in	in	in
D_{16}	0.7	0.1	0.4	0.1	0.3	0.1
D_{50}	2.2	1.1	0.9	0.7	0.5	0.4
D_{84}	5.2	3.8	2.2	1.6	0.9	0.7
D_{100}	12.4	5.2	7.3	2.6	1.8	1.8

Armoring Ratio

$$\text{Armoring Ratio} = \frac{d_{50surface}}{d_{50subsurface}}$$



Borah 1989



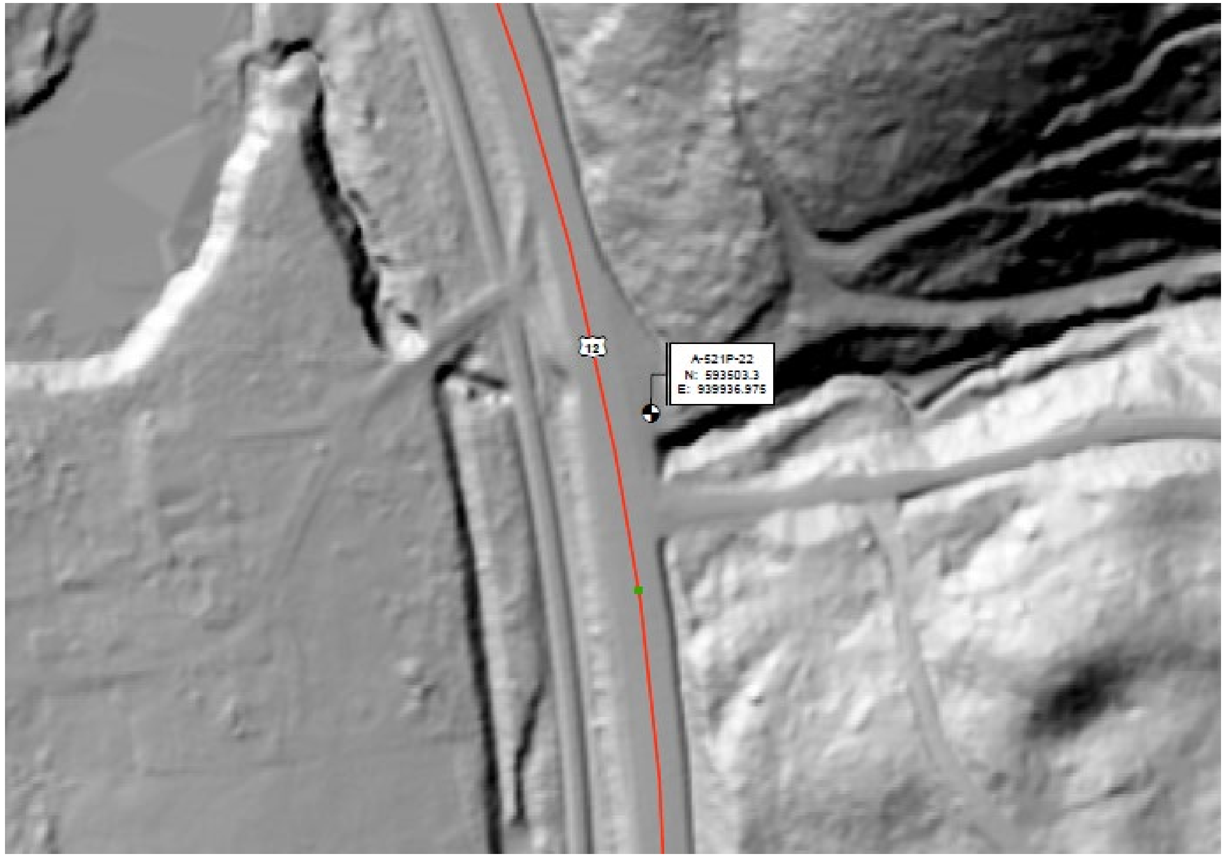
Parker ebook

Legacy Sediment

Snoqualmie River near Carnation, WA.

- An advance glaciolacustrine unit with local till lenses acts as a channel spanning bedrock sill.
- The coarse clasts remain partially embedded and increase the ability of the unit to resist erosion.
- The unit serves as vertical grade control not just for the river, but also for the surrounding landscape.

Geotechnical Borings



Geotechnical borings are typically drilled off to one side of the channel, where the work minimizes impacts to traffic and worker safety.

Geotechnical borings are generally focused on structure foundation design. Borings typically advance through 5 feet of subsurface between each 18" SPT sample.

Geotechnical Sampling Methods

Standard Penetration Test
(SPT) [video]

Shelby
"Undisturbed"
Sampler

Triple-tube
Core Barrel

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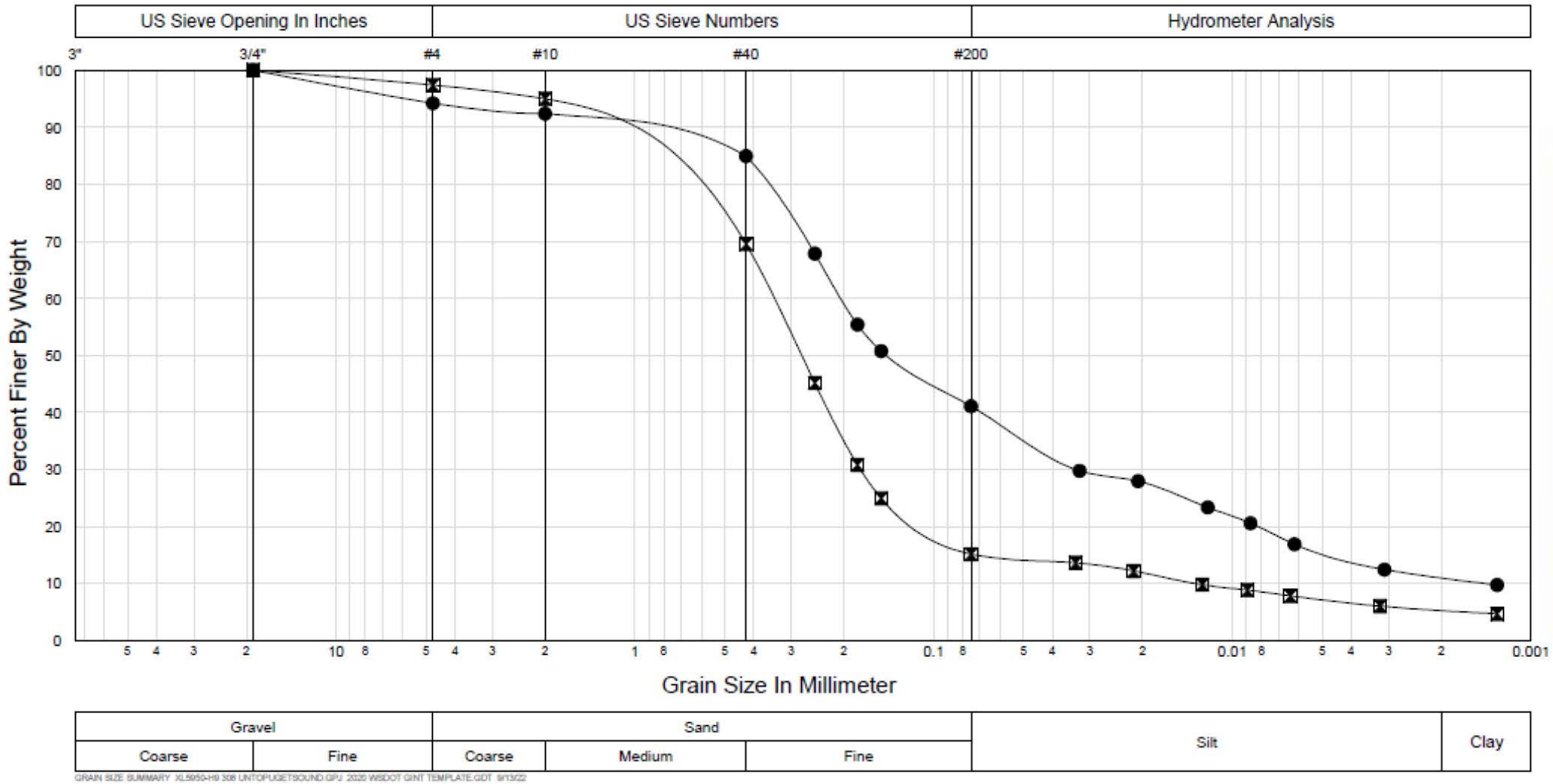
GRAIN SIZE ANALYSIS SUMMARY FOR A-563P-22

Job No: **XL5950**
Project: **Advanced Geotechnical Scoping For Fish Passage: SR 303/Unnamed to Hoot Creek (930408)**

Symbol	Depth (feet)	Sample No.	USCS	Description	Test Date	MC (%)	LL	PL	PI	Moist Density (lbs/ft^3)	Specific Gravity	Gravel (%)	Sand (%)	Fines (%)	C_c	C_u	D_{90} (mm)	D_{60} (mm)	D_{50} (mm)	D_{30} (mm)	D_{20} (mm)	D_{10} (mm)
●	16.0	D-6	SC-SM	SILTY, CLAYEY SAND	9-13-22	23	20	14	6		2.74	5.8	53.2	41.1	3.8	142	1.217	0.203	0.142	0.033	0.008	0.001
⊠	24.0	D-8	SM	SILTY SAND	9-13-22	20	n/a	n/a	NP		2.68	2.6	82.3	15.1	6.7	26	1.477	0.345	0.278	0.176	0.106	0.013



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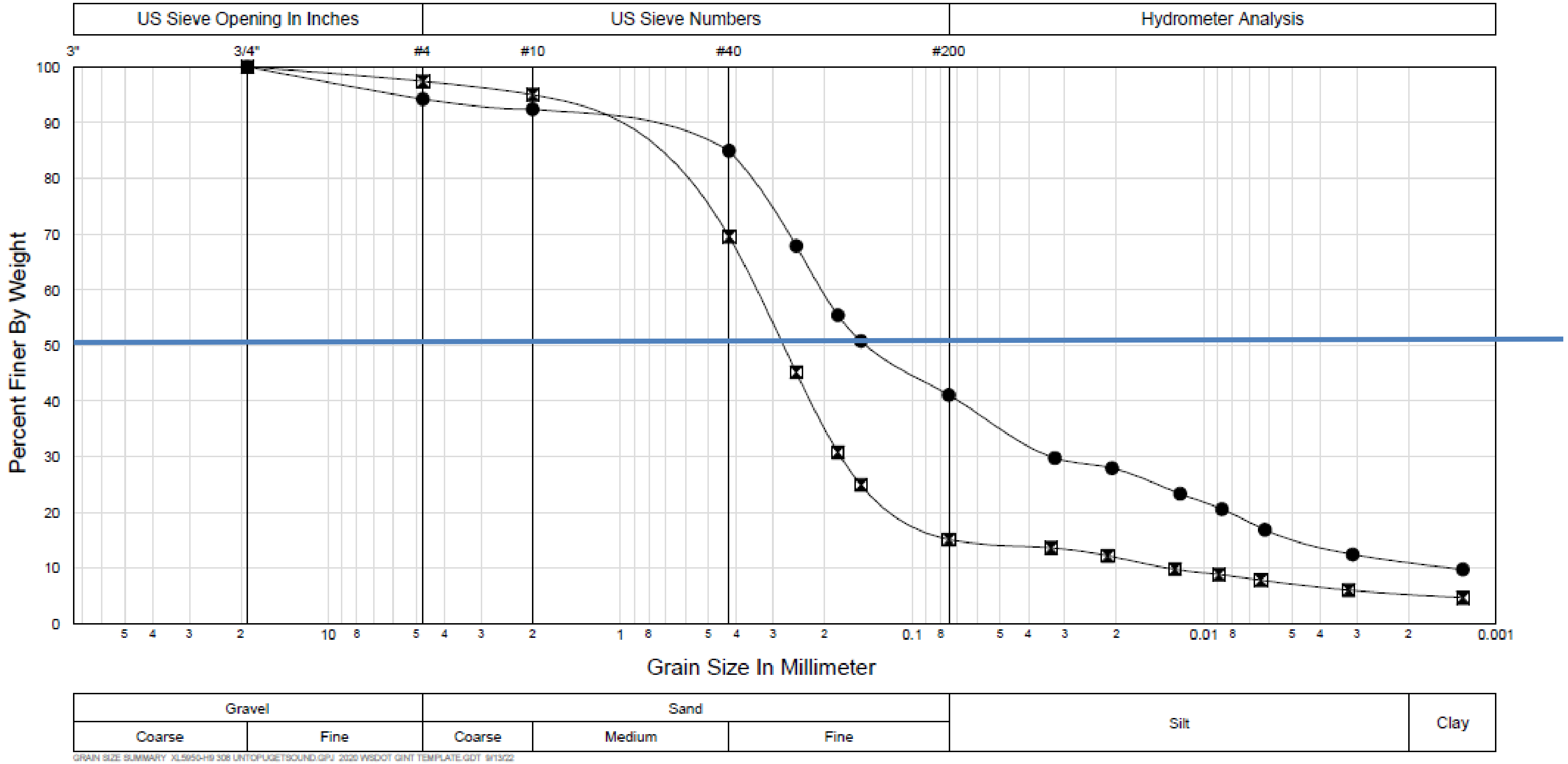

50% passing

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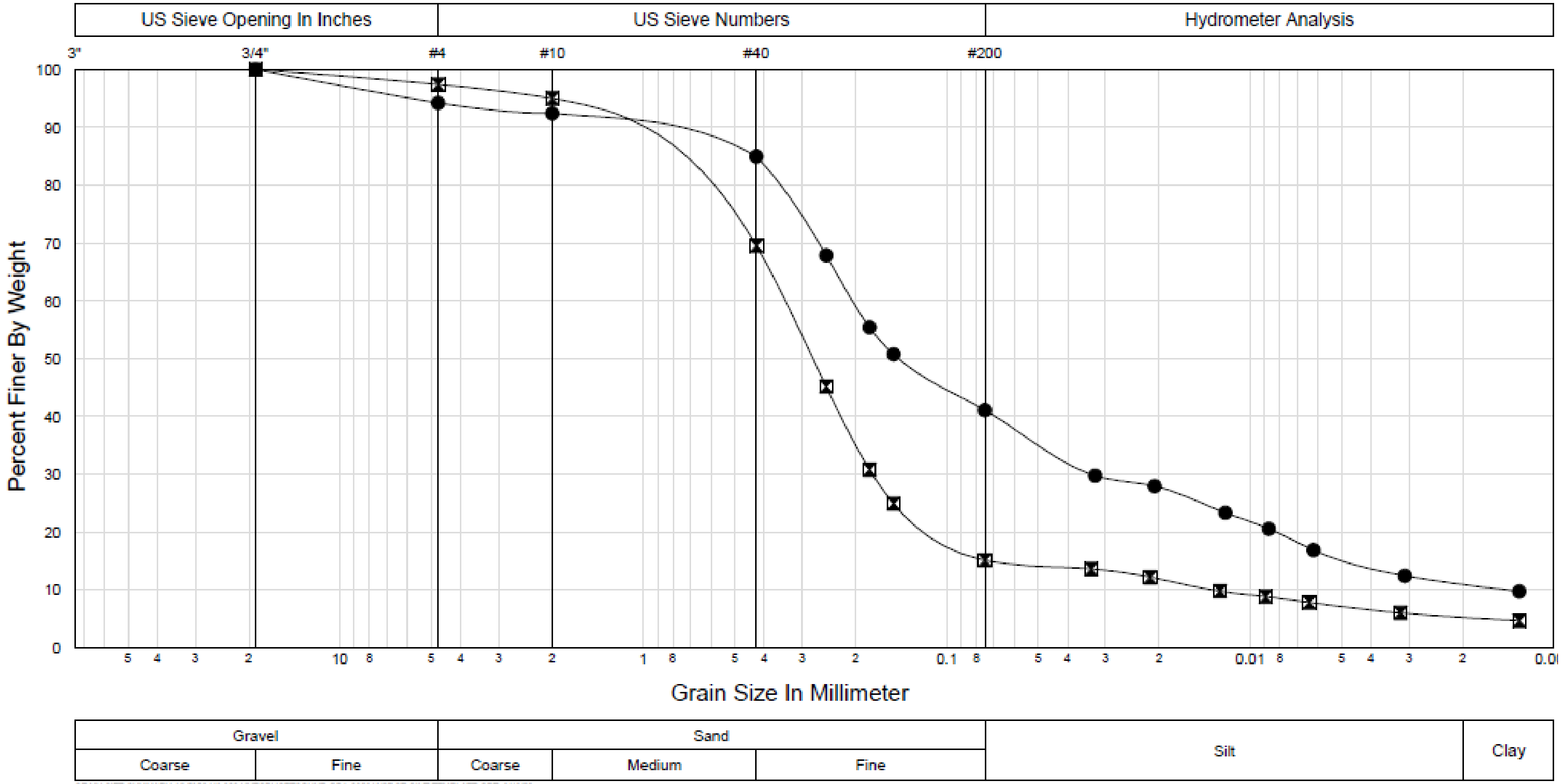
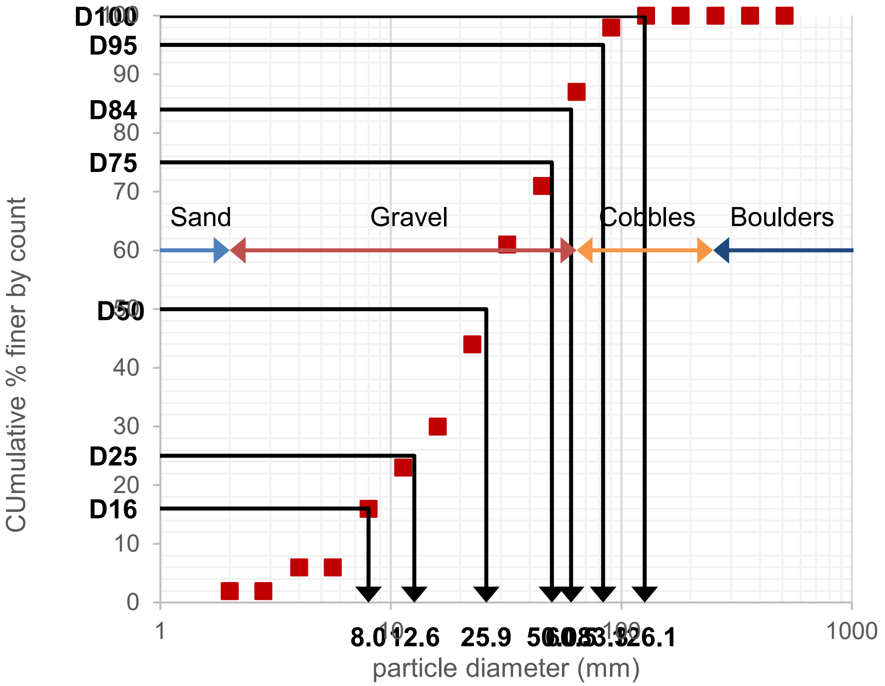
Symbol	Depth (feet)	Sample No.	USCS	Description	Test Date	MC (%)	LL	PL	PI	Moist Density (lbs/ft³)	Specific Gravity	Gravel (%)	Sand (%)	Fines (%)	C_c	C_u	D_{90} (mm)	D_{60} (mm)	D_{50} (mm)	D_{30} (mm)	D_{20} (mm)	D_{10} (mm)
●	16.0	D-6	SC-SM	SILTY, CLAYEY SAND	9-13-22	23	20	14	6		2.74	5.8	53.2	41.1	3.8	142	1.217	0.203	0.142	0.033	0.008	0.001
⊠	24.0	D-8	SM	SILTY SAND	9-13-22	20	n/a	n/a	NP		2.68	2.6	82.3	15.1	6.7	26	1.477	0.345	0.278	0.176	0.106	0.013



GRAIN SIZE SUMMARY XL5950-H9 308 UNTOPUGETSOUND.GPJ 2020 WSDOT GINT TEMPLATE.GDT 9/13/22



Modified Slake Durability Index

Keaton and Mishra 2010

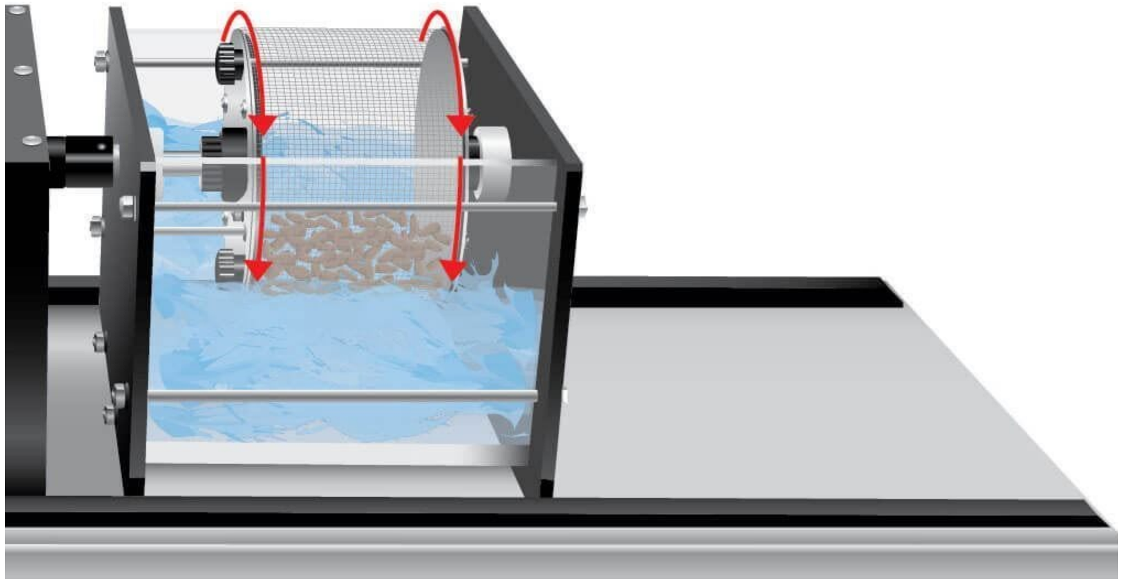
ASTM D4644-08

SAMPLE/TEST INFORMATION

Hole No.	HT-2-20	**Slake Durability Index:**	91.7 %
Sample No.:	C-28	**Water Temperature Avg.:**	19.9 C°
Sample Type:	CORE (ROCK)	**Water Temperature Range:**	19.8 - 20.1 C°
Sample Depth:	111 to 111.5 feet	**Natural Water Content:**	16.5 %
Test Date:	2/3/2021	**Ret. Fragment Appearance:**	Type 2
Classification:	SILTSTONE		

TEST DEFINITIONS (ASTM D4644)

Type	Appearance of Retained Fragments
1	Virtually unchanged
2	Consists of large and small fragments
3	Consists exclusively of small fragments

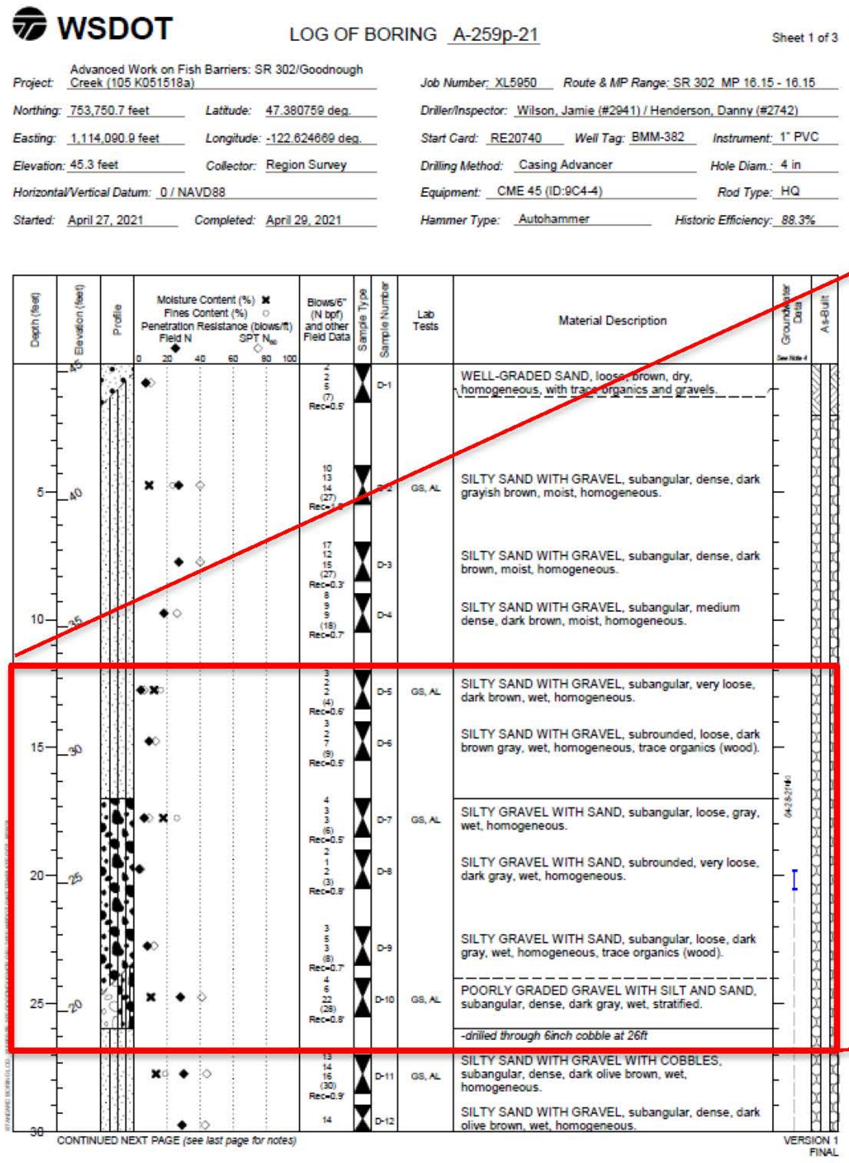


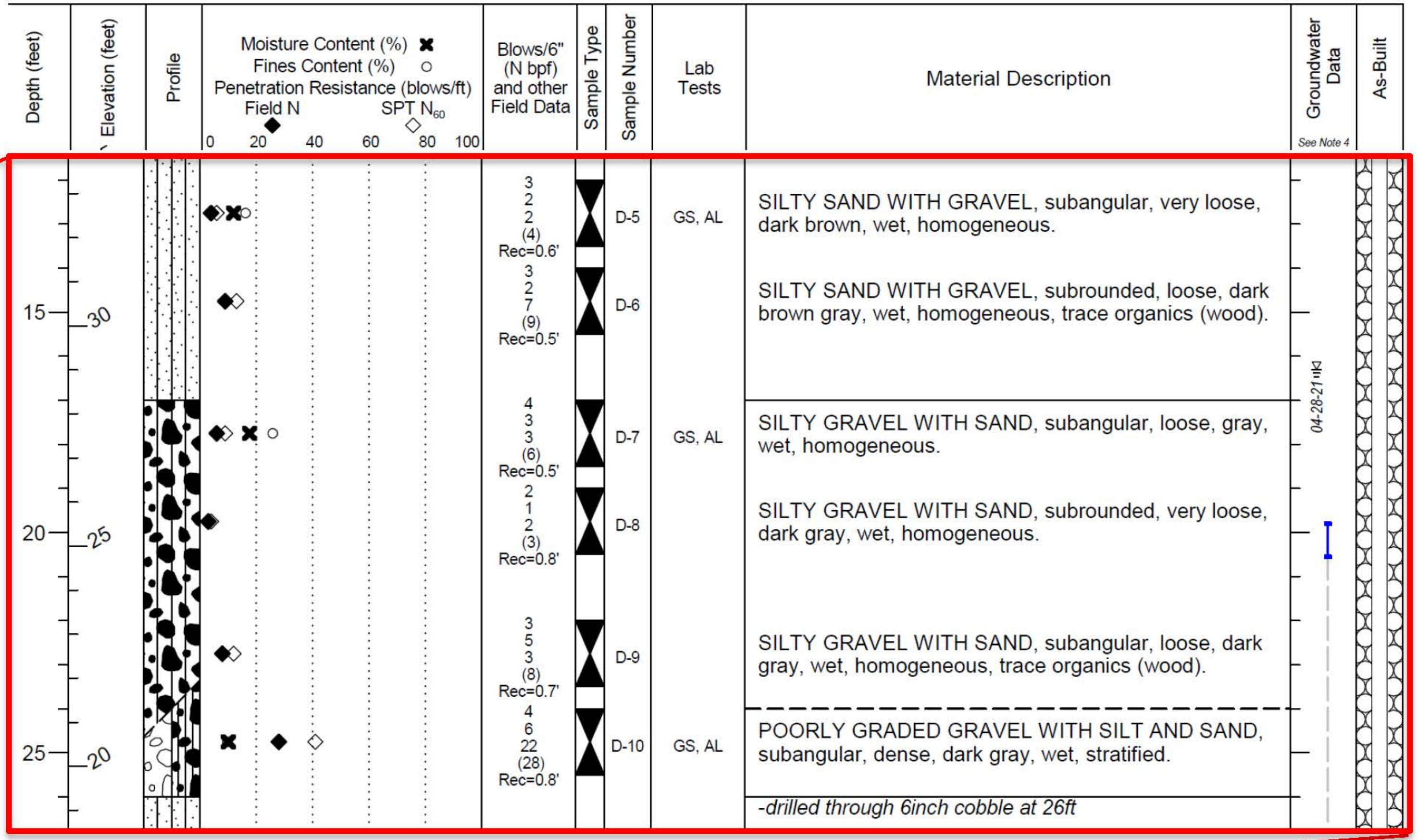
BEFORE PHOTO

AFTER PHOTO

Geotechnical Properties

Boring logs





Angle of Repose

Phi = Φ = "Angle of repose"

$N1_{60}$ from SPT (blows/ft)	ϕ (°)
<4	25-30
4	27-32
10	30-35
30	35-40
50	38-43

GDM Chapter 5:
Correlation between $N1_{60}$ and phi for granular soils

Geotechnical Properties

ESUs

Engineering

Stratigraphic

Units

ESU 1 (Fill): ESU 1 represents fill that was placed during construction of SR 16 and SR 302.

ESU 1 at SR 16 is generally characterized as medium dense to very dense silty SAND with gravels and dense to very dense silty GRAVEL with sand. ESU 1 at SR 302 is generally described as loose well graded SAND with trace gravels, very loose to dense silty SAND with gravel, and loose silty GRAVEL with sand.

ESU 1 was observed to be approximately 24 feet thick in test boring A-259p-21, approximately 80 feet thick in test boring A-260p-21, and approximately 65 feet thick in test boring A-261p-21.

ESU 2 (fan deposits): ESU 2 represents fan deposits, which consist of fluvial sediments locally deposited where streams emerge from confining valleys.

ESU 2 is generally characterized as dense silty SAND with gravel and cobbles, dense to very dense silty SAND with gravel, and dense poorly graded GRAVEL with silt and sand.

ESU 2 was observed to be approximately 15 feet thick in test boring A-259p-21 (SR 302). ESU 2 was not encountered in test borings A-260p-21 and A-261p-21 (SR 16).

ESU 3 (Vashon-age advance glacial outwash): ESU 3 represents advance glacial outwash, which are well-graded fluvial sediments that were locally deposited by meltwater streams, and then overridden by ice during the advance of the Vashon glaciation.

ESU 3 is generally characterized as medium dense to very dense silty SAND with gravel and very dense well graded SAND with silt and trace gravel.

ESU 3 was only encountered in test borings A-260p-21 and A-261p-21 (SR 16). ESU 3 was observed to be approximately 10 to 12 feet thick in test boring A-261p-21. In test boring A-260p-21, ESU 3 extends from approximately elevation 124 feet to the maximum depth of exploration at 106 feet.

ESU 4 (advance glaciolacustrine deposit): ESU 4 represents a Vashon-age fine-grained, laminated to massive glaciolacustrine deposit that is correlative with the Lawton Clay. This material was deposited in proglacial and lowland lakes and later overridden and overconsolidated by glacial ice. This material has been known to lose strength when unloaded or exposed in excavations. Additional information on this geotechnically challenging material is available in the Geotechnical Design Manual.

ESU 4 is generally characterized as a very stiff to hard, SILT and LEAN CLAY with sand.

ESU 4 was only encountered in test boring A-261p-21 (SR 16). ESU 4 extends from approximately elevation 133 feet to the maximum depth of exploration at 119 feet.

ESU 5 (pre-Vashon nonglacial deposits): ESU 5 represents pre-Vashon age sediments that includes nonglacial deposits.

ESU 5 is generally characterized as very dense sandy SILT, very dense silty SAND, very dense silty SAND with gravel, very dense silty GRAVEL with sand, and very dense well graded GRAVEL.

ESU 5 was only encountered in test boring A-259p-21 (SR 302). ESU 5 extends from approximately elevation 7 feet to the maximum depth of exploration at -34 feet.

Geotechnical Tools and Resources

WSDOT Geotechnical Design Manual

https://wsdot.wa.gov/engineering-standards/all-manuals-and-standards/manuals/geotechnical-design-manual

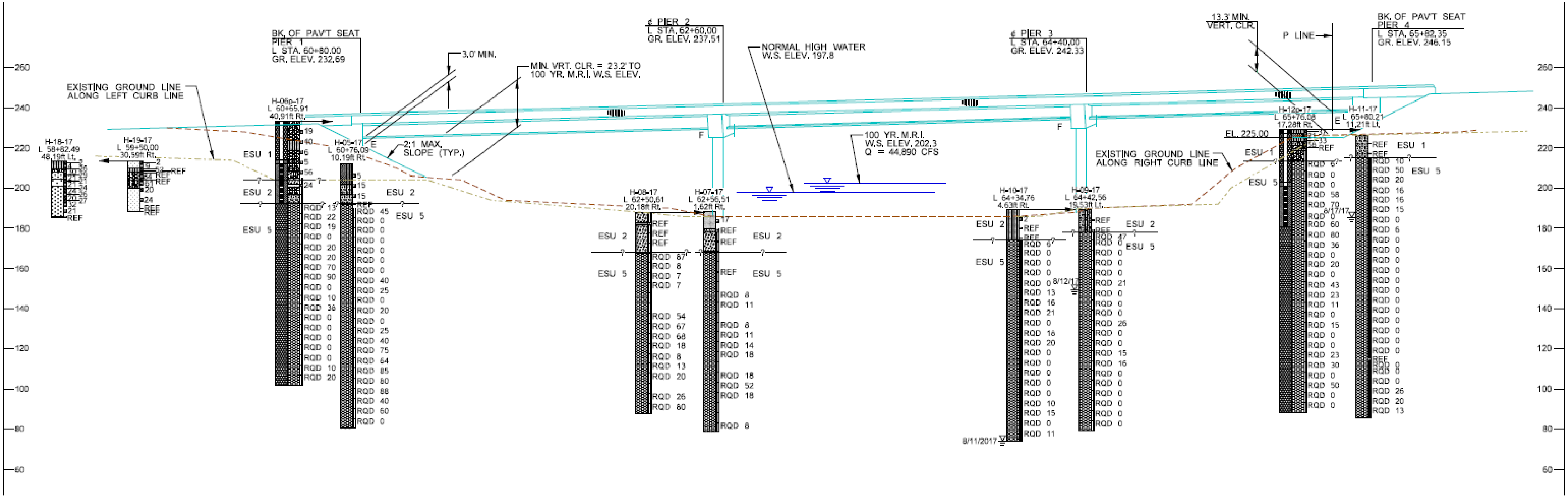
- Chapter 4: Soil and Rock Classification
- Chapter 5: Engineering Properties of Soil and Rock
- Chapter 15: Abutments and Retaining Walls

ISRM Suggested Methods for Rock Mass Characterization

NHI Soils and Foundations Workshop

Sediment Sampling Summary

US 101 / Elwha River Bridge
Subsurface Profile



ESU 1 - Existing Fill: ESU 1 was observed in drilled borings H-6p-17, H-13-17, and H-14p-17, H-15-17, H-16p-17, and H-17p-17 from the current ground surface to a depth of 6 to 47 feet below the ground surface. ESU 1 is characterized primarily as very loose to medium dense well graded gravel with sand, well graded sand with gravel, silty sand with gravel, and silty gravel with sand.

ESU 2 - Delta Deposits: ESU 2 was observed in borings H-5-17, H-7-17, H-8-17, H-9-17, and H-10-17 from the existing ground surface or mudline in the river to a depth of 11 to 22 feet. ESU 2 was also observed in boring H-6p-17 below ESU 1 to a depth of 41 feet below the ground surface. ESU 2 is characterized primarily as very loose to medium dense well graded gravel with sand, poorly graded sand, and silty sand with gravel. Intermittent cobble and boulder sized particles are also present throughout ESU 2.

ESU 5 - Basalt Bedrock: ESU 5 was observed in all borings except H-17p17 below ESU 2, ESU 3, and ESU 4 to the final depth of the borings. ESU 5 is characterized primarily as very weak to moderately strong basalt rock.. Discontinuities are moderately spaced and in fair condition. Discontinuities are generally close to very widely spaced and in poor to good condition.

The end.

Thank you.

Questions?

References: Module 5

WSDOT Resources

- WSDOT Hydraulics Manual:
  - https://wsdot.wa.gov/engineering-standards/all-manuals-and-standards/manuals/hydraulics-manual
- WSDOT Geotechnical Design Manual
  - https://wsdot.wa.gov/engineering-standards/all-manuals-and-standards/manuals/geotechnical-design-manual
- Hydrology and Hydraulics training website:
  - https://wsdot.wa.gov/engineering-standards/project-management-training/training/hydraulics-hydrology-training
- Fish Passage and Stream Restoration Design Training Slides:
  - Module 8: Geomorphic Assessment for Stream Crossings by Cygnia Rapp
    - https://wsdot.wa.gov/publications/fulltext/Hydraulics/hhtraining/FishPassageTraining/8-Geomorphic-Assessment-of-Stream-Crossings.pdf
  - Module 9: Site and Reach Assessments and Reference Reaches by Garrett Jackson and Cygnia Rapp
    - https://wsdot.wa.gov/publications/fulltext/Hydraulics/hhtraining/FishPassageTraining/9-Site-and-Reach-Assessments.pdf

Other Resources

- HEC 18: https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=17&id=151
- HEC 20: https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif12004.pdf
- HEC 23
  - Volume 1: https://www.fhwa.dot.gov/engineering/hydraulics/pubs/09111/09111.pdf
  - Volume 2: https://www.fhwa.dot.gov/engineering/hydraulics/pubs/09111/09112.pdf
- HDS 6: https://www.fhwa.dot.gov/engineering/hydraulics/pubs/nhi01004.pdf
- Bunte and Abt 2001
  - Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring. USDA Forest Service Rocky Mountain Research Station General Technical Report RMRS-GTR-74 May 2001
  - https://www.fs.usda.gov/research/treesearch/4580
- California Water Boards: THE CLEAN WATER TEAM
  - https://www.waterboards.ca.gov/water_issues/programs/swamp/docs/cwt/guidance/522c.pdf
- Parker ebook:
  - Spreadsheet: http://hydrolab.illinois.edu/people/parkerg/excel_files.htm
  - Presentation: http://hydrolab.illinois.edu/people/parkerg/powerpoint_lectures.htm
- FHWA: Standard Method of Test for Determining Riprap Gradation by Wolman Count
  - https://highways.dot.gov/sites/fhwa.dot.gov/files/docs/federal-lands/materials/field-materials-manual/12936/flh-t-521.pdf
- Church, Micahel A., D. G. McLean, and J. F. Wolcott. "River bed gravels: Sampling and analysis, Sediment Transport in Gravel-Bed Rivers CR Thorne, JC Bathurst, RD Hey, 43–88." (1987).Wolcott and Church 1991
- ASTM Slake Durability D 4644 – 04 Standard Test Method for Slake Durability of Shales and Similar Weak Rocks
- Keaton, Jeffrey R., and Su K. Mishra. "Modified slake durability test for erodible rock material." In *Scour and Erosion*, pp. 743-748. 2010.
- ISRM Suggested Methods for Rock Mass Characterization
- NHI Soils and Foundations Workshop