ERFARINGER FRA UDLANDET MED KVALITETS- OG PERFORMANCEKONTROL, MÅLEMETODER OG LANGTIDSMONITERING

engineers | scientists | innovators

Vintermøde 2019, Temadag om Soil Mixing som afværgemetode

Per Lindh, Ph.D.
Trafikverket
per.lindh@trafikverket.se

Christopher A. Robb, P.E. (WI and FL)
Principal Engineer
Geosyntec Consultants, Inc.
crobb@Geosyntec.com

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Quality and Performance Control

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- **An effective quality program is critical to the success of an ISS or ISS/IST project**
  - Benefits from personnel experienced with specific ISS/IST quality and performance control

- **Goal: Rapidly Assess ISS/IST Performance and Identify Potential Construction Issues**

Quality Control – Quality Assurance

- A well planned quality program has two elements:
  - **Contractor QC program:** Provides the construction procedures and material handling requirements that ensure the design requirements for the treatment are met
  - **Owner QA program**: Provides for monitoring, sampling, and testing procedures to verify that the treatment meets the design requirements

- Key elements of an effective QC/QA program
  - Contractor QC Procedures
  - Contractor QC documentation
  - Construction Quality Assurance (CQA) Procedures
  - CQA Sampling

Contractor QC Procedures

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WHY IS CONTRACTOR QC IMPORTANT?

- **CONTRACTOR VERIFIES CONSTRUCTION IN ACCORDANCE WITH DESIGN REQUIREMENTS**

- Contractors Typically Provide:
  - Layout for ISS Treatment Areas and Columns
  - Equipment for ISS CQA Sampling
  - Survey Control for ISS Column Locations and Record Documentation
  - Field Engineer's Notes
  - Daily Deliverables:
    - Batch Plant QC and Mix Verification Logs
    - Delivery Receipts for ISS and Materials
    - Drill Rig QC Report
    - ISS Column Logs

- Batch plant operational parameters

- Mix equipment operational parameters
  - mixing time
  - mixing speed
  - auger diameter
  - column depth
  - column location
  - number of passes
  - grout flow rate
  - rotary head pressure
  - quantity of grout (i.e., Reagents, Additives and water

Quality Control Tools

- QC Equipment calibration
- Scale calibration
- Mud balance
- Flow meter
- GPS / total station

Layout for ISS/IST Treatment Areas and Columns

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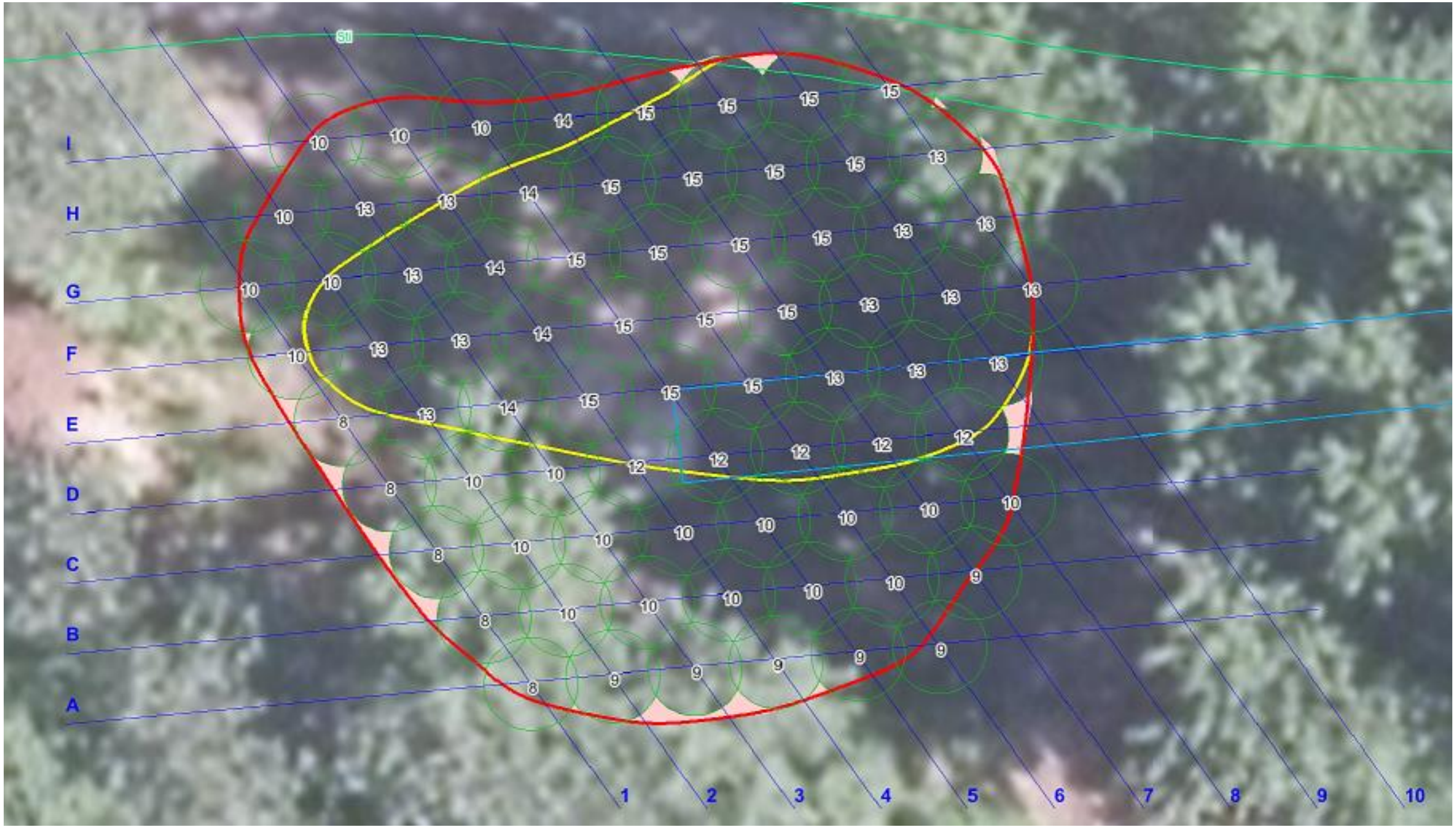

Drill Rig -Electronic Data Acquisition

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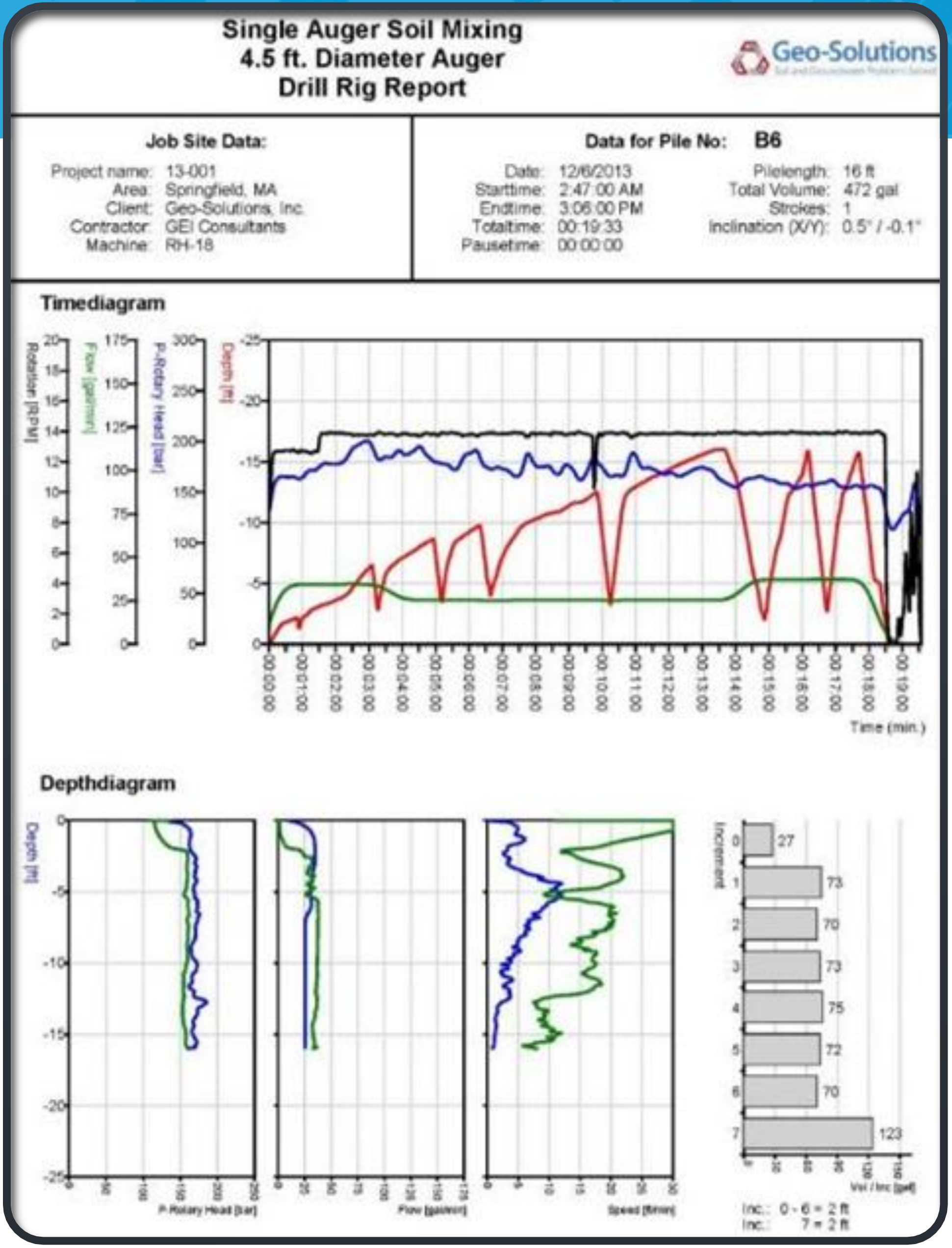
- **<u>ELECTRONIC REPORTING:</u>**
  - TIME
  - DATE
  - COLUMN IDENTIFICATION
  - GROUT FLOW RATE
  - TOTAL GROUT INJECTION
  - PENETRATION DEPTH
  - INCLINATION (DEGREE)
  - ROTATIONS PER MINUTE (RPM)
  - PENETRATION RATE/ WITHDRAWAL SPEED/ (# OF STROKES)
  - ROTARY HEAD PRESSURE (DRILLING RESISTANCE)



- DEPTH
- Grout Flow
- Rotary Pressure

- Down stroke
- Up stroke

Drill Rig QC Report

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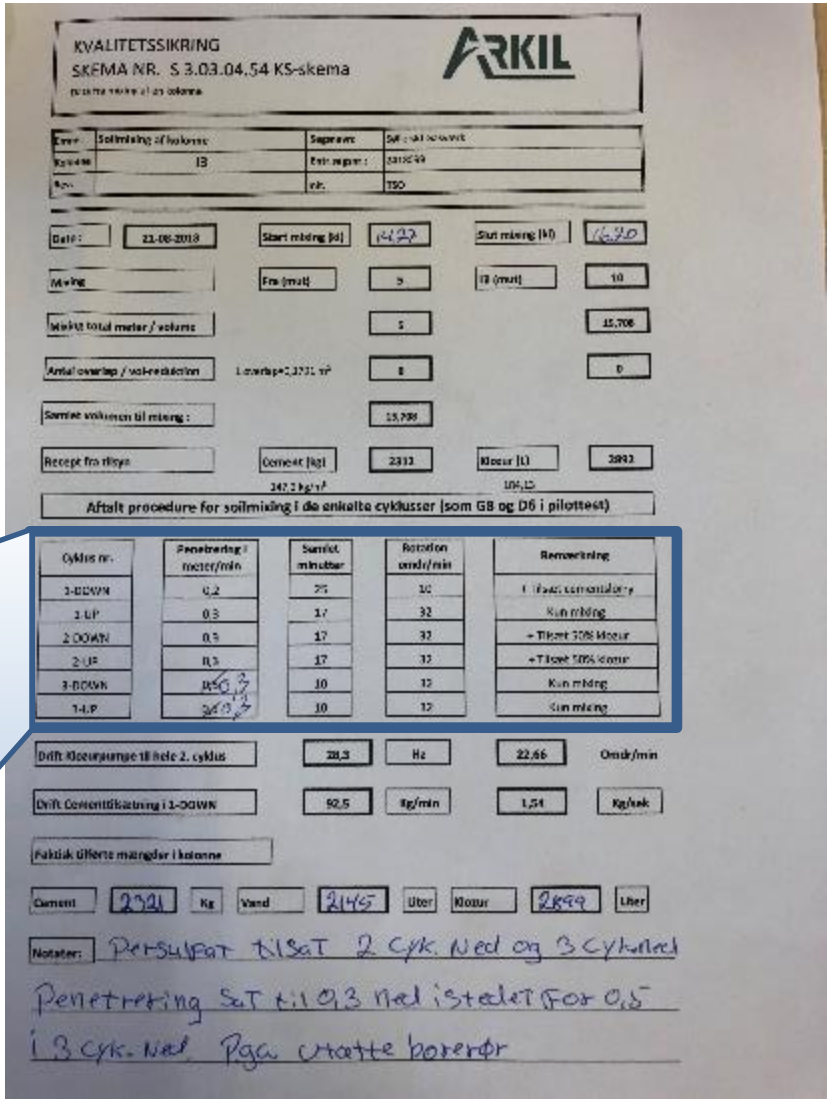
- Mix equipment operational parameters:
  - mixing time
  - mixing speed
  - auger diameter
  - column depth
  - column location
  - number of passes
  - grout flow rate
  - rotary head pressure
  - quantity of grout (i.e., reagents, additives, water)



KVALITETSSIKRING
SKEMA NR. S 3.03.04.54 KS-skema

ARKIL

Emne: Soilmixing af kolonne		Sagsnavn:	
Kolonne	13	Entr. nummer:	
		Init.	TSO

Date: 21-08-2018 | Start mixing (kl) 14:27 | Slut mixing (kl) 16:20

Mixing | Fra (mut) 5 | Til (mut) 10

Mixing total meter / volume | 5 | 15,708

Antal overlap / vol-reduktion | 8 | 0

Samlet volumen til mixing: 15,708

Recept fra rilsyn | Cement (kg) 2313 | Klozur (L) 2892

147,3 kg/m³ | 184,15

Aftalt procedure for soilmixing i de enkelte cyklusser (som G8 og D6 i pilottest)

Cyklus nr.	Penetrering i meter/min	Samlet minutter	Rotation omdr/min	Bemærkning
1-DOWN	0,2	25	10	+ Tilsæt cementslorry
1-UP	0,3	17	32	Kun mixing
2-DOWN	0,3	17	32	+ Tilsæt 50% klozur
2-UP	0,3	17	32	+ Tilsæt 50% klozur
3-DOWN	~~0,5~~ 0,3	10	32	Kun mixing
3-UP	~~0,5~~ 0,3	10	32	Kun mixing

Drift Klozurpumpe til hele 2. cyklus | 28,3 | Hz | 22,66 | Omdr/min

Drift Cementtilsætning i 1-DOWN | 92,5 | Kg/min | 1,54 | Kg/sek

Faktisk tilførte mængder i kolonne

Cement 2321 Kg | Vand 2145 Liter | Klozur 2899 Liter

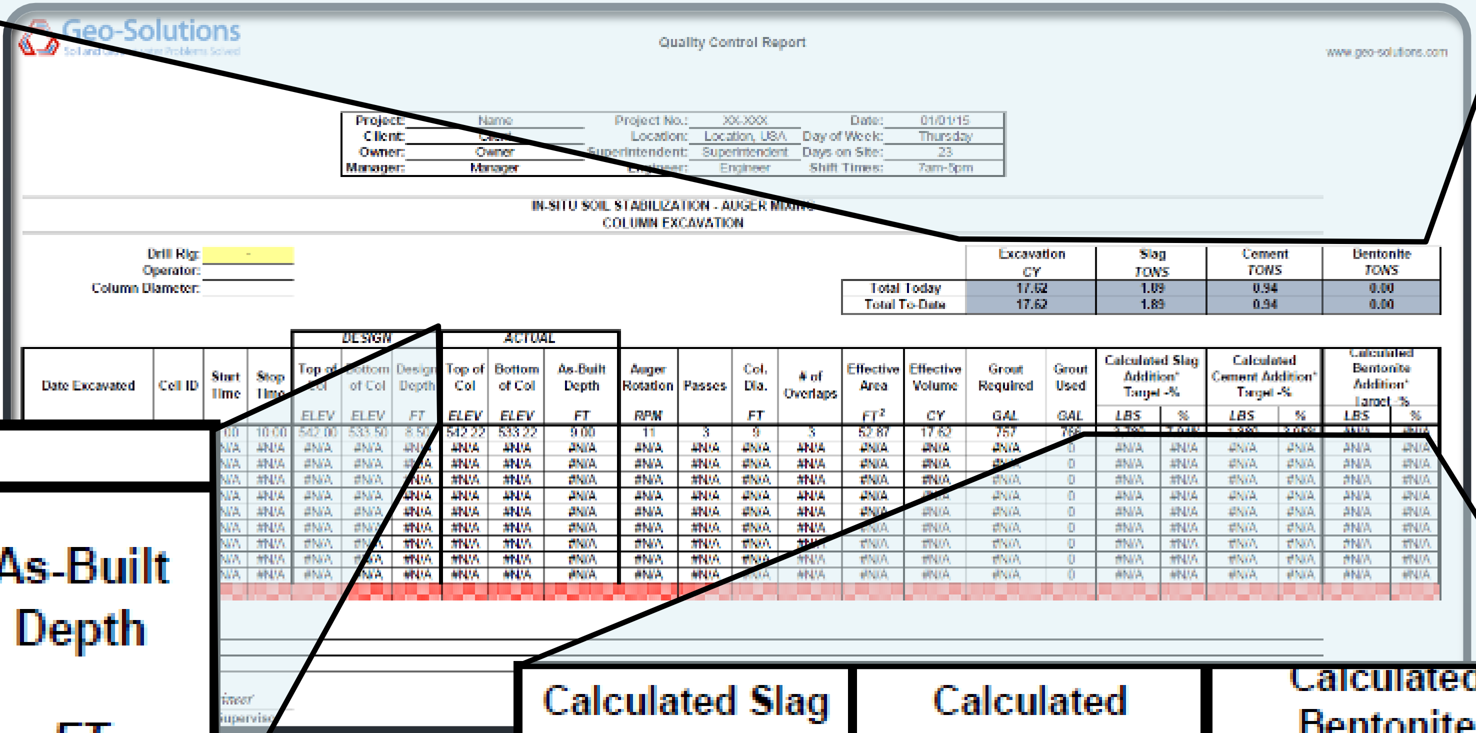
Notater: Persulfat tilsat 2 cyk. Ned og 3 cyk. ned
Penetrering sat til 0,3 ned istedet for 0,5
i 3 cyk. Ned Pga. støtte borerør

Cyklus nr.	Penetrering i meter/min	Samlet minutter	Rotation omdr/min	Bemærkning
1-DOWN	0,2	25	10	+ Tilsæt cementslorry
1-UP	0,3	17	32	Kun mixing
2-DOWN	0,3	17	32	+ Tilsæt 50% klozur
2-UP	0,3	17	32	+ Tilsæt 50% klozur
3-DOWN	~~0,5~~ 0,3	10	32	Kun mixing
3-UP	~~0,5~~ 0,3	10	32	Kun mixing

Production Report

	Excavation CY	Slag TONS	Cement TONS	Bentonite TONS
Total Today	17.62	1.89	0.94	0.00
Total To-Date	17.62	1.89	0.94	0.00

- Confirm design parameters
  - Cumulative reporting
  - Confirm reagents
  - Confirm depths



ACTUAL		
Top of Col	Bottom of Col	As-Built Depth
ELEV	ELEV	FT
542.22	533.22	9.00

Calculated Slag Addition* Target -%		Calculated Cement Addition* Target -%		Calculated Bentonite Addition* Target -%	
LBS	%	LBS	%	LBS	%
3,780	7.94%	1,880	3.95%	#N/A	#N/A

Construction quality assurance (CQA)

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WHY IS CQA IMPORTANT?

- **OWNER VERIFIES CONSTRUCTED IN ACCORDANCE WITH DESIGN REQUIREMENTS**
- **Goal: Rapidly Assess ISS Performance and Identify Potential Construction Issues**

- Owner CQA Includes:
  - Collection of ISS CQA Samples to Verify Treatment (e.g., Field Parameters, UCS and K)
  - Daily Reviews:
    - Batch Plant Logs, Production Logs and ISS Column Logs
    - Visual Assessment of ISS Mixing
  - Review Survey Control
  - Review Field Engineer's Notes as Needed

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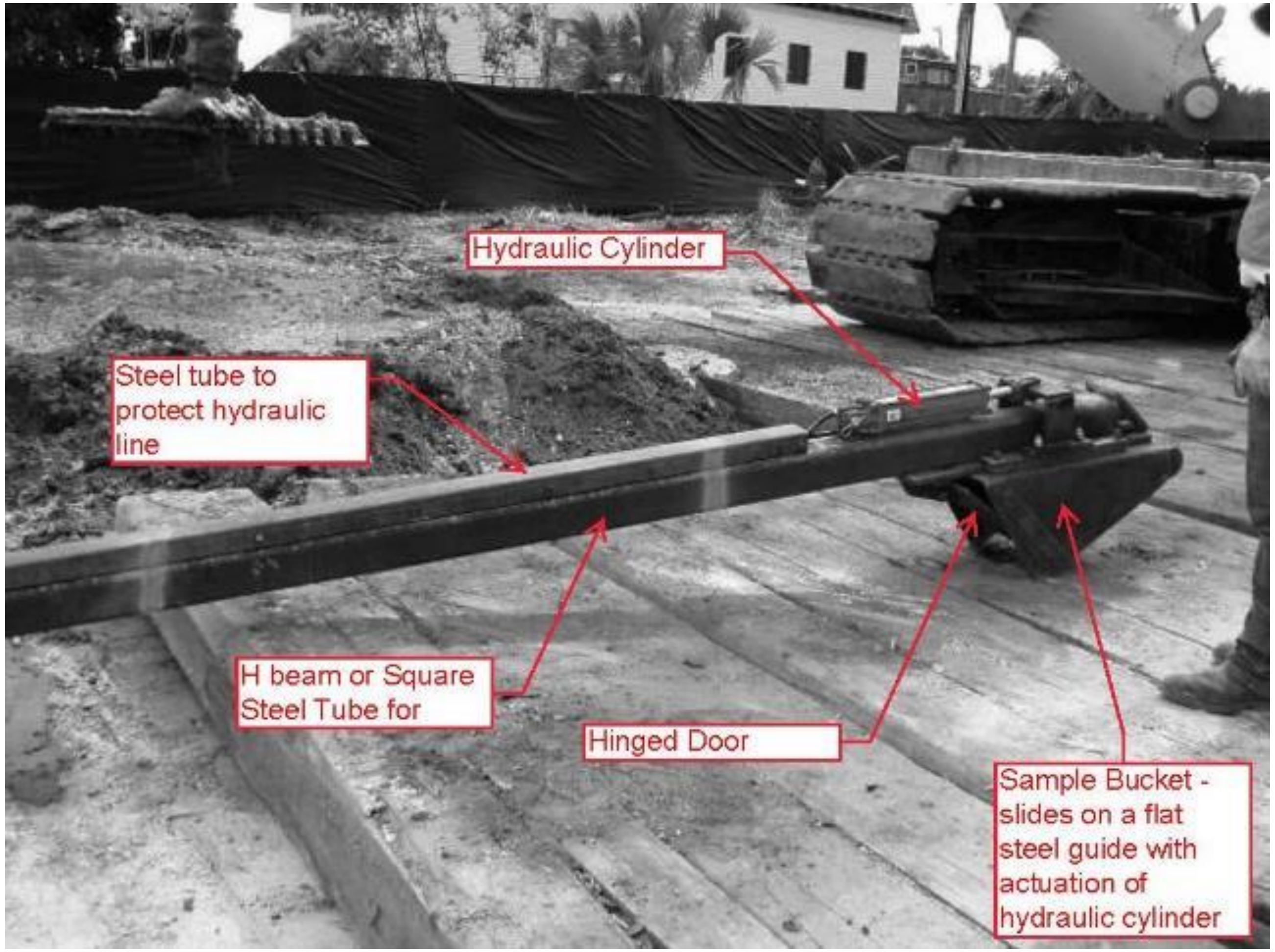
Equipment for Wet Grab Sampling

Hydraulic Sampler



Source: Modified from Robb, C. “Evaluation of *In Situ* Stabilization/Solidification Discrete Zone Applications for Subsurface Soils” June 2010

“Trap Door” Sampler

CQA SAMPLE PROCESSING

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- Verification of homogenous mixing
- Field measurement parameters: moisture content, pH, temperature
- Field Observations: unmixed clods, color/ consistency, free phase NAPL
- Screening and molding CQA samples
- Curing samples

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CQA Sample and Test Frequency

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- Performance criteria based on bench and pilot scale results
  - UCS, Hydraulic Conductivity, Durability (if necessary)
  - *Leaching performance correlated with physical performance at the bench scale level*
- High testing frequency for UCS, hydraulic conductivity
  - One sample every 500 – 1,000 m^3, higher frequency for smaller projects
  - One sample/day minimum
- Low testing frequency for durability
  - One sample every 5,000 m^3
- Additional testing around sensitive structures/areas

Treatment Performance Criteria

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- Unconfined Compressive Strength (UCS) [ASTM D1633 or D2166]:
  - 50 psi [0.345 MPa] (common in USA)
  - Can design to increase/decrease UCS
- Hydraulic Conductivity (K) [ASTM D5084]:
  - < 1 x 10^{-6} cm/s to 1 x 10^{-7} cm/s
  - 1 to 2 orders of magnitude less than native material K is desired
- Leaching [SW-846 LEAF Method 1315]:
  - Determine interval flux; cumulative release to estimate mass transfer – What are your COCs / Receptors?
- Durability [ASTM D4843 and ASTM C1262]:
  - Wet/Dry – Freeze/Thaw < 10% to 15% degradation after 12 cycles
  - May not be necessary
- Contaminant Destruction

Source: *Development of Performance Specifications for Solidification/Stabilization*, Interstate Technology & Regulatory Council (ITRC), July 2011.

Additional CQA considerations

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- Environmental monitoring
  - Turbidity and pH monitoring
  - Air Monitoring

- Structural monitoring
  - Deflection
  - Settlement
  - Deformation

- Alternatives for in situ CQA sampling:
  - Coring
  - Useful for uniformity
  - Need high core recovery w/ low disturbance for strength
  - 2-3 week cure before sampling
  - Coarse soils may prevent acceptable core recovery
  - Not suitable for permeability
  - Expensive – Time Consuming
- In situ direct testing (e.g., CPT, Vane Shear)
- Geophysical Testing (e.g., PS logging)

Considerations for Long Term Monitoring

- Establish Conceptual Site Model (CSM)
- **Objective**: estimate the possible impact to an underlying aquifer of various ISS/IST remediation strategies, typically in terms of possible impacts on groundwater conditions immediately around a source zone and at some distance downgradient of the impacted area where one or more receptors may exist (i.e., Point of Compliance – POC)

Considerations for CSM - ISS/IST

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S/S evaluation factor	Analyses/observations	Significance to technology performance and monitoring
Soil classification/ physical characteristics	Useful measurements: • Gradation • Unified Soil Classification System (USCS) classification • Atterberg limits • Moisture content • Debris content • Porosity • Density • Suspended solids • Free liquid (paint filter)	Property values for each measurement and their variability may have significant impact of overall behavior of the S/S material and on expected outcomes
Soil and groundwater	pH	Controlling variable for inorganic solubility and S/S material durability
Geochemistry	Organic content	Key variable for organic concentrations due to complexation with DOC, which is soluble at high pH (Roskam and Comans 2003, 2007)
	Contaminant levels	High concentrations of some contaminants may affect S/S cure, requiring additives to overcome interference (Conner 1997)
	Sulfate content	Sulfate attack of portland cement blends may lead to aggressive degradation through delayed ettringite formation (Little, Herbert, and Kungalli 2005)
Contaminant characterization	Leaching behavior of untreated material	Defines baseline against which treatability studies and full-scale application may be compared
	Class(es) of contaminants	Defines list of COCs, defines detection limits for analysis
	Presence/distribution of NAPLs	Defines phases/location of source and expected outcomes
Hydrogeology	Hydraulic conductivity	Controlling value in comparison to hydraulic conductivity of S/S material for mode of water contact (e.g., infiltration vs. flow-around)
	Water table depth and seasonal variability	Defines division between vadose zone, capillary fringe, and saturated zone; NAPL impacts at water table
	Geologic strata (including geometry of geology units)	Location of contaminant distribution/accumulation zones
	Groundwater flow direction and gradients	Hydraulic head on S/S mass, evaluate fate and transport with respect to POC

Source: *Development of Performance Specifications for Solidification/Stabilization*, Interstate Technology & Regulatory Council (ITRC), July 2011

Prediction Methods

Prediction Methods – Simple to Complex

Simple → Complex

- Comparison to published standards
- Soil partitioning/attenuation equations
- Numerical Models (e.g., mass flux approximation)
- Groundwater models

Soil Attenuation Equations

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- **Steady state attenuation along the centerline of a groundwater plume**
- $C_{(x)}$ = Concentration of Contaminant in Groundwater at Distance X from the source (mg/L)
- C_{source} = greatest potential concentration of the contaminant of concern in the groundwater at the source of the contamination (leaching from ISS/IST)

Equation R26 – 35 IAC 742 Tiered Approach to Corrective Action Objectives

$$C_{(x)} =$$

$$C_{source} \bullet \exp\left[\left(\frac{X}{2\alpha_x}\right) \bullet \left(1 - \sqrt{1 + \frac{4\lambda \bullet \alpha_x}{U}}\right)\right] \bullet erf\left[\frac{S_w}{4 \bullet \sqrt{\alpha_y \bullet X}}\right] \bullet erf\left[\frac{S_d}{2 \bullet \sqrt{\alpha_z \bullet X}}\right]$$

NOTE:

1. This equation does not predict the contaminant flow within bedrock and may not accurately predict downgradient concentrations in the presence of a confining layer.

2. If the value of the First Order Degradation Constant (λ) is not readily available, then set $\lambda = 0$.

- Longitudinal Dispersivity

$$\alpha_x = 0.10 \bullet X$$

-
- Transverse Dispersivity

$$\alpha_y = \frac{\alpha_x}{3}$$

- Vertical Dispersivity

$$\alpha_z = \frac{\alpha_x}{20}$$

- Error Function

$$erf(\beta) = \frac{2}{\sqrt{\pi}} \int_0^\beta e^{-\varepsilon^2} d\varepsilon$$

Mass Flux Approximation Model

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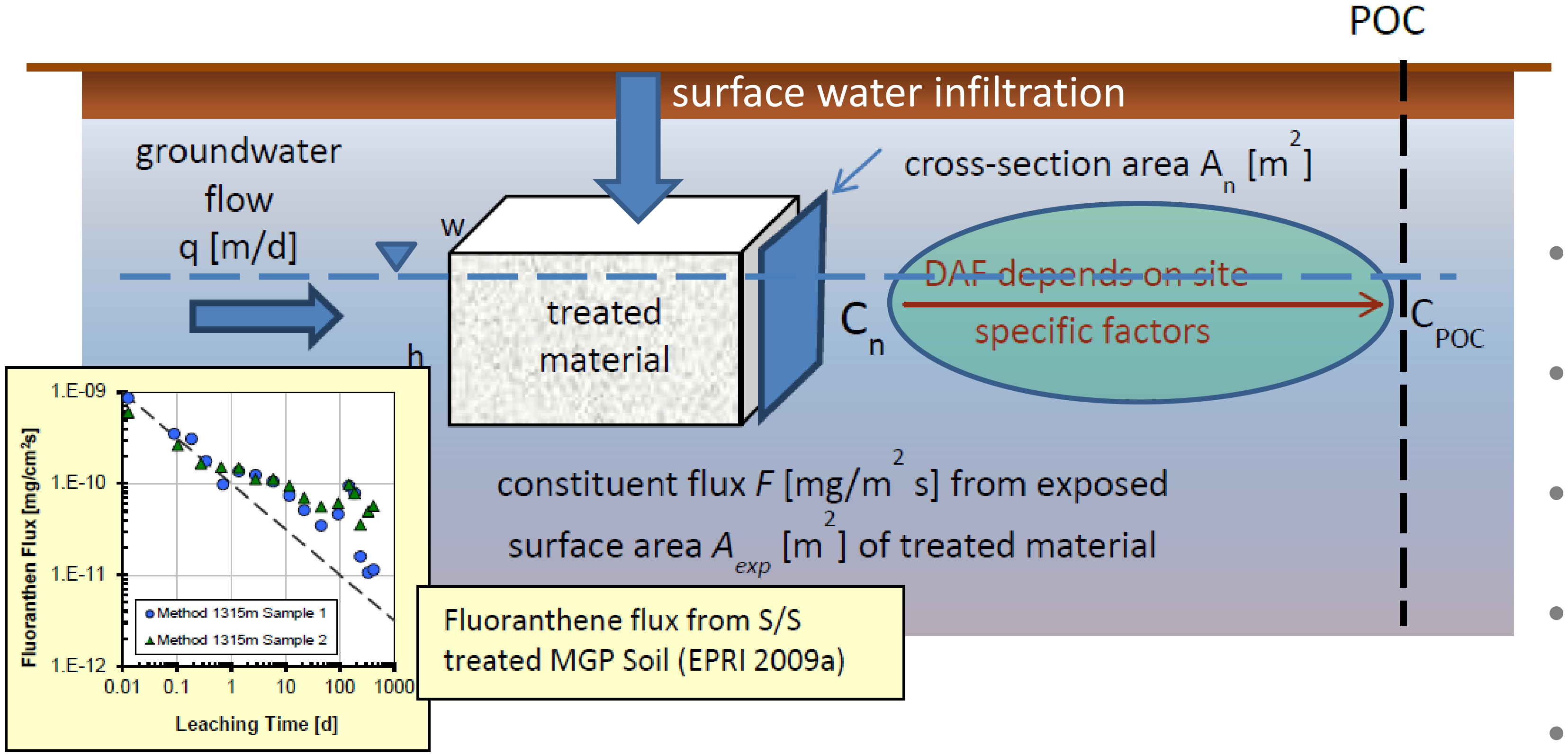

Source: Modified from *Development of Performance Specifications for Solidification/Stabilization*, Interstate Technology & Regulatory Council (ITRC), July 2011

$$C_n = \frac{F \cdot A_{exp}}{A_n \cdot q}$$

- **C_n** – concentration in groundwater (mg/L)
- **F** – mass flux, leach testing (mg/m^2 s)
- **A_{exp}** – exposed surface area of the treated material (m^2)
- **A_n**– cross-sectional area of groundwater (m^2)
- **q**– groundwater flow rate (m/d)

- Relate to a concentration (C_{POC}) at the POC through a dilution-attenuation factor (DAF)
- Accommodate surface water infiltration

Long Term Monitoring – Groundwater Modeling

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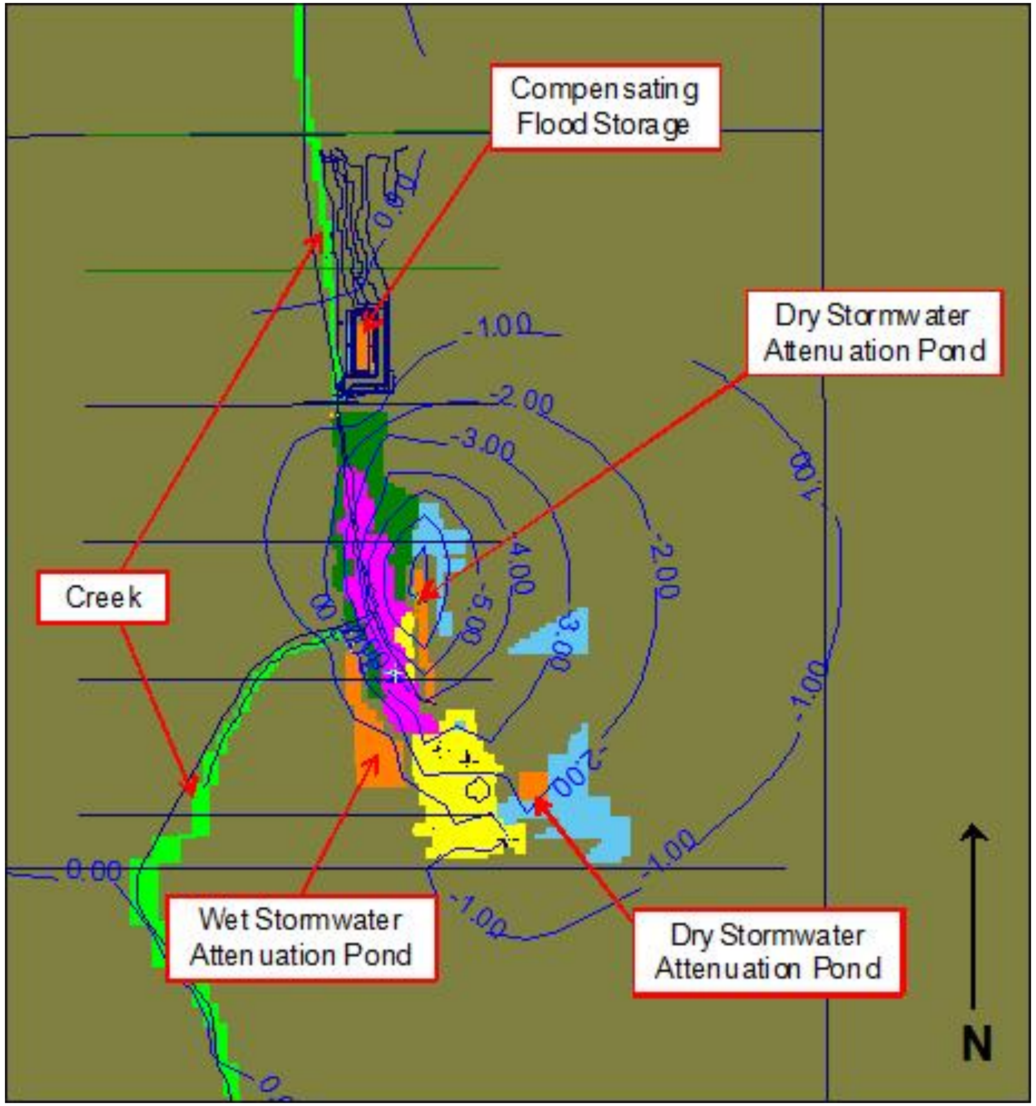
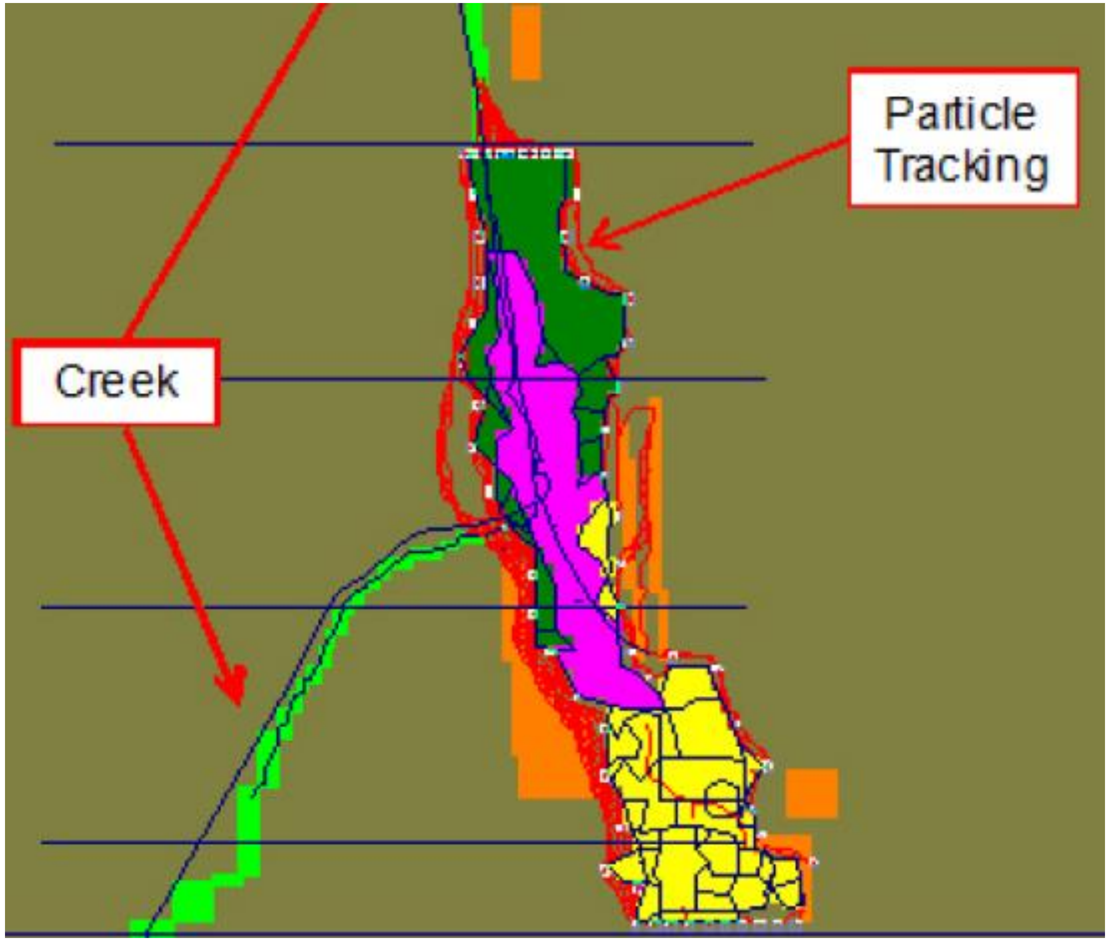


- **Yellow – Purple – Green**: ISS
- **Green** – Cloud Branch Creek
- **Orange** –Stormwater Features
- **Blue contours** – Predicted increase in groundwater elevation
- **Light Blue** – Groundwater expressed at ground surface

Source: Hennings, B. G., C. A. Robb, and R. E. Wittenberg. 2011. Draft In Situ Stabilization/Solidification Design Considerations and Applications for Groundwater Modeling. Natural Resource Technology, Technical Memorandum. *Development of Performance Specifications for Solidification/Stabilization*, Interstate Technology & Regulatory Council (ITRC), July 2011

Long Term Monitoring – Particle Tracking



Source: Hennings, B. G., C. A. Robb, and R. E. Wittenberg. 2011. Draft In Situ Stabilization/Solidification Design Considerations and Applications for Groundwater Modeling. Natural Resource Technology, Technical Memorandum. *Development of Performance Specifications for Solidification/Stabilization*, Interstate Technology & Regulatory Council (ITRC), July 2011

- **Particle tracking - MODPATH**
- Upgradient - travel toward the ISS and captured by the groundwater relief drains or travel along the edge of the monolith until they reached the stream as it exited the box culvert
- Downstream - move very closely along the ISS and be captured within 60 m of the downstream edge of the monolith

Particle Tracking – Design Groundwater Monitoring

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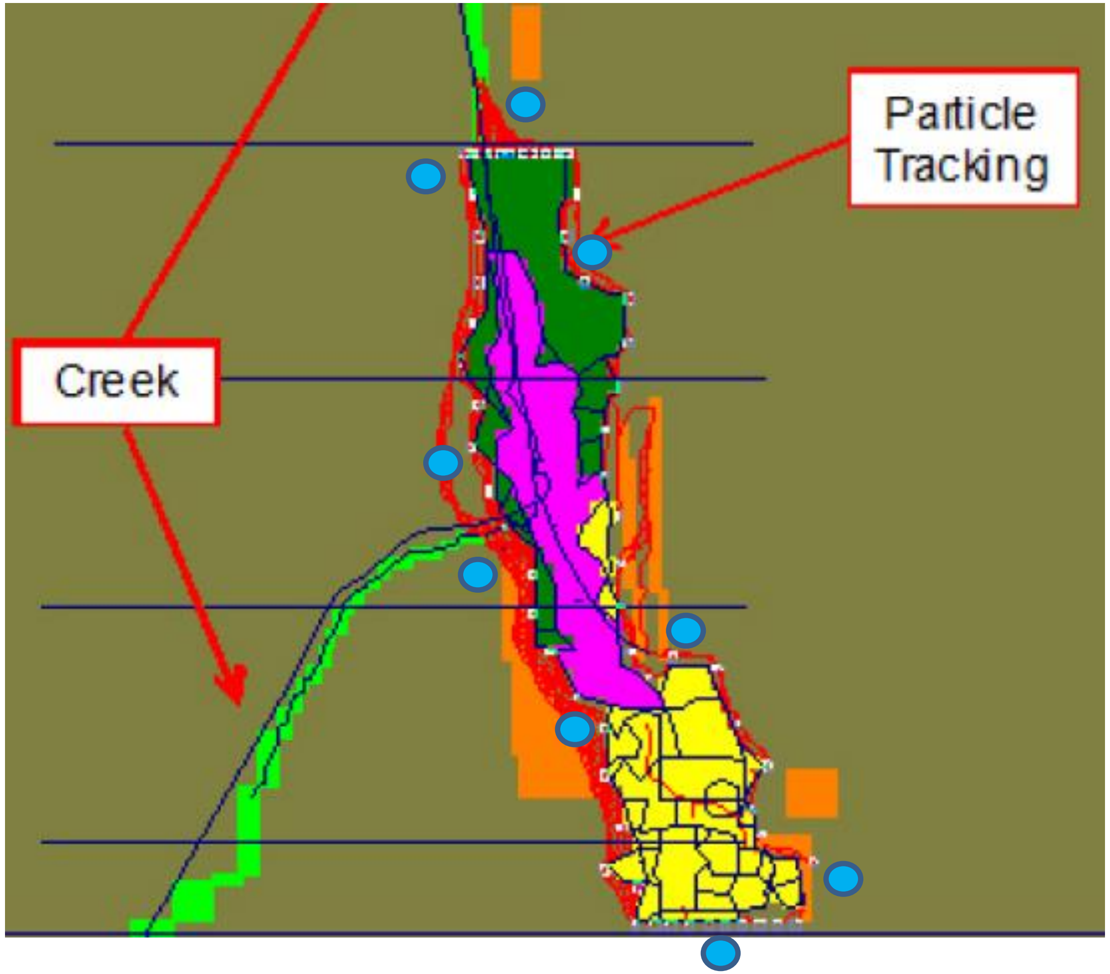

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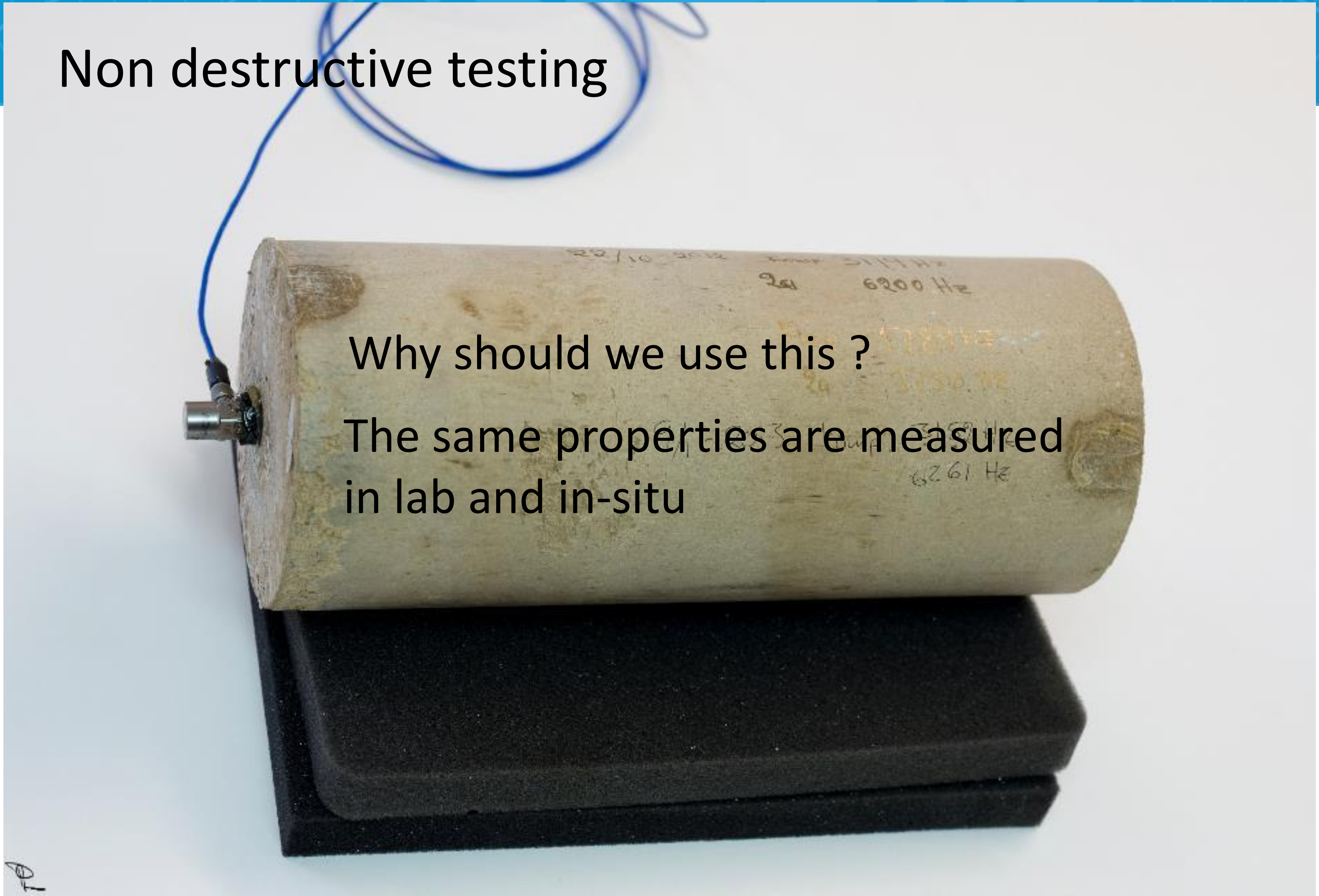
- **Groundwater Network**
- Side-gradient wells located in close proximity along the length of the ISS
- Combine with wells located directly downgradient of the ISS
- Verify with groundwater screening program

Approximate groundwater monitoring well locations

In-situ sampling

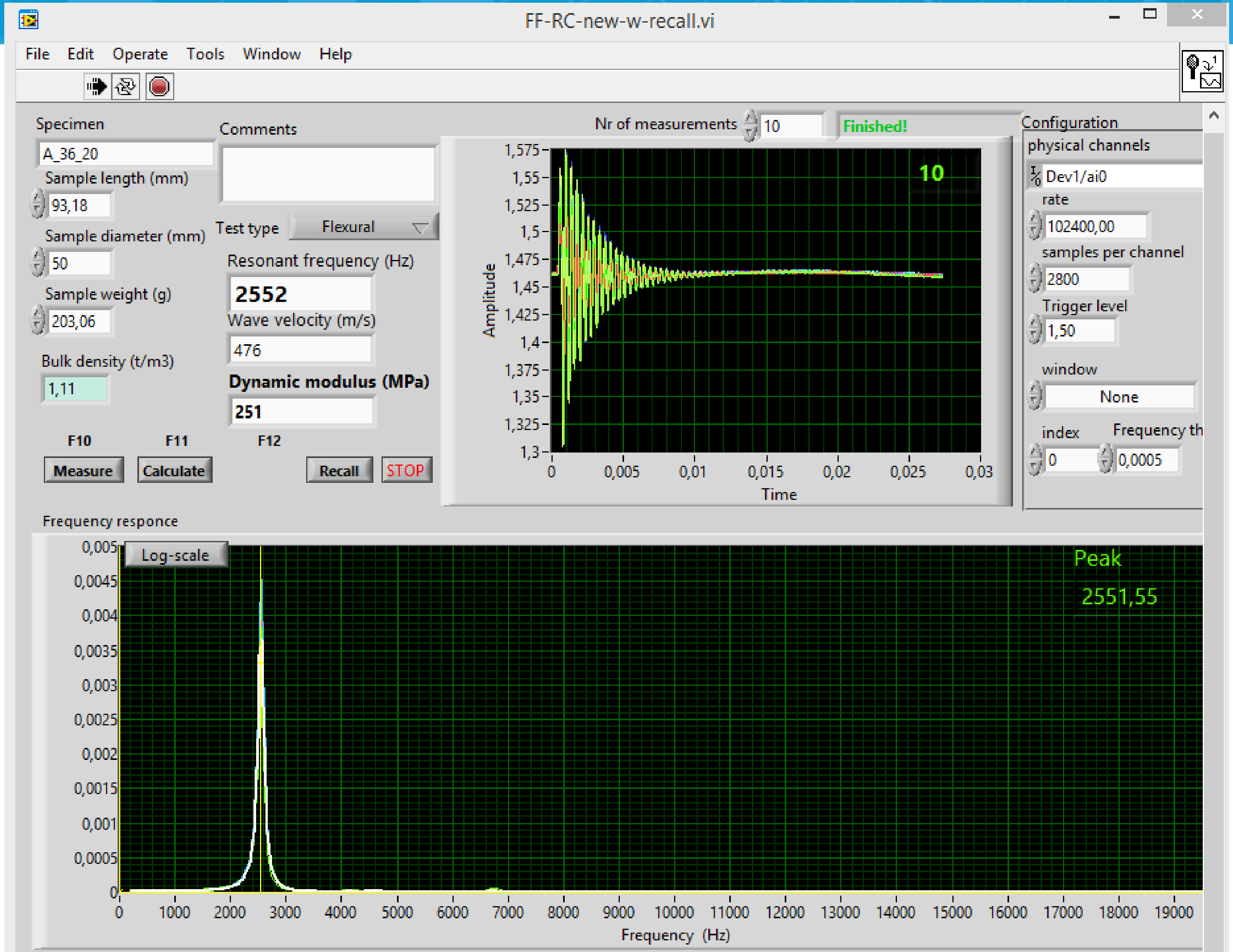
Non destructive testing



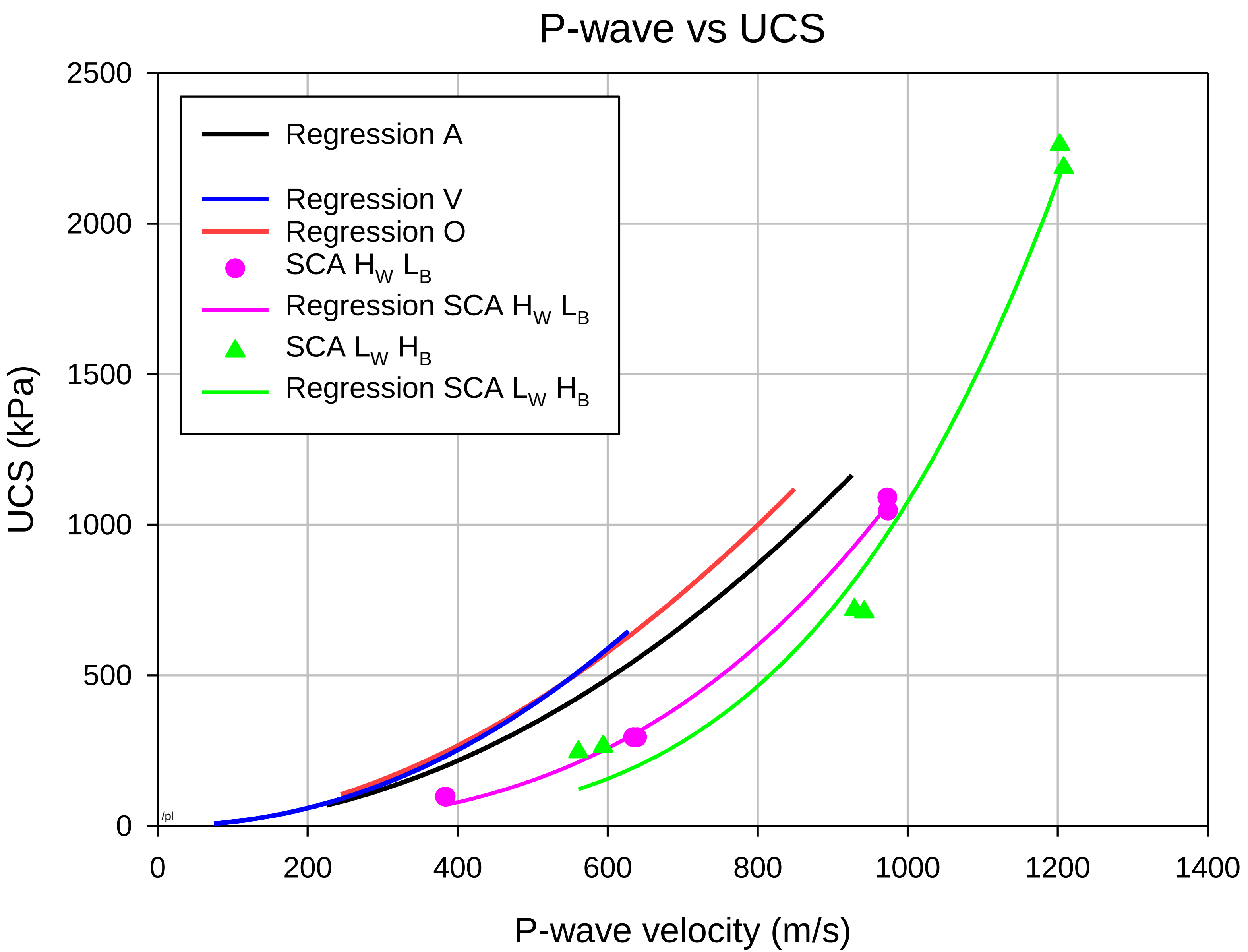
Why should we use this ?

The same properties are measured in lab and in-situ

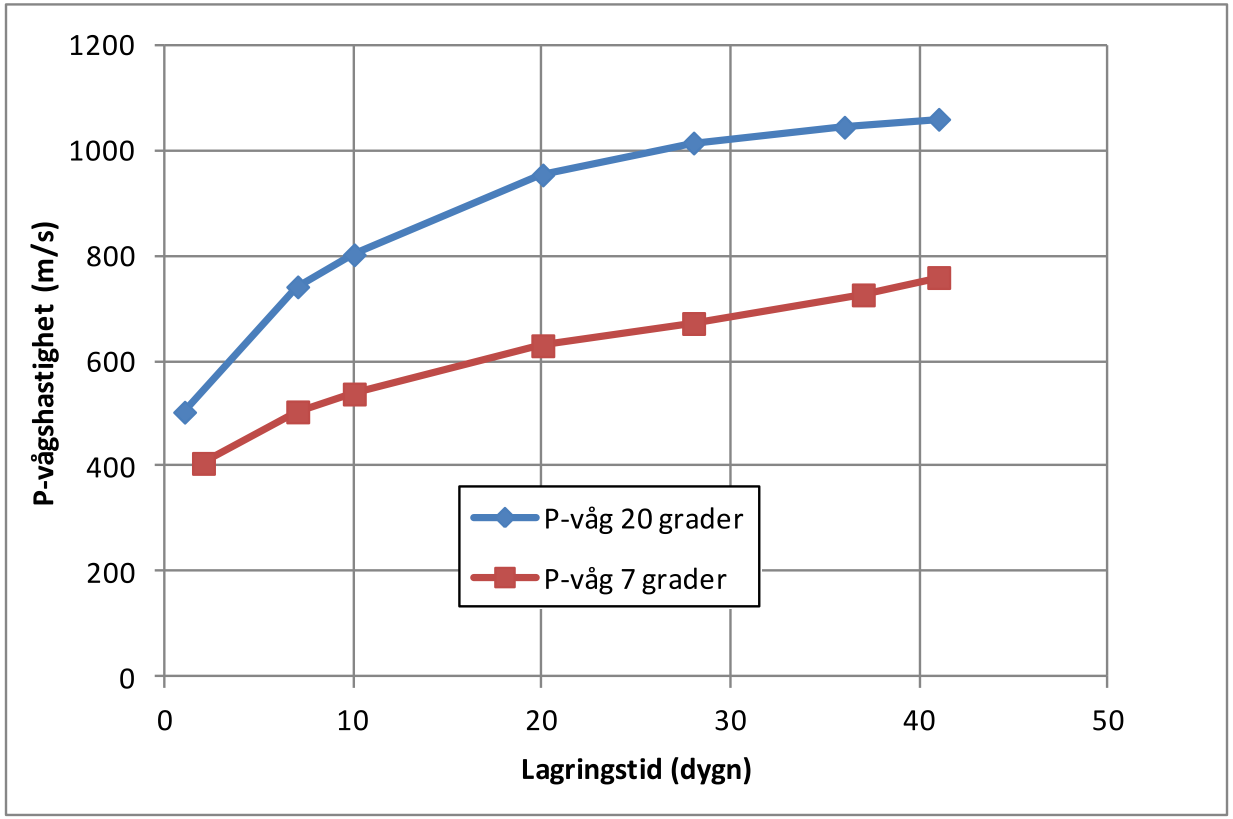
Evaluation of Shear wave

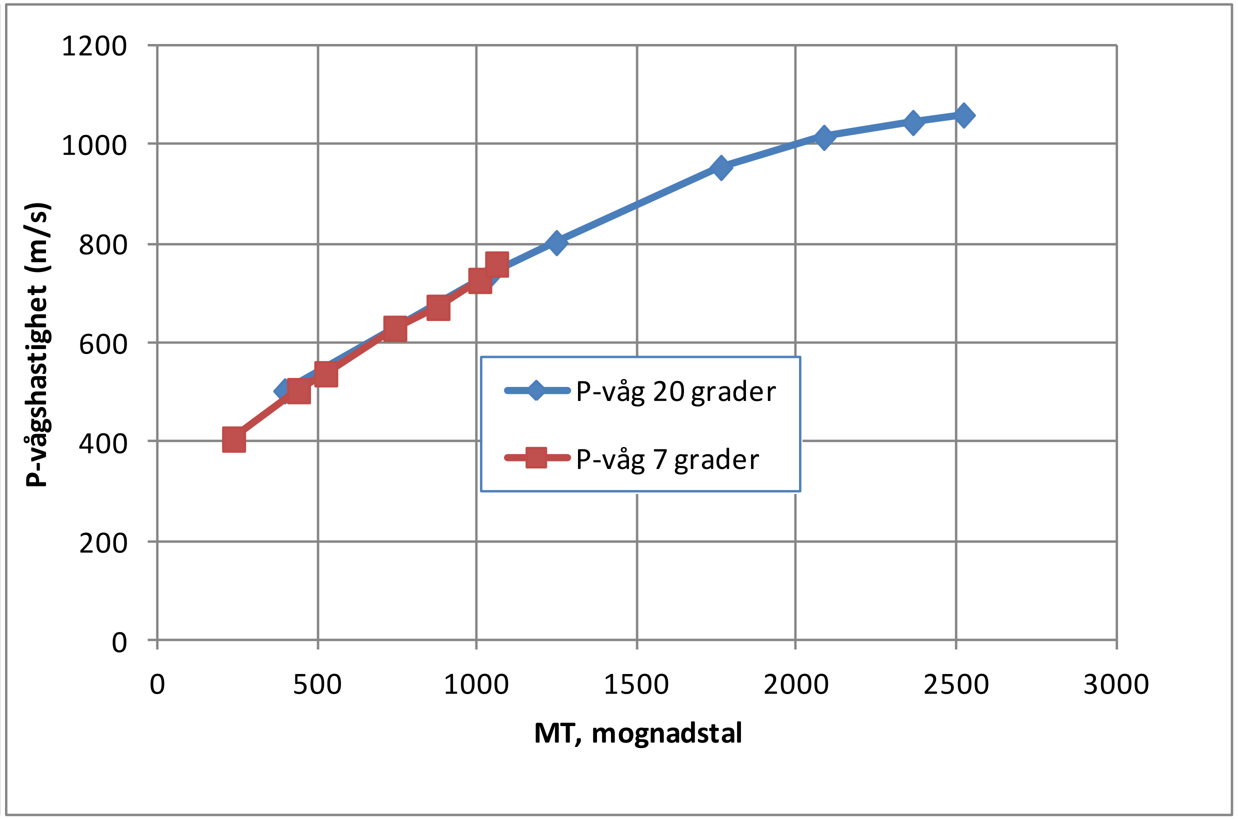


P-wave as a function of strength



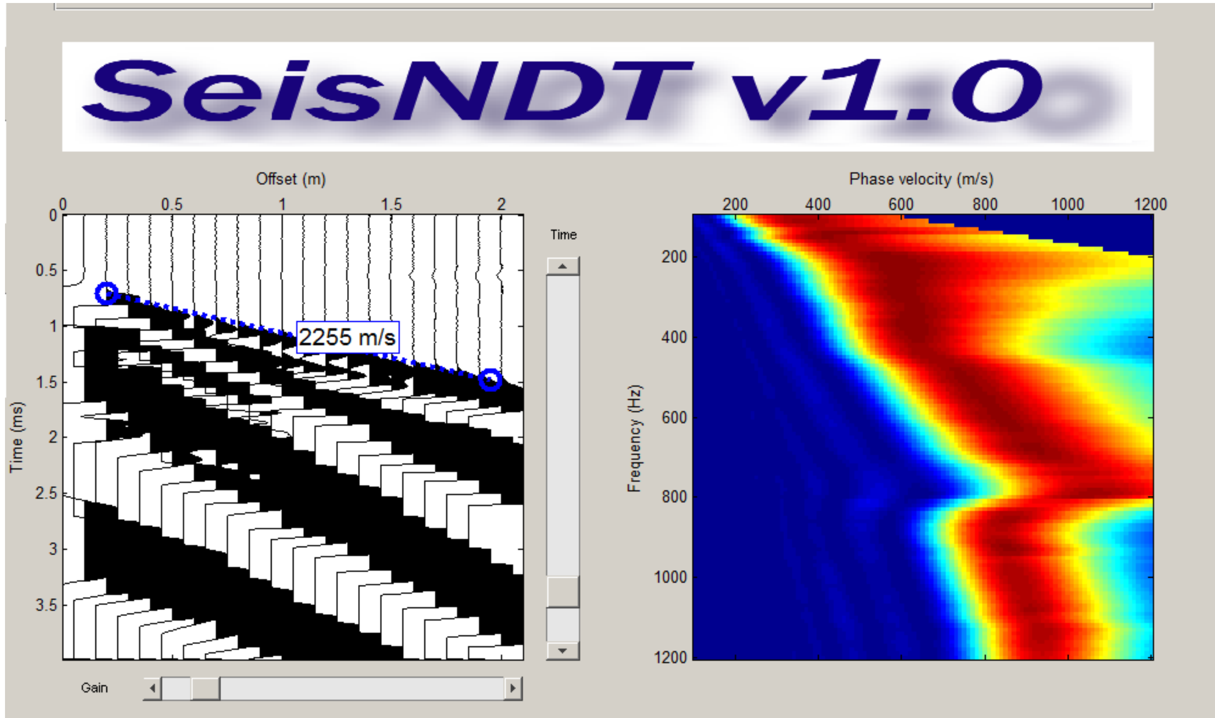
Maturity index





In-situ seismic measurement

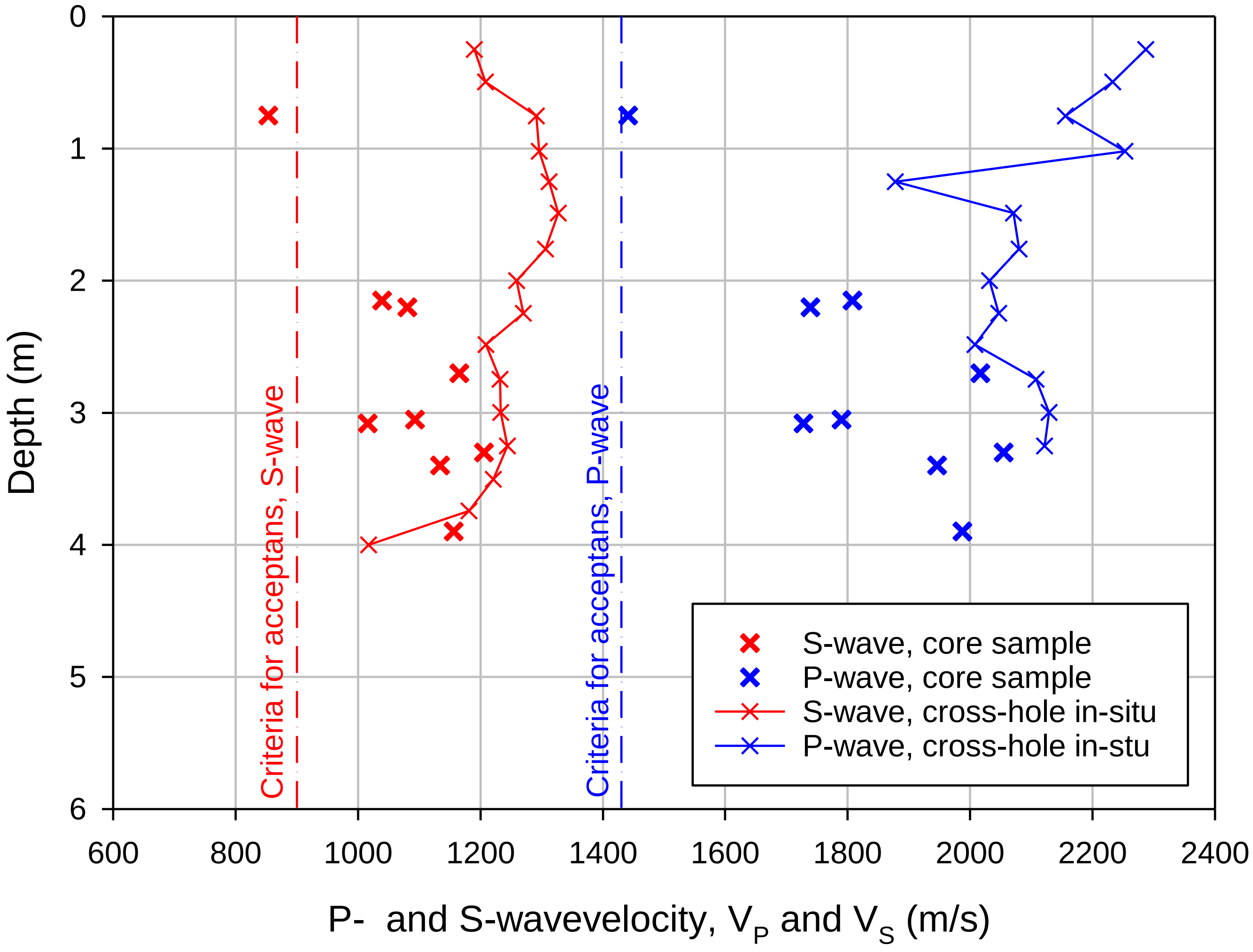
Evaluation of in-situ seismic measurement



Core sampling

Cross-hole seismic

Results from cross-hole seismic



Questions?

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Thank you for your time!

Per Lindh, Ph.D.
Trafikverket
per.lindh@trafikverket.se

Christopher A. Robb, P.E.
Geosyntec Consultants, Inc.
crobb@Geosyntec.com

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Neal Durant, Ph.D.

Dogus Meric, Ph.D., P.E.

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