Royal HaskoningDHV
Enhancing Society Together

# Laboratory Settlement Testing to determine Settling Characteristics of Fine Crushed Rock

**Rick Plain and Greg Britton**
**6th September 2022**

1

## The Problem

- Excavated rock from Tunnel Boring Machines (TBMs) and drill and blast (D&B) techniques.
- Disposal option included subaqueous placement below minimum operating level within the two existing ***freshwater*** reservoirs.

- Questions:
  - How long will the excavated rock take to settle?
  - The Farm Dam problem – what size particles stay in suspension?



2

# Farm Dam

- Colloidal clays – insoluble particles suspended throughout water



3

# Application to Ports and Maritime

- Dredging
  - Sea disposal
  - Beach nourishment
- Construction of breakwaters
- Land reclamation
- Ocean outfall



Project

2

4

# Objectives of Investigation

- Assess the settling performance of crushed samples of the different geological zones.
- Inform placement methodology and understand the risk of elevated turbidity during placement of excavated rock.
- Develop relationships between turbidity and total suspended solids (TSS) for monitoring purposes during placement in the field.

| Geological Formation | Geology Description | Rock Type |
|---|---|---|
| Geological Formation 1 | Dacite | Igneous (extrusive) |
| Geological Formation 2 | Metasandstone | Metamorphic |
| Geological Formation 3 | Interbedded metasiltstone and metasandstone | Metamorphic |
| Geological Formation 4 | Diorite | Igneous (intrusive) |
| Geological Formation 5 | Dolerite | Igneous (intrusive) |
| Geological Formation 6 | Clayey gravel | Completely weathered rock |
| Geological Formation 7 | Ignimbrite | Igneous (extrusive) |
| Geological Formation 8 | Interbedded siltstone and sandstone | Sedimentary |
| Geological Formation 9 | Siltstone | Sedimentary |

5

# Scope of Investigation

Detailed settlement tests for each of the geological zones, which included:

1. Column test to establish TSS-turbidity relationship.
   a. Convert TSS criterion into turbidity values.
   b. Method in accordance with US Army Corps of Engineers Guidelines.

47.5g of crushed rock in 50L of water



6

# Scope of Investigation

Detailed settlement tests for each of the geological zones, which included:

1. Column test to establish TSS-turbidity relationship.
   a. Convert TSS criterion into turbidity values.
   b. Method in accordance with US Army Corps of Engineers Guidelines.
2. Settlement test to determine the settling behaviour of crushed rock.
   a. Tests included surface placement of crushed rock and placement through a fall pipe of varying length.
3. Flocculation trial.
   a. Alum used in the trial. Arbitrarily selected and was not approved for use.
4. Critical particle size analysis to determine the maximum particle size remaining in suspension.



7

# Procedure

- Crush rock with Ring Mill (WaterTest).
- Riffle splitter – ensure representative samples.
- Samples of between 5g and 50g.
- Particle size determined with a Mastersizer 2000 (Geochemical Assessments). Results differ to:
  - sieve analysis due to particle shape.
  - hydrometer (based on Stokes Law) due to shape and charge of particles and salinity of the dispersant.
- Turbidity measured using a Wetlab ECO-NTU sensor.
- Water samples were sent to a NATA-accredited laboratory for TSS and turbidity analysis.



8

# Limitations

- Representivity of Particle Size Distribution
  - Crushed rock samples sieved to less than 250µm (i.e. primarily interested in ‘fines’)
- Representivity of Starting Total Suspended Solids
  - Placement rates or total quantities not scaled (0.8 to 5g/L)
  - Effect of higher concentration of TSS not considered – hindered settlement or agglomeration and increased settlement rates?
- Scale Effects
  - Fluid type and properties (reservoir water) and physical properties of the crushed rock (particle size) were not scaled.
  - Columns inert and as large as practical (~200mm diameter and 2m high). Wall effects may influence settlement.



9

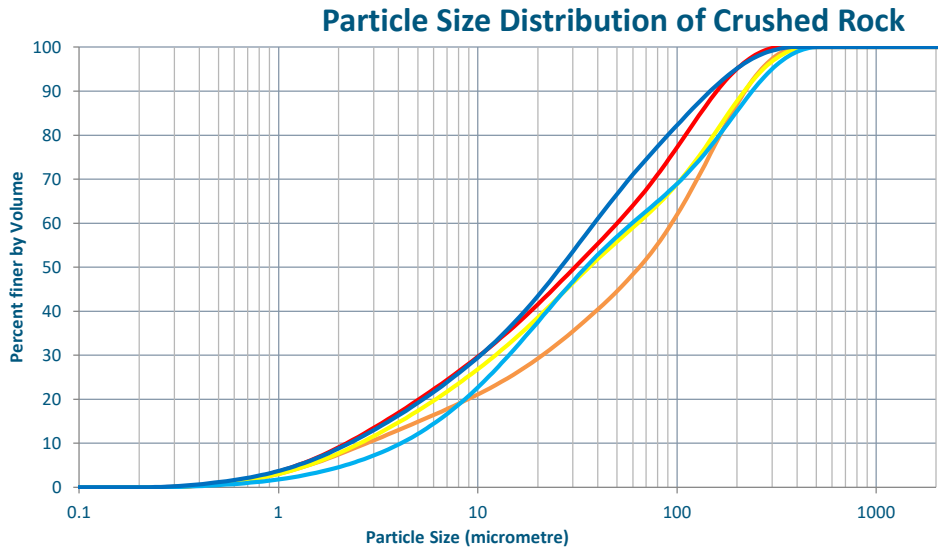
# Limitations

- Measurement of particle diameter.
  - Mastersizer 2000 vs Sieve/Hydrometer
- Hydrodynamic Stability of Placed Excavated Rock



10

# Particle Size Distribution of Crushed Rock



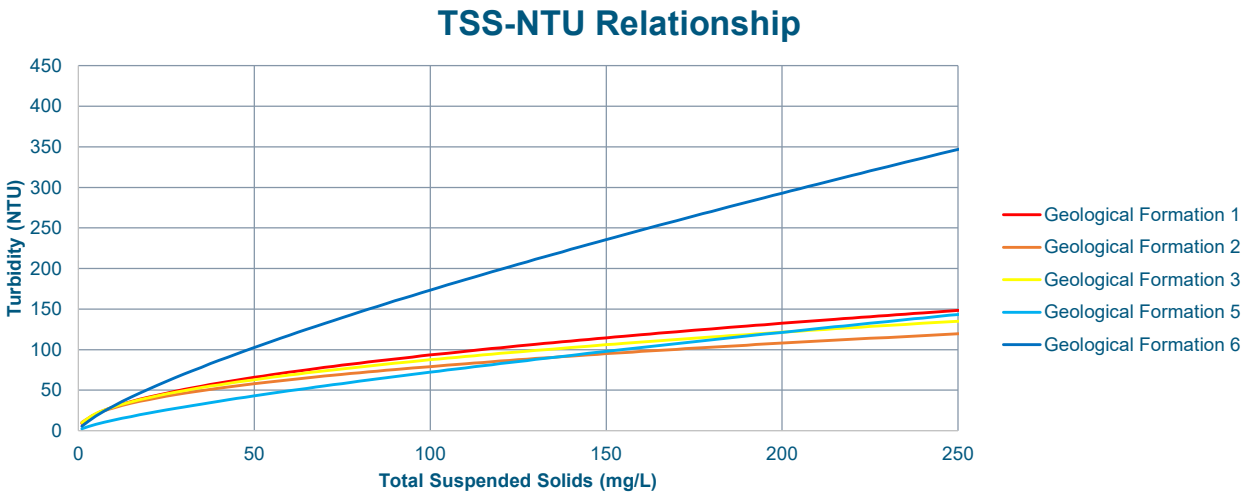

Silt < 75µm (ASTM) or 63µm (Wentworth)
Clay < 4µm



# Column Test – TSS-NTU Relationship

47.5g of crushed rock in 50L of water

# Column Test – TSS-NTU Relationship

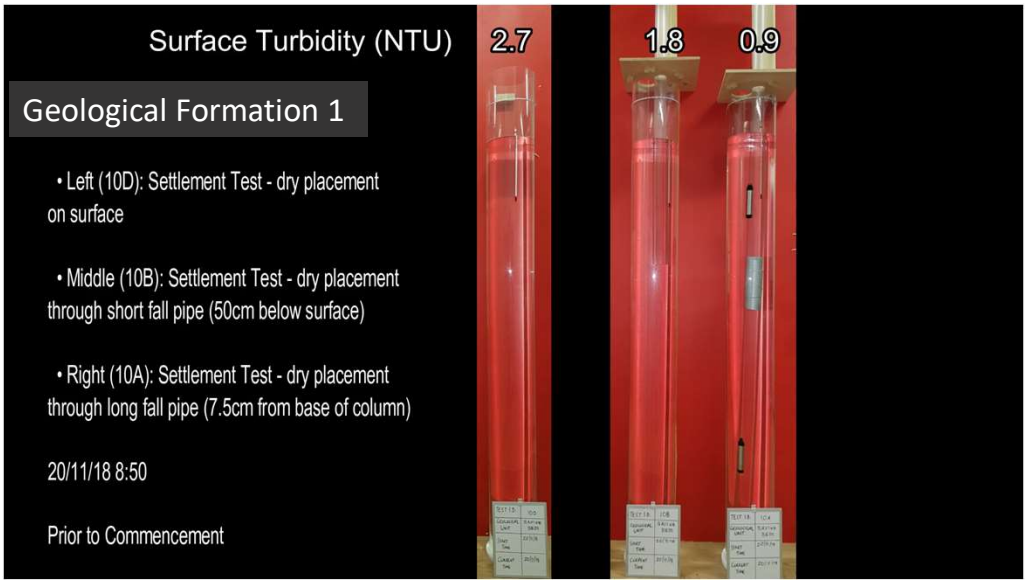



Note: TSS-NTU relationship developed based on turbidity up to 250 NTU. Maybe inaccuracies in the correlation above 250 NTU.



13

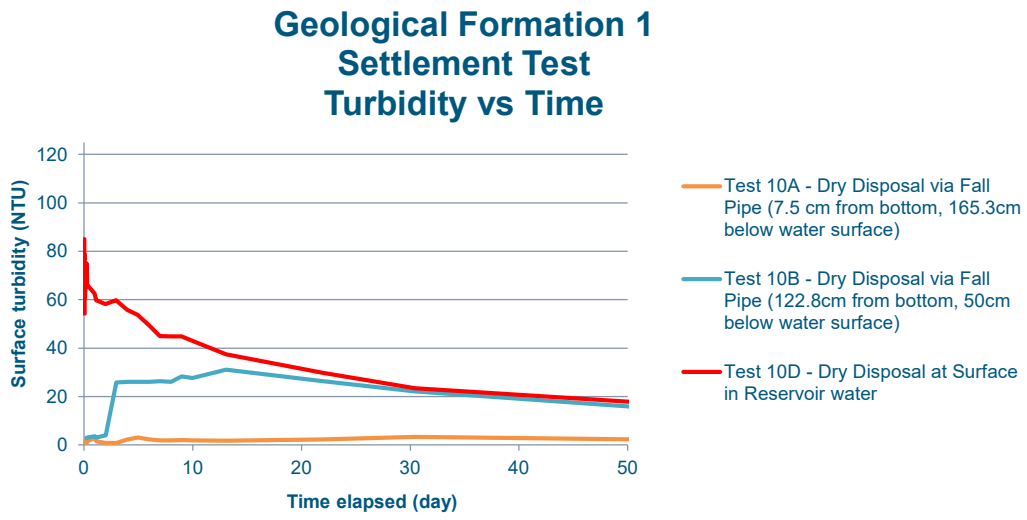
# Settlement Test






14

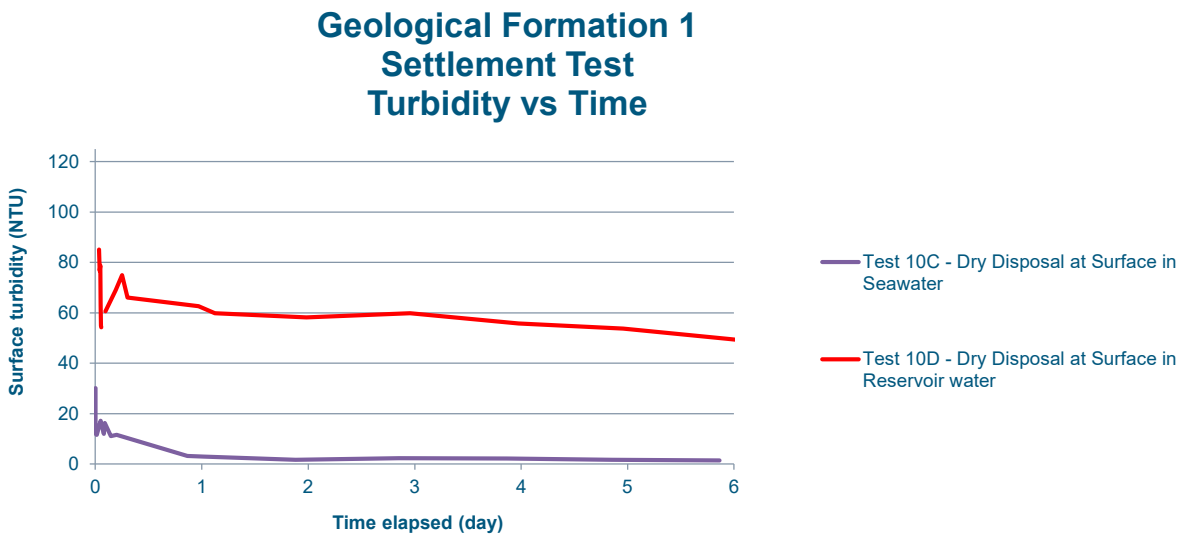
# Settlement Test






15

# Beware – Settlement in Seawater is different to Fresh Water!!






16

# Flocculation Trial

- Alum (aluminium sulphate) is a readily available inorganic **salt**.
- Alum neutralises the charge of colloids, which promotes suspended impurities to coagulate into larger particles and then settle.
- Success! Surface turbidity decreased to less than 3 NTU, within 3 days of the addition of alum.

- Bad News – Aluminium and iron based flocculants produce harmful by-products.
  - The reaction of alum produces metal ions [$Al^{3+}$] or aluminium hydroxide [$AL(OH)_3$] depending on the pH of the water. Alum also decreases pH.
- The use of organic flocculants is also unlikely to be appropriate.

- Inorganic flocculants may be suitable subject to further testing.



17

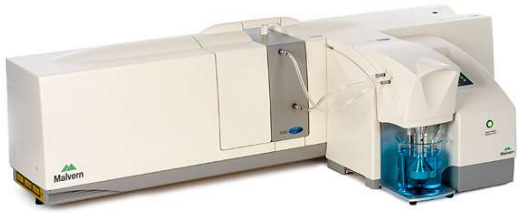
# Flocculation Trial

- Deposition layers of crushed rock and flocculated crushed rock.
- Flocculated material adhered to the wall of the columns.
- The flocculated material forms visibly larger, coagulated particles that appear to be ‘light’ and ‘fluffy’.



18

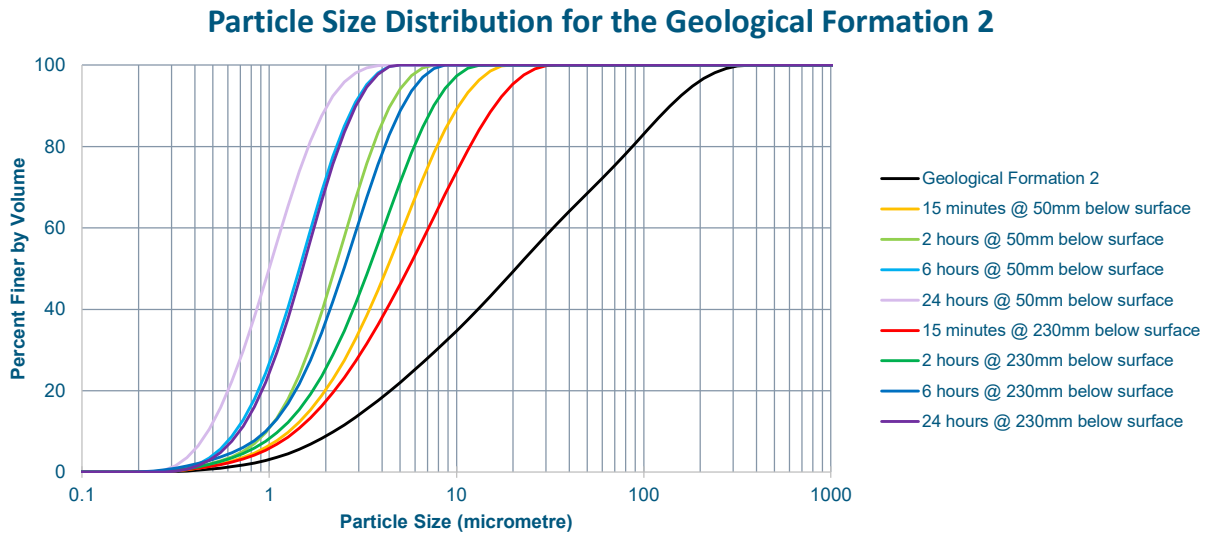
# Critical Particle Size Analysis






19

# Critical Particle Size Analysis





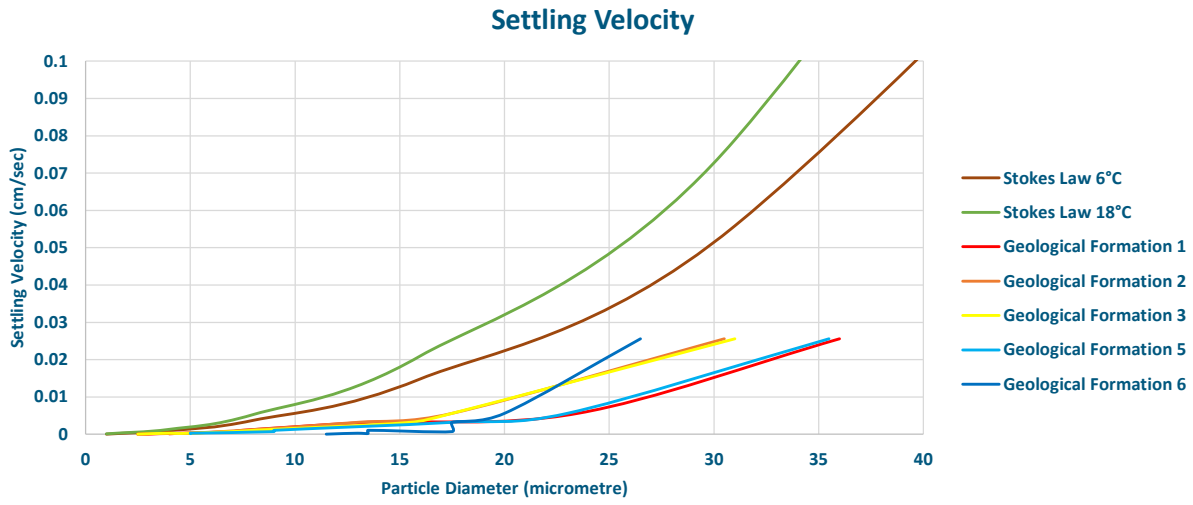

20

# Critical Particle Size Analysis

| Test Number | Depth below water surface | Time (hours) | | | |
|---|---|---|---|---|---|
| | | 0.25 | 2 | 6 | 24 |
| | | Maximum Particle Size in Suspension (μm) | | | |
| Geological Formation 1 | 50mm below water surface | 23.5 | 7 | 4 | 3 |
| | 230mm below water surface | 36 | 13.5 | 7.5 | 4.5 |
| Geological Formation 2 | 50mm below water surface | 17.5 | 6.5 | 4.5 | 2.5 |
| | 230mm below water surface | 30.5 | 13 | 7.5 | 4 |
| Geological Formation 3 | 50mm below water surface | 17.5 | 7 | 4.5 | 2.5 |
| | 230mm below water surface | 31 | 15.5 | 8 | 4 |
| Geological Formation 5 | 50mm below water surface | 23 | 9 | 5 | - |
| | 230mm below water surface | 35.5 | 17.5 | 9 | 5 |
| Geological Formation 6 | 50mm below water surface | 20 | 17.5 | 13.5 | 11.5 |
| | 230mm below water surface | 26.5 | 17.5 | 13.5 | 13 |



# Settling Velocity



# Inferences from the Laboratory Investigation

- Placement of crushed rock near the bed of the reservoir reduces turbidity.
- Placement at depth within the reservoirs when a thermocline is apparent (i.e. during summer) is less likely to result in vertical mixing and advection of crushed rock towards the surface.
- Management measures that minimise or control the release of fine fractions may improve surface turbidity.
- Minor disturbances to the water column are likely to disrupt the settlement process and/or re-suspend fine particles.



# Question Time