Salt-Clay Interactions: Reducing Sediment Loads and Erosion at Snow Storage Sites

17^{th} Street Snow Storage Site

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Introduction

Edmonton gets a lot of snow.

17th Street snow storage site

- Snow removal
  - Plow into windrows
  - Remove to snow storage sites

  - In the past
    - empty fields
    - along the river
  - Recent years
    - engineered sites, monitored

snow storage sites in Edmonton

- snow storage
- clay liner
- setting pond

snow
road salt (NaCl)
road sand
gravel, sand,
silt, clay

melting rates are a challenge

equipment

clay liner

environmental protection
local till source
(sand, silt, clay)
compacted to desired K

long, shallow slope
exposed surface
high flow rates & volumes, seasonally
channel erosion develops

17th Street Snow Storage Facility, July 2008

- *setting pond*
  - *sides HDPE, base RCC*
  - *sediments:*
    - *62% clay*
    - *32% silt*
  - *discharge to storm sewer*

sediment accumulation in settling ponds at engineered snow storage sites requires costly maintenance.

17th Street snow storage site

- After 2 years operation
  - removed 20,000 tonnes wet sediment
  - ~ half a million $
- TSS exceedances
  - silt curtain
  - flocculants
- Value Engineering Session

How can we improve the operational performance and reduce maintenance costs?

Problem Formulation

- Is it possible to help the sediments settle faster?
- Is it possible to reduce the amount of sediment?
- *Where is the sediment coming from?*
  - *snow pile or clay liner?*

- *Objective*
  - *Characterize the pond sediments*
  - *Simulate site conditions, observe settling behaviour*
  - *Investigate potential additives & mitigation strategies*
  - *Identify primary source of pond sediment*

- *Settling Experiment & Mass Balance*

Literature Review…

Clay content controls the engineering properties of soil.

- moisture retention
- cohesion
- plasticity
- hydraulic conductivity
- swelling
- soil texture, structure
- erosion, settling

- variables:
  - – clay mineralogy
  - – solution chemistry: *cations*
    - charge
    - concentration
    - pH

clay – salt interactions

Salt dissolves in water

– positive ion and negative ion

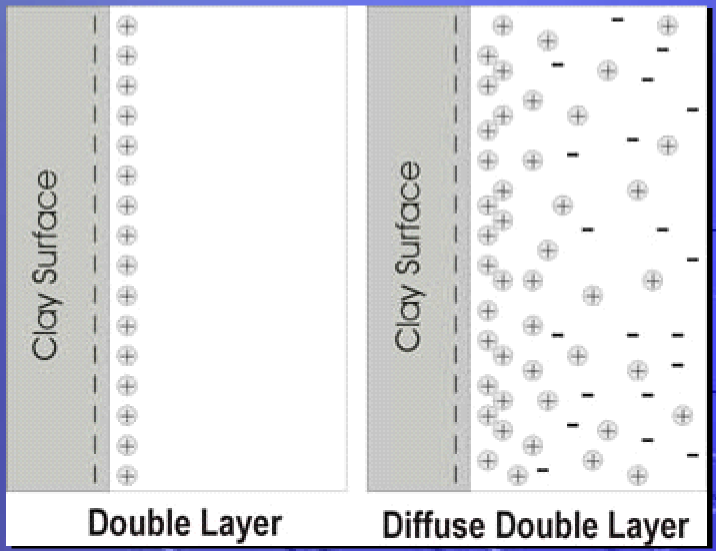
$NaCl \rightarrow Na^+ + Cl^-$

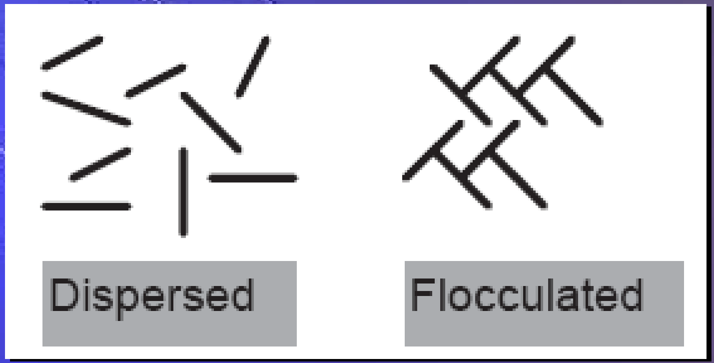
$CaCl_2 \rightarrow Ca^{2+} + 2Cl^-$

- Clay has a negative surface charge
- Clay adsorbs positive ions
  - cation exchange capacity
  - sodium adsorption ratio

$Th^{4+} > Al^{3+} \sim > Ba^{2+} \sim Sr^{2+} > Ca^{2+} > Mg^{2+} > NH_4^+ \sim K^+ > Na^+$

adsorbed ions influence physical properties of clay





- Monovalent ions yield a thick DDL
  - hydrated radius
  - charge density
- cations with higher charge yields thin DDL

- Particles with thick DDL tend to DISPERSE
- Particles with a thin DDL tend to FLOCCULATE

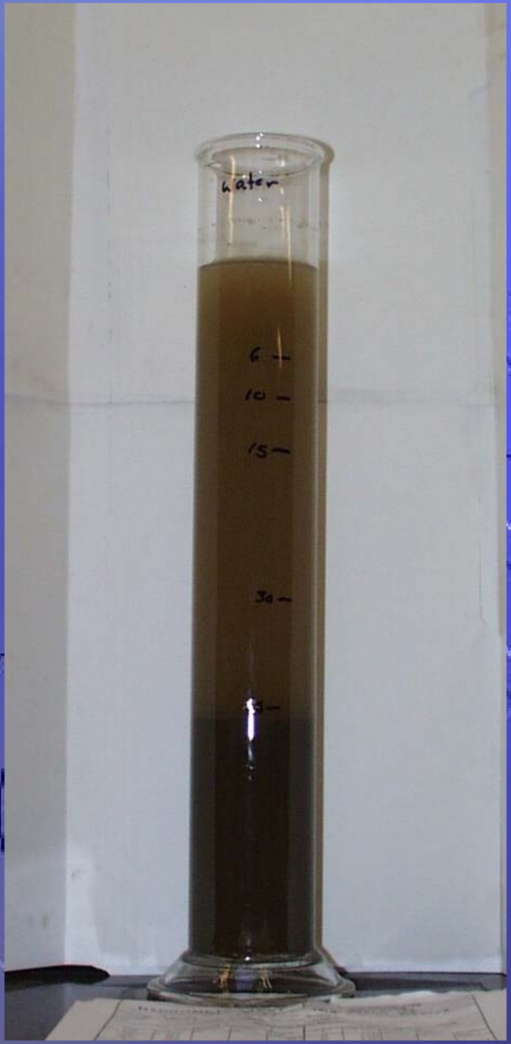
Settling

- Settling rates:
  - increase with increasing cationic charge
    ($Al^{3+} > Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$)

  but also…
  - increase with ionic strength (salt concentration)

- Particles that resist settling are susceptible to erosion.
  - physical disturbance + wet conditions
    - flow velocity, rain, equipment, wind
  - disperse into suspension,
  - stay suspended longer,
  - transport further.

Settling experiments



Pond sediment:

Shake with water and salt solutions;

Observe settling behavior over a 24 hour period.

Adapted the standard hydrometer test for grain size analysis.

Settling Test

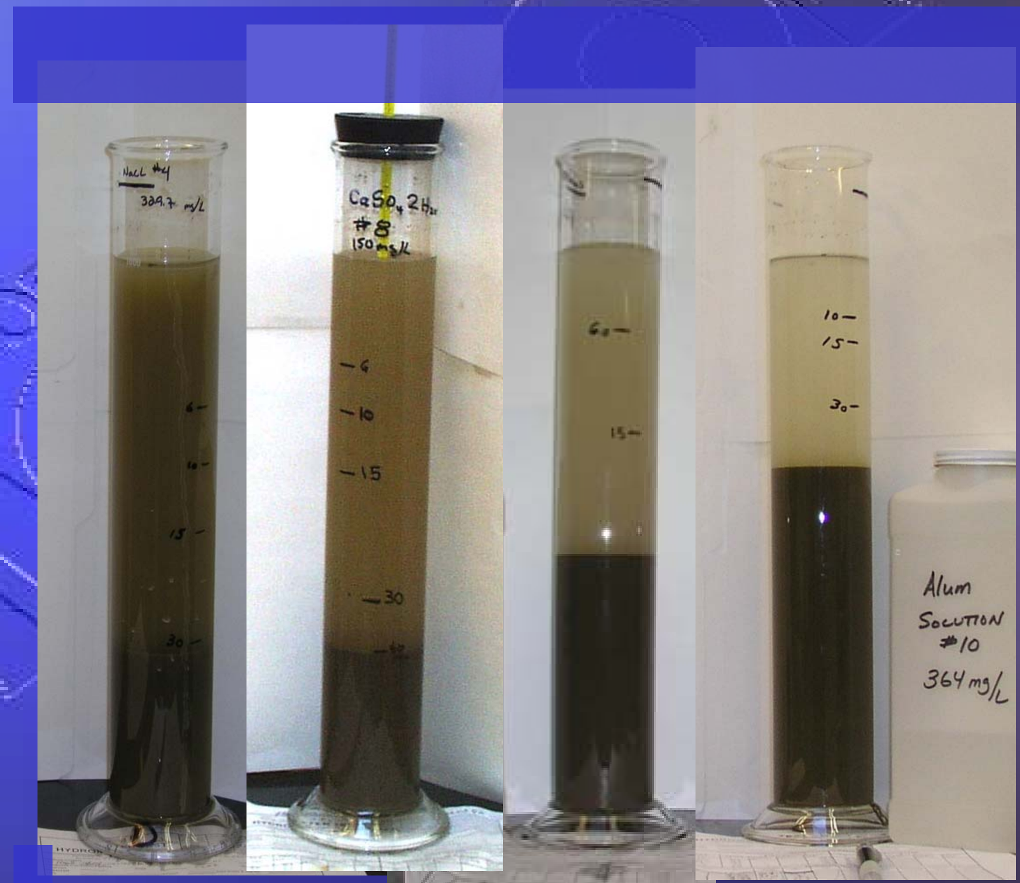
Solution	Concentration (mg/l)		Comments
deionized water	nil	nil	free of ions
NaCl	330	3,300	road de-icer
$CaCl_2$	[illegible]	[illegible]	dust abatement and stabilization additive for unpaved roads, de-icer
gypsum $CaSO_4 \cdot 2H_2O$	150	1,500	fertilizer and amendment to improve sodic soils
alum $KAl(SO_4)_2 \cdot 12H_2O$	364	3,640	A coagulant that is effective in the absorption and precipitation of naturally occurring negatively charged colloidal material (e.g. clay and silt) from surface waters.

Increasing ionic charge

Increasing concentration

Increasing ionic charge

Na^+ Ca^{2+} Ca^{2+} Al^{3+}



NaCl 330 mg/l

gypsum ($CaSO_4.2H_2O$) 150 mg/l

$CaCl_2$ 313 mg/l

alum 364 mg/l

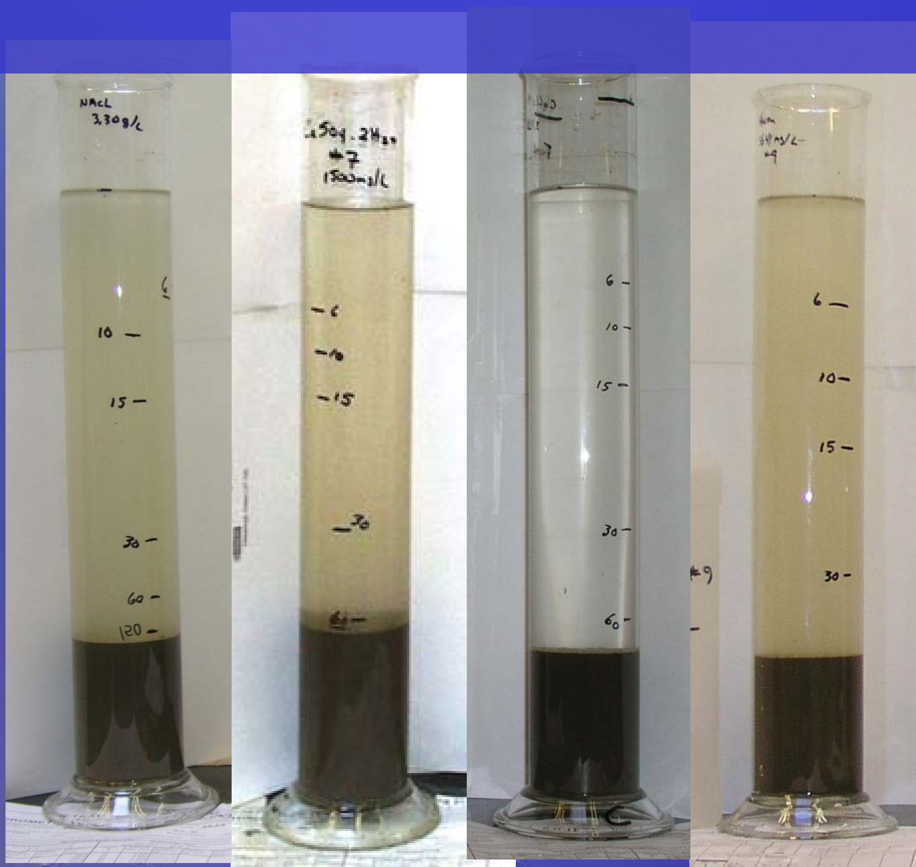
Low concentrations:

Settling improves with increasing ionic charge

Settling time:
30 – 60 minutes

Increasing ionic charge

Na^{+} Ca^{2+} Ca^{2+} Al^{3+}



NaCl
3330 mg/l

gypsum
($CaSO_4.2H_2O$)
1500 mg/l

$CaCl_2$
3130 mg/l

alum
3640 mg/l

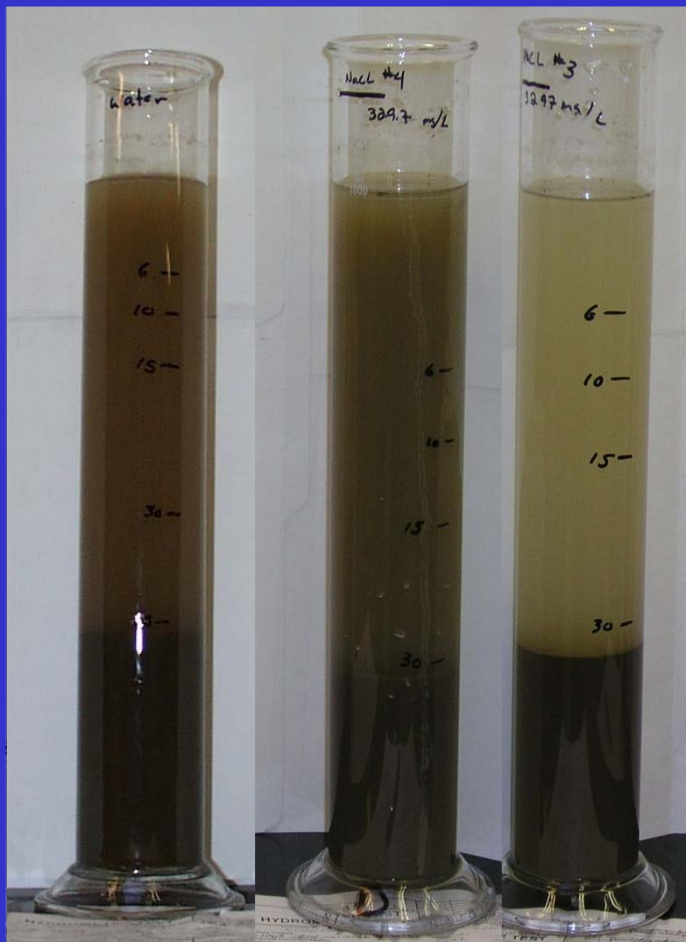
High concentrations:

Settles well,
regardless of ionic charge

Concentration increases, ions in solution are closer together, collapses the DDL

x10 higher concentration
Settling time: 30 – 60 minutes

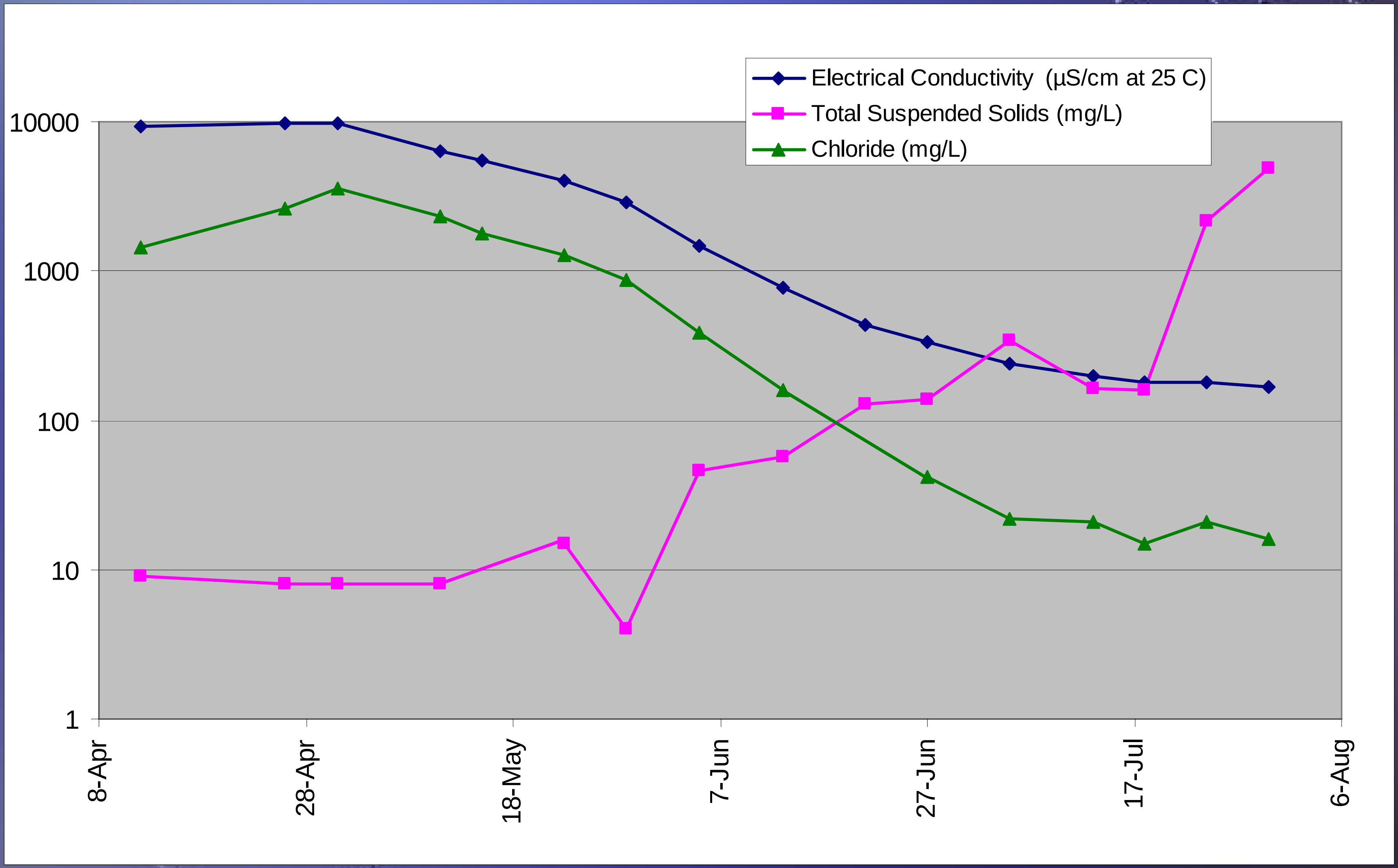
Simulated site conditions NaCl



deionized water | **NaCl 330 mg/L** | **NaCl 3300 mg/L**

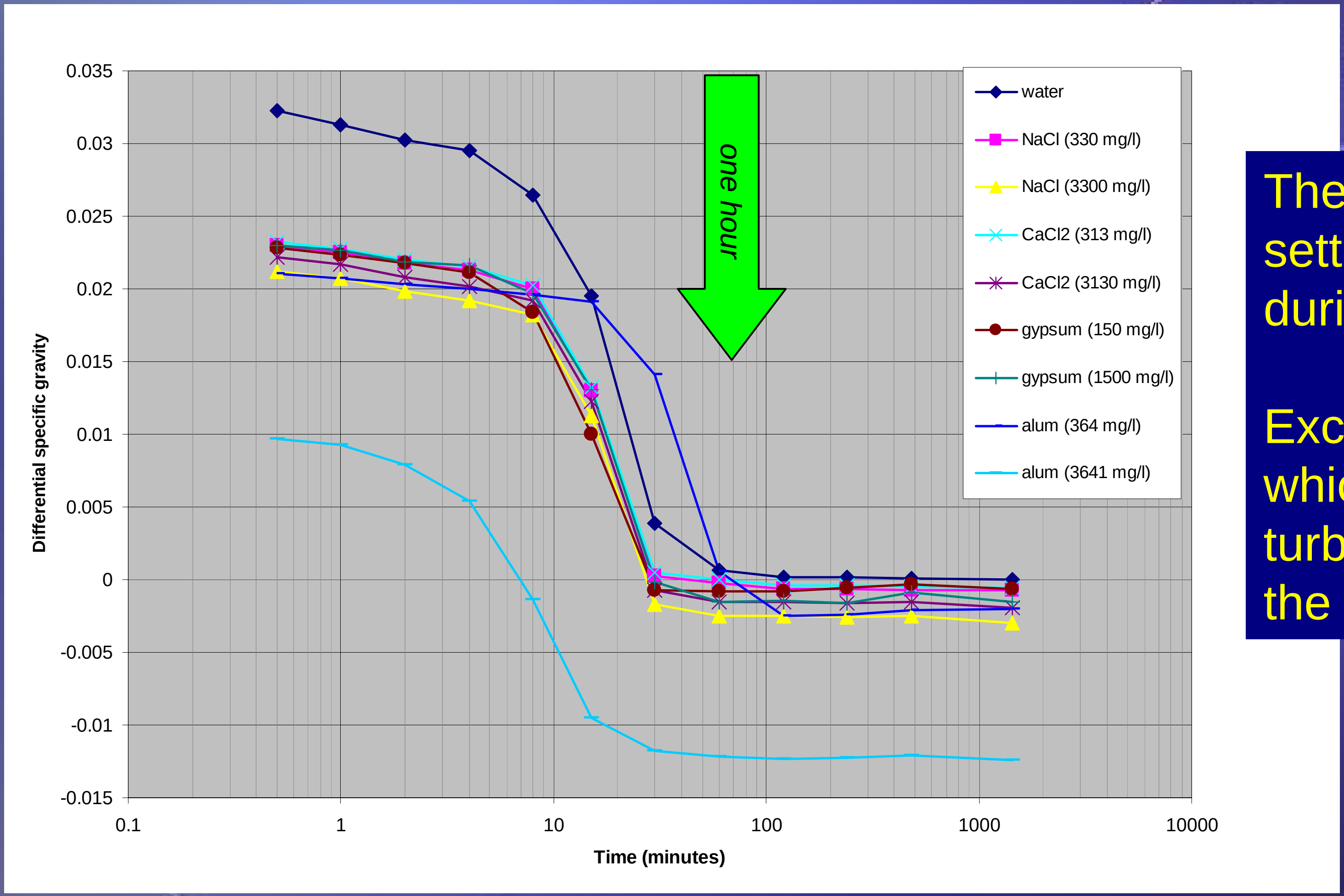
- Salt-laden pond sediment
- High concentration settled well
- ‘clean’ water settled the most slowly, remained turbid for duration of test

Similar performance observed in the field



2007 environmental monitoring data, 17th Street, weir outlet

Time



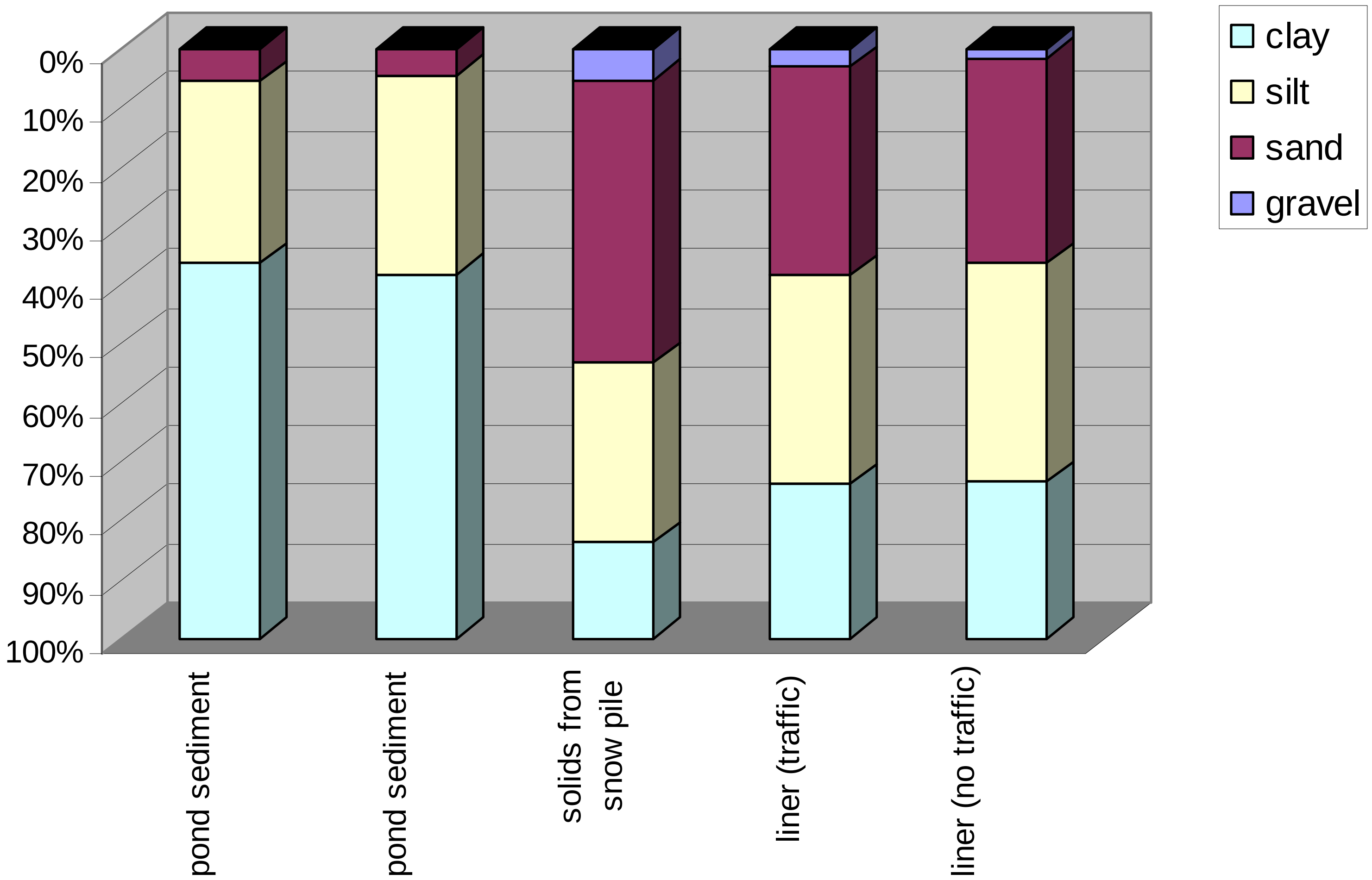
The majority of settling took place during the first hour

Except for water, which remained turbid for duration the test.


Source of pond sediments?
Is it a design problem?
or
Just the way it is? a cost of doing business?

Mass Balance

- Samples:
  - pond
  - liner
    - trafficked and non-trafficked areas
  - snow pile
- grain size distribution
- clay mineralogy
- field records
  - (snow volumes, sand application rates, sand recycle recoveries, etc.



Preferential transport of clay

Sample	Clay mineralogy (%)		
	kaolinite	illite	smectite
pond sediment	38	41	not observed
compacted clay till liner (trafficked area)	21	31	40
compacted clay till liner (no traffic area)	27	33	32
snow pile sediment	25	32	34

Clay minerals illite and kaolinite preferentially transport.
Smectite does not transport (swelling clay).

Mass balance

1. Limiting variable: illite & kaolinite
2. Mass of street sand applied
3. 20,000 tonnes (wet) removed in 2007
4. Estimate
   - 70% of applied road sand recovered and recycled.
   - Assume 30% recovered with snow, no losses.
5. Snow removal inventories, include public contributions.

Mass Balance

20%

of settling pond clay

originated from snow pile

~80%

originates from liner

Calculations likely over-estimate the snow pile contributions.

Operational Implications

- use field monitoring data to predict TSS
  - When salt concentrations in runoff are high
    - expect low TSS
  - When salt concentrations are low
    - expect sediment transport, high TSS

- minimize disturbance
- increase retention time to reduce TSS
- divalent cation amendments may help

17th Street Snow Storage Facility
May, 2008

July 2008

Sediment impoundment ("primary retention pond")

Berms: retain sediment-laden water to allow settling, control location of deposition.

Summary of test results

- High [NaCl] improve settling
- Low [NaCl] settled slowly
- Water + Na-rich sediment is worst performer.
- Most settling occurred during first hour.
- Increase cation charge, improve settling.

- preferential transport of clay
  - illite & kaolinite
- 20% snow pile
- 80% erosion of clay liner
  - "infinite source"

Conclusions

Worst-case scenario for erosion and TSS

- Na^+ + clay
- Low conductivity meltwater & rain
- Physical disturbance
- Clay particles repel each other, disperse, resist settling
- Encourages erosion and transport of clay minerals

Design problem: unsuitable application of technology

- *clay liner for environmental protection:*
    - *diffusion dominated environment*
    - *undisturbed*
    - *not a trafficable or erosion resistant surface*
- *incompatible materials selection*
    - *waste interaction with construction materials*
    - *site operations (running water, equipment)*

Recommendations

Design Modifications

- choose alternate materials
- clay-free, low-fines

and/or

- isolate liner from surface with an erosion-resistant, trafficable surface

Hard surface

- reduce erosion & sediment transport
- significantly reduce clean-out costs (by >80%)
- easier to recover and recycle snow-pile sand
- reduce environmental impacts

- cost

Thank you.

- Questions?