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Road Salt and Source Water Protection: Is Convenience Compatible with Environmental Stewardship?

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TRIECA Conference

March 25th, 2014

UNIVERSITY of GUELPH

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So, **IS** Convenience Compatible with Environmental Stewardship?

YES!

...Sort of

Outline

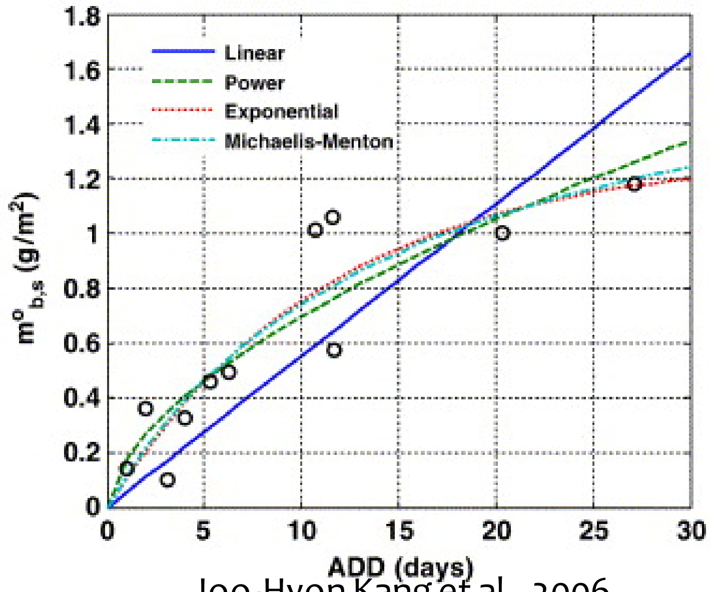
- Background
- Objectives
- Laboratory Testing
- Site Description
- Field Facility
- Preliminary Results
- Next Steps
- Acknowledgements

Background

Between rain or melt events, pollutants tend to accumulate on road surfaces, including:

- Sediment
- Chromium
- Cadmium
- Copper
- Zinc
- Nickel
- Chlorides

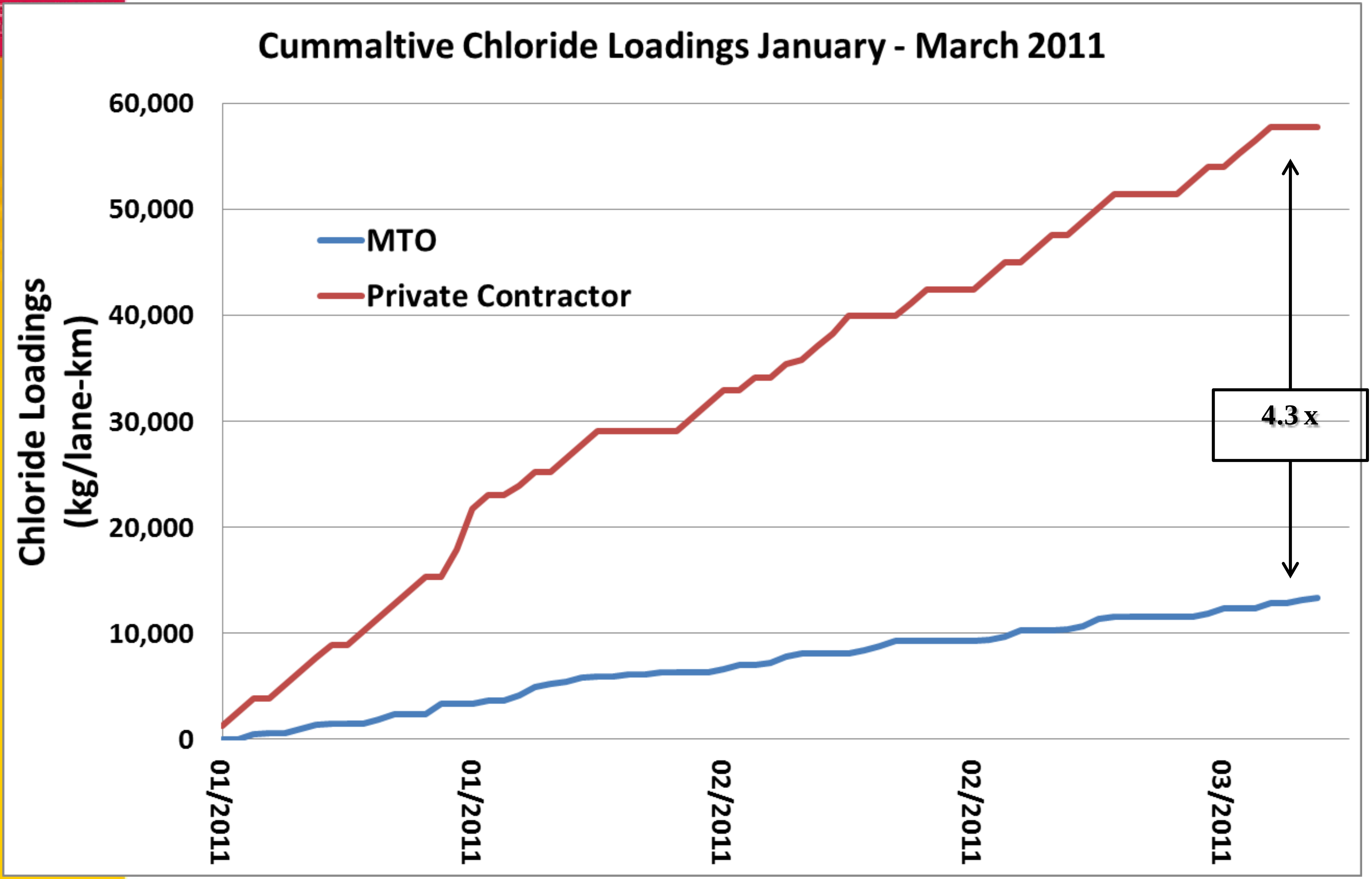
- Concentrations of these pollutants are a function of:
  - Average annual daily traffic (AADT)
  - Duration between washoff events (ADD)
  - Quality of the vehicles on the road



Joo-Hyon Kang et al., 2006

- 5M tonnes of road salt applied annually in Canada (EC, 2007)
  - 1.1M tonnes in Ontario alone (1998)
  - Number is roughly double that in the U.S.

- Private contractors tend to apply salt at a density that is 4X greater than public agencies
  - Application excess is in response to liability issues
  - Total contribution remains unquantified



Cummaltive Chloride Loadings January - March 2011
60,000
50,000
40,000
30,000
20,000
10,000
0
Chloride Loadings (kg/lane-km)
MTO
Private Contractor
4.3 x
01/2011
01/2011
02/2011
02/2011
03/2011

Regulations

- The US EPA has set chronic and acute toxicity thresholds for chlorides which are 230 mg/L and 860 mg/L respectively (EPA, 1988)

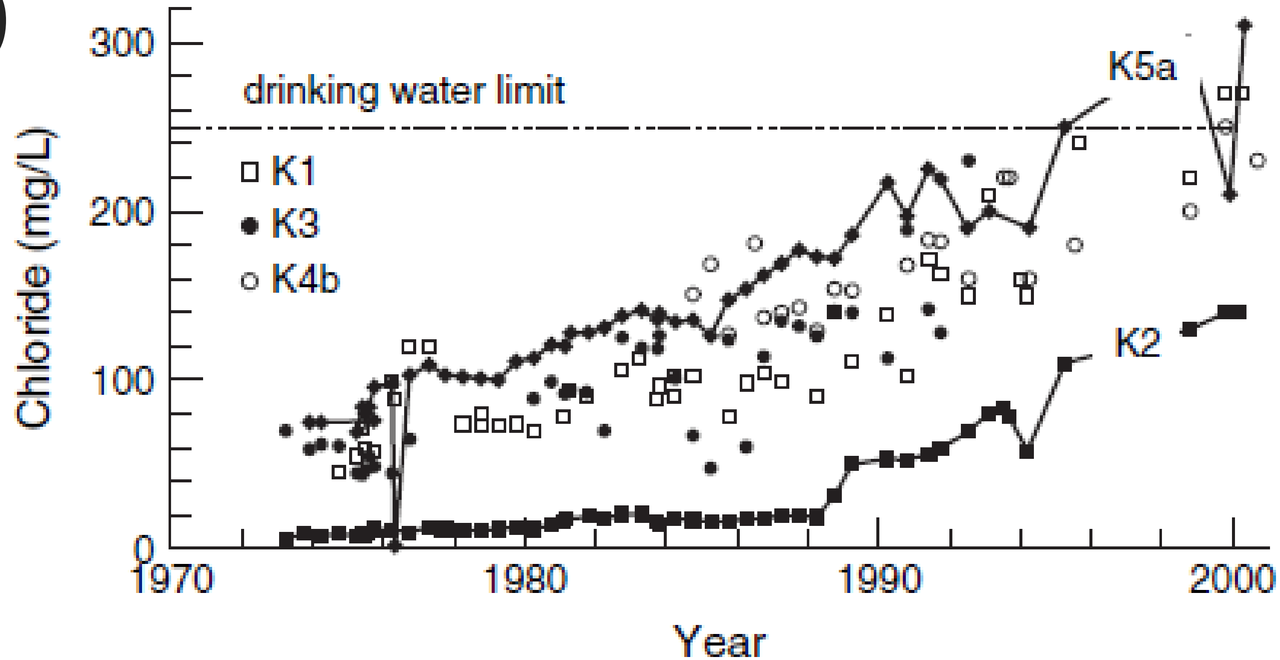
- More recently, the CCME (2011) has introduced a non-binding guideline for chlorides in surface waters:

Long-Term (Chronic) Exposure	Short-Term (Acute) Exposure
120 mg Cl^-/L	640 mg Cl^-/L

Regulations

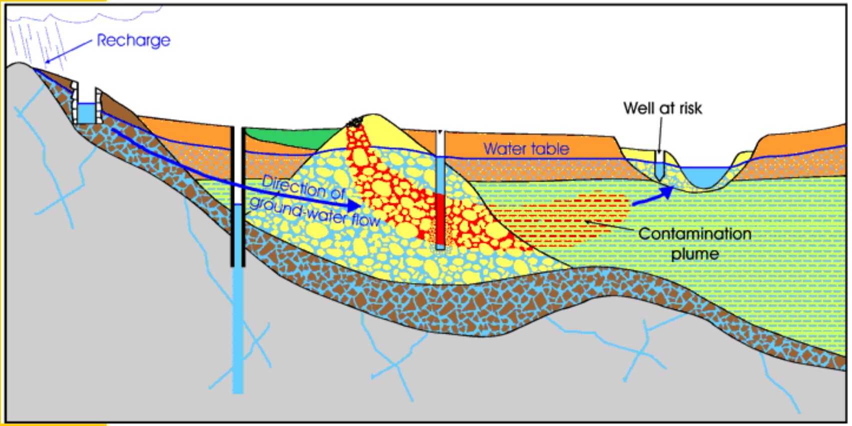
Aesthetic chloride ion concentration (taste) objectives for Ontario drinking water are 250 mg/L Cl^-

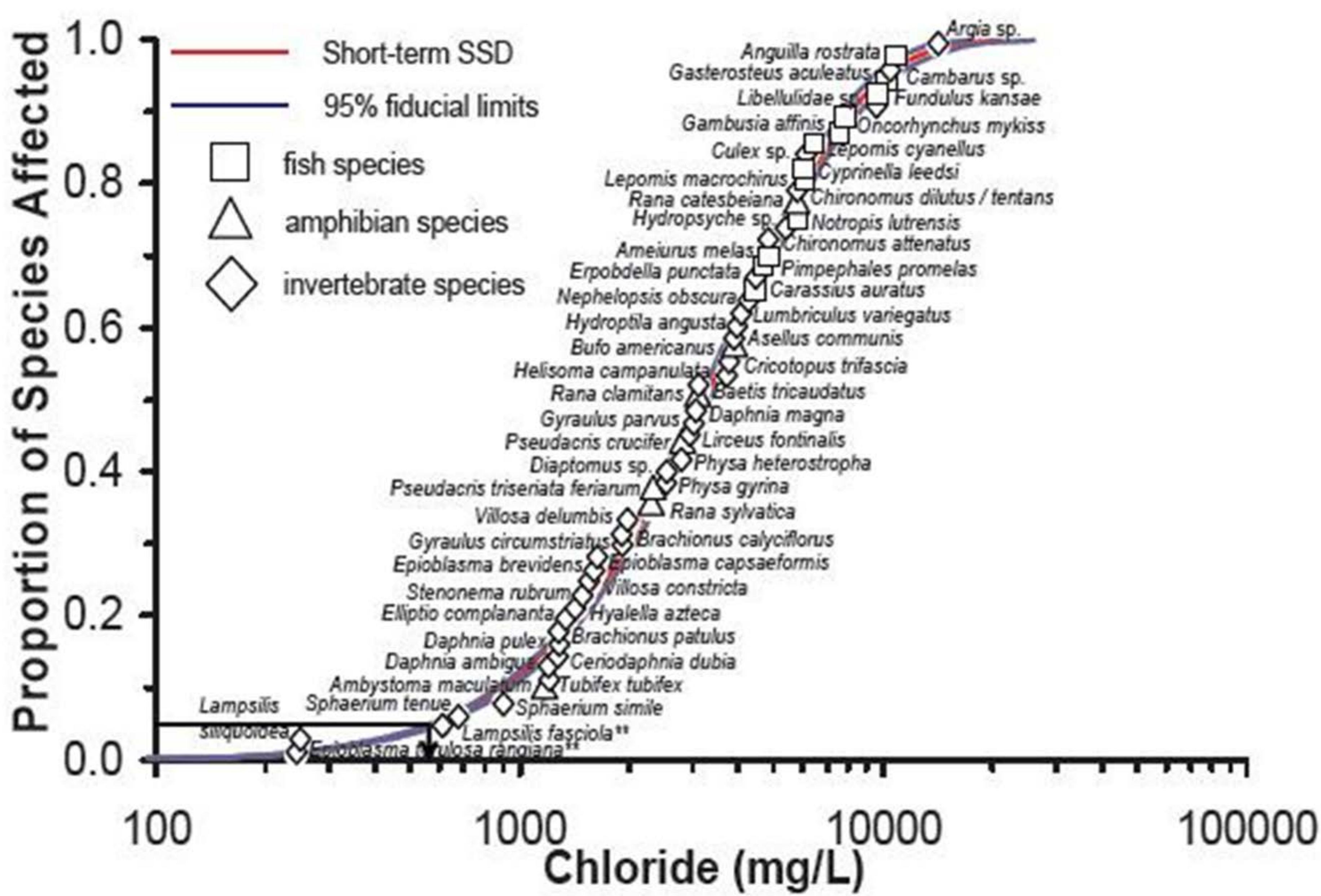
- Exceedances of this have already been detected in urban wellfields in the Waterloo area (Bester et al., 2006)



Implications

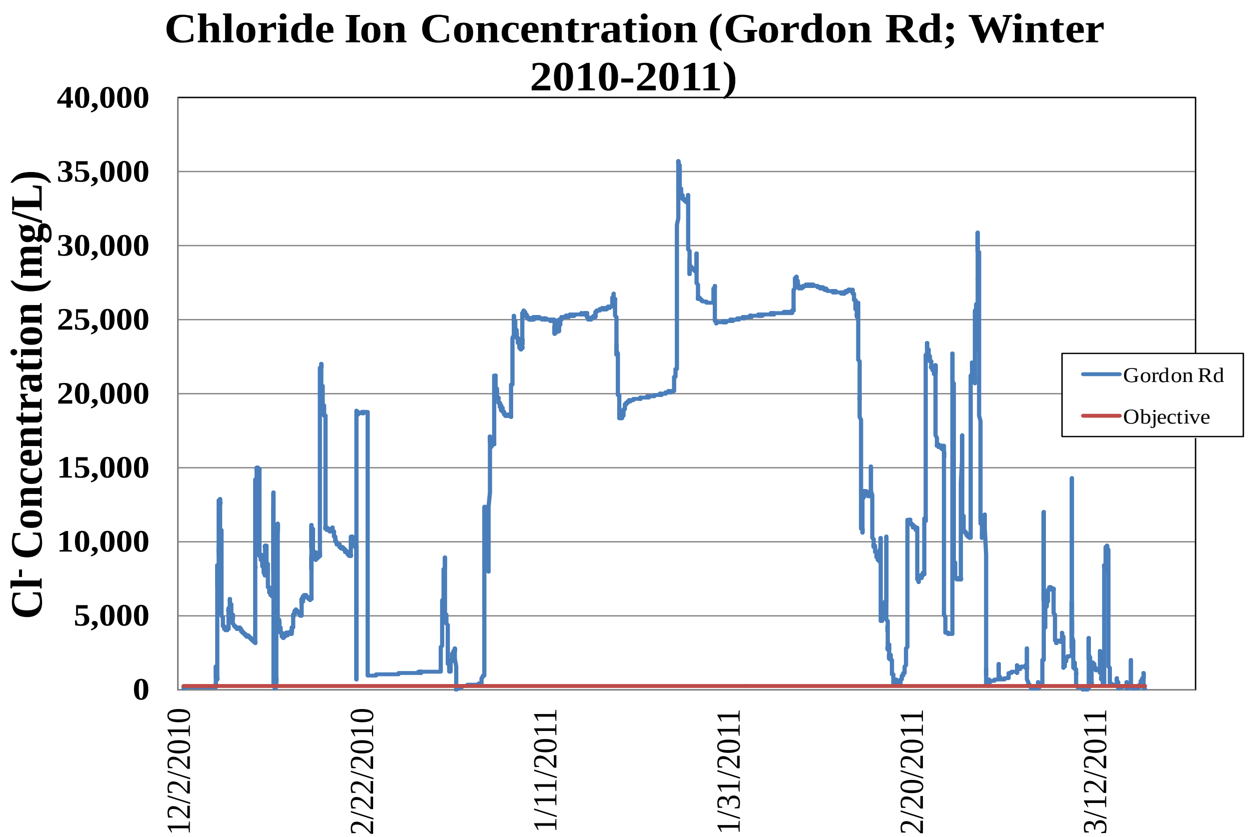
- Chemically-induced meromixis
- Death of aquatic organisms
- Groundwater concentrations of Cl^- in excess of 1,600mg/L found in Pickering
  - Greatly exceeds Ontario drinking water guidelines
  - Exceeds 96h LC50 for some amphibians

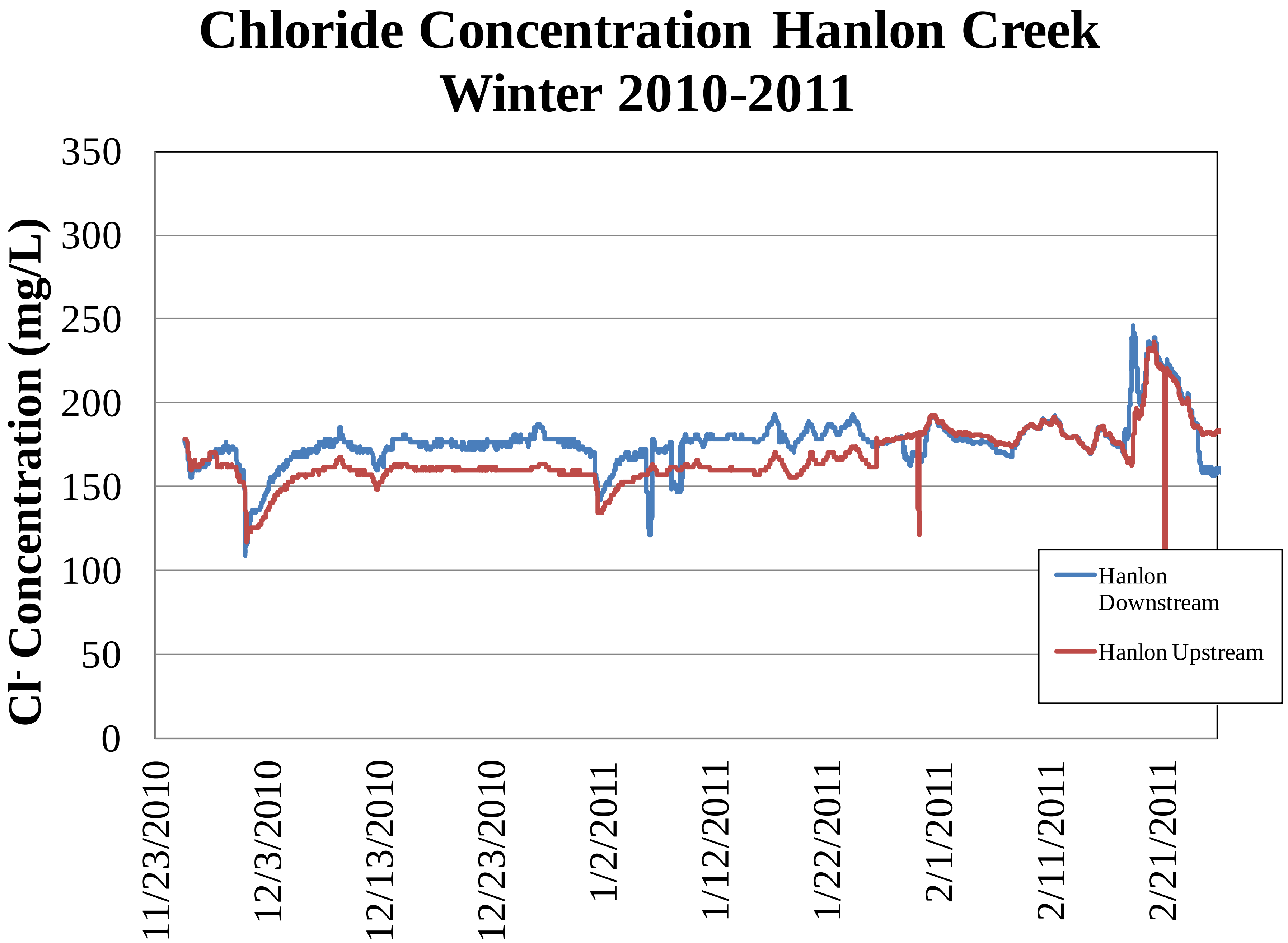



Proportion of Species Affected
1.0
0.8
0.6
0.4
0.2
0.0
Short-term SSD
95% fiducial limits
fish species
amphibian species
invertebrate species
Argia sp.
Anguilla rostrata
Gasterosteus aculeatus
Cambarus sp.
Fundulus kansae
Gambusia affinis
Oncorhynchus mykiss
Culex sp.
Cyprinella leedsi
Lepomis macrochirus
Rana catesbeiana
Chironomus dilutus / tentans
Notropis lutrensis
Chironomus attenatus
Ameiurus melas
Erpobdella punctata
Pimpephales promelas
Nephelopsis obscura
Carassius auratus
Hydroptila angusta
Lumbriculus variegatus
Bufo americanus
Asellus communis
Helisoma campanulata
Cricotopus trifascia
Rana clamitans
Gyraulus parvus
Daphnia magna
Pseudacris crucifer
Lirceus fontinalis
Diaptomus sp.
Physa heterostropha
Pseudacris triseriata feriarum
Physa gyrina
Villosa delumbis
Rana sylvatica
Gyraulus circumstriatus
Brachionus calyciflorus
Epioblasma brevidens
Stenonema rubrum
Villosa constricta
Elliptio complananta
Hyalella azteca
Daphnia pulex
Brachionus patulus
Ceriodaphnia dubia
Tubifex tubifex
Sphaerium tenue
Sphaerium simile
Lampsilis siliquoidea
Lampsilis fasciola**
100
1000
10000
100000
Chloride (mg/L)

Implications

- Our research group has collected streamside chloride ion concentrations in excess of 5,700 mg/L in urban areas





Chloride Concentration Hanlon Creek
Winter 2010-2011
Cl- Concentration (mg/L)
350
300
250
200
150
100
50
0
11/23/2010
12/3/2010
12/13/2010
12/23/2010
1/2/2011
1/12/2011
1/22/2011
2/1/2011
2/11/2011
2/21/2011
Hanlon Downstream
Hanlon Upstream

Can we protect surface and groundwater from spikes in chloride ion concentration?

YES!

...Seriously

Objectives

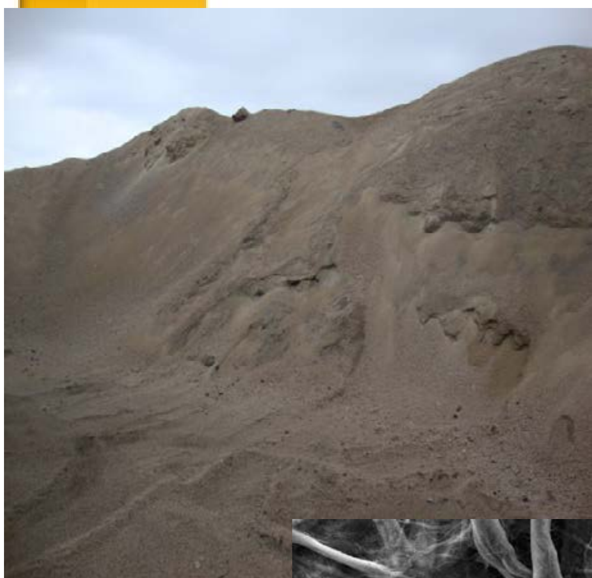
Using bench-scale tests, assess the adsorption capability of several media at removing common highway pollutants

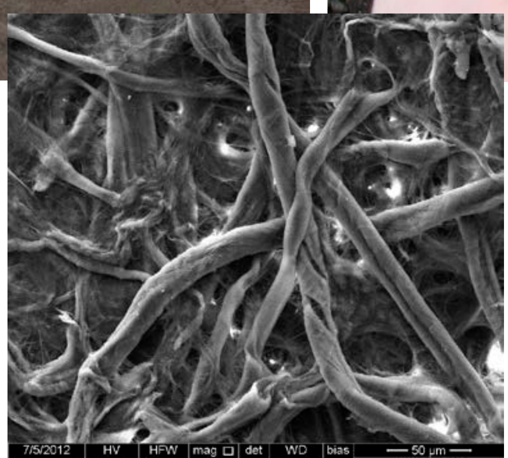
Assess the imperviousness and longevity of several liners under normal field conditions, and quantify their effectiveness at protecting groundwater

Using continuous monitoring techniques, assess the performance of the installed field system at capturing, detaining and attenuating the movement of multiple pollutants

Laboratory Testing

Based on a review of the literature, multiple candidate materials were tested:





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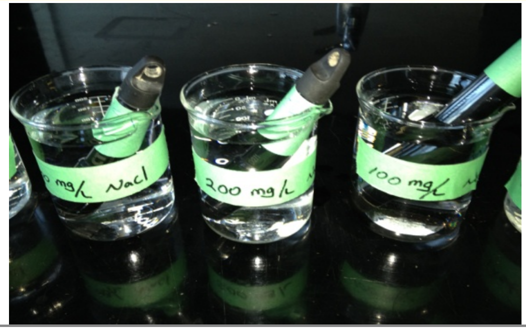
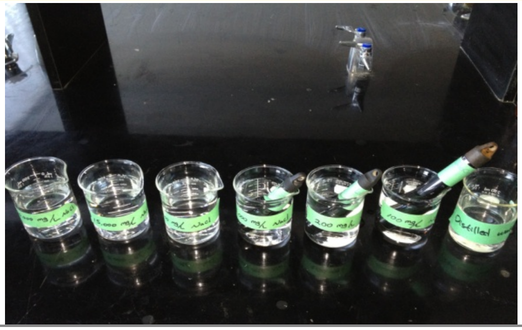
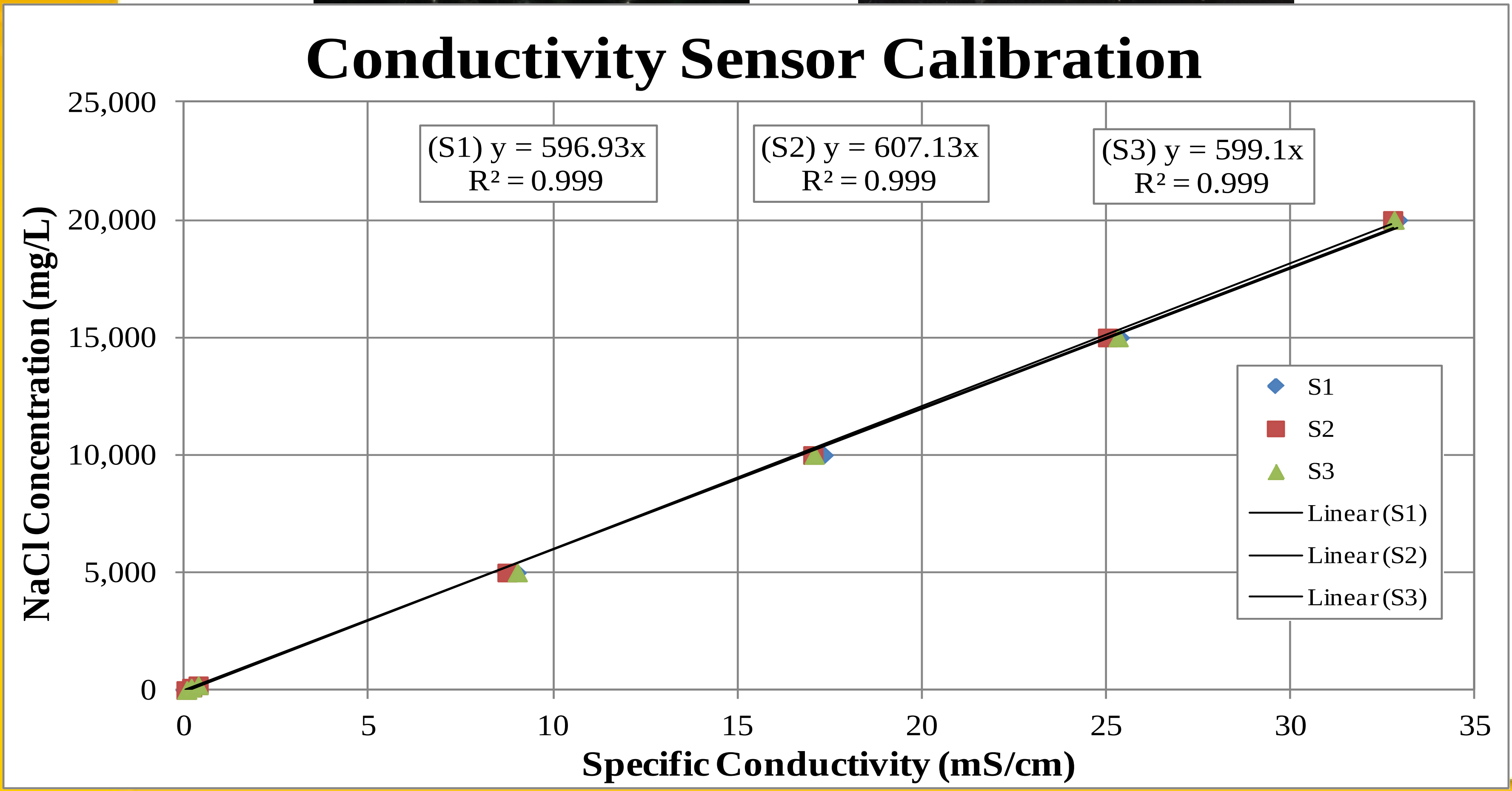
Column and Shaker Tests

- Laboratory shaker tests to screen candidate material
- Column and drip testing for successful materials

Sensor Calibration







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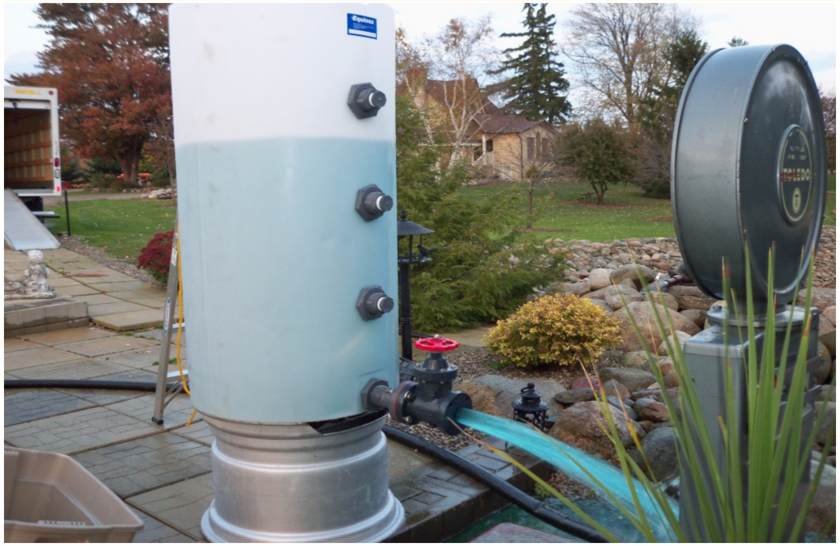
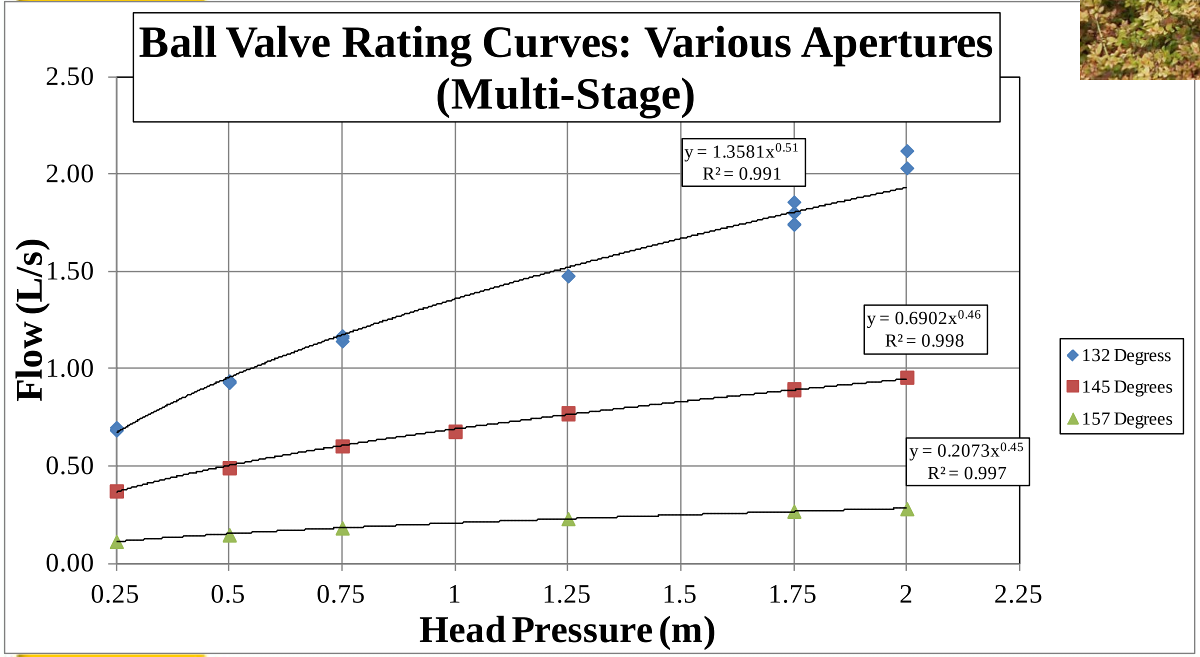
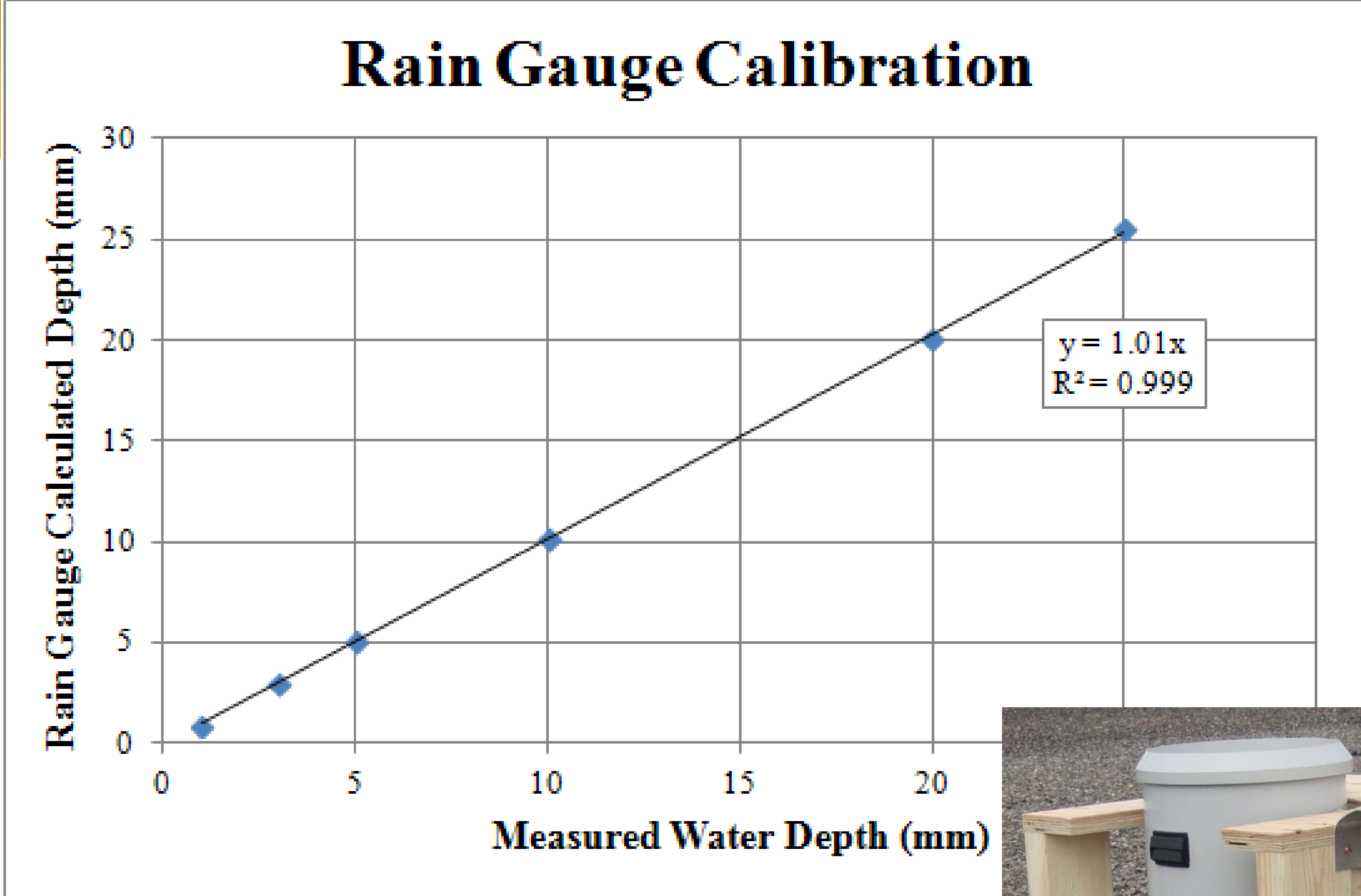
Valve Calibration



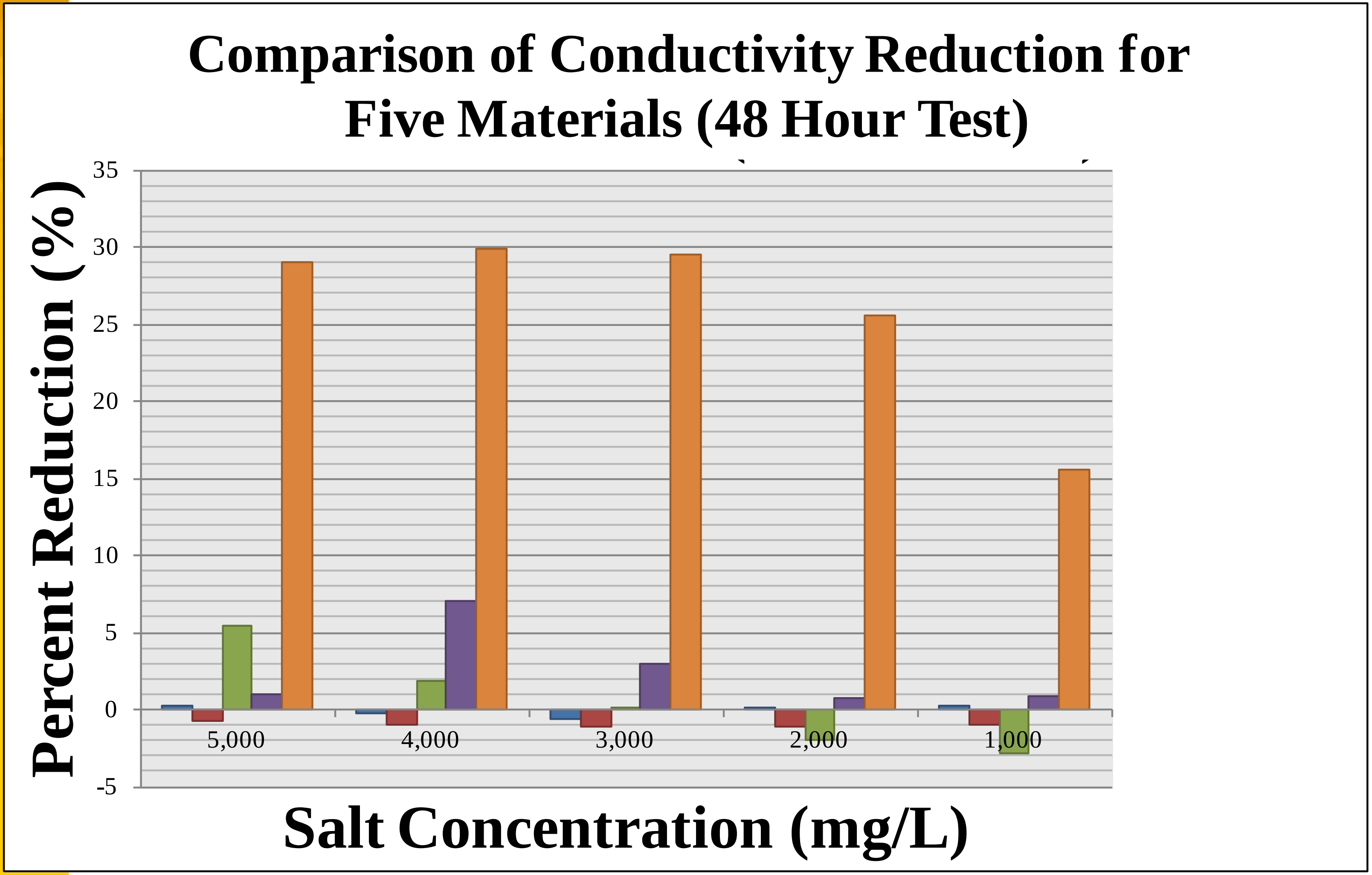




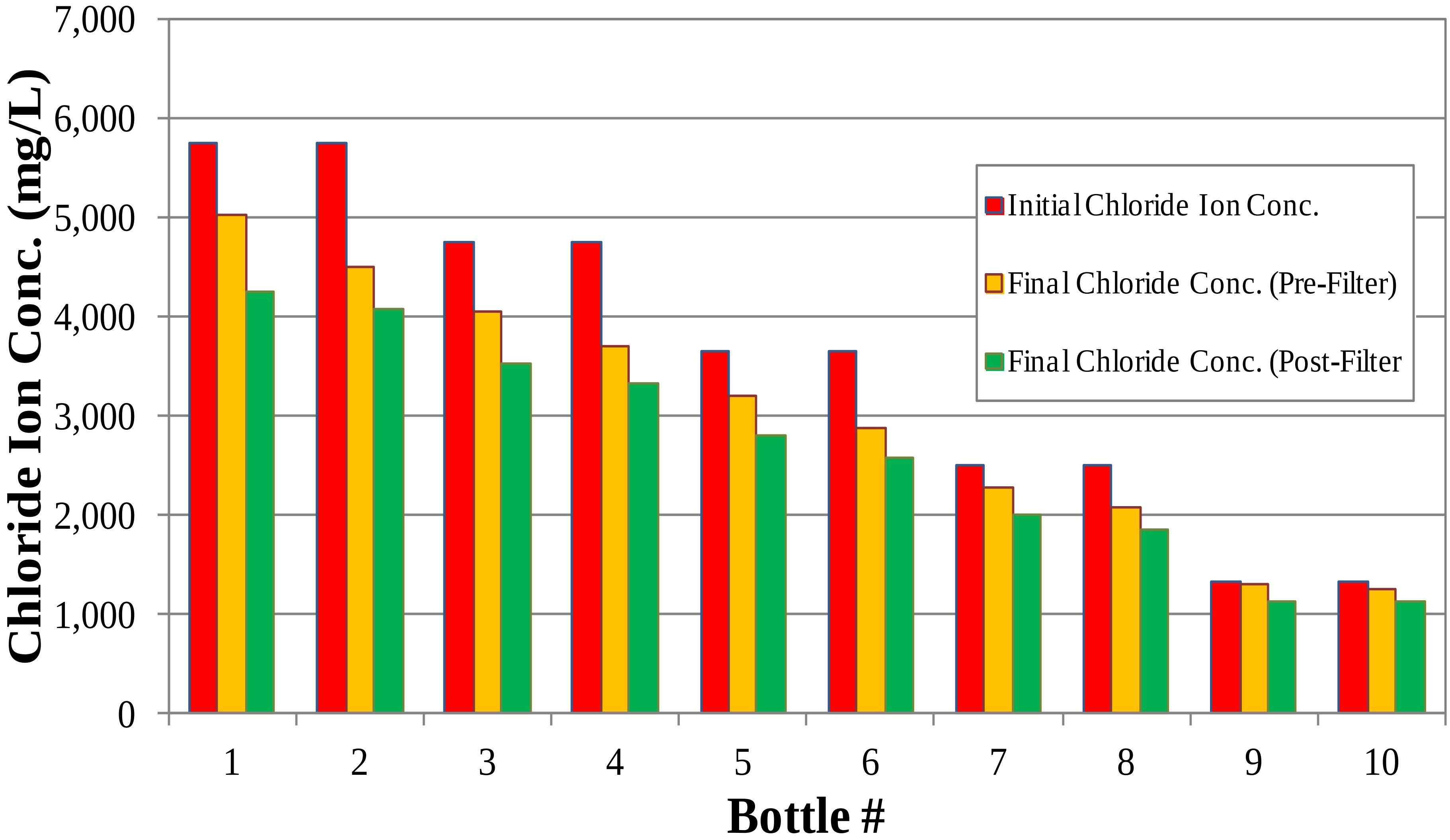
Rain Gauge Calibration
Rain Gauge Calculated Depth (mm)
30
25
20
15
10
5
0
0
5
10
15
20
Measured Water Depth (mm)
y = 1.01x
R² = 0.999

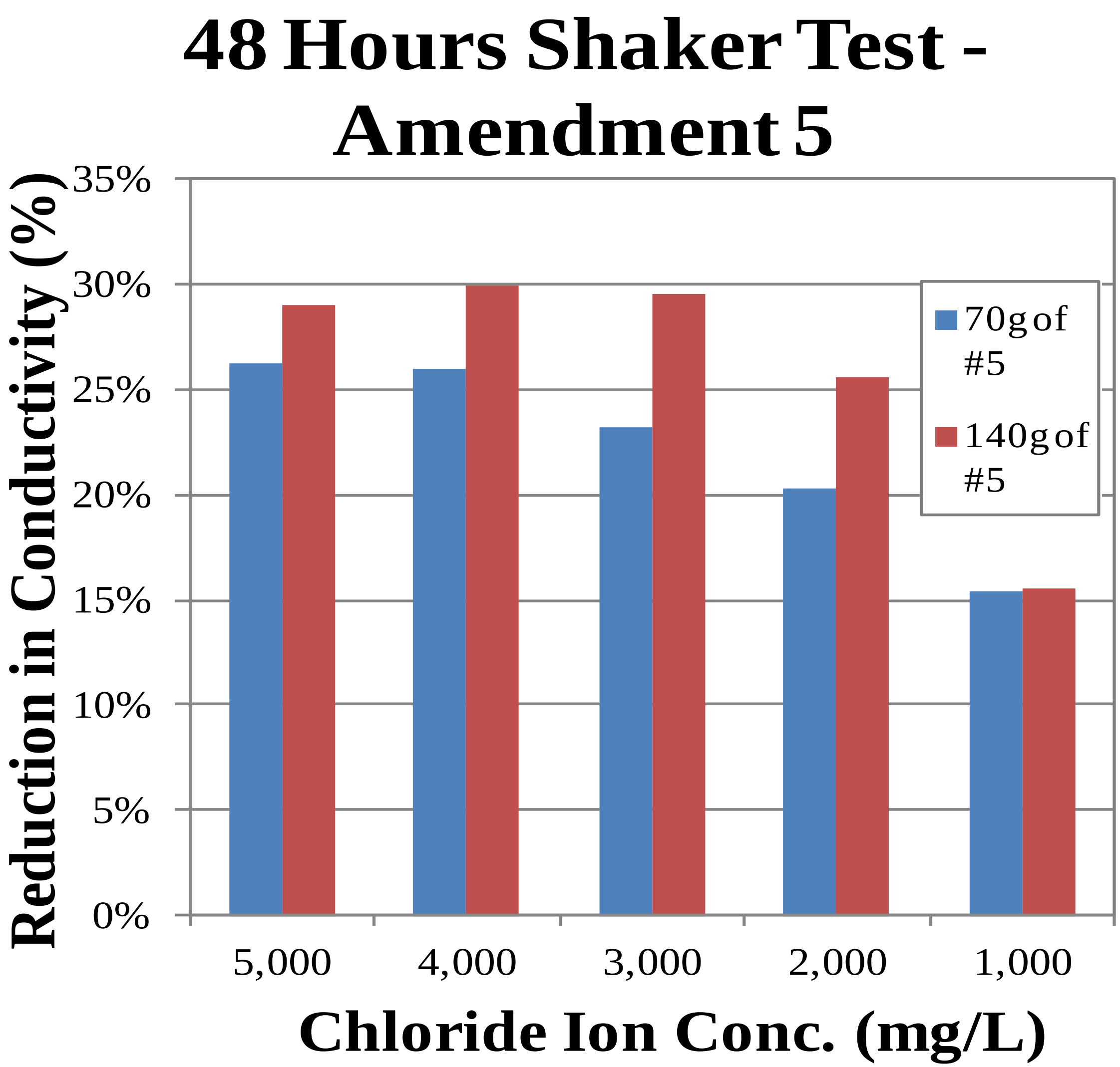
Preliminary Observations

- There are some promising candidate materials:



Chloride Removal for Amendment 5

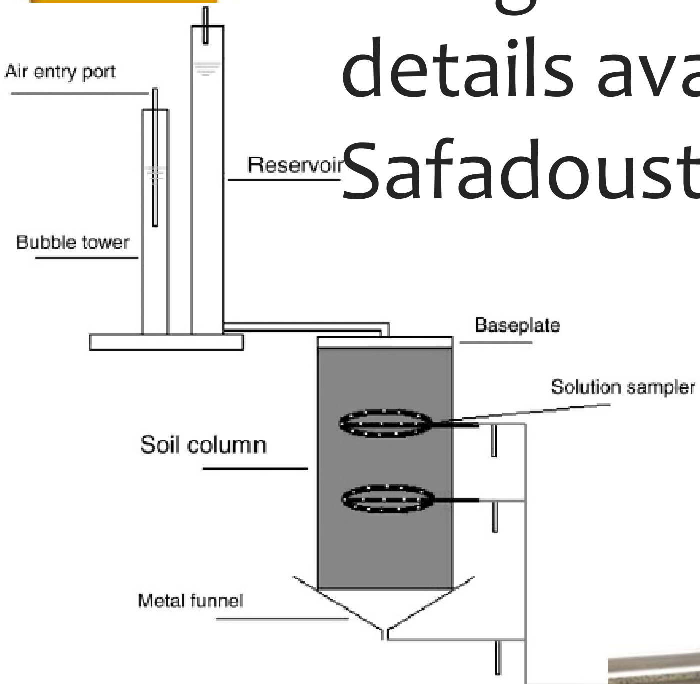


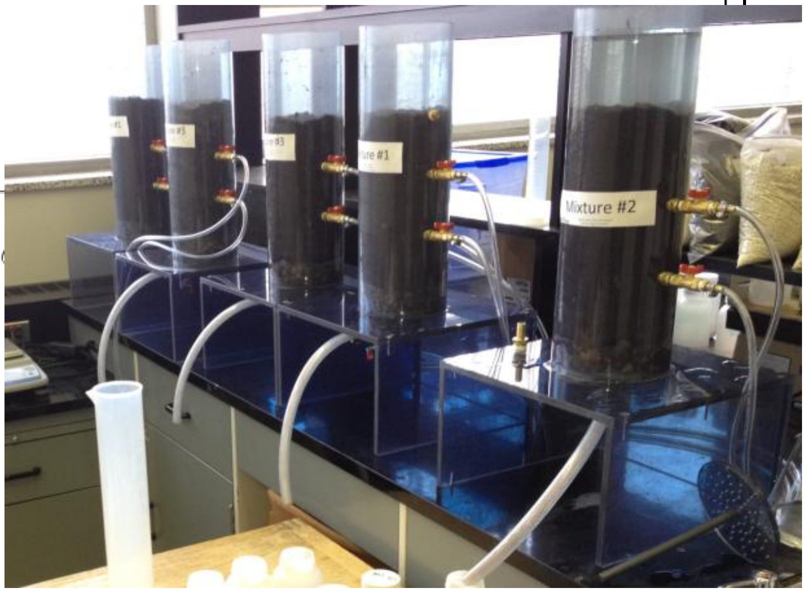


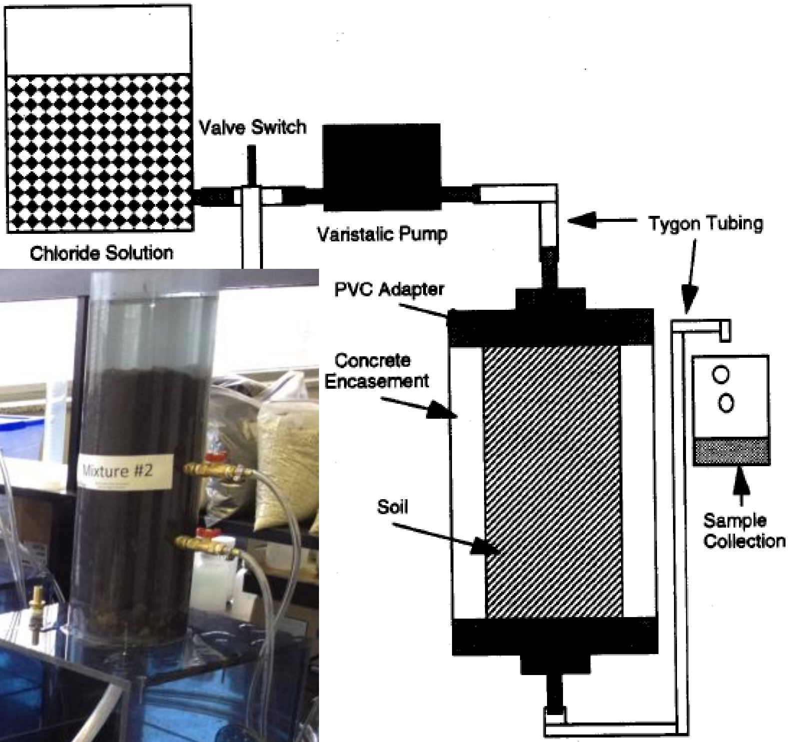
- Calibration is linear, so results correspond to 30% reduction in $[Cl^-]$

Column Construction

- Design based on research objectives and details available in the literature (e.g. Safadoust et al., 2011; Starrett et al., 1996)

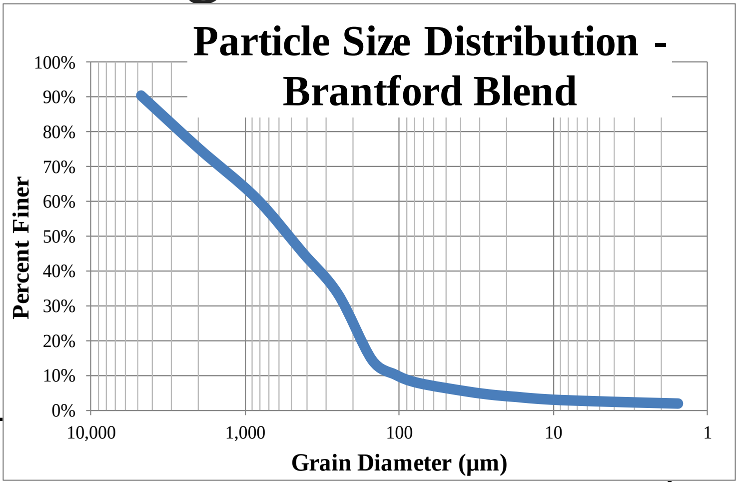






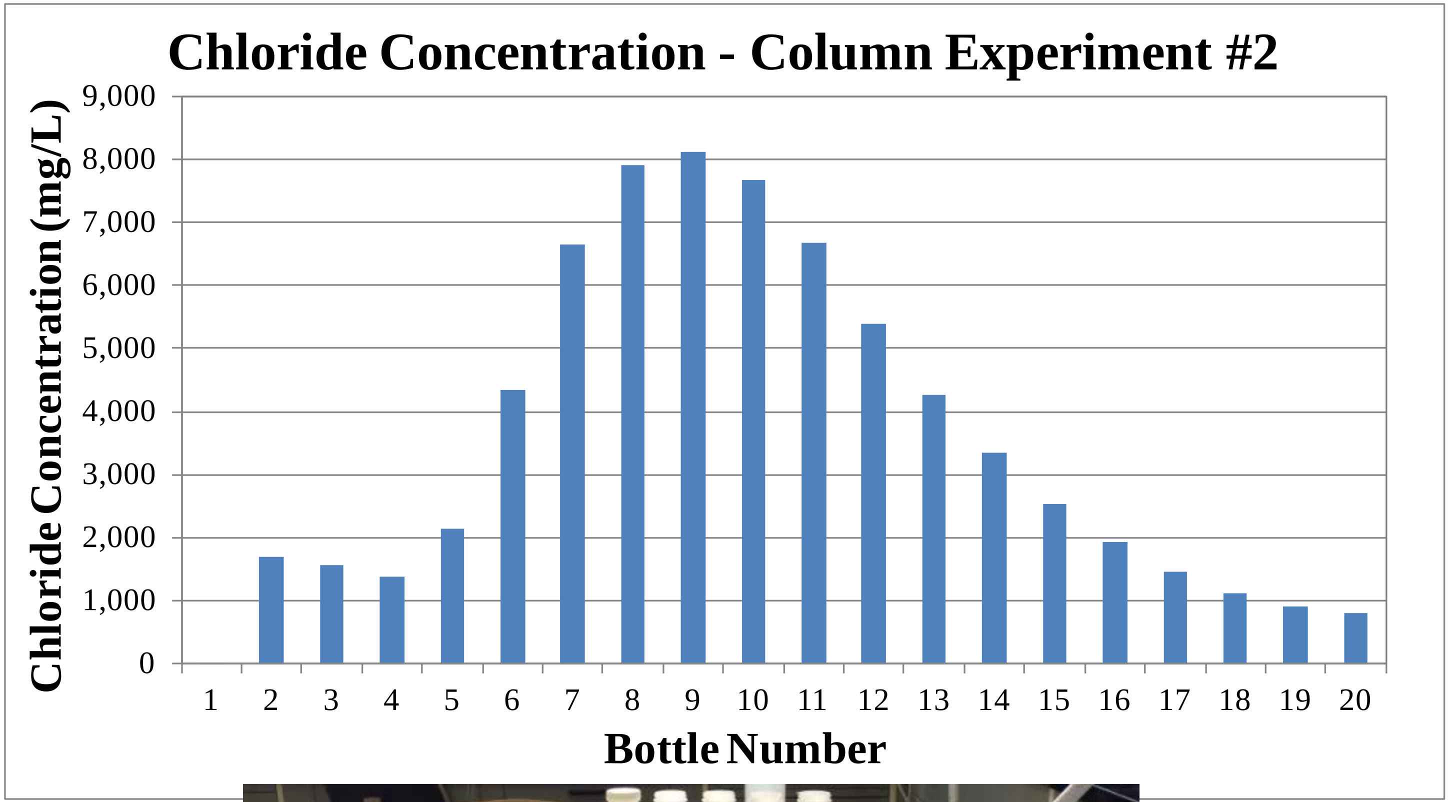
Soil Characterization

- Soils were all high in OM
  - Samples collected from Municipalities of Brantford, Peel, Peterborough as well as private landscape contractors



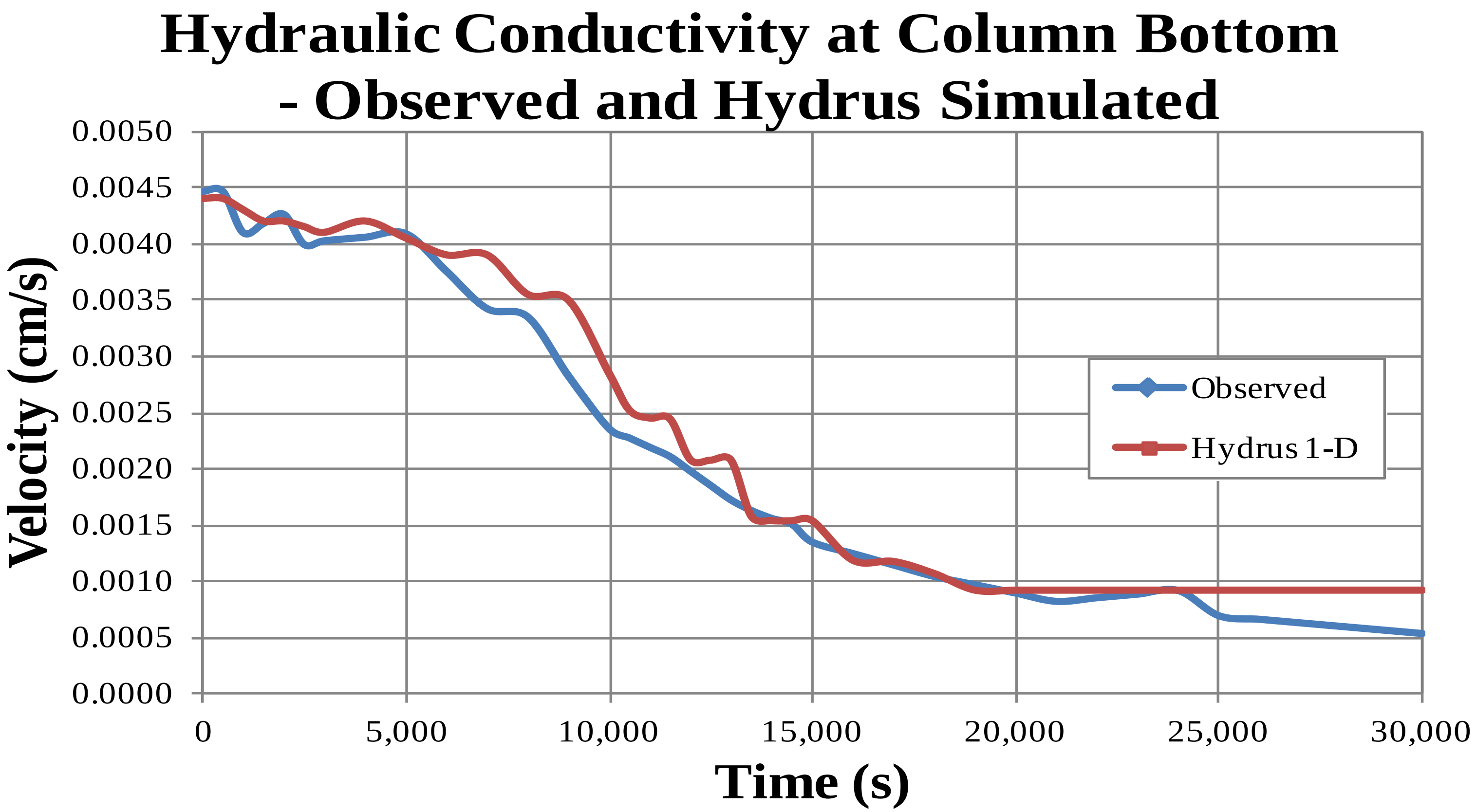
Parameter	Soil Type				
	Brantford	Bimbrook	Peterbrough	Peel Region	Triple Mix
Porosity (φ)	0.47	0.56	0.56	0.54	0.53
Void Ratio (e)	0.89	1.26	1.27	1.18	1.13
Bulk Density (ρ_b; kg/m^3)	1161	674	225	516	910
Specific Gravity (G_s)	2.20	1.53	0.51	1.13	1.95

Laboratory Results

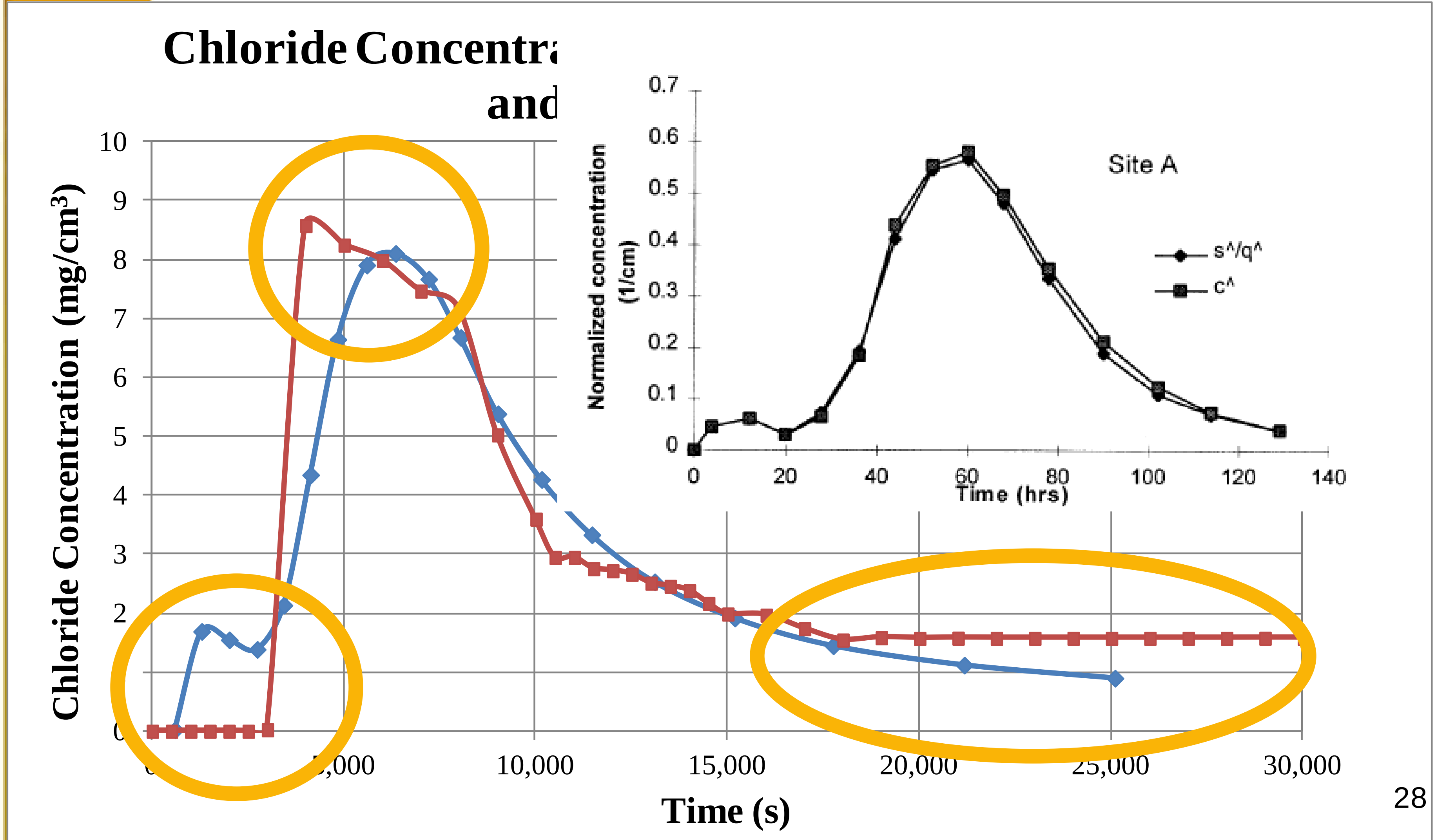


Hydrus Modelling

- Used the collected laboratory data (soil, flow rate & head) to calibrate Hydrus 1-D
  - First calibrated for flow



- A few observations…



Column Modelling Results

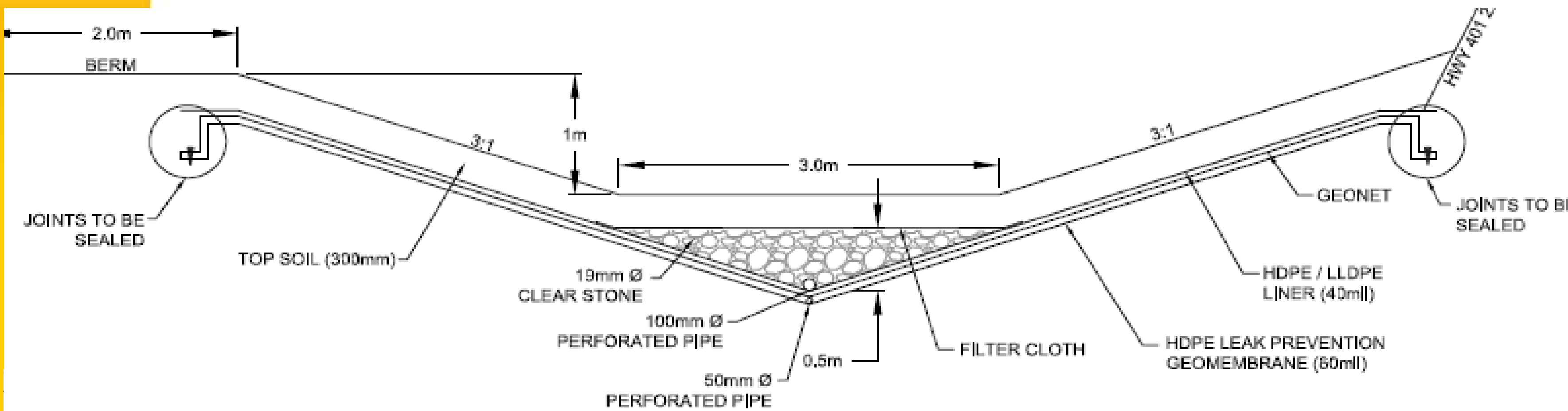
- Hydrus 1-D did a good job of simulating both flow and chloride movement through a simple, homogenous laboratory soil

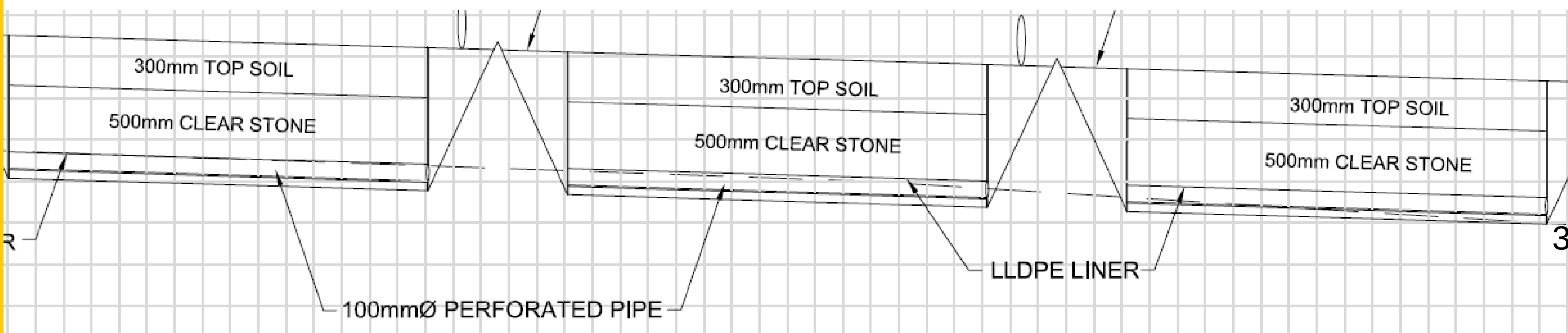
- Despite lots of measured inputs, there was some variability between both the observed and predicted parameters

Field Facility

Upscaling from the Laboratory to the Field

- Peak dampening from diffusion, storage & adsorption
- Testing of Various Liners
- Sub-surface Leak Detection






CANAL 3
WITH
ALUM

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Date/Time	Battery (v)	D1 Pres (cm)	D1 Temp (C)	D1 Cond (mS/cm)	D1 Baro (cm)	D1 Level (cm)	D2 Pres (cm)	D2 Temp (C)	D2 Cond (mS/cm)	D2 Baro (cm)	D2 Level (cm)	D3 Pres (cm)	D3 Temp (C)	D3 Cond (mS/cm)	D3 Baro (cm)	D3 Level (cm)	D4 Pres (cm)	D4 Temp (C)	D4 Cond (mS/cm)	D4 Baro (cm)	D4 Level (cm)	D5 Pres (cm)	D5 Temp (C)	D5 Cond (mS/cm)	D5 Baro (cm)	D5 Level (cm)	D6 Pres (cm)	D6 Temp (C)	D6 Cond (mS/cm)	D6 Baro (cm)	D6 Level (cm)	D7 Pres (cm)	D7 Temp (C)	D7 Cond (mS/cm)	D7 Baro (cm)	D7 Level (cm)	D8 Pres (cm)	D8 Temp (C)	D8 Cond (mS/cm)	D8 Baro (cm)	D8 Level (cm)	D9 Pres (cm)	D9 Temp (C)	D9 Cond (mS/cm)	D9 Baro (cm)	D9 Level (cm)	D10 Pres (cm)	D10 Temp (C)	D10 Cond (mS/cm)	D10 Baro (cm)	D10 Level (cm)	D11 Pres (cm)	D11 Temp (C)	D11 Cond (mS/cm)	D11 Baro (cm)	D11 Level (cm)	D12 Pres (cm)	D12 Temp (C)	D12 Cond (mS/cm)	D12 Baro (cm)	D12 Le
03/25/2014 20:10	17.95	1,009.29	0.41	6.61	994.40	14.89	1,008.29	0.57	6.96	994.29	14.00	1,004.09	0.48	4.65	993.00	11.09	1,008.40	0.67	17.36	993.09	15.31	1,003.90	1.19	5.54	994.40	9.50	1,006.00	1.14	1.96	993.90	12.10	1,007.79	0.84	31.19	996.70	11.09	1,003.79	1.16	2.84	998.59	5.20	1,004.79	0.80	14.93	994.40	10.39	1,005.00	0.53	8.87	997.09	7.91	1,005.59	0.61	9.69	996.09	9.50	1,008.09	0.83	34.16	997.79	10
03/25/2014 20:00	18.27	1,009.09	0.41	6.61	993.40	15.69	1,008.09	0.57	6.96	994.40	13.69	1,003.70	0.48	4.65	992.59	11.11	1,008.20	0.67	17.36	992.50	15.70	1,003.79	1.18	5.53	994.29	9.50	1,005.90	1.14	1.96	994.40	11.50	1,007.40	0.84	31.19	996.50	10.90	1,003.50	1.17	2.85	998.29	5.21	1,004.50	0.80	14.94	994.79	9.71	1,004.79	0.53	8.87	996.90	7.89	1,005.40	0.61	9.68	995.79	9.61	1,007.79	0.83	34.16	997.40	10
03/25/2014 19:50	18.37	1,008.79	0.41	6.60	993.50	15.29	1,007.79	0.56	6.96	994.50	13.29	1,003.29	0.48	4.64	992.40	10.89	1,007.90	0.67	17.36	992.90	15.00	1,003.29	1.19	5.53	993.50	9.79	1,005.50	1.14	1.96	993.59	11.91	1,007.29	0.83	31.19	995.79	11.50	1,003.20	1.17	2.85	997.79	5.41	1,004.29	0.80	14.92	994.20	10.09	1,004.59	0.53	8.86	996.50	8.09	1,005.00	0.61	9.68	995.50	9.50	1,007.70	0.83	34.16	997.29	10
03/25/2014 19:40	18.39	1,008.40	0.40	6.61	992.40	16.00	1,007.59	0.56	6.96	993.50	14.09	1,003.09	0.48	4.64	992.40	10.69	1,007.59	0.66	17.36	992.00	15.59	1,002.90	1.19	5.52	993.20	9.70	1,005.20	1.14	1.96	993.59	11.61	1,006.90	0.84	31.21	995.90	11.00	1,002.90	1.18	2.84	997.90	5.00	1,004.09	0.80	14.92	994.40	9.69	1,004.50	0.53	8.86	996.59	7.91	1,004.90	0.61	9.68	995.00	9.90	1,007.29	0.83	34.16	997.00	10
03/25/2014 19:30	17.74	1,008.40	0.40	6.61	992.59	15.81	1,007.29	0.56	6.96	993.50	13.79	1,003.09	0.48	4.64	992.00	11.09	1,007.40	0.66	17.37	991.79	15.61	1,002.79	1.20	5.52	992.79	10.00	1,005.00	1.14	1.96	993.00	12.00	1,006.70	0.83	31.19	995.70	11.00	1,002.59	1.18	2.84	997.50	5.09	1,003.79	0.80	14.92	993.50	10.29	1,004.09	0.53	8.86	995.40	8.69	1,004.50	0.61	9.68	994.90	9.60	1,007.00	0.83	34.16	996.50	10
03/25/2014 19:20	18.11	1,008.00	0.40	6.60	992.29	15.71	1,007.09	0.56	6.96	993.09	14.00	1,002.90	0.48	4.64	991.90	11.00	1,007.20	0.66	17.37	991.90	15.30	1,002.70	1.20	5.52	993.40	9.30	1,004.79	1.14	1.96	993.00	11.79	1,006.70	0.83	31.20	995.50	11.20	1,002.20	1.18	2.84	997.29	4.91	1,003.70	0.80	14.93	994.00	9.70	1,003.90	0.53	8.86	996.29	7.61	1,004.50	0.61	9.68	994.90	9.60	1,006.79	0.83	34.16	996.59	10
03/25/2014 19:10	17.80	1,007.79	0.40	6.60	992.59	15.20	1,007.00	0.56	6.96	992.90	14.10	1,002.50	0.47	4.64	991.59	10.91	1,007.00	0.66	17.37	991.70	15.30	1,002.50	1.21	5.52	992.70	9.80	1,004.59	1.14	1.96	993.29	11.30	1,006.50	0.83	31.20	995.50	11.00	1,002.40	1.18	2.85	997.29	5.11	1,003.50	0.80	14.93	993.50	10.00	1,003.70	0.52	8.86	995.79	7.91	1,004.29	0.60	9.68	994.50	9.79	1,006.59	0.83	34.16	996.40	10
03/25/2014 19:00	17.81	1,007.79	0.40	6.61	991.90	15.89	1,007.00	0.56	6.96	992.70	14.30	1,002.40	0.47	4.63	991.40	11.00	1,006.79	0.66	17.37	991.50	15.29	1,002.09	1.22	5.51	992.59	9.50	1,004.50	1.14	1.96	992.70	11.80	1,006.29	0.83	31.20	995.00	11.29	1,002.20	1.18	2.85	997.00	5.20	1,003.29	0.80	14.92	993.70	9.59	1,003.50	0.52	8.85	995.40	8.10	1,004.09	0.60	9.68	994.20	9.89	1,006.59	0.82	34.16	996.50	10
03/25/2014 18:50	17.80	1,007.70	0.40	6.61	991.70	16.00	1,006.90	0.55	6.96	992.79	14.11	1,002.40	0.47	4.63	991.40	11.00	1,006.70	0.66	17.37	991.20	15.50	1,002.09	1.22	5.51	992.40	9.69	1,004.50	1.15	1.96	992.59	11.91	1,006.20	0.83	31.19	995.09	11.11	1,002.00	1.18	2.85	996.79	5.21	1,003.00	0.80	14.92	993.00	10.00	1,003.40	0.52	8.86	995.40	8.00	1,004.09	0.60	9.68	994.00	10.09	1,006.40	0.82	34.16	996.20	10
03/25/2014 18:40	18.61	1,007.70	0.40	6.61	991.90	15.80	1,006.70	0.55	6.96	992.00	14.70	1,002.40	0.47	4.64	991.59	10.81	1,006.70	0.66	17.37	991.50	15.20	1,002.20	1.22	5.50	992.20	10.00	1,004.29	1.15	1.97	992.90	11.39	1,006.29	0.83	31.20	995.00	11.29	1,002.00	1.18	2.85	996.79	5.21	1,003.20	0.80	14.92	992.70	10.50	1,003.20	0.52	8.85	995.50	7.70	1,003.79	0.60	9.70	994.40	9.39	1,006.20	0.82	34.16	996.09	10
03/25/2014 18:30	17.89	1,007.50	0.40	6.60	992.09	15.41	1,006.59	0.55	6.96	992.29	14.30	1,002.29	0.47	4.63	991.20	11.09	1,006.59	0.65	17.40	991.50	15.09	1,002.20	1.23	5.50	992.00	10.20	1,004.29	1.15	1.97	992.40	11.89	1,006.09	0.83	31.18	995.00	11.09	1,002.00	1.18	2.85	996.70	5.30	1,003.00	0.80	14.93	993.00	10.00	1,003.20	0.52	8.85	995.00	8.20	1,003.59	0.60	9.70	993.90	9.69	1,006.29	0.82	34.17	995.79	10
03/25/2014 18:20	17.82	1,007.29	0.39	6.61	992.50	14.79	1,006.59	0.55	6.95	992.50	14.09	1,002.29	0.47	4.62	991.09	11.20	1,006.59	0.65	17.40	991.09	15.50	1,002.20	1.23	5.50	992.00	10.20	1,004.00	1.16	1.97	992.09	11.91	1,005.90	0.82	31.20	995.00	10.90	1,002.00	1.18	2.85	996.29	5.71	1,003.00	0.80	14.92	993.59	9.41	1,003.20	0.51	8.85	995.00	8.20	1,003.90	0.59	9.69	994.09	9.81	1,006.29	0.82	34.15	996.09	10
03/25/2014 18:10	18.05	1,007.29	0.39	6.61	992.00	15.29	1,006.40	0.55	6.95	992.40	14.00	1,002.00	0.47	4.63	991.00	11.00	1,006.29	0.65	17.40	991.20	15.09	1,002.00	1.23	5.49	992.59	9.41	1,004.00	1.16	1.97	992.20	11.80	1,005.90	0.82	31.20	994.90	11.00	1,001.79	1.19	2.85	996.59	5.20	1,002.79	0.80	14.93	993.29	9.50	1,003.40	0.51	8.84	995.29	8.11	1,003.59	0.59	9.70	994.29	9.30	1,006.20	0.82	34.15	995.90	10
03/25/2014 18:00	17.97	1,007.29	0.39	6.60	991.59	15.70	1,006.09	0.54	6.96	992.20	13.89	1,001.79	0.46	4.62	991.29	10.50	1,006.20	0.65	17.40	991.29	14.91	1,001.70	1.23	5.49	992.29	9.41	1,004.00	1.17	1.97	991.79	12.21	1,005.70	0.82	31.19	994.59	11.11	1,001.70	1.18	2.85	996.50	5.20	1,002.50	0.80	14.93	993.09	9.41	1,002.90	0.51	8.84	994.59	8.31	1,003.50	0.59	9.70	993.40	10.10	1,006.20	0.82	34.12	995.79	10
03/25/2014 17:50	18.19	1,007.09	0.39	6.60	992.00	15.09	1,006.29	0.54	6.96	992.29	14.00	1,001.79	0.46	4.62	991.00	10.79	1,006.20	0.64	17.40	991.20	15.00	1,001.70	1.23	5.48	991.70	10.00	1,004.20	1.17	1.97	992.00	12.20	1,005.70	0.82	31.20	994.70	11.00	1,001.50	1.18	2.85	996.29	5.21	1,002.70	0.80	14.93	992.70	10.00	1,002.90	0.51	8.84	994.59	8.31	1,003.59	0.59	9.69	994.00	9.59	1,006.00	0.81	34.12	995.59	10
03/25/2014 17:40	17.97	1,007.09	0.39	6.62	991.70	15.39	1,006.09	0.54	6.96	992.00	14.09	1,001.70	0.46	4.62	991.29	10.41	1,006.20	0.64	17.40	990.50	15.70	1,001.50	1.23	5.48	991.70	9.80	1,003.79	1.18	1.97	992.20	11.59	1,005.59	0.81	31.19	994.70	10.89	1,001.50	1.18	2.86	996.29	5.21	1,002.50	0.80	14.93	992.59	9.91	1,002.70	0.51	8.84	994.40	8.30	1,003.20	0.59	9.69	993.59	9.61	1,005.70	0.81	34.14	995.29	10
03/25/2014 17:30	18.59	1,006.90	0.38	6.62	991.70	15.20	1,006.09	0.54	6.96	992.20	13.89	1,001.70	0.46	4.62	990.90	10.80	1,006.20	0.64	17.40	990.79	15.41	1,001.59	1.23	5.46	991.70	9.89	1,003.50	1.18	1.97	991.70	11.80	1,005.40	0.81	31.16	994.40	11.00	1,001.50	1.18	2.86	996.20	5.30	1,002.40	0.80	14.93	992.79	9.61	1,002.70	0.50	8.84	994.29	8.41	1,003.50	0.58	9.69	994.20	9.30	1,005.59	0.81	34.14	995.29	10
03/25/2014 17:20	18.58	1,006.90	0.38	6.61	991.90	15.00	1,005.90	0.53	6.96	992.20	13.70	1,001.40	0.46	4.61	990.70	10.70	1,005.90	0.64	17.40	991.09	14.81	1,001.59	1.23	5.46	992.09	9.50	1,003.40	1.18	1.97	992.09	11.31	1,005.40	0.81	31.18	994.59	10.81	1,001.09	1.18	2.86	996.00	5.09	1,002.50	0.80	14.93	992.79	9.71	1,002.50	0.50	8.84	994.50	8.00	1,003.29	0.58	9.69	994.09	9.20	1,005.59	0.81	34.14	995.29	10
03/25/2014 17:10	18.47	1,006.70	0.38	6.61	991.29	15.41	1,005.90	0.53	6.96	992.00	13.90	1,001.50	0.45	4.62	991.00	10.50	1,005.90	0.63	17.40	990.59	15.31	1,001.40	1.23	5.46	992.00	9.40	1,003.50	1.19	1.97	991.70	11.80	1,005.40	0.81	31.19	994.00	11.40	1,001.40	1.18	2.86	995.90	5.50	1,002.40	0.80	14.93	993.00	9.40	1,002.70	0.50	8.83	994.59	8.11	1,003.09	0.58	9.69	993.90	9.19	1,005.70	0.80	34.19	995.20	10
03/25/2014 17:00	18.12	1,006.70	0.38	6.61	991.00	15.70	1,005.90	0.53	6.96	992.00	13.90	1,001.20	0.45	4.61	990.50	10.70	1,005.70	0.63	17.40	991.20	14.50	1,001.09	1.23	5.46	992.00	9.09	1,003.50	1.19	1.97	991.79	11.71	1,005.00	0.80	31.25	994.09	10.91	1,001.09	1.18	2.86	995.90	5.19	1,002.09	0.80	14.93	992.40	9.69	1,002.40	0.49	8.85	994.70	7.70	1,002.90	0.57	9.69	993.90	9.00	1,005.59	0.80	34.20	995.00	10
03/25/2014 16:50	18.77	1,006.59	0.37	6.61	990.50	16.09	1,005.59	0.53	6.96	991.50	14.09	1,001.29	0.45	4.60	990.40	10.89	1,005.59	0.63	17.40	990.70	14.89	1,001.09	1.22	5.45	991.50	9.59	1,003.29	1.19	1.97	991.70	11.59	1,004.79	0.80	31.26	994.00	10.79	1,001.00	1.17	2.87	995.59	5.41	1,002.00	0.80	14.93	991.90	10.10	1,002.20	0.49	8.85	993.90	8.30	1,002.79	0.57	9.69	993.00	9.79	1,005.29	0.80	34.19	994.90	10
03/25/2014 16:40	19.34	1,006.29	0.37	6.61	991.09	15.20	1,005.50	0.52	6.96	991.70	13.80	1,001.00	0.45	4.60	990.40	10.60	1,005.59	0.63	17.40	990.29	15.30	1,001.00	1.22	5.45	991.29	9.71	1,003.29	1.18	1.97	991.20	12.09	1,005.00	0.80	31.24	993.90	11.10	1,001.00	1.17	2.87	995.70	5.30	1,001.90	0.80	14.92	992.40	9.50	1,002.20	0.49	8.84	994.20	8.00	1,002.79	0.57	9.69	992.40	10.39	1,005.20	0.80	34.17	995.00	10
03/25/2014 16:30	19.06	1,006.29	0.37	6.61	991.00	15.29	1,005.50	0.52	6.96	991.09	14.41	1,000.79	0.44	4.60	990.70	10.09	1,005.70	0.62	17.40	989.90	15.80	1,001.00	1.22	5.44	991.00	10.00	1,003.09	1.19	1.97	991.09	12.00	1,004.79	0.80	31.24	993.70	11.09	1,000.79	1.17	2.87	995.40	5.39	1,001.70	0.80	14.93	992.00	9.70	1,002.09	0.49	8.84	994.20	7.89	1,002.70	0.56	9.68	993.40	9.30	1,005.20	0.79	34.19	994.79	10
03/25/2014 16:20	18.43	1,006.29	0.37	6.61	990.79	15.50	1,005.50	0.52	6.96	991.20	14.30	1,000.79	0.44	4.60	990.09	10.70	1,005.40	0.62	17.40	990.29	15.11	1,000.79	1.22	5.44	990.90	9.89	1,003.09	1.19	1.97	991.29	11.80	1,004.59	0.79	31.24	993.70	10.89	1,000.79	1.18	2.87	995.09	5.70	1,001.59	0.80	14.93	991.79	9.80	1,002.09	0.48	8.84	994.00	8.09	1,002.50	0.56	9.69	992.29	10.21	1,004.90	0.79	34.18	994.59	10
03/25/2014 15:50	18.69	1,006.00	0.36	6.61	990.29	15.71	1,005.29	0.51	6.96	991.00	14.29	1,000.70	0.43	4.60	989.79	10.91	1,005.00	0.61	17.40	990.20	14.80	1,000.70	1.19	5.42	990.79	9.91	1,002.90	1.19	1.97	991.20	11.70	1,004.50	0.78	31.24	993.29	11.21	1,000.59	1.17	2.88	995.40	5.19	1,001.59	0.80	14.92	991.79	9.80	1,001.70	0.47	8.84	993.70	8.00	1,002.50	0.55	9.68	992.20	10.30	1,004.70	0.78	34.17	994.59	10
03/25/2014 15:40	19.13	1,005.79	0.36	6.61	990.59	15.20	1,005.09	0.51	6.96	991.50	13.59	1,000.59	0.43	4.60	989.79	10.80	1,004.79	0.61	17.40	989.90	14.89	1,000.50	1.20	5.41	991.20	9.30	1,002.59	1.19	1.97	990.90	11.69	1,004.29	0.78	31.24	993.59	10.70	1,000.29	1.17	2.88	995.09	5.20	1,001.40	0.80	14.93	992.09	9.31	1,001.50	0.47	8.83	993.00	8.50	1,002.00	0.55	9.68	992.79	9.21	1,004.50	0.78	34.18	994.40	10
03/25/2014 15:30	18.76	1,006.00	0.36	6.61	990.40	15.60	1,005.09	0.51	6.96	991.09	14.00	1,000.59	0.42	4.60	989.40	11.19	1,004.59	0.61	17.40	989.79	14.80	1,000.59	1.19	5.40	991.00	9.59	1,002.59	1.19	1.97	991.29	11.30	1,004.50	0.78	31.23	993.20	11.30	1,000.40	1.17	2.88	995.00	5.40	1,001.40	0.80	14.93	991.59	9.81	1,001.70	0.47	8.83	993.40	8.30	1,002.40	0.55	9.68	992.50	9.90	1,004.50	0.78	34.17	994.29	10
03/25/2014 15:20	18.08	1,005.79	0.36	6.61	990.20	15.59	1,004.90	0.50	6.96	990.79	14.11	1,000.50	0.42	4.60	989.40	11.10	1,004.90	0.60	17.40	989.79	15.11	1,000.59	1.19	5.40	990.70	9.89	1,002.59	1.19	1.97	990.59	12.00	1,004.29	0.78	31.23	993.09	11.20	1,000.40	1.17	2.88	994.90	5.50	1,001.40	0.80	14.94	991.79	9.61	1,001.59	0.46	8.83	993.09	8.50	1,001.90	0.54	9.70	992.40	9.50	1,004.50	0.78	34.17	994.29	10
03/25/2014 15:10	18.74	1,005.70	0.35	6.61	990.59	15.11	1,005.00	0.50	6.96	991.40	13.60	1,000.50	0.42	4.59	989.90	10.60	1,004.90	0.60	17.40	989.40	15.50	1,000.29	1.19	5.39	990.79	9.50	1,002.59	1.20	1.97	990.79	11.80	1,004.29	0.77	31.24	993.09	11.20	1,000.29	1.17	2.88	995.00	5.29	1,001.29	0.80	14.93	991.90	9.39	1,001.59	0.46	8.82	993.29	8.30	1,002.40	0.54	9.69	991.70	10.70	1,004.50	0.77	34.15	994.29	10
03/25/2014 15:00	18.27	1,005.79	0.35	6.61	990.20	15.59	1,004.90	0.50	6.96	990.59	14.31	1,000.29	0.41	4.58	989.79	10.50	1,004.70	0.60	17.43	989.70	15.00	1,000.09	1.17	5.40	990.29	9.80	1,002.09	1.19	1.97	990.50	11.59	1,004.29	0.77	31.23	993.09	11.20	1,000.29	1.17	2.88	994.79	5.50	1,001.09	0.80	14.93	990.79	10.30	1,001.59	0.46	8.82	993.09	8.50	1,002.09	0.54	9.69	991.59	10.50	1,004.50	0.77	34.18	993.90	10
03/25/2014 14:50	19.07	1,005.79	0.35	6.61	990.20	15.59	1,004.79	0.49	6.97	991.20	13.59	1,000.29	0.40	4.59	989.50	10.79	1,004.90	0.59	17.43	989.50	15.40	1,000.09	1.16	5.39	991.00	9.09	1,002.09	1.18	1.97	990.90	11.19	1,004.40	0.77	31.23	993.00	11.40	1,000.09	1.17	2.88	995.00	5.09	1,001.09	0.80	14.94	991.79	9.30	1,001.40	0.45	8.82	993.50	7.90	1,002.00	0.53	9.69	992.20	9.80	1,004.29	0.77	34.16	994.20	10
03/25/2014 14:40	18.01	1,005.59	0.35	6.61	990.29	15.30	1,004.79	0.49	6.97	990.70	14.09	1,000.40	0.40	4.58	989.20	11.20	1,004.70	0.59	17.43	989.20	15.50	1,000.29	1.16	5.38	990.50	9.79	1,002.09	1.16	1.98	991.00	11.09	1,004.20	0.77	31.24	993.09	11.11	1,000.09	1.17	2.88	994.79	5.30	1,001.09	0.80	14.93	991.29	9.80	1,001.40	0.45	8.82	993.59	7.81	1,002.00	0.53	9.69	992.20	9.80	1,004.29	0.76	34.18	994.09	10
03/25/2014 14:30	18.30	1,005.59	0.35	6.61	990.29	15.30	1,004.90	0.49	6.96	991.00	13.90	1,000.29	0.39	4.59	989.09	11.20	1,004.59	0.59	17.43	989.50	15.09	1,000.29	1.15	5.38	990.59	9.70	1,002.09	1.16	1.98	990.90	11.19	1,004.09	0.76	31.23	993.00	11.09	1,000.09	1.17	2.88	994.70	5.39	1,001.09	0.80	14.94	991.59	9.50	1,001.40	0.44	8.82	993.20	8.20	1,001.70	0.53	9.69	991.50	10.20	1,004.29	0.76	34.16	994.20	10
03/25/2014 14:20	18.80	1,005.59	0.34	6.61	990.20	15.39	1,004.79	0.48	6.96	991.09	13.70	1,000.09	0.39	4.57	989.59	10.50	1,004.59	0.59	17.43	989.90	14.69	1,000.09	1.14	5.37	990.90	9.19	1,002.09	1.16	1.98	990.09	12.00	1,004.09	0.76	31.23	993.00	11.09	1,000.09	1.17	2.88	994.79	5.30	1,001.09	0.80	14.93	991.29	9.80	1,001.40	0.44	8.83	993.50	7.90	1,001.70	0.52	9.69	991.90	9.80	1,004.29	0.76	34.15	994.00	10
03/25/2014 14:10	19.23	1,005.59	0.34	6.61	990.00	15.59	1,004.79	0.48	6.96	991.09	13.70	1,000.40	0.39	4.58	989.59	10.81	1,004.59	0.59	17.43	989.29	15.30	1,000.09	1.13	5.36	989.79	10.30	1,002.20	1.16	1.98	990.50	11.70	1,004.09	0.75	31.29	993.00	11.09	1,000.00	1.16	2.89	994.59	5.41	1,001.09	0.80	14.93	991.50	9.59	1,001.40	0.44	8.83	992.40	9.00	1,002.00	0.52	9.68	991.59	10.41	1,004.09	0.76	34.18	993.90	10
03/25/2014 14:00	18.99	1,005.79	0.34	6.62	990.79	15.00	1,004.79	0.48	6.96	990.90	13.89	1,000.50	0.38	4.58	989.59	10.91	1,004.59	0.58	17.43	989.40	15.19	1,000.29	1.12	5.36	990.50	9.79	1,002.40	1.15	1.98	990.90	11.50	1,004.20	0.75	31.28	993.09	11.11	1,000.09	1.16	2.89	994.70	5.39	1,001.20	0.80	14.93	991.59	9.61	1,001.40	0.43	8.82	993.29	8.11	1,002.00	0.51	9.69	992.00	10.00	1,004.50	0.75	34.21	994.09	10
03/25/2014 13:50	18.82	1,005.50	0.33	6.62	989.59	15.91	1,004.59	0.48	6.96	990.20	14.39	1,000.09	0.38	4.57	988.79	11.30	1,004.29	0.58	17.43	989.59	14.70	1,000.00	1.11	5.36	989.79	10.21	1,002.09	1.15	1.98	990.20	11.89	1,003.79	0.75	31.29	992.70	11.09	999.79	1.16	2.89	994.70	5.09	1,001.00	0.80	14.94	991.20	9.80	1,001.29	0.43	8.82	992.59	8.70	1,001.50	0.51	9.68	991.40	10.10	1,004.09	0.75	34.22	993.90	10
03/25/2014 13:40	18.25	1,005.50	0.33	6.62	989.90	15.60	1,004.50	0.47	6.96	991.00	13.50	1,000.09	0.37	4.57	989.40	10.69	1,004.50	0.58	17.43	989.50	15.00	1,000.00	1.10	5.35	990.09	9.91	1,002.09	1.16	1.98	990.29	11.80	1,003.79	0.75	31.28	992.59	11.20	999.79	1.16	2.89	994.70	5.09	1,001.00	0.79	14.93	991.09	9.91	1,001.29	0.43	8.82	992.59	8.70	1,001.79	0.51	9.68	991.59	10.20	1,004.09	0.74	34.20	994.00	10
03/25/2014 13:30	18.99	1,005.59	0.33	6.62	990.20	15.39	1,004.70	0.47	6.96	990.29	14.41	1,000.29	0.37	4.56	989.20	11.09	1,004.50	0.57	17.42	989.50	15.00	1,000.29	1.10	5.35	990.09	10.20	1,002.20	1.17	1.98	990.59	11.61	1,004.09	0.74	31.28	992.70	11.39	1,000.09	1.17	2.89	994.79	5.30	1,001.00	0.79	14.93	990.90	10.10	1,001.09	0.42	8.82	993.00	8.09	1,001.79	0.50	9.68	992.09	9.70	1,004.09	0.74	34.20	994.20	9.
03/25/2014 13:20	18.53	1,005.59	0.33	6.62	990.09	15.50	1,004.79	0.46	6.96	990.70	14.09	1,000.29	0.37	4.56	989.50	10.79	1,004.90	0.57	17.43	989.40	15.50	1,000.29	1.10	5.34	990.09	10.20	1,002.20	1.17	1.98	990.79	11.41	1,004.29	0.74	31.28	992.70	11.59	999.79	1.16	2.89	994.90	4.89	1,001.00	0.79	14.93	991.20	9.80	1,001.29	0.42	8.82	993.09	8.20	1,001.79	0.50	9.68	991.79	10.00	1,004.09	0.74	34.19	994.00	10

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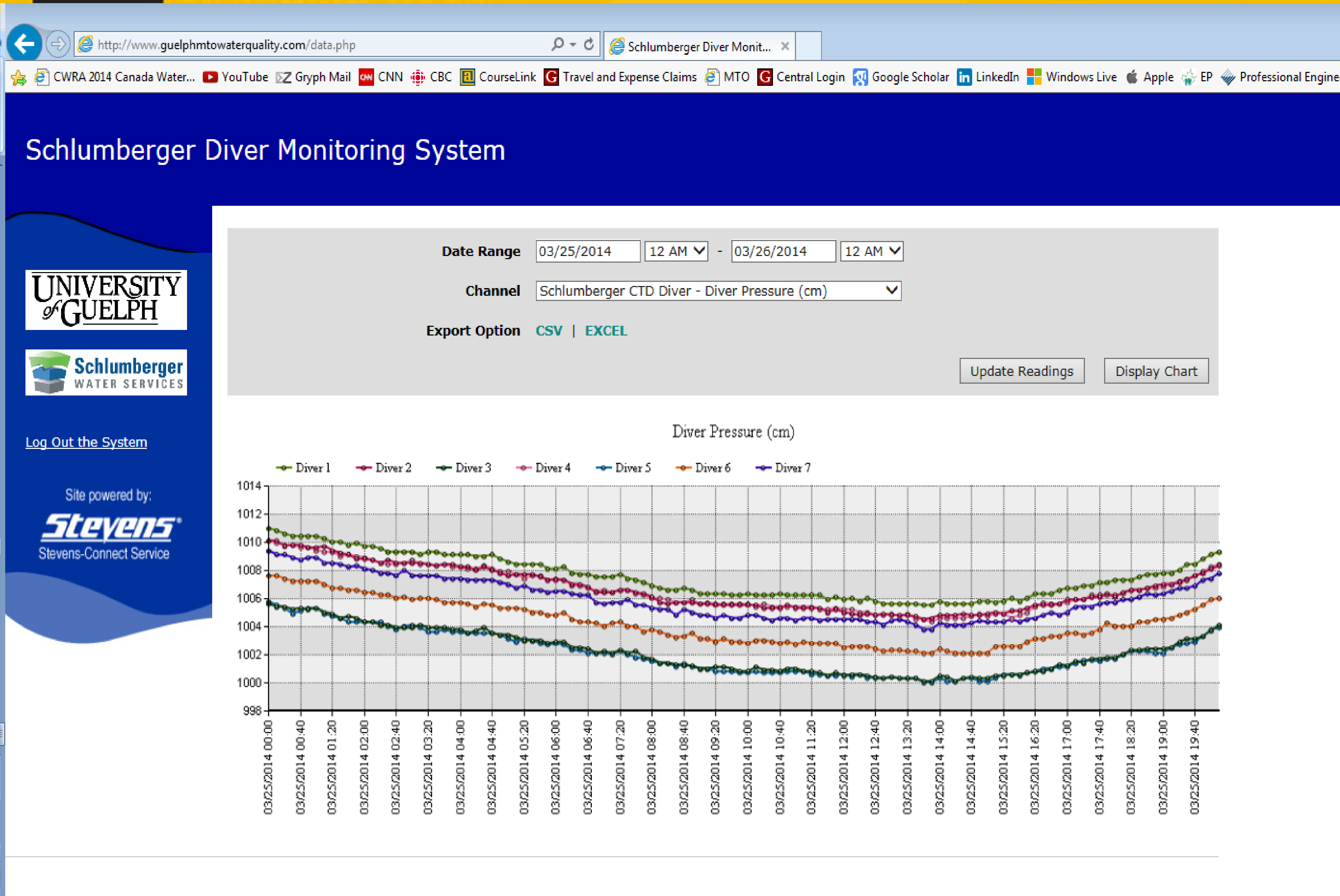


Leak Detection

Storm Dates:		Average	Precipitation	Underdrain Runoff Volume (L)						Leak Runoff Volume (L)					
Start Date	End Date	min (°C)	(mm)	1	2	3	4	5	6	1	2	3	4	5	6
21-Nov-12	21-Nov-12	-3.6	0.0	0	601	0	0	0	0	0	0	0	0	0	0
19-Dec-12	26-Dec-12	-4.1	13.2	0	4000	2240	4354	0	0	0	0	0	0	0	0
25-Dec-12	31-Dec-12	-7.6	7.4	0	10617	0	0	0	0	0	0	0	0	0	0
09-Jan-13	11-Jan-13	-4.0	5.7	0	0	0	0	0	774	0	0	0	0	0	0
11-Jan-13	13-Jan-13	2.2	39.0	3825	1745	2671	0	3020	2026	0	0	0	0	0	0
15-Jan-13	18-Jan-13	-8.4	0.6	1888	1058	1109	0	0	0	0	0	0	0	0	0
21-Jan-13	25-Jan-13	-17.3	0.3	2438	0	0	0	0	318	0	0	0	0	0	0
28-Jan-13	02-Feb-13	-6.2	48.6	0	0	0	0	2855	2842	0	0	0	0	0	0
25-Feb-13	03-Mar-13	-6.0	31.8	265	1037	1113	1896	2399	691	0	0	0	0	0	0
06-Mar-13	07-Mar-13	-2.6	3.3	0	730	0	0	0	0	0	0	0	0	0	0
06-Mar-13	13-Mar-13	-3.2	27.6	4243	8703	8734	6221	3057	8267	0	0	0	0	0	0
22-Mar-13	24-Mar-13	-5.7	0.0	0	0	1011	0	0	1833	0	0	0	0	0	0
01-Apr-13	01-Apr-13	-6.1	0.0	544	410	0	0	0	0	0	0	0	0	0	0
08-Apr-13	11-Apr-13	1.0	67.2	3381	2484	3462	905	41	24	0	0	0	0	0	0
10-Apr-13	13-Apr-13	0.7	49.2	2494	728	2082	2072	186	0	0	0	0	0	0	0
13-Apr-13	14-Apr-13	-0.2	5.7	1726	0	0	0	0	0	0	0	0	0	0	0
22-Apr-13	26-Apr-13	-0.9	8.8	0	204	0	0	0	0	366	453	0	0	238	0
28-Apr-13	29-Apr-13	6.0	9.3	0	834	33	0	120	120	404	684	755	580	1749	0
10-May-13	11-May-13	5.0	18.8	1645	1331	232	0	225	145	1161	1278	378	684	1168	0
17-May-13	18-May-13	6.0	0.0	0	0	0	0	0	0	12502	0	0	0	0	0
23-May-13	25-May-13	1.7	0.0	0	0	0	0	0	0	6357	0	0	0	0	0
28-May-13	29-May-13	12.0	34.8	429	1231	134	0	242	415	0	1793	143	0	246	0
02-Jun-13	02-Jun-13	6.5	9.6	0	286	49	0	0	79	396	1017	0	0	332	0
10-Jun-13	11-Jun-13	14.0	25.2	1493	674	43	0	298	358	0	2491	119	0	408	0
16-Jun-13	16-Jun-13	13.9	10.1	0	73	0	0	45	0	788	0	0	0	0	0
	Total			24370	36746	22914	15448	12487	17892	21975	7716	1396	1264	4141	0

Preliminary Findings - Liners

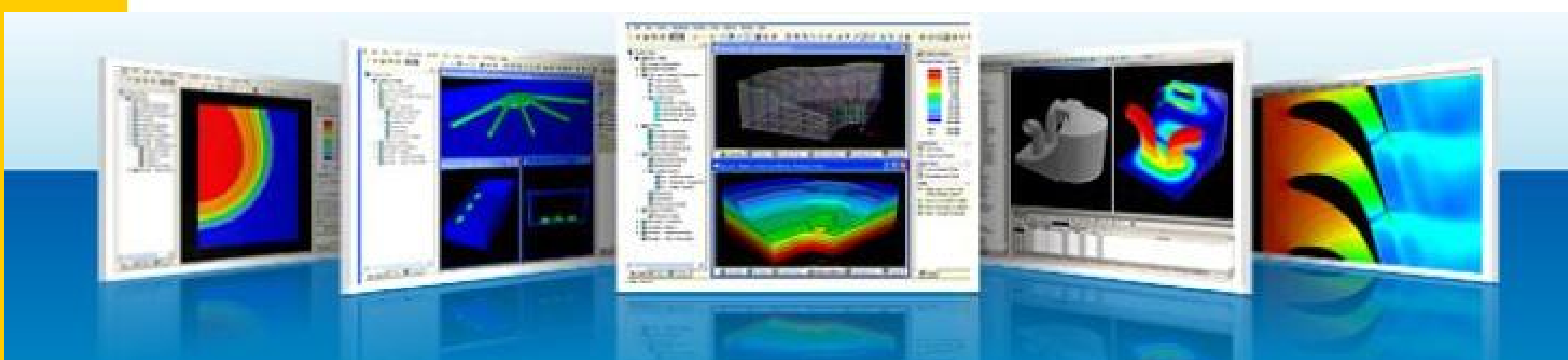
- Compacted Clay allows for upwelling from seasonal water table

- Canal 3 Liner (HPDE) shows promise, as no leaks have been detected in cell # 6 to date

- Seasonally frozen soils appear to inhibit GW/SW interaction → important groundwater implications

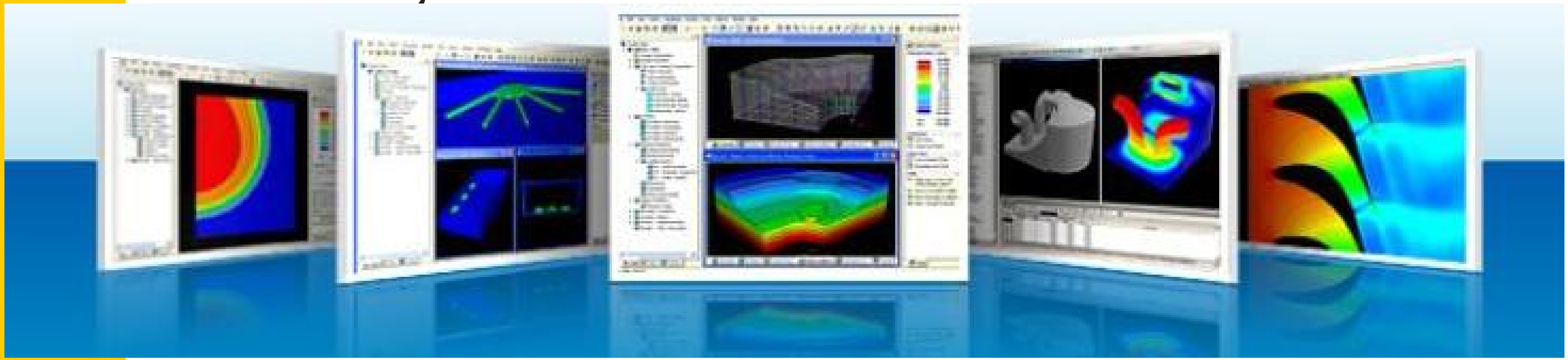
Next Steps

- Initial results are promising, but further testing is required
- More information is needed about the elasticity of the system, as well as the adsorption/desorption parameters



Next Steps

- Begin simulating pollutant transport, capture and diffusion of the field facility using the HYDRUS Model
- Initiate additional monitoring and modelling of the experimental field facility



Acknowledgements

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Thank you

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