DEPARTMENT OF
SOIL SCIENCE
University of Wisconsin-Madison

**Phillip Barak, PhD**
Professor, Department of Soil Science, University of Wisconsin-Madison
1525 Observatory Dr, Madison WI 53706-1207
Tel: 608 263-5450 E-mail: pwbarak@wisc.edu Url: www.soils.wisc.edu/~barak

19 November 2012

Gary Huth, P.E.
Middleton Water Resources Management Commission
Middleton, WI

Dear Gary,

It is my pleasure to transmit this final report as fulfillment of “Causes of the failure of the Costco bioretention system and its remediation”, a grant funded by the City of Middleton and Costco. This report consists of five parts:

- Executive Summary, submitted to the Middleton Water Resource Management Commission prior to their 9/19/2012 meeting
- First Student Report, investigating cause of failure and remediation potential, submitted for fulfillment of Soils 375
- First Presentation to the Water Resource Management Commission, 6/22/2011
- Second Student Report, investigating the rating of an engineered soil for salinity and sodicity hazard, submitted for fulfillment of Soils 375
- Second Presentation to the Water Resource Management Commission, 19/9/2012

In addition to presentations to the WRMC, presentations based on this material have also been made at the NASECA-WI 8th Annual Conference (3 Feb 2011) and the Waukesha County Storm Water Workshop (14 Mar 2012).

This work has enabled the training of six University of Wisconsin-Madison students in their Capstone studies, which provide opportunities for applied, integrative work in teams, with close coordination with university faculty. I hope to encourage a few of them to continue to push this material to its logical conclusion in peer-reviewed publication.

I would never have imagined years ago when I joined the faculty of the UW-Madison that I would have an opportunity to exercise my training in issues of soil salinity and sodicity in this climate. As the WRMC considers how to proceed with the Costco basin, please do not hesitate to consult with me on next steps.

With best wishes,

Phillip Barak

Phillip Barak, PhD

Executive Summary for City of Middleton Water Resource Management Commission:

# Causes of the failure of the Costco bioretention systems and its remediation

Phillip Barak, PhD
Professor, Dept of Soil Science
University of Wisconsin-Madison
12 Sep 2012

In August 2009, Professor Ken Potter (Dept of Civil and Environmental Engineering, UW-Madison) brought to our attention the problem of the impermeable bioretention ponds at Costco, Middleton, WI. Preliminary examination suggested that the problem was caused by excessive exchangeable sodium. A one-yr student research project funded by Costco and the City of Middleton was begun in Dec 2009 and extended to May 2012.

Stormwater infiltration basins are becoming an increasingly popular way to mitigate the negative effects of urbanization on surrounding watersheds. Infiltration basins are designed to receive runoff in order to retain contaminants and recharge groundwater. Failure of basin infiltration due to clogging is a relatively common occurrence. Many studies have found this to be the result of fine sediments washing in and clogging pores, yet the role played by sodium salts has received little attention.

The Costco Middleton basins collect runoff water from roof and parking lot at a ratio of ~30:1 impermeable surface:basins. As originally designed, there was a 30" engineered soil planting bed overlain by 3" of mulch, and underlain by 6" of pea gravel. An overflow pipe was designed to limit ponding depth to 6" and an impermeable barrier and below ground drainage had been added to prevent direct infiltration to the local groundwater. When initially observed by the research team, there was salt crust along the edges of north and east basins, which contained ponded water. Throughout the first spring, summer, and fall, water was present in those two ponds and plans to rigorously grid-sample the dry basin were altered to grab samples from the pond in August 2010, amid cattails, dragonflies and frogs.

Soil cores showed a layer of organics on top and gravel throughout the ~10-20" cores. Bulk density measurements were on the order of 1.5 to 1.9 $Mg/m^3$. Gravel was 29 to 35% of the soil mix by weight. The <2 mm fraction was 79 to 84% sand, 7 to 12% silt, and 8 to 10% clay. The textural class of the <2 mm soil was sandy loam. Loss on Ignition, LOI, measurements on the soil separates indicated that the clay fraction contained 26% colloidal organic matter by weight, and the silt contained 10%.

The exchangeable sodium percentage was determined by extraction with 1 M ammonium acetate. Although there was some variability with depth, both the impermeable north and east ponds averaged 15 to 17% exchangeable sodium in all cores, with individual measurements as high as 28% and 30%. An exchangeable sodium percentage, ESP, greater than 15% is considered sodic and likely to cause impermeability. It was additionally noted that dissolved organic carbon in the interstitial water (extracted by immiscible heavy liquid displacement) exceeded 1000 ppm C, and reached as high as 3000 ppm C, at depths greater than 4".

The saturated hydraulic conductivity, Ksat, of the intact cores from the north and east ponds were measured by a falling head permeameter technique, first with tapwater and then with gypsum-saturated water, 25 mM $CaCl_2$, and 250 mM $CaCl_2$. Values measured were 0.01 to 0.02 cm/h for tapwater, indicating that water loss from the ponds by drainage was likely less than loss by evaporation in most seasons and most water efflux during storm events was by the overflow drain. By contrast, saturated hydraulic conductivity of sandy loam soils is typically on the order of 2.6 cm/h and even clay soils typically can have values of 0.06 cm/h. Saturated hydraulic conductivity improved to 0.09 cm/h for the gypsum-saturated water, and was 0.10 cm/h for the two calcium chloride solutions. These extremely modest improvements indicate that the soil cores were not only extremely impermeable but their permeability was not recovered by ion exchange with calcium and highly saline calcium solutions that should normally improve solution flow if the structure were not degraded as well. Given the damage to soil structure caused by sodicity and the failure of the calcium treatments to restore permeability to the soil cores, it is judged dubious that field treatments can restore the functionality of the existing engineered soil.

The immediate cause of the impermeability of the Costco basins was clearly sodium derived from road salts from the parking lot used for deicing, particularly as the salty meltwater is replaced with rainwater runoff that causes subsequent chemical dispersion of the soil colloids, both mineral and organic, and slaking of soil aggregates. Although no numbers are available for the amount of salt used at the Middleton Costco site, back-of-the-envelope calculations indicate more than enough salt applied in a season to cause the exchangeable sodium percentage to reach the sodic level, 15% ESP. Preventative measures might include avoiding the use of sodium chloride altogether in favor of calcium chloride or adding some calcium chloride to the mix to reduce the SAR of the runoff water. Alternatively, the salty meltwater could be diverted from the basin altogether during winter and early spring, with the rationale that the retention basin could never filter out sodium and chloride but could only store sodium (with concomitant sodicity and impermeability) and never do anything with chloride but pass it through to the overflow drain, groundwater or below ground drainage.

As a follow up to see if an engineered soil could be rated for salt hazard, an engineered soil was procured from Dr. Roger Bannerman and Warren Gebert, USGS. Particle size analysis showed a composition of 90% sand, 5% silt and 5% clay, which places it in the textural class of sand, but very close to the boundary with sandy loam. The color in the Munsell system is light brown (dry), with occasional pieces of dark brown bark.

A column was packed with the loose sand, consolidated by shaking, saturated with water and then subjected to a series of different water treatments, with saturated hydraulic conductivity for each treatment determined by falling head permeameter after sufficient water had passed through the column to effect any ion exchange reactions and rinse out prior treatments. With 'normal water', SAR 1 and EC 0.12 dS/m, Ksat was 38 cm/h. Switching to 'sodic water', SAR 12 and EC 1, Ksat rose an insignificant amount to 42 cm/h. Switching back to normal water caused an insignificant drop in Ksat to 39 cm/h even after prolonged leaching. To force a response, a hypersaline solution of 100 mM NaCl was applied, for which Ksat was 35 cm/h. Switching back to normal water, the immediate Ksat was 32 cm/h, and dropped to 20 cm/h after prolonged leaching that leached out the added salts. Some water-dispersed clay was visible in the effluent, which could become a column clogging hazard if it were allowed to rest, but otherwise this engineered soil maintained a usable hydraulic conductivity even at nearly 100% exchangeable sodium. Not only did the soil mix not contain much expansible mineral clays, such as smectite, but also contained little organic matter that could turn into dispersable organic colloids. There is room for guarded optimism that this engineered soil would not become impermeable under Costco Middleton conditions.

# Sodicity Issues in Stormwater Infiltration Basins

A report submitted in partial fulfillment of the Capstone requirements
for Bachelor's degree in the University of Wisconsin – Madison

Kyle Rudersdorf, David Evans, Glen Obear, Shane Griffith, and Mackenzy Naber

under the supervision of

Phillip Barak, PhD
Professor, Dept of Soil Science
University of Wisconsin-Madison

22 Jun 2011

**ABSTRACT:** Stormwater infiltration basins are becoming an increasingly popular way to mitigate the negative effects of urbanization on surrounding watersheds. Infiltration basins are designed to receive runoff in order to retain contaminants and recharge groundwater. Failure of basin infiltration due to clogging is a common occurrence. Many studies have found this to be the result of fine sediments washing in and clogging pores, yet the role played by sodium salts has received little attention. In this report, we describe a series of stormwater infiltration basins in Middleton, WI, that have ceased to infiltrate and assess the impact of sodium dispersion on surface structure through soil core experiments and physical and chemical analysis. We found significant amounts of sodium in the upper layers of the basin due to the use of sodium chloride as deicing salts on the parking lot that the basin drains. Tests attempting remediation with gypsum and calcium chloride salts suggest little chance of remediation. Future design should include either diversion of deicing salts from the infiltration basins or use of engineered materials rated to withstand winter salts without deterioration of hydraulic properties.

## INTRODUCTION

Storm water infiltration techniques are used to improve groundwater and surface water quantity and quality in urban environments with large areas of impermeable surfaces. These structures can range in form from permeable asphalt to large excavated basins, but they all function to increase the volume of storm water infiltrated into the underlying soil and decrease surface runoff (Weiss et al., 2008). Increasing infiltration is often done to increase water quantity through recharge of ground water tables and improving the base flow to ground water fed streams (Walsh et al., 2005), as well as improving water quality from contaminated runoff (Birch et al., 2005). Decreasing urban runoff to surface and ground water is beneficial to water quality as it often contains undesirable contaminants such as suspended solids, heavy metals, excess nutrients, bacteria, organic compounds, and salts. Contaminants are removed through sedimentation or sorption onto soil colloids, depending on the pollutant, and these mechanisms are often very effective (Birch et al., 2005). In the latter mechanism, storm water must infiltrate into the basin soil and come into contact with the sorbent for the filtering action to be effective. This is necessary in the retention of heavy metals, degradation of organic molecules, and adsorption of phosphorus.

Clogging issues of soils and sediments have been reported for many years and are commonly due to accumulation of fine particles, algal mats, bacterial biofilms, surface crusting, or the precipitation of accumulated salts (Baveye et al., 1998). Many studies on clogging of stormwater infiltration basins make mention only of accumulation of fine sediment on the surface of the basin or at depth where a textural change is encountered, whereby fine sediments have washed in and significantly reduced pore size (Bouwer, 2002) and yet few have discussed the contribution of road-salts to the creation of an impervious surface layer.

An alternative scenario may be imagined in which a sodium chloride solution followed by relatively pure water, as would be the situation when deicing salts mix with melting snow and then infiltrate the soil creating a sodic and saline chemistry, followed by runoff and infiltration of rainwater to leach some of the salts to depth, would create a low permeability sodic environment. By mechanisms discussed later, the sodium causes the finer particles to disperse and soil aggregates to swell and slake, making clay and silt particles more mobile to clog pores and creating poor conditions for infiltration both at the surface and in the matrix, leading to subsequent ponding. In agricultural fields where sodium salts are indeed the major contributor to poor surface structure and infiltration, remediation involves applying gypsum ($CaSO_4 \cdot 2H_2O$) to replace sodium on exchange sites, and then leaching them away with high quality water. It is not clear a priori whether this course of action would be effective with infiltration basins in general, or for these specific basins. Many studies have focused on the infiltration failure due to a clogging phenomenon, while most focus on fine sediment closing pores (Siriwardene et. al., 2006) in our literature search none were found that discussed the role that sodium from road salts has played. In fact, one literature review dismissed the importance of salts as, "soluble, easily transported in surface and sub-surface flow, non-filterable, and do not readily sorb to solids," (Weiss et. al., 2008).

Three stormwater infiltration basins at the focus of the study are located in a suburban shopping center in Middleton, WI, and drain impervious roofs and parking lots. The basins were installed in 2007 and in the following year, the East and North basin began to fail. The stormwater had ceased to infiltrate, or infiltration had become very slow, which resulted in stormwater discharging into the overflow drain during common rain events, bypassing the filtering action of the basin's soil. While infiltration is likely still occurring and may be providing some marginal improvement of storm water, the standing water creates potential breeding grounds for mosquitoes (Metzger, 2004) and water spilling into the overflow drain represents a marked reduction in function of the retention basins. These basins now have the appearance of constructed wetlands, with cattails, dragonflies, and frogs during the summer, with about 6 to 12 inches of standing water in the deepest part of the pond. When visiting in the early spring, water is still in the pond with occasional white crust along the edge, salty to the taste. We have investigated this site as a possible case study of a pond failure due to excess sodium accumulation from de-icing salt applied in the catchment area.

## MATERIALS AND METHODS

**Site description:** The area of study is located in a suburban shopping center in Middleton, WI and consists of three retention basins. The approximate sizes of each basin, South, East and North, are 2,300 $ft^2$; 8,000 $ft^2$; and 8,700 $ft^2$, respectively. The basin to the South, primarily receives runoff from the roof of the nearby building, while the other two basins receive approximately 350,000 square feet of runoff from impervious roof and parking lot. All three basins were constructed similarly: the surface layer of each basin consists of 7.5 cm woodchip mulch layer, followed by 75 cm of an engineered soil mix, and then a 15 cm layer of pea gravel in which the underdrain is embedded. Underneath this is 90 cm of a gravel or sand storage layer, followed by 7.5 cm of sand incorporated with the native soil. The underdrain consists of a perforated pipe that is covered with a filter fabric and drains away to an overflow outlet to surface water drainage. The overflow drain rises above the mulch layer 15 cm, which restricts ponding to this depth. These basins are designed to infiltrate water into the surrounding soil, with the drains available to carry away water in saturated conditions. Wisconsin statutes state that basins are required to be able to draw down ponding within 24 hours, which, with a ponding depth of 15 cm, means these ponds must have a surface hydraulic conductivity of at least 0.64 cm/hr (0.25 in/hr).

**Sample collection:** In August, 2010, four samples were collected from each of the three separate stormwater infiltration basins, along the centerline of the ponds. A 6.8-cm diameter plastic cylinder was inserted by hand into the constructed soil profile. Core depths varied but were between 25 and 30 cm. At the time of sampling, the ponds which were not properly draining, had anywhere from 0 to 0.5 m of standing water in them. Sampling location was dependent on factors making collection easiest; including ease of entry, depth of water and proper footing. After collections, samples were brought to a refrigerated storage room until experiments were conducted.

**Sample analysis:** Saturated conductivity was measured using the falling head permeameter method for two cores from each pond, with varying water composition. In succession, first, tap water was used to obtain a control value of saturated conductivity, without contributing to any further dispersion of material since tap water contains minerals like calcium and magnesium. Deionized water, similar to rain water, was used next, which contains no minerals causing it to bind to ions, such as calcium and magnesium, leaching them out of the soil causing dispersion. Third, the column from each pond was given a solution saturated with gypsum; Fourth, a solution of calcium chloride with a calcium concentration equal to that of saturated gypsum was used; and then followed, fifth, by a concentrated solution containing calcium chloride. The gypsum treatment passed a volume of solution exceeding the total cation exchange capacity of the soil in the column. The calcium chloride treatments each passed two or more pore volumes of solution, sufficient to equilibrate the soil with the increased ionic strength of each. These treatments were designed to simulate possible remediation methods.

In order to understand how the engineered soil in the pond varied with depth, the yet unused cores were opened by splitting the plastic sleeves longitudinally and then sectioned into one 1-cm cross-sectional slices. Half of alternate 1-cm slices were used for analyzing exchangeable sodium using 1 M ammonium acetate displacement; from the other half, interstitial water was extracted by immiscible heavy liquid displacement using HFE (3M Corp., Minneapolis, MN). For every second sample, bulk density was measured on a half-slice using a lab-constructed pycnometer using HFE as an immiscible fluid, whose weight to bring to a reference total volume was weighed; after bulk density measurement, the solids were made to 1% sodium hexametaphosphate, sieved for >2mm gravel, and then analyzed for particle size distribution by laser scattering.

## RESULTS/DISCUSSION

After soil cores were cut open and observed, we noted that there were no visible macropores with little to no structure. This is consisted with the situation of a soil with very poor infiltration and low hydraulic conductivity. In contrast, well-drained soils and, presumably, proper working basins should have aggregates of various sizes, including those visible to the naked eye, and macropores if texture is sufficiently fine. Gravel was mixed into the soil from a depth of 1½ inches (4 cm) to the bottom of the core. Measured particle size distribution, using the USDA system of particle size classification, of the 0-4 cm depth was 19.5% clay, 36% silt, and 44.5% sand, characteristic of a “loam” texture class, and similar values were obtained for greater depths throughout the profile. This is consistent with the idea that this basin was constructed to retain enough moisture for mesic plants to grow and yet still maintain adequate drainage. A sandier substrate would have resisted clogging much better but would likely not have held enough moisture for the desired ornamental plants. The measured cation exchange capacity averaged 20.6 ± 3.1 cmol(+) $kg^{-1}$ in the two cores, without obvious trend with depth or location; these values are consistent with a silt loam soil in Wisconsin.

Except for the top 1 cm, the bulk density was always about 1.5 $g/cm^3$ or higher, with an average of roughly 1.7 $g/cm^3$ (Figure 1). This is quite high for a normal, uncompacted soil, but because about 15% of the volume was occupied by pea gravel, it is expected that the bulk density would be higher. In most cases, coarse fragments like cobbles and gravel have the effect of increasing macropores and hydraulic conductivity in soils. However, in the case of these retention basins it is quite likely that the dispersed clays and organic matter are acting like a seal around the gravel and no macropore formation is possible.

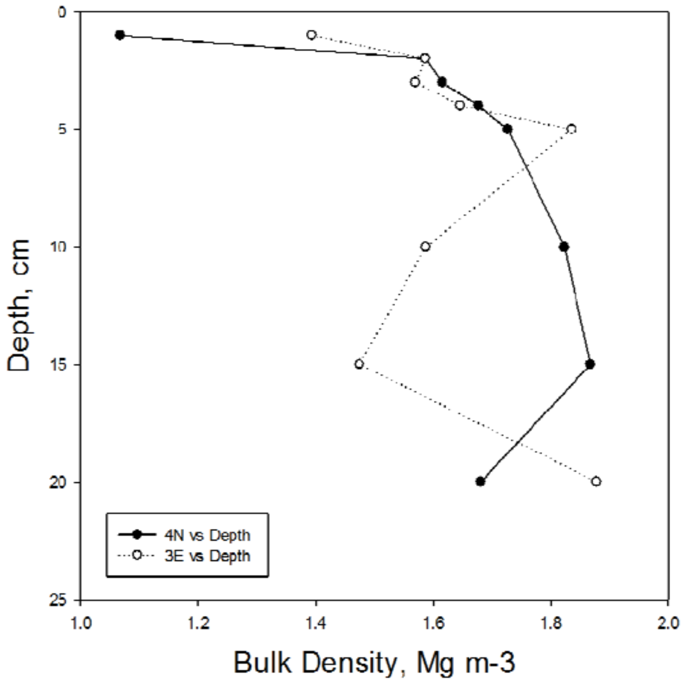


**Figure 1.** Measured bulk density of the cores from the north and east infiltration basins at shopping center in Middleton, WI.

Exchangeable cation analysis revealed an average exchangeable sodium percentage (ESP) that ranged from a low of 7% at 4 cm depth in the east pond to a high of 30 at 5 cm depth in the north pond (Figure 2). The average ESP was 17% in the north pond and 18% in the east pond. These values are much greater than typical ESP values for Wisconsin soils, which are usually around 2-4%, and are clear evidence that the sodium from de-icing salts has accumulating in the basin soil, and are not passing through the basin without impact. It has been claimed (Weiss, et. al. 2008) that infiltration basins have a low capacity for retaining salts because they are dissolved in solution. While this very true for anionic salts and for low concentrations of cations, these sources fail to account for the property of ion exchange, which may alter the composition of the exchangeable cations in the soil.

A back-of-the-envelope calculation shows that the 19,000 sq ft of the three basins to a depth of 0.3 m, with a bulk density of 1.5 Mg $m^{-3}$, CEC of 20 cmol(+) $kg^{-1}$ and an ESP of 15%, contain ~60,000 mol $Na^+$, equivalent to 1.4 Mg $Na^+$ or 3.5 Mg NaCl. By comparison, the

Madison ‘goal’ for city streets is 6 tons NaCl per mile, which at 20 ft width, is equivalent to 25 Mg NaCl per 440,000 sq ft. of parking lot. Madison actually uses x2 to x4 the goal on its streets, depending on season; parking lots, usually salted by private contractors, may be suspected of being salted at yet higher rates. In short, the parking lots of the drainage area could easily have received 7 times more sodium *in a single winter* than the entire amount of sodium measured in the infiltration basins.

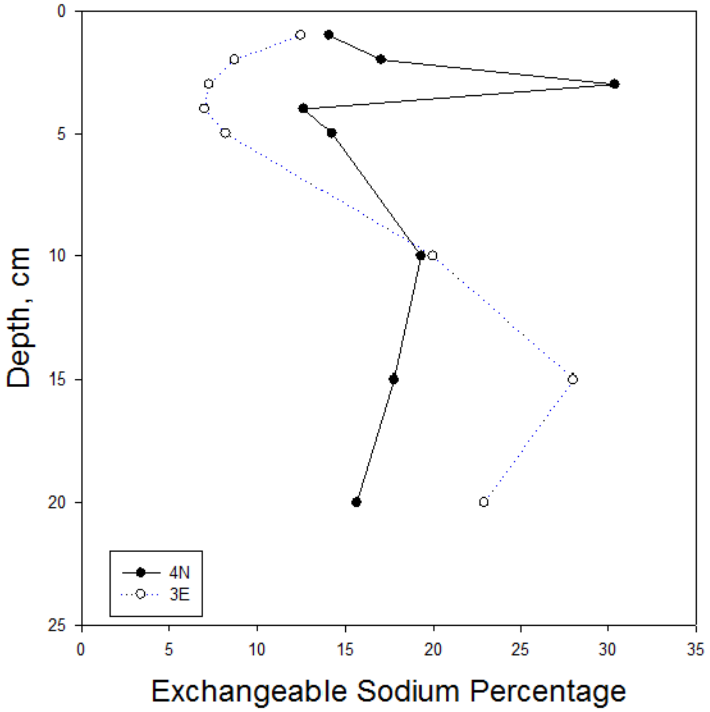
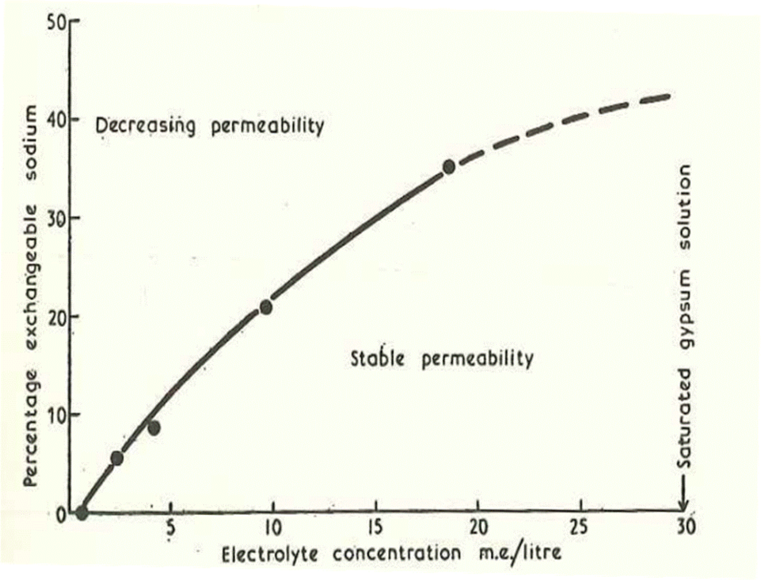


**Figure 2.** Exchangeable sodium percentage, ESP, of the cores from the north and east infiltration basins at Middleton, WI.

The exchangeable sodium in soils has consequences. Aluminosilicate clay particles are the dominant source of negative charge in the soil. These negatively charged sites attract positively charged ions and hold on to them in such a way that they are easily replaced by the substitution of another cation. The cations held at exchange sites are held in a cloud, or diffuse layer, around the clay particle because the ions are attracted to the negatively charged sites but are repelled by the like charges of the other cations and the ever-present agitation of the Brownian motion of the water molecules. If this positively charged cloud is too thick, the clay particles are repelled from one another because of like charge repulsion. But if the cloud is thin, the particles are able to get closer together and share their cation layers and/or are attracted to each other with Van der Waals-London forces. When the latter occurs, termed flocculation, the clay particles stick together to form stacks and form a particle with a much larger diameter. Flocculation is necessary if a soil is to form larger stable aggregates and develop the structure needed for proper drainage and aeration. The thickness or thinness of this ion cloud, termed the electrostatic double layer, is determined by the concentration and valency of the cations in the solution around the clay particle. A high concentration of ions reduces the thickness of the layer as does a higher valency of cations (Hillel, 1998; Tan, 1998). In the Midwest, soil solution will almost always have a sufficient concentration of ions for flocculation and the ions are usually dominated by divalent cations like calcium and magnesium creating a situation conducive to flocculation.

In the case of the affected retention basins, sodium has replaced a significant percentage of the calcium and magnesium that was present at exchange sites. Sodium is a monovalent ion that has a very large ionic radius when hydrated, with the effect of greatly increasing the electrostatic double layer around the clay particles and causing them to swell apart from each other and eventually lose attraction to one another. When this happens, termed dispersion, the clay particles will remain suspended in solution and soil structure is profoundly impacted negatively, resulting in aggregate slaking, macro- and micropore blocking, soil puddling and near cessation of infiltration. In the case of organic colloids, small organic molecules in the soil, dispersion caused by sodium happens in a similar way but with slightly different mechanisms.

The mechanism of sodium saturation and subsequent impermeability of the infiltration ponds can be inferred with the aid of Figure 3. With the application of sodium chloride to the parking lots during periods of ice and snow, meltwater from the parking lot would drain into the infiltration ponds, carrying a high concentration of sodium chloride. The high electrolyte concentration would maintain stable permeability even though the exchangeable sodium percentage was increasing by cation exchange. When the last of the salt had been dissolved by rainwater and washed from the parking lot into the ponds, subsequent rainwater was largely devoid of electrolytes and so, even though the ESP was no longer rising, the reduction of the electrolyte concentration in the soil solution would cause a transition from stable permeability to decreasing permeability as the soil structure transitioned from flocculated to dispersed. Once soil permeability was reduced, permanent ponding of the infiltration basins would be expected in view of the high, ~30:1, impermeable:permeable surface ratio of the site.



Quirk and Schofield. 1957. J. Soil Science

**Figure 3.** Relationship between electrolyte concentration and exchangeable sodium percentage (ESP) on soil permeability.

Remediation of sodic soils in agricultural settings is usually accomplished by the addition of gypsum, calcium sulfate dihydrate, both as a source of calcium ions to displace exchangeable sodium and as a source of electrolytes to maintain a sufficiently high concentration to avoid soil dispersion. In extreme cases, calcium chloride may be used instead of the sparingly soluble gypsum. The falling head permeameter tests on intact soil cores showed an extremely slow initial infiltration rate, on the order of 0.01 to 0.02 cm per hr (Table 1). Under normal conditions, therefore, water would be evaporating or transpiring from these ponds faster than they would be draining. Treatment with gypsum improved the East pond core conductivity by a relatively large factor, but drainage was still much slower than design requirements. Transitioning to up to 250 mM calcium chloride did not further improve the hydraulic conductivity. Although we do not have in hand a sample of engineered soil that has not been sodium-affected as a control for comparison, we are certain that treatment with gypsum or calcium chloride will not recover the lost soil structure, even though sufficient calcium has been added to the soil cores to displace all of the exchangeable sodium.

**Table 1.** Saturated hydraulic conductivity of intact soil cores under a sequence of treatments.

| Saturated Hydraulic Conductivity | **$cm*hr^{-1}$** |
|---|---|
| **East Pond Core** | |
| Tap water | 0.01 |
| Gypsum | 0.09 |
| 25 mM $CaCl_2$ | 0.10 |
| 250 mM $CaCl_2$ | 0.10 |
| | |
| **North Pond Core** | |
| Tap water | 0.02 |
| Gypsum | 0.03 |
| | |
| **Target Conductivity** | **0.64** |

Analysis of interstitial soil solution, shown in Figure 4, revealed significant increases of dissolved organic carbon (DOC) starting at 10 cm below the surface. This increase is likely due to dispersion of organic colloids caused by sodium accumulation and subsequent swelling and destruction of colloid. This migrating DOC has important implications for the migration of nutrients which may be adsorbed to it, like phosphorus, and for heavy metals that could be complexed with it. Amrhein et al. (1992) examined roadside soils that received sodium chloride from de-icing salts and found extensive mobilization of organic matter and increased concentrations of lead, chromium and nickel in the leachate. They concluded that the controlling mechanism was dispersion of organic colloids caused by high levels of exchangeable sodium. For the basin being studied this means that what little water that is flowing through the soil could be picking up contaminants rather than having them being filtered. Measurements we conducted did not include heavy metals but iron and aluminum concentrations were linearly correlated with the organic carbon concentrations and reached as much as 3000 mg/L each.

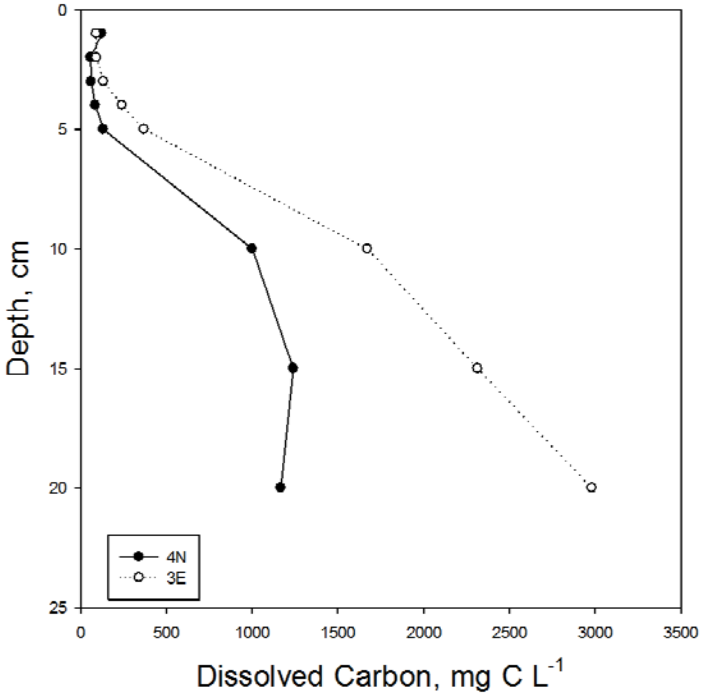


**Figure 4.** Profile of dissolved organic carbon as a function of depth in soil cores.

## CONCLUSIONS

From our results we can conclude with reasonable certainty that the basins studied failed because of sodium accumulation from de-icing salts used in the parking lots of the catchment area. A survey of infiltration works by Lindsey et al. (1992) found that a full third of the 87 basins surveyed were clogged, with less than half of all basins functioning as designed. Lindsey et al. (1992) and others (Hatt, et al., 2006; Le Coustumer, et al., 2007) state that the main cause of failure is due to fine sediment washing into the basin and clogging soil pores.

We have several reasons to believe that sediments clogging pores are not the case for the basins of this study. First of all, these basins were implemented after construction of the shopping center was complete and they drain primarily rooftop and parking lot, surfaces that do not have much sediment to lose. Moreover, the basins failed within a year and a half of being constructed, leaving little time for accumulation of sediment. Third, the soil texture of the top 4 cm did not differ greatly from the soil profile below it showing no build up of sedimentation in any specific part of the basin. These facts lead us to believe that it is improbable that fine sediment is the cause of the catastrophic failure of the basins.

Second, our tests of exchangeable ions revealed a large amount of sodium present on soil colloids, demonstrating that a significant amount of sodium is being retained by the basin material and is not simply leaching through. Based on the existing body of knowledge of soil salinity and sodicity, as well as calculations of likely salt applications, the use of sodium chloride is most likely the proximate cause of soil impermeability and basin failure. The exchangeable sodium is present in high enough quantities to cause serious problems for soil structure, as evidenced by lack of visible structure and the high bulk density. Our soil core experiments showed an increase in hydraulic conductivity after being treated with saturated calcium solutions, which is expected if excessive sodium is causing clay dispersion, but would likely not improve infiltration if sediment was the cause. However, soil hydraulic conductivity did not reach satisfactory values when treated with gypsum or calcium chloride, likely due to irreversible deterioration of soil structure.

An alternative hypothesis for the failure of these basins is biological clogging. Biological clogging would be due to microbial biofilms or algal mats that would plug up the soil pores with organic material. We found no reason for this to be the cause of clogging. There was indeed a layer of loose, living organic material at the surface, but it is unlikely that this could cause impermeability at a macroscale. For a definitive conclusion on the role of biofilms, further experiments with soil cores may include a treatment of an algacide or some sort of sterilization of the biota. Additionally, hydrogen peroxide ($H_2O_2$) could be used to oxidize any organic matter at the surface of a soil core, and it could then be observed if hydraulic conductivity would be improved. Both of the above experiments would merely test the possibility of biological clogging, as they are both impractical for the remediation of the basins; additionally, they may themselves alter the structure in a deleterious manner. However, as noted above, the extent of measured sodium saturation alone is sufficient to explain the soil impermeability.

We found a significant amount of dissolved organic carbon at depth in the basin soil, suggesting that something is causing destruction of stable organic material. This is most likely due to sodium mediated mobilization of organic carbon. This is a well documented phenomenon associated with roadsides treated with de-icing salts (Amrhein, et al., 1992; Norrstrom & Jacks, 1998), but would be not be found in a situation where fine sediments had washed into the basin.

The basins are effectively ruined and very likely beyond the possibility of saving. Any remediation effort must include the application of either gypsum or calcium chloride in order to replace the sodium on the exchange sites with calcium, but reversal of the deterioration of soil structure is likely irreversible. Because the infiltration of the basins is so poor, calcium amendments should be incorporated by some mechanical means, such as hoeing or disking, to better increase the amount of soil that is in contact with the calcium source. Even with these efforts it is unlikely that the basins' hydraulic conductivity would improve enough for adequate drainage.

## RECOMMENDATIONS:

Whether these basins are excavated and replaced with new materials or whether the ponds are left as they are, we highly recommend that either: 1) the drainage from the deicing salts be diverted away from the infiltration ponds through engineered barriers during the winter and early spring, or 2) that use of sodium chloride as a de-icing salt in the catchment area be halted, likely replaced with calcium chloride, calcium acetate, or potassium chloride. The sodium chloride that is extensively used has likely been the cause of failure for many stormwater infiltration basins in Northern regions, whether or not previously recognized, causing millions of dollars to spent on new basin construction and the lost benefit of groundwater recharge and contaminant retention. So while sodium chloride is the cheapest de-icing agent available, changing to a slightly more expensive salt could save money for businesses and municipalities and help stormwater infiltration basins function to properly mitigate stormwater runoff. Further, it would appear that the engineered soils used in these applications has not been tested or rated for sensitivity to sodicity problems nor have guidelines for the use of salts in the catchment areas been devised; these are open questions that deserve further attention.

## REFERENCES

Amrhein, C., J.E. Strong, and P.A. Mosher. (1992). “Effect of deicing salts on metal and organic matter mobilization in roadside soils,” *Environ. Sci. Technol.* Vol 26, pp. 703-709.

Baveye, P., P. Vandevivere, B.L. Hoyle, P.C. DeLeo, and D. Sanchez de Lozada. (1998). “Environmental impact and mechanisms of the biological clogging of saturated soils and aquifer materials,” *Critical Reviews in Environmental Science and Technology,* Vol 28, no. 2, pp. 123-191.

Birch, G. F., M. S. Fazeli and C. Matthai. (2005). “Efficiency of an infiltration basin in removing contaminants from urban stormwater,” *Earth and Environ. Science,* Vol 101, no. 1-3, pp. 23-38.

Bouwer, H. (2002). “Artificial recharge of groundwater: hydrogeology and engineering,” *Hydrogeology Journal*, Vol 10, pp. 121-142.

Hatt, B. E., N. Siriwardene, A. Deletic, T. D. Fletcher. (2006). “Filter media for stormwater treatment and recycling: the influence of hydraulic properties of flow on pollutant removal.” *Water Science & Technology*. Vol 54 no. 6-7, pp. 263-271.

Hillel, D. (1998). *Environmental Soil Physics.* Academic Press: San Diego, CA.

Le Coustumer, S., T. D. Fletcher, A. Deletic, S. Barraud. (2007). “Hydraulic performance of biofilters for stormwater management: first lessons from both laboratory and field studies,” *Water Science & Technology.* Vol 56 no. 10, pp. 93-100.

Lindsey, G., L. Roberts, W. Page. (1992). “Inspection and maintenance of infiltration facilities.” *Soil and Water Conservation*. Vol 7 no. 6, pp. 481-486.

Metzger, M. (2004). “Managing mosquitoes in storm water treatment devices,” *Rep. No.* 8125, Univ. of California, Div. of Agriculture and Natural Resources, Oakland, CA.

Norrstrom, A. C., G. Jacks. (1998). “Concentration and fractionation of heavy metals in roadside soils receiving de-icing salts.” *Science of the Total Environment.* Vol 218, Issue 2-3, pp. 161-174.

Siriwardene, N.R., A. Deletic, and T.D. Fletcher. (2006). “Clogging of stormwater gravel infiltration systems and filters: insights from a laboratory study,” *Water Research*, Vol 41, Issue 7, pp. 1433-1440.

Tan, K. H. (1998). *Principles of Soil Chemistry: third edition, revised and expanded.* 3rd ed. Marcel Dekker, Inc.: New York, NY.

Walsh, C. J., T. D. Fletcher, and A.R. Ladson. (2005). “Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream,” *Journal of the North American Benthological Society*, Vol 24, no. 3, pp. 690-705.

Weiss, P. T., G. LeFevre, and J. S. Gulliver. (2008). “Contamination of soil and groundwater due to stormwater infiltration practices, a literature review.” St. Anthony Falls Laboratory, Project Report No. 515.

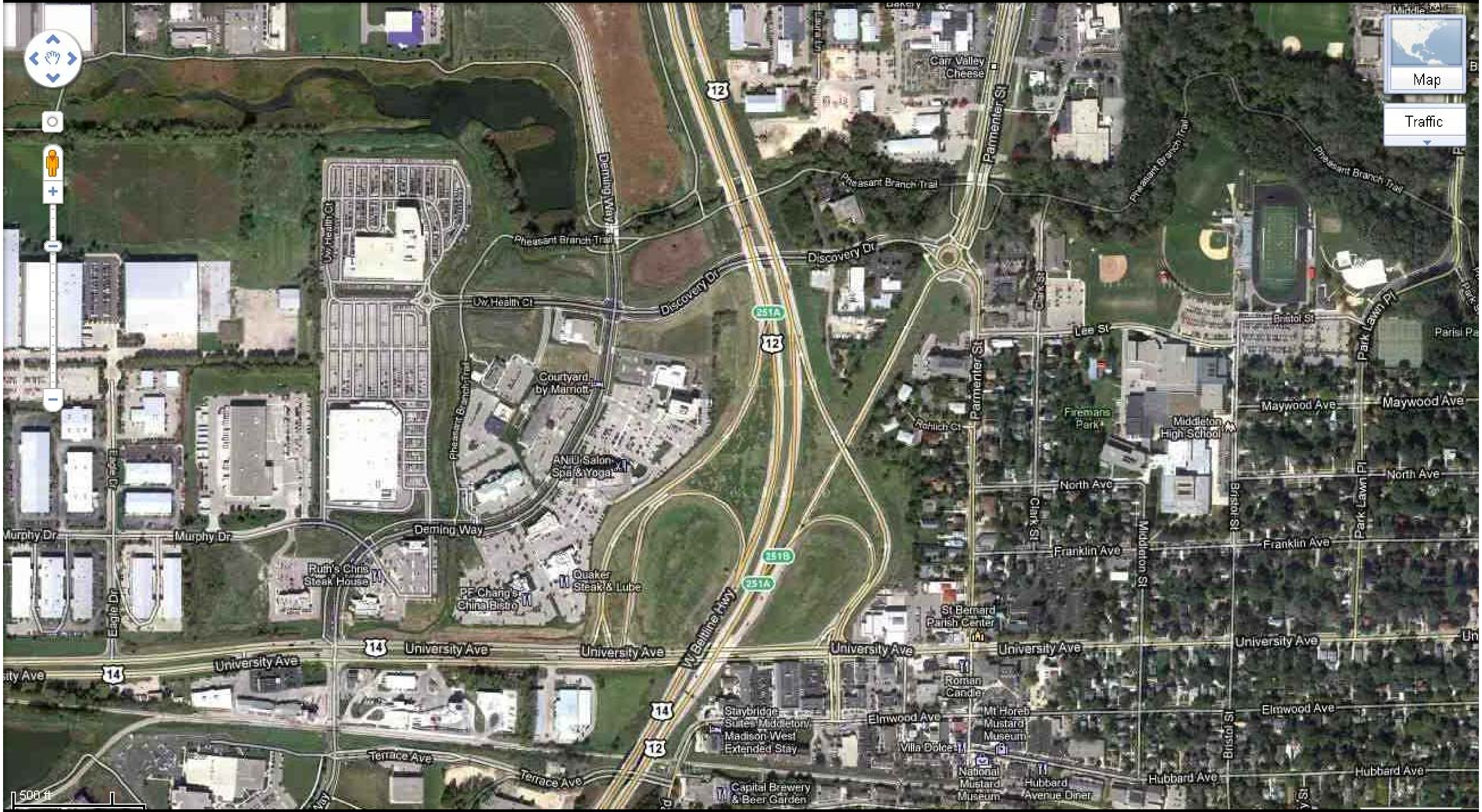
# Saline and Sodic Soils in Wisconsin: The Sad Story of the Costco Infiltration Pond

for WRMC
22 Jun 2011

Kyle Rudersdorf, David Evans, Glen Obear, Shane Griffith, and Mackenzy Naber

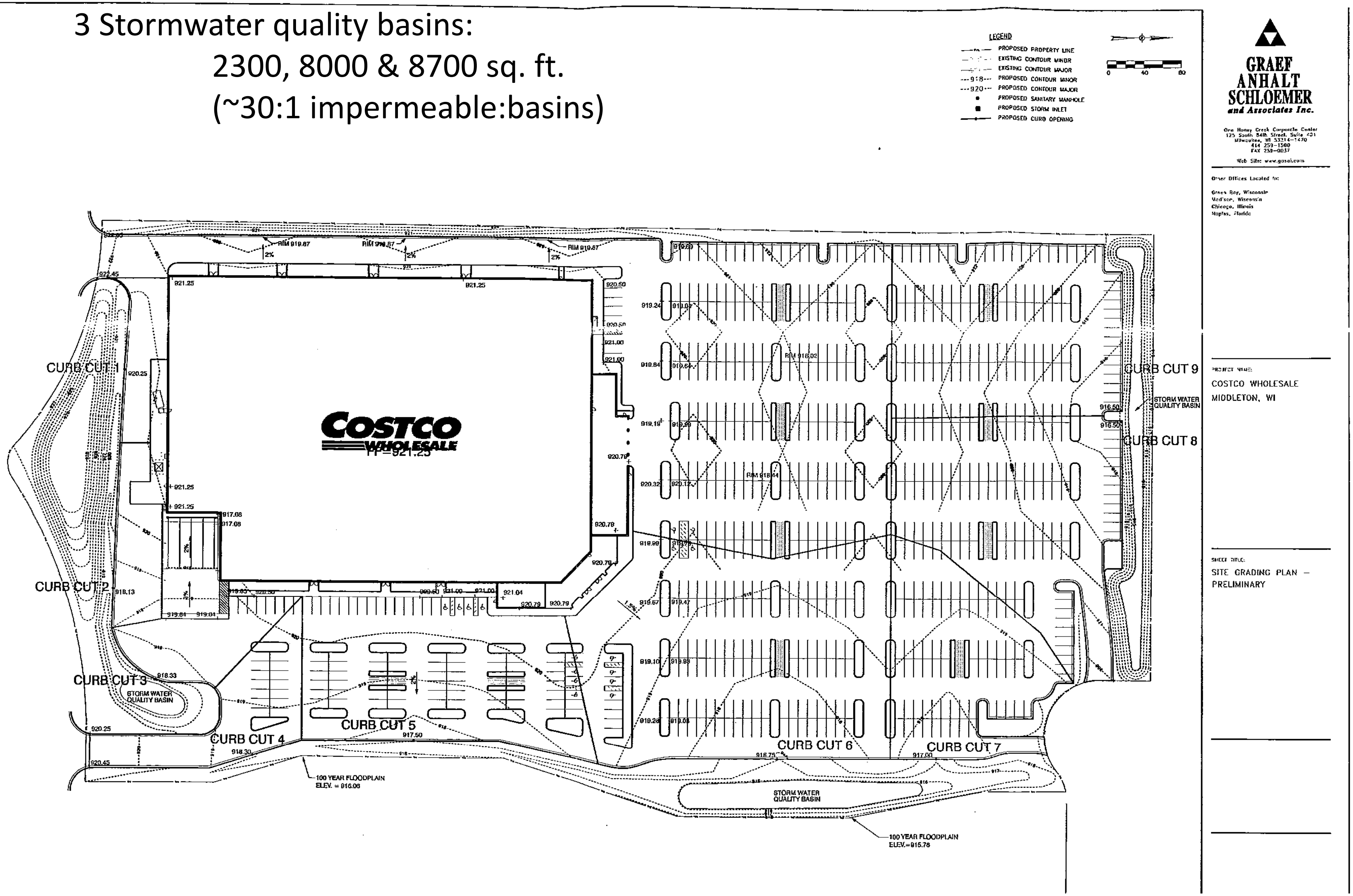
under the supervision of

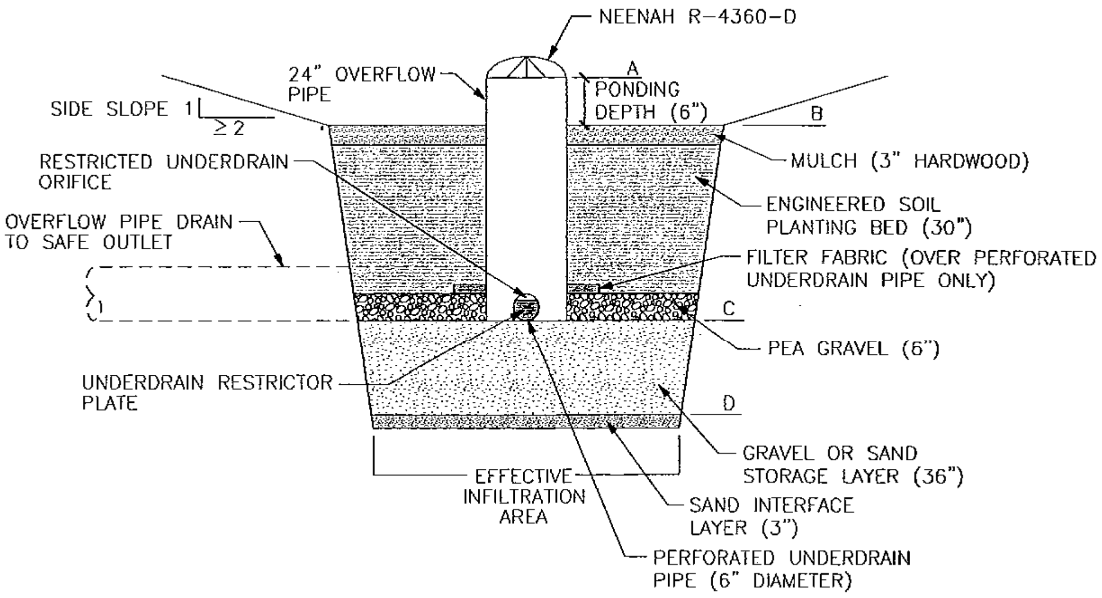
Phillip Barak, PhD
Professor, Dept of Soil Science
University of Wisconsin-Madison
pwbarak@wisc.edu


Map
Traffic
Carr Valley Cheese
Parmenter St
Pheasant Branch Trail
Deming Way
Discovery Dr
Uw Health Ct
Courtyard by Marriott
ANU Salon Spa & Yoga
Ruth's Chris Steak House
PF Chang's China Bistro
Quaker Steak & Lube
Murphy Dr
Eagle Dr
University Ave
W Beltline Hwy
12
14
251A
251B
Lee St
Bristol St
Clark St
Rohlich Ct
Maywood Ave
Fireman's Park
Middleton High School
North Ave
Franklin Ave
Middleton St
Park Lawn Pl
Parisi Pa
St Bernard Parish Center
Roman Candle
Staybridge Suites Middleton/ Madison-West
Extended Stay
Elmwood Ave
Mt Horeb Mustard Museum
Villa Dolce
National Mustard Museum
Hubbard Avenue Diner
Hubbard Ave
Capital Brewery & Beer Garden
Terrace Ave
500 ft

$10.5 million
Opened Aug 2008
2150 Deming Way, Middleton

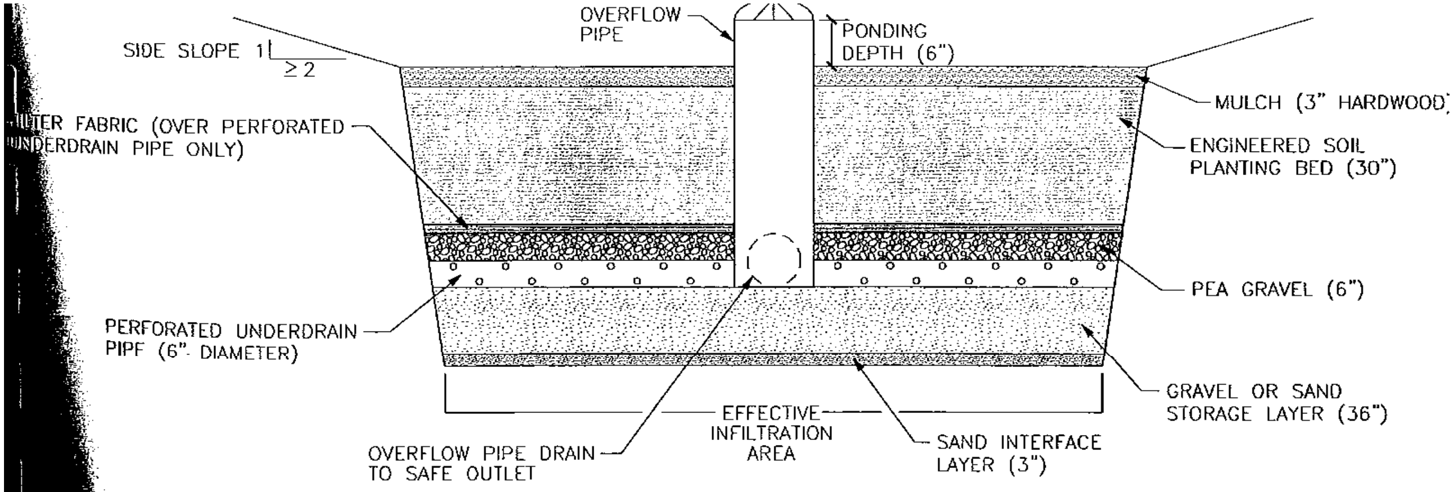
~153,000 sq. ft. bldg
~440,000 sq. ft. parking lot
3 Stormwater quality basins:
2300, 8000 & 8700 sq. ft.
(~30:1 impermeable:basins)





| DEVICE | ELEV. A | ELEV. B | ELEV. C | ELEV. D |
|---|---|---|---|---|
| 2 | 916.00 | 915.50 | 912.00 | 909.00 |
| 3 | 918.25 | 917.75 | 914.50 | 911.00 |

BIORETENTION DEVICE – CROSS SECTION ACROSS WIDTH OF DEVICE



BIORETENTION DEVICE – CROSS SECTION ACROSS LENGTH OF DEVICE


COSTC

# Diagnostic techniques:

Salinity—

- Electrical conductivity (EC) of soil water or saturated soil extract (lab; dS/m or mmho/cm)
- portable electromagnetic (EM) soil conductivity sensor mounted on vehicle (field)

Sodicity—

- Measurement of Exchangeable Sodium Percentage (ESP) by cation displacement
- Measurement of Sodium Adsorption Ratio (SAR) in soil solution, saturated soil extract or irrigation water

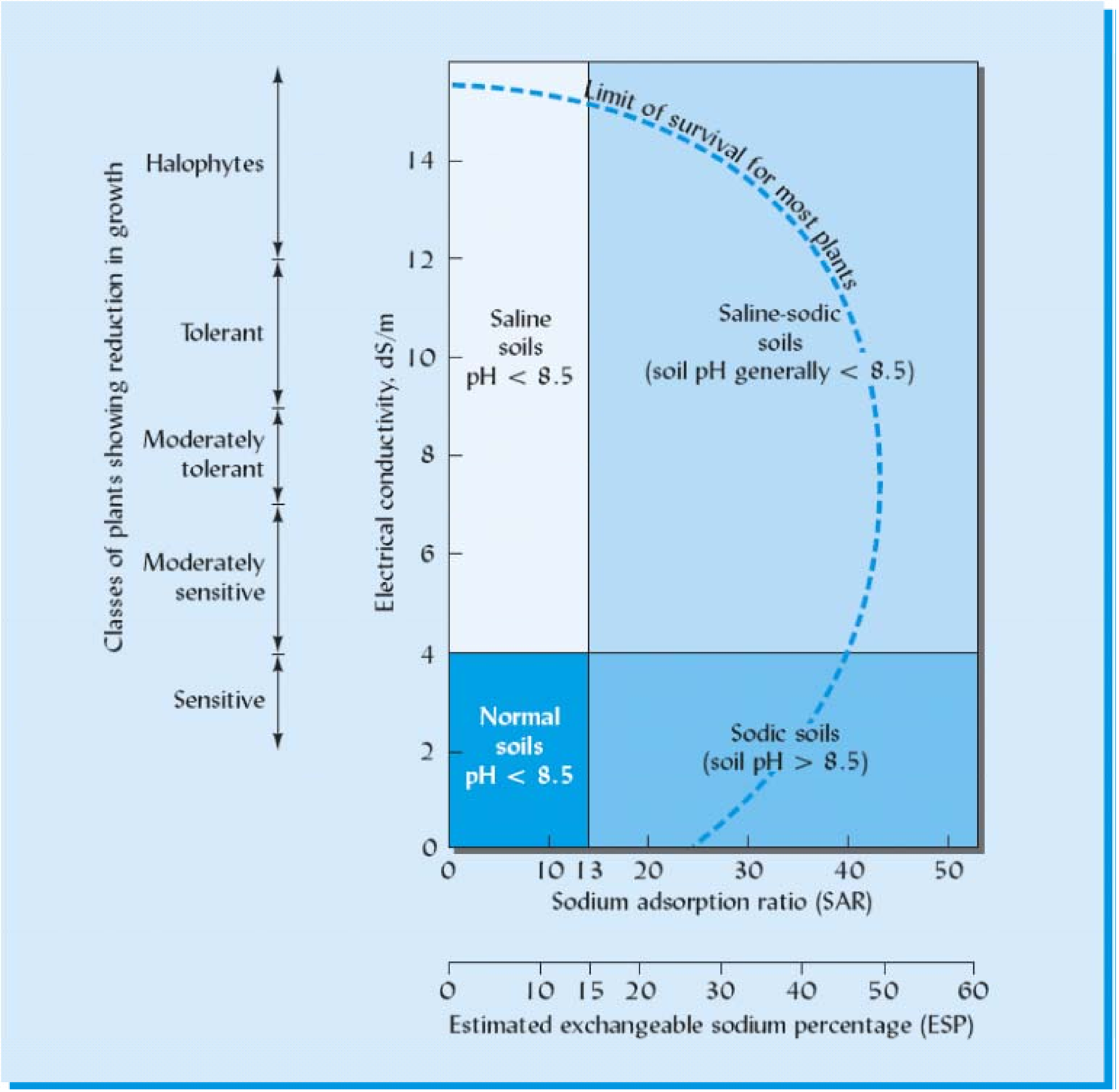


Diagram illustrating the classification of normal, saline, saline-sodic, and sodic soils in relation to soil pH, electrical conductivity (EC), sodium adsorption ratio (SAR), and exchangeable sodium percentage (ESP). Also shown are the ranges for different degrees of sensitivity of plants to salinity.

Brady & Weil.

So what source of salinity and sodicity exists in Wisconsin?

- Deicing salt
- Water-softeners
- Deer and livestock licks
- Fertilizers, particularly potassium chloride

Annual Madison salt application:
10 – 25 tons/mile
(Goal: 6 tons/mile)

Tons of salt applied or purchased by municipality, winter of 2008/9:

| | |
|---|---|
| 27,000 | Dane Co. |
| 9,000 | City of Madison |
| 1,150 | Town of Burke |
| 1,350 | City of Middleton |
| 2,700 | Others |

Madison & Dane Co. Public Health
**ROAD SALT REPORT – 2008/09**
http://www.publichealthmdc.com/publications/documents/RoadSalt2009.pdf

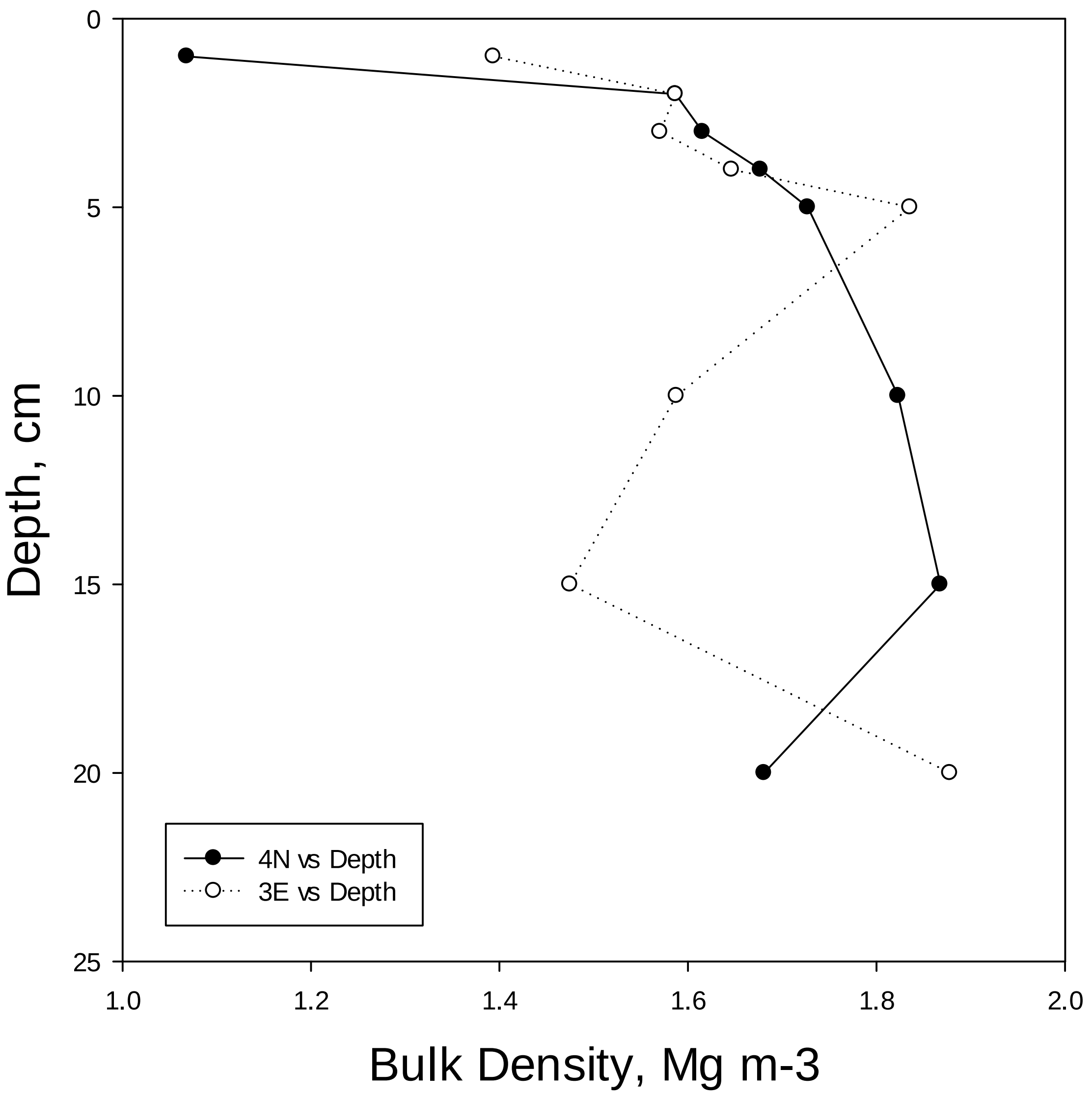
Sampling at Costco retention ponds, Aug 2010

Collection of cores from retention ponds (in background).


529872
Fed scales
ll forecast
Existing ho
om '09


1
2
3
4
5
6

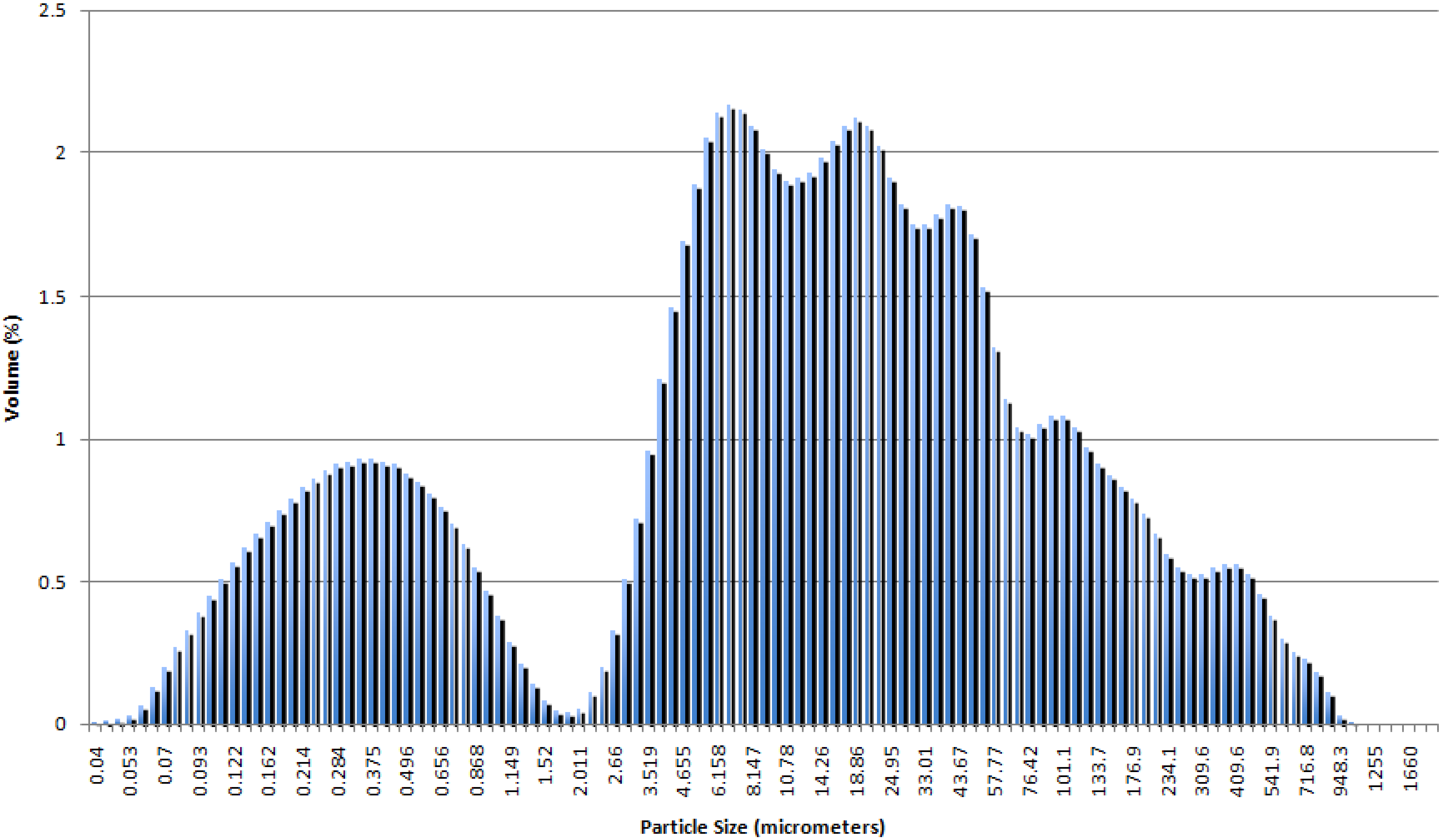

Fed scales back 2011 forecast
Existing hom
er housing starts down from '09

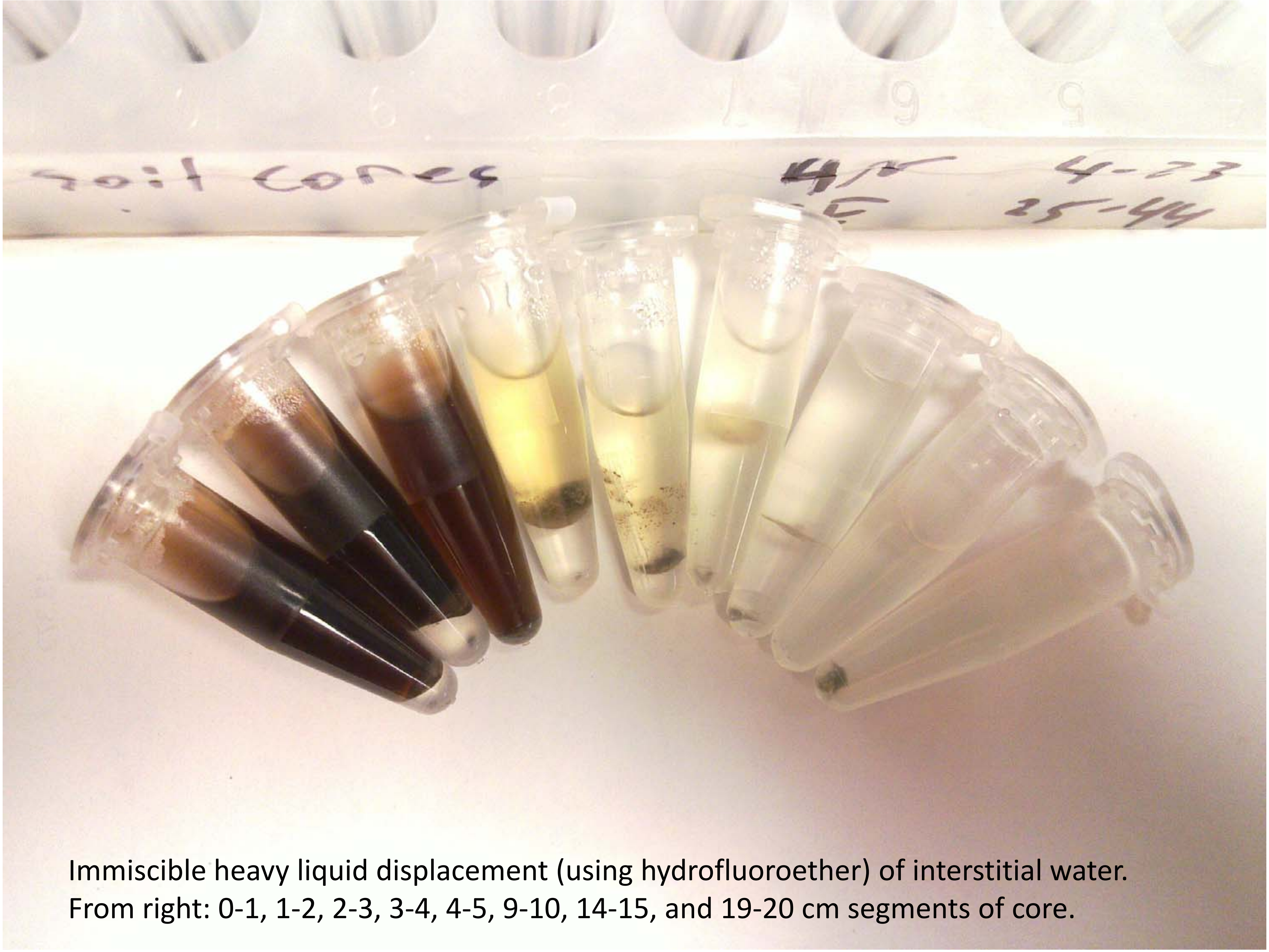


0
5
10
15
20
25
Depth, cm
1.0
1.2
1.4
1.6
1.8
2.0
Bulk Density, Mg m-3
4N vs Depth
3E vs Depth

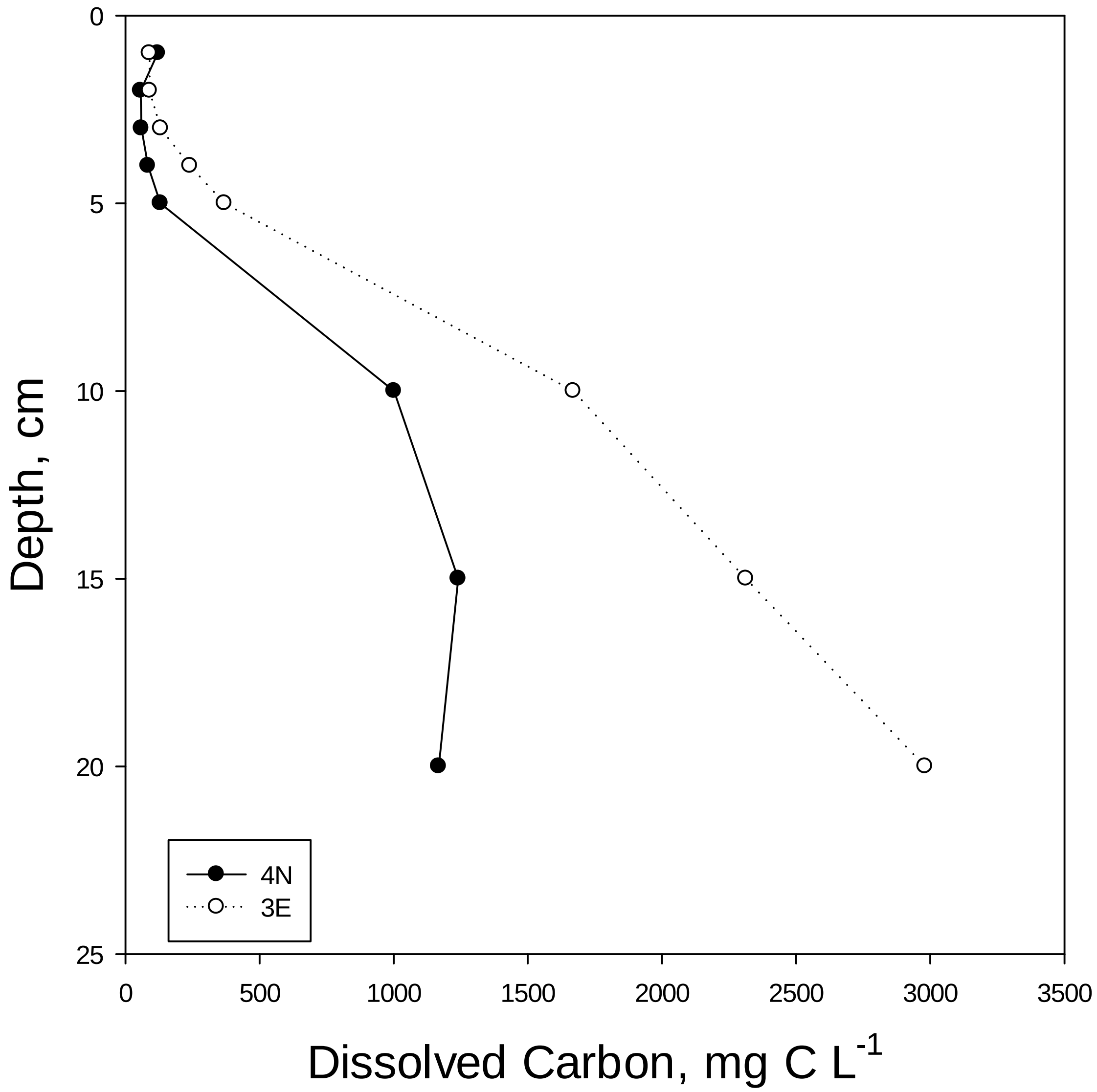
Dispersion of 1-cm core segments in 1% sodium polymetaphosphate and mechanical agitation, here allowed to settle showing bands of sand, silt and suspended clay, for particle size determination by laser scattering—after removal of pea gravel by sieving.

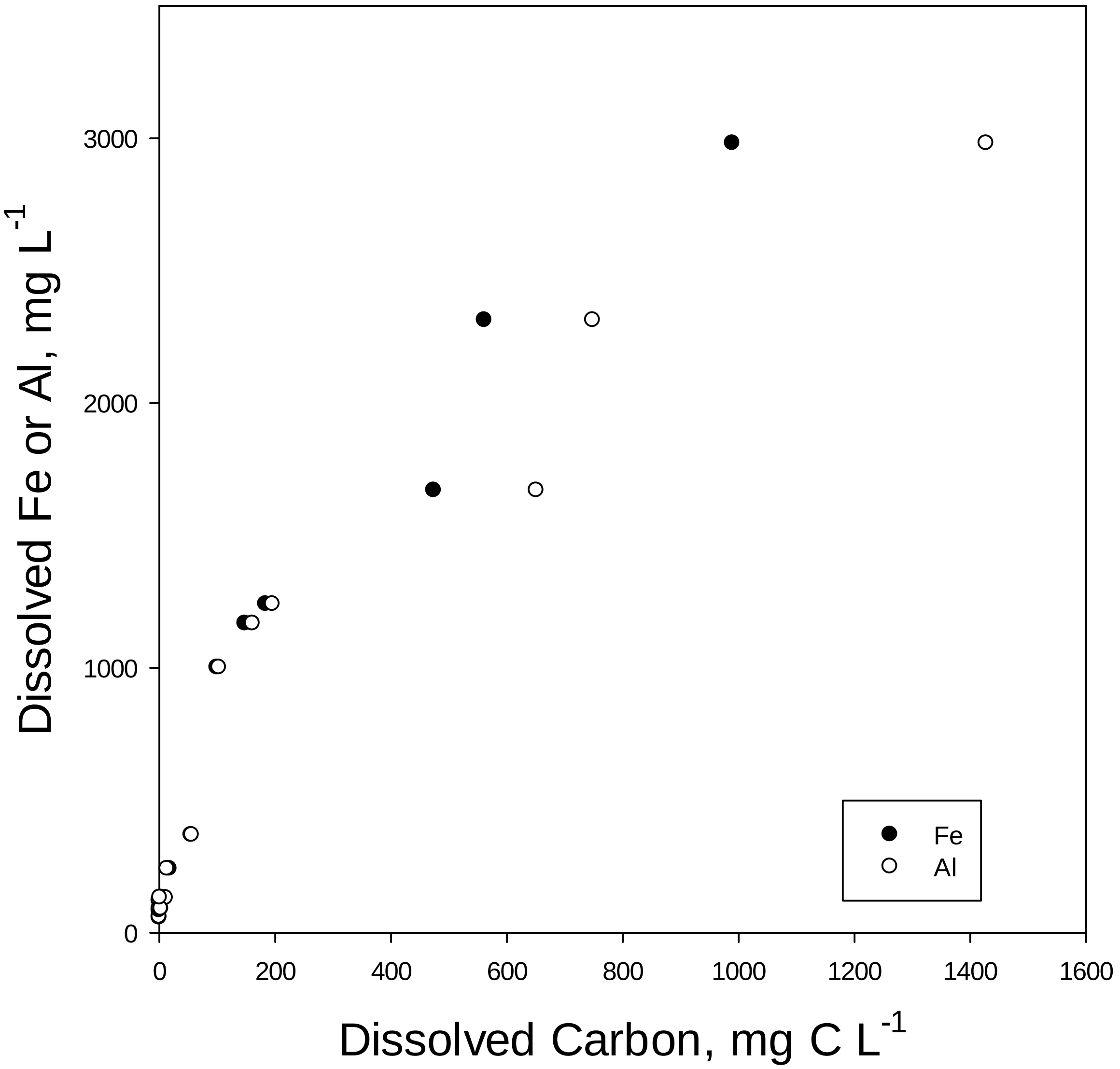
# Particle Size Distribution by Laser Scattering, gravel removed. Gravel was 10-15% of core segment, by wt.



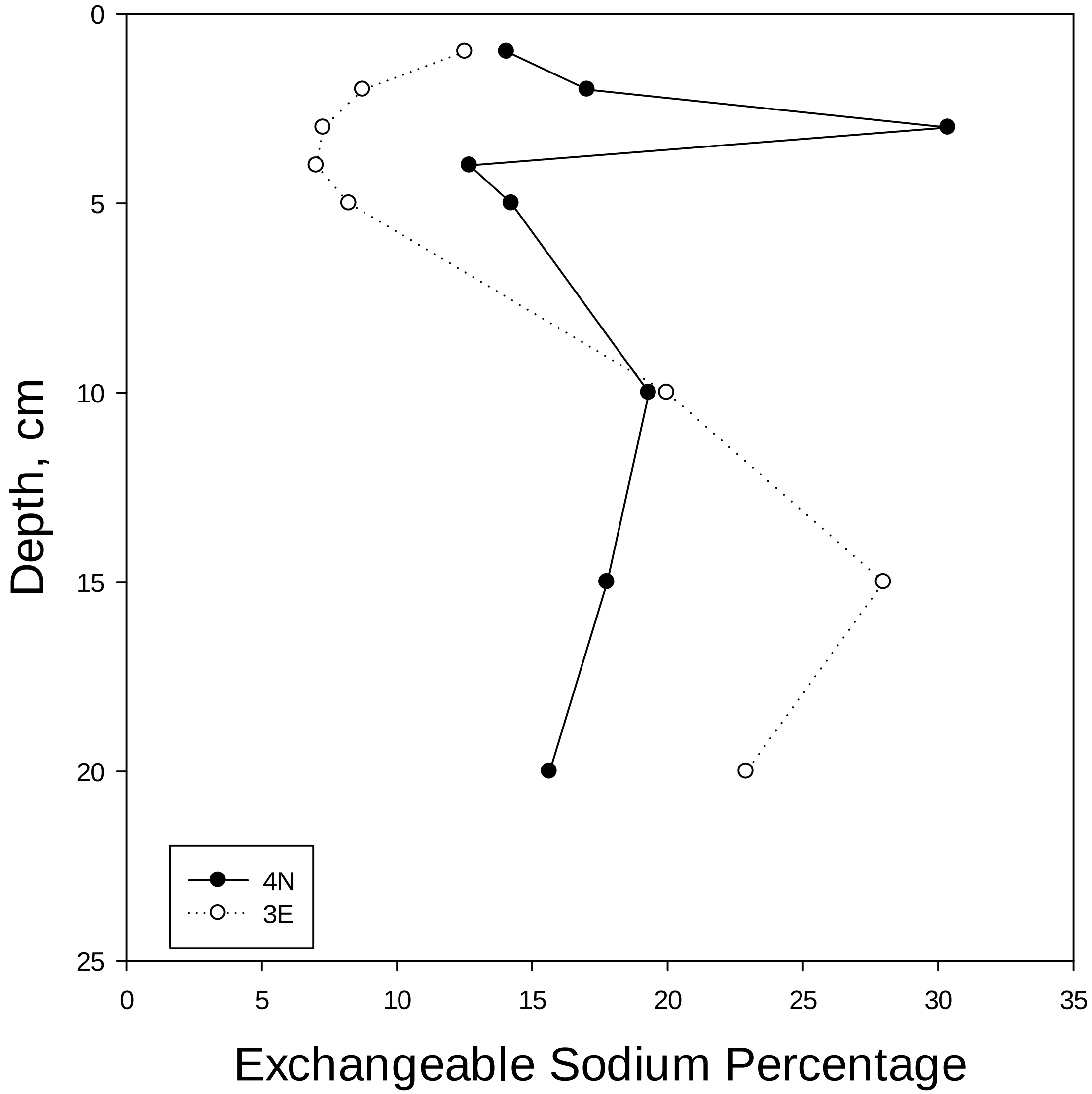


Immiscible heavy liquid displacement (using hydrofluoroether) of interstitial water.
From right: 0-1, 1-2, 2-3, 3-4, 4-5, 9-10, 14-15, and 19-20 cm segments of core.


Depth, cm
0
5
10
15
20
25
0
500
1000
1500
2000
2500
3000
3500
Dissolved Carbon, mg C L-1
4N
3E



Dissolved Fe or Al, mg L$^{-1}$
0
1000
2000
3000
0
200
400
600
800
1000
1200
1400
1600
Dissolved Carbon, mg C L$^{-1}$
● Fe
○ Al


Depth, cm
0
5
10
15
20
25
0
5
10
15
20
25
30
35
Exchangeable Sodium Percentage
4N
3E

# Typical remediation techniques:

Saline soils—

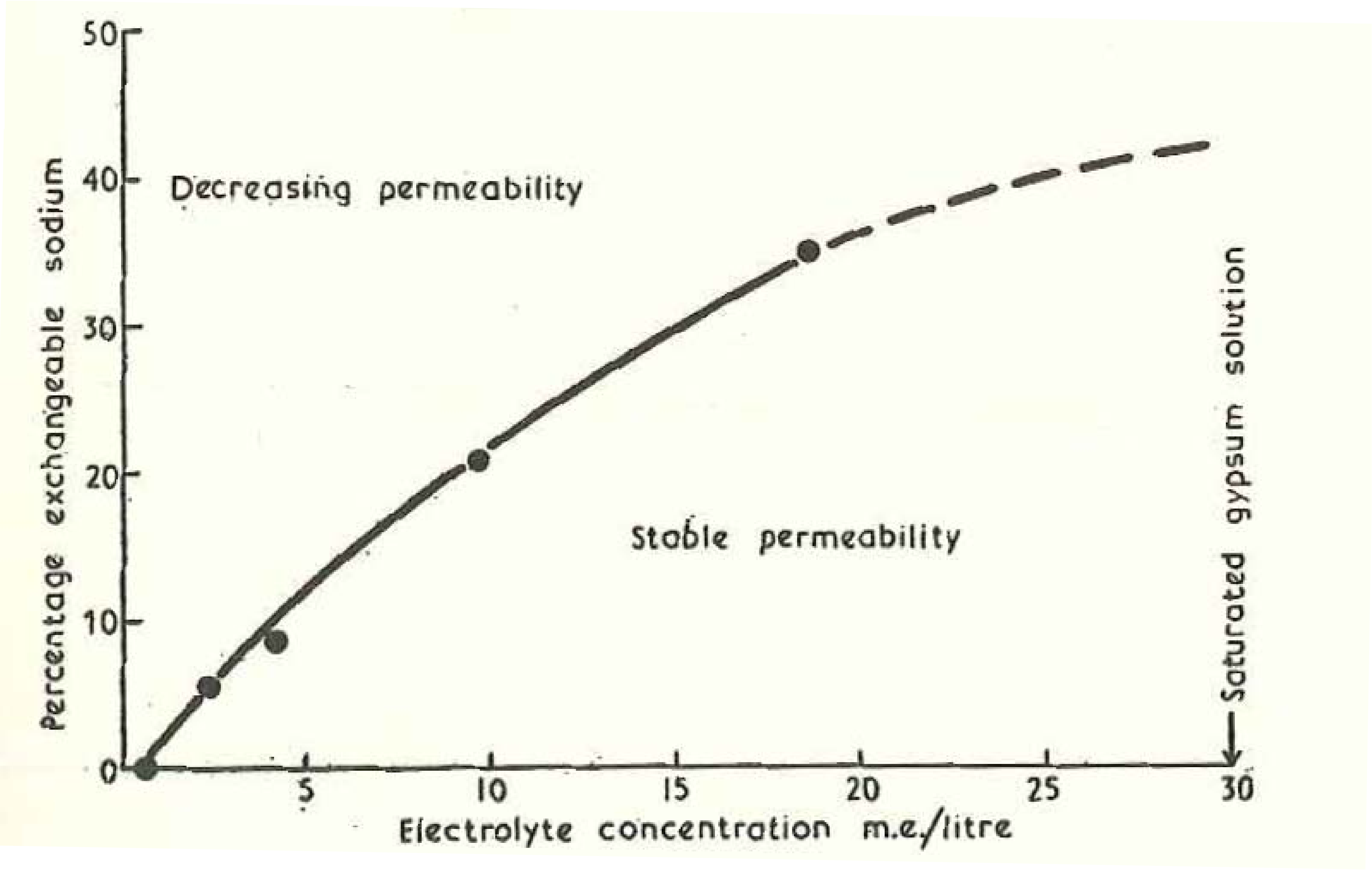
Add high quality water and drain

Sodic and saline-sodic soils—

Add gypsum, $CaSO_4 \cdot 2H_2O$, and then drain

(Gypsum dissolves to provide a relatively high ionic concentration and provides $Ca^{2+}$ to displace exchangeable $Na^+$)

Contraindicated—adding high quality water and draining; likely to cause impermeability



Quirk and Schofield. 1957. J. Soil Science

# Findings for a different West Madison retention pond, for which change in SAR and EC upon gypsum addition were calculated. (Note persistence of high SAR and EC until May.)

| Gypsum Added | Pond Water Characteristics: | | | | | | Gypsum Added |
|---|---|---|---|---|---|---|---|
| | 9/1/200x | | 1/27/200x | | 5/12/200x | | |
| --mM-- | SAR | EC* | SAR | EC | SAR | EC | --g/L-- |
| 0 | 0.9 | 0.1 | 11.7 | 1.2 | 11.6 | 1.0 | 0 |
| 5 | 0.2 | 1.3 | 4.8 | 2.4 | 4.3 | 2.2 | 0.9 |
| 10 | 0.2 | 2.3 | 3.5 | 3.4 | 3.2 | 3.2 | 1.7 |
| Sat’d | 0.1 | 3.1 | 2.9 | 4.4 | 2.6 | 4.2 | 2.6 |

* dS/m or mmho/cm

## Falling head permeameter

to measure $K_{sat}$ on intact cores, using sequence of:

- tap water,
- gypsum-saturated water, and
- 25 mM calcium chloride
- 250 mM calcium chloride

# $K_{sat}$ measured with Falling Head Permeameters

|  | cm $d^{-1}$ | cm $h^{-1}$ | cm $s^{-1}$ |
|---|---:|---:|---:|
| Sand | 504 | 21.0 | 5.83E-03 |
| Sandy loam | 62.6 | 2.59 | 7.19E-04 |
| Loam | 31.7 | 1.32 | 3.67E-04 |
| Silt loam | 16.3 | 0.68 | 1.89E-04 |
| Clay | 1.44 | 0.06 | 1.67E-05 |
|  |  |  |  |
| Core 2E: |  |  |  |
| tapwater | 0.33 | 0.01 | 3.86E-06 |
| gypsum-sat’d | 2.32 | 0.09 | 2.69E-05 |
| 25 mM $CaCl_2$ | 2.35 | 0.10 | 2.72E-05 |
| 250 mM $CaCl_2$ | 2.53 | 0.10 | 2.93E-05 |
|  |  |  |  |
| Core 2N: |  |  |  |
| tapwater | 0.52 | 0.02 | 6.06E-06 |
| gypsum-sat’d | 0.72 | 0.03 | 8.30E-06 |

## Conclusions:

- This is an autopsy, not a resuscitation or remediation
- Engineered soil has puddled and structure has been lost
- Most of runoff water exits directly thru overflow pipes to sewers
- Retention ponds will never be able to remediate salts but will only pass it on, sooner or later, to groundwater or overflow drains

Replacing the soil of the ‘storm water quality basins’, which failed in two winters, should be accompanied by:

- Diversion of sodium chloride used for deicing parking lot, creating a ‘3-season basin’
- Routine addition of gypsum to ponds to raise SAR and reduce tendency to form sodic soil (~2 g/L)
- Substitution of calcium chloride, calcium acetate, or potassium chloride for sodium chloride in parking lots draining into retention ponds will prevent occurrence of clogging due to sodicity
- Rating of engineered soils for sensitivity to sodicity if no change from sodium chloride is feasible.

# Evaluation of the Sodicity Response of an Engineered Soil for Bioretention Pond Application

*A Report by*
***Christopher Long***
*MS candidate, Water and Environmental Resource Management, UW-Madison*
*in partial fulfillment of course requirements of*
*Soils 375 'Bioretention Pond Permeability"*
*under the direction of*
***Phillip Barak, PhD***
*Professor, Dept of Soil Science*
*University of Wisconsin-Madison*
*May 2012*

## Introduction and objectives:

This report investigates how well an engineered soil retains its permeability when saturated with extremely sodic water treatments that induce clay dispersion. The need for the study arose out of the recommendations of a report analyzing the causes of a failed bioretention basin.

The possible site for this engineered soil is the bioretention basins surrounding the Costco building at 2150 Deming Way in Middleton, Wisconsin. These basins receive runoff from the roof and the surrounding parking lot, which totals over 500,000 sq ft of impervious surface. The original bioretention basins were installed in August 2008 and had stopped functioning by spring 2010. A team of students led by Dr. Phillip Barak from the Dept of Soil Science at UW-Madison determined that the reason for failure was a loss of soil structure induced by highly sodic spring runoff from the heavily salted parking lot. The report recommended replacing the soil of the failed basins but testing the permeability of the replacement soil for sensitivity to sodicity before installing it in the basins. No established protocols were available in Wisconsin for making such an evaluation and none were found in the literature.

The following lab experiments were designed to test the new soil before it is installed. These series of tests were designed to replicate the sodic content of early spring runoff to determine its affect on the permeability of the soil.

## Methods and Materials

A sample of engineered soil identical to that used for the demonstration bioretention pond on the premises of the U.S. Geological Survey office in Middleton, WI, was sent to P. Barak in August 2011. Mechanical analysis showed a composition of 90% sand, 5% silt and 5% clay (determined by the hydrometer method at the Soil and Plant Analysis Lab, SPAL, Verona, WI), which corresponds to a texture of sand. Color in the Munsell system is 7.5YR 6/4 (dry), or light brown, with occasional pieces of dark brown bark.

### *Permeameter Setup*

A falling-head permeameter was prepared from a 2.15-cm internal radius acrylic cylinder, with a filter and a rubber stopper at the lower end of the cylinder and a length of Tygon tubing that served as an effluent tube. The cylinder was filled with field moist soil to a depth of 21 cm, with gentle tapping of the column to consolidate the soil. The bulk density, determined by weighing the oven dry contents of the column, was 1.56 Mg $m^{-3}$, indicating a porosity of 41.1% if assuming a particle density of 2.65 Mg $m^{-3}$. One pore volume of the soil was 125 mL. The soil column was initially saturated with Madison tap water from the bottom up to minimize air trapped in the medium. From this point and throughout the duration of the treatment regimes, the column was kept continuously saturated. Measurements of head were made with a meter stick attached to the permeameter (figure 1).

### *Hydraulic Conductivity Measurements*

The first hydraulic conductivity ($K_{sat}$) test of the soil column was performed with tap water. This test established a control $K_{sat}$ for the entire experiment. The procedure for this and subsequent hydraulic conductivity tests involved filling the permeameter to a depth of 25-30 cm above the top of the soil in the column with the test solution. Care was taken to avoid disturbance of the soil surface. Both the height of the water column and the height of the effluent outlet were recorded before beginning the experiment. The initial time was recorded when the effluent outlet was opened. As the water permeated through the soil column, the elapsed time and height of water above the outlet was recorded. The experiment was stopped after 15 to 20 data points were collected (figure 2) over the course of 15 to 60 min.

Two series of experiments were devised to determine the effect of exchangeable sodium on the hydraulic conductivity of the sand column. To begin, the hydraulic conductivity of tap water was measured in the column. This test also conditioned the column for the following experiments. The first experiment (Series A) used a series of water treatments, formulated to specific SAR, EC values, to simulate the sequence of run-off received in the bioretention ponds. The second experiment (Series B) attempted to induce as much soil dispersion as possible by treating the soil with a 0.1M sodium chloride solution. Each water treatment was allowed to permeate the column to ensure complete replacement of the pore volume and complete cation exchange several times over.

The compositions of each water treatment were determined based on chemical analyses of retention ponds in west Madison receiving streets salts. Each treatment represents the highest and lowest SAR and EC values in a year. The water containing the highest concentrations of salt had 100.0 mg/L and 30.4 mg/L $CaCl_2$ and NaCl, respectively, for an SAR of 12 and an EC of 1.0; the water containing the lowest concentrations of street salts had 100.0 mg/L and 30.4 mg/L $CaCl_2$ and NaCl, respectively, for SAR and EC values of 4.9 and 0.12 respectively (see **table 1**).

The first series of treatments (Series A) started with water with low SAR and low EC values to condition the column, followed by water with high SAR and high EC values, then flushing again with water having low SAR, low EC values. Data to calculate hydraulic conductivity was taken during each treatment (A-1, A-2, A-3, A-4). The final low SAR, low EC water was tested twice for hydraulic conductivity (A-3, A-4). The second series of treatments (Series B) utilized the same setup. The sequence of water treatments were; low SAR low EC water, followed by a solution of 0.1 M NaCl, extremely high SAR and high EC treatment and then flushing with a low SAR, low EC treatment again.

### *Calculation of Ksat*

The hydraulic conductivity of each treatment was calculated from the set of time and head data. The elapsed time and head data were plotted and a third order polynomial was computed to fit the data. An root mean square, RMS, value was calculated to estimate the quality of the fit. The polynomial was used to calculate smoothed head values (h) and the instantaneous rate of head change (dh/dt) was calculated from the first derivative of the polynomial. From these values, $K_{sat}$ was calculated for each data point:

$$K_{sat} = dh/dt * l / \Delta h$$

where $l$ is the length of the soil column and $\Delta h$ is the difference in head from the top of the permeameter to the effluent outlet point. Finally, the instantaneous $K_{sat}$ values were averaged to find the mean $K_{sat}$. Mean $K_{sat}$ and the standard deviation for each treatment are reported in **figures 3 & 4**.

### *Water Sampling*

Water samples were taken during the final treatment phases of each series (A-3, A-4 and B-3, B-4) to determine if cations and colloids were being flushed out of the soil. To determine this, the first volumes of low SAR, low EC water permeating through the column after the conditioning treatment were captured in flasks and labeled. From series A, fourteen 50-mL samples of water were taken (samples 1-10, 100-103 in **figure 5**). From series B, twelve samples were collected in 50-mL flasks (samples 201-212 in **figure 6**). Because samples from series B were persistently cloudy, we continued to permeate an additional 5 liters (about 40 pore volumes) of low SAR, EC water and captured part of which (about 8 pore volumes) in 3 subsequent samples (samples 300 and 400 in **figure 6**). When the effluent again cleared, one final sample of water was taken (401).

To prepare the water samples for chemical analysis each flask was swirled to re-suspend all particles. Then a 10-mL portion was collected from each flask and put into test tubes and sealed. Each test tube containing a cloudy sample was centrifuged to separate the large colloidal particles, and then the liquid portion was extracted for testing. In total, 31 water samples were sent to the soil lab, SPAL, for testing; 14 from series A, 15 from series B and control samples of the low SAR, EC water and the high SAR, EC water.

### *Dry weight of sediments*

Several of the water samples collected were cloudy with suspended sediments so, in addition to analyzing the chemical constituents, the mass of total dissolved solids and colloids was measured. This was done with the remaining water sample after a portion was removed for testing at SPAL. The remaining portion was weighed then put into a drying oven. The samples were completely dried than weighed again. Ultimately each sampling flask was cleaned and weighed a final time when completely dry. From these weights, the total volume of water and the total mass of dissolved solids and colloids were calculated.

## Results

### *Hydraulic Conductivity Results*

There was no significant drop in hydraulic conductivity during treatments A-1 - A-4 in Series A (**figure 3**). However in series B there was a 40-50% decrease in hydraulic conductivity. This occurred during the flushing stage between treatment B-2 and B-3(**figure 4**).

### *Water Samples*

Water samples were taken during both Series A and Series B, during and after the final flushing treatment. The effluent from this final flushing treatment was captured in 50-mL samples (**figures 5 & 6**). For Series A, the SAR and EC values declined unsteadily from 4.9 to 0.39 (SAR values) and from 1.1 to 0.21 (EC values). For Series B the SAR and EC values of the effluent declined dramatically between samples 2 and 5, then plateaued for the remaining 7 samples. In both series, the SAR and EC values changed most rapidly between the 3rd and 4th sample, which represented the complete exchange of one pore volume of high SAR high EC water with low SAR low EC water (**figure 7**).

Chemical analysis of water samples from both series showed that during this period of low SAR EC water exchanging with high SAR EC water with the first 4 water samples, a rapid decline in sodium occurred (**figures 8 & 9**) corresponding with the a rapid change in the SAR and EC values. Sodium concentrations in Series A declined by approximately 70% and calcium concentrations declined by approximately 80% within these 4 samples. Similarly during this period of exchange in the first 4 water samples of Series B, sodium and calcium concentrations both declined by approximately 80%.

Also, magnesium and potassium concentrations showed a sharp decline within these first 4 samples. However, only sodium concentrations showed a steady decline throughout both series. Both series also show a spike of iron concentrations in the 4th sample (sample 4 in **figure 8** and sample 204 in **figure 9**) taken from each series. Both series also show a slight but irregular increase in calcium concentration in the last several water sample.

Here the comparison of water sample data between Series A and Series B ends. The concentration of other minerals (P, Al, Mn) in Series A were barely detectable, and no clear observations could be made about them. The concentrations of Fe, P, Al, K and Mn in Series B vary considerably. All 5 constituents in Series B show a spike in concentration at sample 204 and then show a slow decrease in concentration until they spike again at sample 300 in **figure 9**.

### *Leached Colloids*

Water samples from experiments A and B also differed in their amount of cloudiness. All of the water samples in experiment A showed no turbidity except for sample #4, which was cloudy white(**figure 5**). In contrast, all of the water samples from experiment B were brown and opaque except for the first two samples and the last sample (**figure 6**). The chemical analysis from SPAL indicated that the cloudy samples all contained iron concentrations greater than 0.20 ppm. None of the other samples that appeared clear had iron concentrations near to this lower threshold. Within these cloudy samples, the chemical analysis also indicated that concentrations of aluminum and iron are positively correlated for 7 consecutive samples (**figure 9**), strongly suggesting that the iron and aluminum were not soluble but colloids that had passed filtration.

## Conclusions

### *Hydraulic Conductivity*

**After loading with high concentrations of salts and subsequently flushing with a low salinity treatment, the soil column maintained its saturated permeability at a rate that would make it suitable substrate for a bioretention basin.**

Series A, which most closely resembled the extreme SAR and EC values of runoff into the bioretention basins, showed a negligible decrease in hydraulic conductivity over the course of the experiment. The hydraulic conductivity in Series A ranged from 42.1 to 38.7 cm/hr. (**table 1**) The treatments in Series B had a significant effect on hydraulic conductivity. The hydraulic conductivity dropped from a maximum of 35 cm/hr to a minimum 19 cm/hr (**table 1**). Despite this change, 19 cm/hr would maintain the functionality of the basins, provided that the mobilized colloids were swept out of the soil column and did not accumulate into an impermeable clay layer.

### *Soil Dispersion Hypothesis*

Several observations support the hypothesis that soil dispersion is causing the measurable decline in hydraulic conductivity noticed in Series B. If soil dispersion were occurring, we would expect to see a pulse of colloidal material exiting the column accompanying a change in the SAR and EC values of the effluent.

All of these changes were observed in Series B. Twelve of the 15 samples from Series B, representing a liter of effluent, were observably reddish-brown and cloudy with leached colloidal particles (**figure 6**). This pulse of colloids corresponded to a spike in the concentration of Fe, P, Al, K and Mn seen in the water samples (**figure 9**). None of these were present as introduced ions in the water treatments, and all of them are commonly bound to colloids, especially potassium; or they are commonly found as colloidal oxides as in the cases of iron and manganese. This indicates that they were borne on colloid particles that were clouding the sediments.

Also in support of this hypothesis, the colloids began appearing in the effluent only after the low SAR water replaced the high SAR water in the column. This was observed in both series, as the first 3 samples (~150 mL or slightly over 1 pore volume) were clear and the 4th sample of each series appeared cloudy (**figures 5 & 6**). The pulse of colloids in Series A was much smaller, corresponding to the smaller change in SAR and EC values and a negligible decrease in hydraulic conductivity (**table 1**). Thus clay dispersion could be blamed for the change in hydraulic conductivity because a much greater change in hydraulic conductivity was seen in Series B which also showed much more clay dispersion.

**Based in these results, it could be expected that a bioretention basin made from this substrate would not lose functional permeability due to clay dispersion caused by road salts alone**.

**Appendix**

**Figure 1:** Permeameter Setup

**Figure 2:** Measuring Hydraulic Conductivity

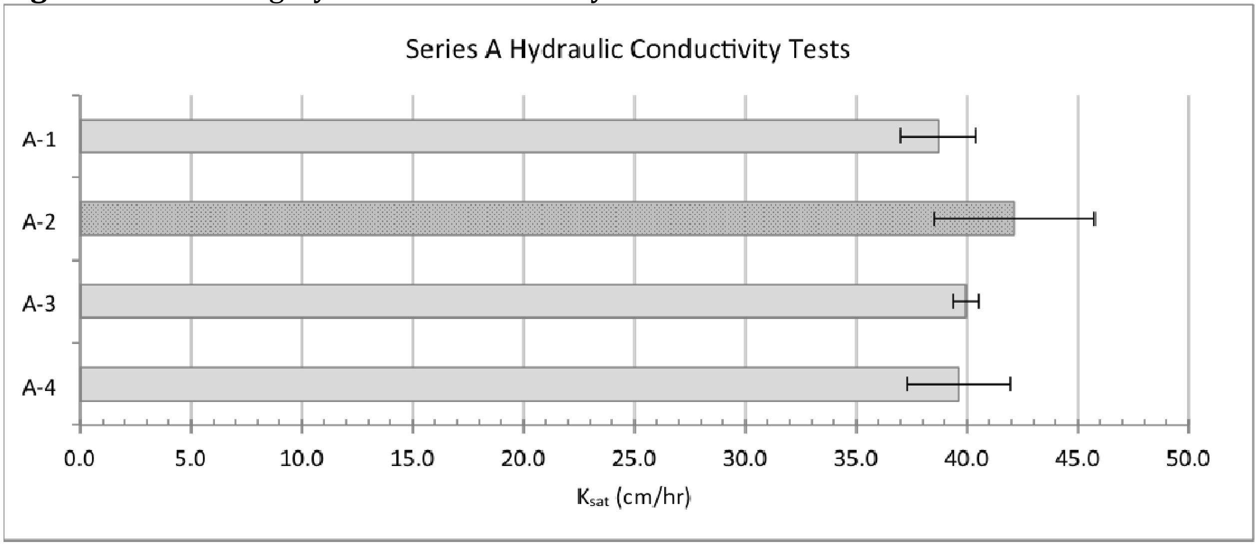


**Figure 3**: Hydraulic conductivity of 4 water treatments in experiment A.

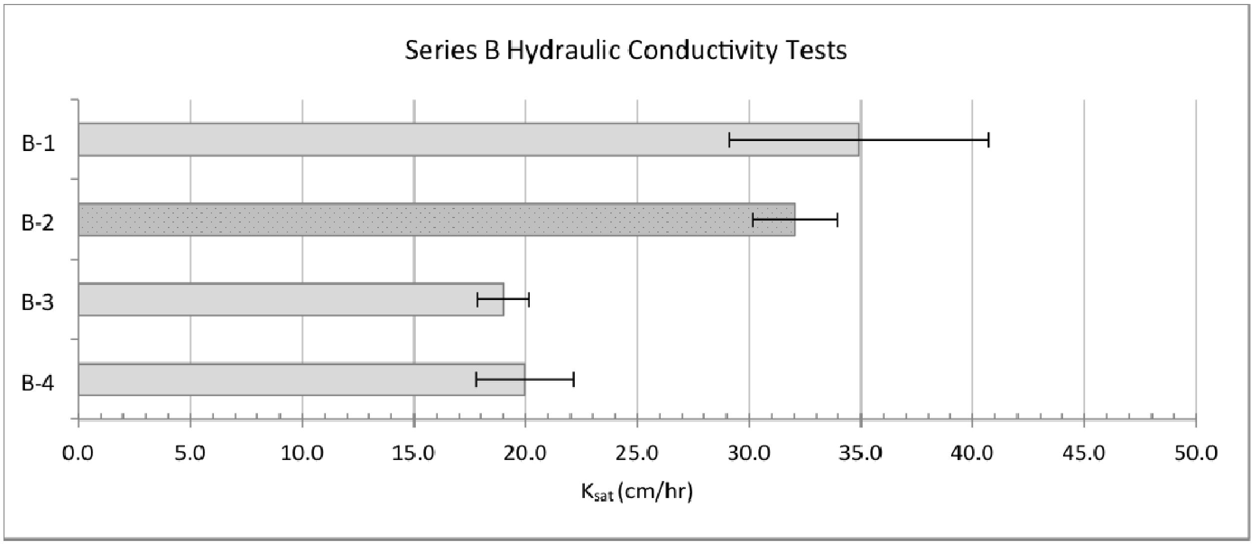


**Figure 4**: Hydraulic conductivity of 4 water treatments in experiment B.

|  | formulated water treatments |  |  |  | effluent |  |  |  | hydraulic conductivity (cm/hr) |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | high | high | low | low | maximums |  | minimums |  |  |  |
|  | SAR | EC | SAR | EC | SAR | EC | SAR | EC | max | min |
| Series A | 12 | 1.0 | 4.9 | 0.12 | 4.9 | 1.1 | 0.39 | 0.21 | 42 | 39 |
| characterization | normal |  | normal |  | normal |  | normal |  |  |  |
| Series B | ∞ | 10 | 0.9 | 0.12 | 31 | 6 | 1.25 | 0.22 | 35 | 19 |
| characterization | saline-sodic |  | normal |  | saline-sodic |  | normal |  |  |  |

**Table 1:** Changes in sodium adsorption ratio (SAR) and electrical conductivity (EC) between the influent and effluent of the permeameter tests. By comparing these changes in SAR and EC to the changes in hydraulic conductivity, one can get the sense of how drastically highly sodic runoff may impact the permeability of the soil.

**Figure 5:** Photo of water samples 1-10 from representing 4 pore volumes of effluent from Series A.

**Figure 6:** Photo of water samples 201-212, 300, 400, 401 representing 13 pore volumes of effluent from Series B.

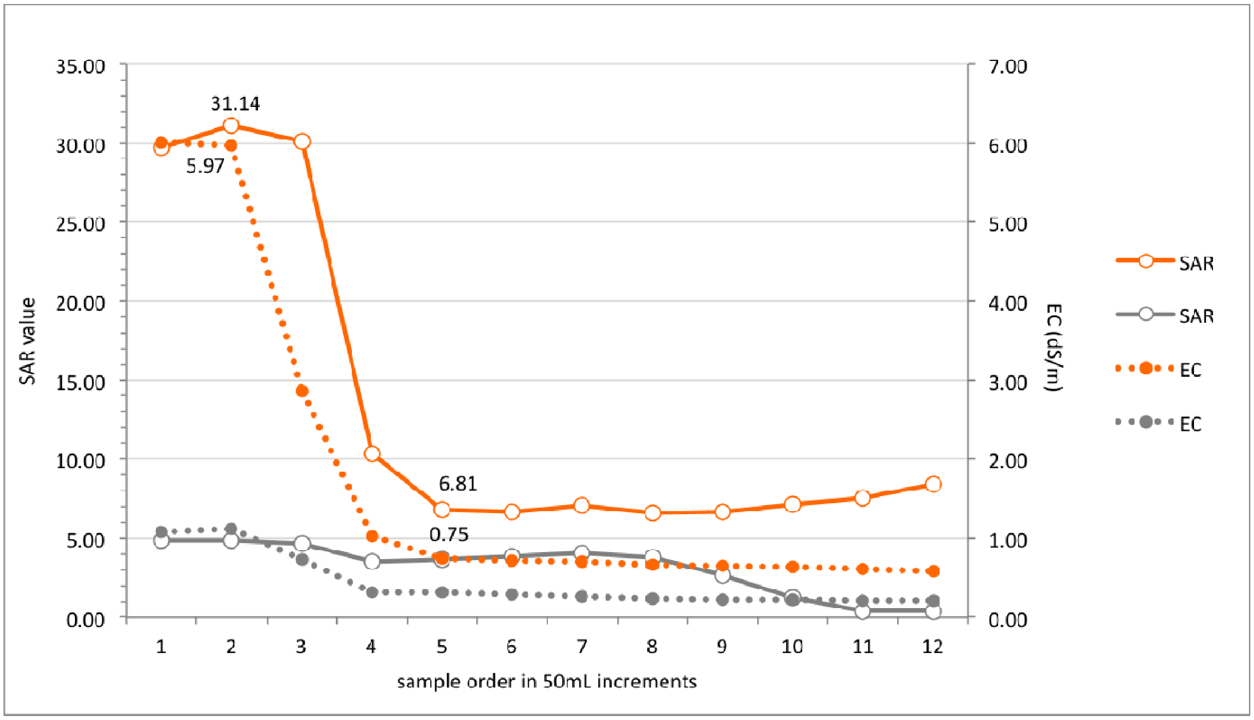


**Figure 7:** SAR and EC values from samples for Series A and B. Series A is grey and Series B is orange.

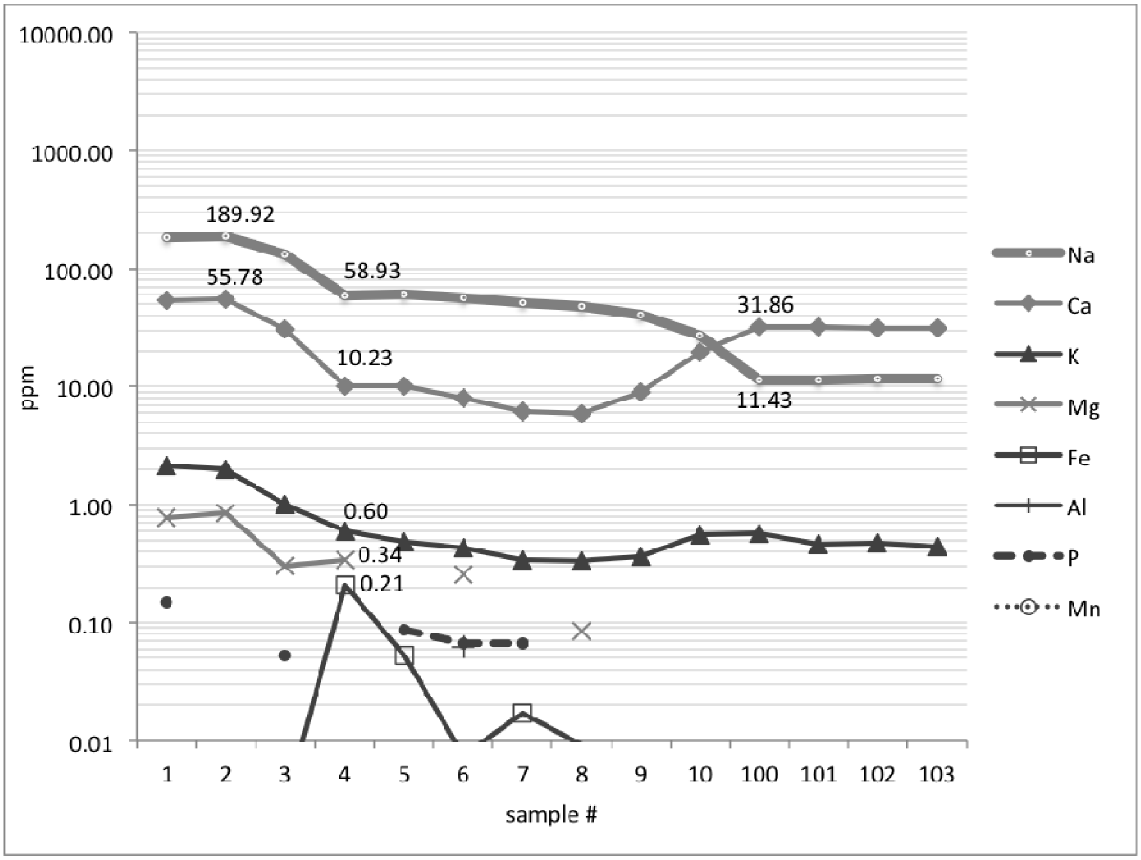


**Figure 8**: Water samples 1-10 and 100-103 were taken as the high SAR, EC water was replaced by low SAR, EC water during **Series A.** These samples were taken in increments of 50mL and represent

700 mL  of effluent which is approximately 7 pore volumes.

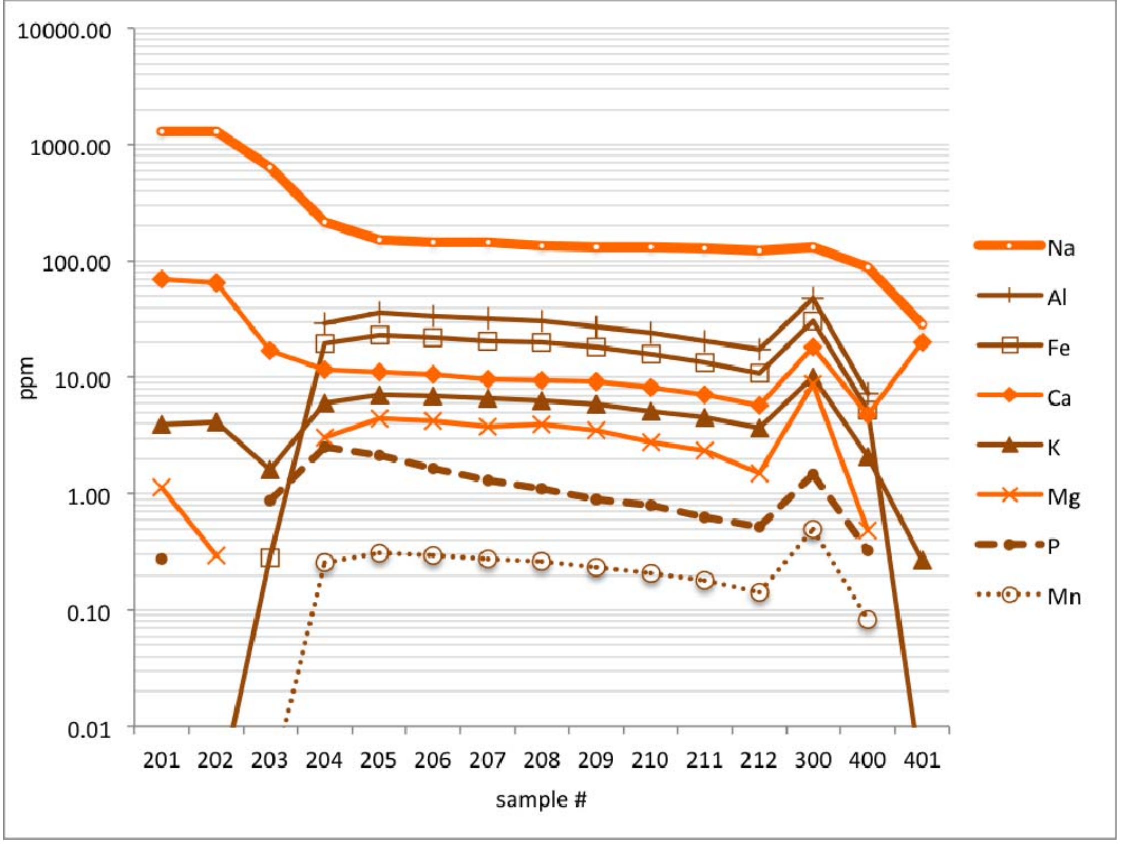


**Figure 9:** Water samples 201-212, 300, 400, 401 were taken as the high SAR high EC water was replaced by low SAR low EC water in during Series B. These samples  were taken in increments of 50mL and represent approximately 13 pore volumes of effluent

# Saline and Sodic Soils in Wisconsin:
# The Sad Story of an Infiltration Pond

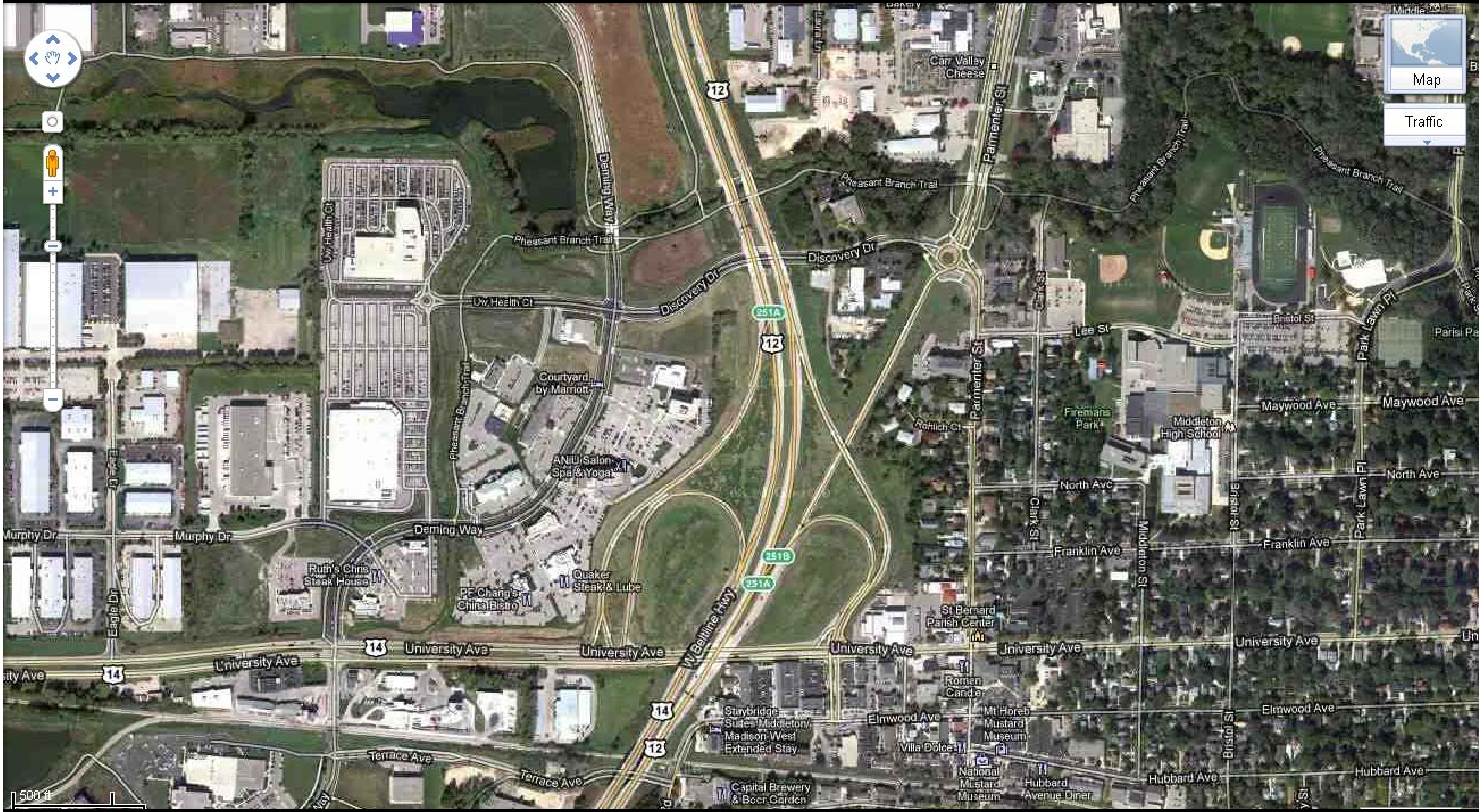
for the City of Middleton Water Resource Management Commission
19 Sep 2012

Kyle Rudersdorf, David Evans, Glen Obear, Shane Griffith,
Mackenzie Naber and Chris Long

under the supervision of

Phillip Barak, PhD
Professor, Dept of Soil Science
University of Wisconsin-Madison
pwbarak@wisc.edu

and with the sponsorship of The City of Middleton and Costco


Map
Traffic
Carr Valley Cheese
Parmenter St
Pheasant Branch Trail
Deming Way
Discovery Dr
Uw Health Ct
12
251A
251B
Lee St
Bristol St
Park Lawn Pl
Parisi Pa
Clark St
Courtyard by Marriott
Maywood Ave
Firemans Park
Middleton High School
Rohlich Ct
ANU Salon Spa & Yoga
North Ave
Middleton St
Franklin Ave
Murphy Dr
Eagle Dr
Ruth's Chris Steak House
PF Chang's China Bistro
Quaker Steak & Lube
W Beltline Hwy
St Bernard Parish Center
14
University Ave
Roman Candle
Staybridge Suites Middleton/ Madison-West
Extended Stay
Elmwood Ave
Mt Horeb Mustard Museum
Villa Dolce
National Mustard Museum
Hubbard Avenue Diner
Hubbard Ave
Terrace Ave
Capital Brewery & Beer Garden
500 ft

$10.5 million
Opened Aug 2008

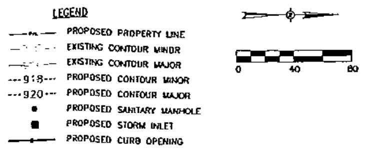
~153,000 sq. ft. bldg

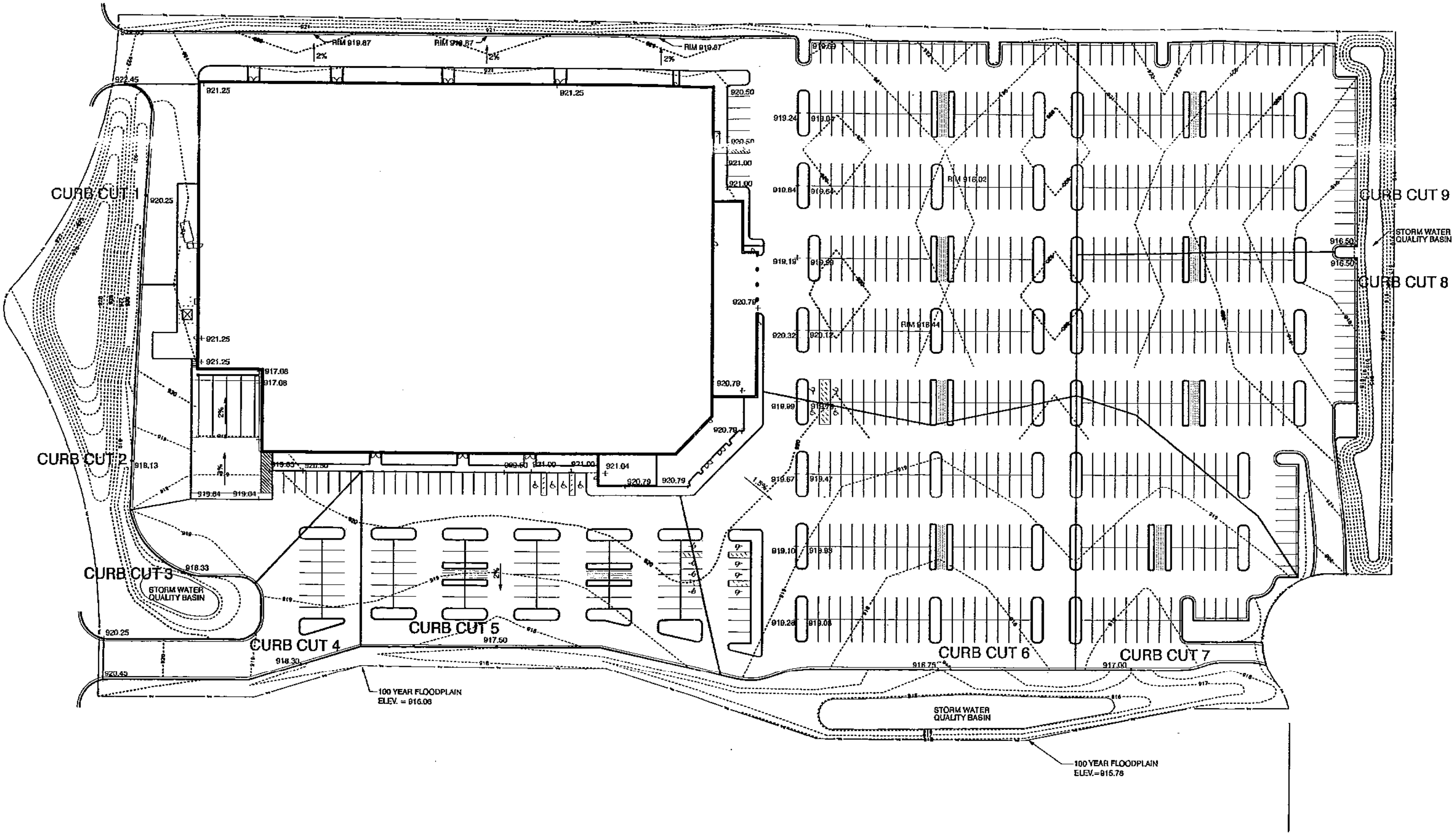
~440,000 sq. ft. parking lot

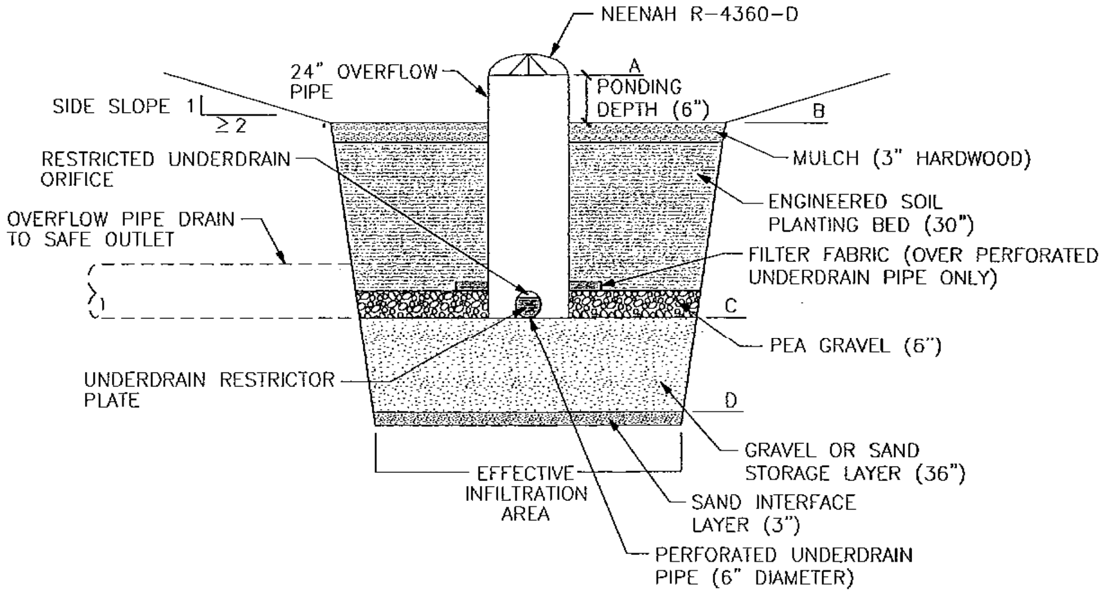
3 Stormwater quality basins:

2300, 8000 & 8700 sq. ft.

(~30:1 impermeable:basins)

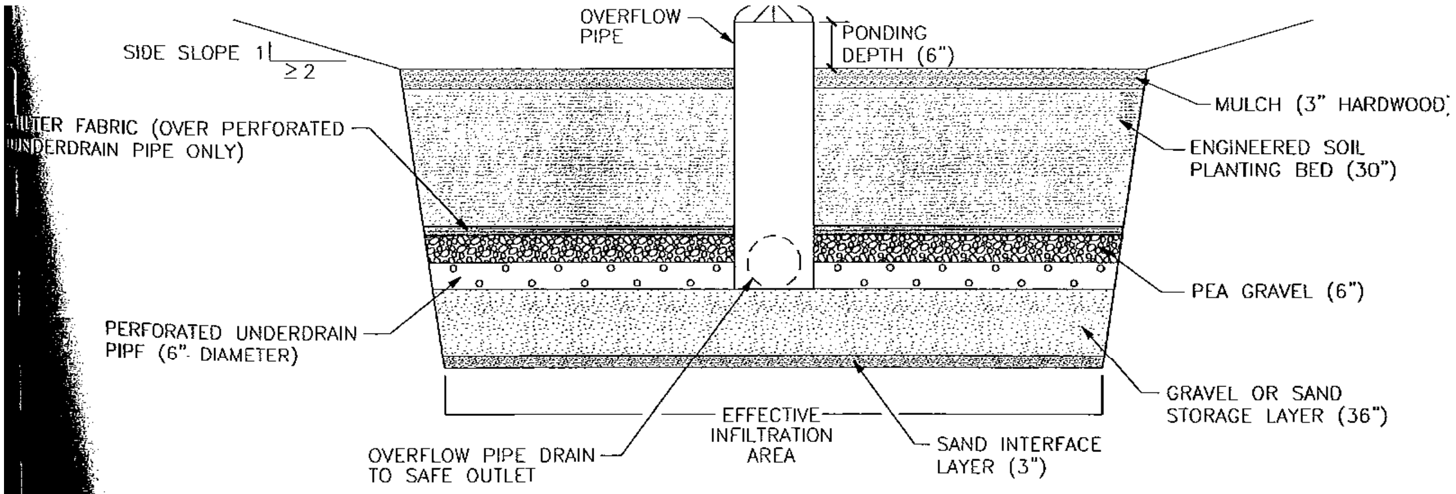






| DEVICE | ELEV. A | ELEV. B | ELEV. C | ELEV. D |
|---|---|---|---|---|
| 2 | 916.00 | 915.50 | 912.00 | 909.00 |
| 3 | 918.25 | 917.75 | 914.50 | 911.00 |

BIORETENTION DEVICE – CROSS SECTION ACROSS WIDTH OF DEVICE



BIORETENTION DEVICE – CROSS SECTION ACROSS LENGTH OF DEVICE

Annual Madison salt application:
10 – 25 tons/mile
(Goal: 6 tons/mile)

Tons of salt applied or purchased by municipality, winter of 2008/9:

| | |
|---:|---|
| 27,000 | Dane Co. |
| 9,000 | City of Madison |
| 1,150 | Town of Burke |
| 1,350 | City of Middleton |
| 2,700 | Others |

Madison & Dane Co. Public Health
**ROAD SALT REPORT – 2008/09**
http://www.publichealthmdc.com/publications/documents/RoadSalt2009.pdf

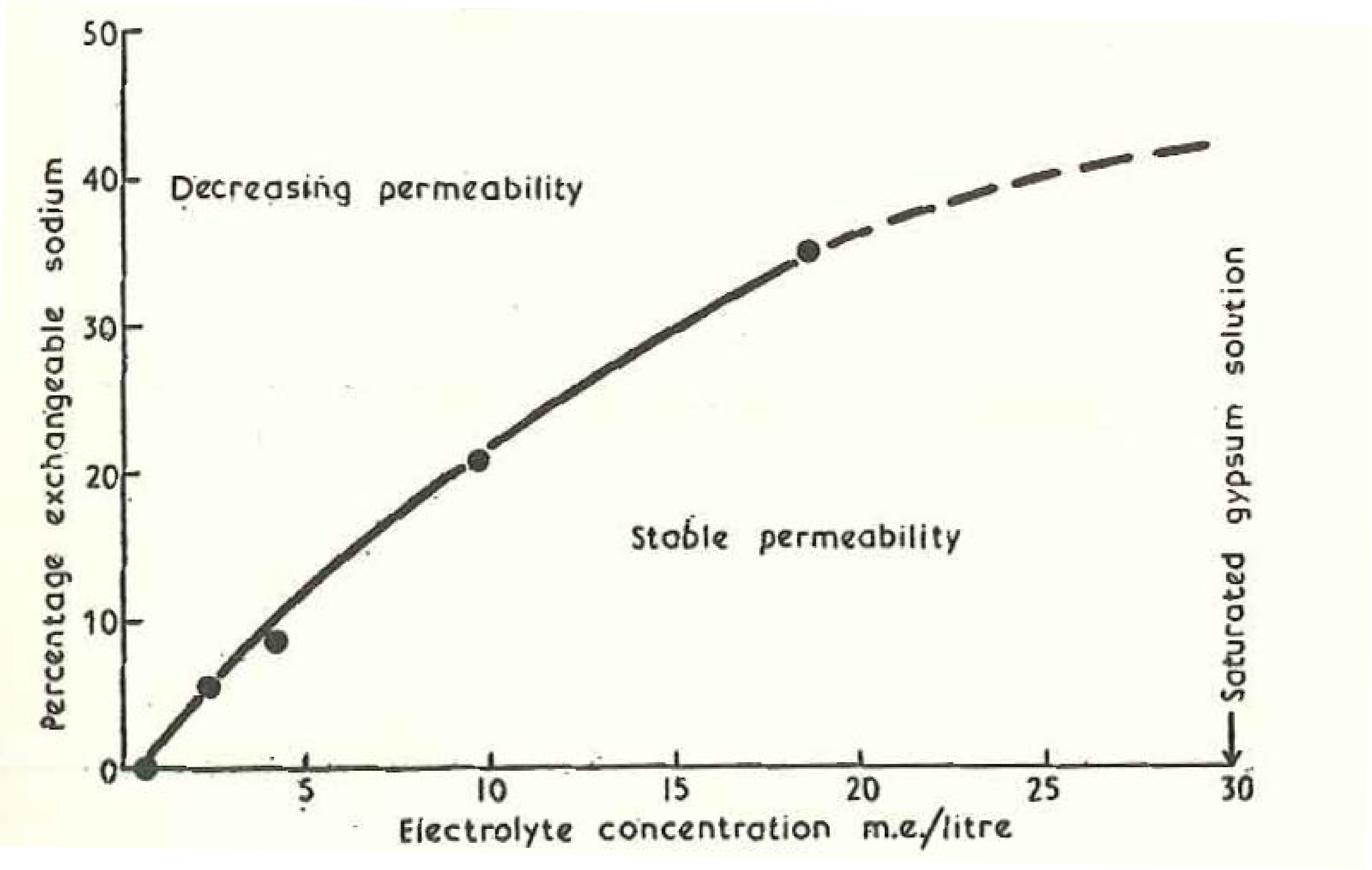
# Diagnostic techniques:

Salinity—

- Electrical conductivity (EC) of soil water or saturated soil extract (lab; dS/m or mmho/cm)
- portable electromagnetic (EM) soil conductivity sensor mounted on vehicle (field)

Sodicity—

- Measurement of Exchangeable Sodium Percentage (ESP) by cation displacement
- Measurement of Sodium Adsorption Ratio (SAR) in soil solution, saturated soil extract or irrigation water



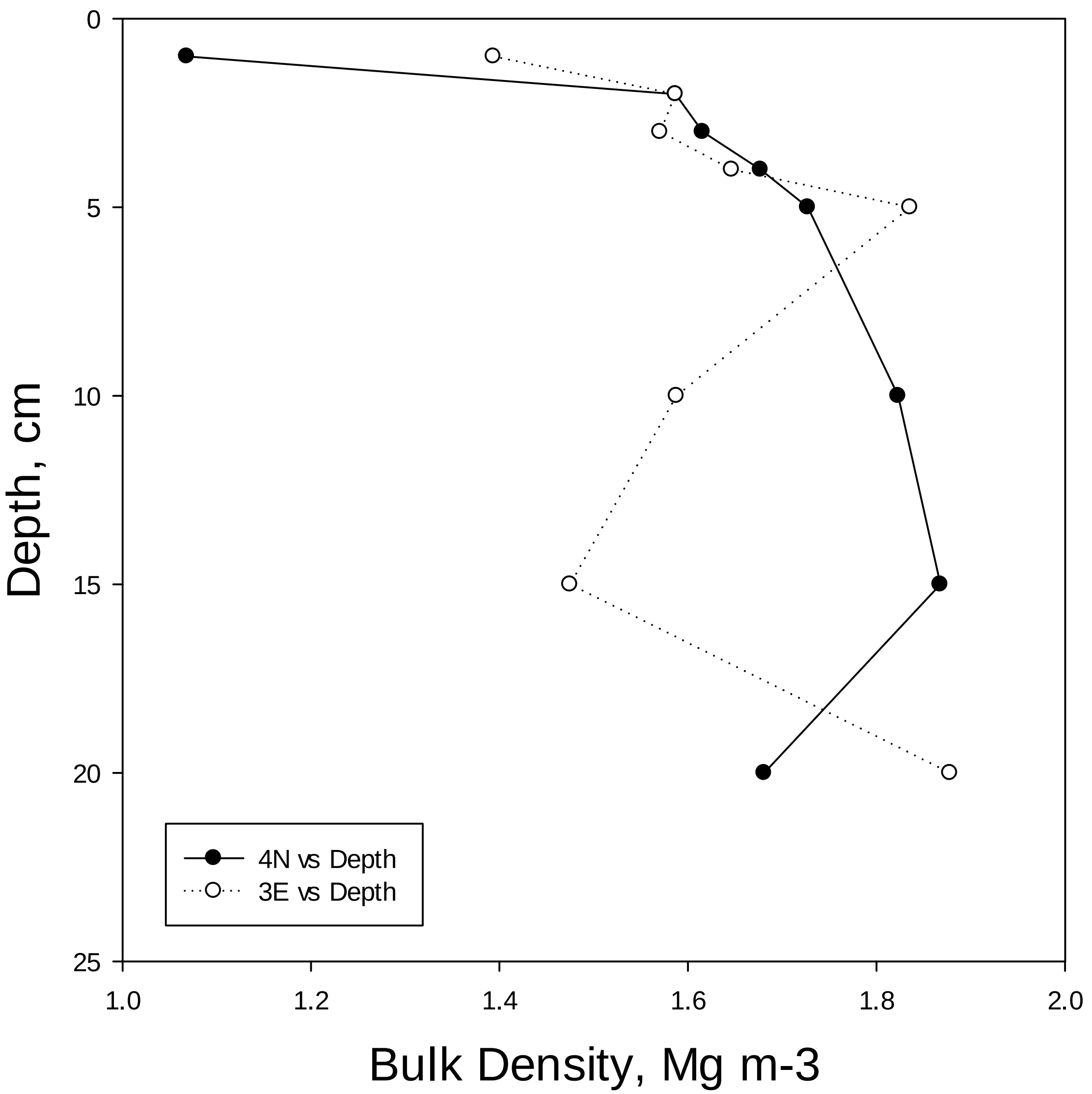
Quirk and Schofield. 1957. J. Soil Science

Sampling at retention ponds, Aug 2010

Collection of cores from retention ponds (in background).

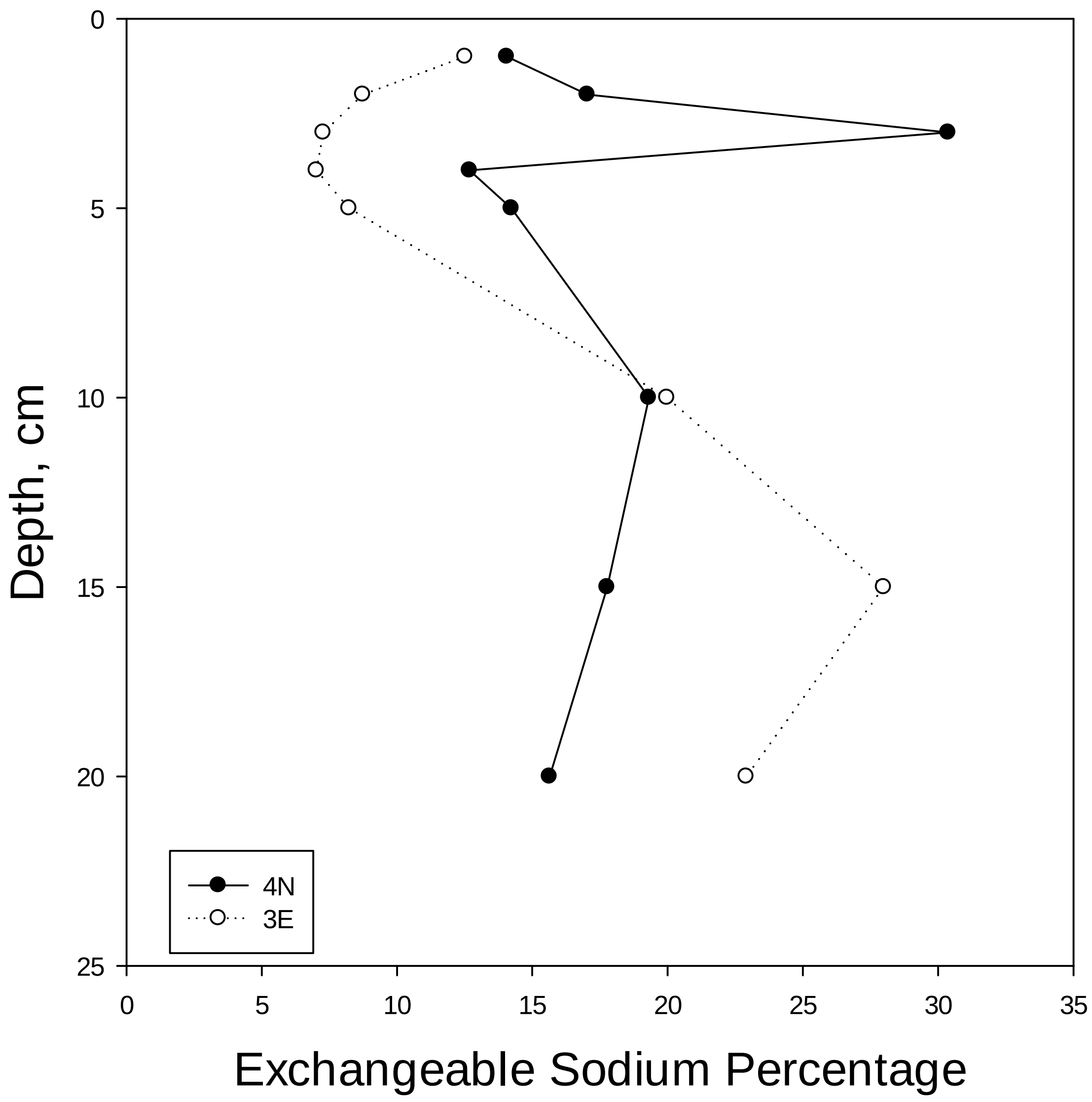

529872
SINESS
Fed scales
ll forecast
Existing ho
om '09


1
2
3
4
5
6



0
5
10
15
20
25
Depth, cm
1.0
1.2
1.4
1.6
1.8
2.0
Bulk Density, Mg m-3
4N vs Depth
3E vs Depth

Dispersion of 1-cm core segments in 1% sodium polymetaphosphate and mechanical agitation, here allowed to settle showing bands of sand, silt and suspended clay, for particle size determination by laser scattering—after removal of pea gravel by sieving.


0
5
10
15
20
25
Depth, cm
0
5
10
15
20
25
30
35
Exchangeable Sodium Percentage
● 4N
○ 3E

# Typical remediation techniques:

Saline soils—

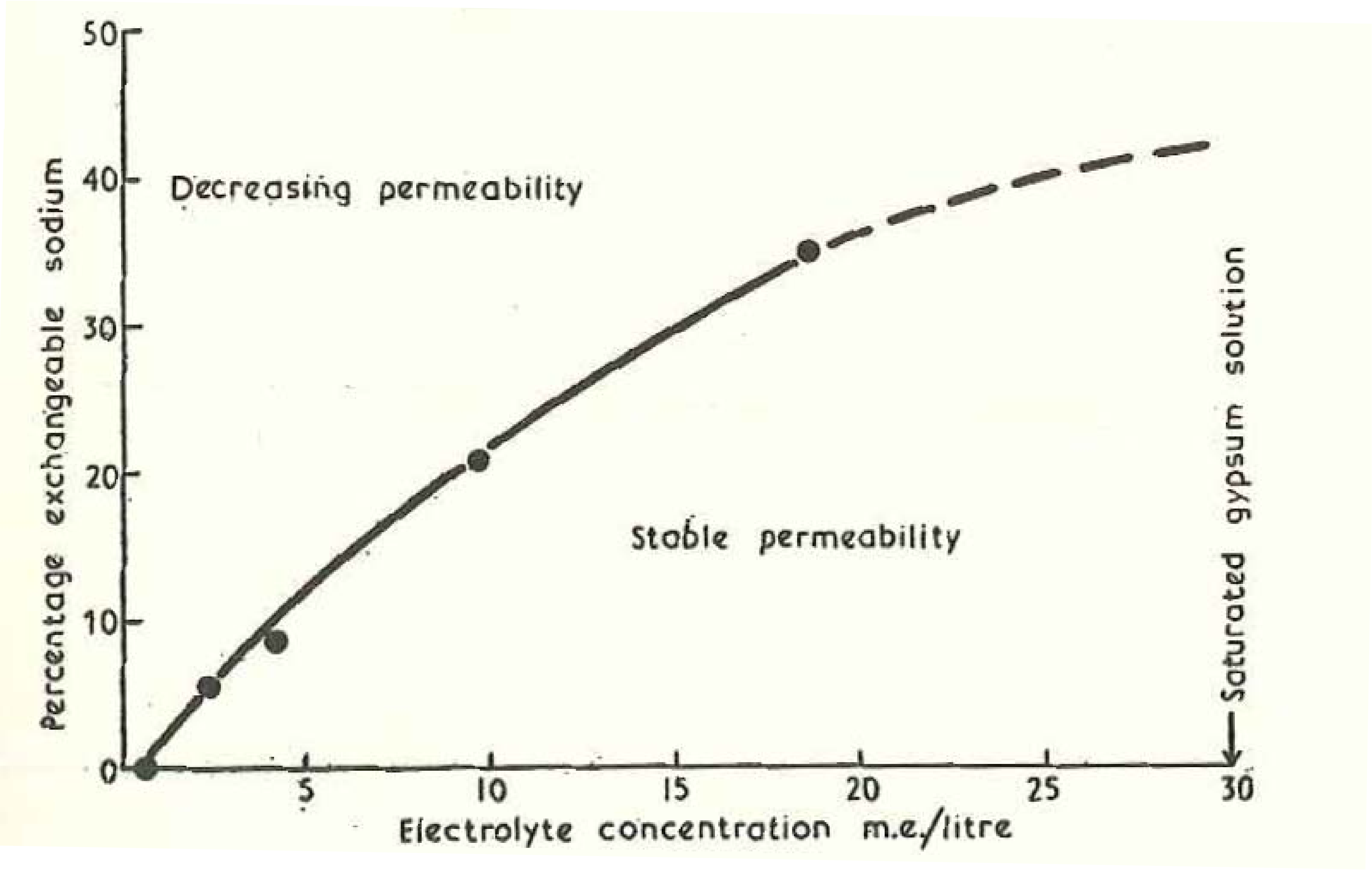
Add high quality water and drain

Sodic and saline-sodic soils—

Add gypsum, $CaSO_4 \cdot 2H_2O$, and then drain

(Gypsum dissolves to provide a relatively high ionic concentration and provides $Ca^{2+}$ to displace exchangeable $Na^+$)

Contraindicated—adding high quality water and draining; likely to cause impermeability



Quirk and Schofield. 1957. J. Soil Science

# Findings for a different West Madison retention pond, for which change in SAR and EC upon gypsum addition were calculated. (Note persistence of high SAR and EC until May.)

| **Gypsum Added** | **Pond Water Characteristics:** | | | | | | **Gypsum Added** |
|---|---|---|---|---|---|---|---|
| | 9/1/200x | | 1/27/200x | | 5/12/200x | | |
| --mM-- | SAR | EC* | SAR | EC | SAR | EC | --g/L-- |
| 0 | 0.9 | 0.1 | 11.7 | 1.2 | 11.6 | 1.0 | 0 |
| 5 | 0.2 | 1.3 | 4.8 | 2.4 | 4.3 | 2.2 | 0.9 |
| 10 | 0.2 | 2.3 | 3.5 | 3.4 | 3.2 | 3.2 | 1.7 |
| Sat'd | 0.1 | 3.1 | 2.9 | 4.4 | 2.6 | 4.2 | 2.6 |

* dS/m or mmho/cm

Falling head permeameter

to measure $K_{sat}$ on intact cores, using sequence of:

- tap water,
- gypsum-saturated water, and
- 25 mM calcium chloride

# $K_{sat}$ measured with Falling Head Permeameters

| | cm $d^{-1}$ | cm $h^{-1}$ | cm $s^{-1}$ |
|---|---|---|---|
| Sand | 504 | 21.0 | 5.83E-03 |
| Sandy loam | 62.6 | 2.59 | 7.19E-04 |
| Loam | 31.7 | 1.32 | 3.67E-04 |
| Silt loam | 16.3 | 0.68 | 1.89E-04 |
| Clay | 1.44 | 0.06 | 1.67E-05 |
| | | | |
| Core 2E: | | | |
| tapwater | 0.33 | 0.01 | 3.86E-06 |
| gypsum-sat'd | 2.32 | 0.09 | 2.69E-05 |
| 25 mM $CaCl_2$ | 2.35 | 0.10 | 2.72E-05 |
| 250 mM $CaCl_2$ | 2.53 | 0.10 | 2.93E-05 |
| | | | |
| Core 2N: | | | |
| tapwater | 0.52 | 0.02 | 6.06E-06 |
| gypsum-sat'd | 0.72 | 0.03 | 8.30E-06 |

# Conclusions:

- This is an autopsy, not a resuscitation or remediation

- Engineered soil has puddled and structure has been lost

- Most of runoff water exits directly thru overflow pipes to sewers

- Retention ponds will never be able to remediate salts but will only pass it on, sooner or later, to groundwater or overflow drains

Replacing the soil of the ‘storm water quality basins’, which failed in two winters, should be accompanied by:

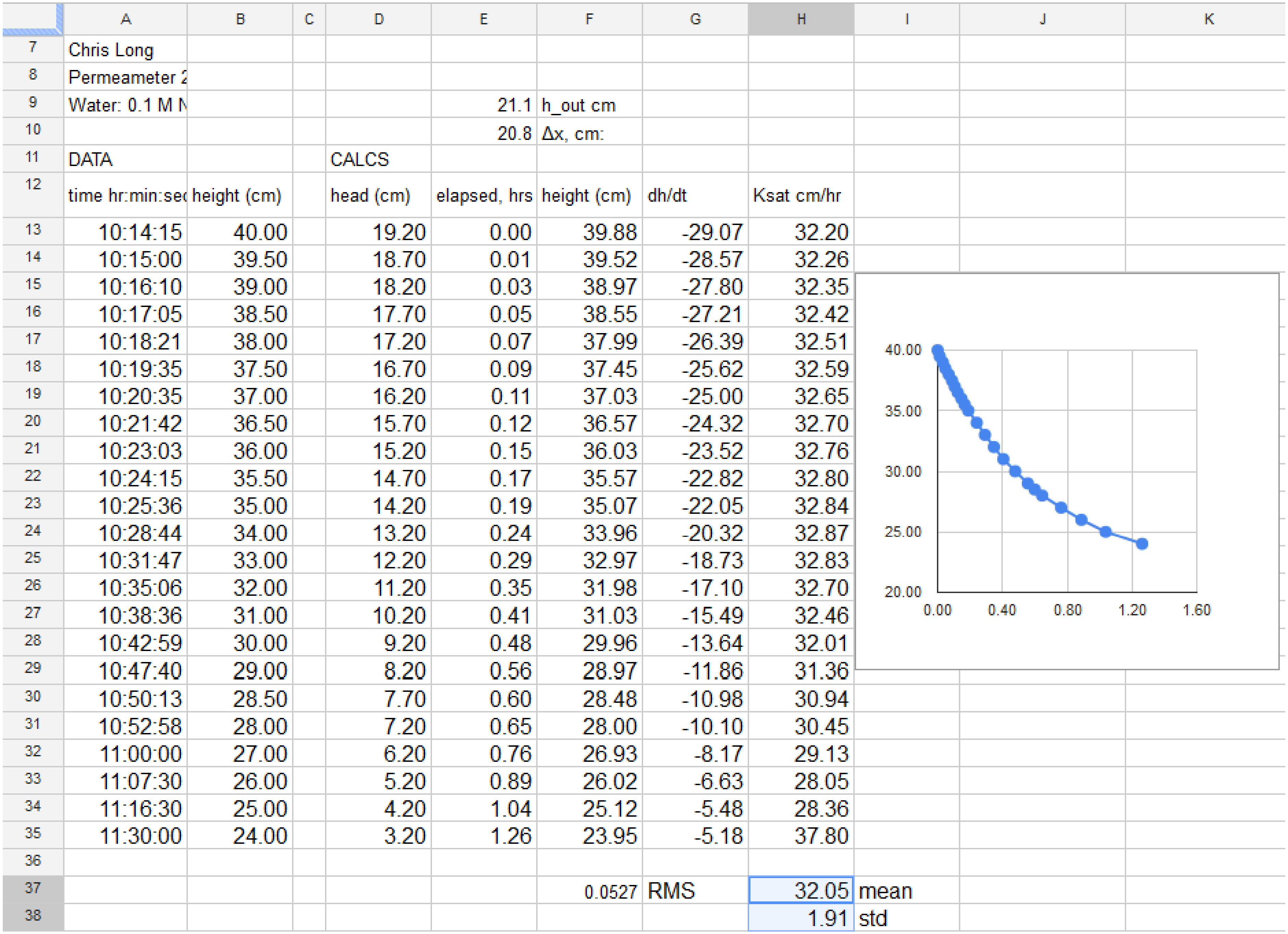
- Diversion of sodium chloride used for deicing parking lot, creating a ‘3-season basin’

- Routine addition of gypsum to ponds to raise SAR and reduce tendency to form sodic soil (~2 g/L)

- Substitution of calcium chloride, calcium acetate, or potassium chloride for sodium chloride in parking lots draining into retention ponds will prevent occurrence of clogging due to sodicity

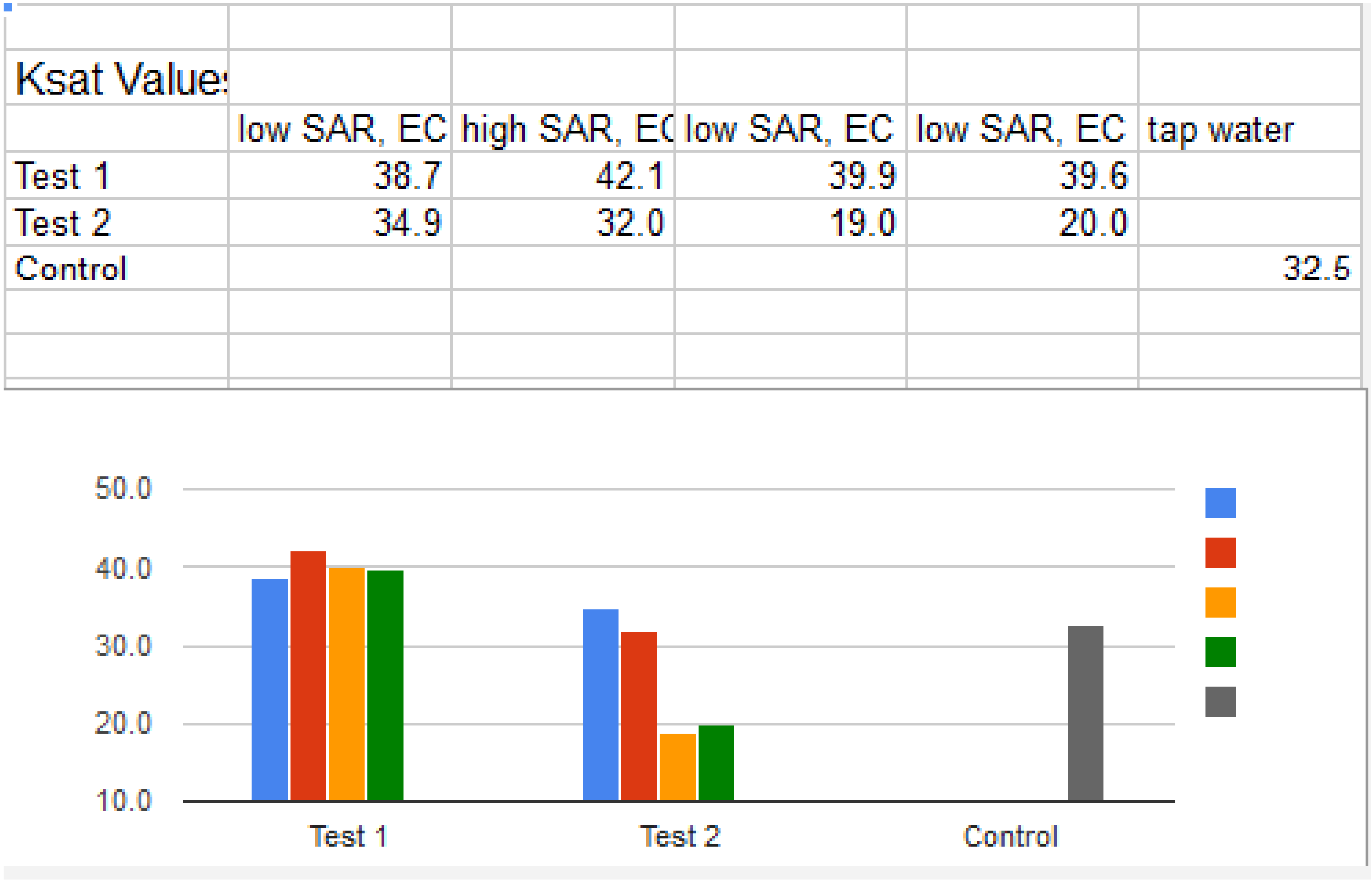
- Rating of engineered soils for sensitivity to sodicity if no change from sodium chloride is feasible.

Engineered soil, sand, <5% clay



| | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | Chris Long | | | | | | | | | | |
| 8 | Permeameter 2 | | | | | | | | | | |
| 9 | Water: 0.1 M N | | | | 21.1 | h_out cm | | | | | |
| 10 | | | | | 20.8 | Δx, cm: | | | | | |
| 11 | DATA | | | CALCS | | | | | | | |
| 12 | time hr:min:se | height (cm) | | head (cm) | elapsed, hrs | height (cm) | dh/dt | Ksat cm/hr | | | |
| 13 | 10:14:15 | 40.00 | | 19.20 | 0.00 | 39.88 | -29.07 | 32.20 | | | |
| 14 | 10:15:00 | 39.50 | | 18.70 | 0.01 | 39.52 | -28.57 | 32.26 | | | |
| 15 | 10:16:10 | 39.00 | | 18.20 | 0.03 | 38.97 | -27.80 | 32.35 | | | |
| 16 | 10:17:05 | 38.50 | | 17.70 | 0.05 | 38.55 | -27.21 | 32.42 | | | |
| 17 | 10:18:21 | 38.00 | | 17.20 | 0.07 | 37.99 | -26.39 | 32.51 | | | |
| 18 | 10:19:35 | 37.50 | | 16.70 | 0.09 | 37.45 | -25.62 | 32.59 | | | |
| 19 | 10:20:35 | 37.00 | | 16.20 | 0.11 | 37.03 | -25.00 | 32.65 | | | |
| 20 | 10:21:42 | 36.50 | | 15.70 | 0.12 | 36.57 | -24.32 | 32.70 | | | |
| 21 | 10:23:03 | 36.00 | | 15.20 | 0.15 | 36.03 | -23.52 | 32.76 | | | |
| 22 | 10:24:15 | 35.50 | | 14.70 | 0.17 | 35.57 | -22.82 | 32.80 | | | |
| 23 | 10:25:36 | 35.00 | | 14.20 | 0.19 | 35.07 | -22.05 | 32.84 | | | |
| 24 | 10:28:44 | 34.00 | | 13.20 | 0.24 | 33.96 | -20.32 | 32.87 | | | |
| 25 | 10:31:47 | 33.00 | | 12.20 | 0.29 | 32.97 | -18.73 | 32.83 | | | |
| 26 | 10:35:06 | 32.00 | | 11.20 | 0.35 | 31.98 | -17.10 | 32.70 | | | |
| 27 | 10:38:36 | 31.00 | | 10.20 | 0.41 | 31.03 | -15.49 | 32.46 | | | |
| 28 | 10:42:59 | 30.00 | | 9.20 | 0.48 | 29.96 | -13.64 | 32.01 | | | |
| 29 | 10:47:40 | 29.00 | | 8.20 | 0.56 | 28.97 | -11.86 | 31.36 | | | |
| 30 | 10:50:13 | 28.50 | | 7.70 | 0.60 | 28.48 | -10.98 | 30.94 | | | |
| 31 | 10:52:58 | 28.00 | | 7.20 | 0.65 | 28.00 | -10.10 | 30.45 | | | |
| 32 | 11:00:00 | 27.00 | | 6.20 | 0.76 | 26.93 | -8.17 | 29.13 | | | |
| 33 | 11:07:30 | 26.00 | | 5.20 | 0.89 | 26.02 | -6.63 | 28.05 | | | |
| 34 | 11:16:30 | 25.00 | | 4.20 | 1.04 | 25.12 | -5.48 | 28.36 | | | |
| 35 | 11:30:00 | 24.00 | | 3.20 | 1.26 | 23.95 | -5.18 | 37.80 | | | |
| 36 | | | | | | | | | | | |
| 37 | | | | | | 0.0527 | RMS | 32.05 | mean | | |
| 38 | | | | | | | | 1.91 | std | | |

# Sandy engineered soil:



| | | | | | |
|---|---|---|---|---|---|
| Ksat Value | | | | | |
| | low SAR, EC | high SAR, E | low SAR, EC | low SAR, EC | tap water |
| Test 1 | 38.7 | 42.1 | 39.9 | 39.6 | |
| Test 2 | 34.9 | 32.0 | 19.0 | 20.0 | |
| Control | | | | | 32.5 |


201
202
203
204
205
12/5/1
206
12/5/1
12/5/
12/5/
210
300
2/9
400
50 mL
±5%
40
30
20
PYREX

# Conclusions/Questions re: sandy engineered soil:

- Hydraulic conductivity can be cut in half by sodicity; more to come later?
- More resilient to salt than engineered soil currently used in these ponds
- Sandy soil still bleeds clay when sodic; will this lead to impermeability over time if a clay lamellae forms?
- Would not something other than sodium chloride be desirable?
- How about something other than a swelling clay, such as attapulgite or biochar, to form a moisture retentive upper horizon for plant growth?