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August 20, 2014

MEMS File: 13-00404
PTAC File: 13-AU-SGRC-01

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Attention: Ole Mrklas

Re: Peer Review of PTAC Report: "*Synthesis of SAR/Hydraulic Conductivity Data from Multiple Column Studies Coupled with Three-Dimensional Transport Modelling to Support Framework for Subsoil SAR Guidelines*"

A peer review of the PTAC document "*Synthesis of SAR/Hydraulic Conductivity Data from Multiple Column Studies Coupled with Three-Dimensional Transport Modelling to Support Framework for Subsoil SAR Guidelines*" (Equilibrium, 2012) was conducted with the overall objective of determining whether the methodology proposed to calculate subsoil sodium adsorption ratio (SAR) guidelines was valid and the whether the guidelines calculated were appropriate.

The original scope of the review was later expanded to include a review of two additional documents:

Characterization of the role of sodium adsorption ratio (SAR), soil electrical conductivity, clay content, clay type, and soil pH on the hydraulic conductivity of soils below the rooting zone for the purpose of subsoil guidelines. (Equilibrium 2011). This document is referred to in Equilibrium (2012) as a source for methodological details.

The SAR section of the Subsoil Salinity Tool Help File. This was provided by Equilibrium Environmental for this review in February

2014. (Equilibrium, 2014). This document contains more information on how the work in Equilibrium (2011) and Equilibrium (2012) was used to develop SAR guidelines.

The review focused on the following questions:

1. Column Experiments Methodology (in Equilibrium, 2012, 2011)
    a. Was the methodology used in the column experiments sufficiently well documented to make it clear what was done?
    b. Was the methodology used in the column experiments appropriate for determining the relationship between SAR and hydraulic conductivity for a given soil?
    c. Is the range of soils used in the column experiments representative of Alberta soils?
2. Column Experiments Results (in Equilibrium, 2012)
    a. Were the results of the column experiments presented in a clear and appropriate manner?
    b. Was the interpretation of the column experiments data appropriate?
3. Water Table Modeling (in Equilibrium, 2012)
    a. Was the methodology of the water table modelling clearly presented?
    b. Was the water table modelling task appropriate for the purpose intended?
    c. Were appropriate conclusions drawn from the water table modelling task?
4. Subsoil SAR Guideline Recommendations (in Equilibrium, 2012)
    a. Were the recommendations appropriate and supported by the data presented?
5. Subsoil SAR Guideline Implementation (in Equilibrium, 2014)
    a. Was sufficient information presented to allow the validity of the SAR subsoil guidelines to be assessed?
    b. Is the methodology used to calculate the SAR subsoil guidelines appropriate?

These questions are addressed in the following sections.

1. COLUMN EXPERIMENTS METHODOLOGY

1.1. Methodology Documentation

Section 3 of the report "Leaching Column Experimental Methodology" contains almost no pertinent information about the apparatus used, the experimental methodology employed, what measurements were made, or what techniques were employed to interpret the results as hydraulic conductivity values. The document indicates that "additional details" can be found in another report (Equilibrium, 2011) which was provided by Equilibrium for review. However, Equilibrium (2011) includes a few photographs of equipment but no additional relevant information on methodology. Details that would be required to enable a reader to be able to evaluate the validity of the work include the following:

- Details of the methodology of sample collection in either plastic tubes or metal Shelby tubes to enable an evaluation of the extent to which these samples are undisturbed.
- Details of the methodology used for re-packing the columns, where this was done.
- Details of the solutions used in the leaching experiments are needed, and an indication of whether the EC values were based on measured values (and if so, how measured) and whether the SAR values were based on analytically determined concentrations, or calculations from the amounts of salts added.
- Details of the column setup are needed:
    - physical setup details showing how a seal is obtained around undisturbed cores, dimensions of core tested, amount of pressure head applied, and duration of testing.
    - Details of the measurements made are needed: what was measured during the experiments and how?
- Details of the analysis performed are needed:
    - How were the results (Ksat) determined from the parameters measured?
    - Indication of the protocol and rationale for changing the EC/SAR of the leaching solution throughout the test, i.e., why was the particular sequence of solutions selected, and what was the rationale for deciding when to change from one solution to the next
    - Discussion of the rationale for, and any shortcomings associated with the methodology used.
- The remainder of this review is necessarily constrained by the lack of methodological information provided.

1.2. Methodology Appropriateness

Without any pertinent information being presented on the methods used, it is not possible to make any but the most general comments on the appropriateness of the methodology. Overall, data from a large number of tests are provided. It appears that the general methodology was to apply a solution of a certain EC and SAR, calculate Ksat, presumably based on the rate of seepage through the column and the applied head, and then change the chemistry of the solution after a certain number of pore volumes. For many of the tests, the EC is decreased at a fixed SAR value, though sometimes SAR is also varied. The rationale for selecting each or any of the combinations of EC and SAR is not explained. Conclusions appear to be drawn from changes in Ksat that occur as EC is decreased at fixed SAR, however, no adequate justification is provided that this is the same change in Ksat that would be observed in the environmentally more realistic situation of increasing from a low EC low SAR pore water chemistry to the combination being tested.

1.3. Range of Soil Types

Table 11.1 in the report lists 86 soil samples that were tested with clay content ranging from 4.4% to 53.4% and texture ranging from sand, through sandy loam, silt loam clay loam and other variations to clay. Organic carbon content is not provided, but most of the samples are from subsoil depths. Overall, the range of soils tested seems to be well representative of the range of subsoils in Alberta.

2. COLUMN EXPERIMENTS RESULTS

2.1. Presentation of Results

The results of all 86 column tests are presented as Ksat evaluated as a function of pore volumes of leachate through the columns. Unfortunately, information on which columns were re-packed is missing from Appendix A. Without this critical piece of information, it is difficult for the reader to get a sense of whether or not this might have been a confounding variable, since data from undisturbed and re-packed columns have been mixed. "Synthesis" figures were generated showing the effect of varying EC on Ksat at constant SAR for various groups of sites/soils/SAR values.

2.2. Interpretation of Results and Report Conclusions

No information is provided on how Ksat was calculated for each test, nor were the raw data provided from which Ksat was calculated, and therefore it is not possible to verify the validity of the Ksat values provided in any of the test results.

Most of the conclusions of the report are fairly general statements about what is already known about how SAR affects Ksat. The one conclusion specifically relevant to the column experiments is that "*High SAR values may reduce Ksat by up to 1-3 orders of magnitude, with the largest effects typically*

occurring at lowest EC's. Some soils may be less sensitive to SAR than others, such as coarse soils or soils initially low in hydraulic conductivity".

For practical purposes, based on the data that are presented, it would be fair to conclude that SAR values in the range 20-115 at low EC values (1-10 dS/m) can cause a decrease in soil Ksat that ranges from insignificant to 2 or more orders of magnitude. While the data suggest some trends (discussed in the report), they do not seem adequate to support predictions of the anticipated Ksat reduction for a given soil.

3. WATER TABLE MODELLING

3.1. Appropriateness of Approach

The approach taken was to build a 3-D groundwater model in Modflow, add blocks of reduced Ksat, and determine what effect this would have on the water table in general, and in particular, what combinations of parameters might lead to raising the water table into the root zone. Overall, this seems like a reasonable approach.

3.2. Methodology Documentation

The basic parameters that would enable model results to be reproduced are provided (Kv, Kh, infiltration rate, water table depth, Ksat reduction in impacted area). However, no information is provided about whether either the base line case or the impacted cases have reached steady state in the model.

3.3. Appropriate Conclusions

The report only draws very general conclusions from the water table modelling section, indicating that "*Water table modeling is a useful approach to evaluate the potential effects of reduced hydraulic conductivity (Ksat) on water transport and potential root-zone water-logging at a site. This water-table modeling can be performed on either a 1-dimensional or 3-dimensional basis, with 3-dimensional models allowing for improved realism and estimation of risk*". As an aside, 1-D modelling is unlikely to yield realistic results due to not being able to model lateral flow of water around the low Ksat block, though 2-D modelling would likely yield a reasonable approximation.

The model results presented, if taken at face value, indicate that the degree to which the water table is perturbed, and whether this becomes significant is a function of:

- water table depth;
- ksat reduction;

- infiltration rate;
- vertical gradient; and,
- impact dimensions.

This seems reasonable. However the report stops short of developing limiting combinations of parameters that could be used to develop a subsoil SAR guideline.

4. SUBSOIL SAR GUIDELINE RECOMMENDATIONS

This section assesses the recommendations made in Sections 7 and 8 of Equilibrium (2012).

4.1. Appropriateness of Recommendations

The report considers a total of 7 exposure pathways for SAR, though only two will be discussed here, current and future risk to soil structure, since these two are specific to SAR in subsoil. The other pathways are standard SST pathways with chloride replaced with sodium. For the soil structure pathways, the report stops short of actually calculating SAR subsoil guidelines or indicating specifically how they would be calculated. However the implication is that a subsoil SAR guideline model would be based on the following:

i. Data from the column experiments conducted for this project would be passed over in favour of using the literature data from Curtin et al., (1994) on which the current Alberta Tier 1 SAR guidelines are based.

ii. In spite of the complexities identified in the water table modelling section, relating root zone waterlogging to a combination of 5 parameters as noted in Section 3.3 of this review, it seems that the intention is to use a 10-fold reduction in Ksat as a threshold for identifying the potential for adverse effect.

Using the Curtin data seems wise, given the much higher variability in the Equilibrium data. However, the selection of a 10-fold reduction in Ksat as a threshold for identifying the potential for adverse effect appears arbitrary, and no effort has been made to justify this value based on the modelling work done. Careful justification would be required to justify why a threshold Ksat value of 10 fold was appropriate and protective. It seems more likely that an approach using several of the parameters identified in the water table modelling section would be appropriate.

5. SUBSOIL SAR GUIDELINE IMPLEMENTATION

Equilibrium provided a draft of the SAR section of the SST manual (Equilibrium, 2014) to support this review. This manual section builds on the work discussed in Equilibrium (2011) and Equilibrium

(2012) and provides more information on the intended direction for calculating subsoil SAR guidelines in the SST.

It is somewhat challenging to review the material in the SAR SST help file, since the document never clearly indicates the methodology used to calculate SAR guidelines. There is an implication, though it is never clearly stated, that the overall method involves identifying Ksat reductions observed in literature work (Curtin et al., 1994) as a function of EC, SAR, and soil texture, and then determining limiting SAR values that do not cause more than a threshold value of Ksat reduction. The comments below are made on the assumption that this is, in fact, the method intended to be used.

5.1. Was Information Sufficient?

Information provided in the help file is insufficient three main areas. These omissions preclude any sort of quantitative review of whether the SAR guidelines calculated are appropriate.

1. The methodology used to calculate SAR guidelines is never clearly stated.
2. It is indicated that the Curtin et al., (1994) work contains data for seven different soil types, however, it is never stated how the appropriate Curtin soil type will be identified for a given field soil type.
3. The text suggests that a threshold value of Ksat reduction will be used to identify situations where SAR is unlikely to have an adverse effect, but never indicates what value of Ksat reduction would actually be used for a given situation. Vague statements are made, including "*subsoil Ksat reductions of 10- to 100-fold appear to be tolerated in many 3-dimensional model scenarios without causing substantial water-logging of root-zone soils*" and "*A 10-fold Ksat reduction threshold often appears appropriate for evaluating SAR/EC combinations at a variety of contaminated sites*". Overall, it is unclear what value of Ksat reduction would be used in the model for a given situation.

5.2. Was Methodology Appropriate?

Considering the big picture, the overall methodology implied seems appropriate, in those using Ksat/EC/SAR/texture relationships from the literature, and evaluating them at particular limiting values of Ksat reduction seems an appropriate way to determine subsoil SAR guideline values.

However, some of the details of the methodology do not seem appropriate, as discussed in the following comments.

- The use of Ksat/EC/SAR/texture relationships from the literature seems appropriate, since the experimental work conducted by Equilibrium (2012) seems to have produced a high degree of unexplained variability, and is likely unsuitable for guideline development.

- Selecting the appropriate set of literature data (soil texture) to apply to a given field soil texture is a critical step, but one that cannot be evaluated here, since the details of how this would be done are not provided.
- The use of a single threshold Ksat reduction factor has not yet been justified adequately. It was demonstrated in Equilibrium (2012) that the appropriate threshold Ksat value is strongly a function of water table depth, infiltration, vertical gradient, Kv and Kh. Further analysis is required to identify the scenarios that would, and would not, be protected by a given Ksat threshold, and a strategy for ensuring that unprotected scenarios would be managed appropriately.

6. OVERALL COMMENTS AND SUMMARY

The overall objective of this review was to determine whether the methodology proposed to calculate subsoil SAR guidelines was valid and the guidelines calculated were appropriate. Unfortunately, as detailed in the text of this review, insufficient information was available to determine either the validity of the methodology, or the appropriateness of the guidelines.

7. REFERENCES

Curtin, D, Steppuhn, H, and Selles, F. 1994. Structural stability of Chernozemic soils as affected by exchangeable sodium and electrolyte concentration. Can. J. Soil Sci. 74:157-164.

Equilibrium (Equilibrium Environmental Inc.) 2011. Characterization of the role of sodium adsorption ratio (SAR), soil electrical conductivity, clay content, clay type, and soil pH on the hydraulic conductivity of soils below the rooting zone for the purpose of subsoil guidelines.

Equilibrium (Equilibrium Environmental Inc.) 2012. Synthesis of SAR/hydraulic conductivity data from multiple column studies coupled with three-dimensional transport modelling to support framework for subsoil SAR guidelines.

Equilibrium (Equilibrium Environmental Inc.) 2014. Subsoil Salinity Tool Help File. SAR section provided by Equilibrium for this review February 2014.

8. CLOSURE

We trust that the information presented herein meets your requirements. Should you have any questions, please call the undersigned at 403 678-4790 or 780 496-9048 at your earliest convenience.

Yours truly;

Millennium EMS Solutions Ltd.

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