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Hydrology and Earth System Sciences Discussions

Interactive comment on "Soil weathering rates in 21 catchments of the Canadian Shield" *by* D. Houle et al.

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Response to "Interactive comment on "Soil weathering rates in 21 catchments of the Canadian Shield" by D. Houle et al. By anonymous referee#1

Daniel Houle et al.

We would like to thank the referee for this thorough revision that will greatly help to improve the ms quality. Briefly, we agree with most of the comments/suggestions. Below (in blue) are some responses to the referee comments.

Anonymous Referee #1 Received and published: 10 August 2011

The release of base cations (BC) from soil weathering to the soil solution and surface waters is an important issue considering acidification of soils and surface waters. The weathering related BC release maintains the natural buffering capacity of terrestrial and adjacent aquatic ecosystems up to a certain degree.

The here evaluated model PROFILE has been widely used to evaluate soil weathering related BC release and thus the natural buffering capacity mainly in boreal landscapes (in North America and Scandinavia) with rather poor soils (mainly shallow podsols) and softwater lakes.

The study by Houle et al. (the MS commented here) applies the PROFILE model to a rather large set of soil profiles (21 forested lake catchments with 3 profiles each) located on the Canadian Shield within a 150 km wide strip parallel to the St. Lawrence River. For the parameterization of this model they apply several other models: the Uppsala model estimating mineralogical composition of a given soil horizon based on the bulk chemistry assessed by lab methods; the BioSIM model to generate monthly precipitation and temperature for each catchment from gauging data; FORHYM to simulate soil moisture, and FORSTEM to simulate soil temperature based on the BioSIM output.

Assuming that lake chemistry is determined by weathering within the soil profiles and the three soil profiles analyzed per lake catchment are representative for the whole catchment, Houle et al. evaluate the PROFILE-output for each base cation and the sum of BC by comparison with measured lake water concentrations. Further, they used the lake water concentration and FORHYM model output to estimate the stream export of BC from the catchments, assuming BC concentrations at the stream outlets equals that of the lakes.

They conclude that the PROFILE model output represents Ca stream exports quite well, while that of Mg is on average overestimated by about 50 %, and that of K (factor 6.9) and Na (factor 2.2) are even more overestimated. Further, they conclude

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that PROFILE is strong enough to reproduce geographical gradients in the weathering rates.

The presented research issue fits into the scope of HESS. However, before the manuscript can be considered for publications, I would like to suggest some major revisions to be done.

General comments First of all, I suggest to present the importance of that particular study in more detail: -Why is this study important? -What can the reader learn from this study? As this is mainly a technical paper: How does this study helps to improve existing methods for application in research and/or environmental survey programs? -Why was this methodology chosen? -What is the advantage of the here applied method compared to other approaches? I suggest to write a specific subsection on this issue in the result & discussion part. -At the end of the conclusion the authors should present an outlook. What are important research question left open?

Response: We agree with these suggestions and will modify the text to take them into consideration.

As the PROFILE model has already been evaluated in previous studies (e.g. Kolka et al., 1996; Hodson et al., 1997; Ouimet and Duchesne, 2005; Whitfield et al., 2006) it might be more appropriate to evaluate the complete methodology presented in the MS, i.e. including the parameterization of PROFILE with the outputs of the UPPSALA, FORHYM, and FORSTEM models.

We will also add some sentences to show how the whole processes (UPPSALA with along with X ray diffraction measurements for determination of mineralogy and modelling of soil temperature and soil moisture + PROFILE), using the best information available at the large scale studied can be validated on independent estimations of weathering rates.

Comments on method section The information on the study sites given in the MS is

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rather short. I suggest giving detailed information on each lake catchment as electronic supplement. This should include a more detailed description of the lithology, of the glacial till as well as of the bedrock. How thick is the till layer? Further, a description of the hydrologic setting would be of interest for the reader. Does every lake have a stream outflow? Are streams the major drainage ways from the lake catchments, or are groundwater exports from the catchments of higher importance? What is the mean groundwater table at the sites where the soil samples have been taken? Further, the average hydrochemical properties for each lake should be listed in a table within the supplement. In the electronic supplement, a description of each soil profile should be given as well.

Response: The vast majority of the requested information can be made available. A part can be given directly in the text but many information can be given as an electronic supplement as suggested, especially for the lithology, the hydrochemical properties and the soil profiles descriptions. We would suggest to give a representative soil profile description for each catchment since there is over 60 soil profiles to the total and that they do not vary by much within a given catchment.

One of the parameters required by the PROFILE model is the DOC concentration within each soil horizon. Unfortunately, it is unclear how this information was derived for the here presented study. Are the applied DOC values based on own measurements or based on literature values assumed to be representative?

Response: The DOC values were based on the results of three calibrated catchments for which we have detailed measurements of soil solution chemistry. The DOC is also known for each lake. So we used averages values that were assumed to be representatives of the studied catchments. However, we tested the model output sensibility to DOC variations and we found that within the range of DOC concentrations that can be encountered, the effect was negligible. If needed, this information can be added in the ms.

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In the method section it is said that for the clay fraction of the analyzed soil samples, mineralogy is assessed by X-ray diffraction. It is said that the results were used to validate the estimation of the mineralogy using the UPPSALA model. Unfortunately, the respective results are not given in the MS. I suggest to give these results as supplement information. The reader could get an idea how well the UPPSALA model really predicts the mineralogy, at least for the clay fraction.

Response: This information could also be given although the supplement information would contain quite a lot of data.

Comments on results & discussion

In the MS, bulk chemistry and estimated mineralogical compositions are just given for the B-horizons of the soil profiles. It is argued that most of the BC release happens there, but it is not shown with data. For this, I suggest giving this Information for the A, E, and C horizons as well, maybe in the electronic supplement.

Response: In the type of soils studied (podzols) the A horizon is an illuviated (Ae) horizon that has been "bleached" over time and that does not contribute to weathering while there is no E horizon. We can however add mineralogic data for the Ae and C horizons in the electronic supplement along with the others information requested above if needed.

The authors describe a spatial gradient and state that their estimation of BC release reproduces these gradients quite well. I suggest producing two small maps showing this spatial gradient: one map giving the spatial patterns of lake chemistry (BCconcentrations, observed data) and another map giving the spatial patterns of estimated BC release from soil weathering.

Response: This is a good idea. We will do it

In the MS, studies comparing the PROFILE model with other approaches to assess BC release from catchments by weathering have been cited (Kolka et al., 1996; Ouimet and

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Duchesne, 2005; Whitfield et al., 2006), but yet not sufficiently discussed. Whitfield et al. (2006) generally compared approaches focusing on weathering within individual soil profiles, incl. the PROFILE model, and approaches addressing weathering within whole catchments. They pointed out two main problems related to the assessment of catchment weathering by approaches focusing on weathering rates within given soil profiles, like the PROFILE model does: 1) The chosen soil profiles might not be representative for the whole catchment, 2) Substantial weathering related BC release might take place within the substrate below the developed soil horizons, which approaches like PROFILE model are neglecting. I strongly suggest to take these two points into account when discussing the results of this studies and associated uncertainties. By assuming BC release is just happening within the soil profile it is implicated that weathering in the till/saprolite below the B-horizon would be negligible. If the authors want to stick to this assumption they should justify it.

Response: We agree and will provide more information and more discussion about these two points. It should be note at this moment, that the till deposit is shallow for these type of catchments and that the C horizon get rapidly heavily compacted with depth then nearly acting as a “waterproof” bedrock . Another reason for which it is assumed that most of the weathering occurs in the B horizons is that the soil solution pH, as observed in intensively monitored watersheds, is often one order of magnitude (one pH unit) higher in the C horizon than in the B horizon thus considerably slowing down the weathering reactions. Clearly, we do not state that there is no weathering at all within the substrate below the developed soil profile but we assumed that most of the weathering products originate from above the C horizon.

When discussing other approaches, I suggest including the WITCH model (Probst et al., 2002; Godderis et al., 2006).

Response: That is something we will do.

The authors stated that the ecosystems on the study sites are obviously not in a steady

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state. They used this as a probable explanation for the overestimation of K-exports. Is there a probable reason for this, e.g. a specific land use history. Are the forests growing (increasing biomass)? Is there any clue on this besides the K-flux overestimation? There is still the problem of the high overestimation of Na fluxes. Is this related to wrong predictions by the UPPSALA model? I suggest stating some hypothesis why Na-fluxes are overestimated? Might this be due to wrongly estimated mineralogical composition by UPPSALA model or by wrongly estimated weathering rates of certain minerals by PROFILE model? Which minerals are of interest in this respect? I suggest to discuss such possibilities for K as well.

Response: We also agree these aspects require more discussions.

Spodic horizons of podsols (B-horizons) are characterized by enrichment in amorphous organic substances and sesquioxides, forming coatings on the mineral grains. It is of interest in how far these coatings might influence the weathering rates of the minerals in these horizons. I suggest discussing this issue as well. Is this a source of uncertainty in the PROFILE model?

Response: The enrichment in amorphous organic substances is particularly observable in the top of the B horizon (5-10 cm, mainly the Bhf horizon). Although we cannot discard a possible effect of organic coating with the actual data, we do not think it was important when each of the distinct B horizons, constituting the whole B horizon, are considered together.

We will consider all the minor comments below.

Other comments p. 5745, line 10-13: cite Garrels and Mackenzie (1971), or earlier works of these authors p. 5752, line 11-13: Especially as the authors refer to the B-Horizon of a podsol, I suggest to write that this mineralogical composition is typical for soils developed in such lithologies, rather than “are typical for Precambrian Shield geologies”. Tables 1 & 2: In the captions, please indicate that it is weight-% to prevent any confusion. Table 2: It is “Feldspar”, not “Feldspath” Table 2: Authors distinguish albite

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from plagioclase. However, albite is a plagioclase. Please, correct this error. In the MS ,base cations (BC) is used for the sum of Ca, Mg, K while Na is excluded. If the authors want to stick to this definition, I suggest giving an explanation why BC does not incorporate Na in this study. Table 3: Here, BC is used as the sum of Ca, Mg, K, Na. This is in contrast to the rest of the MS, for which BC was defined as Ca+Mg+K, excluding Na. p. 5751, line 26: “conservative” instead of “conservator” *References* Garrels, R.M. and Mackenzie, F.T., 1971. Evolution of Sedimentary Rocks. W.W. Norton, New York. Godderis, Y., Francois, L.M., Probst, A., Schott, J., Moncoulon, D., Labat, D. and Viville, D., 2006. Modelling weathering processes at the catchment scale: The WITCH numerical model. Geochimica Et Cosmochimica Acta, 70(5): 1128-1147. Hodson, M.E., Langan, S.J. and Wilson, M.J., 1997. A critical evaluation of the use of the PROFILE model in calculating mineral weathering rates. Water Air and Soil Pollution, 98(1-2): 79-104. Kolka, R.K., Grigal, D.F. and Nater, E.A., 1996. Forest soil mineral weathering rates: C3391 Use of multiple approaches. Geoderma, 73(1-2): 1-21. Ouimet, R. and Duchesne, L., 2005. Base cation mineral weathering and total release rates from soils in three calibrated forest watersheds on the Canadian Boreal Shield. Canadian Journal of Soil Science, 85(2): 245-260. Probst, A., Godderis, Y., Francois, L.M., Labat, D., Schott, J. and Viville, D., 2002. Modelling chemical weathering at river catchment scale: design and calibration of the WiTCh model. Geochimica Et Cosmochimica Acta, 66(15A): A615-A615. Whitfield, C.J., Watmough, S.A., Aherne, J. and Dillon, P.J., 2006. A comparison of weathering rates for acid-sensitive catchments in Nova Scotia, Canada and their impact on critical load calculations. Geoderma, 136(3-4): 899-911. Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 8, 5743, 2011.

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