Hydrol. Earth Syst. Sci. Discuss., 12, C2514–C2521, 2015
www.hydrol-earth-syst-sci-discuss.net/12/C2514/2015/

Hydrology and Earth System Sciences
Discussions

Interactive comment on "Effective damage zone volume of fault zones and initial salinity distribution determine intensity of shallow aquifer salinization in geological underground utilization" *by* M. Langer et al.

Anonymous Referee #3

Received and published: 13 July 2015

This is a review of the manuscript titled "Effective damage zone volume of fault zones and initial salinity distribution determine intensity of shallow aquifer salinization in geological underground utilization" in which the authors conduct a sensitivity study of brine flow through faults. In my opinion this is an interesting topic and the authors are able to show that the existence of faults does not automatically exclude a potential CO2 injection site. While the underlying science seems sound, the presentation needs significant work. In many instances the authors are not precise enough, so that the meaning of sentences is unclear (see detailed comments below). For the most part, the results

section is a pure listing of facts without much analysis. While I realize that some authors (and journal editors) prefer to have different sections for results and analysis, the analysis section is missing in this manuscript. The discussion section is mostly a summary with very little analysis. The title is not really representative of the manuscript. The term "effective damage zone volume" is not really used until the end of the paper and the authors do not test different initial salinity distributions. Once again, I believe this to be an interesting study with relevant results, but the presentation needs to be fixed before this manuscript is published in its final form

Page 5704 Line 7: delete "by" Line 8: what is an "ambient" fault zone Line 16: I would try to avoid "these" here as it is somewhat ambiguous. How about "Different boundary conditions proved to have a crucial impact . . ."? Line 17 "the fluid mass that migrates upward corresponds to the mass of injected fluid"? Lines 16 – 27: this paragraph is too unstructured, too many new scenarios with details (short faults, additional reservoirs, . . .) are being introduced. Even after reading the entire paper, I found this difficult to follow.

Page 5705 Line 3: the initial salinity distribution is discussed, but its effect is not tested in the paper. Therefore, this statement should be softened. Line 11: not sure how "whereby" fits here Line 13: Not sure how the extent and storage capacity of formation leads them to be filled with freshwater. Line 13: above "saline aquifers" here "shallow aquifers". Should be consistent. I think shallow gives the wrong impression. Most would not consider an 800m deep aquifer "shallow". Line 14: "also comprise" Line 14: this sounds as if the storage and freshwater formation are the same. While this is certainly possible (e.g., Ketzin and Kevin Dome), in most cases the injection formation will contain brine. The case modeled here certainly falls in the saline formation category, so I'm not sure why the description is confused here. Line 20: would be good to have some references here. Line 25: The Person et al (2010) paper should be included in Table 1, as it also directly addresses brine migration in the Mount Simon.

Page 5706 Line 2: delete "thereby" Line 2: I am not aware how different initial condi-

tions impacted the pressure results in the two studies. The main difference was the choice of rock compressibility and different representation of compressibility in the two simulators. The authors need to be more precise. Lines 11-12: “whether brine is allowed to spread laterally in the upper aquifer” If the brine can’t flow then it is not much of an aquifer, so I don’t know what this statement means. Lines 23-24: This is a strange statement. I would expect that a low permeability fault will allow very little flow into an overlying aquifer. Delete or explain. Line 29: “should avoid” sounds like the convergence was not tested. Either clearly state is was tested and convergence was reached, or the state the opposite and devalue the results of the numerical model in the paper.

Page 5707 Line 5: “general understanding of underlying processes” It would seem that the underlying processes (i.e., single phase flow in a porous medium) are pretty well understood at this time. Line 8: I’m a little surprised by this very detailed description of the geology. The goals of the paper stated in the previous paragraph don’t include site specific conclusions. In the end a very simple model is used. I would delete this section as it distracts from the paper.

Page 5709 Line 20: Why is the caprock permeability assumed lower than in the previous study? Are there additional measurements? Explain. Line 25-27: I would describe the different scenarios before this.

Page 5710 Lines 8-10: What is the displacement at the faults studied here? Without that information the whole discussion of 250m fault width is not useful. Line 17: I would describe the fault scenarios earlier, so that you can point to the 2km fault opening here as well and reference it in figure 1b.

Page 5711 Line 2: “. . . to be between those of . . .” Line 4: Otherwise there wouldn’t be time dependent flow patterns? Line 9: “. . . first and last . . .” Line 9-10: Why? Line 13 and 16: why the two different volume multipliers? Aren’t both constant pressure boundaries? I’m not sure that the volume modifiers have to be mentioned at all, as they are just a quirk of how TOUGH2 represents boundaries. But these are not quasi-

infinite boundary conditions, as far as I know. These massive-volume cells will keep pressure pretty much constant, while in a quasi-infinite boundary the pressure should be able to increase. Explain. Line 21: Strange sentence: initial conditions are defined at a single point in time; the initial conditions are based on a geothermal gradient, so not constant in space. Authors need to be more precise in their writing. Line 28: not sure how the visualization is relevant here. Doesn’t seem to be used in any figure.

Page 5712 Line 1-2: all models are run for hydrostatic conditions. Do you mean hydrostatic initial conditions? Line 6: I’m missing a reason why the authors didn’t use CO2 for injection as this is a study of CO2 sequestration site. Is it just the computational expense? 1.8x10ˆ6 elements for 20 years doesn’t seem intractable on a 256 processor machine. Line 12: the density “sums up”; strange terminology Line 16: why “while”? Line 21-25: this is too long to just say that diffusion is irrelevant for the problem considered here.

Page 5713: Line 6: I really like system of identifying the different scenarios. Line 17: It would be interesting to which processes the authors are referring to.

Page 5714 Line 1: this result is not surprising for the close boundary case. For a closed incompressible domain all the pressure relief comes from brine flowing up the fault, so that the same mass will reach the freshwater aquifer. However, in an open domain, most of the pressure relief will come from horizontal brine migration in the injection formation. In that case fault permeability should make a difference as the duration of the increased pressure is independent of fault permeability. In addition, I don’t think that retardation should be neglected completely as regional groundwater flow may be enough to dilute in the incoming high salinity formation brine. Line 6: is this a result from a previous study or a result of this study? Either cite the previous study in the text and figure 3 or move to results section. Alternatively, you could describe these as “initial” or “preliminary” results, but then you need to delete figure 3 and reduce the level of detail in discussion here. Line 16: mass flow of what? Brine? Salt? Ideally it would be salt, but for comparisons between different scenarios brine flow rate would

be fine, as salinity is constant. Line 25: more flow into parts facing the injection than parts not facing the injection. Why is brine flowing into the fault from the side not facing the injection? Is brine flowing around the faults or is this brine being drawn in from the boundary? The arrows in the plot in figure 4 (lower left) both point from the same side, so no help in explaining there. What are the colors/size of dots and background color mean in the two left plots? Where is the brine going that is entering the fault, but not leaving it at the top (i.e., more flow at the bottom than at the top)? Is this all compressibility?

Page 5715 Line 1: why is brine not exiting the fault symmetrically? The flow rates are so low, that pressure interference in the upper aquifer would be surprising. Why are there different pressures? Line 6: farther Lines 5-6: Why would salinity be higher farther away from the injection? I think I am misunderstanding the sentence. Line 23: this backflow is surprising. The small increase in density is enough to work against the dissipating pressure gradient, I guess. I think this backflow is somewhat over stated, as mixing from local recharge and regional flow probably will have a strong effect over a 400 yr time period. In figure 5 the white arrow down is as big as the one coming up which gives the impression that the rates are comparable. I realize that the arrows are for direction only, but I would makes them different thicknesses.

Page 5716 Lines 2-6: I think it is obvious that the flow distances will be different for locations with different pressures, so I would not mention that. However, I think it is very powerful to state, as the authors do, that flow into the freshwater aquifer only occurs from the upper part of the fault. At first reading, I was a little confused about where the authors were counting from, so I would suggest that the authors stress that they are counting from the bottom of the freshwater aquifer. Line 14: shouldn't this be "fault" not "faults" as only one fault is active in this scenario. If I understood the setup correctly, then the other three faults and the inactive parts of fault one are "inactive". In my experience, inactive elements in TOUGH2 have constant values, so they should keep the initial pressure. From figure 6a I don't see any pressure for fault three (as

stated in the text). Am I reading the text of the figure wrong? In figure 6a there is not legend for the three lines. I'm assuming it is the same as in figure 6b. Needs to be stated directly. Also in figure 6a: for the short fault, why is the pressure behind the fault increasing? Is the brine flowing through the inactive part of the fault? Line 20: I think this makes a lot of sense, as the injection is right next to fault one.

Page 5717 Line 5: I think this undersells the time-scales involved. Mixing in the freshwater aquifer might make the salinity influx unnoticeable over 300 yr period. Line 14: why is there residual freshwater? This is a single phase simulation, so no residuals. I don't see how the density makes a differences for horizontal flow? Line 21: Didn't this already get discussed earlier?

Page 5718 Line 8: Setting the boundary conditions to constant pressure will not allow the pressure to increase at the boundary. I don't think this needs to be stated.

Page 1519 Lines 1-2: all of these statements would be more meaningful in terms of mass of salt. Again, the time scale is important here. 1500 yrs is a long time. Line 3: I didn't read section 5.3 in detail, as the listing of results is becoming tedious and I'm losing sight of the goal of the paper. In my opinion the entire results section needs to be shortened.

Page 5721 Line 23: "only" is twice in this sentence

Page 5722 Line 15-16: I find this to be a very strong statement. What are the relevant processes other than flow? Line 18: What else than a pressure increase in the injection formation could be a driving factor? Brine is more buoyant than freshwater, so gravity is not a driving factor. What else is there? Lines 23-24: it seems that this is the first time that "effective damage zone volume" is mentioned, other than in the title. Title needs to be changed. Pinning this on volume is strange, as the authors assume a fixed width and only vary length.

Page 5723 Line 10: This entire paragraph's message is that the choice of boundary

conditions is important (open vs closed). Not much of a discussion.

Page 5724 Line 4: what does “effective volume of the hydraulically conductive length of the fault zones” mean. Length and volume? Line 9: more interesting would be total area. Line 11: “impermeable” would mean that no flow crosses them in the injection formation. This is not shown by the results. The authors need to be more precise. Lines 10-12: Location of salinization is pre-determined. I would think that is obvious. Brine is going to leak at the faults, no? Line 15: so was width as far as I can tell

Page 5725: Line 11: How about the Birkholzer et al (2011) “Brine flow up a well caused by pressure perturbation from geologic carbon sequestration - static and dynamic evaluations” paper?

Page 5726: Line 13: it seems the only site-specific insights are that there are more intermediate layers and that the salinity distribution is known. Why not run a model with the known salinity distribution then? Line 25: but only if they have open boundaries, right?

Page 5727 Lines 12-21: I would structure this differently. I would first compare closed to open and then mention the impact of different fault lengths and existence of intermediate aquifer. Line 28: I would make the argument that the larger fault length (and thus more leakage area) leads to lower pressures which leads to less flow which leads to a shallower depth from which leakage is occurring. This gives more or less the same information as written, but in a more logical sequence (at least for me).

Page 5728 Line 2: “very permeable” faults are not discussed in this paper, so should be deleted here Line 4: the entire length of a fault is affected by displacement, so sentence needs to be rewritten Line 10: the term “damage zone volume” is used almost exclusively in this section when the authors really tested different lengths, not volumes. This may sound like semantics, but I would expect a very thin long fault to act differently than wide short one. Line 13: the mention of geomechanics seems out of place here. Maybe the discussion section would be a better fit. Lines 20-21: I think this is a difficult

statement to make as the validity of the modeling results is not tested in any way. Are there processes that might be important that are not represented here? Is the fault structure (highly permeable damage zone without low permeability fault core) a sufficient description? Does a one element wide fault correctly represent flow in and out of the fault zone?

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 5703, 2015.