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Interactive comment on "Identifying recharge under subtle ephemeral features in flat-lying semi-arid region using a combined geophysical approach" *by* Brady A. Flinchum et al.

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General Comments

You highlighted six general comments. All six of these comments are beneficial if implemented and they will not change the scientific data or interpretation instead they will greatly improve readability. In this section I will summarise your general comments and then provide details on how the manuscript will be changed.

1. You suggest that we should discuss and frame the manuscript with the Poisson's ratio (rather than P and S Waves) – particularly in the abstract and results. Too much

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time is spent on individual interpretation of P and S wave data.

First and foremost, it's important that Poisson's ratio be mentioned in the abstract, this is an easy fix and provides the readers a better overview of the data contained within the manuscript. Second, we agree that the context should be framed with Poisson's ratio but still believe it is important to show and describe the P-wave and S-wave data that the Poisson's Ratio profile is based on. From a geophysical point of view it is critically important to highlight the slight rise in P-wave velocities (shown in the travel-time picks in Supplementary Material) and slight drop in S-wave velocities (shown in the dispersion curves in Supplementary Material) to ensure that the subtle rise in the Poisson's ratio profile is not an artifact. Essentially, the calculation of Poisson's ratio is routine but the collection of our P-wave and S-wave data in the same survey is not (see Pasquet et al., 2017). The MASW is traditionally done in a separate survey. Thus, the P-wave and S-wave data come from completely separate inversions (and physics for that matter). This is another reason that the reader needs to see and read our description of the P-Wave and S-wave profiles.

To address this comment, we will do as you suggested later on in the manuscript and combine Figures 2 and 3. In this new figure we would add Poisson's ratio. In this new Figure we will make the Poisson's Ratio profile double the size of the P-wave and S-wave profiles. This seems to be a good compromise of adding emphasis to Poisson's Ratio but also retaining the P-wave and S-wave profiles that the Poisson's Ratio profile is constructed on. We will alter the results section and open with the description of Poisson's Ratio and leave the description of the P-wave and S-wave profiles in two subsequent paragraphs. Again, that way we are stressing the Poisson's ratio profile but the descriptions and data for P-wave and S-wave profiles remain. âĂČ

2. You suggest that we provide more explanation to understanding the difference between the in-situ data (gravitation water content, soil water conductivity) and the geophysical data.

As the reviewer correctly points out we spent a lot more time on the NMR results at the drillhole and limited text was provided on the differences between the NMR water contents and the gravimetric water contents. To address this comment, we would break the single paragraph in section 4.3 into two paragraphs. The second paragraph will now explicitly point out that the soil conductivities are in the same range as the TEM conductivities. It will also be explicitly said that the groundwater is conductive but the TEM is measuring an average of the soil and groundwater conductivities so that's why we are not seeing the high conductivities that were measured in the porewater. Lastly, we will add a sentence stating that the NMR cannot measure all of the water in the smallest pores. Since we are clearly dealing with a clay, visible in the logging core and by the short T2 decay times, it is not surprising that the gravimetric water contents are higher above the water table. We suspect that if we had access to a laboratory NMR device that has the ability to measure water in even smaller pores the improvement between that the two methods would improve. We would have been more worried if the NMR water contents were higher than the gravimetric water contents. We are comforted by the fact that below the water table, where all of the pores are assumed to be full, the gravimetric and NMR water contents are in much better agreement.

3. Suggest that we delete the section on the use of Archie's equation which is unreliable in this context.

We agree with this comment. After reading this section again and again the only point that we want the readers to take away from this section is that it is possible that the electrical conductivity will decrease if a more resistive fluid goes into the pore space. This section was a "thought" experiment that helped convince us that this was possible but doesn't really need to be in the main manuscript. We ran this experiment because typically a material will get more conductive as it becomes more saturated. We just wanted to make sure it was possible to decrease the conductivity even under saturating conditions. The other reviewer, Dr. Inverarity, also remarked on this part of the paper and pointed out that we did not thoroughly test a range of literature values and

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actually suggested we expand the model to potentially predict a probability. That was not the point of the exercise so we would take your advice and move this section to the Supplementary Material. To address this comment in the manuscript we will move Figure 7 to the Supplementary Material and replace two paragraphs of our discussion on the topic with one sentence, "A simplified and general modelling exercise using Archie's Law shows that if we replace the water in the pores with a more resistive fluid, it is possible to get a drop in electrical conductivity even if the saturation is increased (refer to Supplementary Material)."

4. You suggest that the wider context and implications are overplayed. Although the paper identifies recharge occurring, it does not indicate its significance to the overall system, and similarly they have not identified a new conceptual model for groundwater recharge.

We agree. To address this comment, we would point out that the current working conceptual model is that major river systems that have their headwaters in the Mount Lofty Ranges become recharge features (the major recharge mechanism to the underlying aquifer system) as they make their way across the Adelaide Plains (mountain front recharge) as was proposed by Bresciani et al., 2018. We would de-emphasize and remove the idea of competing hydrological conceptualization for the regions. Thus some changes in the introduction section will be made to provide the broader current hydrological framework. In the discussion section (5.3) we will change the wording to say we can extend the ideas of Bresciani et al. (2018) to apply to smaller scale features as well. This way we are no longer proposing a new conceptual model just suggesting that the current hydrological framework might also apply at a smaller scale.

5. In general, you suggest that language and diagrams need some improvement. Particularly the overuse of the word "unique" and some colloquial language throughout the text.

Language like unique and novel did show up too many times in the manuscript and

can and will be removed. During the writing process we focused on what was new about our approach to help us stay focused but if the manuscript is written correctly the readers should pick up on this.

6. Lastly you point out that we provide a tantalizing glimpse of wider data from 47 research boreholes not included in this study. Are they being interpreted elsewhere? Or could they be used to upscale their results?

The reviewer is correct that we did show the 47 boreholes in Figure 1. This has clearly had the unintended effect that we will be using all 47 boreholes in the study. To change this in the manuscript we will remove the data from Figure 1 and add a reference to the report that contains the data (Hatch et al., 2019). We will also add a sentence or two in the Geologic Setting section explaining that we used these data to pick the site location. We knew that we would have limited depth penetration with surface wave measurements so we were looking for a site where we know the water table would be between 3-10 m. This assumption is discussed further in the discussion (section 5.4) of the paper as it is a limitation to our approach. The removal of the 47 data points also helps clean up the clutter of Figure 1 as the reviewer suggest later.

Hatch, Michael, Okke Batelaan, Eddie Banks, Brady Flinchum, and Megan Hancock. “Sustainable Expansion of Irrigated Agriculture and Horticulture in Northern Adelaide Corridor: Task 4 – Assessment of Depth to Groundwater (Proof of Concept).” Technical Report Series. Goyder Institute for Water Research, 2019.

Specific Comments

- Abstract – mention the Poisson’s ratio – delete references to unique. Line 18. Your results show that localized recharge is occurring, not that all recharge is localized. Also, you don’t know how significant this is to the broader system – so change to may play and important role in gw recharge in dryland areas

We would follow this advice by adding Poisson’s ratio in the abstract and point out that

ephemeral features may play an important role which would keep us from overplaying the implication early in the manuscript.

- Line 35 – you've missed out Water level fluctuation method. Probably one of the most common on semi-arid areas. You could quote the recent Cuthbert et al 2019 Nature paper

Sorry we missed this one. We were trying to include as many as possible. We will add a reference to the water table fluctuation method in the Introduction section.

- Paragraph at Line 55 – Not sure you can say that ephemeral stream recharge processes are usually undertaken by time lapse and that there is not a one-off survey method that exists. For example many people have used groundwater chemistry and environmental tracers (using existing boreholes) to identify that groundwater recharge is occurring. Also people have used ERT to show fresh water over saline.

The opening sentence of this paragraph is "ephemeral features are an ideal target for geophysical survey". The intent here was to make sure the reader new this paragraph was going to be all about geophysical measurements and ephemeral recharge. We mentioned calculating recharge via groundwater chemistry and environmental tracers in the paragraph above. To our knowledge a geophysical approach that identifies recharge doesn't really exist without a time-lapse measurement, but this is a broad statement and as you suggest probably not true. This is because we measure geophysical properties such as velocity or electrical conductivity but really want water contents and hydraulic conductivities. This also has to do with the fact that recharge is different than infiltration. To confirm recharge, a confirmation of a change in water table must be observed, hence the application of time-lapse geophysical measurements. Nonetheless, we will weaken this claim and change the last sentence of the paragraph to say, "It is still challenging to find a geophysical approach that can be deployed rapidly (that is without a time-lapse setup) to determine if an ephemeral drainage feature is acting as a groundwater recharge feature."

- Paragraph line 66 – Not really a unique combination. Just say a combination. Would strengthen the paper if you discuss and frame with using Poisson's ratio rather than independent S and P wave

We will follow this reviewer's advice and remove "unique" and "novel" etc.

- Site description section. Much of what is here is wider context and immaterial. Please reduce this section to just describe the site and local hydrogeology of relevance. Also please mention the vegetation. The 47 boreholes also confused me. Is there a separate paper using these data? I was hoping the paper was going to upscale the results using these boreholes. It also raises the question that most of the information reported in the paper could have been gained from rapidly drilling 10 shallow piezometers across the site to 8 m.

We agree with the reviewer on this comment and it is stressed in the clutter of the first figure. Major changes to this section will remove the reference to the Tertiary aquifer systems since they are not the focus of this study. We will also remove the 47 boreholes shown on the map so the reader is not misled into thinking we will be using them. The study site description section will be reduced to four shorter paragraphs where P1 is on the overall basin and climate, P2 is specific features relating to NAP mainly that the groundwater is salty, P3 is about the current working conceptual model of recharge mechanisms, and P4 is a description of our focused site. This approach will also simplify Figure 1.

- Line 300 Soil Sample results. These need much more explanation and are skipped over in the paper. Why are the gravitational water content and conductivity data so different from the geophysical data? Looking at the plots they could be from a different borehole in another location.

See the response to general comment number 2 in the section above. We will address this as you pointed out. Though the use of NMR in the vadose zone is still in its early stages and the samples were never processed through a laboratory NMR device,

they are not a one to one comparison. However, below the the water table, where pores are assumed to be fully saturated, the difference between gravimetric and NMR water contents are similar. We would have been much more concerned if the NMR water contents where higher than the gravimetric water contents in the vadose zone. Furthermore, we provide the NMR signal in the Supplementary Material to show that the signal in the decay curves are strong and that the inverted water contents match those data.

- Results: Line 265. Both the P and S wave interpretation show very little evidence of a “clear and observable feature” showing the recharge from the water table under the ephemeral stream. Would be much stronger if you report the Poisson’s ratio in the results. It’s an established technique – so doesn’t need to go in the discussion. Much less emphasis on P and S Wave interpretation (unless to show that they are much inferior) and report the Poisson’s ratio – which is good.

See general comments above. Good point. We will take these changes into account in the revised version of the manuscript.

- Line 309 – you discuss no changes in lithology – however above you discuss clay below the water table – please clarify

This is a good catch by the reviewer. We are convinced that the method worked well because there was no lithological variation. That being said we also needed to convince ourselves and the readers that the higher Poisson’s ratio was due to an increase in saturation and not something else. An increase in clay content would give a similar response. To fix this in the manuscript we will remove the reference to clay content at the end of the opening paragraph. In the second sentence of the following paragraph we will clarify this statement with: “Although we don’t expect any lithological variation, it is possible that the region of high Poisson’s ratios is a result of higher clay content since materials that are deformed easily will have higher Poisson’s ratios.”

- Line 335 and following. This paragraph needs to be changed. You can’t say “different

physics" and "gravitate towards". Just say the second interpretation is more likely due to the NMR data.

We agree. This was just trying to so that the second interpretation is more likely. This change will be implemented.

- Line 360 and following – first sentence you need to mention the observations from cores and piezometer. Also please revisit line 34 – Nano TEM identified low conductivity area – not an increase in saturation.

This is a great suggestion and will be taken into account in the final revision of the manuscript.

- Line 375 an following. The use of Archie's equation here is questionable and weakens the paper. Youi have already mentioned very high and variable water conductivity and the presence of clays – both of which make applying Archie's equation unreliable. This detracts from the paper and I would delete this whole section

Addressed in the general comment section above.

- Line 410 and following Hydrogeological interpretations. One question here that is not answered is whether this water helps sustain an aquatic ecosystem, or vegetation, or is it "lost" to a saline groundwater system.

This is a great question and one that needs to remain open ended. We did not look at ET or any ecosystem related data in this manuscript. One concern is that with the opening of a new water treatment plant that recycles treated waste water for irrigation reuse in the horticultural industries, the application of new irrigation water could eventually waterlog the soils and bring the much more salty groundwater to the surface. Here we might be able to suggest that these small ephemeral features, visible only in LiDAR, are at higher risk.

- line 441 and following, "impossible to know ahead of time"? Delete this. The geophysical survey particularly Poisson's ration and nanoTEM has helped confirm recharge

occurring and therefore guide the siting of more detailed drilling.

Agreed. We will delete this phrase.

- Line 454 – New conceptual model of groundwater recharge in semi arid areas? Unless I missed something I don't think you have done this. Many have discussed recharge from ephemeral streams of all sizes – you have confirmed recharge has occurred from a very small "0" order tributary using a sensible and well applied combination of geo- physical methods and ground truthed with a piezometer.

See the responses to the general comments. We agree and have addressed these concerns by removing language of a new conceptual model and instead extending the current model to smaller scale ephemeral recharge features.

- Conclusions: please name check the Poisson's ratio – which proved useful Line 490 – Do they play a vital role in recharge to the NAP? I don't think you can conclude this, you can say that you have confirmed that ephemeral recharge occurs – but not how important or significant it is to the overall water balance.

We agree and we have weakened the language in the conclusion section. Once again see our responses to the general comments section above.

- Diagrams Overall could do with improving the quality. Figure 1 is really difficult to follow. I don't think we need all the panels. A location map (that's easy to follow – currently couldn't tell land from sea) than panel C which is the main information. A cross section may also be useful if you want to keep in the wider context Figure 2, 3 – combine and add in the poisson's ratio. Add in the location of the piezometer an ephemeral feature to all diagrams Figure 4 – need more information on how to interpret the residuals. I don't know whether its good or bad. Figure 5 – you need to explain the discrepancy between the geophysical data and the in situ data Figure 6 – delete the line for the water table – and add in the piezometer and point observation Figure 7 – Delete along with the section on Archie's law

For Figure 1 we will remove panel d. We will change the underlying map to Hillshade all together since elevations aren't all that important; we were trying to show the ephemeral stream features. We will remove reference to the 47 data points, but have also added a reference to the report where the data exists in the text and will make it clear that we used the data to site the location of the survey.

We will combine Figures 2 and 3 and add Poisson's ratio. We will make sure that Poisson's ratio is the biggest of the three plots. We will remove the vertical gradient. It's that we like to look at P-wave data, but overall not important to the main message of the paper.

We will remove the residuals. They were low and the inversions were goodâĂŤthat was the point.

To the new Figure 5. We will add the piezometer point for the observation well and make the horizontal line much more transparent. We think it's valuable to have the line in the figure so that your eye can follow the flat water table and the Poisson's ratio contoursâĂŤbut I understand we do only know the water level at that point where the observation well is located along the survey lineâĂŤhopefully these changes makes the figure more clear.

Figure 7 will be removed from the main text and moved to the Supplementary Material.

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