Major revisions to HESS-461-2021: A hydrological framework for persistent pools along non-perennial rivers, Bourke et al.

Dear editor,

Thank you for the opportunity to revise this manuscript. We have made substantial revisions to the manuscript in response to the reviewers' comments. The comments from reviewers and community members were largely consistent, and we are hopeful that this revised manuscript will have addressed their key concerns. Although we haven't explicitly responded to their comments here, the community (students) reviews were particularly helpful and we have implemented their suggestions consistent with our response during the discussion phase. These reviews provided thoughtful and constructive suggestions for how to improve clarity of organisation – we thank them for taking the time, and hope that they receive similarly useful reviews on their own work in the future.

We hope that the manuscript is now suitable for publication (minor revisions not withstanding). In addition to the conceptual framework this paper was originally conceived as, this manuscript now includes an extensive review of literature and field methods relevant to the hydrology of persistent river pools, as well as a substantial demonstration of the application of this framework in the Hammersley Basin using both regional-scale and pool-scale techniques (comprising a substantial novel-data component). While reviewers may pick out small deficiencies in individual components, we believe that this now forms a comprehensive (and long) manuscript that presents a framework of ideas and their application with links to find more information and further considerations on each sub-component that will continue to be useful for the scientific community.

Summary of revisions

Manuscript structure and integration of sections

The order of sections has been revised in-line with the reviewer's recommendation so that the management implications with respect to susceptibility of pools is now before the description of available tools for identifying hydraulic mechanisms.

The description and critique of available tools is now separated into regional-scale and pool-scale tools in acknowledgement that detailed sampling at specific pools is not always possible or required depending on needs of a given study or assessment.

We have also added a separate discussion section after the case study as suggested.

The case study section itself (Section 5) now includes a section explicitly describing the application of regional-scale tools to Hammersley Basin region, followed by the three pool-scale case studies. This division is between regional- and pool-scale tools is consistent with the revised section on available tools (Section 4).

Manuscript Text

A substantial portion of the text has been updated in line with specific comments made by the reviewers (and community members). These changes have focussed on improving clarity and accuracy, as well as adding citations where suggested.

The aim and objectives described in the Introduction have also been updated to reflect the new structure of the manuscript.

The manuscript now refers to m asl (above sea level) rather than the equivalent commonly used in Australia, m AHD.

A new discussion has been added which begins by summarising what has been achieved in the manuscript. It then discusses some additional considerations (e.g., that although we have striven to go back to the basic concepts, there may be more than one mechanism contributing to pool persistence) and suggests that multiple methods from Table 2 be used, demonstrating with the synthetic example how the interpretation of just one type of data may lead to an erroneous conclusion. We also acknowledge the difficulties of conducting fieldwork in the environments that host non-perennial rivers and how limitations of time and funding may call for trade-offs between detail and quantity in data. We then tie all these considerations back to what we learned from the case studies, thus linking the paper together more fully as requested by the reviewers.

The conclusion has also been substantially revised to better reflect the key outcomes of the paper, consistent with the revised objectives in the Introduction.

Figures and Tables

All of the figures in the manuscript have been revised in line with the reviewers' comments to improve clarity and consistency and we have also created new figures and tables.

The conceptual diagrams in Fig 1-4 have been updated to have alluvium labelled rather than alluvial channel, as suggested. We have also used consistent colours for geological layers and clarified impermeably vs permeable basement/bedrock as well as improving the placement and formatting of arrows and surface drainage features.

The map of the Hammersley Basin (Fig 5) has also been updated in line with reviewer comments, and there is now a map showing the locations of pools relative to geological strata (Figure 7), which also includes an inset of NDVI results. The previous figure of photos showing the different types of pools has now been unpacked (see Figs 6, 8, 9) and is accompanied by text describing the regional-scale assessment in a structure that links to the regional-scale tools described in section 4.

We have also moved Table 1 further up the manuscript and created a new table (Table 2) summarizing the available tools so that the reader can rapidly assess which they might find useful for a given study, as suggested. We have also added a table (Table 3) of hydraulic conductivities of the geological formations described in the case study section (as requested).

Following reviewer comments questioning the importance of the water balance equations, we have now included text and a figure (Figure 13) in the discussion on the importance of an accurate understanding of pool water balance components when interpreting measured data.

Additional comments

We considered all of the reviewers' comments and suggestions thoroughly; there were a small minority that we have not made changes in response to:

- We believe that the word "framework", defined as a hypothetical description of a complex entity or process, accurately describes the nature of this manuscript and have therefore not altered the title and continue to use this word in the manuscript.
- The hydrological framework presented in Table 1 was developed primarily from first principles. As such we believe that it is most appropriate to retain the references provided within the accompanying text, rather than adding references to the table.

HESS-2021-461: Author changes in response to Reviewer 1

The manuscript entitled 'A hydrological framework for persistent river pools' by Sarah A. Bourke et al., propose a paper that describes a framework for characterizing the hydrology of semi-permanent river pools, as well as some examples of this kind of pools. Althoug I find interesting the overall idea of the manuscript, it is not adequate for publication in its present form.

Thank you for taking the time to review our manuscript, we appreciate your constructive comments and have done our best to improve the manuscript in response to your comments.

The description of the 'framework' (section 2) is rather overconfident, as this is more a revision of former descriptions than an original one.

While we agree with the reviewer that there are a small number of papers that mention some of the hydraulic mechanisms that sustain persistent river pools, these often have an ecological or management focus, and the treatment of hydrology is incomplete, flawed, or cites this manuscript under review. Therefore, there remains a need for this manuscript to be published as a rigorous hydrological synthesis of these different mechanisms so that future studies can be conducted in the context of a robust hydrological framework. Individual papers mentioned are discussed in more detail in our response to the comments on the pdf below.

We have considered whether the word "framework" is suitable as a description of the work presented in this manuscript, and we believe that it is. A "framework" can be defined as "a hypothetical description of a complex entity or process". We believe that this accurately describes what we are presenting; the hydrologic mechanisms supporting persistent river pools are complex and we have endeavoured to provide a theoretical (or hypothetical) description of them. Table 1, which summarizes our framework, was developed largely from first principles, in the context of our understanding of existing literature and our own experience working on persistent river pools. We therefore continue to use this word in the title and throughout the manuscript.

We have also considered what adjustments could be made to the Introduction given the reviewers comment. We agree with the reviewer that many of the elements described in the framework are mentioned within published literature if one knows where to look. We are not asserting that we are the first people to identify that water can persist in pools that form over impermeable rock. However, as described above, there is no complete, hydrologically robust, synthesis of the key hydraulic mechanisms that support the persistence of river pools, which is what we have aimed to achieve within this manuscript. We have made some adjustments to the Introduction to try to ensure that this point is clear to the reader (L63-85).

Sections 2, 3 and 4 are is too descriptive, too long and repetitive, the equations are obvious and the figures are of poor quality. Most of this part could be synthesized in the table 1 with appropriate references and some auxiliary text like that in section 5.1.

We are glad that the reviewer finds Table 1 useful. While the water balance equations may appear obvious, existing literature does not adequately or robustly describe the water balance of river pools *(see discussion above), and so we feel that it is important that these are explicitly presented and explained so that water balances can be accurately accounted for in future studies. Our work, including data shown in the Case Study Section 5, demonstrates with measured data the spatiotemporally variable nature of pool water balance components. We believe that the importance of comprehensively identifying the components of persistent pool water balances is an important message from our paper. As such, we have retained the water balance equations but changed them equations to in-line so that there is less emphasis placed on them. The importance of understanding spatiotemporal variability is also now discussed within a new Discussion section, which includes (Figure 13) the isotopic modelling results below (see comments on pdf) to demonstrate our point more clearly to the reader.*

Similarly, hydrologic concepts that we may take for granted are often used or interpreted differently by practitioners in related fields. The reviewers' comment that the hyporheic zone as an ecotone or habitat relevant for aquatic life provides a great example of this. While this is true from an ecological perspective (Stubbington, 2012), there is also an extensive subset of hydrology related to the hyporheic zone that focusses not on ecological properties, but on the scales and mechanisms of hydraulic fluxes, which are driven by streamflow and channel morphology (e.g. Stonedahl et al., 2010, Bourke et al., 2014). Thus, when the stream is not flowing, these in-and-out hyporheic exchange fluxes are not operating. In this manuscript (and others, e.g. Leibowitz and Brooks 2008), alluvial water is treated hydraulically as a groundwater storage, with fluxes from the capture zone into the pool considered groundwater inflow, and outflow via infiltration (to the release zone) back into the alluvial groundwater. These fluxes are driven by the hydraulic gradients between the pool and the alluvial groundwater and are not related to streamflow. Conceptually, this hydraulic exchange is most accurately described as analogous to the well-established concept of through-flow lakes found in literature on surface water – groundwater interaction (Winter et al., 1998). While this surface water – groundwater exchange process seems clearly distinct from the relatively short-time scale fluxes of hyporheic exchange associated with streambed contours, we can see that the distinction between this and longer timescale parafluvial flows may be unclear, particularly for non-perennial streams (Del Vecchia et al., 2022). Section 2.2 has now been substantially revised to clarify how the conceptual models of hyporheic exchange and through-flow lakes can be applied to persistent river pools (S2.2, L161-213).

With regard to Figures 1-4 in Section 5.1, these are presented as generalized conceptual diagrams of the hydraulic mechanisms that can support persistent river pools. Although we want to be geologically and geomorphologically plausible, they are not intended to represent particular settings or landscapes and are not to scale. This is now clearly stated in the revised manuscript (L110-112).

These figures were always intended to be non-site-specific conceptual diagrams (even in the first submission of this manuscript they did not represent the settings of specific pools), and are broadly consistent with other published diagrams of incised river valleys and floodplains (e.g. Hayes et al. 2018). As this manuscript has a hydrological focus, we have drawn these figures so as to allow us to demonstrate the hydraulic processes that we are discussing, consistent with our experience of, primarily, Australia, but also North America. In determining the geometries and labels used in these figures we consulted with colleagues who specialize in geology and geomorphology. We received a range of responses, from which we chose those that we thought were simplest, and most effective at conveying the hydraulic processes we were describing to a broad audience (for which this paper is intended).

In my opinion, section 5.2 is of value and deserve publication if some aspects are improved. Mostly, the paper should be readable for everybody not used with Australian geologic units, map coordinates and elevation datum.

This section was added in response to reviewer comments on the previous submission of this work and we are pleased that this reviewer finds value in it. Presumably the reviewer would be more comfortable with elevations in meters above sea level (m asl), which is equivalent to m AHD (Australian Height Datum) that we had used. We have updated the revised manuscript accordingly and now use m asl for elevations.

It is not our intention to assume that the reader is already aware of the Hammersley Basin. As such, the geology of the Hammersley Basin is complex, but is described generally at the beginning of Section 5 (L546-556). We have also now added a new table describing the hydraulic conductivities of key units (Table 3). Regionally, the Hammersley Basin is a fractured rock province that is not considered to host productive aquifers for water supply (Jacobsen & Lau, 1987), so we have not delineated aquifers and aquitards.

The map in Figure 6 should represent more information than just the location of unknown pools and the figures should be of better quality.
Thank you for the useful suggestions. This map (now Figure 5) has been substantially revised to show the locations of towns (Pannawonica, Wittenoom, Tom Price, Paraburdoo, and Newman), as well as the boundaries of surface water catchments. The grid coordinates shown are standard UTM values for Zone 50K, which are used by Google Earth. A statement of this and a north arrow (up) has also been added to the revised figure (S5, Figure 5). The pools used as case studies are also now clearly identified.

The assumptions and interpretations should be better separated from observations.
Each of these case studies is currently structured as beginning with a description of the hydro(geo)logical setting, followed by the data collected and the resulting interpretation of mechanisms supporting pool persistence, and finally the implications for management. The reviewer has not provided any specific guidance on how to improve the structure, but it seems that the existing structure does separate observations (data) from interpretations. No change made

Section 6 is rather a discussion than a conclusion, but some discussion is necessary not for showing the interest of 'framework' but for identifying research gaps and further research goals, not necesarily using heavy instrumentation.
There is now a separate Discussion section and the Conclusion has been thoroughly revised and rewritten. We acknowledge that regional-scale assessments of hydraulic mechanisms supporting pools are possible without detailed, pool-specific data; thank you for pointing out that this was not clear from the previously submitted manuscript. We have now separated the description of available diagnostic tools into (i) regional scale (S4.1), and (ii) pool-scale tools (S4.2). Similarly, the case study now begins by demonstrating the application of regional-scale tools in the Hammersley Basin (S5.1), followed by three pool-scale case studies that incorporate water level and hydrochemical time-series data (S5.2).

Many detailed comments are annotated in the manuscript. Please also note the supplement to this comment: https://hess.copernicus.org/preprints/hess-2021-461/hess-2021-461-RC1-supplement.pdf

Further response to individual comments in the supplement provided is as follows. Where a number of comments were made on one page or section these are addressed collectively as appropriate.

Comments Reviewer 1 made on the pdf

P1 This is not new, but an update of already described schemes (e.g. Fellman et al. 2011; Bonada et al., 2020). Also Jocque, M.; Vanschoenwinkel, B.; Brendonck, L. Freshwater rock pools: A review of habitat characteristics, faunal diversity and conservation value. Freshw. Biol. **2010**, 55, 1587–1602.

While there are publications that describe some aspects persistent pools, we do not believe that there is an existing publication that presents a comprehensive scheme or framework for understanding the hydraulic mechanisms supporting persistent river pools. Specific elements of our framework that are not clearly articulated or present within in existing literature include:

- *the applicability of the theoretical model of through-flow lakes to persistent river pools*
- *the role of catchment constriction in determining the location and persistence of river pools*
- *the need for an impermeable layer for persistent pools in the absence of a connection to groundwater or alluvial through-flow*
- *review and critique of available tools for characterizing the hydrology of persistent pools*
- *demonstration of regional-scale tools for characterizing the hydrology of persistent pools*
- *time-series data demonstrating spatial and temporal variability in pool hydrochemistry and water levels,*
- *the application of timeseries data to characterize the hydrology of persistent pools*

That said, we thank the reviewer for introducing us to the Joque et al. (2010) paper freshwater on rock pools that we had not previously cited and we have added this paper to the Introduction (L79) and the section on perched pools (2.1, L125). As the title suggests, this paper describes the ecology of freshwater that persists over impermeable hard rock. There is a brief hydrological description (1 paragraph of hydrology, 1 paragraph of examples) within the section on "the rock pool habitat: definition and distribution". In the first paragraph authors mention that these features can be filled by precipitation, rivers and groundwater, but that the paper focusses on rain-fed rock pools which are the more typical freshwater habitat (presumably perched pools over impermeable bedrock). Thus, while identifying a relatively broad range of hydrological features that can exist (some of which may be within river channels, others which are not – gnammas for example), it does not detail the hydrological mechanisms that can support persistence of water in pools along rivers (groundwater discharge vs perched rainwater), which is the main focus of our present manuscript.

The reviewer also refers to Bonada et al. (2020), which is a paper on conservation and management of isolated pools in temporary rivers that we are aware of (and had cited). While this paper does provide a brief summary of hydrologic mechanisms that can support pools that is more rigorous than Joque et al. (2010), it cites the earlier version of our paper in HESS-D when doing so. As such, it is a circular argument to say that we are duplicating the work of Bonada (2020) given that they have applied the framework presented here in their manuscript. In revisiting the Bonada paper in response to this review, we have realized that we have not cited Leibowitz and Brooks (2008) chapter on vernal pools and will correct this omission in the revised manuscript; this citation has now been added in the revised manuscript (S2.2 L157). This 2008 book chapter provides a summary of the water balance of *pools that are not perched, which is consistent with the framework presented herein, but does not describe subsurface permeability features that control groundwater discharge.*

The reviewer also directs us to Fellman et al., (2011), which we discussed in the early versions of this manuscript. This paper aims to characterize the hydrology of a particular set of pools as controls on dissolved organic matter biogeochemistry. While this manuscript does describe perched and alluvial through-flow pools along river channels, it does not robustly describe the hydrology of these features. It draws conclusions about the hydraulic mechanisms supporting pools based solely on stable isotope values of water (beginning and late dry-season), which are subject to uncertainty that has not been described. In their paper, the water balance of the pools is assumed to consist of inputs from rainfall and groundwater inflow and losses to evaporation. The calculation of evaporative loss from stable isotopic enrichment was made on the basis of a steady state model of evaporation divided by input (E/I). Perched and alluvial through-flow pools are then identified using this ratio (high E/I ratio implies perching). As such, although a subset of the pools are identified as through-flow pools, the conceptual model that underpins the analysis does not account for outflow of water from the pool back into the alluvium (Liebowitz and Brooks, 2008).

The stable isotopic enrichment of a pool with an initial volume of 400 m^3 can be simulated using the water balance equations presented in the current manuscript under review (Figure 1 below - now Figure 13 in the paper). The evolution of stable isotopic values is simulated using the approach of Bourke et al., (2021). A perched pool will have no inflow during the dry season and losses to ET only; a through-flow pool will have losses to ET, inflow of alluvial groundwater and loss via outflow (infiltration) of pool water back into the alluvium (ET + GW inflow + Outflow). For a perched pool with a volume of 400 m^3 at the beginning of the dry season, water volume over 112 days will reduce to 178 m^3 with $\delta^{18}O$ enriching from -8 to 3.5 ‰. The addition of a groundwater inflow of 0.0002 m^3/min (0.3 m^3/d) results in similar end-point values (210 m^3 and $\delta^{18}O$ of 2.4 ‰). In this example, using the line of thought presented in their paper, Fellman et al. would have concluded that groundwater in this second pool is not an important component of the water balance. However, over 112 days this groundwater inflow equates to 8% of the initial volume of the pool and may be important for hydrochemical parameters in the alluvial water (or regional groundwater) that have different values than the pool water. Furthermore, alluvial through-flow pools will usually have water losses associated with infiltration to the streambed sediments, which Fellman did not account for. Thus, the inflow of groundwater may be larger than otherwise thought, if it is balanced by infiltration from the pool of a similar magnitude. For example, groundwater inflow of 0.0008 m^3/min balanced by outflow via infiltration of 0.0006 m^3/min will result in the same pool water level as a groundwater inflow of 0.0002 m^3/min, but the isotopic enrichment will be slightly smaller ($\delta^{18}O$ of 1.3 ‰). Over 112 days, the groundwater inflow in this third scenario adds up to 128 m^3, or 32% of the initial pool volume. A fourth scenario where the water balance is consistent with Fellman (ET and GW inflow terms are as per scenario 2), but the pool area is halved (initial volume remains the same) demonstrates that the water balance of the pool and stable isotopic enrichment are sensitive to the pool geometry (volume to area ratio), which Fellman et al. did not report on or consider explicitly in their analysis. Thus, the identification of hydraulic mechanism supporting pools was made on the basis of unsupported assumptions about pool water balances.

Their analysis approach, based on an incomplete water balance, led Fellman to conclude that many of the pools studied were isolated from the alluvium water table, but this conceptualization (see their

Fig 1) is not hydrogeologically robust. All but one of the pools in their paper occur on permeable alluvial sediments with pools 1-12 shown overlying a similar thickness of alluvium. If the pools were not connected to the alluvial (and/or regional) water table, without the presence of a low-permeability layer beneath these pools, the pool water would infiltrate into the alluvium (Brunner et al., 2009) and the pool would not persist. Thus, the inset diagram of "pools isolated from alluvium water table" is hydraulically implausible (as previously discussed in the manuscript).

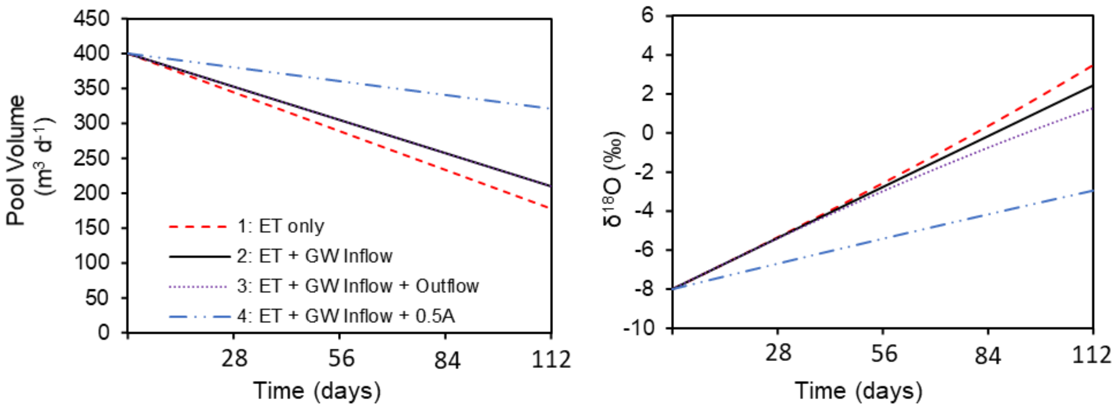

Figure 1 Evolution of pool volume and values of stable isotopes of water in pools with varying water balance components over approximately 4 months of dry season (ET = evapotranspiration, GW = groundwater, A = pool area). Model modified after (Bourke et al., 2021)

P5 Deep perched pools may persist without groundwater flow, ?,

This text has now been modified and moved to the Discussion section.

This kind of pools was earlier described, as e.g. Fellman et al., **2011**, 47, W06501.

We agree that Fellman does mention perched pools and we have cited and discussed it in this section. However, for the reasons described above in detail we do not consider this to be a robust or complete hydrological discussion of the key elements of perched surface water as they relate to persistent river pools. The literature on disconnection of surface water and groundwater is also important here (e.g. Brunner et al., 2009), and therefore in our manuscript we combine these elements (as well as Joque 2010) in our discussion of perched surface water.

The negative role of riparian vegetation transpiration may be more important than its shading effect.

We agree that evapotranspiration is an important element of the pools water balance, and already state this in that same sentence. This paragraph is outlining the theoretical considerations, and we do not feel that it is appropriate at this point in the manuscript to make an assertion that either shading or ET loss will be more or less important in controlling pool water balances – this will depend on the characteristics of individual pools and the types of vegetation they support. No change made.

P6 Is this necessary?

The reviewer refers here to identifying a low-conductivity layer to support perching in sandy sediments. A low-conductivity layer is essential for supporting perched surface water in otherwise permeable sediments (Brunner et al., 2009). We are not saying definitively that it wasn't there, but we do think this is an important feature of perched surface water within permeable sediments (as opposed to overlying *impermeable bedrock) that was not acknowledged or discussed by Fellman et al. (2011). No change made.*

Bedrock is assumed of low permeability but this is not stated (otherwise the upper pool could not exist).

We thank the reviewer for highlighting the inconsistency in the implied permeability of the bedrock. We have updated Figs 1-4 to consistently differentiate between impermeable (or low perm) bedrock and permeable bedrock.

The picture is too simplistic/naive. (exaggerated relief, disconnection between the main stream and the tributary, "valley fill" of poor geomorphic meaning).'Alluvial channel' should be 'alluvium' It seems that the authors tried to generalize the pictures of their early manuscript in HESSD, but 'Tertiary detritals' cannot be directly converted into 'valley fill' because the last one can be assumed as of Quaternary age and therefore having a form related to the recent and present-day alluvial landscape (flood plain with Pleistocene terraces)

The reviewer has suggested "Alluvium" as a replacement for "Alluvial channel" – we are not sure of the basis for this suggestion but have made the replacement in Figs 1-4. Similarly, the lack of a defined surface drainage line between the hillslope and river in Fig 1 has been rectified.

We have used the term "valley-fill" to refer to any sediments within the geological river channel (as distinct from the flowing channel that a hydrologist may consider) and do not intend this to make any reference to a particular age of sedimentary deposition – hydraulically, the time of sediment deposition is not of primary importance. This is consistent with general definitions of valley-fill (unconsolidated sedimentary deposit which fills, or partly fills a valley) that do not refer to a specific time of deposition. A more suitable alternative has not been suggested by the reviewer and no supporting citations for this comment were provided so we are unable to determine a replacement term for the generalized conditions that we are trying to show in these conceptual diagrams. No change made.

Water means here water saturating the alluvium.

P7 The occurrence of pools depend on much detailed scales (10 - 1000 m) whereas this concept of gradient is valid for 10-1000 kilometers.

Bedrock must also be of low permeability.

Evapotranspiration by riparian vegetation may deplete relevant volumes of water. Brooks, R. T., & Hayashi, M. (2002). Depth-area-volume and hydroperiod relationships of ephemeral (vernal) forest pools in southern New England. Wetlands, 22(2), 247-255.

P8 shallow

This lacks of scientific meaning. Hyporheic zone defines an ecotone or habitat relevant for aquatic life; the water and life in shallow groundwater in exchange with those in surface water. Hyporheos refers usually to the shallow groundwater in the alluvium.
https://en.wikipedia.org/wiki/Hyporheic_zone

This section on through-flow of alluvial groundwater (S2.2) has been significantly modified to improve clarity. Thank you for drawing our attention to Brooks and Hayashi, which we had omitted when *discussing the importance of ET as part of the water balances of persistent river pools and groundwater throughout the manuscript. We have now cited it at multiple suitable points in S2.2.*

p9 These pictures are rather naive and of very poor geomorphic quality. The 'valley fill' should take the form of a flood plain and/or a terraced system and the water table should be not so far from the surface of the floodplain.

Figures 1-4 are conceptual diagrams, which are not to scale. Figure 2b represents the case of a perched water table beneath a river that resides in an arid or semi-arid climate where the regional water table can be tens of metres below the surface (Villeneuve et al., 2015). The key feature of this diagram is that the regional water table is below the valley fill, within the weathered basement. In our view, this diagram reasonably represents a valley fill on the order of say 10-20 m and a depth to water table of 15-30 m, which are plausible values in our experience. No change made.

P10 this discussion lacks of interest

This text was added in response to reviewers of our previous submission of this manuscript who were of the view that the hydraulic processes relevant to persistent river pools were all covered in literature on groundwater springs. Given that the term "sphere of influence" is quite vague, we have unpacked this framework or schema further so that it is evident to the reader why it is not helpful for persistent river pools. We are pleased that the reviewer finds this self-evident, but we would be deleting the text to satisfy the current reviewer, at the expense of not addressing comments from previous reviewers. Thus, we suggest retaining the text. No change made.

Some hard rocks may be permeable, such as sandstones.

Agreed. Sentence modified to refer to effective hydraulic conductivity rather than fracture aperture.

P12 Again, the generalization of the figures from the former paper is not successful, particularly for the 'valley fill' and the lower boundary of the aquifer, that there was the lower boundary of the weathered rock

See comments above regarding use of the term valley fill. The reviewer has also made this comment about the lower boundary of the aquifer in Fig 3b. This figure depicts the generalized case where valley fill sediments are relatively thin and the lower boundary of the regional aquifer is determined by the lower boundary of weathering in the bedrock, which is hydraulically connected to the valley fill. It is unfortunately not clear what issue the reviewer has with this depiction, which is consistent with our experience. No change made.

P13 Unlike in the other figures, here 'bedrock' is permeable.

Thank you for bringing the inconsistent implied permeability of bedrock to our attention, we have updated Figs 1-4 to ensure clarity and consistency.

'Valley fill' fully lacks of sense in this setting.

These unconsolidated sediments that are below and adjacent to the stream are now described as alluvium.

None of the former aquifers was confined, so this adjective is unnecessary here.

Deleted.

P15 This is excessive, more adequate for a textbook than for a research paper

Text deleted.

P17 and transpiration if riparian vegetation is present (as frequently occurs)

Evaporation changed to evapotranspiration. Transpiration was already mentioned but not explicitly in this term, thank you for bringing this to our attention.

P19 and along the river path (Dogramaci, S., Firmani, G., Hedley, P., Skrzypek, G., & Grierson, P. F. (2015). Evaluating recharge to an ephemeral dryland stream using a hydraulic model and water, chloride and isotope mass balance. Journal of Hydrology, 521, 520-532).

Thank you for the encouragement to self-cite; citation added and sentence updated.

Unclear

"Concentration" replaced by "strontium values".

This discussion is not well founded here; Fellman et al (2011) seem to assume that bedrock is impervious, as the Authors do in Fig. 1.

This comment was referring to pools that overly unconsolidated alluvium; the permeablity of bedrock is irrelevant. Nevertheless, this sentence has been deleted.

P22 Phreatophytes can abstract relevant volumes of water from the alluvial aquifer. New tree plantations may have similar effects than pumping.

True. We have replaced "abstraction" with the more general term "withdrawals" which may include by pumping or ET as stated at L332.

P23 This table can substitute most of the previous text. But this is not original, so appropriate references are needed.

The hydrological framework presented in Table 1 was developed primarily from first principles in the context of our understanding of published literature and our experience working on the hydrology of persistent river pools. As such we believe that it is most appropriate to retain the references provided within the accompanying text, rather than adding references to the table.

Solutes and heavy water isotopes may increase downstream due to cumulated evaporation.

Of a pool? You must mean in the alluvium, yes of course. But here we are talking about the pool.

Phreatophyte stands or plantations may cause relevant water abstraction

In the absence of precipitation.

Thank you for these helpful suggestions, they have all been added to Table 1.

The units for the variables in the equations are welcome.

The terms are defined in the text with units given.

P24 Before explaining the 'valley fills', a description of the diverse bedrock (basement?) units is necessary, and a small table defining their names and hydrological properties would be very welcome.

More details are needed, as stated before

The description of geology of the region has been updated in the text and a new summary table has been added that reports hydraulic conductivities (Table 3).

P25 Which is the size of the total set?

New paragraph

shaded, so evaporation is minimised

Which percentage from the total amount of pools?

Bat? I expected aquatic life

How many? which percentage?

New paragraph

How many? which percentage?

We recognize that this summary was not particularly useful for the reader. This text has been deleted and replaced with a new section on the application of regional-scale tools to understand hydraulic mechanisms supporting persistent river pools in the Hammersley Basin (S5.1).

P27 As shown, this map is not useful to the reader and it should be deleted. If a location appearing in Google Earth is shown on the map, the visualization of satellite images of the area would be easier to the reader. Some identification of the pools must appear in the map; pool type or the names of the 3 pools in section5.2. Coordinates should be adequate for a reader not used with the GDA94 ones.

This map has now been updated to include towns, surface water catchment boundaries and identify the 3 pool-scale case studies. All spatial reference points are reported as projected coordinates so that linear distances are obvious from their values. These UTM projections are a global standard, and they are readily available within Google Earth.

P28 The features at the pools are too small. The 'alluvial channel' is not visible in the figure, so the throughflow pool looks as a regional groundwater one. The relief seems very exaggerated. Hammersley Group and Fortescue Group are not described in the text. 'Valley fill' is too ambiguous concept. Why aquifers disappear in depth?

This figure has been removed.

Which is the altitude of the pool AHD?

Pool water level elevations now reported in the text (data shown in Fig 10b)

P29 Some adjective would be welcome: dykes of intrusive, or porphyritic rocks or…

The dykes consist of dolerite, as previously described in the text and now also stated in Table 3.

AHD (Australian Heigh Datum?) is not necessarily known to readers from other countries

AHD has now been replaced with m asl (metres above sea level). These are effectively equivalent (https://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/datums-projections/australian-height-datum-ahd).

Presumably a dyke (as assumed below)

Now stated

is attributed to

text added

although the occurrence of barriers (dikes) may force the groundwater to emerge (?)

In this instance the dykes compartmentalize the aquifer, but because they don't continue up to surface they do not force the groundwater to emerge at surface.

P30 Is this dyke the barrier cited above?

Yes. 'nearest' added for clarity

The water table between the two wells should not be shown as an horizontal solid line. The text about the pool depth should be moved to the text. The geologic units are shown in too similar colours and should be described in the text. V.E. should be fully stated as vertical scale exaggeration (?). The coordinates are not universal. Lettering font is too small.

VE is now stated and annotations added to clarify permeability relationships. These x and y coordinates were UTM coordinates are a global standard that is available within Google Earth. Nonetheless, they were not required on this conceptual diagram and have been removed.

P31 BIF?

BIF is now defined as banded iron formation in Table 3.

P32 All the information on the geological units and their permeability should be shown in a table, otherwise it is impossible to the reader to follow their relevance

This is now done in Table 3, and we have also revised the figure annotations for clarity.

P34 Issues like in other figures. Yellow letters are not legible, dashed blue line is not defined

Yellow letters converted to black. Dashed blue line is water table, as now indicated by the standard inverted triangle symbol.

P35 over

Fixed

values at the bottom of pool 1 are not shown

'top' and 'bottom' replaced with up-stream end and down-stream end for clarity

P36 Some less overconfident expression is suggested, e.g: These data allow us to infer …

Done.

Is this feasible??

This is common in mining impacted areas like the Hammersley Basin. The removal of overburden and ore can substantially reduce area of surface catchments. This is now clarified in the text

P37 c) Please, use a similar notation for both isotopes: 18O and 222Rd, or Oxygen-18 and Radon-222. What means Sub-pool? d) Lettering too small. Temperature scale would be better with the higher values on the upper part. e) Some lettering is too small. Alluvium GW flow arrow is located within the bedrock. What means 'Alluvial Bore? What is the orange colour below Wittenoom Fm?

Sub-pool deleted, isotopic notation now consistent. Sub-fig e) revised.

P38 MoIs of this is rather a discussion than a conclusion

Summarizes

This is really overconfident!

Gather

Only in intricate places all this is necessary.

We have now created a separate Discussion section and the Conclusion has been substantially revised. We acknowledge that some inferences about the hydraulic mechanisms supporting pools from regional-scale information. As such we have separated the methods into regional- and pool-scale tools and present a new section (5.1) applying the regional scale tools in the Hammersley Basin.

HESS-2021-461: Author changes in response to Reviewer 2

Anonymous Referee #2
Referee comment on "A hydrological framework for persistent river pools" by Sarah A. Bourke et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2021-461-RC2, 2021

This paper contains a lot of information and is in a way a literature review with a proposed methodology for diagnostic and an application to study sites. I believe the contents are appropriate and people interested in the topic will find this a useful guide. Because of its nature, the paper has very little quantitative results, so the authors struggle to find a common synthesis or a final message.

I believe readers will benefit from a more succinct treatment in some of the sections. For example, sections 2 and 3 have lengthy introductory paragraphs that tell the reader what the authors are going to do next…I wonder if that is really necessary or if it is better to just mention what points are going to be touched upon and why. A better connection between sections 2,3 and 4 can be provided, with a bit of a synthesis and perhaps based on Table 1.

Thank you for this suggestion, the extended text at the beginning of sections 2 and 3 has been deleted, edited or moved as appropriate. The link between sections 2-4 has also been enhanced by re-ordering the sections so that management implications are discussed before diagnostic tools. We have also re-structured the section on diagnostic tools (Section 3) to better align with the case studies (Section 5), in both cases clearly distinguishing between regional-scale tools and more data intensive local-scale approaches.

Table 1 should be moved up the manuscript, within section 2.

Table 1 was originally cited in the first sentence of Section 2. As such we have not moved the initial citation, but we have now placed the Table immediately before 2.1 so it is closer to the in-text citation.

The end of the manuscript is rather abrupt. After going through the application sites the authors go straight to the conclusions, which is most of a summary. There is no discussion of differences or similitudes between sites, lessons learned or future work. I am sure that there are elements of all of this somewhere in the manuscript, but they need to be clearly synthesised at the end. This is, I believe, the main weakness of the manuscript.d

A separate Discussion has now been included as Section 6 that discusses the similarities and/or differences across the case studies, summarizes the lessons learned from the field sites and suggest future work.

The Conclusion presented in Section 7 has been re-written to provide a more suitable concluding statement in line with the study aims.

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