Dear Prof. Efrat Morin,

Please find attached the revised discussion manuscript (hessd-11-11905-2014) submitted to Hydrology and Earth System Sciences: "Impacts of a changing climate on a century of extreme flood regime of northwest Australia", co-authored by A. Rouillard, G. Skrzypek, S. Dogramaci, C. Turney and P.F. Grierson. We sincerely thank you for giving us an opportunity to revise our manuscript. We greatly appreciate the valuable comments from the reviewers, who were very constructive in their discussion of our paper. Their input has helped us to further focus the manuscript and improve its clarity. We summarise our responses to the reviewers' suggestions below. Pages and lines numbers provided refer to the first version of the discussion manuscript published online.

We hope that the manuscript is now suitable for publication in its revised form. However, we would be happy to accommodate any further questions or suggestions that you may have. We look forward to hearing your comments on the resubmitted manuscript.

Sincerely,

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**Responses to Referee #1 and list of changes in the manuscript**

**Overall this paper is good, interesting and suitable for HESS. However, you nearly lost me in the abstract and the first paragraph (see details below). There are a few other questions and comments I have which if satisfactorily addressed would make this paper acceptable for publication. Hence my decision "accept subject to major revisions".....the revisions listed are mostly minor but there is a lot and i would like to re-review hence the choice of "major revisions".**

**My comments, questions and suggested additions/revisions are listed below:**

**1. The first paragraph I think should be deleted. It isn't needed (better to start with line 19 "Quantifying the "hydroclimatic expression" of regional events remains challenging. . ...") and what is written has several problems:**

*Response*
This suggestion from the reviewer has helped to better focus the paper. As suggested, we have shortened and edited the initial opening paragraph. We also agree that the concept of trends in such highly variable context may be misleading (this is a very good point to make), especially when relatively small temporal windows are provided. We have thus also included numerous edits throughout to the manuscript to better acknowledge the importance of variability and potential 'cyclicity' in this system, as opposed to 'trends'. We think that our reconstruction now highlights the more 'periodic' hydrological expression of rainfall variability (rather than 'average conditions') and reveals the importance of the 'extreme' features of this regime, such as protracted drought, severe inundations or prolonged wet periods.

*p. 11906*
Replaced: "Globally, there has been much recent effort to improve understanding of climate change-related shifts in rainfall patterns, variability and extremes. Comparatively little work has focused on how such shifts might be altering hydrological regimes within arid regional basins, where impacts are expected to be most significant."

by: "Long-term hydrological records provide crucial reference baselines of natural variability that can be used to evaluate potential changes in hydrological regimes and their impacts. However, there is a dearth of studies of the hydrological regimes for tropical drylands where intraseasonal and interannual variability in magnitude and frequency of precipitation are extreme."

*p. 11907*
Removed: lines 2-18; 19 until "Quantifying hydroclimatic…"

*l. 19*
Replaced: "Quantifying the "hydroclimatic expression" of regional events remains challenging for not only the Australian northwest but for arid environments more generally; these regions…"

by: "Quantifying the hydrological responses to changes in the rainfall patterns remains challenging in arid environments, especially for remote tropical and minimally gauged drylands such as the Pilbara region of northwest Australia. Tropical drylands …"

*l.24*
Replaced: "…the Pilbara region of northwest Australia can reach…" by "…the Pilbara can reach…"

*l. 28*
Replaced: "…challenges for prediction of consequences of changes in intensity and frequency of extremes."
by: "…challenges for prediction of resultant impacts of hydroclimate change on catchment hydrology. Several lines of evidence suggest the Pilbara has been particularly wet during the late 20$^{th}$ century (e.g., Cullen and Grierson, 2007; Shi et al., 2008; Taschetto and England, 2009; Fierro and Leslie, 2013) and that the frequency of extreme precipitation events may be increasing (e.g., Gallant and Karoly, 2010). However, there is no consensus on whether the observed higher summer rainfall can be attributed to an overall 'wettening trend' or whether the recent 'wet' period may be a feature within the range of natural 'extreme' variability characteristic of this region."

**a. My understanding is TCs are weather events not climate**

<u>*Response*</u>
Please refer to above response to comment #1. The reviewer is correct and we have revised our wording accordingly.

**b. TC, rain and drought "are projected to become more intense and less frequent". According to IPCC (and hundreds of other references I could cite) my understanding was: (i) the jury is still out on whether TCs/typhoons/hurricanes would become more/less frequent or intense; (ii) same with whether or not extreme rain will become more frequent or intense (see IPCC special report on extremes where they classify this as something with "high uncertainty"); and (iii) for Australia, IPCC, CSIRO, BoM and many other studies suggest drought will become more frequent but again there is high uncertainty. If you want to make such a statement then I think you need a lot more evidence and references to existing literature to support it (while also fairly representing the published literature that says the opposite). Bottom line is there is a high degree of uncertainty about what will happen to intensity and frequency (and duration for droughts) of extremes in the future. This is a complex issue and doesn't need to be covered in this paper. My suggestion is delete first para.**

*Response*
Please see the above response to comment #1. We have revised as the reviewer suggests.

**c. Post-1955 wettenning in north-west Australia (line 12) is also misleading. . .. . ..both in terms of what the literature says and what your own data and model says (e.g. fig 3a and fig 3c). Yes there was a wet period from ~mid-1950s to mid-2000s and yes 1999- 2006 appeared to be particularly wet. . .. . but since about 2006 things have not been so wet (maybe with exception of 2012). . ..with 2006-2012 mostly back to average (maybe even drier than average).......either way it is misleading to lump 2006-2012 in with 1955-2012 and say "post-1955 wettenning" as the so called trend appears to be more of a cycle (See next point). . .. . ..again better to avoid the semantics and controversy and just leave this paragraph out (but you will need to fix the abstract)**

*Response*
Please see the above response to comment #1. Revisions made as suggested.

**d. Talking about "trends" in this paragraph is misleading. . ...looking at the data (e.g. figure 3 and other observations from the area) what I see is dry (~1988-1996), wet (1999- 2006) then dry again post-1997. . .. . .I don't see a trend in either fig 3a or 3c. . .. . ...i see cycles or variability or interannual to multidecadal wet/dry phases. I am aware the papers cited (and others) say otherwise but I disagree and the very recent literature is beginning to recognise this. You also recognise this on page 11920 (lines 23-27) when you mention the importance of exploring "cyclicity". I would avoid mentioning trends. . ...and in the case of para 1 just delete it and start at line 19.**

*Response*
Please see the above response to comment #1. This is an important point and we agree that there has been a shift in thinking moving from generalising to trends to trying to understand cyclicity across different time frames. We are in fact attempting such an approach by combining the presented results with tree ring and other records in the near future.

**2. Abstract. . ...2nd sentence. . ..you mention inundations of 1000km2 and 300km2 but reader cannot put this into context without knowing the total possible area. . ...this is covered on page 11910 line 15 but the total area ~1300km2 also needs to be in the abstract**

*Response*
Unfortunately, to date there has been no published high-resolution delineation of the total possible floodplain area for the Fortescue Marsh, either from inundation extents or from high-resolution vegetation survey. The outline currently provided in official map layers from Geoscience Australia or at the Department of Water is coarsely resolved, roughly corresponding to the 410 m elevation contour; we have

used this estimate to constrain our analysis (i.e. ~1300 $km^2$) and included the information in the Abstract.

*p. 11906, l. 16*
Replaced "The most severe inundation (~ 1000 $km^2$) over the last century was recorded in 2000."
by:
"The most severe reconstructed inundation over the last century was in March 2000 (1000 $km^2$), which is slightly less than the 1300 $km^2$ area required to overflow to the adjacent catchment."

**3. Abstract. . ..line 22„„1999-2006 were "above average". . ...average calculated on what period? 1988-2012 or 1912-2012 or both or something else??**

<u>*Response*</u>
We suggest the following replacement to clarify the message here:

*p. 11906, l. 21*
Replaced: "Duration, severity and frequency of inundations between 1999 and 2006 were above average and unprecedented when compared to the last century."
by: "The prolonged, severe and consecutive yearly inundations between 1999 and 2006 were unprecedented compared to the last century."

**4. Abstract. . .final sentence. . ..in line with comment 1c and 1d. . ...yes if wet epochs like 1999-2006 continue then wetland will become more persistent. . .. . ..but where is the evidence that frequency or intensity of rain/TCs etc will increase or be same as 1999- 2006?? I don't see it in this paper (in fact Fig 3a and fig3c suggests opposite) and I don't see it in other literature. . .. . ...therefore need to tone this done a bit. . .. . .something like "While there is high inter-annual variability in the system, it is clear that that the wetland will become more persistent if the frequency and intensity of extreme rainfall events for the region were to increase (or be similar to 1999-2006), which in turn will likely impact on the structure and functioning of this highly specialized ecosystem."**

<u>*Response*</u>
Edited as suggested by the reviewer:

*p. 11906, l. 21*
Replaced "While there is high inter-annual variability in the system, changes to the flooding regime over the last 20 years suggest that the wetland will become more persistent in response to increased frequency and intensity of extreme rainfall events for the region, which in turn will likely impact on the structure and functioning of this highly specialized ecosystem."

by: "While there is high inter-annual variability in the system, if the frequency and intensity of extreme rainfall events for the region were to increase (or be similar to

1999-2006), surface water on the Marsh will become more persistent, in turn impacting its structure and functioning as a wetland."

**5. Page 11908, line 4....suggest the following Australian specific references should also be included here. . .. . ..you should also include this when talking about ENSO/IOD cycles on page 11920:**
**a. Flood**
**i. Kiem, A.S., Franks, S.W. and Kuczera, G. (2003): Multi-decadal variability of flood risk. Geophysical Research Letters, 30(2), 1035, doi:10.1029/2002GL015992.**
**ii. Ishak, E.H., Rahman, A., Westra, S., Sharma, A. & Kuczera, G., 2013, Evaluating the non-stationarity of Australian annual maximum floods, Journal of Hydrology, 494, 134-145, DOI: 10.1016/j.jhydrol.2013.04.012.**
**iii. Kiem, A.S. and Verdon-Kidd, D.C. (2013): The importance of understanding drivers of hydroclimatic variability for robust flood risk planning in the coastal zone. Australian Journal of Water Resources, 17(2), 126-134.**
**iv. Pui, A., A. Lal, and A. Sharma (2011), How does the Interdecadal Pacific Oscillation affect design floods in Australia?, Water Resour. Res., 47, W05554, doi:10.1029/2010WR009420.**
**b. Drought**
**i. Kiem, A.S. and Franks, S.W. (2004): Multi-decadal variability of drought risk – Eastern Australia. Hydrological Processes, 18(11), 2039-2050.**
**ii. Verdon-Kidd, D.C. and Kiem, A.S. (2010): Quantifying drought risk in a non-stationary climate. Journal of Hydrometeorology, 11(4), 1019-1031.**

*Response*
We thank the reviewer for providing these very supporting references that substantiate our study rationale and findings on the long-term variability of floods and droughts. These references have been cited in the text as follows.

*p. 11908, l. 14*
Replaced: "In the case of the Pilbara, TCs and other low-pressure systems forming off the west Australian coast in the tropical Indian Ocean often result in extreme flooding events (WA Department of Water, 2014)."

by: "In the Pilbara, tropical cyclones and other low-pressure systems forming off the west Australian coast in the tropical Indian Ocean often result in severe flooding events (WA Department of Water, 2014)."

*p. 11908, l. 10*
Added "(e.g., Kiem et al., 2003; Kiem et al. 2004; Verdon-Kidd and Kiem, 2010; Ishak et al. 2013)." after "…and temporal scales."

*p. 11920, l. 23*
Replaced: "The appraisal of multi-decadal trends in the hydrological regime could be improved by exploring the impact of cyclicity of known larger scale climatic drivers of (summer) rainfall in the northwest of Australia such as the El Niño –Southern

Oscillation (ENSO), the Indian Ocean Dipole (IOD) and the Madden–Julian oscillation (MJO) – phasing of these different modes (Risbey et al., 2009)."

by "However, rigorous analysis of periodicities would be required for the appraisal of multi-decadal trends in the hydrological regime against such a high background of variability (e.g., Kiem et al., 2003; Kiem et al. 2004; Verdon-Kidd and Kiem, 2010; Ishak et al. 2013). In fact, future investigations and risk analyses in the region should strive to assess the potential influence of known larger scale climatic drivers and their interaction of intraseasonal and interannual hydroclimate variability in the northwest of Australia (e.g., Kiem and Frank, 2004; Pui et al., 2011; Kiem and Verdon-Kidd, 2013), such as El Niño-Southern Oscillation, the Indian Ocean dipole, the Madden Julian oscillation and the southern annular mode (Risbey et al., 2009; Fierro and Leslie, 2013)."

**6. Page 11912. . ...line 25. . ..are the units correct?? I think what you are saying is 22 mm of rain per rain day??.....but what does 22 mm of monthly rain per rain day mean?? Please check and clarify.**

*Response*
Thank you to the reviewer for picking up this mistake: we meant "22 mm of rain per rain day" and clarified this in the text.

*p. 11912, l. 25*
Replaced "…22 mm monthly rain rain d-1)" by "…22 mm of rain per rain day)"
Replaced "…10 mm monthly rain rain d-1)" by "…10 mm of rain per rain day)"

**7. Page 11913. . ...30 out of 60 mths when extremes happened were associated with one or more cyclones. . ..so 50%.....what were the other 50% of extremes associated with or caused by?? Need a comment on this. What else causes rainfall extremes in this region?**

*Response*
Tropical cyclones and other closed lows were found to account for most of the extreme rainfall events in the northwest of Australia by Lavender and Abbs (2013); these authors did not distinguish between weather systems. We are not aware of any other study that has directly identified other specific drivers of rainfall extremes in the region but they are likely to include troughs, monsoonal depressions, and onshore circulations. The relative contribution of each of these potential sources of rain has not, to our knowledge, been investigated even though, as the Reviewer points out, they can account for ~ 50% of extreme rainfall events. We have thus been more careful with our wording and included the following modifications to the text to clarify that heavy rainfall events are not only associated with tropical cyclones:

*p. 11912, l. 6*
Included: "Rainfall in the Pilbara comes from troughs, monsoonal depressions, and onshore circulations (Leroy and Wheeler 2008; Risbey et al. 2009)".

*p. 11912, l. 19*
Added after: "…2014).":
"Tropical cyclones and other closed lows accounted for most of the extreme rainfall events in the northwest of Australia over the 1989–2009 period (Lavender and Abbs, 2013)."

**8. Page 11913. . ...line 10-26„„, all these other sources of verification sounded interesting to me (especially the field and helicopter groundtruthing). . .. . .I might have missed it but I couldn't find where the results of this are reported or discussed. I think you need a section that covers:**
**a. how your reconstruction compares with Landsat (Appendix A, sect A2 describes this but you need images/plots to verify and demonstrate your model/reconstruction is realistic)**
**b. how your reconstruction compares with the 40 cm and 5 m ortho images. . ... again, plots, figures etc would be good**
**c. demonstrate how your reconstruction compares with the groundtruthed info (helicopter and field expedition)**

<u>Response</u>
We have now included an additional supplementary figure (Fig. A1 in the resubmitted version) that allows visual comparison of the water delineation with the ortho-photos and the groundtruthing, which we undertook by helicopter in 2012 after Cyclone Heidi and on foot during the 2012 dry season. However, while the model reconstruction itself can be compared with Fig. A1 (p. 11943) for validation ($R^2_{adj}$ = 0.79; p value < 0.001, $E_{RMSP}$ = 56 km$^2$), it is not sufficiently spatially explicit to compared with the images directly. Of course, similar extents of water resulted in similar spatial patterns of inundations, but they also varied depending on whether several consecutive months had inundations, the maximum FA for the year, and other factors. Fig. 6 illustrates the range of observed extents from the calibration dataset for visual comparison with reconstruction values, which we hope at least partly addresses the suggestions of the Reviewer. We have also modified the text.

Replaced: "To provide further confidence in our dataset within the estimated errors we used two 40 cm digital ortho-images produced from aerial photographs taken in July 2010, April 2012 (Fortescue Metals Group Limited, Perth, Australia) and one 5 m resolution image taken in August 2004 (Landgate, Government of Western Australia), to confirm that our flood areas mapped from Landsat images taken on similar dates (i.e., within one week of the ortho-image dates) were within 1 pixel (30m) of the flood area visible in the ortho-images. A groundtruthing expedition from the dry season (November 2012) and a helicopter delineation of the inundation plume in the wet season (February 2012) were also conducted."

by: "To provide further confidence in our dataset within the estimated errors we used two 40 cm resolution digital ortho-images produced from aerial photographs taken in July 2010, April 2012 (Fortescue Metals Group Limited, Perth, Australia) and one 5 m resolution image taken in August 2004 (Landgate, Government of Western Australia), to confirm that our flood areas mapped from Landsat images taken on similar dates (i.e., within one week of the ortho-image dates) were within 1 pixel (30m) of the flood area visible in the ortho-images (Fig. A1a). A groundtruthing expedition in the dry season (November 2012; Fig. A1 b, c) that noted boundaries by GPS route tracking while walking along the water edge (~1-2 m distance from standing water) of the Moorimoordinia Native Well and a delineation of the inundation plume in the wet season (February 2012; Fig. A1 d) by GPS route tracking during low altitude helicopter survey along the water plume were also conducted and confirm that our thresholding method captured standing water on the Marsh (Appendix A2)."

*p. 11943*
Included:
"**Figure A1:** Validation and groundtruthing of standing water on the Fortescue Marsh, including: **a)** standing water on the 14 Mile Pool extracted from Level 1T Landsat image (Jul 2010; solid white line = threshold pixel value ≤ 40; LT5; USGS) and close up against a 40-cm resolution ortho-photo (Jul 2010); delineation by GPS route tracking while walking along the water edge (1-2 m distance from standing water; solid white line) and close up against **b)** a Level 1T Landsat image of Moorimoordinia Native Well (Nov 2012; blue fill = threshold pixel value ≤ 40; LE7-SLC-off, USGS) and **c)** a RGB image showing the extent of the dry channel bed (Dec 2006; SPOT-5); **d)** delineation of standing water by GPS route tracking during a low altitude helicopter survey along the water plume of the Fortescue Marsh (2012 Feb 12; solid red line) and close up against standing water extracted from Level 1T Landsat image (2012 Feb 14; blue fill = threshold pixel value ≤ 40; corrected LE7-SLC-off; USGS), overlain on a 2.5 m resolution RGB image taken during dry season (Dec 2006; SPOT-5)."

**9. page 11918, first para. . ..this is confusing and I think needs to be reworded. . ...rather than speaking about years you need to talk about months since F(A) and change in F(A) are monthly terms. . ...are you saying that all preceding months in 1941 were drier than 1999??? i think what you are saying is that if the Marsh is inundated in mth x to say 80% then the decrease from that month of inundation to the next is larger than if month x was inundated to say 50%??? Is that right?? If so that would make sense as more water to lose to evaporation etc. . .. . ...or are you saying something else??? Either way this para is confusing and needs clarification.**

<u>*Response*</u>
The reviewer interpreted our meaning correctly and we apologise for the confusion around terms: we have made the following changes to the text:

*p. 11918, l. 2*
Replaced: "When still inundated from the previous month ($F_{At-1}$> 0 km2), decrease of the total area flooded was significantly larger ($F_{At-1}$ = 29 km2; p value < 0.001). For example, although the largest inundated area was recorded in 2000, the 1942 net $\Delta F_A$ was larger but resulted in slightly less inundated area at the Marsh owing to the drier conditions than in 1999 in the previous month."

by: “Water loss ($-\Delta F_A$) on the Marsh from one month to the next was larger over a months after higher inundation extent ($F_{At-1} > 0$ km$^2$). For example, after large 560 km$^2$ inundation in August 1942, the water extent decreased by 100 km$^2$ over the first month. In contrast, an extent of 200 km$^2$ in May 1912 decreased by 50 km$^2$ over the first month, despite a lack of rain in both cases.”

*l. 10*
Included before “Unsurprisingly…”: “Loss of surface water on the Marsh through evaporation and transpiration was reconstructed to be up to 150 km$^2$ (i.e., lowest $\Delta F_A$). The most severe water losses occurred during especially dry April, May and June (i.e. <3.5 mm rainfall; Fig. 4) following very wet summers.”

**10. Page 11920. . ..line 14-20. . ..you said it. . ..”significance of this finding should be treated with some caution”.......yet abstract and intro does not show the caution you recommend......see previous comments on apparent trends and their spurious significance. . ..suggest remove or reword so it is toned down and caveats above are included........there are also issues with using linear regression tests for processes that are inherently non-linear and non-stationary....see refs listed above for further details on this**

*Response*
We agree with the reviewer that this section should be altered to better reflect the limitations in our findings, as per our earlier comment and suggestions for the abstract. We have modified the Abstract and Introduction accordingly (see also our earlier comments).

*p. 11920, l.14*
Replaced: "The increased flood severity and duration over recent decades relative to the previous 80 or so years observed in our flooding record is consistent with the increasing trend in heavier summer rainfall events recorded in the region for the same period (Shi et al., 2008; Taschetto and England, 2009; Gallant and Karoly, 2010; Fierro and Leslie, 2013). A simple linear regression between time and yearly duration of floods (FA > 0 km2) further demonstrates slightly increased inundation length since the beginning of the century (p value = 0.046). However, the significance of this finding should be treated with some caution given the non-independence of the FAmax (especially be- tween two consecutive years) and the limited number of observations included (n = 25 flooding events)."

by: "The near yearly recurrence of severe and prolonged inundations over the 1999-2006 period in our record is unprecedented relative to the previous 80 or so years and consistent with the heavier summer rainfall events observed in the region over the recent decades (e.g. Shi et al., 2008; Taschetto and England, 2009; Gallant and Karoly, 2010; Fierro and Leslie, 2013)."

**11. Page 11920. . ..line 17. . .Fierro and Leslie 2013 ref not in ref list....check all cites and references as there may be others missing also.**

*Response*
p. 11927, l. 11
Included: Fierro, A.O., and Leslie, L.M.: Links between Central West Western Australian Rainfall Variability and Large-Scale Climate Drivers, J. Clim., 26, 2222-2245, 2013.

**12. Page 11920.....line 25-28.....this is good.....and I think this point should be included in the abstract. . .. . ..also suggest including Interdecadal Pacific Oscillation (IPO) and cites to refs listed in comment #5 which discuss its role in driving multidecadal variability of flood and drought risk in Aust. . ...most of this work has focused on eastern Aust but it is still relevant and needs to be investigated for WA.**

*Response*
We have included theses references earlier and very much agree with the reviewer that such work, on both floods and drought risk, is necessary for WA and believe our dataset may be useful for such future investigations, especially when coupled with other proxies (see below).

For the interest of the reviewers, we report our preliminary analyses of periodicity and regime shifts, below (Figs. S1 & S2). We have begun more robust analyses of these components of long-term variability by integrating our "inundation" dataset with newly developed, regional tree-ring based records that encompass longer time-spans (> 200 years), which would better likely help identify decadal and multi-decadal cyclicity and large-scale drivers of hydroclimate change. However, we feel that this analysis is beyond the scope of the current study and we would rather not include these additional figures in the manuscript.

Wavelet analysis of periodicities:

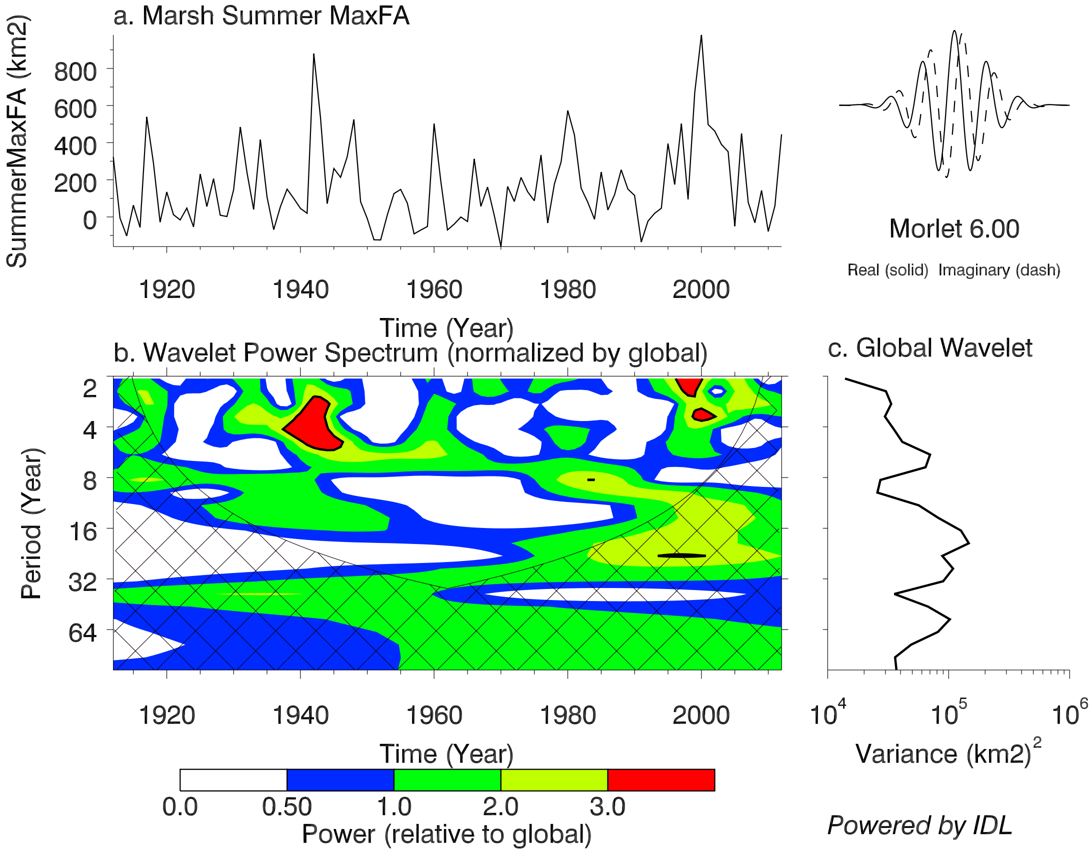


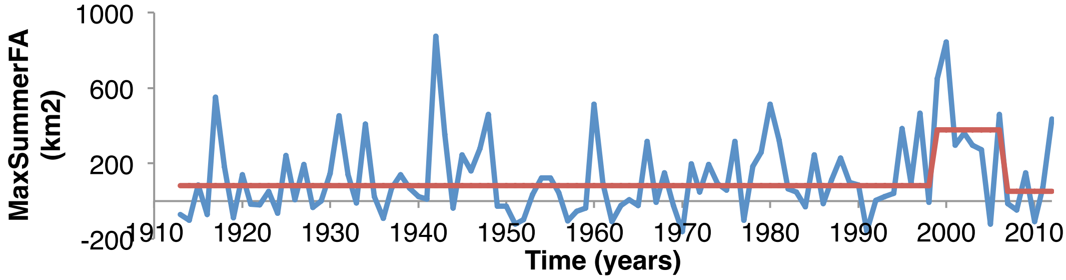

**Fig. S1**: **a)** Fortescue Marsh maximum inundated area in summer (Nov-Apr); **b)** The wavelet power spectrum. The power has been scaled by the global wavelet spectrum (at right). The cross-hatched region is the cone of influence, where zero padding has reduced the variance. Black contour is the 5% significance level, using the global wavelet as the background spectrum; **c)** The global wavelet power spectrum. (source: paos.colorado.edu/research/wavelets/)

Reference:


Torrence, C., and Compo, G.P.: A practical guide to wavelet analysis, Bulletin of the American Meteorological society, 79, 61-78, 1998.

Regime shift analysis:

a.




b.

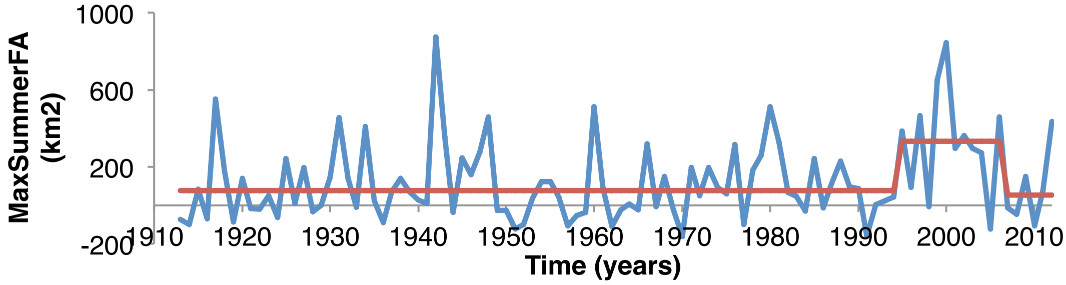



**Fig. S2**: Regime shifts (i.e., point changes in the -weighted mean- red line for **a)** $p<0.05$ and **b)** $<0.1$) were detected based on the mean level of fluctuations shifts using a sequential t-test method that can signal a possibility of a regime shift in real time (Rodionov, 2004; source: www.beringclimate.noaa.gov/regimes/). To account for the presence of serial correlation in our time series, the time series was filtered prior to testing with a first order autoregressive model to estimate red noise using the IP4 (Inverse Proportionality with 4 corrections), which is based on the assumption that the bias is approximately inversely proportional to the size of the sample, as described in Rodionov (2006).

References:


Rodionov, S.N.: A sequential algorithm for testing climate regime shifts, Geophysical Research Letters, 31, L09204 1-4, 2004.

Rodionov, S.N.: Use of prewhitening in climate regime shift detection, Geophysical Research Letters, 33, L12707 1-4, 2006.

**13. Page 11908. . .line 7. . ...severity, intensity, duration. . ..what is difference between severity and intensity? Do you mean frequency, intensity and duration?**

*Response*

We agree with the reviewer that intensity may be used to infer severity in some contexts even though they are quite different attributes of a disturbance e.g. in forest fires where hot fires (more intense) can result in greater consumption of biomass/fuels and thus more tree deaths (more severe effects). Disturbance size and severity are also distinct properties, even though they are often related. Magnitude is often used synonymously in the literature, but severity does NOT equal intensity, even though for physical processes one may be used to infer the other. In lotic systems, for example, intensity may be an appropriate surrogate for severity if measuring severity is too hard but they remain different aspects of a disturbance regime. However, that is not our intention here. For example, a disturbance can be large and severe, or small and severe. Intensity might be measured (if systems were gauged) by flow velocity and bed movement in the surrounding streams. However, additional factors influence severity of the disturbance: aerial extent (whole Marsh, only parts of the Marsh, etc) and timing of the event (relative to prior events). We thus believe that the term severity is correctly applied here.

**14. Fig 1. . ...in legend PLACES NAME should be PLACE NAME. . .. . ..also places indicated in Fig 1c (e.g. Roy Hill, Warrie Outcamp) should also be included on Fig 1b so easier to get bearings etc**

*Response*

Suggestions have been included in Fig. 1.

**Responses to reviews from Referee #2 and suggested manuscript corrections**

**The authors should be commended on developing a record of lake / marsh extent using remote sensing data, especially from an arid region (very underrepresented in the literature) and increasingly under climate and human pressures. This kind of data is therefore extremely valuable for science and management.**

We thank the reviewer for this observation.

**Unfortunately, I do not support a large part of the analyses and some of the interpretations. There is also a poor (and inconsistent) use of terminology throughout the paper. For example, flood regime is in the title and within the paper, yet no clear analysis of catchment flooding is provided (e.g. magnitude and frequency structure), probably since the data is not available. This is not simply semantic, we have to reserve 'extremes' for when we have some understanding of the distribution of catchment hydrological events.**

*Response*

The reviewer is correct in pointing out the need for careful definition in our analysis and for suggesting a refinement in our terminology for greater consistency. These comments are consistent with Reviewer #1, and we refer to our earlier responses. We have made some additional further changes summarised below to improve clarity and consistency. In particular, the paper title has been made. However, we believe that the use of 'extreme' hydrology in the title accurately reflects the highly contrasting hydrological features (characterised by very high magnitude) that we reconstruct over the last century at the Fortescue Marsh, as opposed to 'average conditions' (low magnitude).

*p. 11905*

*Title*

Replaced: "Impacts of a changing climate on a century of extreme flood regime of northwest Australia"

"Impacts of high interannual variability of rainfall on a century of extreme hydrological regime of northwest Australia"

*p. 11908, l. 8*

Replace "(floods and droughts)" by "(floods, inundations and droughts)"

**Moreover, no catchment hydrology information is provided (or available?), only the lake / marsh extent, which is obviously related to, but definitely not the same thing as catchment flooding.**

*Response*

We agree with the reviewer that we have not described catchment hydrology; there are simply insufficient data for this remote area for a full hydrological description sufficient to develop an accurate catchment water balance model. We have thus summarised the catchment hydrological data (or lack thereof) to better explain that the building of a sensible water balance modelling approach for this catchment is not possible because of the lack of gauging data and only fragmented meteorological information.

As noted by the reviewer, we acknowledged in the Introduction that such approaches have been used elsewhere but in generally smaller and well-gauged catchments (e.g. Karim et al. 2012; Trigg et al., 2013). We provide an overview of recent literature in the introduction (p. 11909, l. 14-20; e.g., Bates, 2012; Neal et al., 2012; Wen et al., 2013). In addition, official daily pluviographs (www.bom.gov.au) are sparse in the catchment and not temporally consistent over the last 100 years (described in Appendix B and Table A1, p. 11932), or even for the period covered by satellite imagery (Fig. 1; Table A1). Official sub-daily pluviographs are also mainly available for the northwest coastal area (www.bom.gov.au). In the large (31,000 $km^2$) Upper Fortescue River catchment, however, data is not sufficiently well resolved in time nor space to calculate inflow, retention times, evaporation etc., from the different sub-catchments and their relationship to rainfall, which is also highly heterogeneous.

We did not intend to reconstruct catchment flooding  because of the above ( as it requires temporal data at a much higher resolution than our monthly images dataset), but rather point out that the inundation extent observed at the Fortescue Marsh as an indicator that flooding occurred on the catchment and general moisture availability (p. 11918, l. 14; Haas et al., 2011). We concur with the reviewer's comment that the hydrological regime we describe is that of the Fortescue Marsh wetland, i.e. inundation magnitude, duration, return interval, interannual variability. We have thus suggest modified the text to clarify our interpretations (e.g., intense rainfall resulted in fast and severe inundations at the Marsh, potentially due to one or more large catchment runoff events).

To summarise, the use of a direct water mass balance model based on (limited) gauging data from the catchment is not possible without very high uncertainty. The use of linear modelling linking rainfall with the area of Marsh inundation is a simplified way of comparing to a full water mass balance model but it is not an oversimplification. As the linear model calibration shows ($R^2_{adj}$ = 0.79; p value < 0.001, $E_{RMSP}$ = 56 $km^2$) it is robust in statistical sense. The uncertainty in the model fit provided results from non-linear components of the hydrological regime mentioned by reviewer #2 that cannot be fully integrated in such model.

*p. 11911, l. 10*
Replaced: "The Marsh acts as an internally draining basin for the 31 000 km2 upper Fortescue River catchment (21–23˚ S; 119–121˚ E; Fig. 1). The flood level required for the Marsh to overflow to the Lower Fortescue catchment is not formerly established but digital elevation models (Geosciences Australia, 2011) suggest water could flow if inundations reached > 410 m a.s.l. The upper Fortescue River is the main drainage of the catchment, flowing north to northwest into the wetland system. Flow in the Fortescue River is characterized as "variable, summer-dominated and extremely intermittent" (Kennard et al., 2010), where very large volumes of runoff are

generated following heavy rainfall, which is in contrast with the empty beds of the dry season (WA Department of Water, 2014)."

by: "The Marsh acts as an internally draining basin for the 31 000 $km^2$ Upper Fortescue River catchment (21–23°S; 119–121°E; Fig. 1), which is physiographically separated from the Lower Fortescue River catchment (www.water.wa.gov.au). The upper Fortescue River is the main drainage of the catchment, flowing north to northwest into the wetland system. However, numerous ephemeral creeks on the southern and northern flanks of the Fortescue Valley (Fig. 1) discharge to the marsh directly (www.water.wa.gov.au; Table A1). Flow in the Fortescue River is characterised as "variable, summer-dominated and extremely intermittent" (Kennard et al., 2010), and only very large rainfall events generate continuous flow, which contrasts with the normally dry stream beds of the dry season (WA Department of Water, 2014). Only one official daily stream gauging station is currently operational on the river (>100 km upstream of the Marsh). The other stations were only installed along the main creeks in two of the 13 sub-catchments of the Upper Fortescue River catchment (Fig. 1), and records did not overlap consistently in time (Table A1). Recently, sub-daily gauging stations were installed along Coondiner Creek and sections of Weeli Wolli Creek with pluviographs and used to implement stable isotope water balance models for these sub-catchments over relatively short (i.e., < 6 years) time periods (Dogramaci et al., 2015)."

*p.11935*
Modified Figure 1 to include sub-catchments (provided in separate file).

Replaced: "Geoscience Australia, 2011), and meteorological stations (green circles, see full list in Appendix A, Table A1"

by: "Geoscience Australia, 2011), stream gauging stations (blue circles, see full list in Appendix A, Table A1; WIN, 2014) and meteorological stations (green circles, see full list in Appendix A, Table A2"

*p. 11932*
Added table in Appendix:

Table A1: Temporal coverage of all official stream gauging stations in the Upper Fortescue River catchment and maximum recorded daily discharge

| Site number | Stream Name | Name | Operational date | Last measurement | Max discharge ($m^3$/sec) | Total discharge (GL) |
|---|---|---|---|---|---|---|
| 708001 | Marillana Ck | Flat Rocks | 15/08/1967 | 23/02/1983 | 1327 | 72 |
| 708006 | Fortescue River | Goodiadarrie Crossing | 01/12/1972 | 01/10/1986 | * | * |
| 708008 | Fortescue River | Roy Hill | 01/09/1973 | 29/09/1986 | * | * |
| 708011 | Fortescue River | Newman | 09/01/1980 | Present | 1730 | 78 |
| 708013 | Weeli Wolli Ck | Waterloo Bore | 30/11/1984 | Present | 4137 | 142 |
| 708014 | Weeli Wolli Ck | Tarina | 10/05/1985 | Present | 2100 | 62 |
| 708016 | Weeli Wolli Ck | Weeli Wolli Springs | 08/10/1997 | 14/07/2008 | 423 | 10 |

Note: * Only daily stage height available; location of stations marked on Fig. 1

Table A1 shows all available gauging data for the Upper Fortescue River catchment. The temporal coverage of the different gauging stations is poor (only three of the sub-catchments), inconsistent with one another and the satellite imagery cover. Consequently, these data are insufficient for the building of a sensible water balance model for this catchment.

*p. 11930, l. 24*
Include: “Water INformation (WIN) database - discrete sample data. [21 May 2014]. Department of Water, Water Information section, Perth Western Australia.”

**Of course it is reasonable to suppose that a quick rise in lake extent must be due to a large catchment runoff event, but this response is likely to be highly non-linear (especially concerning the role of antecedent conditions) therefore it is not possible to link lake extent alone to a formal analysis of flooding without more information.**

<u>*Response*</u>
The relationship between change in surface water extent ($\Delta F_A$) and the four instrumental parameters incorporated in our model is perhaps simplified compared to a regular whole catchment hydrological model, however, the discussed response is linear and statistically sound, as can be assessed by the performance of the multiple linear regression model ($R^2_{adj}$ = 0.79; p value < 0.001, $E_{RMSP}$ = 56 $km^2$; p. 11943, Fig. A1; p. 11931, Table. 1). The proposed method, despite simplification, still provides very valuable information about the extent of FM inundations and this is the best what can be done in such remote but important from mining perspective catchment.

**A smaller point relates to the attribution of a changing climate on the hydrology, the variability is so large I’m not sure it would be possible to extract a statistically meaningful trend from this data, and nor have the authors attempted it, so it is unclear why the authors do not instead try to assess the role of extreme climate variability rather than climate change.**

<u>*Response*</u>
We acknowledge the Reviewer about this point and have modified our discussion to focus on climate variability rather than trends (see also our responses to Reviewer #1) (p. 11920, l.18). Nevertheless, in the analysis of surface water on the Marsh, a significant trend (p value = 0.046) was obtained using “a simple linear regression between time and yearly duration of floods (FA > 0 km2)”, which showed a slight increased length of inundations since the beginning of the century. However, as bot Reviewer 1 and 2 have pointed out, we think this approach does not take into account the influence of periodicities and other drivers of interannual variability in the system and thus decided to replace it with the more useful characterisation of ‘wet’ of ‘dry’ periods. We have revised the wording referring to cyclicity and trends throughout (please also refer to changes suggested in response to referee #1, comment #5). The large variability, particularly in precipitation, actually makes the model more robust. Crucially, analysing data with less variability would make

interpreting the relative changes in the flooded area more difficult when taking into account the uncertainty in the data and model.

**My main concern is with the data analysis and the lack of a water balance to at least provide some realism for the extrapolated time series.**

<u>*Response*</u>
Please refer to response in previous comment. A water balance model is simply not appropriate or possible in this system, which is why we have used an alternative approach.

**The construction of the linear regression model is unclear, but it seems the final model has four variables, all of which would seem to be highly correlated with each other (monthly rainfall and number of rainfall days for example), but most importantly given the extreme variability, I have no doubt that the correlation structure between all these variable should shift over time. Given this noise, the parameters derived would have very little robustness, and thus any extrapolation (over 4 times the observation length in this case!) would have substantial errors (though the authors have made no attempt to quantify this), and I suspect therefore little value for prediction. This is of course one reason why multiple linear regression models are rarely used in trying to conceptualise highly non-linear catchment hydrological processes.**
**That being said, lake extent could be tackled using a simple water balance approach very effectively, and one that is much more robust to the variable hydrology, and the authors clearly have much of the requisite data to achieve this.**

<u>*Response*</u>
Standard statistical information for this model and the details of the different parameters are also provided in Table 1 and in Appendix (Table A3; Fig. A1). The validation steps of the model's predictive abilities are described in section "2.4.2 Validation of model and 1912–2012 reconstruction", and error was assessed by RMSE, RMSECV and RMSEP. As suggested by the reviewer, the error we provide (e.g., RMSEP = 56 $km^2$) is likely the results of the non-linear processes such as the influence of evaporation, transpiration and infiltration. These nonlinear components of hydrological cycles adds uncertainty to other ways linear relationship, as statistically confirmed in this study ($R^2_{adj}$ = 0.79; p value < 0.001, $E_{RMSP}$ = 56 $km^2$), between precipitation and extend of inundation of the Fortescue Marsh. In addition, we also accounted for the error associated to the image resolution and estimates in calibrating the model (Section **2.3 Mapping flood history based on the Landsat archive (1988–2012)**; Section **A2 Flood area delineation and error**), and point out that both spatial and temporal distribution of rainfall has an influence on accuracy of estimates (p. 11914, l. 9; p. 11924, l. 5). We also acknowledge that our model likely provides underestimations of the maximum area flooded at the time of large rainfall events (happen earlier in month) due to the limited number of high quality sat images (2-weekly snapshot and cloud cover during these events.) We acknowledge that the correlation structure between variables may change with time, however the Pearson correlation matrix (Appendix Table A3) shows only two of the variables, *R*

(total rainfall) and $R_d$ (number of rain days), are in fact correlated with one another. Typically in a regression model, $R$ and $R_d$ may have been included as one variable, but here were included separately as to account for their potential changing effect in time. In addition, our 25 year-calibration period includes a very high degree of interannual variability that provides more confidence in the model testing. Overall, we do not think changes in these variables would seriously affect the model's predictions ability beyond the uncertainty provided and taking into account the monthly scale of observations and reconstructions.

Despite our model uncertainty and considering that a catchment water balance approach, even if possible, would also result in relatively high uncertainties due to the lack of historical data (see above), we believe our reconstruction provides a useful background of monthly hydrological change (supported by historical evidence) and tool for management. It is certainly the first attempt to do so for the entire northwest of Australia and provides the first extended baseline of natural variability in hydrology for the region.

**A more minor concern relates to the vague catchment description, the authors mention there is an upper and lower catchment (with the Marsh in the upper part), and that the Marsh may overflow, but then end it there! Surely the dynamics of the overflow are fundamental to the marsh hydrology, so why isn't this analysed in further detail or taken into account in any of the further analyses? How can we have confidence in the large time series extrapolation if we don't know anything about how the outflow dynamics of the system operate? This would not be particularly onerous to achieve, but its omission detracts from confidence in the results and interpretation.**

*Response*
We agree with the reviewer that our hydrological description of the catchment was insufficient and have elaborated on our earlier description, including reference to our previous studies (e.g. p. 11911, l. 10; see previous response).

**For these reasons I do not recommend the manuscript be published in its current form, and given the scale of the required changes, a new paper would basically need to be written.**

*Response*
As we understand form Reviewer 2's comments, the main issue identified by the reviewer for endorsing the publication of this paper is that we have not used or validated against a catchment water-balancing modelling approach. However, our approach was used precisely because the catchment that we have worked on, while encapsulating a large and significant proportion of the northwest of Australia, is remote, sparsely populated and with poor records, let alone systematic gauging of the many ephemeral and intermittent streams that feed the Fortescue marsh. We have thus tried to explain this aspect of the study better in our revisions. We have highlighted in our responses several problems specific to our area of study that precluded the use of a water balance approach. We also consider the alternative

used to be valid and well-corroborated and that our interpretations are in line with our study objectives.

**Some more specific comments are provided below:**

**Introduction**
**“Changes in hydroclimatic patterns and extremes that might alter the natural distur- bance regime...” what would be a ‘natural disturbance regime’ in one of the most variable climates on earth, and how would we know if it is altered?**

*Response*
The reviewer is correct that defining "normal" or average is challenging in a system that is known to be highly variable. More information is available in this seminal reference (and >3500 citing articles) and in the more recent review by Mori et al. (2011). We have moderated our introduction accordingly, consistent also with the input of Reviewer #1.

As to how would we know if the regime were to become altered, the reviewer highlights a very important point, where the interpretation relies completely on the temporal window available for comparison and the understanding of the underlying mechanisms. Further, it relates to the setting of targets that may for example be entirely human-defined depending on conservation goals. In the most recent Environmental Protection Authority strategy plan for the Fortescue Marsh Management Area, several of the management objectives aim to “Maintain the natural flow regime of the Marsh”, “Protect [aquatic invertebrate, waterbird and halophytic vegetation] species and their habitat” (EPA, 2013). Taking a definite stance on how to make these important decisions is beyond the scope of this paper, however we hope that our reconstruction may inform decision-makers of the range of hydrological variability (natural variation in the extend of the Fortescue Marsh inundation in the scale of last 100 years) that have been for the last century and some of the hydroclimatic determinants that may most influence functioning of the Marsh to assess the risk and potential impacts of changing hydrological regimes.

Reference:
Environmental Protection Authority: Environmental and water assessments relating to mining and mining-related activities in the Fortescue Marsh management area. Report and Recommendations of the Environmental Protection Authority No 1484., Perth, The Government of Western Australia, 51 pp., 2013.

**“the interannual variability of rainfall is high” is used repetitively in the introduction, once is enough.**

*Response*
We agree with the reviewer and suggest the following changes (in addition to those included in earlier responses):

*p.11909*

*l. 6*

Removed: "As interannual variability of rainfall is high in arid regions, long temporal series are essential to capture the background variability of systems at appropriate temporal scales (Mori, 2011).

**Study site**

**"as the largest freshwater feature" how fresh is this if it is dominated by 'salt tolerant species'? Perhaps there is a short lived pulse of freshwater during initial inundation, but how quickly does this deteriorate?**

*Response*

We collected water from the Fortescue Marsh over the course of three years (2010-2012). The flood-related freshwater become increasingly more brackish with time, and the rate at which this happens depends on the initial volume of freshwater discharged originally. A fine crust of salt is left on the surface over a relatively very limited area as the water evaporates completely; if the vegetation withstood the inundation and soil waterlogging (which recent research has shown *Tecticornia* spp dominant on the Marsh can do for some time through physiological adaptations), it then has to grow in relatively salty soils, hence their salt-tolerance. In general, the surface water on the marsh is fresh to brackish and groundwater is highly saline. The prevailing dry condition of the marsh results in a lack of salt accumulation on the surface. The subsequent inundation events dissolve the limited amount of salt from the surface and wash it down to the groundwater aquifer during the initial pulse of water. We refer to Skrzypek et al. (2013) for more information on the hydrochemical dynamics of the Marsh, which have been previously described. Therefore, the conditions on the marsh are generally fresh to brackish and salt deposition is very limited, but only allow for salt tolerant plants to grow. We have added further details to the manuscript to better characterise the marsh.

**"The marsh acts and an internally draining basin" but just below you say it can overflow into the lower Fortescue catchment, so how is it an internal basin? The authors say the lake can overflow at 410 m asl, but we have no way to compare this to the data in the rest of the paper since no depth scale is ever used, so the corresponding marsh extent would be very useful. This feeds into the larger issue regarding the overflow dynamics mentioned above in the general comments.**

*Response*

We agree with the reviewer that this section is unclear. The official boundary for the Upper Fortescue River catchment suggests that the 'Upper' and 'Lower' Fortescue catchments are physiographically separate systems, isolated by a low range of hills (www.water.wa.gov.au). They might have been hydrologically connected in the geological past, however there is no overflow at present or in the recent past. The two sub-catchments are thus considered hydrologically disconnected unless exceptionally high inundation would occur. The overflow is possible from a geomorphological point of view, i.e., if water reached 410 m a.s.l. However, this water level would require a surface area of 1300 km2 (and a volume of >3000 GL;

Fig. 8), which was not observed in the last century. We have clarified this text (see responses to reviewer #1).

**"the residence time of water in the upper sections of the catchment is short" how do you know, and what do you mean by short? Do you have age data, or tracer studies to determine the transit time distribution? If so then it would seem very important to include.**

*Response*
We have recently published a paper encapsulating some of these data and now refer to Dogramaci et al. (2015) for further information.

*p. 11911, l. 25*
Replaced: "The residence time of water in the upper sections of the catchment is short: surface runoff is high via the steep gradients of creeks and gorges."

by: "Surface runoff is high via the steep gradients of creeks and gorges; recent tracer studies from the Weeli Wolli Creek and Coondiner Creek (Fig. 1) showed that residence time of water in the upper sections of the catchment was short (days to weeks) (Dogramaci et al. 2015)".

**"does not retain water significantly diluted nor flushed by groundwater" if the groundwater is salty then I guess the pool is not really diluted by this inflow**

*Response*
We agree with the reviewer that it is not; however, the shallow aquifer groundwaters in this systems are fresh on alluvial fans and marginal areas of the Fortescue Marsh (see our results published in Skrzypek et al., 2013).

**Mapping flood history**
**"a groundtruthing expedition . . ." and did it match the remote sensing?**

*Response*
See added Figure A1 and please refer to suggestions to Referee #1, comment #8. We agree that we did not explain what groundtruthing was undertaken and have now explained this more fully.

**Model development and selection**
**The use of the dFa metric means a water balance would not at all be difficult, see general comments**

*Response*
There are no gauging stations for all of the Upper Fortescue River sub-catchments (added Table A1) nor has meteorological data been consistently recorded (Table A2) over the 1988-2012 calibration period. Please see the more detailed responses above.

**Results**

**"Because it was not possible to calculate dFa. . ." why not, shouldn't it just be 0? Lines 8-15: this is completely beyond the explanatory capacity of the 'model' and is crazy that the authors try to explain their model extrapolation in this way, please delete. There is no data or water balance to verify any of this**

*Response*

We agree with the reviewer that negative surface area values are not commonly used in mass balance approaches/hydrology. Here, we attempt to conceptually explain the meaning of these data based on our understanding of the Marsh's hydrogeology.

*p. 11916, l. 4*

Replaced: "The enhanced performance of the subset models built without as many "dry" periods highlights an important limitation of the observation dataset. Because it was not possible to calculate deltaFA from the calibration set when the surface water at the Marsh was dry, water loss, i.e., soil water storage depletion, was therefore underestimated during these periods. Concurrently, however, the reconstruction of monthly FA values below 0 km2 reflects the ability of our model to provide quantitative information on soil water storage, or the unsaturated zone of the Marsh where rapid infiltration of rainwater was observed following heavy rainfall at the Marsh (Skrzypek et al., 2013). This zone between water table and ground surface likely acts as a buffer to net surface water gain or loss."

by "A lack of surface water is returned by the model as areas ≤ 0 $km^2$. The negative values (≤ 0 $km^2$) for 'area' can conceptually be explained as the depletion of the groundwater resources and lowering of the water table below ground level."

**Spatial and temporal patterns of inundations**

**To me this is the most interesting part of the paper (and could be done with the remote sensing data alone), however the timing, duration, and magnitude dynamics of the marsh extent change are barely touched on (mostly aggregated statistics of the dataset). Teasing out the dynamics of these changes with different event magnitudes and possible thresholds would be a very interesting addition to this work.**

*Response*

We thank the reviewer for this observation and agree with this comment. We have thus better summarised the key aspects of the inundation dynamics. We have also undertaken a wavelet analysis exploring some of the cyclicity in the data (see responses to reviewer 1). However, while we agree that a more comprehensive analysis of the dynamics and particularly the identification of thresholds is very interesting, this would be better undertaken using a multi-proxy approach (see earlier comments to Reviewer 1).

**Line 23: this makes me ask about any possible impacts of mining (given there is so much in the area) on the marsh hydrology. Has there been persistent mine**

**dewatering, and if so, has some found it's way into the system which, even in a small way, might be a causal factor here?**

*Response*
This is an interesting question and certainly underpins much of the motivation for better understanding the hydrogeology and functioning of the Pilbara region. Dogramaci et al. (2015) recently demonstrated that no direct impact to the volume of surface water discharged to the Marsh could be found from the continuous release of water along the Weeli Wolli Creek line (Fig. 1), where one of the largest iron ore mine operates and which has been discharging dewatering water to the creek for > 6 years, corresponding to the period a major mining expansion in the vicinity of the Fortescue Marsh. Overall, the volumes generated by large rainfall events have been driving inundations at the Marsh and the magnitude of volume delivered during a single event (e.g. Cyclone Heidi in 2012) is similar to the total discharge from mining sites upstream in the catchment over the last 8 years or so. However, this does not mean that the cumulative impacts of mining expansion and dewatering in the region may not ultimately influence the system, particularly at smaller and more localised scales and especially during relatively dry years. For example, mining discharge can increase groundwater levels, particularly in alluvial fans, reducing the saturation zone and therefore the buffering capacity of this zone during future flooding.

Reference:
Environmental Protection Authority: Environmental and water assessments relating to mining and mining-related activities in the Fortescue Marsh management area. Report and Recommendations of the Environmental Protection Authority No 1484., Perth, The Government of Western Australia, 51 pp., 2013.

**Lines 26-28, shouldn't the marsh overflow also be critical to consider here?**

*Response*
Overflow to the Lower Fortescue River is limited by a physiographic barrier (Goodiadarrie Hills) and is unlikely to have occurred in the last 100 years at least. Please see earlier response.

**3.3 significance of predictability and persistence of drought**
**Lines 4-5: this is an arid climate, how would you expect a different result?**

*Response*
We agree we the reviewer that this sounds rather obvious, nevertheless we believe this result was important to highlight, especially because the most recent period (>1999) has been particularly wet (a relative measure in an arid environment) when compared to the longer-term record. Hence, using only the most recent years as 'background', which is often the case in the area because water resources have been monitored only during those year, may be particularly misleading in assessing impacts of change to the regime.

**The use of drought in this section is also problematic, since it seems the authors simply mean low marsh water extent.**

<u>*Response*</u>
There is no doubt that the term 'drought' may be defined as e.g., meteorological (i.e. lack of rain), hydrological or from a 'moisture availability' perspective in the agricultural context, and may be defined as 'below average'. Here, as the reviewer has pointed out, we use 'drought' in a hydrological context as being an absence of surface water. We have made the following changes to the text to clarify our use of drought.

*p. 11921, l. 5*
Replaced: "Our reconstruction shows that the Fortescue Marsh floodplains have more often been dry than wet over the last century (Fig. 3c). Droughts of at least one year were frequent (21 %) between 1912–2012 (Figs. 3c d, and 7)."

by: "Our reconstruction shows that the Fortescue Marsh floodplains have more often been dry (i.e., where no surface water is evident on the Marsh, or $F_A \leq 0$ km$^2$) than wet over the last century (Fig. 3c). Hydrological droughts (i.e., series of consecutive months where $F_A \leq 0$ km$^2$) of at least one year were frequent (21 %) between 1912–2012 (Figs. 3c d, and 7)."

*l. 8*
Removed: "(where no surface water is evident on the Marsh)"

*l. 17*
Replaced: "this documented drought corresponded to largely dry conditions ($F_{Amax} <$ 150 km$^2$)"

by: "this documented drought corresponded to minimal surface water ($F_{Amax} <$ 150 km$^2$)"

**Moreover, I'm not sure how conceptually useful it is to describe arid areas as being in drought or not, since they fundamentally lack surface water for most of the time, otherwise they would not be arid.**

<u>*Response*</u>
We agree that drought is a relative term. According to the PDSI, for example, the Pilbara has been "in drought" for all but two brief periods over the last two hundred years (O'Donnell et al., unpublished data based on tree ring reconstructions). However, both the presence and lack of surface water, particularly in a drought-ridden landscape, are important components of the hydrological regime that contribute to the ecological functioning in different ways and thus we consider it important to characterise both.

**If this is the norm, then a more useful exercise is to analyse the frequency and dynamics of wet punctuations in an otherwise dry (or drought ridden) landscape.**

The reviewer makes a very good point and this observation is consistent also with Reviewer #1. We completely agree that with the reviewer and have thought long and hard about ways to characterise systems were the dynamics and their natural variations may also occur as very long (multi-decadal) cycles.  As described in our earlier responses, we will attempt to do this in a coming analysis by extending the time period and using a multi-proxy approach.  We thus consider this analysis might be better suited in a different article (e.g., Kiem et al., 2003; Kiem et al. 2004; Verdon-Kidd and Kiem, 2010; Ishak et al. 2013).

**Additional changes to the discussion manuscript by the authors**

*p. 11908, l.13*
Replaced: “by the most variable”
by: “by some of the most variable”

*l.20*
Replaced: “…population dynamics…”
by: “…population dynamics across the region…”

*l.22*
Replaced: “…regime play…”
by: “…regime in turn play…”

*l.26*
Removed: “However, while the ecological response to extreme flood or drought has been documented for several arid and semi-arid river basins, characterization of the disturbance regime has focussed primarily on the rivers only, and generally been qualitative and coarsely resolved both temporally and spatially (Kennard et al., 2010; Mori, 2011; Stendera et al., 2012).”

*p. 11909, l. 3*
Replaced: "variability of arid zone remote wetlands (e.g., McCarthy et al., 2003; Bai et al., 2011; Thomas et al., 2011), as well as understanding ecohydrological processes"

by: "variability of arid zone remote wetlands in the arid zone (e.g., McCarthy et al., 2003; Bai et al., 2011; Thomas et al., 2011), as well as and improved understanding of ecohydrological processes at the regional scale particularly"

*l.25*
Replaced: "(Roshier et al., 2001; Viles and Goudie, 2003)"
(Roshier et al., 2001; Mori, 2011; Ishak et al. 2013; Kiem and Verdon-Kidd 2013)

*p. 11925, l. 12*
Added prior to “This research…”: “We thank the two anonymous referees and the Editors for their helpful comments, which have helped focus and improve the quality of the manuscript.”

*p. 11926, l. 15*
Removed: “Berry, G., Reeder, M. J., and Jakob, C.: Physical mechanisms regulating summertime rainfall over northwestern Australia, J. Climate, 24, 3705–3717, 2011”.

*l. 28*
Removed: “Coumou, D. and Rahmstorf, S.: A decade of weather extremes, Nat. Clim. Change, 2, 491–496, 2012.”

*p. 11927, l. 4*
Included: "Dogramaci, S., Firmani, G., Hedley, P., Skrzypek, G., and Grierson, P.F.: Evaluating recharge to an ephemeral dryland stream using a hydraulic model and water, chloride and isotope mass balance, J. Hydrol., 521, 520-532, 2015".

*l. 7*
Removed: "Emanuel, K. A.: Downscaling CMIP5 climate models shows increased tropical cyclone activity over the 21st century, P. Natl. Acad. Sci. USA, 110, 12219–12224, 2013.

*l. 24*
Removed: "Goebbert, K. H. and Leslie, L. M.: Interannual variability of Northwest Australian tropical cyclones, J. Climate, 23, 4538–4555, 2010".

*l. 31*
Removed: "Hassim, M. E. E. and Walsh, K. J. E.: Tropical cyclone trends in the Australian region, Geochem. Geophy. Geosy., 9, 1–17, 2008".

*p. 11928, l. 1*
Included: "Ishak, E.H., Rahman, A., Westra, S., Sharma, A., and Kuczera, G.: Evaluating the non-stationarity of Australian annual maximum flood, J. Hydrol., 494, 134-145, 2013".

*l. 7*
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