Hydrol. Earth Syst. Sci. Discuss., 10, C7148–C7153, 2014
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Hydrology and Earth System Sciences
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Discussions

Interactive comment on "Attribution of detected changes in streamflow using multiple working hypotheses" *by* S. Harrigan et al.

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Received and published: 7 January 2014

We thank Sergiy Vorogushyn for his thorough review and valuable comments. Below is a point-by-point response to the referee comments (indicated by RC).

RC: The presented work provides a systematic evaluation of all possible drivers of hydrological change in a small Irish catchment using a multiple working hypotheses framework. Although not all of the hypotheses are quantitatively analysed and some are ruled out based on soft evidence (e.g. effect of urbanisation and forest cover), the presented approach is a great step forward in attribution of hydrological change. The paper strikingly demonstrates how using a systematic hypothesis testing framework based on establishing the causal link between drivers and responses with hydrological

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models helps to avoid the confirmation bias and to identify the entire spectrum of possible drivers of change. Besides considering multiple hypotheses on potential drivers, the study follows an ensemble approach using three different conceptual hydrological models for isolation of driver effects. Additionally, the parameter uncertainty is taken into account by identifying a set of behavioural parameters in a Monte Carlo analysis. Hence, both model structural and parameter uncertainty is accounted for in the final attribution statement. The manuscript is well-written, concise and logically structured. The authors reach substantial conclusion and comprehensively use the relevant literature. This manuscript is an evidence of change in culture of attribution studies and I strongly support its publication in HESS after satisfactorily addressing the comments below.

RESPONSE: We thank the referee for his very supportive remarks.

RC: With regards to the description of previous studies attempting the hydrological change attribution discussed on P12375, L3-29, a clearer distinction to the framework proposed by Merz et al. (2012) would be appropriate. Most of the previous attribution studies attempted to isolate an effect of a single or two drivers and not to explain the entire change signal. The attribution framework by Merz et al. (2012) provides a general setting and rather looks at the explanation of the entire variability signal due to multiple drivers as a final goal. And this is a gap to fill in hydrological studies in the coming years. In this regard, I support the comment of another anonymous referee that the explanation of the entire change signal presumes the knowledge and data availability about all potential drivers. We cannot guarantee this, particularly the availability of data. However, at least the knowledge of potential causes of change can reasonably be gained in many cases. A short discussion on this point would be appropriate in the introductory part. It is essential that authors consider the possibility of other drivers that are currently unknown (Table 1) and admit this in the discussion (Section 5.2).

RESPONSE: We are grateful for this helpful point. We will more clearly distinguish

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between the Merz et al. (2012) approach and literature cited. We will also include the sources mentioned below in this section, which is more in line with the Merz et al. (2012) framework. Our Table 1 outlines the multiple drivers of change considered, including other unknown drivers (WH 11) which was intended to address exactly the point raised. We will clarify the explanation of this WH and give it greater prominence in the discussion. We will also include a short discussion on the presumption of knowledge on all available drivers in the introduction.

RC: The authors may also find recent article by Hundecha & Merz (2012) suitable for discussion on previous attribution studies. It provides among the first the reliability statements on attribution based on confidence values taking into account natural climate variability. Another study by Frans et al. (2013) claimed the explanation of observed trends in runoff in the Upper Mississippi River Basin with Land Use/Land Cover Changes (LULC) and climate changes, but their work should rather be seen as a model sensitivity study than an attribution of observed trends. It, however, attempts to quantify the relative contribution of LULC changes and climate changes on modelled runoff. By the way, it also identified artificial field drainage to be of significant importance for modelled runoff changes.

RESPONSE: We thank the referee for these suggestions and will include them where appropriate within the revised manuscript.

RC: With regards to the discussion part, I have a problem with the assertion that the dominant driver of change is arterial and field drainage (P12394, L1-2). This seems to be the case for the change point in AMF looking at Figure 9 (top panel). But in case of March flows I am not confident. Looking at Figure 10, reconstructed and observed mean flows before and after the change point seem to differ by a factor of 2. So, one would conclude that the impact of both drivers is similar, wouldn't one? Although, just comparing the medians is poor characteristic for degree of driver contribution. Please, explain your assertion or differentiate the time scales (annual vs. March) and be more precise in the text. The same applies to the statement on P12394, L14 and the statement in conclusions (P12397, L14).

RESPONSE: We agree with the referee that this is an important point and will make this distinction clearer throughout the revised manuscript. The attribution statement for the change in Annual and March flow will be differentiated. The dominant driver for the observed Annual change in streamflow is drainage with no evidence of an important contribution from precipitation, while there is substantial evidence that both drainage and a precipitation change was responsible for the change point in March. This highlights the importance of investigating signals of change across the entire flow regime. The purpose of Fig. 10 was to complement Fig. 9 (bottom panel) and aid interpretation of discrepancies between observed and modelled March flow. It is more of an exploratory/visual aid than a result on which to base definitive conclusions about degree of driver attribution.

RC: Furthermore, I cannot follow, where the number of 20% of increase in annual flows (P12394, L8) comes from? How was it computed? Either explain or delete. Do you mean annual mean flows or sums or volume?

RESPONSE: This sentence will be deleted from the final manuscript. The value was based on the PBIAS results but is somewhat redundant.

RC: The discussion of the effect of drivers is focused on abrupt changes for different indicators/timescales (Section 5.1). In this way the study is related to the results by Kiely (1999). However, the presented work also contains an extensive analysis of gradual changes, which deserve some discussion in Section 5.1 with regards to the role of different drivers.

RESPONSE: we will include more discussion of gradual changes in section 5.1 highlighting that the presence of change points can cause apparent trends and therefore both should be tested. In addition, we present the actual time-series to visually identify the nature of changes. It is clear from the Boyne that the change is abrupt in nature (Fig. 1, 5, 6, 7 and 10). We will strengthen the discussion by highlighting how the nature of change and the methods used for analysis can provide insights about drivers of change.

RC: Kiely (1999) found the changes in NAO index not only for March but also for October which suggest more intensified westerlies. I am curious to which extent this change is visible in discharge and why is it not pronounced for October flows compared to March?

RESPONSE: Kiely (1999) does indeed highlight an NAO signal in October as well as March in Irish precipitation. However, Table 7 in that article shows only a non-significant increasing change point ($p = 0.282$) in 1968 for Boyne discharge at Slane Castle. We confirm this finding in our analysis. Future research is needed to more formally attribute changes in streamflow, not caused by internal disturbances, to specific large-scale atmospheric circulation variables.

RC: I feel uncomfortable with the quantity 'Sum of flows' used in Figures 5, 6 and 7. As far as I understand, the mean daily flows are just summed up here for each year. This quantity does not really have a physical meaning. The y-axis notation 'Flow (m3/s)' is thus misleading. Why not to use mean annual flow in this context? Or if you want to stress that the effect of drivers causes volumetric change you can use flow volume integrated over the year?

RESPONSE: We agree that this can be misleading and will change sum of flows to average flows. In addition we will change the y axis label for all cumulative sum plots in Fig. 5, 6 and 7 to "Cumulative flow (m3/s)" to make the interpretation clearer.

RC: P12375, L29: 'from' instead 'form'

RESPONSE: This will be changed in the revised manuscript.

RC: P12392, L10: Reformulate the sentence: March is not an indicator.

RESPONSE: This sentence will be reformulated so that it is clear that we mean total March precipitation in the revised manuscript.

RC: P12393, L4-5: Which precipitation indicators are meant here? Do you mean P10 and precipitation sums in winter month? Reformulate the sentence. I would not link P10 to Q10 directly if it is somehow meant here. P10 does not necessarily cause Q10.

RESPONSE: This sentence will be reformulated to improve clarity. It is true that P10 and Q10 should not be directly linked. Rather, it is additional evidence in support of our claim that the increase in streamflow was not caused by a change in precipitation.

ADDITIONAL AUTHOR COMMENT: We would like to highlight an additional typo on p. 12396 L19-20, "quantitative" will be changed to "qualitative" in the revised manuscript.

REFERENCES:

Kiely, G.: Climate change in Ireland from precipitation and streamflow observations, Adv. in Water Resour., 23, 141–151, 1999.

Merz, B., Vorogushyn, S., Uhlemann, S., Delgado, J. and Hundecha, Y.: HESS Opinions "More efforts and scientific rigour are needed to attribute trends in flood time series", Hydrol. Earth Syst. Sci., 16, 1379–1387, doi:10.5194/hess-16-1379-2012, 2012.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 12373, 2013.