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Interactive comment on "A regional scale ecological risk framework for environmental flow evaluations" *by* Gordon C. O'Brien et al.

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RESPONSE TO REF COMMENTS MS: HESS-2017-37 (V1) Title: A regional scale ecological risk framework for environmental flow evaluations. Author(s): Gordon C. O'Brien et al. MS No.: hess-2017-37 MS Type: Research article

RC1: (31 MAR 2017): RC1-1 Comment: This paper presents an advance on holistic environmental flow assessments at catchment and broader spatial scales by applying advanced risk assessment procedures and Bayesian Belief Networks (BBNs) to evaluate scenarios of water use for environmental and social purposes. It builds upon earlier work that assessed the ecological and social risks associated with development of water resources in the Lesotho Highlands via the Lesotho Highlands Water Project (Phase I) using a framework known as DRIFT (Downstream Response to Imposed Flow Trans-

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formation). Differences lie in the application of BBNs as the formal procedure to assess risks. The use of BBNs in environmental flow assessment has several precedents, including a framework to incorporate BBNs into the DRIFT framework (Arthington et al. 2007, see additional references below). The description of PROBFLO sets out 10 procedural steps (see flowchart) and works through them for two case studies (Lesotho Highlands and Mara River). For the uninitiated this paper will be a tough read, but for those with deep insight into the history of e-flow assessment and holistic approaches, it will be very rewarding. RC1-1 Response: NA

Specific comments: RC1-2 Comment: There are strong similarities between this paper and O'Brien & Wepener (2012) who provide detailed descriptions of the main steps of PROBFLO minus the use of BBN to assess risks. Reading O'Brien & Wepener (2012) alongside the present paper will greatly assist the reader's comprehension of the 10 procedural steps which I found easier to follow and understand in the 2012 paper. RC1-2 Response: There are published examples of the use of the Regional Scale Risk Assessment approach (Incl. O'Brien & Wepener 2012) which focus on the approach, this paper however focuses on the application of these procedures within an E-flow context. More information can be provided if necessary, but we would like to leave it as is with reference to papers that address aspects of the approach in greater detail such as O'Brien & Wepener 2012. RC1-3 Comment: The PROBFLO paper states (page 9, line 19-) that "Data used in the [Lesotho] case study was derived from a series of biophysical surveys of the study area which sought to illustrate the hypothesised causal relationships from the BN models. Data obtained from the surveys, historical information and specialist elicitations were used to establish CPTs and describe input node rank thresholds. Risk ranking definitions and justifications for indicators and measures of each input node and the CPTs are available in the technical report of the study (LHDA 2016)". My searches failed to locate this report on the LHDA website, and frustrated my desire to see some of the raw data from field surveys, and trace the steps from field data to risk assessment. These steps are described in the Lesotho DRIFT assessment procedure (Arthington et al. 2003; King et al. 2003), for example. RC1-3

Response: The technical report of the study (LHDA 2016) is with the client who has not released it yet. They may only release the information when they have made a final decision pertaining to the scenarios to accept for the operation of the development, and or completed all of the socio-ecological consequence studies that are ongoing. Consider that we would like to publish another paper with the use of the "evidence" obtained in the study to evaluate the risk of altered flows in the study area as a complementary paper to this methodology development paper soon. We would like to publish this paper and a Mara River case study paper in HESS as supporting manuscripts and keep this paper focused on the establishment of PROBFLO as a methodology. RC1-4 Comment: An important feature of the definition of risk regions is that "The approach can address spatial and temporal relationships of variables between risk regions, such as the downstream effect of a source on multiple risk regions, in the context of the assimilative capacity of the ecosystem or the upstream connectivity requirements of a migratory fish between risk regions". Spatial and temporal connectivity are important features of river networks, and somewhat neglected in e-flow assessments, especially the effects of barriers combined with changes in flow regime. Strangely enough, they seem to be evaluated via separate management programs. RC1-4 Response: The question/comment is unclear. The approach is "holistic" and does allow for spatial and temporal dynamics of the ecosystem to be considered and evaluated in a relative manner using the selection of multiple "risk regions". We can demonstrate this better in the MS? RC1-5 Comment: PROBFLO is said to confirm to the requirements of the regional e-flow assessment framework known as ELOHA (Poff et al. 2010). It does not quite do so, in that hydrological and geomorphological classification do not appear to form part of the "risk region" assessment process, but I agree that PROBFLO can be adapted for use within an ELOHA regional context. I was interested to read that the "Nile Basin regional scale E-flow framework expands on the ELOHA framework to include an initial situation assessment, data review and alignment phase and a governance and Resource Quality Objectives setting phase". These developments of ELOHA sound very worthy and a paper describing the expanded framework would be

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most useful. RC1-5 Response: This can be addressed in the paper – consider that a strength of the PROBFLO approach is its transparency that can facilitate additional E-flow assessments on multiple spatial scales that use hydrology and geomorphology as foundational evidence for comparisons/regions upscaling of assessments as required in ELOHA. RC1-6 Comment: A decided advantage of PROBFLO and the development of multiple BNs is its capacity to examine the sensitivity of the input variables to each BN using the "Sensitivity to Findings" tool in Netica (Marcot, 2012). This step can be used to show stakeholders (and water managers) where there are sensitivities in the input data, and thereby provide evidence to motivate for more research and monitoring to strengthen knowledge gaps. RC1-6 Response: Agreed! This can be expanded on if required in the MS. RC1-7 Comment: I noted the comment that "The Senqu River case study addressed the second phase of a water resource use development that already has two substantial flow altering developments with more than 15 years of pre and post-development E-flow assessment (using holistic EFA methods, (Arthington et al., 2003)) monitoring and evaluations." The holistic EFA was, of course, DRIFT in it its early manifestation, and I wonder why it is not referred to directly, and the paper by King et al. (2003) about its conceptual development is not cited here and elsewhere in the paper. RC1-7 Response: We the authors have purposefully attempted not to compare PROBFLO and DRIFT directly and or discuss why PROBFLO was selected instead of DRIFT for the second Phase of this study. We believe these comparisons can be made by 3rd part – objective stakeholders and ensure that PROBFLO "complements" the suite of E-flow assessment methods and does not propose to replace or criticize DRIFT. RC1-8 Comment: Another strong feature of PROBFLO is the sequence through to monitoring and adaptive management of the e-flow assessments and trade-off evaluations, following best practice holistic e-flow assessments. RC1-8 Response: NA. And yes we like this feature too!

Technical corrections RC1-9 Comment: I noted some rough writing in places but no outright technical errors. However I do think that the overall description of the BBN process is inscrutable, and wonder if a worked example (not just a figure) could be

provided for one example of a source-stressor-habitat-biota wellbeing chain. In e-flow science even the relatively simple 'flow-habitat-biota' step can be quantified using well-established methods (e.g. PHABSIM). Was this step achieved using stream cross section data, velocity profiles and fish habitat requirements, etc (see the DRIFT procedure in Arthington et al. 2003) and other developments of DRIFT (King and Brown 2010). RC1-9 Response: Think referee referred to BN = Bayesian Network and demonstration of the generation of evidence for a BN assessment. We can demonstrate this as recommended using a similar process from "cross section data, velocity profiles and fish habitat requirements, etc" as proposed by the referee. RC1-10 Comment: Useful references that appear to be missing from this paper include: Arthington, A.H. (2012). "Environmental Flows: Saving Rivers in the Third Millennium". University of California Press, Berkeley, CA. 406pp. [Academic book on the science and management of e-flows. [This book includes descriptions of DRIFT, ELOHA and other holistic e-flow assessment frameworks]. Arthington AH, Baran E, Brown CA, Dugan P, Halls AS, King JM, Minte-Vera CV, Tharme R, Welcomme RL (2007). Water requirements of floodplain rivers and fisheries: existing decision support tools and pathways for development. Comprehensive Assessment of Water Management in Agriculture Research Report 17. International Water Management Institute: Colombo, Sri Lanka. [This report presents a framework for e-flows assessment incorporating BN models into the DRIFT methodology]. King JM, Brown CA (2010). Integrated basin flow assessments: concepts and method development in Africa and South-east Asia. Freshwater Biology 55: 127–146. King JM, Brown CA, Sabet H (2003). A scenario-based holistic approach to environmental flow assessments for rivers. River Research and Applications 19: 619–640. [This paper describes the original Lesotho Highlands e-flows assessment using DRIFT. Coupled with Arthington et al. 2003, which you do cite, it will show readers how e-flow scenarios were assessed in Lesotho rivers using risk assessment procedures built into DRIFT] RC1-10 Response: We have considered some of these references and can "re-evaluate" them for relevance to the approach, particularly for context in the discussion? RC1-11 Comment: Missing references and

errors Brisbane Declaration (2007) Dudgeon 2014 – missing King, J. and Pienaar, H.: Sustainable use of South Africa's inland waters, 2011 – no publication details. LHDA: Specialist Consultants to Undertake Baseline Studies (Flow, Water Quality and Geomorphology) and Instream Flow Requirement (IFR) Assessment for Phase 2: Instream Flow Requirements for the Senqu River – Final report No 6001/2/e, Lesotho Highlands Development Authority, Maseru., 2016. - please provide the electronic address McDonald et al. 2016 - missing Vörösmarty 2010 – this should be Vörösmarty et al. 2010 in the text. King, J. and Pienaar, H.: Sustainable use of South Africa's inland waters, 2011. RC1-11 Response: We will address these reference errors!

RC2: (06 APR 2017): Overview RC2-1 Comment: The manuscript presents an important development in the field of environmental flow assessments being able to bridge the gap between the biophysical constraints under which e-flows are set, and the requirements to maximise benefit for socio-economic/socio-ecological needs. The spatial discretization in relative risk regions for both aspects in a catchment is novel. This is achieved through the development of the PROBFLO e-flow assessment model which incorporates the relative risk procedures (bio-physical), meanwhile the construction of coupled Bayesian Belief Networks (BBN) allows for participatory scenario planning. As demonstrated through two case studies the authors make a case for the usability and adaptability of the combined PROBFLO-BBN Relative Risk model for a broad range of e-flow applications. The spatial representation of the RR presents an important contribution to modern catchment planning in this regard. RC2-1 Response: NA

Some specific comments: RC2-2 Comment: 1. Field data was used to derive causal probability thresholds for the relative risk calculations, although none of this data is presented. In order to ensure that the proposed methodology is salient and credible, one would expect to see this information. Although given the length of the manuscript this could be compiled in a supplementary document for the published manuscript. RC2-2 Response: See above (RC1-3 and RC1-9), we would prefer to publish the evidence in complementary manuscripts. But can demonstrate the type and use of evidence in

the assessment to address this comment. RC2-3 Comment: 2. It was not clear to me where the driving hydrological data was sourced – modelled or gauged data (sources – where can the reader find that information)? RC2-3 Response: Depending on each case study the hydrological data/statistics is based in gauged data where available and or modelled using established hydrological methods. Data availability and or the use of established hydrological models affects the uncertainty of the assessment. This is discussed in the paper but can be expanded? RC2-4 Comment: 3. There were several examples within the manuscript that point to the utility of the tools for participatory approaches. Seeing that is probably a key selling point of the proposed tools, I would have expected some presentation/further discussion on the stakeholder 'uptake' of the tool – how do we know that the stakeholders: 1. Trust the methodology?; 2. Embed this information into their catchment vision? RC2-4 Response: We have access to a suite of stakeholder/Interested and or Affected Party engagement or vision/objective evaluation/management procedures. This has been presented in the manuscript. In particular our case studies made use of the Resource Quality Objectives determination procedures established as a part of the South African Water Act and widely used throughout Africa. They can somewhat address Sustainable Development Goals. Should we elaborate on this? RC2-5 Comment: 4. Frequent reference was made to Adaptive Management, and the potential for these e-flows tools to be used in a learning-by-doing approach, this implies that the methodology becomes an operational tool, rather than a benchmarking tool. What was not clear from the discussion is how one would use this methodology iteratively to manage adaptively. This should be elucidated in the manuscript. RC2-5 Response: We can elaborate to address this. RC2-6 Comment: 5. The issue of uncertainty and sensitivity was recognised in the manuscript, but no data was presented – it would be beneficial to also include this in a supplementary file. RC2-6 Response: See above (RC1-3 and RC1-9), but we can demonstrate/discuss outcomes associated with these case studies in more detail.

Further comments are included in an annotated version of the manuscript RC2-7 Comment: General language suggestions throughout MS missing words/incomplete

sentences/synonyms etc. (Pg1-L14 , Pg3-L11; Pg3-L20; Pg4-L15; Pg4-L29; Pg4-L30; Pg5-L15; Pg5-L17; Pg6-L31; Pg12-L19; Pg15-L6; Pg15-L11). RC2-7 Response: These will all be changed to meet RC2 requirements. RC2-8 Comment: Pg2-L2 Adaptive management processes applied in the context of catchment management? - this sentence could be re-writtent to be a bit more succinct. RC2-8 Response: Yes we will amend it. RC2-9 Comment: Pg3-L20 for the interest of the reader and advancements in the state of the art for e flows - a comment or two on why LHWP phase II opted for a model other than DRIFT (does Katse and Mohale still use DRIFT for operational purposes?), what are the new advantages of bringing in Probflo? i.e. why not DRIFT. RC2-9 Response: See comment RC1-7. RC2-10 Comment: Pg3-L28 so no e-flows have been developed for the Mara river, ever? if so, this should be stated. RC2-10 Response: No there are some preliminary results but nothing has been accepted/adopted which is why we are working with them now for the reserve to be established and implemented. RC2-11 Comment: Pg4-L4 for the readers clarity: is PROBFLO used to determine the e-flows, or assess the performance of eflow implementation. Perhaps change the terminology here and throughout, where this may lead to some confusion. RC2-11 Response: Yes we will separate discussion of E-flow determination, E-flows them selves and or management of flows to meet E-flow requirements etc. to remove confusion. RC2-12 Comment: Pg4-L17 I think 'socio-ecological end points' needs some elaboration - are these indicators, and if so of what? part of visioning process? RC2-12 Response: Agreed, we will elaborate the PROBFLO approach has been designed to be "holistic" and representative of both social and ecological aspects of ecosystems that being managed. Within PROBFLO we select "ecological" and "social" endpoints that represent the objectives of stakeholders i.e. not just biodiversity or fish/products for human consumption but how much and in what quality to achieve the balance between the use and protection of these socio-ecological systems established by stakeholders. RC2-13 Comment: Pg4-L21 is it a vision if it is part of a treaty? - a vision implies softer goal setting, but water treaties are usually more explicit with targets. The sentence is bit confusing - I think what is meant is that the vision as

developed within this particular study is based on the treaty?? Perhaps the sentence should be rephrased slightly RC2-13 Response: We will elaborate – the vision is informed by the treaty so that it can be established "within a legislative context" and be accepted/adopted by stakeholders (including regulators). RC2-14 Comment: Pg5-L2 Fish what RC2-14 Response: missing text, we will correct – fish selected as indicator for ecological component of system and as indicator for fishery for social endpoints. RC2-15 Comment: Pg5-L2 being what? having biological integrity (biotic/abiotic), or aesthetic value for people, or both. Needs better definition. RC2-15 Response: Ecological endpoints = ecological integrity indicators. See previous comment. RC2-16 Comment: Pg5:L10 query "and" from "Biodiversity and Strategy Action Plan which describes. . ." RC2-16 Response: "and" denotes Biodiversity Plan and Strategy Action Plan are two separate but complementary plans. RC2-17 Comment: Pg5-L28 O'Brien and Wepener 2012 - any citations of this methodology tested? RC2-17 Response: there are some papers that have now been accepted for publication and will appear in 2017. This approach is a part of the PhD of O'Brien which is all being unpacked and published now. We will reference complementary risk assessment papers that reference O'Brien and Wepener. RC2-18 Comment: Pg7-L10 not clear what point 3 is - flow-ecosystem and flow ecosystem service? RC2-18 Response: We will elaborate. To make PROBFLO conform to best E-flow practice which considered requirements of new E-flow frameworks. Assessments should be based on evidence that describes flow – ecosystem relationships. We are highlighting the importance of adding flow - ecosystem service relationship evidence explicitly. This makes the approach more "holistic". RC2-19 Comment: Pg8-L3 citation for requisite simplicity? RC2-19 Response: Agreed, we will provide a suitable citation. RC2-20 Comment: Pg8-L19 check is there calibration/benchmark data presented within this study? RC2-20 Response: We can add some additional validation information from the case studies. Consider in the context of our responses to comments RC1-3, RC1-9 and RC2-2. We would like to publish this information an complementary MS. RC2-21 Comment: Pg9-L19 This data used from field survey to derive the CPT is not presented - it should be

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available to reader (at least in summary form) as a supplementary file, in order to understand the process, as to apply elsewhere. RC2-21 Response: Again consider responses to comments RC1-3, RC1-9 and RC2-2. We would like to publish this information an complementary MS. RC2-22 Comment: Pg9-L23 Netica used in similar settings/studies? - if so shoudl be referenced RC2-22 Response: Yes we have examples and will provide them. RC2-23 Comment: Pg10-L1 what data was used to run scenario 2? Pitman, WR2009/2012 natural hydrology data? _ or was this available from the LHWP studies? RC2-23 Response: Our hydrologist/co-Author R Stassen will elaborate on this in the study to reduce uncertainty. RC2-24 Comment: Pg10-L8 rationale for selecting the different e-flow releases e.g 36% and 25% MAR, was this from the LHWP studies? RC2-24 Response: We can elaborate. Stakeholders requested the team to evaluate the socio-ecological consequences of a range of scenarios based on water availability in the context of operational range for the case study. These scenarios were the resultant determinants of the scenarios they requested testing. RC2-25 Comment: Pg12-L3 how exactly did the stakeholders use the risk profiles to select e-flows - I think the manuscript would warrant some elaboration or narrative data on the uptake of the BN-RR method - in order to demonstrate the applicability of the tools described - furthermore, how one uses this in adaptive management context needs to be developed further in the manuscript. RC2-25 Response: We can provide this, stakeholders were provided with risk profiles that describe (with associated uncertainty) the probable risk to social and ecological endpoints in a relative manner. This enabled stakeholders to consider trade-offs and cost-benefit options, informing the decisions making process of the study. RC2-26 Comment: Pg12-L13 Pg12-L13 BN models in Supplementary files again, this input data may be worthwhile summarised in a supplementary file. RC2-26 Response: Consider RC1-3, RC1-9 and RC2-2. We would like to publish this information an complementary MS. But these files can be included as examples in *.net formats. RC2-27 Comment: Pg12-L19 Repetitive RC2-27 Response: Agreed, this will be corrected. RC2-28 Comment: Pg12-L20 it's not clear to me that there is surplus water compared to demand (i.e. the catchment

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is not closed in terms of its water allocation). The manuscript would benefit with the presentation of summary hydrological data in this respect (the Senqu should also be included). RC2-28 Response: We do not intent to distract from the intention of this MS as a presentation of the PROBFLO approach but this information can be summarized and included for clarity. RC2-29 Comment: Pg12-L22 are you now referring to Figure 10?? RC2-29 Response: Yes, reference to the figure and additional information will be provided in the MS. RC2-30 Comment: Pg12-L27 not clear - what is meant by a 'flow reduction source'? RC2-30 Response: Sources (derived from water users (stressors)) contributing to reduced flows that were identified. Reference can be made to figure 4 for clarity. RC2-31 Comment: Pg13-L19 agreed that the uncertainty/sensitivity analysis is critical for determining the versatility of the BN-RRM-Probflo model. to this end, and in keeping with the manuscripts aim of demonstrating the potential usability of the model, presentation of the uncertainty information and sensitivity analysis is important. Again, this should be placed in a supplementary file. RC2-31 Response: We can elaborate on this in the MS but again would like to keep this MS methods focused and present the results in a complementary MS. RC2-32 Comment: Pg13-L26: I have yet to see what adaptive management means i.e. an explanation with reference for this would be useful (obviously it's a key component to the implementation of e-flows, but needs to be substantiated - i see the Step 8 describes this, but it's important that a greater explanation of adaptive management comes early on in the manuscript). RC2-32 Response: Agreed, this will be addressed/amended in the MS with reference and an example. And see next comment. RC2-33 Comment: Pg14-L30 Communicate outcomes - since this section is perhaps the most critical aspect of a participatory eflow RR assessment as advocated by the authors, it seems a little light on content. I would expect to have a bit more elaboration on the techniques and tools utilised to ensure appropriate buy-in and credibility of the proposed BN-RRM/Probflo tools. What other literature can be drawn on to substantiate this? Was there any stakeholder feedback during the two studies that is documented? RC2-33 Response: Agreed, we can improve on this and elaborate how stakeholders used/interacted with the study

team and intend using the approach in an adaptive management context. RC2-34 Comment: Pg15-L16 OK –this follows my comment in the previous section - the manuscript makes a string conclusion in this regard, but the stakeholder buy-in has not been adequately elucidated. RC2-34 Response: Agreed, we can improve on this section to demonstrate the features of PROBFLO to allow stakeholders to determine "sustainable socio-ecological trade-offs". In essence, with probabilistic risk profiles for multiple social and ecological endpoints that represent the socio-ecological system of interest and alternative use/protection scenarios that are relative, stakeholders can make these "sustainable socio-ecological trade-offs". RC2-35 Comment: Pg15-L21 what is meant by 'wide range of water resources'? do you mean 'wide range of water resources availability settings/contexts'? RC2-35 Response: We will elaborate on this – this approach allows various water resource use/protection scenarios and the management of the resources. RC2-36 Comment: Pg26-L5 can you give the basic BN model set-up for both the Senqu and the Mara studies - this will assist the reader RC2-36 Comment: this "setup" has been presented in the methodology in detail. Does the reviewer wand a better demonstration? I think that the available Bayesian Networks and their respective tutorials/manuals etc. can provide this. We can provide some of this if required.

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/hess-2017-37/hess-2017-37-AC1-supplement.pdf

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