MS No.: hess-2017-37

General comments

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 Transformation). 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.

Specific comments:

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.

The PROBFLO paper states (page 9, line 19-) that "Data used in the [Lesotho] case study was derived from a series of bio-physical 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.

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.

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 most useful.

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. 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.

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.

Technical corrections

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).

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]

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.