THE USE OF COMBINED TOP-DOWN AND BOTTOM-UP CLIMATE CHANGE IMPACT ASSESSMENT IN HYDROLOGICAL SYSTEMS

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Abstract: *Climate change impact assessment in hydrological systems in the past is of a top-down nature. In particular, future climate states are predicted using scenarios and climate models. Although the approach could provide optimal adaptation measures for the intended future, its applications may be increasingly limited as there are large uncertainties. The top-down approach provide too much of the wrong information for policy makers. Bottom-up approaches in climate change impact assessment have also been used in the past as an alternative. The strength of the approach lies in its ability to provide robust adaptation options since the focus is on the vulnerability space, not the prediction of future climate space. Nonetheless, without the information from a top-down approach, the bottom-up approach would lack a basis for selecting the range of climate states to test the vulnerability of the system. The vulnerability exploration would be imprecise and unbounded, and of limited decision-making value. For this reason, a more recent development of a combined top-down and bottom-up approach has been advocated. The combined top-down and bottom-up approach uses top-down information such as climate model outputs while still focuses on the vulnerability space of the system. Through the approach, relevant climate conditions that poses threat to the system could be identified. This paper provides a summary of the top-down and bottom-up approach and introduces more recent development in the combined top-down and bottom-up climate change impact assessment approach.*

Keywords: *climate change, impact assessment, top-down, bottom-up, combined.*

1. Introduction

The interaction between science and policy have been formalized into three categories namely: "science push", "demand pull", and "science push and demand pull" (Dilling and Lemos, 2011; Stokes, 1997). A "science push" mode is characterized by the pursuit of knowledge serving as the driver for scientific discoveries (Stokes, 1997). A "demand pull" mode on the other hand, is where the demand for a solution to a specific problem from stakeholders drives science into production. A combination of the two modes result in a "science push and demand pull", where the research agenda is determined through a process of knowledge exchange between producers and users (Lemos and Morehouse, 2005).

One important component in the modes of science production is who drives the agenda for what is produced. Science products obtained from a "science push" mode may be useful for real life applications, but in many cases can be of limited practical use. This can be represented by a "loading dock" approach where information is simply loaded and may not be picked up by the users (Cash et al., 2006). A "demand pull" mode of science production is more practical since it attempts to solve a real problem. However, in many cases, the demand for information and science to be produced may be highly infeasible for scientists (Weiss, 1978). Therefore, in an ideal state, a co-production scheme and exchange of information between user and producer, i.e.

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"science push and demand pull" mode is desired.

Within the context of climate change impact assessment in hydrological systems, traditionally, a top-down scheme is applied. Scenarios of future climate state is predicted through climate models such as General Circulation Models (GCMs). Hydrological models are then used to predict the response of the hydrological systems based on the predicted future climate to determine the impacts. Finally, adaptation responses are proposed. The approach has been formalized into a seven step procedure by the United Nations Framework Convention on Climate Change (UNFCCC).

However, it has been contested that there exist an imbalance of focus between climate science production and climate change adaptation responses. More scientific effort is being expended on characterizing the uncertainty in climate change projections than on developing adaptation responses to a range of plausible climate outcomes (Wilby and Dessai, 2010). Scientists have been producing too much of the "wrong type of information" for policy makers. (Prudhomme et al., 2010; Brown et al., 2012; McNie, 2007; Dilling and Lemos, 2011). Information provided from a top-down approach is limited and highly impractical for adaptation responses development. The type of climate science information provided by a top-down approach have been characterized by a "science push" mode. Little attention has been paid to the "demand pull" side.

Given the limitation of the previous approach in supporting decision making, more appropriate approaches are required. A bottom-up approach in climate change impact assessment in hydrological systems have been used as an alternative. The approach focuses on the vulnerability of the system and shifts away from predicting future climate conditions. The bottom-up approach, however, is not without its limitations. More recently, a combined top-down and bottom-up approach has been advocated. Such an approach attempts to combine the strength of the top-down and the bottom-up approach while eliminating their limitations. This paper discusses the three approaches in climate change impact assessment in hydrological systems mentioned above. The purpose is to provide a general overview of the different methods and their applicability for future potential users such as policy makers and other relevant stakeholders.

2. The top-down approach

2.1. Overview of top-down approaches

Early impact and adaptation studies of climate change adopted a scenario-based approach under given GCM scenario. Within each scenarios, risks and vulnerability in future climate states are identified and adaptation responses proposed. Although the impact assessments can vary to some degree, earlier impact and adaptation studies of climate change follows a formal step-by-step approach. The approach was presented as a seven-step analytical framework by the first UNFCCC Conference of the Parties in 1995 (Carter and Mäkinen, 2011).

This type of approach is more commonly referred to as a top-down approach to climate impact assessment because it relies on top-down information of global climate projections (Carter and Mäkinen, 2011). The true analysis starts with climate change projections from a single or a range of GCMs. The projections from GCMs are normally coarse in resolution (several hundred kilometres). To make use of these projections, downscaling techniques needs to be applied so that the results could be represented at the similar temporal and spatial scale with the hydrologic projections of climate change to drive water resources systems models (Brown et al., 2012). The depiction of a top-down approach is shown in Figure 1.

2.2. Downscaling in top-down approach

One key component in the top-down climate adaptation studies, as mentioned above, is the GCMs. To date, GCMs are still considered to be the only credible tools available for simulating global climate system response to increasing GHG concentrations (Tofiq and Guven, 2014). However, the coarse spatial scale of GCM meant that to be able to utilize the projections at local

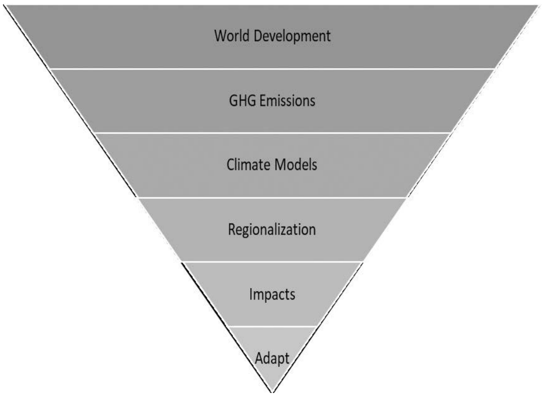


Figure 1. Top-down climate change impact assessment

scale, downscaling is required.

Scientific literature of the past decade consists a large number of studies regarding the development of downscaling methods and the use of hydrological models to assess the potential effects of climate change on a variety of water resource issues. Hydrological models provide a framework to conceptualize and investigate the relationship between climate and water resources (Xu, 1999). The most relevant meteorological variables for hydrological impacts studies are temperature and precipitation (Maraun et al., 2010).

The statistical downscaling approach seeks to establish a statistical relationship between large scale variables such as atmospheric pressures and a local variable such as wind speed at a particular site of interest. A number of studies were conducted by using statistical downscaling and different GCM scenarios to predict the runoff based on precipitation and rainfall-runoff models (Yonggang et al., 2013; Chen et al., 2012; Nam et al., 2011).

Dynamic downscaling relies on driving Regional Climate Models (RCM) using outputs obtained from GCMs. RCM have higher spatial resolution and can represent climate variables at the local scale of interest (Tofiq and Guven, 2014). Examples of researches in the past that used the dynamical downscaling approach includes Vo et al. (2016), Maraun et al. (2010), and Xue et al. (2014).

2.3. The limitation of a top-down approach

One of the major criticism of the traditional approach has been the uncertainties that entails climate prediction, i.e. GCMs and downscaling. Three main sources of uncertainties include scenario development uncertainty, scientific uncertainty, and natural variability. Within each phase of the top-down approach, uncertainties cascade, creating an even larger envelop of uncertainty once adaptation response are proposed (Figure 2).

The first source of uncertainty lies in the future economic development and emissions scenario. Emissions of greenhouse gasses in the future is highly dependent on socio-economic development and demographic change in the future, technology advances, and policies (García, L.E. et al., 2014). Given the limited information at present time, it is not possible to provide an accurate depiction of the future state to these variables.

Scientific uncertainty is another factor within the cascade of uncertainty. This is a result of the imperfect knowledge of the functioning of the climate system and of the affected systems. For instance, one can clearly state that there are uncertainties related to the response of the global mean temperature to a given quantity of GHGs together with the uncertainty in the regional effects of climate change (Stéphane Hallegatte et al., 2012).

Natural variability contributes further to the lists of uncertainties in the top-down approach. The uncertainty arise due to the natural dynamics of the climate system, linked to the chaotic nature of the system that has been observed

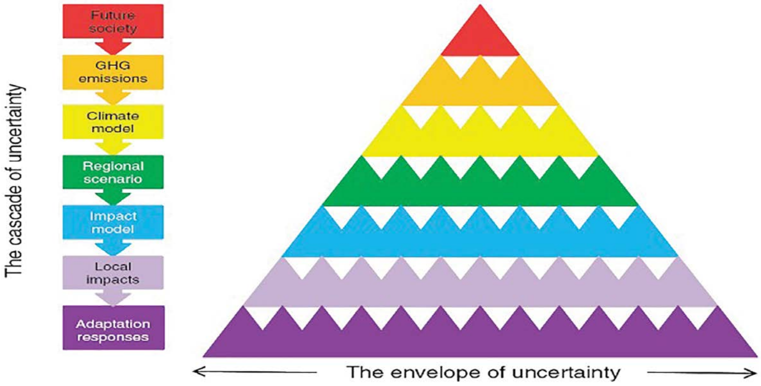


Figure 2. Uncertainties related to a top-down approach (Wilby and Dessai, 2010)

in the past. In that, climate models can estimate statistical nature (averages, variance, likelihood to exceed threshold) but not forecasts, i.e. deterministic prediction of the future (Stéphane Hallegatte et al., 2012).

The top-down climate impact assessment approach provides a useful tool to assist the process of adaptation. However, it fails to deliver the required information that may be useful to decision makers. This is mostly due to the heavy reliance on GCM models. Firstly, by relying heavily on GCMs, the approach only assesses a number of scenarios based on global emissions scenarios including the more up-to-date RCPs (representative concentration pathways) as described by IPCC (2013). This is because downscaling of GCMs is demanding. Secondly, there are large uncertainties in GCMs as described above (García, L.E. et al., 2014). In utilizing GCMs, there is a risk of having a cascade of uncertainty starting with hard-to-predict human behavior to derive emissions scenario, uncertainties in model parameters and structures, natural climate variability, and the underlying science that is being used to develop GCMs. The uncertainty is represented by a range of projected scenarios by different GCMs. Variability in projections from different models can be so large that to plan for one projection will strictly be contradictory to the other. In cases where there is a consensus between a broad range of models and scenarios, the implication is that there exists a consensus between the assumptions in the different range of models (García, L.E. et al., 2014).

Traditional decision making processes work through the prediction of a future state, and the design of plans or projects for the conditions of that state. This approach produces optimal results for the intended future; however, its application may be increasingly limited as there are large uncertainties.

3. Bottom-up Climate Change Assessment

3.1. Overview of bottom-up approaches

Another approach to the study of climate change follows a different path by shifting the focus away from impact assessment to adaptation. This is due to the understandingthat the inertia of climate change will necessitate adaptation measures in the long term (Bhave et al., 2014). An important implication of such a shift includes relying less on GCM models. The shift resulted in the use of a bottom-up approach.

In contrast to top-down approaches, bottom-up climate assessments start with the vulnerability domain (instead of GCMs). A bottom-up approach analyze the important system characteristics, local capacities before testing the sensitivity and robustness of adaptation options against climate projections (García, L.E. et al., 2014). The difference between a top-down and a bottom-up approach could be best understood using the equation describing risk by Plate (2002):

$$R(x)=\int_{0}^{\infty} C(x)f(x)dx$$

where *R(x)* describes risks, *f(x)* is the probability density function of the event (e.g. the occurrence of a future climate state) and C(x) is the consequences of the event. The consequence can be either listed as positive or negative. A negative consequence would be a case where damage to lives and property is done, on the other hand, a positive consequence is where benefit from the event is yielded. The top-down approach to climate change impacts assessments emphasizes estimating f(x), that is, the future distribution of climate or hydrological variables. With a bottom-up approach, the focus is on C(x), i.e. the response of the system to all the possible values of x, , without regard to f(x) (Brown et al., 2011).

The key strength of the bottom-up approach is describing the characteristics and local vulnerabilities of the system. Bottom-up approaches are more relevant than top-down approaches since climate change impacts on hydrological systems are difficult to untangle or correlate with hydrological changes (García, L.E. et al., 2014). Results obtained from such an approach is, hence, more usable to the decision making community. This aspect of the approach provides more relevant tools to bridge the gap between researchers and decision makers in the water sector in particular.

The bottom-up approach allows low-regret adaptation measures as well as promotes robust adaptation for a wide range of uncertainty in future climate projections. In general, a bottom-up approach provides the tools for a "demand pull" mode of scientific production. In that, stakeholders and policy makers could provide researchers the information required for a risk assessment; researchers in turn, uses the expertise to determine the level of vulnerability and risk for a particular area/project and provide feedback information that are useful to decision makers. A visual depiction of a bottom-up approach is shown in Figure 3.

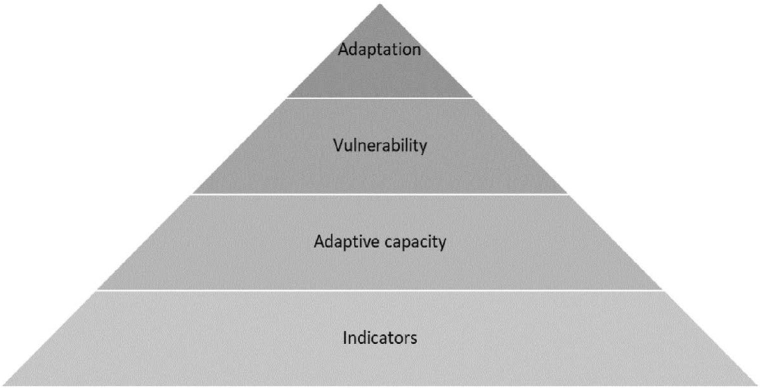


Figure 3. Bottom-up climate change impact assessment

3.2. Robust decision making in bottom-up approach

Bottom-up approaches accepts uncertainty via robust decision processes. A robust decision process implies the selection of a project or plan which meets its intended goals, e.g. increase access to safe water, reduce floods, and upgrade slums, or many others- across a variety of plausible futures. The approach starts by looking into the vulnerabilities of a plan (or set of plans) to a field of possible variables. A set of plausible futures are then identified, incorporating sets of the variables examined, and evaluate the performance of each plan under each future. Finally, plans that are robust to the highly likely or important future scenarios could be identified (Stéphane Hallegatte et al., 2012).

As robust processes imply the acceptance of uncertainty, they also demand a process of dialogues to determine which project vulnerabilities to consider, which performance metrics suggest success, acceptable levels of risk, and which possible scenarios to evaluate. The stakeholder information exchange process is an opportunity to further fortify the project against uncertainty, as a variety of viewpoints and concerns can simultaneously be addressed in distinct scenarios. Incorporation of multiple scenarios builds consensus on the outputs (the project) despite differing inputs.

Methods that have been proposed to cope with deep uncertainty in investment decisions are rich in the literature. Most notably among those are the cost benefit analysis, and real option analysis (Dotsis and Makropoulou, 2005; Stéphane Hallegatte et al., 2012).

The cost-benefit approach (CBA) involves six individual steps namely: 1) identify competing projects; 2) identify sources of uncertainty and future possible states of the world; 3) evaluate the costs and benefits for each project; 4) calculate the present value of costs and benefits; 5) calculate the net present value of different competing projects; and 6) evaluate the robustness of the results (Stéphane Hallegatte et al., 2012). The CBA is highly useful and should encompass the whole set of possible assumptions to check its robustness. In situations with limited uncertainty, CBA can be helpful to identify the best investment options. In a situation of deep uncertainty, CBA could be used as a complement tool to open consultations and discussions (Stéphane Hallegatte et al., 2012).

In a context of increasing knowledge and thus decreasing uncertainty, the decision on an investment project is no longer between investing or not investing but between investing now and investing later with more information. To help making this type of decision, some have proposed to mobilize the real option approach, which was initially developed for financial markets (Dotsis and Makropoulou, 2005; Stéphane Hallegatte et al., 2012). The analysis of real options does not differ from a classical cost-benefit analysis, except that the Net Present Value includes additional consideration, namely the options created and destroyed by the project.

4. Combination of top-down and bottom-up approaches

A bottom-up approach allows robust, and low-regret decision making in the context of climate change adaptation in hydrological systems. However, it still requires top-down information to inform the likelihood of future climate conditions. The scientific understanding of physical climate mechanisms (and specifically, response to changes in radiative forcing) informs the experiments performed used bottom-up techniques. Without these inputs from the physical climate modeling community, the bottom-up approach would lack a basis for selecting the range to test the vulnerability of the system. The vulnerability exploration would be imprecise and unbounded, and of limited decision-making value (García, L.E. et al., 2014).

For this reason, a number of researchers have attempted to use a slightly modified bottom-up approach where scientific information from a top-down approach is also included. The result is a combined top-down and bottom-up approach. While a top-down approach represent a “science push” mode of scientific production, a combined top-down and bottom-up approach attempts to represent a “science push and demand pull” mode of scientific production. The main rationale of the combination is the hope that more reliable and useful information could be produced for climate change adaptation in hydrological systems.

Prudhomme et al. (2010) proposed a scenario-neutral approach in assessing flood risks in two river catchments located in the UK. The study differs from the top-down approach in the way climate change risks (the hazard) is separated from the catchment responsiveness (the vulnerability). The approach proceeds in three steps. Firstly, a reference climatology period for the region of interest was determined. Secondly, the absolute or percentage changes in the equivalent variable are calculated for the GCM grid-box closest to the target site using projections for a specified period in the future. Thirdly, the change suggested by the GCM is simply added to the reference climatology and the resulting time series are used for impacts modeling. Four main information sources are used in the framework: (1) the climate change allowance or safety margin, (2) a mathematical model of the climate response system, (3) an ensemble of climate change projections, and (4) metrics to show the likelihood that the safety margin is robust to the available sample of climate change projections. The conceptual framework is shown in Figure 4.

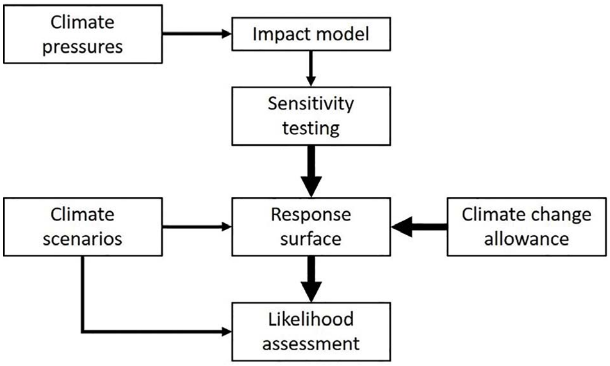


Figure 4. Scenario-neutral conceptual framework (Prudhomme et al., 2010)

Wilby and Dessai (2010) described a process that sifts for robust adaptation, measures that are low regret or reversible. This includes constructing an inventory of adaptation options containing both hard engineering as well as soft solutions. Through screening, adaptation measures that reduce vulnerability in current climate regime could be identified. For shorter life-time projects for a few years or less, the measures could be tested using current climate schemes. However, if the life-time of a project exceeds multiple decades (such as irrigation systems and reservoirs), performance of the adaptation projects would need to be evaluated across a range of scenarios. The use of Regional Climate Downscaling is then utilized for such cases. The full conceptual framework is shown in Figure 5.

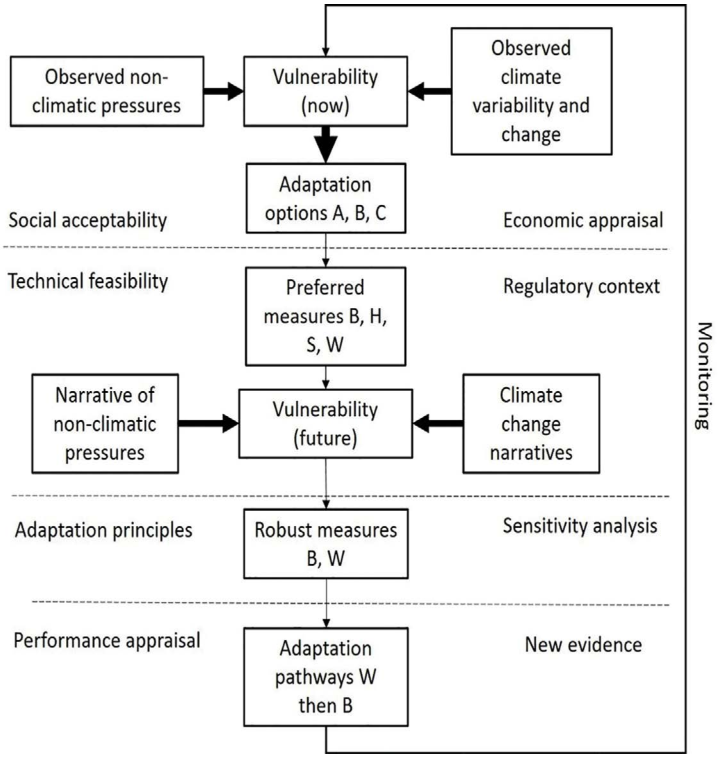


Figure 5. Conceptual framework in Wilby and Dessai (2010)

Bhave et al. (2014) combined the two aspects of bottom-up and top-down climate change adaptation via the use of hydrological models to assess the effect of stakeholder prioritized adaptation options for the Kangsabati River catchment in India. A series of 14 multi-level stakeholder consultations are used to ascertain locally relevant no-regret adaptation options using Multi-Criteria Analysis (MCA) and scenario analysis methods. A validated Water Evaluation and Planning (WEAP) model is then used to project the effect of three options: check dams (CD), increasing forest cover (IFC), and combined CD and IFC, on future (2021-2050) streamflow. High resolution (roughly 25 km) climatic projections from four Regional Climate Models (RCMs) and their ensemble based on the SRES A1B scenario for the mid-21st century period are used to force the WEAP model. The authors then concluded that such an integrated approach is advantageous and could provide relevant adaptation information for local policy makers. The schematic of the approach is depicted in Figure 6.

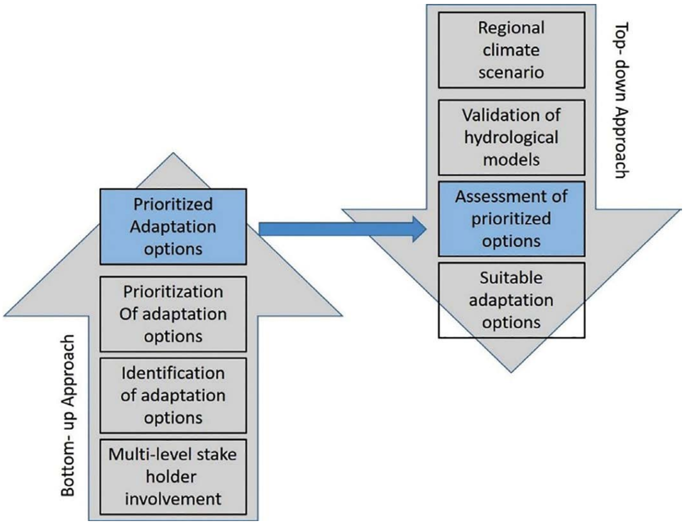
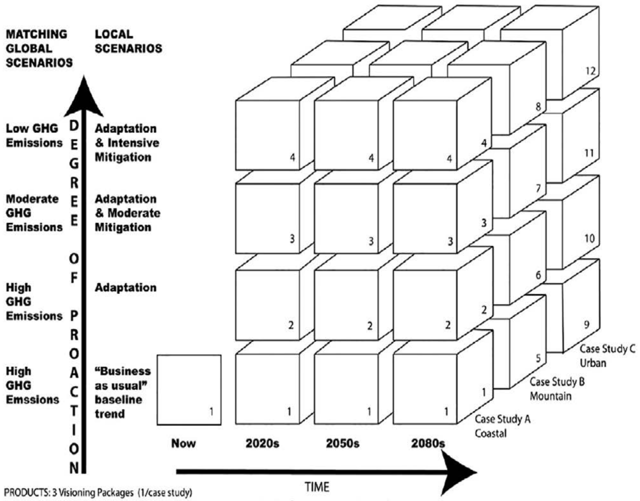


Figure 6. Schematic representing the approach used by Bhave et al.(2014)

Shaw et al. (2009) and Sheppard et al. (2011) adopted a combination of top-down and bottom-up approach through a future visioning process (Figure 7). The studies identified that uncertainties of a top-down approach with heavy reliance on GCM complicate the process of policy making in climate change adaptation. The studies propose a future visioning process, a conceptual framework that generates alternative, coherent, holistic climate change scenarios and visualization at the local scale, in collaboration with local stakeholders and scientists. In essence, a range of future climate scenarios that is deemed relevant through scenario development workshops with stakeholders was chosen so that local impacts could be determined. Local visualization are then determined showing the effects of the climate change scenarios with and without adaptation measures.

Another recent framework that has gained attention is the decision scaling process (Brown et al., 2012; Brown, 2011; Brown et al., 2011). The approach links bottom-up, stochastic vulnerability analysis with top-down use of GCMs. In that, it uses stochastic analysis for risk identification and uses GCM projections for risk estimation, assigning probabilities to hazards, thus linking the two methods. Three different steps would be required. Firstly, the vulnerabilities of the system to changes are evaluated in a large climate space. Secondly, the climate domain is mapped onto the vulnerability domain. Thirdly, the risks to project performance are determined. Adaptation measures are then evaluated to reduce the risks associated with the project (Figure 8).



PRODUCTS: 3 Visioning Packages (1/case study)
Each Package has 4 scenarios (Worldss 1-4) illustrating increasing levels of proactivity on climate change
Each scenario illustrates 3 time-steps, relative to existinq conditions (2006)

Figure 7. Future Visioning Process (Sheppard et al., 2011)

Combined top-down and bottom-up climate change impact assessment in hydrological systems has been extensively advocated and used by the research community. The approach does not provide one silver bullet to solve the issue of uncertainties related to climate change impact assessment in hydrological systems, but provided an alternative to the less capable traditional top-down and bottom-up approach. Given the approach is recent as compared to the top-down approach, there has been no formalized procedural steps established that could work with all problems in general. Different researches have created their own conceptual framework that may or may not be relevant for a particular research as can be seen.

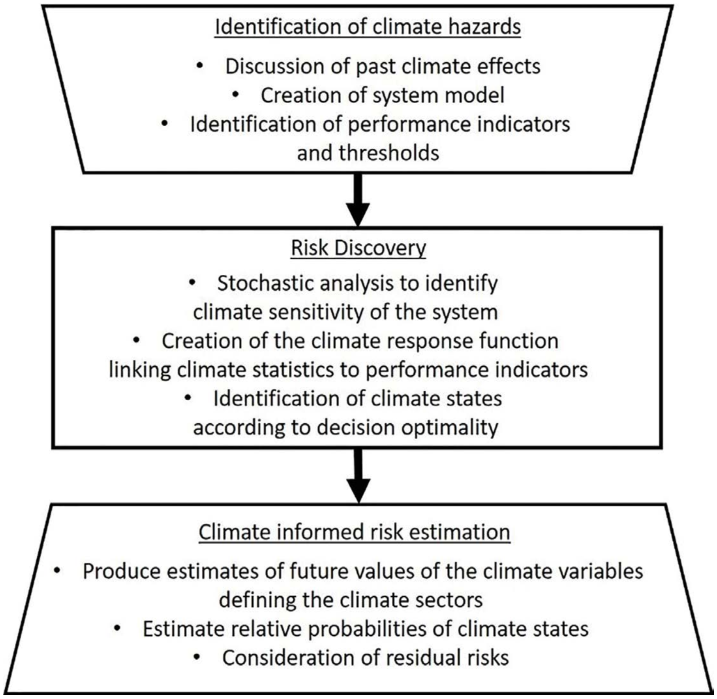


Figure 8. Decision-scaling conceptual framework (Brown et al., 2012)

The implication for future combined top-down and bottom-up climate change impact assessment in hydrological systems is manifolds. Future climate change impact assessment could potentially adopt an entire conceptual framework, or be selective on the components to be included, and even combine the several components within each combined top-down and bottom-up conceptual schemes. For example, one could very well combine a decision scaling process with the future visioning process as described above. A decision scaling framework would allow the assessment of relevant climate conditions while the future visioning process allows the communication of these conditions to both local population and policy makers. This provides an even greater research demand in formalizing the combined top-down and bottom-up approach.

5. Conclusions

Climate change impact assessment in hydrological systems have historically relied on a top-down approach. Although the approach could potentially provide useful information for decision makers for adaptation measures, this has not been the case. This is due to the large uncertainties that entails the top-down approach including scenario development uncertainty, scientific uncertainty, and natural variability uncertainty.

To overcome such uncertainties, a bottom-up approach has been used. For most climate change impact assessment applications in water resources management, bottom-up approaches are more relevant than top-down approaches since climate impacts are difficult to untangle or correlate with hydrological changes. However, bottom-up approaches still require input from top-down approach to provide the basis for selecting the range over which to test the vulnerability of the system. The vulnerability exploration from a bottom-up approach would be imprecise and unbounded, and of limited decision-making value without top-down information.

For this reason, a combination of top-down and bottom-up climate change impact assessment method has been advocated. The aim of such a new approach is to combine the strength of the previous two approach while reducing their limitations. Through such an approach, climate change scenario screening could be performed to filter climate conditions that are potentially problematic and requires adaptation measures. Information provided from the approach could then be used by decision makers so that robust adaptation policies could be proposed.

Given that there is no formalized procedures for a combined top-down and bottom-up approach, researchers have normally created their own version of the process. This have created a large number of different conceptual frameworks. The selection of the appropriate framework is up to the researcher based on the research demand and objectives. However, one could also be selective on the choice of the framework and their components, and even combine different components within each framework.

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