White Paper 1: Caveat Adaptor

FAQs: The Best Use of Climate Model Simulations for Climate Adaptation & Freshwater Management

General Circulation Models (GCMs), also known as climate models[1]*, have emerged as a widespread tool for projecting future states of the climate and water resource systems and to guide adaptation strategies. However, climate models were not designed for adaptation purposes. There is a growing recognition that climate models have serious gaps for supporting robust water resources management decisions. As a result, climate model–based projections may have difficulty providing the information water managers or decision makers require for risk analysis* [2]*, which is central to climate adaptation and water resources management. This briefing statement describes some of the limitations of climate model projections for resilient water management* [3]*. Alternative approaches are emerging, however, for developing robust adaptation strategies.*

Were global circulation models (GCMs or climate models) designed for climate adaptation purposes?
No. GCMs were designed to evaluate global policies concerning some greenhouse gases,[2] *and they serve as scientific hypotheses about how regional and global climate components function and how the global climate system may respond to external forcing, particularly as a result of historic and future greenhouse gas emissions.* While projections of climate change may indicate a range of possible challenges for water systems, they can only partially inform decisions about climate adaptation. Climate models may be particularly useful for assessments of vulnerability at the national and regional scale and for the estimates of broad changes in climatic parameters.[4] Regional Circulation Models (RCMs) are narrower in focus and are believed to capture some dynamics better, though this has recently been questioned as well [5].

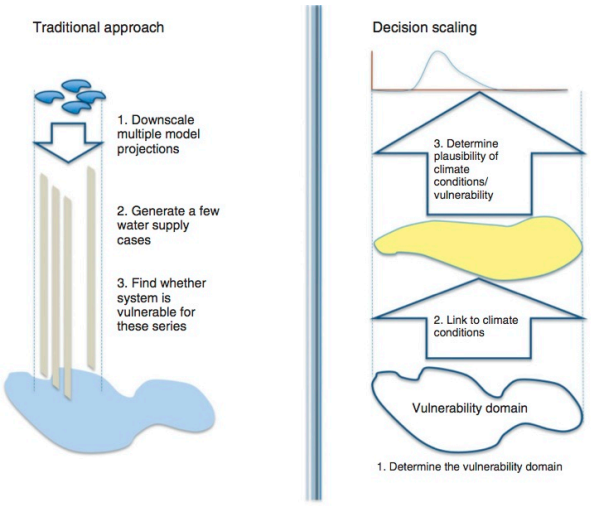

Figure 1. Contrasting top-down and bottom-up (decision scaling) risk assessments [6].

How do bottom-up and top-down approaches to risk assessment differ?
*Heavy reliance on GCM outputs for describing local and regional climate impacts is considered a top-down approach. Bottom-up approaches take important system characteristics and local capacities into account before the sensitivity and robustness of possible adaptation options are tested against climate projections such as GCM outputs (**Fig 1**).* Bottom-up methodologies such as "decision scaling" may be more appropriate for assessing the vulnerabilities of water resources, the design and operation of long-lived infrastructure, some economic issues, and local- to regional-scale ecosystem and livelihood questions. Bottom-up approaches account for particular intrinsic system characteristics such as exposure, sensitivity, and adaptive capacity as important elements for describing risk[7]. In contrast, top-down approaches use GCM downscaling to "predict, then act" in response to a narrow range of climate variables. [6]. For some applications, bottom-up approaches are more relevant since climate impacts are difficult to untangle or attribute to reactions for some applications [8,9]. Rather than choosing one approach over another, both approaches can potentially provide complementary information [10]. The selection of an approach — alone or in combination — should be guided by the level of specificity and confidence

[1] Climate model: "A numerical representation of the climate system that is based on the physical, chemical, and biological properties of its components, their interactions, and feedback processes, and that accounts for all or some of its known properties"[1].
[2] Some sources are not accounted for, such as black carbon (soot) and methane from the thawing of permafrost, especially in Asia and North America.

necessary: local scales, operations decisions, and the maintenance or stress testing of water infrastructure have different governance and decision making needs compared to national or global priority setting exercises to allocate limited capacity or funds [11,12].

What do GCMs show accurately? What do they not show?

GCMs can with reasonable accuracy simulate changes in observed air temperature, ocean heat content, and some features of interannual variability such as the El Niño Southern Oscillation (ENSO). Changes in the water cycle, particularly precipitation, are not well simulated. Such elements include precipitation quantity, seasonality, shifts in extreme events (such as the frequency or severity of droughts and floods or tropical cyclones), the form of precipitation (e.g., rain vs snow), and evapotranspiration (which contributes to plant respiration). Temporal resolution of climate model data is generally limited to seasonal or monthly projections. Moreover, these outputs are often applied within other types of models, such as runoff or flow models, which amplifies these uncertainties (see **Fig. 2**). Another potential gap is the ability of climate models to describe substantially new aspects of climate processes, such as abrupt changes or new patterns in snowpack or monsoon precipitation. As a result, evaluating GCM projections is difficult, particularly for applications that require significant precision and accuracy. Systematic evaluations of their use suggest that they low potential for informing quantitative decision making and are better at setting the context rather than informing investment decisions [4]. Most water management decisions historically have assumed that future conditions could be determined with a relatively high level of precision and accuracy, prompting a significant crisis in the water community in recent years.

If several climate model projections are in agreement for a particular region, does that mean their projections are useful for vulnerability assessment and adaptation planning?

Even when climate models show "consensus" in a region, the level of confidence in these projections should be guided by application. Climate models are simplifications of the climate system and represent some of our best hypotheses of how that system functions. That does not mean that this knowledge is comprehensive or accurate, even when many climate models converge in the projections. The global climate system is complex, and the paleoclimate record suggests that many impacts — the movement of major ocean currents, interactions between global climate engines such as the Indian Dipole and ENSO, the rate and scope of climate trends — are difficult to understand even in retrospect. Moreover, most climate models share many assumptions and may have similar gaps and strengths. A consensus across a suite of models, therefore, may simply reflect a convergence in these assumptions rather than a convergence in a set of independent hypotheses.

Does the use of climate models in combination with other sets of knowledge reduce or increase uncertainty in future projections?

Uncertainty about the future is not a new problem. However, our new awareness of climate change, particularly its speed and scope, undermines many decision-making approaches once assumed to be robust and effective for many types of uncertainty. The primary reason for this weakness is that past climate records are now understood to be an incomplete and insufficient predictor of the future when the climate is shifting rapidly, a condition sometimes referred to as "non-stationarity" [13]. The so-called "cascade of uncertainty" (**Fig. 2**) shows that climate models are one of many sources of uncertainty that challenge the development of adaptation interventions. In recent years, many adaptation methodologies have attempted to minimize the contribution of GCMs to this cascade by the selective use of particular climate models and/or scenarios, masking the full range of variation. In some cases, users have also hidden this

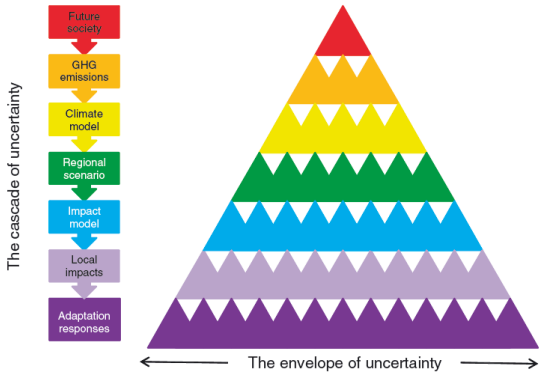

Figure 2. The cascade of uncertainty [11].

uncertainty by nesting climate model output within other model approaches, such as hydrological, urban planning, or species climate-envelope models. The temptation for the selective but unscientific reduction of uncertainty is strong, given that using the full range of climate model and scenario outputs can produce a bewildering array of projections. Rather than the selective use of climate model data, a more credible approach is to use this data in parallel with full-spectrum reporting of the range of variation combined with other types of data sources, such as paleoclimate data and historic records. In most cases, this also means planning for multiple futures and using more process-oriented decision making processes[2].

In many cases, such an approach prompts frustration by endusers accustomed to highly quantitative, high-certainty decision-making processes. The new types of uncertainty associated with climate change, particularly in regard to the water cycle, necessitate a more process-based approach, using qualitative or semi-quantitative approaches, and a step-wise and gradual design and operations methodology. Particularly for high precision / high accuracy applications such as infrastructure design, we may no longer be able to afford making rigid, inflexible decisions about water management.

Will new assessments of knowledge on climate change, such as the IPCC AR5 report be more appropriate for climate adaptation than AR4?

Some recent developments in climate modeling help to improve our understanding of future climate change, as well as the use of simulation information in adaptation-related decision-making, but serious gaps will continue to remain for a long time. Increasing attention is being paid to model evaluation and performance in the IPCC's AR5, but this report will not be finalized until 2014. A new generation of scenarios now being deployed in climate model simulations (the RCP scenarios) explicitly take into account emission mitigation policies, which the previous SRES scenarios did not. More attention is also being paid to short term (10-30 years) as well as seasonal and decadal predictions, which are much more of immediate relevance to adaptation decision makers than the end-of-the-century projections that have been widely applied over the past decade, which have provided limited insight and high levels of uncertainty into how complex climate and water processes will evolve.

Are new approaches for decision-making under high uncertainty emerging?

Detecting the current and future influence of climate change relative to other factors is difficult, particularly when social or institutional needs demand that decisions be made before collecting comprehensive sources of information. For example, scientists showed that existing data sources are too small for detecting shifts in extreme discharges for the Rhine river [14], which has a relatively long observational record compared to most systems in the developing world.

For endusers with extensive financial, computational, and technical resources, robust decision making may be a useful strategy. However, this approach is inappropriate for many issues. A less technically and financially demanding bottom-up approach is to define a problem using the adaptation "tipping point" concept [15], which attempts to determine how much climate change can be coped with before the system or policy action performs unacceptably, which defines options limiting future actions. Unwanted path-dependencies can be mapped out with an "adaptation pathways" methodology [16,17], which can define actions that should be taken now to keep options open against reasonable costs in a process-based approach. Other approaches include decision scaling, safety margins, and "real options."

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