What are the key issues that need to be considered when planning “climate change resilient” water systems?

The study of “climate change resilient” water systems incorporates the discipline of hydrological modelling with the study of socio-economic adaptation. These two disciplines interact in different ways in different hydrological basins in space and in response to different climatic conditions projected by various meteorological climate models. In this essay, I shall explore how hydrological processes are set to change with climate change in different parts of the world, examining the key issues that water companies, scientists, engineers and planners should consider. I shall also examine adaptation principles related to climate change and examine key socio-economic issues related to planning resilient water systems.

The basic water balance equation is: Q = P – E + ΔS where Q = runoff, P = precipitation, E = evaporation and S = storage. If the values of P and E are known, then ΔS can be estimated by knowing Q or vice versa. Thus, the goal of modelling is to measure these values and simulate complex interactions between them, to estimate not only how the values change, but how the rate of processes affecting S, E and Q change over time with changes in P. We are interested in other climatic variables such as temperature, which may decrease soil moisture and increase evaporation, affecting both E and Q in the above equation. In particular, water systems tend to modify the natural water balance equation via the extraction of water (decreasing S) and increasing S through building dams. Humans introduce a flux, and focussing on this flux is important for managing future water systems.

The first issue relates to uncertainty in climate prediction. In Figure 1, percentage change in predicted annual runoff varies across different climate models. Each climate model uses different parameterisations, feedbacks and physics. The level of change across models in the Amazon ranges between -30% and >30% and shows that uncertainty in the sign of precipitation as well as a 60% range. Convection is difficult to model. Furthermore, studies have shown uncertainty in climate models to be substantially greater than uncertainties in hydrological models (Kundzewicz et al, 2007). A perturbed physics ensemble is a methodology that uses different physics parameters across multiple models, forced with different initial conditions and climates. This methodology was used to produce probabilistic predictions of simulated precipitation and temperature change which was applied to daily flow regimes in the River Thames (New et al, 2007). The results indicated a much larger spread of results than a single scenario-based model. The standard HadCM3 model produced a rather high estimate of future water resource availability when compared with other parameter combinations. Each black curve in Figure 2 displays a frequency histogram obtained by the perturbed physics ensemble, and the green curves are the response of each CATCHMOD (hydrological model) version combined with all results from the ensemble. The greater frequency range of the black curve is indicative of the greater uncertainty, but hydrological model uncertainty is about 23% of the total range of frequencies. These two uncertainties are two key issues related to the estimation of the input, or supply-side, of the flux.

Uncertainty in hydrological models can be divided into a separate list of issues that each interact differently within the hydrological system. These are: surface waters, groundwater, floods and droughts, water quality and soil erosion (Kundzewicz et al, 2007). A very robust finding due to climate change is that warming leads to changes in the seasonality of river flows where much winter precipitation currently falls as snow, as projections in the Alps and Himalayas have shown (Kundzewicz et al, 2007). In the Himalayas for example, a projected warming in the 2050s under the A1 scenario will result in increased levels of evaporation, which moistens the atmosphere, increasing already increased levels of rainfall, and then runoff. Thus the key issue for water system planners is how to adapt rivers to a different hydrological regime than before, e.g. increased summer runoff by 50-120% in the Ganges (Fung et al, 2011). Furthermore, surface runoff is affected by plant growth. An increased level of CO2 reduces the level of stomatal opening resulting in decreased evaporation. It also increases the rate of plant growth leading to increased evapotranspiration. These both affect surface runoff, the former in the positive and the latter in the negative. Generally, a dynamic global climate model predicts a 5% increase of global runoff due to these effects (Kundzewicz et al, 2007).

The second major robust result to be extracted from hydrological modelling is that higher precipitation extremes are likely to occur in warmer climates. Higher precipitation intensity in the subtropics is likely to cause flooding events at a greater magnitude and frequency than before (e.g. in some areas, 100 year periodic floods become 2-5 year periodic floods – Kundzewicz et al, 2007) as well as prolonged periods of drought in summer. These impacts thus feed back into the water balance equation and alter all aspects of P, E, S and Q. But there are issues for planners designing reservoirs. Typically, a known soil type produces a known low flow, and so maximum deficit values are estimated – in the UK, a water deficit is expected in summer. This produces a Rippl curve (Jones, 1997), which allows planners to design reservoir capacity and predict water levels based on this flow, and plan to maintain levels for two or more successive dry years. In Africa, critical threshold limits between areas of high, intermediate and low precipitation are responsible for large reductions in perennial drainage in the intermediate case, and a sudden drop from 0% loss to 25% loss in areas currently receiving 1100mm annual rainfall as a result of a 10% decrease in rainfall (Maarten et al, 2006). Thus, a greater proportion of rivers will dry out.

The water system model is heavily impacted by changing land use, which itself is a product of climate change and socioeconomic change. Land use change is also a factor impacting climate change – the two feed back on each other. Population growth leads to greater water stress, defined as the product of current demand due to domestic (D), agricultural (A) and industrial (I) use, divided by discharge (Q). This value should be maintained below 0.4 at current levels (Vörösmarty et al, 2000). The global values of DIA/Q for two scenarios, climate change and population growth, and population growth, are very different. In the former, increased levels of precipitation due to climate change result in a DIA/Q value of <0.8 (i.e. not severely water stressed) in the mid-latitudes (China, North America and Russia), but values in these areas, and the entire world, as a result of ‘population change only’ result in DIA/Q values >1.2 (i.e. severely water stressed). Indeed, in Asia, the effect of population change only is predicted to increase DIA/Q by 58% (Vörösmarty et al, 2000). Therefore, the key issue is that population growth will severely impact all hydrological systems, which highlights the importance of socio-economic adaptation. In the water balance equation, the value of S will decrease significantly through increased water demand. A secondary finding is that agricultural land accounts for 60% of the vulnerability, increasing the importance of distinguishing between different C3/C4 plants.

Institutional adaptation in the majority of less developed countries presents a major issue for policymakers. There is a direct link between poverty and difficult, i.e. flood-prone or drought-prone, hydrology. As climate change is set to worsen most hydrological basins, the need for international institutional change, infrastructure development, and sustainable change, the so-called “S” curve of development (Grey and Sadoff, 2007 – see also Figure 3). This can be enhanced by local indigenous knowledge and consultation. Not all countries will benefit from this growth curve, but those that do increase the rate at which water security is achieved.

In conclusion, the main issues for water planners are: uncertainties in climate and hydrological models, over-reliance on single models, the interaction of hydrological model components with climate change (reservoirs in particular), climatic variability, flooding and drought, population growth and land use change, and socio-economic adaptation. All these interact in a very complex fashion, and I have highly simplified many of the processes occurring within hydrology.

Grade:52%

**introduction,**

Very strong introduction. Demonstrated a clear understanding of the problem, its frustrating to see that the rest of the essay focussed so much on modelling aspects.

**overall structure of essay**

Fairly well structured and easy to read, some minor errors in sentence structure.

About 2/3 of the essay spent on modelling aspects

 **key issues covered**

Too much time spent on modelling aspects: water management was presented as a series of absolute targets imposed on a static linier function, this over-simplified the response.

Little discussion of robust decision making and the meaning of resilience in water resource systems

Brief and limited discussion of social, political, economic aspects: both in terms of impacts and adaptation

Limited discussion of importance of spatial and temporal scale

**depth/quality for those issues actually covered**

Good detailed discussion of model outcomes and quantitative aspects.

clarity of presentation and argument,

**conclusion.**

Conclusion was a list of concepts without much attempt at analysis and argument.