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Editorial

Sustainable Water Policy Must Deal with Risk and Uncertainty

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1. Introduction

As a starting point for this *Special Issue* we were reminded of an important quote from Prof Richard Howitt, which underpins a fundamental problem for designing applied water policy:

> "*...theoretical models and empirical analysis usually bog down when faced with the three scourges of quantitative institutional analysis: nonconvexity, irreversibility, and uncertainty*" (Howitt 1995, p. 1192).

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These three issues continue to jeopardize our ability to sustainably access, supply and utilize water resources from the individual to global scales. Firstly, elementary economics relies on assumptions of convex supply and demand functions, sometimes using these to establish the parameters for sustainable water management. In reality, water resources characterize nonconvex functions providing multiple optimal solutions clouding our understanding of how consumers and producers respond to the supply of and demand for water resources. Nonconvex problems spell trouble for market-based policies and, as such, practical options for sustainable water management. This is because an inconsistent water supply reduces the effectiveness of markets, while the demand and use of the resource create negative externalities that generate new nonconvexity. Advances in nonlinear programming (NLP) and genetic/evolutionary algorithms have been insightful but these solutions generally have not coupled allocation changes to user behavioral responses to tease out nonconvexity issues.

Second, irreversibility poses the fundamental challenge of trade-offs and consequences from actions. Irreversibility is defined as trade-offs caused by technical transformation (e.g. loss of pristine natural area to dam development) where the cost of reversing that transformation is prohibitive. This is known as technically irreversible development. Irreversibility can also occur when: (i) there is a complete failure by water users to incorporate risk into decision-making, (ii) there is a recognized but inaccurate perception of the true risk of water supply/demand; and (iii) a water user's risk-taking attitude leads to a situation where the capital invested is irretrievably lost (e.g. failure to have sufficient water supply results in the death of perennial rootstock).

Finally, uncertainty in the most extreme form (i.e. Knightian) is concerned with concepts or events we are completely unaware of — and, as such, unprepared for — which will drive both significant nonconvexity and irreversibility outcomes. However, in the case of water, we know the resource exists so uncertainty is generally limited to an incomplete picture of its supply going forward (i.e. drought or flood), water users' demand, and any adaptation to that realized supply. In other words, uncertainty in water is about understanding the risk of supply and either the economic consequences from failing to predict supply/demand, or how to optimally allocate water resources over time to prevent an irreversible outcome. This all threatens sustainable water management.

If you know our work, you'll know we have been thinking about water and these concepts raised by Howitt for a long time. In our works, we've commonly had conversations either following presentations or the publication of a paper where a common assessment has been that people haven't thought about risk to water resources as we explained it. This is satisfying because it is nice to have a research agenda that seems original even if we are just the latest in a long line of people trying to focus attention where it is needed. This is also deeply alarming where evidence around us suggests the risks to water are growing, we are running out of time, and the price to pay will be significant for many of us. Hence, we envisaged this *Special Issue* as a means to place emphasis again on risks to sustainable water resources, and identifying what work was being done by others.

The result was a little disheartening, but maybe not too surprising, to say the least.

Over the development of the *Special Issue* two factors became evident. First, while risk and uncertainty are undoubtedly fundamental to understanding and managing water, we are either very comfortable with the tools we have, and/or attempting to deal with a lack of certainty is no longer deemed as important to manage. The second is that when we attempt to work between disciplines the focus on risk is very different — principally from a supply and demand point of view. While the economics literature has in some limited circles moved into exploring decision-making as per adaptation at the demand level, other professions such as engineering have remained focused purely on the concepts on managing risk with supply measures. We will return to this later. There *is* good work being done, and water resource management continues to attract intelligent people with good minds focused on our next steps. Mostly that work has been on making our limited water resources — so essential for all of us and our survival — sustainable into the future, hence, our interest on sustainability as a part of the focus for this *Special Issue*. However, despite our hopes, there was less focus on risk as a motive for submissions. This is a major oversight, as we cannot sustainably manage a resource that is likely to be fundamentally different from what we have known before. That is, the past is never a very good predictor of the future. This is the base concept of risk; it is not an outcome for which we have no reference or experience (e.g. uncertainty as per Knight), but rather events that we can attribute probabilities to as a means of testing human, infrastructure or institutional responses into the future (e.g. climate change impacts). This is usually the focus of our work where we attempt to consider, represent, model and learn from water resource risks — and where systems might break. It was also what we hoped others out there would be exploring. But risk research as we view it, despite excellent starting points, is lacking in the economics space.

Reasons for the lack of research in this area may be obvious. Many see risk as complex and difficult to parameterize thus turning to simple concepts, representations and modelling. In water while increasing research involves systems-thinking and two-way coupling between human and natural systems this approach has been used to deal with sustainability rather than issues of risk. A water sustainability focus which hinges on the fact that futures are static is nonsense, and as such the risk to our future is high and potentially irreversible. The core question within a sustainable water management framework is that, while an adaptive approach may help to keep water use at or below the sustainable threshold, will adaptation be enough when the risk of threshold change is high? For example, some estimate water demand will continue to grow in agricultural production as population and standards of living increase out to 2030 — now only seven years away! They also suggest efficiency improvements (i.e. water savings) may drive higher yields from similar water consumption, but that these will likely not exceed 20%. Further, while raw water capture and storage infrastructure may result in an increase in supply via business-as-usual approaches they too may only achieve a 20% increase. The remaining gap of 60% between forecast demand and possible supply growth is a significant risk with a real probability (Figure 1), suggesting sustainable water levels or demand increases will have to be pushed lower over time. In our view risks such as this are not being considered in the literature. A good example of ignoring nonconvexity, irreversibility and uncertainty.

Complicating this, in our view, is the fact that common solutions to water supply have been investments in water-use efficiency (WUE) to “save” water in one system to then allow use elsewhere. Investments in WUE typically remove any perceived slack resources from a system, as discussed above, and by doing so we lower a system’s capacity to cope with future variation (e.g. climate change risks) because the additional resources to cope with change no longer exist. Such constricted systems have a higher probability of breaking rather than flexing as needed under adaptive management approaches aimed at maintaining water sustainability. This puts water sustainability and risk at odds with one another, and

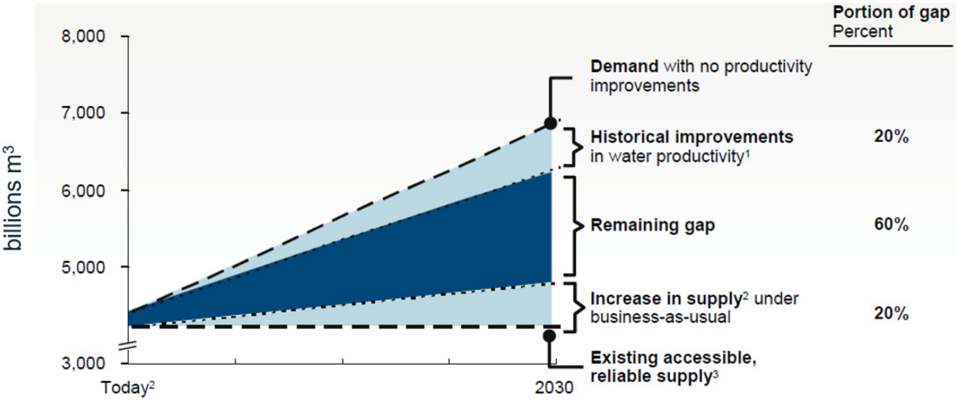

Figure 1. Gap Between Future Demand and Technical Improvements in Water Supply (WRG 2009)

signals future catastrophe in our water systems. As such, we had hoped to see some discussion of these issues in our submissions but that did not emerge and plausible solutions to future catastrophes remain unknown. More than anything, an overreliance on "zombie" WUE solutions in the water space globally — but with limited performance with respect to environmental gains and no consideration of future risk — has us extremely worried about nonconvex and irreversible outcomes.

So, with respect to risk and its impacts on water resources, what features in the literature, and how does this *Issue* contribute? In the economics discipline, there is a focus on markets as a method for pricing risk and spreading it across a large set of users via products such as insurance. Problems with this approach occur where the scope for effective risk spreading is reduced as more and more users become affected at the same time, and/or where insurance suppliers determine the risk is too high ahead of an event and premium increases price many outside the market. Despite the clear externality and market failure issues with insurance economics, it does not seem to have explored any additional set of solutions. The main driver of water risk — climate change — is left to other disciplines, and adaptation at market or individual levels remains a perennial research gap. Climate change is a global issue that will impact a wide variety of water and human systems at basin and catchment scales through vegetation loss, soil erosion, wildfire damage, tropical crop yield declines and dryland water scarcity lowering agricultural production, food supply, and environmental fundamentals. These risks will trigger continuous adaptation such as higher field irrigation, crop changes and farm management practice shifts. This is vexing for producers and rural stakeholders struggling to determine the best way to adapt in response to predictions of more frequent and severe drought in 75% of years by 2050 — surely a large risk in anyone's view. Yet economics is mostly silent in the water risk space.

The other discipline, engineering, has a focus on supply such as storages and efficiency technology for agriculture. Put simply, if more water is needed, we can increase supply as we have done in the past. However, as we have seen in Figure 1, there is a significant gap between the expected total demand and supply potential — if we are able to address considerable environmental and business-case concerns surrounding supply augmentation. Like WUE, many of those set to gain from rent seeking (e.g. farmers, construction companies, regulators, irrigation suppliers) favor such public investment, but none of them will typically be required to pay the costs of building, operating and maintaining the infrastructure. These costs can be significant over time, and the small rates of return recovered will go nowhere close to what it actually costs in full. Engineers do consider risks to these structures using robust analysis of their exposure longer-term, as storages may last

150 years or more in the landscape (i.e. an example of technically irreversible development). However, the adaptation potential by such structures to the impacts of climate change does not seem to be considered more widely with respect to water where, for example, in future rainfall may occur nowhere near the catchment for a dam, making it redundant. Further, any focus on WUE typically tends to reduce flexibility in the water system — to say nothing about the human component — with a focus on mean and variance as signals of relevant risk; but which also downplays the fact that the human part of water systems adapt quite regularly and in ways likely not seen before.

In our view, neither of these disciplines is doing much to help us focus on the risks associated with water resources, where the future will be very different from what we have experienced to date. In particular, neither is helping to identify real solutions to the 60% gap between demand and supply out to 2030 as an alternative to common storage/WUE technology strategies which are already failing globally. We have already had plenty of arguments with engineers who simply do not see that WUE has limitations or that there is anything wrong with robust analysis that does not take human behavioral change into account. In a future dominated by water–human systems thinking this will become an issue for solution discovery. But often the political nature of water resources, where they remain publicly owned and regulated, tends to position short-term political gains over longer-term practical solutions with higher total costs monetarily, socially and environmentally. There is little reason to expect or rely on changes to the politics of water management globally until the risks have become real, but by then far harder and more expensive to adapt to.

2. Overview of Papers in the Issue

2.1. *"Environmental regulation and economic development: Evidence from the river chief system in china"* by Liu and Bai

The authors apply robustness tests on a series of bottom-up regulations aimed at addressing pollution — where in other disciplines (e.g. engineering) robustness tests are aimed at the management of risk. They then join this to a sustainable objective of balancing economic development with environmental protection via structural upgrades (which are similar to WUE products) and other technological innovations. The authors seem to correctly observe that regulation for environmental gains does not rule out economic progress. But the robustness tests apply backward-looking data to inform how things will pan out in future, which is not really an accurate assessment of what we would term risk. This is mainly demonstrated by the regression modelling and its reliance on historic data, as well as the failure to assess how the gap between demand and supply levels undermines any reliance on technology and structural innovation. So, while we appreciate what the authors have written from an informative economics and engineering perspective the risk problem as we have described above continues. This is an interesting difference not appreciated by both disciplines, nor explored much in the literature.

2.2. *"Optimizing Long-term irrigation of areas above an unconfined aquifer: Quantity and quality considerations" by Simsa*

As a useful contrast, the human element with respect to water planning and decision-making is covered by this paper. Using Israeli water use as a case study the author argues that any absence of longer-term planning may lead to deteriorated water assets and the high probability (irreversible risk) of shutdown or failure. A solution may arise from optimal planning (convex solutions), regulation and spatial location of groundwater pumping stations as part of the total consumptive supply mix which may enable exploration of the economic and environmental management objectives to meet sustainability issues. But again, the perspective is backward-looking — and free of nonconvex outcomes — so not necessarily incorporating threshold issues never previously experienced. Importantly, the work shows that while changed economic and water-supply conditions alter decisions in sensitivity analysis Simsa fails to achieve the research objective of identifying an optimal state path toward a steady-state equilibrium using current (i.e. historical) aquifer data. However, the author concludes that substantial (i.e. Knightian) uncertainties affect steady-state outcomes — among other things in complex water management — requiring a focus on future risk.

2.3. *"Local communities' willingness to contribute toward the improved water quality of the River Yamuna" by Tandon and Das*

In a similar issue of water quality from India, the authors explore the important contribution of community or public engagement with pollution programs. Using a contingent valuation method, they determine what incentives may work among more receptive groups (e.g. younger women) to encourage participation and improvement. The issue again remains one of risk, where past data inform future choices, and a key lack of public enforcement. As observed in this paper, a lack of trust in governments to do the right things may limit engagement with certain programs, while smaller community or personal arrangements trying to meet health, food or habitat may appeal more. As such, while ever the future risk of water pollution and health issues remains high, localized participation may offer a way forward but only where the scale and impact of those risks are made clear; which does not seem to be the case in the paper. This makes individual choices more difficult to model, and risk becomes another casualty of the analysis approaches.

2.4. *"Overcoming deterministic limits to robustness tests of decision-making given incomplete information: The state contingent analysis approach" by Adamson and Loch*

To explore the issue of robust analysis and its implications for policy/program decisions the authors explore the nature of human decision-making in water resource uses, with a focus on learning as an example of how risk may feature in an individual's experiences with water resources to then inform and alter future choices, planning and investments. This may seem simple enough, but it is surprisingly absent from much of the literature apart from water-human systems thinking. To address this, they examine expected-value (EV) models that are commonly, and rightly, used around engineering projects; but argue they have little to no value in human systems. In such cases, state contingent analysis (SCA) modelling which can accommodate tail-end scenarios within shifting probability distributions may offer superior analysis outcomes. In the paper, risk associated with future climate change employs little to no reference to backward-looking conditions making any use of mean/variance data particularly pointless, and highlighting the value of scenarios as a means of testing robustness in human systems.

2.5. *"A hydro-economic model to calculate the resource costs of agricultural water use and the economic and environmental impacts of their recovery" by Sapino, Pérez-Blanco and Saiz-Santiago*

Finally, the economic and environmental interests in access to water resources remain a popular research topic, especially from a sustainability perspective. In their paper, the authors utilize two separate models: a hydrological model and an economic optimization model to explore environmental water recovery options from determining the true water supply cost. It has long been argued that full cost recovery provides the necessary conditions for a sustainable level of water use to be determined, so this paper explores the literature debate concerning the winners and losers from full cost recovery. Such a strategy provides the capacity to bring the best models together to be used in an iterative way, and then into a well-developed and respected economic model. Subsequent work should be aimed at progressing towards merging the models so they solve simultaneously and not sequentially which would offer a range of advancements to explore risk and sustainable water policy settings by the internalization of nonconvex supply/demand issues to minimize irreversible losses.

3. Synthesis and Policy Implications

One of the major lessons that comes out of this examination of water sustainability and (to a lesser degree) the problems of increasing risk is that governance, management and academic study of water and its problems is critical for adaptation and furthering resource use/access; but none of these institutions is applying themselves as they should. A major problem of addressing water shortages, demand increases and supply limitations/costs is that eventually the human–water systems will snap. With respect to water resources risk neither economics or engineering have progressed very far in recent decades, and politics is clearly going backward under increasing challenges of declining trust, perceptions of incompetence, or limited social license for relevant commercial entities. Generally, there is much to do but no real reason to be held accountable. This may be acceptable for issues other than water but, as we can't live without it, the importance of water supply and management is life-threatening. Globally we need to find the means and incentives to change this situation.

Further, WUE won't save us by providing increased supply — the need is for alternative solutions that present ideas outside the box. And if we think insurance will cover the losses as advocated by economic theory the answer is also no. For example, as climate change impacts and risks shift there are parts of Australia which no longer attract insurance cover (e.g. northern Queensland above the Tropic of Capricorn which may no longer be eligible for policy exposure or assessment). If we are unable to identify reasonable ideas to deal with this demand/supply risk the sustainably of human, ecological and other species needs for water resources remains perilous. We may need to think about the suspension or outright cancellation of some water rights to limit exposure to risk, and investing (substantial) transaction/abatement costs to establish new studies and inducements to change behavior. And given the difference between future data outcomes those scenarios should be represented using 'new' futures based on historical data, but with clear exploration of the impacts of extreme tails in distributions.

Ultimately, the risks associated with tail events and the changing probability of variations/impacts should be well studied, understood and factored into planning, reform and adaptation options going forward. The future risk of water shortages is quite prominent which, as we've shown, is not present in most papers of the *Issue*. The past is always comforting to researchers/users as a basis for calibrating base lines and then building scenarios. But what happens if the future has no correspondence with (local) base lines? Robustness tests have very different perspectives and bases for setup, representation and test-objectives. This must be explored more, and separated across humans/infrastructure. We argue there is much economists and engineers can learn from one another, but some in the engineering discipline appear fixated on augmenting water supply only. This has been disappointing, but there is scope for change if we extend invitations to work together in future. Economics also has much to learn about how to do risk assessments differently, to improve risk assessment beyond insurance market solutions given expected future change. The opportunity in this area appears rich for collaboration on needed answers.

Finally, climate change will lead to longer and more severe droughts that may only be interrupted by more intense and destructive floods with significant negative impacts. Policy-makers must deal with these vagaries in water demand and supply, but again we see little to no evidence of that in their behavior. This is unsurprising where water authority understanding of how to manage the conjunctive resource (i.e. groundwater, surface water, wastewater and transfers), both in terms of the quantity of the resource available and the quality of that resource, is becoming increasingly complex. It would be nice if risk probability as an entry-point to analysis via scenarios, human investment or other decision-making, valuing seasonal climate forecasts, adaptation choices and outcomes, or policy evaluation were used to properly frame and represent complex water issues. Until wider applications occur, we will remain ignorant of the nonconvex outcomes, irreversible costs, possible alternatives to business-as-usual and solutions beyond water markets, the limits of WUE, and the need for flexible water management options in response to climate impacts.

We think this *Special Issue* may have failed to address the problem. So, the challenge is back on the reader, and researchers more widely, to help find solutions.

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