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Water and the Politics of Quantification: A Programmatic Review

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ABSTRACT: Quantification of states, corporations, nature or self has become pervasive in the past 40 years. The water world's struggles are rife with, and shaped by, numbers, indicators, metrics and models. This review explores how the production, promotion and use of 'water numbers' conceals deeply political processes, hypotheses, worldviews, intents, old habits and new fashions. Whether embodied in scientific or expert practices, or in indicators, thresholds, water accounts or cost–benefit analyses, water numbers promote specific values and interests; they also obfuscate complexity, heterogeneities and uncertainties, they manufacture legitimacy and authority, and they act as control devices to shape behaviour. We offer a more detailed analysis of water indicators that describe water scarcity, ecological status, progress towards SDG 6, and embody New Public Management principles. We end with a call for critical water studies to more forcefully engage with these debates, in line with the centrality of quantification in water management and policy.

KEYWORDS: Sociology of quantification, indicators, legitimacy, reductionism, ontologies, NPM, science-policy interface, commensuration, modelling, numbers

In the heat of the political battles, some numbers beat no numbers every time
(King and Kraemer, 1993)

INTRODUCTION

The water world's struggles are rife with, and shaped by, numbers whether accurate or shoddy, constructed, absent or misdirected. People expect information about water to be conveyed through numbers, in terms of depth, stock, flow, chemical or biological characteristics, or associated economic values, costs and benefits. Some of this quantification is relatively straightforward and based on direct measurements such as flood peak discharges, rainfall amounts, depths to groundwater and salinity levels. Other seemingly objective numbers are, in practice, strongly subjective; this includes, for example, those derived from modelling (Lane, 2014; Melsen et al., 2019; Melsen, 2022); per capita consumption and crop water requirements are two such examples. Yet other numbers are more obviously connected to social and political norms and contestations, for example abstraction entitlements and environmental flows. In each of these types of quantification, numbers do not only describe water, they also depoliticise it. Depths, discharges and volumes are seemingly as uncontroversial as our age, height or body temperature; they are generally seen – and branded – as resulting from a neutral and natural operation that is conducive to improved, objective and rational decision-making (Porter, 1995). Even when numbers or data are viewed as lacking or inaccurate, this is seen not as a consequence of their inherent subjectivity, but rather as something that can be remedied with time, technology and money.

In the light (or shadow) of numbers, the particular water world of 'modern water' has sought to 'harness', 'control', 'develop', 'share' or 'conserve' water resources for human use (Linton, 2010). The concept of 'water demand', for example, is often reduced to commonplace numbers such as 150 litres/capita/day or 5000 m^3/hectare/year. 'Demand' is actually plastic and variable, not fixed and established; it varies in space and time but also has to do with social practices that reflect preferences, lifestyles, affluence, prices, legal frameworks, scarcity, technology, weather conditions and ease of access (Dalstein and Naqvi, 2022). Opening the Pandora's Box of such clean, familiar and handy rounded-up averages reveals myriad issues regarding metrology and accuracy, or naturalised factors such as excess, satisfaction, need, comfort, luxury, waste, losses, shortage, stress, equity and dignity.

In political projects, numbers can be abused to orient planning towards specific interests such as justifying new supply augmentation projects (see, for example, Tiwale, 2021, on Mumbai's water supply) or making them economically attractive.[1] Water numbers can be tampered with to communicate success in meeting pre-established targets (the '*Gosplan* syndrome'), or frozen to obfuscate infelicitous trends. Even the seemingly hard science behind the estimation of crop water requirements is fraught with uncertainties at all stages; these add up and propagate to deliver wildly varying demands, as emphasised by Puy et al. (2022).

It is critical to the state, firms and other governing bodies, however, that citizens keep faith in numbers. This faith is vital to faith in society and to faith in social order and rule (Porter and Haggerty, 1997). During the COVID pandemic, debates raged around numbers that tried to capture the extent of casualties, health impacts, risks, or likely evolutions (Saltelli et al., 2020). To stem the confusion, the French government put out an advertisement claiming that "one can debate anything, except numbers". The bluntness of the message is disturbing, as is the likelihood that most people read it without thinking further.

The desirability of (more) data is made 'obvious' by ubiquitous storylines such as "You can't manage what you don't measure", or "Imperfect data is better than nothing", which support a call for more, better or improved, data.[2] Databases that fuel Earth Science (Vance et al., 2024), 'big data' and machine learning (Sun and Scanlon, 2019) and AI validate the importance of gathering as much data as possible, however this focus on data quantity glosses over issues of quality, relevance, bias or ontological domination (Moore et al., 2018).

Interrogating the role of data in water resources management and governance is *not* meant to suggest that data is not important or that management without data is better or desirable. We particularly do not discount the importance of quantitative assessments of water supply and demand. These metrics help manage and debate the sharing of limited water across time and space to many users and uses (Carnell et al., 1999).

Our aim, rather, is to emphasise how the production, promotion and use of 'water numbers' conceal deeply political processes, hypotheses, worldviews, intents, old habits and new fashions. Whether embodied in scientific or expert practices, or in indicators, thresholds, water accounts or cost–benefit analyses, water numbers promote specific values and interests, obfuscate complexity, heterogeneities

[1] On this old debate on cost–benefit analysis, see, for example, Goldsmith and Hildyard (1984) on dams, or Berkoff (2002) and Molle and Renwick (2005) on irrigation schemes.

[2] A report on the implementation of California's *Open and Transparent Water Data Act* (Cantor et al., 2018) well epitomises the standard vision that "Making rational and equitable water management decisions depends upon timely knowledge of the current and projected state of the water system. This, in turn, requires robust data and information. (…). Without basic information on where, when, and how much water is available and being used, as well as physical, chemical, and biological measurements of water quality, we cannot improve how we manage our water resources. A modern water data system that enables accurate, timely, transparent accounting of water supply, quality and use could enhance water security and sustainability."

and uncertainties, manufacture legitimacy and authority, and act as control devices to shape behaviours. To paraphrase Jasanoff (2004), reality and the numbers we use to order and act upon the world are co-produced.

The increasingly hegemonic use of metrics, indicators and quantification practices has raised red flags for scholars in social studies of science and the sociology of quantification who analyse the social/political role of numbers and how they, in turn, modify society (Porter, 1995; Star and Bowker, 1999). The performativity of numbers is brilliantly summarised by Espeland in her foreword to Mennicken and Salais (2022):

> Numbers do things. They highlight and obscure. They integrate and disaggregate. They mark and measure. They represent and intervene. They tame and inflame. They structure people's interactions. They create new objects and new kinds of people. They possess a power that hides itself. They are rhetoric that is anti-rhetorical. What all of these features of numbers share is that they express a certain agency. They perform.

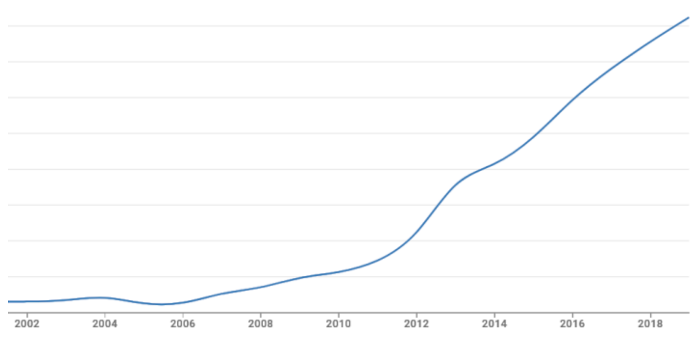
Alexius and Vähämäki (2024), in a recent book, coined the expression 'Obsessive Measurement Disorder' to typify an increase in often counterproductive control mechanisms; Muller (2019) identified a "tyranny of metrics"; and Bell and Morse (2011) referred to a "new frontier in 'indicatorology'". The heavy reliance of water science on quantification is drawing critical interrogation in studies on water accounting (Zwarteveen et al., 2018), modelling (Sanz et al., 2019; Melsen, 2022; ter Horst et al., 2023), remote sensing (Venot et al., 2021), and indicators (Molle and Mollinga, 2003).

In this introductory paper, we present insights from the sociology of quantification illustrated with relevant literature on water, including the nine papers featured in this Special Issue. We conclude that the consideration given to the social and political dimensions of numbers in critical water studies is still relatively limited, at least with regard to the pivotal role of quantification in water governance, planning and policy. We call for more intense scholarly engagement with the politics of water quantification.

THEMES IN THE SOCIOLOGY OF QUANTIFICATION AND WATER

The sociology of quantification has witnessed a spectacular growth in the past two decades, building on germinal works such as Theodore Porter's (1995) *Trust in Numbers*, Desrosières' (1998) *The Politics of Large Numbers,* and Espeland's (1998) *The Struggle for Water*. While Berman and Hirschman (2018) noted that Google Scholar returned only nine results for the phrase "sociology of quantification" in 2007, and 448 one decade later, in 2024 the count had risen to 1910. Several recent books and position papers have fuelled this scholarship (Mennicken and Salais, 2022; Supiot, 2017; Muller, 2019; Rottenburg et al., 2015; Mennicken and Espeland, 2019; Berman and Hirschman, 2018).

Figure 2. Relative trend in the occurrence of 'sociology of quantification'.



Note: This graph shows the frequency of appearance of the phrase in printed sources (Google Ngram Viewer).

In this section we distil a few themes at the heart of the sociology of quantification, reviewing the related water literature.

Trust in water numbers and legitimacy building

A central theme in the sociology of quantification is the perceived authority and legitimacy conveyed by numbers that are seen as impartial and objective, a perception that is deeply embedded in the scientific tradition, educational practices, and cultural norms of Western culture (Porter, 1995; Espeland and Stevens, 2008). These qualities are very much in demand, particularly by states, as illustrated by the above case of COVID in France. As Ogier (2020) puts it, the use of numbers is often much less about their absolute value and substance, and more about their social value, that is, the extent to which they are endowed with the property of being "true, neutral and indisputable".

But the credibility and effectiveness of numbers use and usability is not an intrinsic property of those numbers; rather it "is determined in context and shaped by the processes of interaction involved in its production and use" (Turnhout et al., 2019). For Brooks (2017),

> emphasizing the "doing" of numbers further reveals that numbers do not exist "out there" in nature waiting to be found, but rather are produced by and grounded in specific knowledge-making practices and political actions. The ways in which their supposed accuracy, objectivity, or trustworthiness are activated result not from their veracity, but from particular values (e.g. the "openness" or transparency of bureaucratic regimes) and social practices.

Brooks (ibid) analysed the competing water narratives in Smoketree, California, which promoted, respectively, '500 years of water (abundance)', '50 years of water', or 'Sustainability – zero (growth)'. She emphasises that these "number narratives" do not only produce "assertions of transparency, trust, or objectivity" that reflect the putative authority of their production; they are also "literary and social technologies".

The authority of numbers and modelling is also shaped by that of the actor networks that have developed, promoted and copied them (Melsen, 2022). Jensen and Venot (2023) showed how the calculation of gas emissions from paddy fields leveraged "the scientific credentials and authority of the IPCC, confer[ing] legitimacy upon climate assessments". Likewise, Jesinghaus (1999) stressed that the success of the Environmental Pressure Index is linked to the fact that it comes from Eurostat, the Statistical Office of the European Communities and a Directorate General of the European Commission – "in other words, a highly credible and official source".

Numbers incorporated (or not) into public and community-facing communications are also fraught with political judgement and discrimination, particularly when resources are co-owned and co-managed (Bielak et al., 2008; Tadaki, 2024). Specific numbers relevant to local stakeholders are more scrutinised and the way they are produced and shared greatly impacts their 'effectiveness'. Nelson (2019), for example, has noted that the form in which often complex (ground)water information is currently disseminated in Australia may not be appropriate for public audiences, impacting issues of trust and legitimacy.

Legitimatisation via quantification is not only directed 'outward' in public-facing fora and reports; it is also visible in the internal processes whereby water numbers are defined and positioned. Voelker et al. (2002) explored the role of metrics in the water-energy-food nexus governance within the European Commission; they showed how nexus metrics are instrumental in legitimating policy objectives within the particular institutional culture of the European Commission and in EU policy-making more broadly. New nexus metrics may make systemic interactions and their biophysical impacts more visible, promoting tools such as intersectoral impact assessments and thus challenging the status quo around entrenched 'sectors' and 'portfolios'. The ability to develop and use new metrics, however, is constrained by "existing institutional practices" and "dominant political orderings" (ibid).

Reductionism and ontological issues

Another key theme is the inevitable simplification and reductionism associated with water metrics, standards, categories and quantification. This is true for biophysical representations (see discussions on models below) but also for social realities. The translation of complex ideas or realities into a set of measurable variables is not only mutilating - reifying, distorting or obfuscating intangible social phenomena (Fukuda-Parr and McNeill, 2019; Porter, 1995; Jackson et al., 2023; Tadaki, 2024) - but it also reinterprets them and fosters particular views and conceptions of the social or of nature (see the subsection below on environmental indicators).

The numerical artefacts through which reality is apprehended and knowledge produced have cognitive, but also ontological, effects (Star and Bowker, 1999; Porter, 1995; Espeland and Stevens, 2008). There is a growing awareness of how particular abstractions make some actors, values and concerns visible while hiding and backgrounding others. This backgrounding can result from the simplification inherent in quantifying a complex (water) world, but it can also be intentional (see more on the politics of water data below). Or it can reveal deeper ontological issues: what is overlooked is just not there because it is foreign to the cognitive structures, values and worldviews that have shaped the numbers in the first place.

Venot et al. (2021) have shown how the binary and simplistic categorisation of landscapes into 'irrigated' and 'non-irrigated' that is used in land use monitoring through remote sensing not only did not do justice to the diversity of practices, but also works to 'invisibilise' water use by small-scale irrigators, notably when allocating water in times of shortage. A similar concern was raised by Zwarteveen et al. (2018) in their study of water accounting; they pointed to the risk that emphasising efficiency and productivity will "eclipse concerns of equity or diversity". In a discourse that is imbued with modernist objectivity, 'efficient' users receive support and priority, while others who appear as wasteful or environmentally destructive are sanctioned or targeted for training and awareness raising.

Acharya (This Issue) notes that, in an Indian city, TDS, which measures the total organic and inorganic substances dissolved in water, "produces a numerically simplified engagement with the complex materiality of drinking water quality". They note further that this "supplant[s] a more embodied, experiential, and gustatory understanding of the same expressed through a rich lexicon of local terms". MacAfee (2023), likewise, offers a case study in Senegal that describes the tension between scientific knowledge production on water quality (with a focus on measurability) and consumer perceptions, knowledge and preferences (with a focus on acceptability). She points to a reductionist application of the World Health Organization (WHO) Guidelines for Drinking-Water Quality that results in a lack of recognition of the social and relational aspects of drinking water quality.

Zwarteveen et al. (2018) underline that "water accounting treats, defines, and analyses water as something that is in essence, 'natural' [rather than 'social'], the behaviour of which can be explained through reference to a universal natural order or logic". This, they add, "suggests that water can be rather straightforwardly read off actual realities 'out-there', as if these realities unequivocally exist prior to being mapped, measured, or known. This conceals the hard, and often messy, work involved in water accounting science-in-action (…)". Espeland (1998), in her seminal work on the Bureau of Reclamation in Arizona (BUREC), addressed the issue of commensuration in the Orme Dam project, which pitted the rationalities and values of the BUREC against those of the Yavapai Indians. She reveals the cultural and cognitive dimensions of quantification practices in cost-benefit analysis and the ontological problems of commensuration.

Molle and Collard's study of the definition of environmental flows (e-flows) in France (This Issue) emphasises that e-flow is based on specific reductionism, classifications and simplifications that produce a metric that is anything but neutral or objective and which fosters particular representations and implications. By choosing to collapse the suitability of freshwater habitats into a simple discharge value, the Quantitative Water Management Policy prompts specific solutions that are framed in the language of flow rates, abstraction, losses and efficiency, one of hydraulics rather than (eco)hydrology. Guimont (2018) studied a national park in the north of France and the imposition by the neo-managerial state of 250 indicators that were meant to monitor its progress towards the achievement of set objectives. She showed that the indicators promoted a fragmented and reductionist view of ecosystems and minimised the decline in biodiversity, while considering administrative spatial boundaries and time frames that were at odds with natural processes.

Bhatt (This Issue) looks at water utility performance benchmarking and excavates its ideological and institutional foundations, shedding light on "those who quantify in the name of transparency". Quantification appears as "integral to economisation because it transforms entities into calculating, performance- and efficiency-oriented agents through technologies that include, but are not limited to, indicators and benchmarking". Experts' indicators strengthen orthodox economic reasoning and foreground service quality, operational efficiency and financial autonomy, rendering inequity invisible. Perramond (This Issue) contrasts the flexible and socially controlled sharing of water through the traditional *surcos* (ditch) system in New Mexico with current water rights expressed in acre-feet (volume). While the surcos allocated water based on water availability and needs, adjusted to microtopography, with disputes resolved internally and equity as the guiding principle, new imposed metrics define water as a user right, individually defined and privatized, and detached from the intricacies of irrigation water distribution. Linton and Saadé (This Issue) trace how an early hydrological interest in global water balances ontologically reduced multiple variegated place-based water scarcities into one global water sufficiency figure, which in turn has ushered in a highly questionable planetary framing of a 'global water crisis' (GCEW, 2023; Puy and Lankford, This Issue).

Several ways out of the 'ontological trap' have been proposed, investigating the emancipatory potential of numbers and how they can lead to more inclusive governance (see Mennicken and Espeland, 2019). Leonard et al. (2023) advocate for the merging of Indigenous knowledge, as further illustrated by Russel et al. (2020) who document the use of cross-cultural indicators of billabong water quality in remote Australia (see also Wöelfle-Hazard, 2022). Another option is to 'delegate' the definition of indicators and audit systems. Vogt (2021) show how an NGO's audit of water supply in Bengaluru, India, succeeded in embedding moral logics into inherently reductionist and abstract numerical technologies, thereby avoiding "a politics of reduction, alienation and abstraction (…) by thoroughly socialising its water auditing processes".

Yet another option is to produce alternative narratives, indicators or numbers. Bhatt (This Issue) describes how two Indian professors championed benchmarking orthodoxy by engaging in 'counter-quantification', proposing that indicators explicitly accounting for equity be integrated into utility benchmarking systems. She notes, however, that quantifying equity could also "transform a situated concept into a universal category, thereby risking prescriptive solutions that are divorced from the elemental conditions that produce specific injustices". Kovacik (2018) notes the contention around the use of quantitative information in guiding policy, building trust, and constructing authority, and proposes alternative uses of quantitative information for governance.

Water numbers and the science-policy interface

If "much mainstream policy and practice simplifies and standardises real-world messiness, promoting uniformity in the face of heterogeneity and diversity" (Whaley, 2022), then the associated quantification practices can be seen as quintessential tools to 'simplify' interfaces between science, policy and citizens. There is ample evidence, however, that policy numbers are generated in "multiple, two-way and dynamic interactions between processes of knowledge production and decision-making" (Wesselink et al., 2013: 2) and that they seldom escape the messiness of political processes. Numerical artefacts are part and parcel of controversies, organisational turf battles, and political or policy debates. Fernandez (2014) showed how desired minimum flows in the Garonne River Basin could change with policy values and objectives prioritising navigation, irrigation, pollution dilution or environmental health, but also with the bargaining power of associated constituencies.

This is also what Molle and Collard (This Issue) have found in the case of the definition of an environmental flow (e-flow) in the Têt River Basin, France, that was aimed at drawing a quantitative line between what constitutes 'permissible' and 'excessive' water withdrawals. While science is called upon by all actors, either in support of the e-flow produced or through initiatives to produce alternative numbers, they show that the e-flow acts as a shifting boundary number that embodies and reflects the evolving bargaining powers of main actors as wells as their perception of the implication of e-flow numbers in terms of efforts and constraints. It is not the validity of the e-flow number that makes the settlement possible but, rather, the acceptability by all of the political (e.g. regulations, threat of state intervention) and economic (e.g. subsidies) terms of the debate that allows for the bridging of 'social worlds' and interests.

A similar attitude towards the role of science has been identified by Jensen and Venot (2023) in their study of the rice-field methane emission calculator that is used by the French AFD (*Agence Française de Développement*) to decide on the climate compatibility of the development projects to be funded. When the number produced by the calculator is in line with the AFD's intentions, its scientific validity is enhanced. In the opposite case, uncertainties and complexity are emphasised to legitimise the overriding of the number by an 'expert-driven' assessment, thus offering a way to circumvent the constraint created by the number.

Imposing limits and curtailing the use of resource is politically uncomfortable. Policymakers or managers, understandably, find it tempting to affirm that such a necessity is dictated by science and not by subjective or ideological whims. This leads inevitably to 'stiffening' the validity of the numbers that are produced to give shape to what is desirable and what is not. Rockström,[3] for example, asserts that "a rise of 1.5C is not an arbitrary number, it is not a political number. It is a planetary boundary (…). This is real science – it is a real number. Now we can say that with a high degree of confidence".[4] A more constructivist view is that such targets, just like other planetary boundaries, result from political processes that reflect a combination of interests, values, bargaining powers and scientific information "that is at once robust, uncertain, imprecise and evolving".[5] While science is not absent from the debate – and even shapes it to a substantial extent – it is only one element of the wider decision-making political process.

Puy and Lankford (This Issue) examine the production of such water 'planetary boundaries'. These are the quantitative thresholds on global blue and green water use that are tasked with defining a "safe and just operating space" and an undesirable 'beyond'. They show that the criteria for defining such key numbers are crude and variable and that no uncertainty analysis is produced to help understand the robustness of the approach. Puzzled by the attempt to fit the blue water square peg into the round hole of the global 'safe operating space', they surmise that the ideological and political project of limiting resource use globally obfuscates the evidence that the planetary boundary concept is ill-adapted to water resources and overstretches what science can ascertain or inform (see also Molden, 2009).

Berry et al. (This Issue) have investigated the concept of perennial yield of a groundwater basin that is used by the Nevada Division of Water Resources to determine, "the maximum amount of groundwater that can be withdrawn each year over the long term without depleting the groundwater reservoir" (Division, 2023). They show that while these target numbers are used as evidence of regulatory

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[3] Rockström is co-chair of the Global Commission on the Economics of Water as well as of the Earth Commission (https://earthcommission.org). He is one of the promoters of the planet boundaries concept.

[4] https://www.theguardian.com/environment/2021/oct/30/climate-experts-warn-world-leaders-15c-is-real-science-not-just-talking-point

[5] See https://rogerpielkejr.substack.com/p/planetary-boundaries-and-the-rise and https://rogerpielkejr.substack.com/p/the-15-degree-temperature-target

consistency, objectivity and credibility, the Division's self-proclaimed mission "to responsibly manage Nevada's limited water resources in accordance with State law and best available science" (Sullivan, 2022) accommodates ambiguities and loose definitions that offer 'flexibility' and room for manoeuvring and discretion. Anand's (2015) study of Mumbai water system and leaks also showed the importance of selective ignorance and the limits of governing by audits and measurements. Anand found that knowledge about leakage was unstable because of intermingled physical and social factors but that the claims about leakage numbers were important in legitimizing expertise, allowing political claims or justifying reform/privatization.

Specific interests are therefore woven into numbers and metrics. Tiwale (2021) shows how, by constantly warning of an impending water crisis and imposing a (high) water demand target of 240 l/capita/day, water experts in Mumbai have been able to justify large-scale water resource development projects and secure more water. Although slums, by their number, helped justify such plans, they remained subject to intermittent supply. He emphasises the associated 'number narrative', showing how it was made up and consolidated over time. Acharya's study on Bhuj city in India (This Issue) showed that the collapsing of reality into TDS also "serves to stabilise market demand for membrane-based reverse osmosis (RO) water purifiers – the only technology that promises to address the 'problem' of 'excess' TDS in drinking water". Perramond (This Issue) likewise stresses that individual rights and volumetric monitoring were necessary to fully integrate water into the circuits of capitalism through the distancing of water from humans. The new acre-foot "metrics 'flatten' the complexity of past cultural water metrics to simplify legibility for the state", any acre-foot of water being "one that can be traded, moved; expunged in one place and used in another". These observations echo Lave's (2012: 30) argument that the translation by neoliberal science of complex ecosystems into easily measurable and comparable units produces "market-enabling metrics".

The politics of access to water data

In most cases, the quantification of water requires data, generally in the form of specific measurements. Raw data are the stuff of quantified knowledge and are therefore tantamount to power. As such they are also subject to all kinds of translations, transactions, massaging or retention/disclosure.

Some literature has addressed the question of data availability and the constraints on open-access to water data. Notable among these is the stock-taking paper by Sugg (2022) which goes beyond mere questions of cost, logistics and technicalities to discuss 'social barriers'. Sugg (see also Zuiderwijk and Janssen, 2014; and Ruijer et al., 2020) identifies several disincentives for water administrations to share data or make them open access. These include the risk of misinterpretation of water data, an increased chance of the public finding errors or inconsistencies, and a loss in revenue when data is sold, whether officially or otherwise. Government data constitutes a strategic resource for organisations but also for some individuals within them and, as such, is often made selectively available, producing "strategically opaque transparency" (Ruijer et al., 2020).

Many countries' water strategies and policies include calls to make water data available, but this rarely occurs. In Morocco, for example, the National Water Information System was supposed to centralise existing hydro-climatic data but this never materialised (Molle and Mayaux, 2023). Echoing the Water Minister's[6] acknowledgement that monitoring "does not allow the production of reliable information on water withdrawals", a group of Moroccan experts deplored "the lack of a reliable and accessible information system on water resources" (Groupe Eau des Lauréats IAV, 2022). The numbers provided by the government vary inconsistently or are opportunistically inflated; this includes, for example, figures on the water savings realised by the *National Irrigation Water Saving Programme*, the achievements of

[6] *L'Economiste,* "Gestion de l'eau un plan national à 230 milliards de dh", 6 Mai 2014.

the Green Morocco Plan, the extent of boreholes and wells, or the amount of available water resources (Molle and Mayaux, 2023).

Selective ignorance is commonplace. Kroepsch (This Issue) examines a case of intentional non-quantification/metering of groundwater abstraction in the western United States. In contrast to the intensive metering of surface water diversions "groundwater's un-metering has been produced, widened and maintained in the region over the last 140-plus years". This is due to biophysical reasons, knowledge production issues, and political economic factors that are linked to power and profit. In other words, groundwater-use quantification is problematic in practical terms but is also undesirable from the point of view of certain constituencies. Jozan (2012) has similarly shown how local administrators and experts in Uzbekistan failed to compute, in their statistics, the irrigated areas growing maize. The failure stemmed from the fact that this "invisible second crop" did not fit the categories inherited from the Soviet planned economy, which were centred on cotton; it was also because the water flows received by maize fields were usually ascribed to 'losses' and poor management.

The political dimension of crop water requirement is illustrated by 20 years of (failed) attempts by the Egyptian Ministry of Water Resources and Irrigation and the Ministry of Land Reform and Agriculture to agree on the value of crop water requirements. While the former has an interest in minimising these values to show that it delivers enough water, the latter has the opposite interest as it is a way for them to claim more water.[7] The commonplace difficulty with sourcing and interpreting the data produced by ministries (responsible for agriculture, water or environmental preservation) and associated politics have hardly been addressed; this dearth of critical studies can tentatively be ascribed to the political sensitivity of the issue and the lack of openness to scrutiny.

In response to the need for, or pressure to, make more data available, many governments have designed websites where variables such as daily water levels in rivers or reservoirs can be accessed and monitored. Beyond their claim to be sharing data openly, however, the usefulness of such sites is dubious since they rarely provide access to the time series that are needed to conduct analyses; furthermore, administrators are not only gatekeepers of official data, they also decide what counts as valid information. Verran (2010) has examined the production of water quality numbers by Waterwatch Victoria volunteers, an environmental NGO that provides services mainly under contract to governments. Unlike the 'official data', the confidence limits of the 'community data' are not specifiable and it therefore cannot be included in the data warehouse of the Victorian state.

Another emerging field of inquiry concerns communication technologies, big data, and the Internet of Things. Here, again, the growing literature on the technical opportunities they offer and challenges they bring (Sun and Scanlon, 2019) dwarfs the more urgent reflections on the social and political implications of digital transformation (see, for example, Goldstein and Nost, 2022). As emphasised by Hoolohan et al. (2021), "Important questions regarding how digital transformations reproduce and reconfigure water governance are not typically considered and the socioecological injustices that digital developments may disrupt or maintain remain unacknowledged". Big data, unsurprisingly, appears to further entrench the cognitive structures typical of 'modern water'. A sub-field concerns water data-intensive 'smart cities' (see, for example, Taylor and Richter, 2017).

WATER INDICATORS

Indicators and indices have been the object of considerable attention in the literature on quantification and intersect with many of the issues reviewed above (Rottenburg et al., 2015; Merry, 2011; Lehtonen, 2015). With neoliberalism their use has dramatically expanded, both through the introduction of New Public Management in administrations, and the requirement for reporting or corporate social

[7] Personal communication to the first author (anonymity requested). See a critical analysis of the variability of crop water requirements in the Nile Delta in IWMI and WMRI (2013), and in southern Sri Lanka by Molle and Renwick (2005).

responsibility (CSR) obligations in the corporate sector (Desrosières, 2015; Power, 1997). They have also shaped governance on the global stage through international organisations (notably UN agencies) and the rolling-out of rankings and country-level comparisons (Merry, 2011; Shore and Wright, 2015). In all cases, the commensuration of phenomena and the aggregating, classifying and quantifying through indicators "encode particular cultural understanding, political interests and ontologies" (Rottenburg and Merry, 2015). Indicators serve the powerful people and entities that have designed them but they may also become advocacy tools for activists (Bruno et al., 2014). They also affect the behaviour of the agents whose performance is monitored and that of the 'quantified actors' (Desrosières, 2015), and have substantial unintended or hidden effects (Fukuda-Parr and McNeill, 2019).

Water scarcity and sustainability

One area of interest is the quantification of water availability or lack thereof. Molle and Mollinga (2003) have unpacked the conceptual and policy problems posed by water scarcity/poverty indicators. Early water indicators focused on the physical availability of water (generally at the country level) and how it related to population. The Available Water Resources (AWR) per capita measured the ratio of the renewable water in the hydrological cycle to the number of people (Falkenmark et al., 1989; Gleick, 2000). But 'renewable water' can include floods and more generally all the renewable water resources that are not controlled, neither of which helps much in assessing the situation. One of the key problems with country-based indicators is their conflating of contrasting situations, averaging, for example, Brazil's Nordeste and Amazon, the USA's Colorado and Mississippi basins, or China's Yellow and Yangtze rivers. Critiques of oversimplification have spurred an industry of composite indicators. The Water Poverty Index (WPI), for example, combines no less than 17 sub-indicators that are meant to measure water availability but also people's capacity to access water (Laurence et al., 2002; Sullivan, 2002). Aside from the question of how qualitative dimensions of water scarcity can be quantitatively assessed or how non-commensurate data are pulled together, composite indicators must combine and weigh the sub-indicators arbitrarily. Once this is done, the information included in each of them ends up being lost and the final apex indicator becomes largely meaningless.

More recent concepts such as water security, the food-water-energy nexus, or (green/blue/grey) water footprint are also extremely data intensive; they have therefore absorbed a lot of efforts and resources to generate, combine and analyse water-related data (Brown and Matlock, 2011; Wang et al., 2021; Damkjaer and Taylor, 2017; Ioris et al., 2008; Babel et al., 2020; Seager, 2001; Zwarteveen et al., 2018). Octavianti and Staddon's (2021) meta-analysis has identified no less than 80 metrics with which to measure water security at the city, river basin, regional or national levels. They found that the relevance of indicators increased as the scale became more local. Wilder (2016) highlights several vexing dimensions; these include: the lack of agreement on what model(s) to use and how to weight factors, the lack of evaluation of the validity and robustness of the instruments, and deficits in engaging public participation in instrument design and use. This literature is mostly concerned with the nuts and bolts of how to make 'better' indicators; few papers address deeper political, epistemological or ontological dimensions.

Critical works include Beltrán and Velázquez (2015) (see also Beltrán, 2016), who ask "What does virtual water conceal?" and unpack the discourse that promotes the concept of virtual water and its methodologies to show that they are framed within market logic and the rationality of international trade, and merely geared towards maximising resource use efficiency. Norman et al. (2013) developed a multivariate approach that, together with multi-stakeholder involvement, enables communities to determine appropriate indicators on the basis of available resources, long-term assessments, comprehensive reporting, and community goals.

Many numbers supposed to define drought or emergency thresholds, generally considered as neutral statistical optimums derived from equations or modelling, fail reality checks. Research on the hydrological thresholds that are set to trigger drought emergency measures in France (see, for example, Barbier et al., 2010; Riaux, 2015) has shown how social and political judgements combined with science to produce 'bricolage' and ad hoc arrangements. Another example is that of dam 'rule curves', which are frequently overridden by ad hoc political decisions in times of emergency.

Much of the work on country-level indicators uses aggregate data from databases such as the FAO's Aquastat or the World Bank's Open Data.[8] While research has investigated the underbelly of macroeconomic indicators and statistics (see, for example, Jerven, 2013; Samuel, 2013), to our knowledge no work has documented how Aquastat is populated. Although this assuredly commendable initiative is marred by several difficulties, the numbers provided by Aquastat are so unique and so handy for churning out rankings and comparisons between countries that few bother to ask how these numbers are produced.

According to Aquastat data – to take just one example – available water resources in Morocco have been constant since the start of the series in the 1990s; this is at loggerheads with reports that they have declined by around 33% over the last 40 years (Groupe Eau des Lauréats IAV, 2022). It matters little whether data is lacking, crudely estimated for lack of real field data, opportunistically frozen, over/underestimated, or massaged: the machine grinds what it is fed with. It is thus possible to access, for example, the productivity of water use in the service sector in, say, Afghanistan, in US$/m^3, with two decimals. Likewise, FAO advertises (Figure 3a) its calculation of global economic efficiency (in US$/m^3) and reports that it rose by 10% between 2015 and 2018. This is presumably good news, irrespective of how it was calculated and whether it has any meaning at all in the first place.[9] The number is legitimised

Figure 3a. Global water numbers

Figure 3b. Political use of water poverty indicators

[8] https://www.fao.org/aquastat/fr/ and https://data.worldbank.org/

[9] A war or a drought may raise the global price of food commodities, creating suffering and possibly riots; however, this will appear as good news from an 'economic (water) efficiency' point of view.

by FAO's authoritativeness and conveys a sense of monitoring and control that 'creates reality', enabling comparisons and trend analyses.[10]

Made literally 'real', country-level indicators are ripe for use by state bureaucracies and politicians. The most ubiquitous example is the use of country-level per capita water endowment figures that are transformed into a water stress indicator by virtue of thresholds that are supposed to indicate the boundary between water scarcity (endowments < 1000 m^3/capita/year) and absolute scarcity (endowments < 500 m^3/capita/year). Variously ascribed to Malin Falkenmark, the UN, the FAO, or the World Bank, these 'magic numbers' are routinely used to explain and predict problems and doom by analysts or governments (see Figure 3b).[11]

Another development in the domain of water security/scarcity indicators comes from Earth Science, with remote sensing and global modelling spurring a wave of publications that produce pixel-based quantitative values and 'global' numbers. They purport, for example, to be assessing 'water stress' and to predict that "By 2050, economic growth and population change alone can lead to an additional 1.8 billion people living under at least moderate water stress, with 80% of these located in developing countries" (Schlosser et al., 2014). Another paper estimates that "by 2050, environmental flow limits will be reached for approximately 42 to 79 per cent of the watersheds in which there is groundwater pumping worldwide" (de Graaf et al., 2019). Another fascinating example is the statement that "by 2030, freshwater demand will exceed supply by 40%", with more than half of the world population facing water shortages. This prediction initially appeared in a 2009 report by the 2023 Water Resources Group, commissioned to McKinsey, and has been recycled and drummed up ever since by UN agencies, development banks and agencies of all stripes.[12] The social life of such 'global water numbers',[13] their erasing of uncertainties, their attractiveness to politicians or the media, or the role they play in policy-making are only beginning to attract academic scrutiny.

SDGs

With 169 targets and 232 indicators, the Sustainable Development Goals (SDG) have taken the indicator industry to new heights, triggering a wave of concerns (see, for example, Bandola-Gill et al., 2022; Grek et al., 2023; Bell and Morse, 2011).[14] SDG 6 on water and sanitation "seeks to ensure safe drinking water

[10] A further development of datafication at FAO includes the open-access Hand in Hand (HIH) Geospatial Platform which, "unlocks millions of data layers from different domains and sources to serve as the key enabling tool for FAO's HIH Initiative and serve digital agriculture experts, economists, government and non-government agencies, and other stakeholders working in the food and agriculture sector"; https://www.fao.org/hih-geospatial-platform/en

[11] Under the headline "CAIRO — Egyptian President Abdel Fattah al-Sisi has recently revealed that his country has reached the stage of water poverty with less than 500 cubic meters of water per capita a year", one reads: "[A] former Egyptian irrigation minister, told Al-Monitor that water poverty, as defined by the World Bank, is when a country's renewable internal freshwater resources per capita is less than 1,000 cubic meters annually, which is the minimum rate to meet the citizens' needs of water and food." Many governments use this Malthusian indicator, which mechanically decreases when population grows, to explain water availability and management problems, deflecting blame. https://www.al-monitor.com/originals/2022/01/egypt-officially-enters-state-water-poverty

[12] Recently, and although 2030 is now around the corner, the prophecy again made headlines on the occasion of the UN 2023 Water Conference in New York. The pre-summit report restated it, and so did various UN statements, (for example, https://shorturl.at/RTWY2), the self-appointed 'Global Commission on the Economics of Water' (https://turningthetide.watercommission.org), and the World Economic Forum (https://shorturl.at/jsLV3). Each time this, or other, global numbers are uttered by a seemingly authoritative source like the UN, the world media picks them up and fuels another reincarnation (see, for example, *The Guardian*; https://shorturl.at/EGQR4). Interestingly, at some point the numbers take on a life of their own and do not even need referencing.

[13] The 'father of all big numbers' is probably that tossed out in a paper by Constanza et al. (1997) for the value of the world's ecosystems. They suggested a figure of US$33 trillion per year, as compared to a value of US$18 trillion for global annual GNP. Google Scholar showed this paper to have gotten 33,000 hits.

[14] See also the article in *Global Policy*, "Special Issue: Knowledge and Politics in Setting and Measuring SDGs", at https://onlinelibrary.wiley.com/toc/17585899/2019/10/S1

and sanitation for all, focusing on the sustainable management of water resources, wastewater and ecosystems, and acknowledging the importance of an enabling environment" (www.sdg6data.org/en), and uses 11 global indicators spanning issues such as drinking water, sanitation, hygiene, wastewater, water quality, efficiency, water stress, water management, transboundary, ecosystems, cooperation and participation.

Most of the work on SDG 6 indicators is dedicated to calculating them (for example, Giupponi et al., 2018; McCracken and Meyer, 2018), disaggregating them within countries (Fraser et al., 2023; Fehri et al., 2019), identifying methodological flaws and suggesting improvements (see Hellegers and van Halsema, 2021; Guppy et al., 2019). There is little work on the process and politics that undergird their elaboration or shape their implementation.

Mdee et al. (This Issue) reflect on the political dimensions of countries' selection of numbers for SDG 6 surveys. They note that "numbers themselves must perform to particular audiences, both national and international. Aid-recipient countries, for example, must signal both to their development partners and to national audiences". Examining the SDG 6.5.1 indicator, which is aimed at assessing the degree of implementation of Integrated Water Resources Management (IWRM), they find that it hardly "drives meaningful reflection on the aims or outcomes of IWRM. Instead, [numbers] tend to hide the actually-existing political and institutional dynamics that sit behind the wicked complexity of the global water crisis". They add that maintaining a focus on the indicator allows technocrats and politicians to blur the structural underpinnings of the issue at hand and to deflect blame and responsibility. Regarding SDG water governance indices, Stefano et al. (2016) remarked that they can "trigger and feed public debate about institutional reform, but they can also become an excuse for implementing superficial changes that merely meet formal requirements".

Ecological indicators

Environmental policies and the pressure to 'govern nature' and demonstrate control over environmental health or degradation have generated a demand for environmental data and information (Waterton and Wynne, 2004; Le Bourhis, 2016). The use and growing hegemony of environmental indicators has attracted many critiques (Butt, 2018; Turnhout et al., 2007; Lehtonen, 2015; Tadaki, 2024). Indicators come in different forms. Some are merely descriptors of the state of the environment and are used to convey information, assess environmental health, or monitor evolutions. Oftentimes, a desirable state of the environment is associated with particular quantitative values, levels or thresholds. Policy objectives are therefore translated into targets (e.g. maximum level of pollutant concentration, maximum volume of groundwater that can be abstracted, or minimum environmental flow to be respected in rivers). The descriptive indicator then becomes an instrument of power and government (Bouleau and Deuffic, 2016; Lascoumes and Le Galès, 2004).

The design process of indicators shows many instances of debates between opposing coalitions that are trying either to impose a 'command and control' logic whose objective is to create stringent standards, or to monitor progress and create emulation through benchmarking. Le Bourhis (2016), for example, has documented the struggles between policy actors around the French sustainable development indicators and the European indicators that measure the 'good status' of water bodies; they show how the indicators became watered down as a result of the conflict. Likewise, Bourblanc (2016) studied the 'green algae bloom' controversy in Brittany, France they showed the entanglement of science and politics that was at play in the process of choosing whether to base an indicator on nitrogen (therefore pointing to agriculture as responsible) or phosphorus (pointing to domestic wastewater).

As we have seen above, thresholds that define the boundary between what is desirable and what is not implicitly come with causal assumptions. It may sound unproblematic that levels of pollution be correlated with human health, even despite the uncertainties and politics that are also associated with their definition. In Europe, for example, the Drinking Water Directive set the maximum allowable concentration for nitrate at 50 mg NO_3/litre in order to protect human health and water resources. Determining other thresholds, however, can be less straightforward. The e-flow studied by Molle and Collard (This Issue) commensurates widely different data on fish species, habitats, river morphology, water circulation, sediments but also human uses, all subsumed in one number that redefines the vision of what is an adequate aquatic environment, reallocates water, and reorders relationships between agriculture, society and the environment.

Another indicator that is generally understood as an objective term of the water balance is the groundwater 'safe yield'. This is frequently and mistakenly conflated with aquifer recharge. The idea is that withdrawing groundwater is 'safe' if the amount withdrawn is less than the recharge rate of the aquifer. In fact, abstracting a volume of water that is equal to the recharge volume actually draws all outflows to zero over time, with very drastic impacts on surface water and ecosystems and a spatial/social reallocation of the resource. Because this idea has long ago been demonstrated to be flawed (Bredehoeft, 1997; Sophocleous, 1997), its pervasiveness is puzzling (Molle, 2023). Balancing what is gained through pumping with what is lost (through, for example, the drying up of groundwater-dependent vegetation, springs, wetlands or rivers) and considering who is affected and how, is the perfect definition of a political process whereby the resulting 'safe yield' embodies the values, perceptions, interests and power of the various parties.

Bouleau and Deuffic (2016) have examined the politics around the construction of ecological indicators and shown how they were negotiated on the basis of their implications for stakeholders, for example in terms of assigning responsibilities or constraining behaviours and choice. Several studies have shown how, in the South of France, the controversies and negotiations around the modalities of defining e-flow thresholds reflected the shifting priorities given to pollution dilution, irrigation, or aquatic ecosystem preservation, as well as the changing interests and political clout of the parties involved (Fernandez, 2014; Fernandez and Debril, 2016; Gaudin and Fernandez, 2018). Through an analysis of lake and river indicators in France, Bouleau et al. (2009) revealed how the indicators reflected social change and shifting values/objectives, while at the same time being constrained by law and path dependency.

Simplified and streamlined to the extreme in order to be legible, such scientific tools become instruments of power and regulation (Lascoumes and Le Galès, 2004). They may integrate national or even international environmental databases, such as that of the European Environmental Agency, that claim to provide "objective, reliable and comparable" information of European significance (Waterton and Wynne, 2004).

Several authors have noted how 'successful' indicators tended to become institutionalised. Once inserted into the routine of state administrations or other authorities and regularly mobilised for the analysis of trends, indicators are taken for granted. Their users, unwittingly, further entrench both the implicit categories with their inclusive and exclusive effects, and the commensurations of values that they harbour (Rottenburg and Merry, 2015; Bouleau and Deuffic, 2016). Puy and Lankford (This Issue) also note that when a specific scientific narrative, such as the planetary boundaries framework, becomes institutionalised,

> all the assumptions, abstractions, idealizations, ethical stances, value-ladenness and worldviews ingrained in its design are forgotten and become invisible. The more papers added to that dominant body of literature, the more difficult it is to unearth its key tenets: its embedded worldviews get buried beneath conforming literature, creating the illusion that the model is a neutral simulation devoid of personal biases.

New Public Management, the corporate sector and performance indicators

New public management (NPM) is "a rationalisation drive based on the myths of efficiency and business specialisation" (Barone et al., 2018). It seeks to apply to public service administrations the performance-driven and customer-oriented type of management that is found in the private business sector (Bezes, 2020). To govern corporations as well as administrations, "[a]n entire global industry of measuring, ranking and auditing organisations and individuals has arisen based around ideas of enhancing 'quality', 'efficiency' and 'transparency', and as technologies for producing calculative, responsibilised, self-managed subjects" (Shore and Wright, 2015). While both NPM and corporate management have been fertile ground for the sociology of quantification (Bezes, 2020; Power, 1997; Mennicken and Espeland, 2019), the water sector has been little studied. Performance indicators contribute to putting NPM principles into practice for the modernisation of public water services; they particularly use a form of benchmarking called 'sunshine regulation', or 'naming and shaming', which uses the reputational effect to incentivise utilities to perform better (Bolognesi et al., 2021). On the positive side, benchmarking is also expected to incentivise improved performance and productive competition.

Canneva and Guérin-Schneider (2011) have shown how the very definition of performance indicators is strongly influenced by measurement difficulties, the expected use of indicators for benchmarking, lobbying, and the interest in foregrounding the technicity of utilities while obfuscating their less-favourable aspects such as, for example, the status of sanitation and sewerage systems. Renou (2017) has also stressed the "incessant territorialised tinkering" around the performance indicators of water and sanitation utilities in the aftermath of the EU Water Framework Directive.

Bolognesi et al. (2021) examined the performance indicators of the water utilities in the Grenoble area of France. They found that differences between the reported indicators and the actual performance of the system could be ascribed to a large number of constraints and practices they call 'socio-technical resistance', including cognitive resistances, bounded rationality, and intentional tampering or non-reporting, but also to administrative fragmentation or the technical characteristics of infrastructure.

Studies on the impact of NPM and performance indicators in the WASH sector are not paralleled by similar studies in the irrigation or hydropower sectors. This is puzzling because large public water bureaucracies – notably irrigation agencies – have also been the object of policies that are aimed at improving and benchmarking their performance. On the corporate side, however, the need for international companies to identify water-related risks, the recruitment of Environmental, Social and Governance (ESG) analysts to respond to the need to report on environmental sustainability to shareholders and the wider public, and for investment and regulatory purposes, are likely to further boost the demand for quantification (Lankford, 2022).

WATER, MODELLING AND MODEL ADVOCACY

Although the sociology of quantification has delved less into modelling than into other expressions of quantification (Saltelli and Puy, 2023), perhaps there is no more opaque, normative and therefore criticisable arena in the political production of water numbers than how mathematical models reflect, embed, evidence, and propel current water preoccupations (ter Horst et al., 2023; Krueger and Alba, 2022). From the simplest algorithms to multi-stage complex hydrological computations, models can be constructed, selected and refined to support what one seeks to prove. Models are seductively totalising because their design reflects and shapes our perceptual model of the world (Beven, 2002; Lane, 2014) and, if unqueried, of the real world itself (Savenije, 2009). In so doing, models encapsulate the objective, nature and scope of the system, their visible/visitable variables and calculations, their hidden 'black-box' assumptions and choices (ter Horst et al., 2023); they also reflect who commissions and constructs them (Melsen, 2022; Addor and Melsen, 2019). Models get to dictate not only what the resulting numbers are but how and why they are arrived at. Models beguilingly infuse political decision-making with numbers of purported neutrality (Saltelli and Di Fiore, 2020). In short, models authorise worlds.

Entwined with how mathematical abstractions licence how we see the world is the more advocational art of the politics of modelling; the manner and degree to which models are promoted, championed and disseminated. We place a strong advocacy of modelling/models (Pielke, 2007) as the antithesis to a wider and more inclusive debated scrutiny of models that many increasingly call for (ter Horst, 2023; Saltelli and Puy 2023). We characterise two advocacy pathways, one steady and amassed by peer usage and a second that is more active and rapid.

In the first pathway, a steady accumulation of use has led to widespread application often seen in peer-reviewed literature. Consider the Soil and Water Assessment Tool (SWAT), found in 3443 papers between 2008 and 2019 (Wang et al., 2019), the global water balance model (Linton and Saadé, This Issue) or the long-established FAO model or procedure for planning irrigation systems (Allen et al., 1998). Although the authority and ubiquity of these models appears unassailable (having been built over a long period of use), they contain practices and precepts that mirror a more water-abundant natural-hydrology era (Lankford, 2004) and their widespread use results from habit and convenience (Addor and Melsen, 2019). Refusal to question existing models or to develop new ones can exclude non-modellers, other scientists, and non-irrigation actors from discussions and can thus foreclose urgently needed innovation and debate (Godinez-Madrigal et al., 2024).

A second advocacy pathway is the more accelerated and often funder-enabled version. Here, in the absence of peer review and long-term iterative development, funders' interests in simple fashionable narratives can fundamentally shape models and their results. Under such circumstances, narrative world-making, modelled calculations, model testing, and dialogue have manifestly failed to cross-inform. As Beven (2002) puts it, the perceptual model of the world and the formal (mathematical) model of the world have not worked together towards an acceptable realism. To illustrate this, Puy and Lankford (This Issue) discuss how the planetary boundaries framework and modelled calculations employed by the Global Commission on the Economics of Water (GCEW, 2023) are poorly co-constructed, resulting in a weak response to their own called-for and much-needed global debate on water. GCEW's modelling is not even a case of 'all models are wrong but some of them are useful' (Box, 1976); their planetary boundaries modelling failed to stress-test and improve their perceptual model. Meanwhile, claim-making and enrolment of users and supporters, notably through social media, goes into overdrive.

Scholars have long recognised the politics of models and modelling, and the relationships between models and society's concerns (Saltelli et al., 2020; Saltelli and Di Fiore, 2023). Addressing these, their recommendations involve, among other things, an appetite for more accurate empirical data to guide model development; enhanced transparency of the modelling process and objectives (Melsen, 2022); fostering of greater model competition and choice (Addor and Melsen, 2019); encouragement of wider and more inclusive dialogue (Godinez-Madrigal et al., 2024); close interconnection between model development and its practical application (Box, 1976); and being comfortable with how models treat uncertainty and what they explicitly omit (Chong et al., 2018). Jackson (2006), however, observing the use of modelling in California's water policy, showed that "the real-world challenges of 'modeling democratically' within realms of complex and bitterly contested public policy are immense". Opening up the black box of modelling practices exposed not only technical simplifications and limitations, but also a host of "broadly sociological registers of trust, confidence, and credibility which modelers and water managers are ill-equipped by training to deal with".

CONCLUSION

Just like storylines, narratives and discourses, numbers do important political work. They produce legitimacy, conceal complexity, 'render technical', select 'what counts', give meaning to social and physical phenomena, and govern behaviour. Although the importance of quantification, numbers, metrics and indicators in society is increasingly emphasised and debated, it appears, however, that critical water studies have engaged only modestly with this debate. This is surprising given the centrality of quantification in water management and policy.

This review has identified several broad themes that call for scholarly attention. These include: the reductionism and politics of indicators in both their definition and use; the social life, use and impact of 'big numbers' as generated, in particular, by Earth sciences; the opportunistic use or ignorance of uncertainty; and the boundary work played by numbers at the science-policy interface. There is a need to unravel both the small-p and big-P politics of science-making (King and Tadaki, 2018). This refers both to the value-laden choices that scientists make at four moments of choice (theory, methodology, data, and how and for whom to apply their research), and to the process by which scientific facts are championed into social facts.

In other words, we conclude that it is urgent to extend to water sciences Espeland's (2015) call to "look at the stories that numbers generate. These stories will help us to understand how people who make and are governed by indicators make sense of them, understand the stakes of their simplification, and resist them".

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