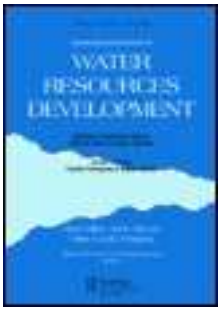

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# A critical examination of models and projections of demand in water utility resource planning in England and Wales

Gareth Walker [a]

[a] School of Geography and Environment, University of Oxford, United Kingdom

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# A critical examination of models and projections of demand in water utility resource planning in England and Wales

Gareth Walker*

*School of Geography and Environment, University of Oxford, United Kingdom*

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Demand modelling plays a vital role in water resource management yet has rarely been critically reviewed. This paper adopts a critical realist framework for a historical analysis of demand modelling practices and their role in long-term water resource management in England and Wales from 1945 to 2010. It then focuses on recent domestic demand models in the English and Welsh private water sector. A critique of scientific realist assumptions regarding demand models is presented and the role of the current regulatory environment in encouraging a highly strategic use of demand models is discussed. Policy recommendations toward more effective modelling practices are made.

**Keywords:** water demand projection; domestic demand models; critical realism; privatization; water resource planning; England and Wales



## Demand models and resource planning policy

Models and projections of demand form an essential component of long-term resource planning in water utilities. Supply-oriented planning has traditionally employed large, long-term, sunk investments which rely upon the accuracy of demand forecasts to ensure economic efficiency and security of supply. Policy has tended to regard such models of demand as scientific and objective in nature, their assumptions and projections remaining an uncontested basis for legitimizing supply projects. In more recent years, demand-side management has gained traction in resource management policy. Demand-side measures call for the use of increased efficiency in the consumption and allocation of water resources in securing a supply–demand balance and therefore represent demand as a system subject to analysis and manipulation, rather than passive prediction. The transition to demand management policy therefore comprises a change in the epistemic status of demand and its models. Policy must accept the contentious nature of demand models and projections; it must be aware of their discursive role in presenting a specific interpretation of demand which in turn prescribes specific approaches to demand management. Where this is not openly acknowledged and integrated into the planning process, there is a risk of demand models being employed to serve the strategic interests of their originators, rather than to reach socially optimal outcomes.

This paper employs a school of philosophy called 'critical realism' to analyze the structure, content, and strategic context of demand models and projections in resource planning in England and Wales from 1945 to 2010. Through critiquing the status of models as objective and scientific, the analysis demonstrates how models have been

*Email: gareth.walker@keble.ox.ac.uk

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employed strategically as discursive tools to legitimize resource management strategies. Simultaneously, the role of institutional structures in reinforcing specific approaches to demand modelling as well as shaping power and information asymmetries between stakeholder groups in resource planning is outlined. The paper concludes by discussing the need for new approaches which openly acknowledge the uncertainty inherent in demand models and their role in wider resource planning governance procedures. Specifically, UK policy must address the conflicting incentives and strong information asymmetries which privatization and its regulatory environment have generated.



## Models of demand as scientific knowledge

Boyd (1983) outlines 'scientific realism' as assuming that (1) a model's theoretical terms are understood to refer to relatively similar observable and non-observable external objects and forces; (2) models are confirmed as true through a process of scientific observation and methodological processes; (3) the historical progress of models is a case of successively more accurate approximations to the truth; and (4) the reality which models describe is largely independent of the scientist's thoughts or theoretical commitments.

Constructivist objections to scientific realism as applied to models of consumption point to their diverse and often incommensurable assumptions, observing that they do not form a consistent epistemic body of research (Sharp et al., 2011). The independence of knowledge derived from models is also questioned through observing their prescriptive nature; models of consumption are situated within a spectrum from economic-atomistic to structural-cultural models which often reflect the so-called 'deep versus light green' debate surrounding sustainable consumption (Fuchs & Lorek, 2005). Furthermore, projections and scenarios may not only endorse one course of events (Midttun & Baumgartner, 1986; Nielsen & Karlsson, 2007) but also make others inconceivable (Slaughter, 2004). A positivist–post-positivist debate emerges, in which the need for rational scientific enquiry is pitted against a need to make the biases and vested interests inherent in models explicit (Patomäki & Wight, 2000).

Critical realism makes the case that the positivist–post-positivist debate stems from a failure to separate questions of a reality independent of the observer (ontology) and the observer's socially embedded, restricted knowledge of that reality (epistemology). The scientific process is understood to be partially socialized and therefore fallible, but still relating to an external material reality and therefore subject to the scientific rationale of hypothesis testing and instrumental reliability. Social systems are argued to be 'open' or non-stationary in behaviour, generating events and temporary tendencies which emerge for periods of time, and which are in turn subjectively experienced. Scientific enquiry into such systems is therefore a constant process of abduction and hypothesis testing in which partially socialized models are employed to explain temporary regularities (Bhaskar, 1986).

The research presented employs critical realism to examine demand modelling in England and Wales in two stages. In the first, a historical analysis of the practice of long-term water resource planning and the role of demand models in England and Wales from 1945 to 2010 is carried out. The models employed in the industry are assessed in terms of the commensurability of their mathematical form, their proposed generative mechanisms, and their quantitative accuracy in projection. To test the socialized nature of models, a critical discourse analysis (Fairclough, 2003) is applied to documents which site or generate water demand data from 1945 to 2010. Sources include national resource planning strategies, water company plans, industry regulatory reports, water policy documents, independent research body outputs, and non-governmental group lobbying documents. Specific

documents are referenced throughout the article, and a complete list of documents reviewed is available from the author upon request. Having presented historical evidence for the vulnerability of long-term projections to unexpected shifts in demand and the socialized nature of demand modelling, the paper then addresses the specific case of domestic per capita modelling in contemporary water resource planning in England and Wales. A survey of the production, distribution and consumption of demand forecasts in water resource planning is presented, as well as data from 20 semi-structured interviews with key informants within the water industry, research bodies, and regulators. The interviews addressed, in order of discussion: (1) the structure and performance of demand models and the influence of regulation; (2) the impacts of (1) on approaches to demand management; (3) the role of demand model outputs in the negotiation of future resource scenarios with regulators; and (4) an open ended discussion. Interview anonymity was assured and so identities cannot be disclosed. A copy of the interview structure is available from the author.



## Results

Research outcomes are summarized below and are followed by sections detailing research findings through a historical analysis of demand modelling and resource planning in England and Wales. The historical analysis is split into three periods of reconceptualization and explores how new models are actively selected and retained by a wider context of rules, social norms, institutions, laws and policies, collectively referred to as the 'mode of regulation' (Benassy, Boyer, & Gelpi, 1979; Lipietz, 1986). The analysis then focuses on the specific case of domestic demand modelling in order to expose the impact of conflicting incentives and institutional arrangements on the demand modelling process.

A striking outcome of the quantitative analysis of long-term (5 to 10 years) national demand projections in England and Wales from 1945 to 2010 was the lack of any significant improvement in accuracy. Instead, a period of increased error in projection corresponded to a period of rapid socio-economic restructuring in the 1970s, highlighting the vulnerability of traditional demand forecasting to unexpected and complex social change (Figures 1 and 2). This period of high error coincided with a crisis in policy concerning the legitimacy of demand models and the resource strategies they prescribed. In response, the mathematical structure of models and the causal mechanisms evoked to explain demand were radically revised and replaced, suggesting a degree of incommensurability between models (see "Endorsed methods" and "Ways of representing" in Figure 3). In the last decade (2000–2010), water policy in the England and Wales has attempted to address the vulnerability of longer-term projections to complex social and climate change issues through moving away from 'models as predictions' and towards 'models as scenarios'. This has required a new form of demand modelling which explicitly acknowledges uncertainty and addresses diverse stakeholder perceptions. However, this is undermined by current institutional arrangements.

In terms of institutional design, the analysis confirms the significance not only of changes in the structure and theoretical grounding of models, but also in the context in which they are produced and shared. Wider discursive institutional structures define the conditions under which models are considered to produce legitimate knowledge (see "Epistemic frameworks" in Figure 3) and the channels through which models are produced, distributed and consumed (see "Discourse practices" in Figure 3). Major changes in model structure and practice coincided with the institutional restructuring of the water industry, suggesting a significant influence of institutional design on the successful uptake of new modelling approaches. This has significant policy implications for demand modelling in the

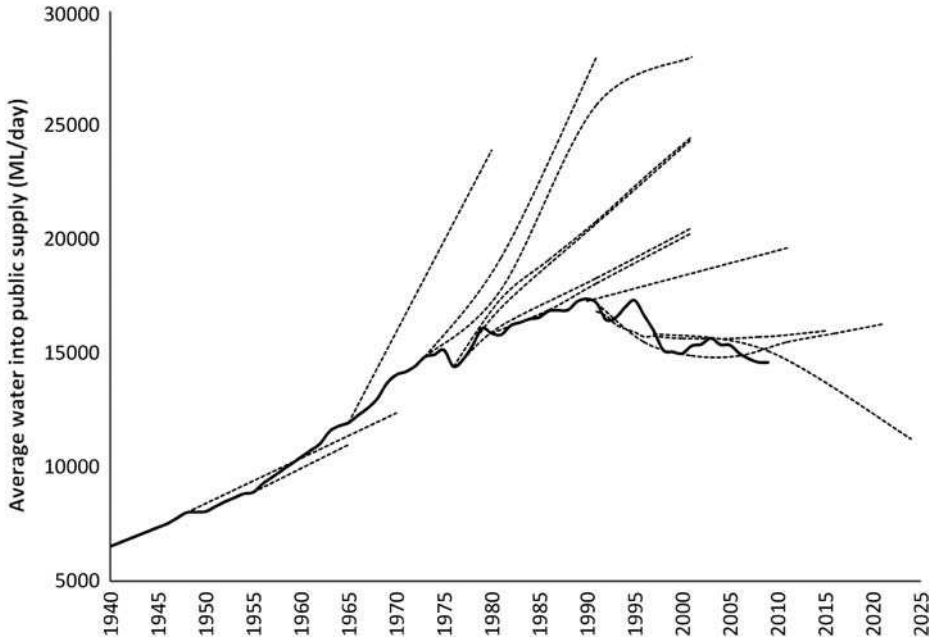


Figure 1. Selected projections of water into supply (dashed) vs. reported (solid), England and Wales. Notes: Pre-1955 "water into supply" data based on industry surveys acknowledged as incomplete and hence likely to be underestimates. Post-1955 data based on standardized industry reporting. Projection sources displayed (in chronological order of origin) are: Ministry of Health (1949); CAWC (1959); industry opinion as quoted in Skeat (1965); "locally based" industry projections from WRB (1973); "alternative" government projections from WRB (1973); CWPU (1976); "upper" projection from CWPU (1977b); NWC (1982); composite of water company projections from NRA (1992); "managed" "most likely" projection from NRA (1993); composite company projections from Ofwat (1994b); "delta" scenario from EA (2001); composite of water company business plan projections submitted to Ofwat in 2009.

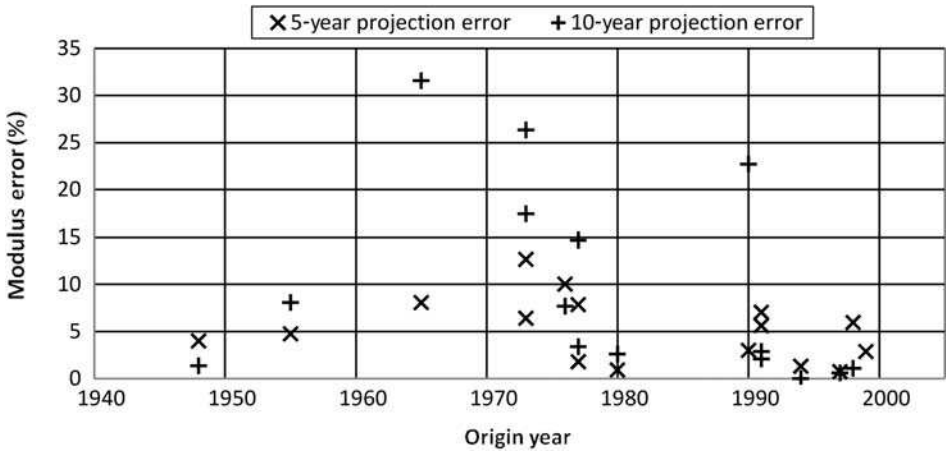


Figure 2. Modulus error for 5- and 10-year projections, sorted by year of origin. Note: Errors calculated on discrepancy between "water into supply" and projected values. Data sources listed under Figure 1.

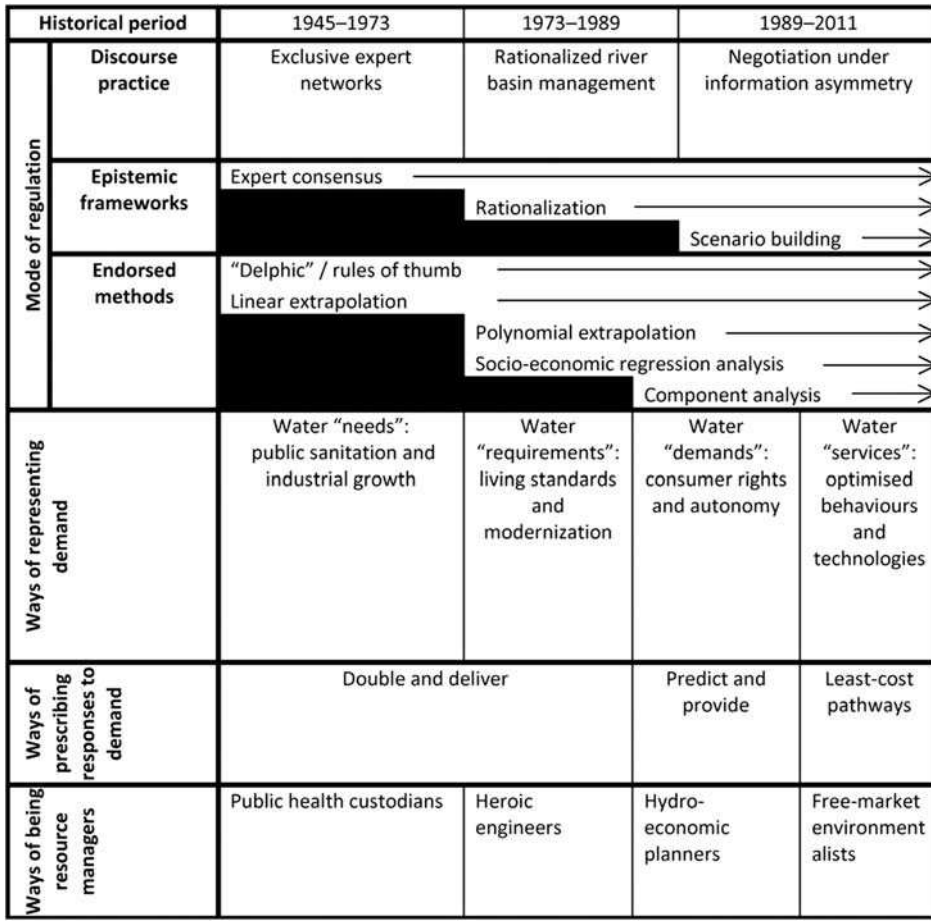


Figure 3. Representations and practices surrounding demand modelling across time.

context of the current privatized water industry, as standardized regulatory reporting tends to resist experimentation and innovation in demand modelling methods.

Finally, models not only provide projections of future conditions, but specific representations of demand and endorsed responses which are shaped by wider socio-political contexts (see "Ways of representing", "Ways of prescribing" and "Ways of being" in Figure 3). A historical analysis shows many instances of demand models being employed discursively as a mechanism to underpin coordinated action in resource planning. Models provide a shared, intersubjective rationalization and explanation of observed demand patterns and prescribe and legitimize resource planning decisions (Jessop, 2004). As such, they are powerful strategic tools which often reflect the interests and strategies of their originators. This is of particular relevance to the current institutional context of privatized resource planning, where principal-agent problems drive a strategic use of modelling in transferring financial and political risk between government, regulators, and private companies.

### *1945 to 1973: the age of experts and no surprises*

Post-war water resource planning in Britain was heavily influenced by a remit of rehousing and economic development and carried out by a self-governed group of engineers and experts, later formalized in 1963 through establishment of the Water Resource Board (WRB) which took on a central advisory role for all resource planning in England and Wales (Guy & Marvin, 1995; McCulloch, 2006). Operating under a sense of stewardship over public health and with the authority of expert knowledge, successive committees assessed current and future water consumption at a national scale. Each assessment consisted of a fairly informal and incomplete survey of local water managers' "best estimates" of unmeasured (domestic and leakage) and measured (industrial) consumptions, and each described a vaguely linear increase of net water into supply and per capita consumption (PCC).[1] Each attributed this trend to the "rising standards of health and personal hygiene" (Ministry of Health, 1949) which had seen dramatic increases through the nineteenth century as well as the period of post-war economic development and growth in industry (CAWC, 1959, 1962; Hassan, 1998; Ministry of Health, 1949). This interpretation cemented the view that there was "no reason to suppose that this increase will not continue" (CAWC, 1959). Water demand was essentially a black box, external to the industry, linear in behaviour, and to be accommodated; hence resource planners "should not themselves determine the pattern of development" (CAWC, 1971, p. 45).

The consensus generated through successive advisory committees and later through the WRB meant that a rigorous examination of the assumptions driving demand forecasts was unnecessary where a cautious, business-as-usual, linear extrapolation would suffice. Herrington (1973, p. 30) summarizes the dominant process for legitimizing demand forecasts at the time:

> A forecast based on something little more advanced than a hunch (usually extrapolation) may be quoted over and over again, and often come to be uncritically accepted by those charged with the prediction of demands.

Any suggestion that projections were overestimates was deemed an unnecessary risk, and attempts to influence consumption were strictly limited by concerns of public health and economic production. In commenting on the possibility of demand management, the Ministry of Health (1949) stated, "it is not within the national interest to attempt to restrict the consumption of water put to legitimate use" and warned that "the task of providing homes for all with modern sanitation will take many years to complete". Similarly, any attempt to influence industrial consumption "might do serious damage to individual industries" (Herrington, 1973, p. 3) and in any case it was "beyond the powers of any single water undertaking to decide what was appropriate in each case and to refuse to supply any more" (HLG, 1963, p. 3).

As housing and industrial growth accelerated over the 1960s, resource planners altered their trend-based approach to include exponential projections of growth in consumption, and by 1973, the Water Resources Board estimated that water into supply would effectively double, from 14,000 ML/day in 1973 to 28,000 ML/day in 2001 (Figure 1: WRB, 1973, the highest projected consumption for year 2000).

### *1974 to 1989: restructuring and rationalization*

The practice of demand modelling and its place within water resource planning shifted dramatically in the period from 1974 to 1989. While the WRB had achieved consensus in representations of demand and its projection, it was at most an advisory body (McCulloch, 2006). The government argued for an authority able to manage competing

demands and coordinate development at the river basin scale (CAWC, 1971; WRB, 1973), and in 1973 the industry was consolidated into 10 river basin authorities and 24 water supply companies. The National Water Council (NWC) and Central Water Planning Unit (CWPU) were established as a means of standardization in measurement and reporting across water authorities. The CWPU keenly observed in its annual report that reorganization provided "the opportunity for rationalising the administrative mechanisms by which the industry formulates its forwards demands" (CWPU, 1976, p. 18). In contrast to the expert-driven forecasts of the WRB, the legitimacy of demand forecasts was now defined by the formalized approaches embodied in this new institutional structure.

> Until 1974 responsibility for demand forecasting lay with a large number of mostly small water supply undertakings and sewerage and sewage disposal authorities. Only since 1974, when 10 large Water Authorities were created, has there been much interest in the formal modelling of water demands and discharges. (CWPU, 1977c, p. v)

This drive for a standardized approach coincided with a dramatic change in the behaviour of demand. From 1975 onwards, economic recession struck and industrial demand not only changed pace, but began to reverse (Figure 4). Similarly, a period of unusually low rainfall in 1975–76 and subsequent restrictions on consumption saw the first observed case of a decrease in domestic consumption (visible in Figure 4 as a dip at 1976), triggering the first genuine discussions concerning the potential of public communications and efficiency measures to contribute to security of supply (NWC, 1978). Linear projections fell out of favour on both their empirical and philosophical merits. The CWPU put forward an almost Humean criticism of the inductive logic which had previously supported trend analysis:

> Even where the past trend has been stable and is easy to identify there is no guarantee that the trends will not change in the future, and for this reason projections of past trends cannot be regarded as forecasts in the strict sense of the word. (CWPU, 1977b, p. 3)

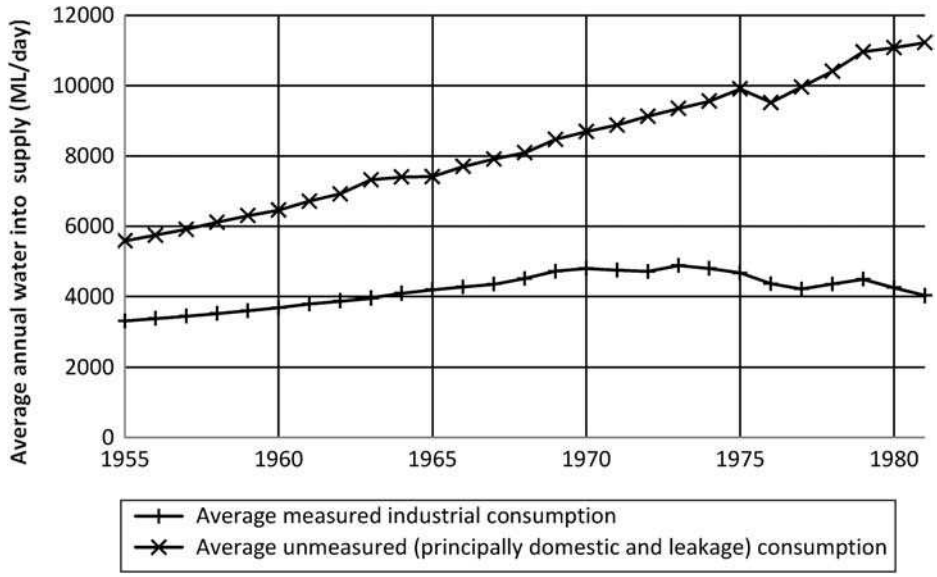


Figure 4. Reported average measured and unmeasured consumption of water in public supply in England and Wales, 1955–1981. Data sources: CAWC (1959); CWPU (1977b); WSA (1990).


Figure 5. Measured industrial consumption and industrial production in England and Wales, 1955–1990. Data sources: Index of industrial production ONS (2012); Measured industrial water consumption (CAWC 1959); CWPU (1977b); WSA (1990).

Extrapolation and trend analysis were ill-equipped for the task of explaining a complex system such as consumption because they made "no attempt to understand why consumption is rising or falling" (CWPU, 1976). Planners were forced to re-evaluate the mathematical structure of their models and the causal mechanisms they enlisted. Multiple studies investigating the predictive power of socio-economic variables in both metered (industrial) and unmetered (domestic and leakage) demand were carried out. The results were not encouraging; a movement of employment away from manufacturing to the service sector had dissociated economic growth from metered demand (CWPU, 1977b; Figure 5). Studies which attempted more complex trend analysis or the use of socio-economic factors in explaining unmeasured domestic consumption revealed little more than a strong relation to occupancy and multiple possible trends (CWPU, 1978a, 1978b). As a result, water planners began to speculate that the assumed mechanism of increasing basic services and economic growth no longer agreed with observation, and that in turn the "scope for additional uses is limited" (CWPU, 1977b, p. 24). Ultimately this left planners with the unsettling conclusion that trends in future demand "will be attributable to different factors from those which have been important in the past" (CWPU, 1977b, p. 3).

The loss of legitimacy in industry demand projections coincided with a growing resistance to large capital projects, and as a result demand forecasts became a key battleground for competing philosophies of resource management. Kielder Reservoir, approved in 1973 (prior to the shift in demand behaviour), was becoming an increasingly obvious example of the vulnerability of large irreversible capital investments to inaccuracies in demand projections. By the time of its completion in 1982 at a cost of £150 million, it was evident that most of the water would not be required and was earmarked for transfer schemes (NRA, 1995a). This sense of economic evaluation driving the scrutiny of demand projections was summarized by the Monopolies and Mergers Commission in their review of water authority economic efficiency:

> Given its high capital intensity, avoidance of undue premature provision of facilities is a matter of importance to cost containment and budgeting. [ . . . ] the fixed capital resources involved in the supply or provision of water services are buried or otherwise immovable. Hence forecasts must relate not simply to total demand but to demand in particular areas and localities if the right service is to be provided at the right location at the right time. (MMC, 1981, p. 166)

In 1976, only three years after the approval of the Kielder Water Scheme, plans drawn up by the Southern Water Authority to flood 700 acres of farmland at Broad Oak were rejected on the basis of their use of linear projections in demand forecasting, as well as a lack of emphasis on water conservation in the form of leakage control (NRA, 1995a). A similar enquiry into raising the levels of Ennerdale Reservoir would later (in 1980) be rejected entirely on the basis of failing to take control of leakage into consideration (NRA, 1995a).

In response to the need to reclaim authority over demand projections, the water industry was forced to begin picking apart the "unmeasured" component of demand which for so long had been considered a black box of linear consumption and which, by then, represented the majority of water being placed into supply. The incidence of domestic monitoring programmes steadily increased from reorganization onwards (Figure 6), and with this increase in data came the need to develop new models of consumption. This led to the establishment of an informal network of water planners, engineers and economists who began meeting regularly under the banner of the Water Use Studies Group with a remit to propose new modelling approaches (NWC, 1982, p. 5). By 1981, the group was formalized. It included all regional water authorities, and further members from the CWPU and NWC, and became the channel through which information and best practices concerning demand modelling in the industry were communicated.

In light of the failure of top-down modelling approaches, the group began to emphasize bottom-up, reductionist approaches which explicitly sought to identify the causal mechanisms driving demand.

> Ultimately from the point of view of the development of demand forecasting models, it is causation which is of greater interest, and regression analysis, however successful it may appear, can never be considered the final word. (CWPU, 1978b, p. 13)

A "component" approach to demand forecasting was promoted which aimed to isolate domestic consumption from leakage and then further reduce domestic PCC into its

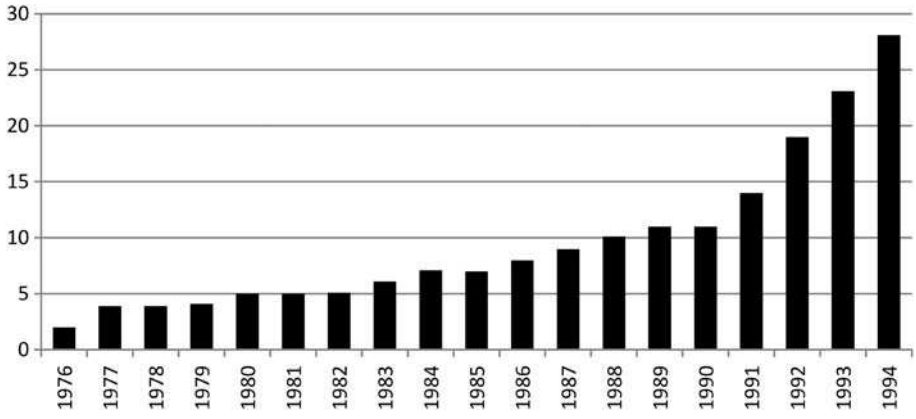


Figure 6. Number of domestic consumption monitors running in given year. Digitized copy of graph in NRA (1995b).

constituent components of appliance ownership, frequency of use, and volume per use (CWPU, 1975b). The group hoped to "construct a series of 'universal equations' for per capita household demand" (CWPU, 1975b, p. 2) which would serve alongside empirical data as a basis for demand forecasting. In reality, the approach did not represent a causal model, but served to provide a vocabulary through which to express uncertainties regarding the drivers of demand. While great effort had been put into quantifying the causal factors and providing an objective means of projection, the industry once again resorted to a consensus amongst experts as its main means of projecting consumption, albeit on a more informed and detailed platform.

> Medium-term forecast makes use of an economic analysis of past patterns of demand. Beyond five years the reliability of historically based equations is considered to be limited and a more judgmental approach is used. A Demand Forecasting Group within SWA arrives at a consensus on the longer-term forecast taking into account projections of various types of consumption and peak levels of demand. (MMC, 1986, p. 93)

By the 1980s, the component approach was widely endorsed as a replacement for trend-based and socioeconomic projections. Discussion began in earnest to establish a "national consumption monitor" which would provide component-based information. However, as the prospect of privatization became more obvious, the collaborative culture of the Demand Studies Group came into question. As one former member of the group observed:

> As privatisation approached there was a mood that "why should water authorities who had invested a great deal of work share the findings?" The group was broken up by privatization although there was some contact between individual companies. (Interview subject, 2011)

### *1989 to 2005: regulatory games and strategic constructs*

The privatization of the water industry in 1989 critically changed the distribution of information within the industry and the channels through which it was shared. As Shapiro and Willig (1990) observe, a key aspect of privatization is that it "gives informational autonomy to a party who is not under public control". Where private water company and societal objectives were misaligned, regulatory intervention became necessary and regulators were tasked with clawing back information from companies to inform policy. Under these conditions of misaligned incentives and asymmetric information distribution, a principal-agent problem ensued in which demand projections became a part of a "game" between companies and regulators.

Tasked with addressing a lack of competition and incentives for economic efficiency within the industry, the Water Services Regulatory Authority (Ofwat) employed a price-cap mechanism which required companies to report on projected costs and revenues over a five-year planning period. An unintended consequence was that forecasts for measured consumption significantly affected projected revenue and in turn represented a contested area between companies and Ofwat. As Ofwat noted in its initial analysis of demand forecasts in 1994:

> Companies have also shown caution in their forecasts of water delivered to measured customers (households and non-households) in order not to be optimistic over future levels of revenue, hence causing some understatement of the future level of demand for water. (Ofwat, 1994a, p. 11)

As domestic meter penetration began to grow, so too did the influence of demand projections on projected revenue. Ofwat repeatedly cited this misalignment of incentives in periodic reviews and tended to revise measured demand projections upwards in

approved company business plans (Ofwat, 1999, 2000). However, privatization also tasked the National Rivers Authority[1] (NRA) with a duty to assess "actual and prospective demand for water" to inform environmental protection and national resource planning. Contrary to Ofwat's view of demand as an indicator of revenue, the NRA interpreted demand under a new philosophy of "demand management".

> In the past, it has generally been practice to develop new resource to keep ahead of the rise in demand. Now, however, it is considered appropriate to identify what steps can be taken to control demand to see if new developments are really essential. (NRA, 1993)

By 1989, unmeasured demand, which included both leakage and domestic consumption, represented 72% of water placed into supply and so became the focus of the NRA's new management philosophy. Increasing unmeasured consumption was reconceptualized from an indicator of increased health and modern living standards to one of a consumer-driven demand for new levels of services embodied in high-consumption goods combined with redefined standards of "comfort, cleanliness and convenience" (Shove, 2003). Government policy redrew the boundaries of efficiency in line with this new model of consumption; beyond leakage reduction, efficiency was now to include economic principles of demand control through expanded domestic metering, the regulation and incentives towards efficiency improvements in products, and the provision of information to consumers in support of informed economic decision making. As the Department of Environment (DOE) outlined in its policy document *Using Water Wisely*:

> In order for ordinary citizens to make the maximum contribution to greater efficiency, not only in droughts but all year round, they need to have authoritative and comprehensive guidance readily available about preventing waste, and what are the most efficient ways of using water, and the relative costs. (DOE, 1992, p. 7)

A Pareto definition of optimized consumption defined not only what demand management was, but also what it wasn't. In particular, the autonomy of the consumer was not to be questioned, and any actions to address the drivers of demand for these services themselves were to be avoided.

> These uses are legitimate and necessary for the continuance of our way of life. Sometimes they are of positive benefit as in the case of a properly treated discharge, helping to supplement how the river flows. (NRA, 1993, p. 4)

This perspective continues to this day in the oft-quoted slogan of the leading water-efficiency body in the UK: "the key to water efficiency is reducing waste, not restricting use" (Waterwise, 2012).

These new concepts of demand led the NRA to interpret the calculation of "prospective demand" as a representation of its own policy aspirations rather than a summary of company forecasts. Arguing that measures to impact leakage and domestic efficiency were easily achievable, NRA forecasts became a form of coercive argument in resource planning. As the NRA noted in its consultation document at the time:

> It is considered that the "managed" forecast represents a realistic basis for the focus of the development strategy work as it is believed that it incorporates realistic assumptions of growth together with easily available measures in relation to demand management. (NRA, 1993, p. 3)

While it was recognized that NRA and water company demand projections might not align, it was not considered to be a pressing issue because they were initially in vague agreement (NRA, 1993). However, discrepancies in regulatory and water company understandings of the role of demand forecasting in resource planning would become more apparent as resource planning was progressively "reregulated" (Bakker, 2003). Successive

droughts, in particular that of 1995, resulted in water shortages that drove unprecedented public hostility towards the privatized water industry and sparked a series of reviews and regulatory interventions. In particular, the new definition of waste was on the agenda. While customers were urged to reduce wasteful behaviour and outdoor use, water companies were in return accused of not addressing leakage (POST, 1995).

Over the following years, regulation's influence on demand forecasting and reporting grew, and with it the competition between companies and regulators to shape the discourse surrounding demand. Demand was no longer exogenous to resource planning – to be objectively predicted and responded to; instead, projections took on a hybrid form of policy aspiration, economic planning and resource management. This left the identity of projections somewhat ambiguous and brought forward the risk of losing the shared rationalization of demand which was so important for collaborative planning. Having been granted a consultative role in the development of water company 25-year resource plans,[2] the Environment Agency[3] (EA) became increasingly aggressive in promoting demand projections as a reflection of the government's policy aspiration of driving down consumption. In 2005, an independent body (Waterwise) was established by industry with a remit to reduce the upward trend in PCC by 2010, and a government-supported network of water companies, regulators, local government bodies and building research bodies was formed with a specific remit to "reduce per capita consumption in households". Similarly, the government Department for Environment, Food and Rural Affairs (Defra) established an "aspirational aim" of reducing PCC to 130 litres by 2030 (Defra, 2008) and gradually introduced new regulations for newly built properties to limit water consumption to approximately 125 litres. Meanwhile, Ofwat interpreted demand management in economic terms of increased metering and tariff reform, combined with a framework of "least cost planning" which assessed "economic levels" of leakage reduction and demand management. In both cases, the need to regulate leakage and domestic consumption led to renewed emphasis on the need to differentiate between their relative contributions to unmeasured demand – an issue repeatedly identified as a weakness in regulation (HOCCPA, 2007; Ofwat, 1996, 1997). In the absence of universal metering, the component approach promoted prior to privatization was adopted as a means of calculating leakage and domestic consumption separately (Herrington, 1996; UKWIR, 1995, 1997). The EA began to require companies to project component trajectories up to 2035 in their resource plans, establishing the approach as the principle means of regulating and measuring the impact of policy mechanisms and aspirations on future domestic demand.

To address the problem of information asymmetry, regulators began to rely more heavily on inter-company comparisons of PCC and leakage figures as indicators for "reasonable" estimates. Unfortunately, a growing picture of high spatial variance in PCC emerged, which the industry struggled to explain, and once again the problem of providing a causal model for demand re-emerged in the privatized context; studies repeated the search for explanatory variables in socio-economic data and once again failed (Chambers, 2005; EA, 1998). A tension was developing between the need to standardize and compare demand projections, the seemingly unexplainable spatial variance of demand patterns across water companies, and poorly defined boundaries between economic, resource-planning and policy interpretations of demand projections.

### *A case study of domestic demand modelling*

Domestic demand represents the majority component of water into supply and as a result PCC has become the focus of many of the issues in demand projection and regulation

Table 1. Sources cited for observed demand in England and Wales.

| Sources cited for observed demand | Not used/ mentioned in document | Primary observation | Demographic analysis | *Referenced third-party bodies* | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | UK Water Industry Research (UKWIR) | Market Transformation Programme (MTP) | Water Research Council (WRC) | Waterwise | National Policy Targets |
| Household demand | 0% | 84% | 12% | 0% | 0% | 4% | 4% | 4% |
| Per capita demand | 4% | 52% | 16% | 0% | 0% | 0% | 0% | 4% |
| Micro component values | 28% | 56% | 0% | 12% | 24% | 16% | 36% | 12% |

Notes: Percentage based on: "household demand" or "per capita demand" or "micro component values". Based on complete sample of draft Water Resource Management Plans submitted to the E.A.Only sources which occurred in more than 5% of water resource management plans sampled in January and February of 2011 are included. Resource planning documents do not represent a complete summary of data used by companies, and are therefore only an approximate measure of the relative role of information sources.

Table 2. Sources cited for projected domestic demand in Enlgand and Wales.

| Sources cited for projected demand | Not used | Demographic analysis | Meter impacts | *Referenced third-party bodies* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UKWIR | MTP | WRC | Waterwise | CCDEW study | Herrington (1999) | EA | National Policy Targets |
| Household demand | 0% | 0% | 32% | 8% | 0% | 4% | 0% | 16% | 0% | 0% | 32% |
| Per capita demand | 4% | 12% | 20% | 12% | 0% | 12% | 0% | 40% | 4% | 8% | 56% |
| Micro component values | 24% | 0% | 4% | 4% | 32% | 16% | 16% | 16% | 16% | 20% | 12% |

See notes for Table 1.

reviewed above. Having identified multiple and conflicting conceptualizations and incentives relating to demand modelling, as well as the limited performance of long-term demand projections, the research focused specifically on the construction of PCC projections. A review of resource plans (see Table 1 notes for details), reveals that current and projected domestic PCC figures are constructed through several distinct epistemic frameworks. Estimates of current domestic demand are a hybrid of primary observation through company metering, surveys and monitoring programmes; demographic analysis; referenced third-party sources; and national average policy values (Table 1). Projected demand also represents a mixture of economic and demographic extrapolation and modelling; referenced third-party projections; and government policy aspirations (Table 2). This mixture of empiricism, consensus and aspiration as the driving frameworks for legitimizing knowledge concerning demand in turn creates tensions and conflicts in the interpretation of final figures.

In observed demand, the need to accurately describe local variance in domestic consumption patterns conflicted with the widespread practice of circular referencing, in which isolated studies would continually be re-referenced until they were gradually accepted as "standard", an issue previously identified by Herrington in the 1970s. In projected demand, the status of model outputs as scientific "projections" conflicted with both circular referencing and the inclusion of government policy targets. For example, while many companies project new properties to conform to a building code standard of 125 litres per head per day, original documents outlining the use of those building codes specifically stated:

> It [the Building Code estimate of water consumption] is also not capable of calculating the actual potable water consumption of a new dwelling. Behaviour and changing behaviour can also have an effect on the amount of potable water used throughout a home. (CLG, 2009, p. 5)

A further prominent example was the government "aspiration" of achieving a PCC of 130 per day by 2030 (Defra, 2008), which over the course of the resource planning process gradually assumed the form of a target (in the perception of many of the interviewees). While a broad expectation was placed on companies to demonstrate progress towards this figure as well as a mandatory water efficiency target of one litre per property per day (Ofwat, 2007), the aspiration will ultimately be missed under current industry projections (Figure 7). Demand projections therefore struggled to reflect local variances while simultaneously accounting for homogeneous national average targets employed by policy and regulation. This relatively murky process of constructing PCC figures was noted by Portsmouth Water in its resource plan:

> The Environment Agency collected micro component data from the water companies for the Draft Water Resources Management Plans (May 2008). This data was not published by the Environment Agency and some of the companies radically altered their pcc forecasts for the Final Water Resources Management Plan. Radical changes in pcc would have required a major revision to the micro components. There does not appear to have been any public debate about the logic of such major changes to micro component. (Portsmouth Water, 2009, p. 3)

### *Triggers and alarm bells*

The impact of modelling demand without expressing uncertainty or epistemology became particularly obvious in cases where projections were scrutinized by regulators. Demand projections were often described in interviews as setting off "triggers" or "alarm bells" with regulators under specific conditions. One trigger was a projected but narrow supply–demand deficit, in which companies were considering resource options such as reservoirs. As seen in earlier cases prior to privatization, the environmental and social concerns surrounding such developments triggered a scrutiny of demand forecasts as a means of

contesting their legitimacy. In the case of South East Water (one of three companies brought to public enquiry over their 2006 resource plans), the EA's statement of case outlined that:

> Resource (and in particular reservoir) developments appear to feature heavily in South East Water's selected options and more so than seems necessary, particularly if demand forecast and demand management assumptions are critically examined. (EA, 2010, p. 5)

The EA correctly observed the large uncertainty surrounding future demand forecasting assumptions and the possibility of alternative trajectories of demand. However, the debate surrounding the grounds for generating future projections emphasized the possible, the probable and the reasonable interchangeably, and as a result the final conclusions of the planning inspector simply accepted that under conditions of high uncertainty, a competition over the "correct" forecasts was futile:

> Water resources plan-making is principally based on the forecasting of water demand and water supply over the planning period of 25 years. Forecasting is not an exact science. It cannot predict future levels of water supply or water demand with certainty, and it does not purport to produce the 'right' answer. The statutory language recognizes this, hence, for example, the Act requires the plan to contain '*the water undertaker's estimate*' of the quantities of water required to meet its obligations, and the '*likely*' sequence and timing of final plan options. Differences of opinion will arise as to what assumptions or judgments should or should not have been made, as to the reliability and interpretation of data upon which forecasts are based, and so on. These inevitable uncertainties increase as the forecasting period runs into the future. (Planning Inspectorate, 2010, p. 11)

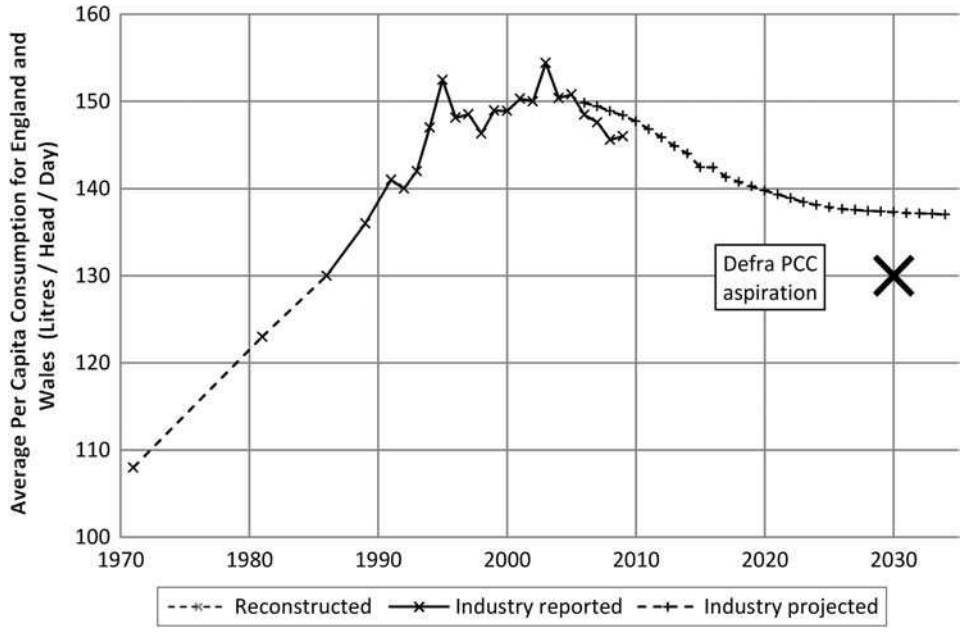


Figure 7. Reconstructed, reported, and projected average per capita consumption (PCC) for England and Wales. Per capita consumption data sources: Reconstructed: 1971, 1981, Herrington (1996); Industry reported: 1986, 1989, WSA (1990); 1991, Ofwat (1992); 1992–1994, Ofwat (1993–1995); 1995–2000, Ofwat (1997–2001); 2000–2006, Ofwat (2003–2007); 2006–2008, Ofwat (2011). Industry projected: sourced from "Normal Year 2006/07 Baseline" projections in draft Water Company Resource Management Plans submitted to E.A. in 2007 (weighted by population).

The second "alarm bell" sprang from the use of comparative regulation in assessing demand forecasts. Where companies were identified as being outliers, their projections were often challenged and recalculated to be in better agreement with neighbouring company assumptions. However, the industry still struggles to explain the remaining variance in demand projections (Figure 8), and, partially in response, an informal network of water resource planners has developed to share information and generate consensus over a legitimate means of generating demand forecasts. This Demand Forecasting Group shows a striking similarity in function and provenance to the Water Use Studies Group of the 1970s. However, comparative regulation bears the risk of artificially normalizing projections; consensus may be reassuring when arrived at independently, but when artificially generated it may simply represent an endorsed narrative or "majority rules" opinion.



### *Demand models and the transfer of risk*

The lack of transparency in the generation of demand forecasts and their uncertainty, the conflicting incentives of various actors involved in the modelling process, and the asymmetry of information between them have combined to turn demand forecasting into a form of risk negotiation (Figure 9). Demand forecasts become intensely contested narratives of future events, each legitimizing different objectives, each relying on very different epistemic frameworks. These risks are broadly divided between short-term economic and long-term resource planning, and between private company and regulatory incentives.

In resource planning, the risk of policy failure is negotiated against risk to security of supply. As Bristol Water observed, any failure of government policy concerning demand would directly affect supply–demand balances. This issue was particularly evident in the most recent public enquiries. In Thames Water's recent experience, per capita projections formed a component (but not a dominant one) of the debate surrounding the legitimacy of their plan. Thames Water's resistance to assuming complete ownership of domestic demand trends is summarized in a commissioned report presented in their resource plans:

> At this moment in time, Thames Water are justified in their statement that achieving the vision is particularly high risk for companies with a supply demand deficit. The vision should be aimed for, but there is considerable uncertainty in the outcomes and timescales of achieving this and therefore, planning on the basis of 130 l/h/d is potentially high risk. (Artesia Consulting, 2008)

Similarly, in the Planning Inspector's report on South East Water's public enquiry, it was concluded that:

> The demand forecasts in a water resources management plan should be "realistic", rather than purely aspirational. This is because the consequences of having too little water supply are greater than those of having too much. As a generality, it can be said that it is easier to defer a planned new resource should demand at some point in the future turn out to be lower than expected than it is to accelerate a new resource if demand is higher than expected. (Planning Inspectorate, 2010, p. 9)

Demand forecasts at a resource planning level therefore began to represent a proxy through which government and the water industry negotiated the relative importance of risk in policy failure versus risk in security of supply, albeit in an indirect, non-transparent way.

A similar negotiation arose between economic and resource-planning objectives. Internal to the companies, a number of resource planners interviewed noted that projections of domestic consumption sometimes conflicted with economic planning within the company. Interviewees noted that uncertainties surrounding demand management options may translate to uncertainties in revenue streams and that in other cases forecasts

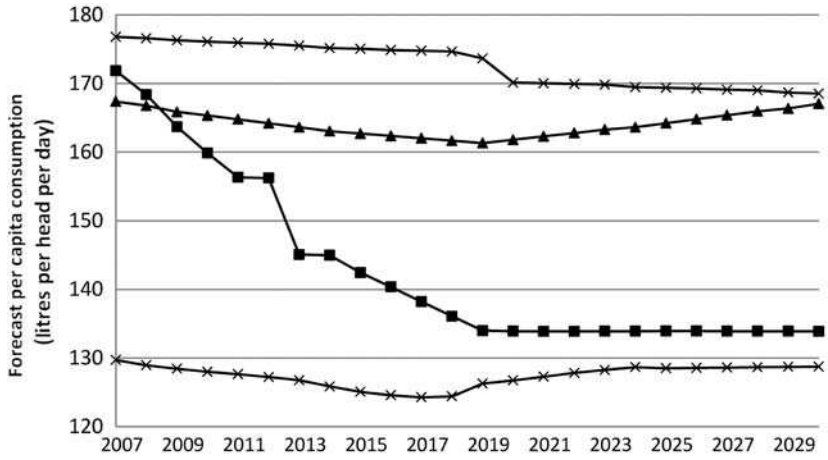


Figure 8. Four sample water company dry year PCC projections. Specific water companies not stated for neutrality purposes. Data sourced from projections in draft Water Company Resource Management Plans submitted to E.A. in 2007.

which were deemed too high were believed to result in lower price allowances from Ofwat. These negotiations are carried out in separate 5-year economic plans, resulting in a potential mismatch in projected demand. Instances of measures to influence demand (in particular metering and water efficiency) in water company resource management plans confirmed by the EA but rejected by Ofwat on the grounds of economic efficiency were frequently cited by interview subjects. By September 2009, the head of the industry's representative body commented on the observed discrepancy between the plans by stating it was "hard now to say whether companies, Ofwat and the government are still going down the same track" (*Utility Week*, 2009).

## Conclusions

The adoption of demand management principles in resource planning requires a new interpretation of the knowledge derived from demand models and the institutional structures which channel it. Demand modelling must move away from a purely predictive practice and instead become a means for actively learning and re-evaluating our understanding of consumption while discussing possible trends of socio-technical change. Where the challenges facing water resource planning involve complex socio-ecological systems, it will often be the case that shared problem perceptions are not initially aligned. New approaches to modelling must attempt to facilitate collective learning and the development of shared problem perceptions in the modelling process. This reflects a wider need for participatory policy design in water resources (Pahl-Wostl, 2005).

In the case of the English and Welsh water sectors, the regulatory process plays an essential role in shaping the generation and dissemination of demand projections. Current institutional structures introduce conflicting incentives between agents involved in the modelling process, and as a result the EA, Ofwat, water company resource planners, water company financial planners and other external stakeholders approach demand modelling in resource planning from a highly strategic, competitive vantage point. Models are often pitted against one another and compete for legitimacy. As a result, transparency in the generation of knowledge from demand models is undermined; the inherent uncertainties of model projections are not expressed, the conflicting incentives and biases of the agents

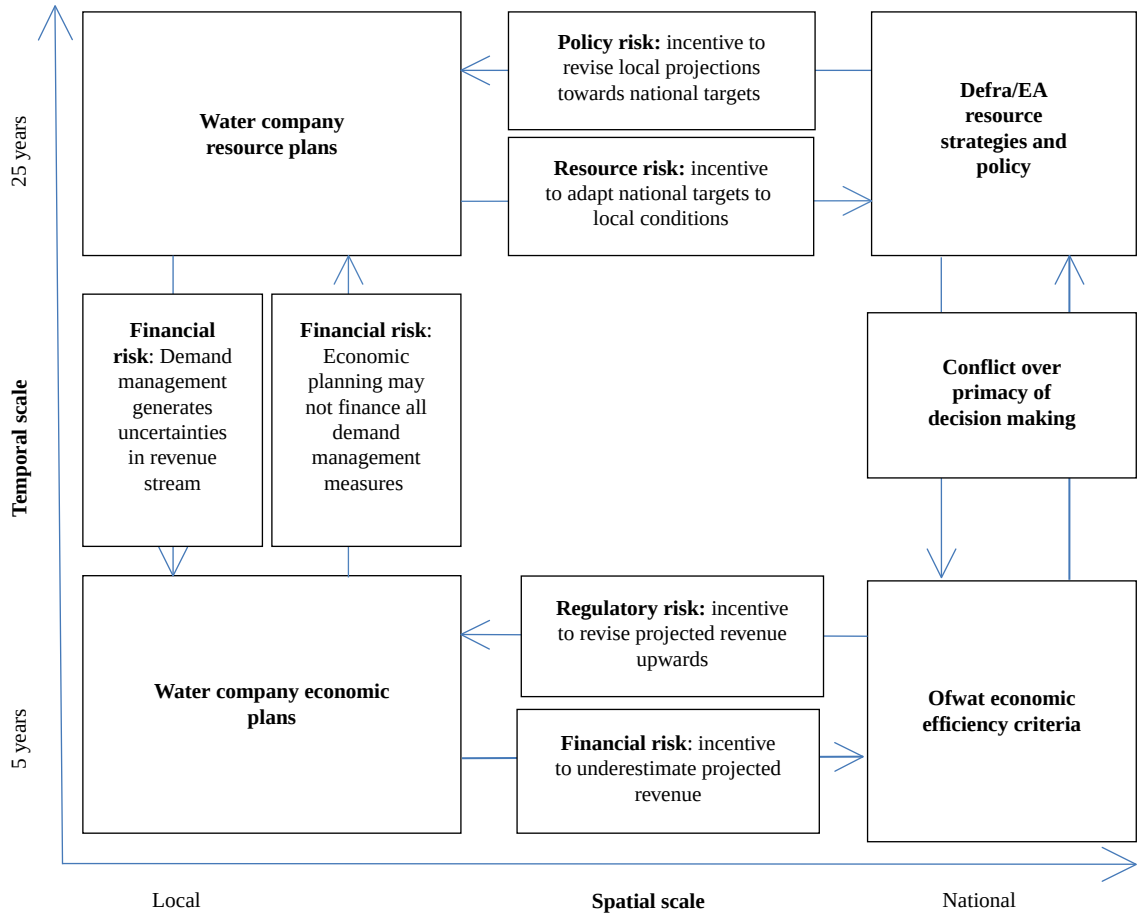


Figure 9. Conceptual model of transfer of risk.

involved remain unacknowledged, and the risk of models being used as a form of discursive power is overlooked. To mitigate such behaviour and support a more learning-based approach, UK policy must seek a means of removing demand modelling from the 'regulatory game' which is played out between companies and regulators.

To this end, the critical realist interpretation of scientific enquiry as a partially socialized process becomes an appropriate position for theoretical analysis. The critical realist hypothesis of social systems as *open systems*, governed by underlying generative mechanisms which may be inactive or interactive processes, argues that what is observed is in fact only a set of temporary regularities. This has significant implications not only for the status of long-term demand projections, but also for any effort to predict the outcomes of efforts to alter water users' behaviour. A historical analysis argued that the process of demand modelling is one in which temporary regularities are observed and mathematical models are hypothesized. These models are underpinned by assumed but only partially observed causal mechanisms. Following unexpected shifts in demand behaviour, radically new conceptualizations of demand are proposed which tend to be incommensurate with their predecessors. With respect to the critical realist claim concerning the socialized nature of models, the paper has cited multiple examples of how models of demand are inherently value-laden and employed strategically to legitimize actions. It is therefore important to recognize this as an issue not only of policy but, at a more fundamental level, of epistemology.

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**Notes**

1. Later the Environment Agency.
2. Reinforced in later years by the 2003 Water Act, which made the consultation and publication of these plans a statutory requirement.
3. Having taken over responsibility for environmental regulation from the NRA in 1996.

**References**

Artesia Consulting (2008). *Defra's vision for new and existing household per capita consumption: Study for Thames Water*. Bristol: Artesia Consulting.

Bakker, K. J. (2003). *An uncooperative commodity: Privatizing water in England and Wales* (1st ed.). New York: Oxford University Press.

Benassy, J. P., Boyer, R., & Gelpi, R. M. (1979). Régulation des économies capitalistes et inflation. *Revue Économique*, *30*(3), 397–441.

Bhaskar, R. (1986). *Scientific realism and human emancipation* (1st ed.). London: Verso.

Boyd, R. N. (1983). On the current status of the issue of scientific realism. *Erkenntnis*, *19*, 45–90.

CAWC (Central Advisory Water Committee). (1959). *Sub-committee on the growing demand for water (interim report)*. London: Her Majesty's Stationery Office.

CAWC. (1962). *Sub-committee on the growing demand for water (final report)*. London: Her Majesty's Stationery Office.

CAWC. (1971). *The future management of water in England and wales*. London: Her Majesty's Stationery Office.

Chambers, V. K. (2005). *Increasing the value of domestic water use data for demand management: Summary* (Summary Report No. P6805). Swindon: WRc.

CLG (Communities and Local Government). (2009). *The water efficiency calculator for new buildings*. London: Communities and Local Government Publications.

CWPU. (1975). *Household use of water*. London: Her Majesty's Stationery Office.

CWPU. (1976). *Annual report 1975/1976*. London: Her Majesty's Stationery Office.
CWPU. (1977). *Public water supply in 1975 and trends in consumption*. London: Her Majesty's Stationery Office.
CWPU. (1977b). *Modelling of water demands and waste-water discharges in England and Wales*. London: Her Majesty's Stationery Office.
CWPU. (1978a). *Long term trends in per capita consumption from public supplies*. London: Her Majesty's Stationery Office.
CWPU. (1978b). *Impact of social and economic factors on consumption from public water supplies*. London: Her Majesty's Stationery Office.
Defra (Department for Environment, Food and Rural Affairs). (2008). *Future water: The government's water strategy for England*. London: Her Majesty's Stationery Office.
DOE (Department of Environment). (1992). *Using water wisely*. London: Her Majesty's Stationery Office.
EA (Environment Agency). (1998). *Review of selected water company reports on the estimation of unmeasured household per capita consumption*. London: Her Majesty's Stationery Office.
EA. (2001). *Water resources for the future: A strategy for England and Wales*. Bristol: Her Majesty's Stationery Office.
EA. (2010). *Environment agency statement of case: Inquiry in connection with a draft water resources management plan prepared by South East Water PLC*. London: Her Majesty's Stationery Office.
Fairclough, N. (2003). *Analysing discourse: Textual analysis for social research*. London: Routledge.
Fuchs, D. A., & Lorek, S. (2005). Sustainable consumption governance: A history of promises and failures. *Journal of Consumer Policy*, *28*(3), 261–288.
Guy, S., & Marvin, S. (1995). *Planning for water: Space, time and the social organisation of natural resources* (Working Paper No. 55). Newcastle Upon Tyne: University of Newcastle.
Hassan, J. (1998). *A history of water in modern England and Wales*. Manchester: Manchester University Press.
Herrington, P. (1973). *Water demand study*. Leicester: University of Leicester.
Herrington, P. (1996). *Climate change and the demand for water*. London: Department of Environment.
HLG (Housing and Local Government). (1963). *Conference on water resources in the north west*. London: Her Majesty's Stationery Office.
HOCCPA (House of Commons Committee of Public Account). (2007). *Ofwat: Meeting the demand for water. Twenty-fourth report of session 2006–07*. London: Her Majesty's Stationery Office.
Jessop, B. (2004). Critical semiotic analysis and cultural political economy. *Critical Discourse Studies*, *1*(2), 159–174.
Lipietz, A. (1986). Behind the crisis: The exhaustion of a regime of accumulation. A "regulation school" perspective on some French empirical works. *Review of Radical Political Economics*, *18*, 13–32.
McCulloch, C. S. (2006). The Kielder Water Scheme: The last of its kind? In *Improvements in reservoir construction, operation and maintenance: Proceedings of the 14th conference of the British Dam Society at the University of Durham from 6 to 9 September 2006* (pp. 196–210). Durham: University of Durham.
Midttun, A., & Baumgartner, T. (1986). Negotiating energy futures: The politics of energy forecasting. *Energy Policy*, *14*(3), 219–241.
Ministry of Health. (1949). *Committee on causes of increase in consumption of water (interim report)*. London: Her Majesty's Stationery Office.
MMC (Monopolies and Mergers Commission). (1986). *A report on water supply and distribution services of the authority and the companies: Forecasting and leakage control*. London: Her Majesty's Stationery Office.
MMC. (1981). *A report on water services supplied by the authority and the companies*. London: Her Majesty's Stationery Office.
Nielsen, S. K., & Karlsson, K. (2007). Energy scenarios: A review of methods, uses and suggestions for improvement. *International Journal of Global Energy Issues*, *27*(3), 302–322.
NRA (National Rivers Authority). (1993). *National water resources development strategy: Water company consultation paper*. London: Her Majesty's Stationery Office.
NRA. (1995a). *Measures to safeguard public water supplies*. London: Her Majesty's Stationery Office.
NRA. (1995b). *Domestic consumption monitoring survey* (DMC Project 5). London: Demand Management Centre.

NWC (National Water Council). (1978). *The 1975–76 drought: A report*. London: Her Majesty's Stationery Office.
NWC. (1982). *Components of domestic demand*. London: Her Majesty's Stationery Office.
Ofwat. (1992). *Water delivered report: An analysis of information reported by water companies for the year 1990/1991*. Birmingham: Her Majesty's Stationary Office.
Ofwat (1993–1995). *Annual report: The cost of water delivered and sewerage collected*. Birmingham: Her Majesty's Stationary Office.
Ofwat. (1994a). *Future charges for water and sewerage services*. Birmingham: Her Majesty's Stationery Office.
Ofwat. (1994b). *Future levels of demand and supply*. Birmingham: Her Majesty's Stationery Office.
Ofwat. (1996). *Report on recent patterns of demand for water in England and Wales*. Birmingham: Her Majesty's Stationery Office.
Ofwat. (1997). *1996–1997 report on leakage and water efficiency*. Birmingham: Her Majesty's Stationery Office.
Ofwat (1997–2001). *Annual report: Report on leakage and water efficiency*. Birmingham: Her Majesty's Stationary Office.
Ofwat. (1999). *Prospects for prices*. Birmingham: Her Majesty's Stationery Office.
Ofwat. (2000). *Final determinations*. Birmingham: Her Majesty's Stationery Office.
Ofwat (2003–2007). *Annual report: Security of supply, leakage, and the efficient use of water*. Birmingham: Her Majesty's Stationary Office.
Ofwat. (2007). *Water efficiency targets* (RD 15/07). Birmingham: Her Majesty's Stationery Office.
Ofwat (2011). *Summary of performance report*. Birmingham: Her Majesty's Stationary Office.
ONS (Office of National Statistics). (2012). Seasonally adjusted index based on all industrial production industries in England and Wales (Data series "CKYW"). Retrieved from http://www.statistics.gov.uk on 05/03/12.
Pahl-Wostl, C. (2005). Participative and stakeholder-based policy design, evaluation and modelling processes. *Integrated Assessment*, *3*, 3–14.
Patomäki, H., & Wight, C. (2000). After postpositivism? The promises of critical realism. *International Studies Quarterly*, *44*(2), 213–237.
Planning Inspectorate. (2010). *Report to the Secretary of State for Environment, Food, and Rural Affairs: Enquiry into the South East Water Resource Management Plan 2010–2035* (APP/WRMP/09/02). London: Her Majesty's Stationery Office.
Portsmouth Water. (2009). *Updated Water Resources Management Plan*. Appendix 25: Microcomponents. Portsmouth: Portsmouth Water.
POST (Parliamentary Office of Science and Technology). (1995). *The 1995 drought*. Technical Report 71. London: Her Majesty's Stationery Office.
Shapiro, C., & Willig, R. D. (1990). On the antitrust treatment of production joint ventures. *Journal of Economic Perspectives*, *4*(3), 113–130.
Sharp, L., McDonald, A., Sim, P., Knamiller, C., Sefton, C., & Wong, S. (2011). Positivism, post-positivism and domestic water demand: Interrelating science across the paradigmatic divide. *Transactions of the Institute of British Geographers*, *36*, 501–515.
Shove, E. (2003). *Comfort, cleanliness and convenience: The social organization of normality*. New York: Berg.
Skeat, W. O. (1965). Trends in water engineering in Great Britain. *Journal of American Water Works Association*, *57*(7), 824–830.
Slaughter, R. (2004). *Futures beyond dystopia: Creating social foresight*. London: Routledge.
UKWIR (United Kingdom Water Industry Research). (1995). *Demand forecasting methodology* (95/WR/01/1). London: UKWIR.
UKWIR. (1997). *Forecasting demand components* (97/WR/07/1). London: UKWIR.
*Utility Week*. (2009, 16 September). Water sector seeks clarity from Ofwat over long-term strategic plans.
Waterwise. (2012). Save water: Be water wise. Retrieved from http://www.waterwise.org.uk/pages/save-water.html.
WRB (Water Resources Board). (1973). *Water resources in England and Wales*. London: Her Majesty's Stationery Office.
WSA (Water Services Association). (1990). *Waterfacts*. London: Water Services Association.