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Regulating agricultural land use to manage water quality: the challenges for science and policy in enforcing limits on non-point source pollution in New Zealand

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Abstract:
The management of non-point source pollution from agricultural land use is a complex issue for the management of freshwater worldwide. This paper presents a case study from New Zealand to examine how predictive modelling and land use rules are being used to regulate diffuse pollution to manage water quality. Drawing on a science studies conceptual framework, the research evaluates the deployment of a numeric regime to enforce compliance with resource limits. It shows that in contrast to claims that a quantitative modelled 'outputs-based' approach would provide certainty and clarity and remove ambiguity in the implementation of resource limits at the farm scale, the opposite is unfolding. It is argued from the case study that in the development of land use policy greater recognition and understanding is needed of the social and political dimensions of numbers and predictive models. This research highlights epistemological, institutional and practical challenges for the workability and enforceability of policy regimes seeking to regulate diffuse pollution that tightly link numbers derived from predictive models to compliance and enforcement mechanisms.

Keywords: New Zealand, non-point source pollution, resource limits, water quality, predictive modelling, science policy, knowledge governance

Highlights

- In contrast to assertions that numbers and models would provide clarity and remove ambiguity, the opposite is unfolding
- Seeking to resolve 'upstream' effects presents a range of challenges that centre on credibility and accountability
- While the need for credibility is shared, criteria to achieve it differ across the science policy interface
- Regulating diffuse pollution is not just a scientific and technical endeavour – it is also a social-political one

- Relying on numbers presents epistemological, institutional and practical challenges for implementing resource limits#

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1. Introduction

Worldwide, non-point source pollution from agricultural production is contributing to the nutrient enrichment of freshwater and the diminishment of water quality. Management efforts are exacerbated by lag effects. In New Zealand, the erosion and nutrient leaching legacies of past and current land use change from sheep and beef to dairy farming are merging with challenging implications for science and policy (PCE, 2013). Even with extensive improvements in land use practices and expensive mitigation, authorities have to explain to communities that water quality is likely to get worse before it gets better. This is due to nutrient losses from past land practices still moving through the system into waterways and contributing to the growth of nuisance algae and eutrophication (Goolsby et al., 2001; Howden et al., 2013; PCE, 2012, 2013; Sanford and Pope, 2013; Sims and Volk, 2013; Skelton and Caygill, 2013).

This paper examines how predictive modelling and land use policy are being used in New Zealand to manage water quality by establishing and enforcing resource limits at the farm scale to regulate non-point source pollution. It focuses on the South Island region of Canterbury where 70 per cent of the country's irrigated agriculture is situated. It is also where land use for dairy farming has expanded significantly over time. For example, dairy cattle numbers increased from 312,000 to 2.1 million between 1989 and 2009 in comparison to the North Island where the numbers shifted from 3 million to 3.8 million over the same period (Statistics New Zealand, 2010). The resource limit setting approach adopted in Canterbury has become a blueprint for recent proposals from central government to further reform water management beyond a significant national policy statement introduced in

2011. Therefore, what occurs in the region of Canterbury is of national significance. In comparison with approaches adopted in Europe and the United States, it is internationally significant given its outputs-based approach to setting resource limits and their enforcement at the farm scale.

The starting point for this research are assertions that certainty and clarity and the removal of ambiguity would be achieved under a water quality management regime that creates enforceable quantitative limits and a regulatory link between the catchment and the farm in the regulation of diffuse nutrient pollution. The analysis highlights the challenges for delivering on these claims by bringing to the fore the social-political dimensions of numbers and predictive models. The paper proceeds in five additional parts. Beyond this section, which provides further background, section 2 sets out the methodology of this research and summarizes its empirical resources. Drawing on science studies theory, section 3 presents the conceptual framework. Section 4 provides an overview of New Zealand's limit setting regime. This includes background on, and limitations of, New Zealand's unique compliance tool, a nutrient cycling model known as Overseer®, which is the key to its outputs farm-based approach to nutrient limit setting. Section 5, the discussion, renders a social-political perspective on the issues challenging the implementation of nutrient limits in New Zealand and the region of Canterbury. Section 6 presents conclusions and makes a recommendation for a different approach to the use of predictive modelling.

1.1 The Promise of Numbers

A science policy framework for limit setting in New Zealand was outlined in 2009 by New Zealand's Crown Research Institute, the National Institute for Water and Atmospheric Research (NIWA). It argued in a report commissioned by the Canterbury Regional Council

(CRC) that a lesson to be learned from its work on the potential and existing eutrophication of iconic lakes in the North Island of New Zealand (e.g. Lake Taupo and Rotorua Te Arawa Lakes) was that an approach was necessary to limit land intensification that would send clear signals well before ecological thresholds were reached or breached:

> It would be more certain for environmental outcomes, fairer, less time-consuming and more cost effective, if appropriate water quality objectives and related nutrient load limits were established before the assimilative capacity of a lake (or a river system) is exceeded. This would make the ground rules for land developers clear before they make investment decisions. Measurable plan objectives and nutrient load caps would clearly quantify the sustainable capacity of the lakes in terms of catchment land use (Norton et al., 2009, pp. 4-5).

In terms of how the numeric regime could work in practice, NIWA explained that the enforcement of limits was now possible given the existence of models that could calculate nutrient losses at the farm scale:

> Farm-scale models are now available to estimate the quantity of nutrients lost from land under specified landuses. Farm-scale models can be used to assist with allocating a catchment-based sustainable nutrient load cap amongst farm owners … Once the full allocation has been made it would be clear that the only way to intensify existing land use would be to "free-up" some nutrient credit by employing nutrient reduction measures on some other existing land in the catchment (e.g., reduced fertiliser and/or stocking rates, riparian buffer strips, wetlands etc) (Norton et al., 2009, pp. 4-5).

It has been argued by NIWA that the quantitative approach that links catchment scale loads with farm scale compliance is the only way to achieve sustainable environmental outcomes. This was its advice on the technical and scientific considerations for limit setting to the Ministry for the Environment in 2010:

> Because of the need to remove ambiguity we propose that the desired environmental outcomes should be defined by measurable (preferably numeric) and SMART (Specific, Measurable, Achievable, Relevant, and Time-bound) plan objectives. The plan's policies and rules can then justifiably set limits to resource use, such as water quality standards, that are clearly linked to achieving those measurable objectives. Plans that contain measurable objectives *and* linked limits such as water quality standards can achieve a further five important benefits for managing regional water resources (Norton et al., 2010, pp. 3-4).

These further benefits included “increased clarity” in terms of “certainty of environmental outcomes”, resource availability and conditions on users. Also included were means to manage point and non-point source discharges and their cumulative effects as well as the ability to monitor policy effectiveness. To reiterate, the key components of this framework are that it seeks to manage nutrients at the farm scale as well as instituting a regulatory link between the catchment and the farm. It is this approach that is now embodied in the region of Canterbury’s limit setting regime and central government’s proposed amendments to its 2011 National Policy Statement for Freshwater Management (NPSFM) (MfE, 2011a). It will be argued that these claims and the consequent numeric regime fail to recognise the social-political dimensions of numbers and predictive models and the implications of these critical aspects for policy implementation. Hence, the case study highlights important epistemological, institutional and practical challenges for the workability and enforceability of policy regimes seeking to regulate diffuse pollution by tightly linking numbers derived from predictive models to compliance and enforcement mechanisms.

2. Methodology

This research adopts a case study methodology (Yin, 2013). It utilises a conceptual framework to evaluate the empirical resources and draw research findings. The conceptual framework draws on literature from the field of science studies highlighting the social-political dimensions of quantification and predictive modelling. The empirical resources include publically available scientific, policy and government documents, reports and statements; sub-regional committee meeting minutes, notes and attendance observations; documentation, plans, public submissions and evidence that have contributed to the development of regional plans in Canterbury between 2011-2013; clarification and exploration discussions with those involved; the author’s observations and recordings of proceedings from attendance at regional plan hearings during October and November 2012 for the sub-region of the Hurunui Waiau; and participation in limit setting focus groups for the sub-region of Selwyn Waihora during 2012.

3. Conceptual Framework

3.1 Anticipatory Knowledge for the Preventive Paradigm

In contemporary resource conflicts public and stakeholder distrust and challenges over resource allocation and regulations are commonplace. Regulatory agencies rely on the numerical outputs of predictive modelling (and the notions of rules and objectivity they embody) to inform decision-making about current and potential environmental effects and warrant resource allocation decisions (Bocking, 2006; Pilkey and Pilkey-Jarvis, 2007; Sarewitz et al., 2000). For policymakers, management by numbers raises the prospect of rule by "autonomous knowledge and independent morality" (Latour 2004, p. 4; Stone, 2002, pp. 163-187). Shifts to collaborative governance have not markedly changed this situation (Duncan, 2013a; Scholz and Stiftel, 2005).

In New Zealand, a numeric approach to limit setting is intended, where thresholds have not been exceeded, to prevent environmental effects before they occur rather than waiting until damage is done (Norton et al., 2009). While this precautionary approach is, at least in principle, conventional wisdom, it means that our understanding of environmental effects has to be addressed with "anticipatory knowledge", as do our actions (Wynne, 1992, p. 111). Brian Wynne argues that addressing 'end of pipe' effects has been difficult enough to assign responsibility and compel change, but seeking to resolve 'upstream' effects (i.e. before they occur) presents a range of epistemological challenges that centre on credibility and accountability. While Wynne does not question the wisdom of what he identifies as the "preventive paradigm", he raises questions about the scientific knowledge we produce to operate within it and the limited capability of science and predictive modelling to address complex societal issues that are permeated by social-political and ecological indeterminacy (1992, p. 111; 2007).

3.2 Grappling with the Limits of Science

Wynne is critical of the empirical methods of science and our virtual exclusive reliance on them for operating within the preventive paradigm to the extent that such methods aggregate, standardise and average away the complexity and contingency of the real world (1992, 2006, 2007). He maintains that "[s]cience can define a risk, or uncertainties, only by artificially 'freezing' a surrounding context which may or may not be this way in real-life situations" (1992, p. 116). Furthermore, Wynne (1992, p. 119; 2007) argues that in the institutional co-production of science and policy, whereby quantitative means of science are conveniently matched with political ends, tacit normative assumptions about how the world works, and about how people and institutions behave within it, travel silently with co-produced knowledge claims. Such conditionalities are difficult to pin down and call into question when they become embedded in a string of complex predictive models (Duncan, 2008). According to Wynne (1992, 2006, 2007) they can go unnoticed until they are deployed in the real world, at which point they are realised to be inaccurate, or initial assumptions about how a policy (and the world into which it intervenes) might respond are recognised as unrealistic, too simplistic or unworkable. Overall, Wynne's work raises important questions about our ability to understand and grapple with the limits of science and its methods, how and where we produce knowledge, and how we use it to pre-emptively address environmental effects and assign responsibility for them when the indeterminacies are so extensive, yet ostensibly so unrecognisable by the science policy institutions that co-produce and deploy it (Wynne, 1992, 2006, 2007; see also Jasanoff, 2004).

3.3 The Allure of Numbers and Predictive Modelling

According to Theodore Porter, who has documented the history of accounting practices and statistics and their role in public administration, management by numbers is widely assumed to be objective and unambiguous given the "highly structured language" of mathematics (1992a, p. 644; Stone, 2002). Porter describes numbers as a "technology of trust" and a "technology of distance" (Porter, 1992a, p. 640). Numbers, and the objectivity they invoke, encourage confidence when one cannot be present to check all the details or be sure how answers have been arrived at. Hence, quantification is represented as a means for trust to be extended over long distances (Porter, 1995; 1992b). As a mode of "mechanized judgment", the apparent application of impersonal rules is assumed to eliminate the exercise of personal judgment (1996, p. 40).

The quantified language of predictive modelling contributes significantly to its allure and acceptability as an authoritative source of anticipatory knowledge. Notwithstanding the well-known limitations, for example, the extent to which predictive models are limited by data inputs and driving assumptions (Duncan, 2008), they have become the standard *modus operandi* for producing anticipatory knowledge for issues that range from climate change to fisheries management. Wynne and Shackley (1994) argue that the apparent contradiction between the limitations of predictive models and their and extensive use derives, at least in part, from the dual role they can play across the science policy interface. These authors characterise this duality in terms of a discursive repertoire (c.f. Mulkay, 1980) that embodies a tension between the use and understanding of predictive models as "heuristics", whereby they are represented as helping to improve understanding and test scenarios, as opposed to "truth machines", whereby they are represented as depicting reality and suitable for policy purposes (1994, p. 8). This tension is not only discursive. As model outputs move from sites of production (e.g. the predictive models of institutional science) to sites of use (e.g. regulatory authorities) they become reified as uncertainties and conditionalities become obscured from view and difficult to unearth and disclose (Duncan, 2008 citing McKenzie, 1990).

3.4 The Challenges in Making Numbers Work for Public Purposes

According to Porter (1996), when consistent and transparent measurement is required to demonstrate whether and/or when a regulatory threshold has been breached, a reliance on numbers can present unexpected challenges. For example, the administrative and oversight arrangements, as well as the surveillance systems that are required to keep numbers reliable and trustworthy for regulation, can become resource intensive:

> Where there is incentive to deceive, the job of keeping the numbers honest will depend on ever more detailed regulations, and on spies and auditors who are in a position to examine things in relatively full detail. *This means opening up black boxes, thus compromising those key virtues of detachment and economy that made the numbers valuable in the first place* (1996, p. 49, my emphasis).

In other words, when the stakes are high, as they are in issues of resource allocation, administration, oversight and surveillance have to be continually ramped-up and verification kept delving deeper to respond to the ambiguity inherent in the interpretation and enforcement of numbers (see also Stone, 2002). These moves are necessary to ensure the credibility and accountability of public policy. Numbers that are not standardised in some way are difficult to verify with consistency. Also, assumptions that sit behind reported numbers can be difficult to access. Furthermore, new rules intended to close off identified loop holes are difficult to introduce without undermining the entire system.

Porter argues that “[m]easurement for public purposes is rarely so simple as applying a meter stick” (1996, p. 37). A moment’s reflection on tax law in Australia or the United States and the extent of government systems and institutional infrastructure required to collect taxes illustrates how complex the enforcement of thresholds and limits can get. The risks lie in assuming that numbers can speak for themselves to resolve conflict. They also lie in failure to anticipate how ‘rule by numbers’ changes people’s behaviour. The escalation of required effort and resources can undermine the legitimate reasons for adopting a quantitative approach, such as achieving clarity and certainty in the regulation of diffuse pollution at the farm scale. Therefore, failure to make numbers work is not only resource intensive, it can lead to the loss of trust in policy frameworks and regulatory agencies thus creating challenges for implementation.

These insights, which are used here to evaluate nutrient limit setting in New Zealand, draw attention to the social-political dimensions of numbers and predictive models that are important to consider in a contested regulatory context. To summarise, I began by highlighting that our understanding and regulation of environmental effects relies on anticipatory knowledge. The task of producing knowledge that not only anticipates environmental effects but has sufficient credibility and legitimacy to substantiate regulation presents a number of epistemological challenges and opens questions about how and where we produce knowledge, whose knowledge can or should be relied upon, and what assumptions about the future underpin the knowledge used to regulate environmental effects. These are questions of knowledge governance that present strains on regulatory agencies to produce defendable knowledge. The adoption of quantitative approaches and predictive modelling, with their language of mathematics, are the assumed means to this end. While a numeric approach is compelling, its use in the policy sphere to underpin potentially punitive regulations present a range of epistemological, institutional and practical challenges when the social-political dimensions of numbers and models are brought into view. Critiques of science policy have drawn attention to the limits of the methods of science in responding to complex social-ecological issues and the normative assumptions about people and the world that unwittingly (or not) become embedded in anticipatory knowledge. The escalation of effort that has to be exerted to reduce the inherent ambiguity of numbers and their use in contested contexts can undermine the credibility and enforceability of regulatory policy. It will be argued that greater attention and recognition needs to be given to the social-political dimensions of numbers and models and the challenges that arise when the numbers derived from predictive modelling are tightly linked to enforcement and compliance mechanisms to regulate non-point source pollution.

4. Limit Setting in New Zealand

4.1 Recent Reforms

In response to concerns about existing and potential water over-allocation and the cumulative effects of agricultural land use on water quality (PCE, 2012; Land & Water Forum, 2010), in 2011 New Zealand's central government released its NPSFM. This was long-awaited central government direction on water management under the nation's *Resource Management Act, 1991* (RMA) (MfE, 2011b). The purpose of the NPSFM is to institute quantitative "enforceable limits" on water quantity and quality by local authorities across all regional jurisdictions (MfE, 2011a, p. 3). Central government amendments already alluded to seek to underpin the NPSFM with a National Objectives Framework to provide guidance to local authorities to facilitate limit setting by creating 'bottom lines' in terms of water quality standards across the country (MfE, 2013a, 2013b; New Zealand Government, 2012a, 2012b).

4.2 Aspects of Limit Setting Unique to Canterbury

There are two unique aspects to limit setting in Canterbury that have become part of central government's national reform package. Under the CRC's Canterbury Water Management Strategy (CWMS) (2010), which was put in place prior to the introduction of the NPSFM, limit setting involves collaboration at the sub-regional level to bring together community groups to decide on water quantity and quality objectives and limits. At the outset, the CRC established a science policy body known as the Land Use and Water Quality Project (CRC, 2012a; LUWQP, 2010) to help identify and translate community decisions on water quality objectives into resource limits. While this collaborative approach is seen by the regional council as eschewing inadequate top-down approaches of the past (e.g. Robson et al. 2013), Duncan (2013a, p. 221) argues that the instituted collaborative process serves to "recalibrate, aggregate and standardise" knowledges, thus stripping them of their "complexity, contingency and ambivalence". She argues that the contributions of the invited communities were deemed relevant and valid only to the extent that their inputs could be translated into the numeric regime. As well as adopting a collaborative approach to identify water quality objectives for translation into land use restrictions, Canterbury's approach seeks to formalise a regulatory link between a catchment nutrient load (CNL) and farm-scale nutrient losses to stay within or achieve that overall load (CRC, 2012a; Norton and Kelly, 2010; Robson et al., 2013).

4.3 A Nutrient Outputs Approach and How it Compares Internationally

Beyond Canterbury, limit setting frameworks vary and in many regions are not well progressed (Baker-Galloway, 2013). What is common is an outputs-based approach to nutrient limits and management. This means that land use policies apply to the quantity of nutrients leached from the root zone of land on the basis that their ultimate fate is surface or groundwater. This approach is promoted as a distinct advantage for New Zealand and is portrayed as non-prescriptive. It is maintained that rather than telling farmers what they can and cannot do on their land, it focuses on 'what comes out the other end' (CRC, 2012b; MfE, 2013a). This approach aligns with New Zealand's effects-based RMA. It differs from the land inputs-based approach to nutrient management in Europe where the focus is on the reduction of nitrogen from the use of fertilisers and statutory rules apply to zones deemed vulnerable to nitrogen leaching (Howden et al., 2013; European Commission, 2010). In New Zealand, both nitrogen and phosphorus are addressed (although in varying degrees given the tools available to quantify the losses from the root zone), and the NPSFM applies everywhere. Therefore, while the aim of prevention is shared, the policy of New Zealand compared to Europe is substantially different in implementation and coverage.

New Zealand's approach is similar to the Total Maximum Daily Load (TMDL) regime in the United States (US) where predictive modelling is used to set numeric limits by predicting the assimilative capacity of water bodies and their potential nutrient enrichment from predictions of current and/or future land use and pollutant sources (Copeland, 2012; EPA, 2013; Norton and Kelly, 2010; Sims and Volk, 2013). Like Europe, New Zealand's approach differs from the US in terms of coverage where limit setting and remedial action are triggered by impaired waters status. In New Zealand, all water bodies and/or their catchments are subject to enforceable limits and regulations under the NPSFM (and its recent proposed amendments). In New Zealand, the policy aim is prevention rather than cure where thresholds have not been exceeded (PCE, 2012, 2013).

4.4 Curtailing Democracy to Protect the Numbers

For several New Zealand locations, for example, Lake Taupo and the North Island region of Manawatu-Wanganui, limit setting has landed parties contesting and defending regional plans in the courts over several years. It is this situation, as well as high profile adversarial court cases over water allocation for dairy farming in Canterbury (New Zealand Environment Court, 2005; Weber et al., 2011), that recent reforms seek to avoid (MfE 2013a; New Zealand Government, 2012a). The portrayal of the freshwater planning system as "slow, litigious, expensive and uncertain" (New Zealand Government 2012a, p. 2) provides a persuasive argument in support of the proposal to provide an option to regional councils to suspend appeal rights on regional plans (and the nutrient limits they set) to the Environment Court and limit appeals to the High Court on points of law. It is suggested by central government that limit setting will get done faster if the existing statutory RMA process is bypassed (MfE 2013a; see also Land & Water Forum 2012a, 2012b). The finalisation of the Hurunui Waiau River Regional Plan (HWRRP) in the space of around three years supports this assertion. However, it is yet to be implemented and many issues remain to be resolved. These relate to the catchment nitrogen and phosphorus loads in the regional plan, how large scale irrigation can occur within those limits, and who should or could 'own' nutrient 'headroom' created in the past (through the conversion of border dyke to spray irrigation) still moving through the system (HWZC, 2013; Duncan, 2013b). If the changes are successful (which will require political support at the national level to amend the RMA), regional councils will be able to opt in to a fast-track limit setting process (MfE, 2013a; New Zealand Government, 2012a).

The region of Canterbury has served as a trial site for these political manoeuvres. In 2010 the publically-elected regional councillors were dismissed by central government and replaced by its chosen representatives. The basis for dismissal was that the elected council had become dysfunctional in its management of water given that a decade of work had not delivered a regional plan for the management of Canterbury's natural resources. Also, several large scale irrigation projects were stalled (Creech et al., 2010). The *Environment Canterbury (Temporary Commissioners and Improved Water Management) Act 2010* mandates the implementation of the CWMS. As explained earlier, the CWMS institutes a collaborative approach to water management decision-making (see Memon et al., 2012 for a preliminary review). It requires sub-regional zone committees to develop programmes that align water management with the following regional planning targets: drinking water, irrigated land area, energy security and efficiency, ecosystem health/biodiversity, water use efficiency, kaitiakitanga [indigenous stewardship of natural resources], regional and national economic growth, natural character of braided rivers, recreational/amenity opportunities, and the setting of environmental limits (CWMS, 2010, p. 8). Not to diminish any of these targets, two that have been especially controversial and challenging in the Hurunui Waiau and Selwyn Waihora sub-regions are the ostensibly irreconcilable objectives of setting environmental limits while, at the same time, increasing the area of irrigated land via large scale irrigation projects. It is this issue that is currently stalling the implementation of key aspects of the HWRRP.

4.5 Limit Setting in Canterbury

In Canterbury, under the CWMS and the NPSFM, CNLs and farm scale land use nutrient loss limits are being derived from modelling and incorporated into the region's now operative Land and Water Regional Plan (LWRP) via sub-regional collaborative processes and chapters that fall under the overall plan. With the modelling approach, in line with that proposed by NIWA in 2009, for most regions, a CNL is calculated and farm scale rules are used to restrict nutrient losses to an apportionment of the catchment load with a nutrient discharge allowance (NDA). Enforcement of the link between the two is important because the catchment load represents, although is not necessarily equivalent to, the assimilative capacity of a water body. Under the CWMS and the existing NPSFM, the former could be set above or below the latter, although, in proposed amendments, it will not be possible to set a CNL that would result in water quality standards going below those specified in the NPSFM – the so-called 'bottom lines'.

New Zealand's effects-based RMA provides an opportunity to enforce compliance with rules at the farm scale, which can entail a reduction in nutrient losses to those designated by good management practice or by 20 per cent of a calculated baseline. It can do this via its hierarchy of land use activities that range (in terms of their attributable environmental effects and the need to set consent conditions) from permitted through to prohibited. Failure to comply with the rules in a regional plan, such as the development of a Farm Environment Plan (FEP), having farm nutrient losses quantified using Overseer® or meeting (or going beyond) specified or good management practice nutrient loss levels, means that a permitted or controlled land use can be imposed or moved by the regional council to a restricted discretionary class or even non-complying (see http://www.rmaguide.org.nz/rma/resourceconsents/typesofactivities.cfm). This means that a farm business might be required to apply for a consent (when one was not needed previously) or a business could lose its existing consent and have to reapply for a new one and meet new requirements under a different set of conditions and restrictions (CRC, 2011; CRC, 2013). Therefore, the penalties for non-compliance (or being cast as non-compliant) are potentially significant.

4.6 Catchment Nutrient Loads and Nutrient Discharge Allowances

At the catchment scale, the nutrient load of a waterbody can be derived from predictions of a catchment's land use using a predictive model known as CLUES (Catchment Land Use for Environmental Sustainability) (see https://www.niwa.co.nz/freshwater/our-services/clues-%E2%80%93-catchment-land-use-for-environmental-sustainability-model). In effect, a CNL is an aggregation of estimations of nutrient losses from the mix of different land use types which can be extrapolated via modelling into future land use and leaching scenarios. The estimations can be used to predict catchment-wide land use nutrient losses, as well as existing and potential future states of environmental impact in rivers and lakes in terms of the effects of nutrient enrichment. From these estimations, a calculated CNL can be apportioned into a farm scale NDA. In this way, the catchment and farm scale limits can be linked – the latter is derived from the former.

4.7 Predictive Modelling for Farm-scale Compliance

Overseer® is the means by which to verify compliance with (or going beyond) specified nutrient losses in several regions across New Zealand (Baker-Galloway, 2013). It is an annual time step long term equilibrium model that was first developed in 1998 to help farmers understand their fertiliser needs and model 'what if' scenarios for their farm system. Continually updated ever since, the current version 6 was introduced in August 2012 and has already had several updates. Overseer® is jointly owned by the Ministry for Primary Industries, the Fertiliser Association of New Zealand and AgResearch, a Crown Research Institute (see www.overseer.org.nz). While it quantifies phosphorus, the numbers it produces represent only risks of run off as the model does not contain a sediment transport component that would allow predicted losses to water to be fully quantified. Hence, for the purposes of limit setting, Overseer® is very much about nitrogen leaching.

For policy purposes, the reason for using a modelling approach is that direct measurements of nitrogen leaching are impractical. Landcare Research maintains that measuring nitrate losses from grazed pasture requires many sampling devices costing tens of thousands of dollars per year. The problem is that cows urinate randomly and, given the variation in so many variables across a typical Canterbury Plains paddock, it is not possible to representatively sample urine patches and thus directly and accurately measure nitrogen losses (Lilburne, et al., 2011). Therefore, modelling is the only realistic option for regulatory purposes. Of course, these limitations make modelled conclusions difficult to verify.

4.8 Overseer® and Shifts in the Science

Although Overseer® is the critical link between the catchment and the farm scales, concerns about its use as a regulatory tool have been raised for some time by scientists, farmers, industry groups, and the owners of the model. It was a prominent issue in contention in the Environment Court challenge and High Court appeal of Horizons Regional Council's 'One Plan' by Horticulture NZ and Federated Farmers of NZ. The model's well-known levels of inaccuracy of between plus or minus 20-30 per cent in terms of predicting nutrient losses, its use by regulators in absolute rather than relative terms, and the continued release of new versions have been just three of many arguments made against extending its use beyond that of a voluntary decision support tool (e.g. agKnowledge Ltd. 2013; FAR, 2103). Notwithstanding, the Courts have to date dismissed the appeals which has served to validate Overseer® for use as a regulatory tool. Responses to the various issues have been to: a) keep improving the science that sits behind the model b) extend the coverage of the model to all farm systems and work with industry groups to ensure applicability c) not specify a particular version of Overseer® in a regional plan d) develop a protocol for Overseer® practitioners to ensure consistency of model inputs and e) require three or four year average numbers from farmers rather than a single year.

The introduction of new versions of the model, which derives from the first response to keep improving the science, has already been shown to be a significant challenge for policymakers and on-ground farm businesses regulated by the numbers. Indeed, recently, an appeal in the High Court on the Canterbury LWRP (notified on 18 January 2014) has been lodged citing this issue. In the past, it was maintained (and demonstrated statistically) that there was good correlation of outputs between different versions of Overseer® (Ledgard, 2010). This changed with version 6. For example, in the recent implementation of the Horizons Regional Council's One Plan, a farm business that was calculated to be leaching on average 28 kg/ha/pa of nitrogen with version 5 was leaching 44 kg/ha/pa with version 6. The farm's limit, according to the regional plan, was to be 22 kg/ha/pa (Nimmo-Bell, 2013). Therefore, the required reduction in nutrient losses went from 6 to 22 kg/ha/pa with the change in version. For the regional council this resulted in 80 rather than 20 per cent of consents in need of review (Bell, 2013). This was a considerable and unexpected administrative burden with far more constituents caught in the regulatory net. According to the Fertiliser Association of NZ (2012, p. 1), one of the owners of the model, version 6 has "improved" the model's drainage component to provide "more reliable estimates on shallow and stony soils which drain quickly and where there is growing use of irrigation". Hence, although nothing had changed on farm, the new version reflects more up-to-date science and data that predicts certain soils as posing a greater risk of leaching than previously predicted and, from a policy perspective, requiring greater mitigation to reduce potential losses.

Importantly, this means that with each new version of Overseer®, more *or* less leaching could be calculated from the same model inputs. These outcomes could derive from changes made in the model, which depend on what science is done (which is dependent on a range of variables, for example, research funding) and what decisions are made by the model's governance group on what should be incorporated into the model. Second, they could arise from improvements in input information to Overseer, for example, soil and climate data. For example, an update to version 6 allows information from a nationally significant soil database known as S-Map to be pulled into Overseer®. This is a new optional feature to improve the model's soil inputs. Importantly, the soil data in S-Map has recently been updated. Consequently, changes to calculations for Profile Available Water (PAW) publicised in August 2013 are characterised as very significant and somewhat surprising as new estimates indicate that, for example, the lapilli (i.e. tiny pyroclastic stones) of pumice soils hold "significant amounts of plant-available water" (Landcare Research, 2013, np):

> previous estimates of PAW in pumice soils near Lake Taupo [where a nitrogen trading scheme is in operation] have greatly underestimated water storage characteristics in these soils. We are somewhat surprised at the large PAW values that have been estimated for pumice soils containing lots of lapilli (Landcare Research, 2013, np).

According to initial calculations in Overseer®, underpinned by now-overturned conclusions about the zero water holding capacity of lapilli, these pumice soils would have been calculated to be high nitrogen leaching soils. With new understanding and calculations, these soils have a higher capacity to hold water. This means that nutrients are held for longer in the soil making those nutrients more available to plants rather than running through the soil profile (depending on climatic conditions and weather events). Consequently, the leaching potential of these soils would reduce with implications for model outputs with the reduction of leaching losses and how far away a farm business would stand relative to a farm scale limit or an NDA.

The quandary for farm businesses and policymakers is illustrated in Table 1 drawn from evidence tendered to the Canterbury LWRP hearings. It shows how variable nutrient loss calculations from Overseer® have been over four years across a group of Canterbury farms with three different versions of the model.

Year	**Overseer® version** [there are several editions of each version]	**Nutrient loss (kg/ha, average of 4 farms)**	
		N leaching	**P runoff**
2009	4	43	0.3
2010	5	40	0.3
2011	5	46	0.3
2012	6	86	0.8

Table 1: Illustration of changes in outputs of Overseer® between 2009-2012 with "no substantial change in the operation and management" of four properties in Canterbury (agKnowledge Ltd, 2013, pp. 13-14).

Furthermore, a submitter with considerable knowledge of farm systems and nutrient leaching presented evidence on the extent of errors that could arise from the wrong choice of model inputs which he concluded ranged between 40 to 270 per cent (agKnowledge Ltd, 2013). With this error range and the generally accepted plus or minus 20-30 per cent arising from errors within the model, and with land use change defined as a 10 per cent increase in nitrogen leaching, a farm business could get caught up in land use rules without doing anything. These examples highlight how radically and unexpectedly the science can shift the numbers up and down and the challenges this modelling outputs-based approach presents for the enforcement and credibility of land use policy that is so tightly linked to scientific numbers at the farm scale that are, by necessity, constantly on the move.

4.9 Linking the Catchment and the Farm

The approach in the Horizons region sets farm scale limits using land use capability (LUC) classes to set limits on nutrient leaching, which are influenced by factors such as soil type, slope and climate (Baker-Galloway, 2013) rather than a CNL. This means that farm scale losses are not linked back to an overarching pool of nutrients (Nimmo-Bell, 2013). In Canterbury this is the crucial regulatory link between the catchment and the farm and, according to NIWA, the means by which to send the required signals about resource allocation and achieve the claimed certainty and clarity. Not having this link raises questions about how farm scale limits can link to overall water quality objectives. Having the link, which is the Canterbury approach, raises further questions about the workability and enforceability of the derived catchment and farm scale resource limits given the inaccuracies and shifts in Overseer®. For example, in the Selwyn Waihora CWMS sub-region of Canterbury, a CNL has been calculated for the coastal lake Te Waihora/Lake Ellesmere. The CNL has been determined via a collaborative process (under the CWMS) whereby the community has established future water quality objectives for the lake that align with its social, environmental, cultural and economic needs and aspirations (CRC, 2013; Duncan, 2013a). As the modelling stands, having established the CNL, depending on how far the science shifts in Overseer®, the NDAs are likely to require adjustment in the future. To illustrate, a farm business might have an NDA of 20 kg/ha/pa (as its apportionment of the CNL). When using version 6 of Overseer® the land might be calculated to be leaching an average of 19 kg/ha/pa which is below the NDA. On the basis Table 1 shows a propensity for updates to increase leaching, a new version of the model might calculate leaching of 30 kg/ha/pa which would trigger shifts in the land use rules and require mitigation back to within the NDA allocation. Obviously, the greater the divergence, the higher the cost of mitigation. With each new version of Overseer® land owners could be calculated to be leaching more or less nutrients without changing anything on farm by virtue of Overseer® calculating higher or lower nutrient losses from, for example, different soil types and farm practices as a result of more research and better data resolution. This potential scenario highlights the challenges that updates to the science create for the development and implementation of resource limit policy regimes.

5. Discussion

To recap, in the South Island region of Canterbury, CNLs for rivers and lakes across its ten CWMS sub-regions are progressively being modelled and incorporated into the regional planning framework for implementation via NDAs under its CWMS and the NPSFM (with the exception of the HWRRP which sits outside the LWRP). The farm scale nutrient budgeting model Overseer®, in concert with catchment modelling, land use rules, and governance arrangements unique to the region, are being used to institute a regulatory link between the catchment and the farm and to enforce resource limits at the farm scale. What is occurring in Canterbury is a blueprint for national reforms. There are very good reasons for constructing the limit setting regime in this way. It means that farm scale limits are linked to what are deemed sustainable management objectives that communities decide upon. This means farm-scale limits can be linked to these objectives rather than poorly justified numbers not linked to specified outcomes (Norton and Kelly, 2010; CRC, 2012a; Robson et al., 2013). In theory, as a package, the enforcement of the numbers via Overseer® to trigger land use rules is intended to drive and verify changes in practices on farm to keep diffuse nutrient losses within or moving towards the CNL. It has been argued consistently by science policy actors that without this regulatory link the limit-setting regime cannot provide clarity for governments and resource users or certainty for the delivery of the required environmental outcomes (e.g. Norton and Kelly, 2010; Robson et al. 2013). However, it has been shown that this link is, at best, tenuous, and presents challenges for credible compliance with, and legitimate enforcement of, resource limits at the catchment and farm scales. Bringing into view the social-political dimensions of numbers and predictive models highlights a number of epistemological, institutional and practical challenges for the implementation of resource limits, which draw into question their credibility and the prospects for public accountability, to which I now turn.

Epistemological Challenges

In the realm of science, the pursuit of accuracy is not only standard practice but an underpinning of its epistemic authority (Jasanoff, 1987, 2004). In both the science and policy contexts, the pursuit of accuracy is represented as the means to engender credibility for Overseer®. However, while scientists pursue credibility by continually updating and extending the science (and receiving research funding to do so), policymakers are seeking to simplify the model's use by standardising inputs and users of the model with a protocol and regional plan rules to give these provisions legal effect. Hence, while the need for credibility is clearly shared, criteria across the science policy interface to achieve it differ. This divergence highlights the irresolvable tension between the accepted open-endedness of knowledge in (and which drives) the scientific sphere, and the need for closure around the science in the policy sphere to ensure resource users can be efficiently and legitimately regulated and policy outcomes feasibly monitored and measured.

While the quest to update the science to engender credibility is understandable, the practical implications of doing so appear very difficult to manage legally and administratively, especially within New Zealand's effects- and consents-based planning framework under its RMA. An unrealistic normative assumption embedded in Canterbury's limit setting framework would appear to be that the existing planning system (as well as resource users) can accommodate continual updates to the science and shifting resource limits. The Horizons Regional Council example provides useful insights into what can occur when the science shifts to reflect a more detailed understanding of the complex interactions occurring between land and water. Unexpected challenges were created for local authorities with unexpected administrative burdens that easily translated into angry and stressed constituents who were surprised to find themselves caught in a regulatory net and potentially being required to undertake more mitigation and expend more capital than was initially expected and planned for (Bell, 2013). In this case the council had to create an alternative ad hoc process, which was possible to do given that there was no overarching CNL. With the numbers potentially so variable and negotiable, the credibility of the resource limits rests in large part on existing and potential institutional changes that protect the numbers by the removal of appeal rights to the Environment Court.

The tension between the accepted openendedness of knowledge in the scientific sphere and the need for closure in the policy sphere plays out in other ways. Central government's cabinet papers characterise predictive models as a "simplified representation of reality" but also "useful". They are further described as being able to "simplify complex natural processes that occur over time and space to predict nutrient losses from catchments or farms" (MfE, 2012b, p. 20). This conception of modelling implies that although the models are simplifications, the conclusions about nutrient losses that they derive for regulation and the potential triggering of punitive land use rules somehow are not. The distinction made by Wynne and Shackley (1994) between models as ‘heuristics’ in contrast to ‘truth machines’ is useful for seeing how Overseer® serves to reify numbers for regulation that are demonstrably indicative surrogates for water quality. When the model is updated, the credulity of those subject to the numbers (who have historically used the model for heuristic purposes) will be continually stretched (Wynne, 1992). The science policy framework does not recognise this tension as problematic and seeks to override it with claims that Overseer® is the best model available. Its inability to do so is reflected in continued court challenges on the use of Overseer® as a regulatory compliance tool.

Given the *many* millions of dollars that have been invested in it, it is understandable there are no plans to turn back from Overseer®. Currently, its legitimacy and credibility rest on assertions from virtually all quarters that it is the “best product of its type currently available” and that it is reliable as a regulatory tool when it is “used correctly and its limitations are understood” (CRC, 2012b, p. 2). While it currently appears possible to bridge its empirical gaps and explain away its limitations with these assurances, implementation of the land use rules that seek to reduce nutrient leaching to water have only just begun to take force in Canterbury.

Institutional Challenges

This case study illustrates the institutional challenges of the shift in policy development to operationalise resource limits on diffuse pollution by tightly linking numbers to compliance and enforcement. The political ambition to ‘rule by numbers’ in Canterbury, is conditional upon institutional arrangements that curtail democratic rights to challenge decisions in the Environment Court. In effect, these moves protect the models and the numbers from the legal system (New Zealand Environment Court, 2005; Russell et al., 2011; Weber et al., 2011) and those who disagree with setting resource limits and where they are set. Given the historical context of expensive litigation, seemingly unbridled water allocation going to those that could pay for the best lawyers and most accomplished witnesses (Weber et al., 2011), and the regional council seemingly left with little control over water allocation, there is broad agreement that these arrangements are necessary to manage New Zealand's freshwater resources (Land & Water Forum 2012a, 2012b). Currently in Canterbury, these new arrangements mean that the science policy actors have the comfort of knowing that the science that sits behind the CNLs and farm scale NDAs will not be deconstructed in the courts. If the proposals to amend the NPSFM and the RMA are put in place, these governance arrangements will be formalised and rolled out further across New Zealand. While few would advocate protracted and expensive litigation and a loss of control on resource allocation, these are significant institutional adjustments that protect numbers that are highly contingent.

The substitute process in Canterbury involves regional council-appointed independent commissioners conducting public hearings of public submissions to determine how the regional plan and its sub-chapters written by the CRC should be amended or not. In Canterbury, these commissioners are the final authority on provisions that are either accepted or not by the regional council. If not, the process has to start all over again. The only recourse is to appeal to the High Court if a case can be mounted on points of law, or via a plan change, which also means the process would have to start all over again. Hence, currently, the options are limited to critique and/or contest the numbers and to change them if they are found to be wrong or unworkable. Of course, regional plans are required under the RMA to be reviewed at intervals but these are lengthy and infrequent processes.

From personal observations at the public hearings for the HWRRP there were few opportunities for interested parties to question the numbers, there was no scrutiny of the predictive models that produced the numbers, no obvious concerns about Overseer® and there was no cross-examination. In terms of the latter, questions could be asked of a witness but these had to go via the Chairman. While the independent commissioners questioned witnesses within very tight time frames, the level of critique that they were able to undertake, while not absent, was quite limited. Hence, it would appear that the numbers can sail through this sort of process virtually unhindered – which would appear to be the intention (MfE, 2013a; Land and Water Forum, 2012). Notably, under central government's RMA amendments, the process for fast track limit setting would be to "hold a hearing with Environment Court rigour (including cross examination)" (MfE, 2013a, p. 25). Being like the Environment Court but not going there places considerable power in the hands of regional councils who can decide whether or not to enforce the land use rules they write in regional plans (HWZC, 2014). This outcome raises questions about the accountability and transparency of the planning system.

Practical Challenges

There are also practical issues associated with New Zealand's limit setting regime. Notwithstanding the development of a user and input protocol for Overseer®, insights from Porter (1996) draw attention to the multiplicity of ways that numbers going in and coming out of Overseer® can be interpreted when it comes to implementing the land use rules and complying with NDAs. Wittgenstein's edict that "no rule can specify completely what is to count as following or not following that rule" (1953 cited by Mulkay, 1980, p. 111) encapsulates the challenge. For example, the architects of the HWRRP and the LWRP appear to have assumed that farmers and their consultants will simply use Overseer® as they always have done with the exception of printing out a report for inspection by the regional council. Yet, Porter (1995, 1996) illustrates how the enforcement of numbers changes people's behaviour. In the past, nutrient budgets were done to tailor the sale of fertiliser to the needs of a farm business. Now that numbers of nitrogen leaching are required for regulation and auditing, the purpose of the model has substantially shifted and so too will the behaviour of the model users, which cannot be proscribed by a protocol or the certification of consultants. The new regulatory context of the model creates strong incentives for farmers and their consultants to look much more closely at its intricacies. Much more scrutiny will be given to what information gets put into the model to find justifiable ways to stay below a threshold or to demonstrate a prescribed movement towards it. What might have been clear-cut and easy to decide in terms of data inputs, definitions and input category choices in the past when the stakes were very low in comparison, suddenly become ambiguous and negotiable. This is not unlawful – it is a pragmatic response to 'rule by numbers'.

6. Conclusions

This research shows that New Zealand's land use policy, as far as it seeks to regulate diffuse pollution to manage water quality, has been built around the assumption that 'rule by numbers' would remove ambiguity and provide clarity and certainty for both governments and resource users. It has been shown that the opposite is unfolding, and is likely to continue. As foreshadowed by Porter (1996, p. 49), making numbers work in practice is never straightforward and can compromise "those key virtues" for adopting a quantitative approach in the first place. While in theory these aims are justifiable, as is the enforcement of a regulatory link between the catchment and farm scales to achieve the desired freshwater objectives, in practice, they are appearing unrealistic and unworkable. Importantly, it is not being argued that policymakers should not use science and predictive modelling to develop policy and better understand how and under what conditions nutrients from land make their way to water and the consequent cumulative effects. Indeed, having reviewed many reports highlighting a lack of consistent and extensive long-term data arising from under-funded and under-representative environmental monitoring, scant ground-truthing, inconsistent data sets, the scaling back of monitoring sites and laboratory analyses, and poorly understood social-ecological relationships (e.g. Lilburne et al. 2004; Carrick et al., 2013; Beca Carter Hollings & Ferner Ltd, 2012; Kelly et al., 2014), the effort clearly needs to be intensified and far more resources dedicated to it.

It has been argued from this analysis that assertions about clarity, certainty and the removal of ambiguity embed unrealistic assumptions about numbers, predictive models and the social-political dimensions of this policy issue and its context for implementation. It has been further argued that policy development for regulating diffuse pollution is not just a scientific and technical endeavour – it is also very much a social-political one. From the case study it has been argued that the workability and enforceability of policy regimes that seek to institute resource limits can be undermined by these broader social-political aspects. This research highlights the epistemological, institutional and practical challenges of tightly linking numbers derived from predictive models to compliance and enforcement mechanisms.

Although it is beyond the scope of this research to propose an alternative or new framework for setting and enforcing resource limits for regulating diffuse pollution and managing water quality, it does propose a different approach to the coproduction of knowledge for policy purposes (Duncan, 2011). It is envisaged that this could involve harnessing predictive modelling in sub-catchment deliberative participatory forums. A key academic resource in this respect could be what have been termed "competency groups" (Landstrom et al. 2011, p. 1619). Distinct from what is commonly termed participatory or mediated modelling, which is conducted within or directed by science policy institutions (with constrained agendas and fixed problem-solutions), competency groups seek to "redistribute expertise" and coproduce knowledge outside such institutions and in local contexts (Landstrom et al. 2011, p. 1619). This mode of knowledge governance could produce a different kind of anticipatory knowledge with more capacity to overcome the epistemological, institutional and practical challenges identified in this paper.

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