

Overseer and regulatory oversight:

Models, uncertainty and cleaning up our waterways

December 2018



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1

Overview

How this review came about

A review of Overseer was one of a number of topics that my staff suggested to me when I took over my role. It struck me as a challenging but potentially useful mission. It was featuring in two major environmental policy debates and yet it was, for most people, a black box. It seemed useful to ask whether it merited either the confidence being placed in it by some or the scepticism expressed about it by others.

Shortly after I announced my decision to conduct a review of Overseer, I was exposed to two entirely different reactions in the same week. The first, from a person confident in the model's capabilities, was a warm endorsement of the idea. Overseer, he felt, needed support and could only benefit from independent scrutiny. The second was from someone equally enthusiastic to see Overseer being used but who drew the opposite conclusion – was it wise to ask too many questions when Overseer is “all we've got”?

How could two people who understood the model's value – and supported its use – come to such different conclusions about the merits of reviewing it? In the weeks that followed, I was consistently surprised by how many people had a view about something that is 'just' a model.

Perhaps I shouldn't have been surprised, given the wide settings in which it has been talked about. From the outset, it was designed to be accessible to farmers and the advisors they work with. More recently it has been drawn into two major environmental management debates.

Abroad, Overseer has been cited by officials as a tool that can provide assurance that New Zealand has the means to reckon with on-farm agricultural emissions. At home, it has increasingly featured in regional-level battles to turn the tide on nutrient pollution.

Here its reception has been, to put it mildly, mixed. Its use in regulation has caused significant disquiet in the farming community. Updated versions have in some cases thrown farmers' resource consent obligations into doubt. Councils have understandably been cautious about imposing nutrient limits on the basis of modelling results they cannot easily explain to those affected by them.

Verdicts on Overseer are not made in a vacuum. The confidence with which it is promoted or accepted is closely related to the purpose for which it is being enlisted, and the interests of the party affected. Whether it is 'good enough' for that purpose is not a scientific judgment. It depends on the use to which it is put.

Overseer's ability to assist in one debate (e.g. nutrient pollution and water quality) may shed light on its potential in another (e.g. accounting for on-farm greenhouse gas emissions). However, as the uses are different, the answers to the question of whether Overseer is fit for purpose may also be different.

This is why I have focused my report on Overseer's use in a regulatory setting to assist with the management of diffuse nutrient pollution. The suitability of Overseer for estimating biological greenhouse gas emission of farms I will leave to others. However, the recommendations of this investigation touching on transparency and openness would certainly apply to any regulatory use of Overseer.

I do not pretend that this report makes for exciting reading. Models for most people are zones of algorithmic mystery. But those who use the model, or are affected by its use, need to know what it can and can't do, and how much confidence can be placed in its outputs.

Models, Overseer the model, and how it is currently being used

In writing this report, I felt the need to go right back to the beginning – both in terms of asking what purpose models serve, and what this particular model may be able to contribute to the management of diffuse nutrient loss on farms.

As chapter 2 explains, a model is a simplification and an approximation of reality. Models enable us to make sense of complex interactions and test different possible future outcomes. Indeed, this ability to help make informed decisions about the future is one of the greatest strengths and values of models. However, those simplifications that make a model possible are also a source of limitations. We can't ask a model to do more than it was designed to do.

Reference to Overseer's intended purpose is a leitmotif that runs through the entire report, particularly in view of the fact that it has been appropriated for multiple uses. Overseer was initially developed to help farmers make more efficient use of nutrients with the aim of boosting both productivity and profitability.

The company responsible for developing and maintaining Overseer – Overseer Ltd – still sees it very much as an on-farm management tool. The company's Strategic Plan 2015-2017 envisions making Overseer “the trusted on-farm strategic management tool for achieving optimal nutrient use for increased profitability and managing within environmental limits.”

This investigation has not sought to contest Overseer's usefulness to farmers. But the very reference to 'environmental limits' in the company's strategic plan highlights an undeniable reality: the same information that is valuable to a farmer is equally valuable to a regulator. Whether it was an original part of Overseer's purpose or not, the same model that optimises nutrient use mechanically estimates nutrient loss from the root zone of a paddock.

Excessive nutrient loss is not only costly from a farming point of view. It is also costly from an environmental point of view. And it is regional councils that have to determine the 'environmental limits' the company refers to. It would be strange for a regional council trying to limit nutrient losses to water to ignore an estimate that farmers themselves are generating and, one assumes, have confidence in. Furthermore, it is an estimate that relates to a real working business unit, which is ultimately where policies and regulations have to be directed.

Beyond that, there are obvious advantages in having a model that can treat both production optimisation and pollution minimisation in a joined-up way. It avoids a battle between estimation tools and ensures that scarce resources are used to come up with the best possible account of how land uses and water quality are related to one another.

This investigation is about Overseer's fitness for purpose in a *regulatory* context. Can we be confident that its estimates of nutrient loss provide regional councils with a basis for making regulatory decisions, notwithstanding the simplifications and approximations that are inevitable in having recourse to models?

Regulators must be able to defend their decisions to their citizens. Furthermore, the Resource Management Act 1991 requires them to evaluate the costs and benefits of their proposed remedies. So they need to be sure that a key tool like Overseer can convincingly support the measures they propose.

It is in the nature of modelling that necessary simplifications and approximations will entail a certain level of uncertainty. Uncertainty is a recurring theme in this report. How significant is the uncertainty that surrounds Overseer's outputs? Does it undermine its use in determining limits to nutrient losses? Would recourse to completely different instruments that eliminate uncertainty be any more acceptable?

Whether the particular simplifications and approximations Overseer makes are acceptable will depend on how it is used. That acceptability will, crucially, depend on what's at stake – who carries the risks of decisions being taken on the basis of the model's outputs?

The same person can demand very different levels of assurance depending on how the model is being applied. For example farmers who use Overseer to make decisions on fertiliser applications will likely view the risks of any uncertainties as being acceptable, as they are fully in control of the commercial risk that is being run.

But the same farmer is likely to be much more demanding if those risks are imposed by a regional council in a way that could be used in a dispute about compliance. Few farmers today will argue with the need to be part of the national effort to clean up our fresh water. But they want to know that the analysis behind the measures they are being asked to take stands up to scrutiny.

My starting point is that nutrient pollution from a wide variety of agricultural and horticultural activities is a major contributor to degraded water quality in New Zealand, and that that degradation is socially and environmentally unacceptable. The question elected representatives at national and regional levels of government are grappling with is *how* they should limit that degradation and drive improvements where they are needed.

There are many regulatory interventions that could be promoted to bring the problem under control. For instance, quantitative limits could be attached to any number of inputs like fertiliser, or to livestock numbers themselves. The costs of any such regulations attaching to easily quantifiable inputs would not be shrouded in any uncertainty. But they would be very inflexible.

Farmers and their advisors have overwhelmingly stated a preference for effects-based measures rather than input controls. Focusing regulation on limiting environmental pressures leaves the land user with the maximum flexibility in choosing how to respond. As such, an effect-based regime is an incentive to innovate.

But because the environmental effect of one farm's diffuse nutrient pollution cannot be measured separately from the combined effects of all farms in a catchment, the regulator is forced to fall back on using nutrient leaving the property as a proxy for the environmental damage it will cause. And since that nutrient cannot be physically measured, paddock by paddock, farm by farm, the regulator is thrown back on having to estimate the loss – which is where Overseer is called into action.

Given the scale of the nutrient pollution challenge and the variability of farm types, management systems, soils, climates, and many other variables, expecting a single model to make sense of it all might seem heroic given the sheer complexity of the biophysical systems that are being addressed.

But this is the story of a long process of evolution and improvement. The Overseer model farmers and councils use today has its roots in developments launched in the 1980s. A great deal of public and private money has been invested in it, and it has become as near to being a household word as any model in rural New Zealand is ever likely to be. The model's functionality is described in some detail in chapter 3.

However, if Overseer is going to be able to command the confidence my enthusiastic interlocutor expressed at the outset, it has equally to be able to withstand the scrutiny of a more sceptical audience, namely those whose farms are being regulated. They are entitled to ask whether the model is fit for use in a regulatory setting. Its current use by regional councils is outlined in chapter 4. It is by no means being universally used to set nutrient limits, but those regions facing the most acute nutrient pollution problems have turned to it in different ways with differing degrees of conviction.

Some of the problems councils have encountered can be resolved through better policy design. But there are other limitations not within councils' power to resolve, and these have given rise to caution on the part of councils, and scepticism on the part of farmers.

What needs to happen if Overseer is to be confidently used in a regulatory context?

Chapter 5 is the heart of this report and tries to explain what is known about the model's engine, and the extent to which there are weaknesses that could compromise its performance. It assesses Overseer in the light of what might reasonably be regarded as best practice when using models in a regulatory setting. In the absence of any official guidance in New Zealand on how to determine whether models are of sufficient quality to support regulations, I drew heavily on advice provided by the United States Environmental Protection Agency.

Using that advice I have come to the conclusion that in some important respects, Overseer does not meet the levels of documentation and transparency that are desirable in a regulatory setting. Important issues remain to be clarified concerning the uncertainty that attaches to its outputs. All of these things are resolvable if there is a desire to do so.

That leads me to a fundamental question which I have addressed to the Government: does it *want* to see Overseer used by councils to help achieve policy goals and water quality outcomes? If the answer to that question is yes – and there are good reasons why that should be the answer – then a significant level of government commitment, guidance and support is required.

Critically, a number of key model evaluation and quality assurance steps are required. To this end, I have recommended that the owners of Overseer (AgResearch, the Ministry of Primary Industries and the Fertiliser Association of New Zealand) undertake a comprehensive and well-resourced evaluation of the model, which should embrace a peer review of the whole model, formal sensitivity and uncertainty analyses and provide public access to the 'engine' of the model.

This last step is proposed in the name of transparency. Transparency emerges from this investigation as a key issue that needs to be addressed if confidence in the model's use in a regulatory setting is to be cemented. The current proprietary nature of the intellectual property Overseer represents is a barrier to the sort of transparency that is needed.

Opening up the model in this way inevitably raises fundamental issues about the closed, proprietary nature of the model. The history of how the model came to be owned and curated is set out in chapter 6.

It is clear that none of the owners have invested resources in developing the model to make commercial profits or spin off a stand-alone business. Indeed, Overseer Ltd's constitution expressly prohibits the payment of dividends to shareholders, and requires income to be reinvested in the maintenance and improvement of Overseer and the business.

It is my conclusion that the proprietary nature of Overseer has been driven by the search for a sustainable funding model. If the model is to be opened up, there are implications for Overseer Ltd's ownership, governance, and resourcing that will need to be considered. I have recommended that the Minister of Primary Industries and Minister for the Environment consider how the model might be mandated, managed and resourced.

A review of resourcing should consider the extent to which Overseer can rely on subscriptions, and the relative contributions of public good research funding and regional council investment to further the model's development.

A full evaluation along the lines I propose would take time and could lead to significant changes in model outputs, in much the same way experienced with the shift from Overseer version 5 to version 6. For this reason, regional councils should take particular care to ensure plans are written in a way that can accommodate changes without disruption to farmers.

Much advice on how to achieve this is already available in the report by Freeman and others (2016).¹ But it could be valuably enhanced if the Ministry for the Environment, in consultation with regional council staff, scientists and planners, were to prepare guidance for council planners on the design of relevant plan provisions. This could take the form of non-statutory guidance, or a more formal regulatory tool such as a National Environmental Standard or Resource Management Act regulations.

More generally, I am recommending that the Minister for the Environment task his officials to develop guidance on the development, evaluation and application of environmental models in a regulatory setting. Overseer is by no means the only model being used by regulators. Models are essential tools and it is vital that when they are used, the wider community can be confident that development, maintenance and use meet appropriate standards.

¹ Freeman et al., 2016.

Beyond Overseer

For all the fascinating detail this investigation has traversed concerning Overseer and farm-based nutrient management, I am left with a keen sense that resolving nutrient pollution will have to commandeer a much wider array of tools.

While nutrient pollution originates in the paddock, Overseer only records its transport 60 centimetres below the surface – the so-called bottom of the root zone. The environmental consequences are measured at the level of the catchment, which can be thousands of square kilometres.

Chapter 7 explores the world beyond Overseer, the research and modelling tools being deployed there, and the need to augment them. I have concluded that the Minister for Science and Innovation, in consultation with the Minister for the Environment, should take a look at the ownership, use and development of the many models and databases that inform our understanding of catchments. Access to these models and databases, and future investment in them, should ensure that we give ourselves the best chance of realising the goal of protecting ‘the life-supporting capacity of air, water, soil and ecosystems’.

The full text of my formal conclusions and recommendations can be found on page 117.

A handwritten signature in black ink, consisting of a series of fluid, connected strokes. The signature is stylized and appears to be 'Simon Upton'.

Simon Upton

Parliamentary Commissioner for the Environment

Tā te Kaikōmihana tirohanga whānui

Ko te pūtake o tēnei arotake

Ko te arotake i Overseer tētahi o ngā kaupapa i marohitia e aku kaimahi i taku urunga mai ki tētahi tūranga. Ki a au nei, he wero nui tēnei, engari he whakatakanga whai take pea. He mea whakaatu ki ngā taupatupatu kaupapa here taiao matua e rua, heoi anō, mō te nuinga o ngā tāngata, he kaupapa huna tēnei. Me pātai te pātai mēnā e tika ana te hunga e whakamanawa ana i tēnei mea, mēnā e tika ana rānei te hunga e whakaparau ana i tēnei mea.

I muri tata iho i taku tauākī i taku whakataunga ki te ārahi i te arotake i Overseer, i rangona e au ngā uruparenga rerekē rawa i te wiki kotahi. Ko te uruparenga tuatahi, i puta mai i te tangata i whakamanawa i te āheitanga o te tauira, i kaha tautoko i te whakaaro. Ki a ia, me tautoko a Overseer, ā, ka whaihua te whakatātare motuhake. Ko te uruparenga tuarua, i puta mai i te tangata ōrite tana whakamanawa i te whakamahi o Overseer, engari he tauaro tana whakataunga – he pūmahara rānei te patapatai mēnā ko Overseer "te mea anake kei a tātou"?

Kua pēhea ngā tāngata e rua nei e mārama ana ki te uara o te tauira – ā, i tautoko i tana whakamahi – e tauaro ai ngā whakataunga mō te painga o te arotake? I ngā wiki i muri iho, i ohorere tonu au i te tokomaha o ngā tāngata i whai whakaaro mō te mea nei, he tauira 'noa iho'.

Tērā pea, he tika kia kua au e ohorere, nā te mea he tino whānui ngā wāhi i kōrerotia ai tēnei. Mai i te tīmatanga, i hoahoaina kia āhei ai ki ngā kaipāmu me ā rātou kaitohutohu. Ināia tata nei kua uru ki ngā taupatupatu whakahaere taiao matua e rua.

Ki tāwāhi, kua kōrerohia a Overseer e ngā āpiha hei taputapu e whakawhiwhi i te whakataurangi he tūturu te pūrongo i ngā putanga ahuhenua ā-pāmu nō tēnei whenua. Ki te kāinga, kua piki te whakaatuhia o Overseer ki ngā pakanga ā-rohe ki te whakahuri i te tai o te parahanga taiora.

Ki konei, ko te whiwhinga, me pēnei te whakamāmā i te kōrero, he rerekē. Ko tana whakamahi i roto i te waeture kua whakaputa i te āwangawanga ki te hapori pāmu. Ko ngā whakaaturanga whakahou kua whakararu i ngā whakaaetanga rawa taiao o ētahi kaipāmu. He mārama te take kua tūpato ngā kaunihera ki te whakatūturu i ngā tepenga taiora, nā te āhua o te whakatauirā kāore e taea e rātou te whakamārama ki te hunga e whakaaweawetia ana.

Ko ngā whakataunga e pā ana ki Overseer kāore i te whakatauhia ki te korekore. Ko te whakamanawa o te whakatairanga, o te whakaae rānei, e tino tūhonoa ana ki te take e whakamahia ana, me ngā whaipānga o te tangata i whakaaweawetia ai. Mēnā he 'pai noa iho' mō tēnā take, ehara i te whakawākanga pūtaiao. Me titiro ki te take e whakamahia ai.

Ko te āheitanga o Overseer ki te tautoko i tētahi taupatupatu (hei tauira, parahanga taiora me te kounġa wai) ka whakamārama pea i tana māiatanga ki tētahi atu (hei tauira mō ngā putanga haurehu kati mahana ā-pāmu). Heoi anō, nā te mea he rerekē te whakamahi, ko te whakautu ki te pātai mēnā e tika ana a Overseer mō te aronga he rerekē pea.

Koinei te take kua arotahi taku arotake ki te whakamahi o Overseer ki te wāhi waeture kia āwhina ki te whakahaere o te parahanga taiora horahora. Ko te pai o Overseer hei whakatau tata i ngā putanga haurehu kati mahana koiora o ngā pāmu, ka waiho au ki ētahi atu tāngata. Heoi anō, ko ngā tūtohunga o tēnei uiuinga e pā ana ki te whakatāhotanga me te whakatuwheratanga ka pā mai ki te whakamahi ā-waeture o Overseer.

Kāore au e whakataruna ko tēnei pūrongo he mea whakaihiihi. Ki te nuinga o ngā tāngata ko ngā tauira he wāhi hātepe pōkikī. Engari, mō te hunga e whakamahi ai i te tauira, e whakaaweawetia rānei i te whakamahi, me mōhio ki ngā mea e āhei ana, me ngā mea kāore e āhei ana, ā, me pēhea te whakamanawa ki ana putanga.



Simon Upton

Te Kaitiaki Taiao a Te Whare Pāremata



2

Models - uses, approaches and limitations

“Essentially, all models are wrong, but some are useful.” (George Box)²

Aotearoa New Zealand has a major water quality problem associated with diffuse farm nutrient losses.³ It is commonly said you cannot manage what you cannot measure. Being able to measure nutrient losses defines the scale of the problem and provides a benchmark against which we can measure progress. But those nutrient losses are very difficult to measure directly.

Farmers have always been interested in managing nutrients to maximise production and profitability. But managing nutrient flows to minimise unwanted environmental impacts as well requires far more information. This is because the questions being asked are no longer just about how nutrient flows end up in valuable productive output, but now also about how much nutrient is lost from a farm, where it comes from, and where it ends up.

To answer this, farmers need to be able to understand the complex interactions of a large number of factors. These include soil properties, rainfall and drainage, the requirements and uptake rates of nutrients by plants, the rate and feed requirements

² Box, 1979, p.2.

³ Diffuse sources of nutrients include indirect discharges originating from a (relatively) large area. The other source of nutrients is “point sources”, which discharge directly into a receiving waterbody at a discrete location (OECD, 2017, p. 17). For more information about nutrient sources and their contributions to water quality see PCE (2012) and OECD (2017).

of animals, and the redistribution of nutrients in the form of animal excreta. The interaction of all these factors poses a serious measurement problem.⁴

And even if it could be solved satisfactorily, knowing how much nutrient is lost to the environment wouldn't tell us what the environmental impact is likely to be. This is because nutrient loss from a single farm may travel, mix with losses from other properties and sources, and impact distant waterbodies. However, farm nutrient losses provide an indication of environmental stress exerted far away.⁵



Source: Richardprins

Figure 2.1 Bay of Plenty Regional Council has determined it must reduce the quantity of nitrogen and phosphorus entering Lake Rotorua to reach the water quality target set for the lake. In response, it has proposed rules to reduce nitrogen losses from farms, along with non-regulatory measures such as an incentives scheme and gorse programme.

In the absence of practical direct measurements, models of nutrient movement have been developed to quantitatively estimate losses from a variety of farm systems.⁶

⁴ For example, measurement techniques called lysimeters have been developed to quantify nutrient leaching losses from soil by capturing all the water leaving a defined area of soil, which can then be analysed for its nutrient concentrations. The area in question will be a small fraction of the paddock and is unlikely to capture all the physical processes going on at a paddock scale. For example, lateral spread of roots or lateral flow of water will not be captured. If these are important, the leaching measured will not represent the whole paddock. The results can be modelled to calculate the loss at the paddock scale depending on the urine patch coverage of a grazed pasture.

Lysimetry is useful for conducting component research to determine different treatment effects on nutrient leaching losses. However, lysimeter techniques are not well suited to on-farm monitoring of nutrient leaching in grazed pastures. Lysimeters are also expensive. A single 50 centimetre diameter and 70 centimetre deep lysimeter on a pastoral farm can cost around \$5,000 to \$10,000 (pers. comm., Keith Cameron and Hong Di, 2018).

A minimum of four replicate lysimeters may be required to measure the nitrogen losses of a particular treatment such as under a urine patch. The cost can become very high to measure paddock-scale leaching losses in situ because the random deposition of urine patches can require large number of lysimeters. The cost rapidly becomes prohibitive. And in any case, there can be significant variability of soil and drainage even within paddocks.

⁵ Monaghan et al. (2007), for example.

⁶ See Cichota and Snow (2009) for examples.

To do this, models integrate data and information from farm enterprises with scientific understanding of concepts and processes to develop a fuller picture of nutrient movement and losses.

The major benefit of modelling is that it can investigate and quantify nutrient losses in a relatively cost-effective manner, and can be tested and improved over time. Models can also be used to study and improve management practices (either directly or as part of a farm management plan).⁷ Finally, the outputs from farm-level nutrient models can provide a basis from which the nutrient stress on receiving waterbodies can be investigated.

In New Zealand, OVERSEER® Nutrient Budgets (for simplicity referred to as Overseer throughout this report) is the model most widely used to estimate farm nutrient flows. However, before discussing Overseer in detail, it is important to understand what models are, how they vary and what they can tell us.

What is a model?

A *model* is a simplification or *approximation* of reality.⁸ Models are frequently used in the physical, biological, economic, and social sciences to synthesise current knowledge, and can help to understand and explain the interaction of complex processes. Importantly they can be used to predict what may happen in the future.⁹

However, models should not be viewed as ‘truth’ generating machines.¹⁰ Rather they are tools designed and developed for a specific task or purpose.

What to consider when developing a model?

Model development is influenced and constrained by a combination of:

- the intended purpose and use of the model
- model structure and approach
- the knowledge base available at the time of model development
- the availability and quality of input information
- assumptions and uncertainties.

Identifying and articulating these constraints is important for developing a model that is fit for purpose. Users also need confidence in the model’s output and the extent to which it can be relied on.

⁷ A farm management plan provides a farmer with a set of tailored management strategies to improve nutrient management and other aspects of the farm enterprise (e.g. erosion control, water efficiency, stock management, etc.). More specific farm environment plans (or other similarly named plans) can also be developed to target management practices to improve environmental outcomes. Farm plans in general are becoming a common requirement as part of the consenting process governed by regional councils.

⁸ Models can come in many forms, the main two being conceptual and computational (or empirical) models. Conceptual models represent a hypothesis of the interaction of important factors and interactions in a system, whereas computational models use empirical and mathematical relationships to produce quantitative outputs. In this report we are largely concerned with, and discuss, computational models.

⁹ For a general introduction of models and nutrient models in New Zealand, the reader is directed to Understanding the practice of water quality modelling (Anastasiadis et al., 2013), which can be found at www.pce.parliament.nz.

¹⁰ Beck et al., 1997.

In particular, defining the purpose, scope, scale, and intended use of a model is of cardinal importance. These need to be considered throughout the model's development, use, and evaluation (i.e. the model's life cycle). This is to ensure that the model focuses on the objects of interest and does not include irrelevant details that can contribute unnecessarily to model *complexity* and *uncertainty* associated with its outputs.

Models can be quite simple. For example, a model to work out how large a population is might look like this:

$$\text{Population this year} = \text{population last year} + \text{births} - \text{deaths}$$

This model would explain some systems well, how many birds there are in an aviary for example. Indeed, for an aviary we do not really need a model, we can just count the birds directly. However, as situations become more complex and harder to measure, for instance when evaluating the bird population on an island, models become more valuable.

However, we may not be able to measure all processes in a system directly. For example, to know exactly how many births there were on an island, we would need to find and monitor every nest and see how many chicks hatched and survived. Similarly, we would need to monitor every adult bird to see if it survived, or died.

To simplify data collection we can gather information on births and deaths by sampling parts of the population and arrive at an estimate of how many birds there are on the island. But sampling part of the population will not be perfect, there will be more or less certainty about the sample results depending on the quality of the sampling technique.



Source: Dr James Newman

Figure 2.2 Counting the entire population of titi (sooty shearwater) on an island is a difficult task. Sampling part of the population and using a model can make the task simpler, but will introduce uncertainty into population estimates.

To get even this far we have to make *assumptions*. For example, we assume that sampling *part* of the population is representative of the *whole* population, and we also assume that we have understood and captured all the processes that contribute to population size. For example, birds will not only be born or die, some will fly away from the island and others will move in and stay. We could expand our model to include additional *parameters* that capture these processes:

Population this year = population last year + births – deaths + immigration – emigration

We can carry on including more parameters into our model, and these may help us to better understand the factors that affect population size. However, more parameters mean more complexity and the need for more data. This may make the model less useful in other settings unless large amounts of new data can be gathered.

As model complexity increases, there is also often a need to introduce parameters that we do not have much information about. In our island example, we may not have any information about the contribution of immigration to the population. But there may be data on immigration rates for other populations. These could be used but they will add an element of uncertainty.

One of the major benefits of building such a model of bird population is the ability to use it to predict future population sizes. For example, scenarios, such as what might happen if the birth rate increased, or the immigration rate decreased, or indeed any combination of the parameters, can be tested.

Model uncertainty

Irrespective of how complex our population model is, our estimate of the population size will not be exactly right. If we have only counted some of the nests or monitored some of the birds, if we have included all important parameters, or if we have had to include assumptions about outward and inward migration, there will be *uncertainty* in the estimate. The term uncertainty is used to describe the lack of knowledge about the system being modelled. Uncertainty affects model development, implementation and its use.

In general, three categories of uncertainty are associated with model development:¹¹

- natural variability – uncertainty associated with natural variations in the system that is investigated
- modelling uncertainty – does the *model framework* truly represent the current scientific understanding of the system being modelled, and do the *model inputs* accurately represent the real world (e.g. due to measurement error, input error, analytical imprecision, and limited sample size for model parameters)
- deep uncertainty – current unknowable factors of the system that contribute to uncertainty.

¹¹ MfE, 2016, p.6.

Discussions of uncertainty in this report are largely focused on model uncertainty, as this is the component that can largely be managed. However, this is situated in the wider context of natural variability and deep uncertainty.

Model developers, users (e.g. farmers) and decision makers (e.g. regional councils) that may require a model to be used want the level of uncertainty to be as low as possible – they want to know there is a good chance that an action will lead to the expected outcome. But uncertainty cannot be eliminated, so having a good understanding of the level of uncertainty is going to be almost as important as a model's output if it is to be confidently relied on. Understanding uncertainty, and being transparent about incomplete knowledge, is essential if policies or regulations based on models are to be credibly defended.¹² How much uncertainty is acceptable will depend on the risks being run and who will bear the consequences.

Simple and complex models

Model complexity is largely dictated by the trade-off between intended use, the resolution of all the elements that have been incorporated, the availability of representative datasets, and the form and function of the modelling approach used. There is no single defining factor that separates simple and complex models. Rather, there is a continuum of model complexity.

A useful analogy is to think about maps, how they are developed, and what they show.¹³ At one end of the spectrum you may have a simple road map that has only one *intended* use – ensuring a person can get from point A to point B. At the other end there will be extremely detailed maps showing not only roads, but also power lines, buildings, vegetation, and topography (e.g. LINZ topo50 maps). Similarly, the intended use of a map will dictate the level of spatial detail. A large amount of detail may be needed but it may only need to cover a small area (e.g. a map used by maintenance contractors digging up roads and pavements in a busy city).

Given the range of uses and scales needed by different users, it is not practical for any one map to include all the information that would ever be needed to describe the world in all its detail. Similarly, no model can capture all of the complexity of biological and physical systems like a farm system.¹⁴

The simpler the model framework, the more likely it is that important factors and processes will not be well represented in model outputs. This can increase uncertainty in whether outputs are capturing relevant aspects of a system, and if it is at a scale that is useful or required. Conversely, simple models are more likely to be used by a wider range of audiences.

More complex models are required when we need to understand the structure and processes occurring in a system in more detail. For example, to model processes at

¹²MfE, 2016, p.19 and 28.

¹³Maps are in fact a type of model that translates the complex physical environment into understandable graphical representations.

¹⁴NRC, 2007, p.18.

finer scales, greater detail must be included in the model – increasing the amount of information required to develop and run the model.

However, increased model complexity also comes at a cost. As the number of processes and parameters increases, greater uncertainty is introduced in model outputs. This is because each process or parameter will have a level of uncertainty attached to it, which is then compounded through model calculations.¹⁵

Because uncertainty tends to increase at both ends of the scale – both as models become simpler or more complex – a middle ground needs to be reached to ensure that the model captures the required detail, but does not include unnecessary or poorly defined elements. The phrase often attributed to Albert Einstein summarises this point well:

“Everything should be made as simple as possible, but not simpler.”

Modelling approaches

To fill out this brief introduction to modelling, it is useful to understand something of the different modelling approaches that exist. Without being exhaustive, three broad distinctions in approach can be identified: empirical vs mechanistic, deterministic vs stochastic, and steady-state vs dynamic. Choosing between these different modelling approaches is not simple but will have important ramifications for how a model can be used.

Empirical vs mechanistic models

Empirical models rely on correlations that have been observed, either experimentally or in the field. They do not rely on complex scientific theories that may be difficult to model, or attempt to fully describe the real world implications of these correlations. They simply try to model the ‘best fit’ for available observations. However, to ensure the model is performing as intended, a large amount of data may be needed to accurately characterise the relationships. Extrapolation beyond the bounds of the sample dataset will also introduce increasing uncertainty.

Mechanistic models, by contrast, focus on simulating detailed processes (e.g. biological or physical) that explicitly describe system behaviour, with each model element having a corresponding real-world equivalent. Mechanistic models are appealing due to their close alignment with the system being modelled. However, they require more model elements – some of which may be poorly defined or unreliable.¹⁶

To highlight the difference, we can think about modelling the likelihood of a flipped coin coming up heads or tails. An empirical model can be developed by flipping a coin several times to generate the likelihood of the next coin flip. As the sample size

¹⁵ For example, parameters may have greater uncertainty due to limited sample size in the original dataset used to develop the parameter, measurement error, limited scientific understanding, and so on (United States EPA, 2009, p.13).

¹⁶ Recall the island bird population model described above, in which immigration and emigration were added to the model. Trying to accurately sample immigration and emigration is very difficult, introducing uncertainty into an estimate of population size using the model (i.e. increasing model input uncertainty). However, excluding these parameters may result in not accurately accounting for all important aspects of the island bird population (i.e. increasing model framework uncertainty).

increases, the modelled likelihood will tend towards 50 per cent for either result. In contrast, a mechanistic model could include parameters of the initial state (heads up or down), coin shape, angle and force of flipping, distance to the surface, air resistance, gravity, etc, to predict the result. The mechanistic model may be theoretically more accurate, but requires significantly more information to develop. On the other hand, the empirical model does not give any information explaining the physical reason for the different results – just the probability of either occurrence.

Deterministic vs stochastic models

Deterministic models use a specific combination of parameters and initial conditions to produce an output. The result is the same for every model run. This means that deterministic models are good at producing a single output value for a set of conditions. However, they do not take into account the effects of uncertainty and variability of model inputs when reporting results.

Stochastic (or probabilistic) models include variability in model inputs and parameters. Variability is a function of changing environmental conditions, averaging parameters and inputs over time and space, and random natural variability. The solution obtained is a function of variability, often represented as a probability distribution of model outputs.¹⁷ The result may better represent output uncertainty, but requires more data for each input and parameter to generate results. Where limited data is available, uncertainties will be greater and reflected in the range of outputs the model produces.

An example of a deterministic model is a GPS navigation device that estimates the best route between two points based on distance and assuming an average travel speed. This is deterministic because the distance and speed are set prior to the model run, with the choice of route between the same points always the same.

In contrast, a stochastic model could take into account the probability of something like traffic congestion when selecting the preferred route. In this case, the variability of traffic conditions with respect to time of day is included in route selection. A different route may be selected based on the likelihood and magnitude of any congestion and the effect it has on total travel time.

Steady-state vs dynamic models

Steady-state (or static) models assume constant conditions. They can provide a snapshot of the systems at a given time, but often produce long-term or time-averaged outputs. Most variability is averaged out by targeting the predictions to large spatial areas and long time spans – allowing a simpler description of many combined processes. The relatively modest amount of input data makes this approach appealing. However, conditions or situations which deviate from the average might not be represented.

¹⁷ United States EPA, 2009, p.47.

Dynamic models describe the change in a system over time. To do this the model ‘remembers’ model outputs at one point in time and uses this information to update the model as it iterates through a model run to predict estimates for the next time step. Because dynamic models often handle a large variety of processes, they require more input data and computer processing power. Dynamic models tend to be more complex than steady-state models, which limits the range of users who can run them.

A simple estimation of an island bird population, as described earlier in this chapter, is an example of a steady-state model, as each parameter represents a yearly total. However, the same model could be considered dynamic if it were used to predict population trends over, say, a 30-year period.¹⁸ The predicted population is dependent on the previous year’s total. Therefore, the model needs to use the previous year’s modelled population to calculate the current year. The model output is not a single population number as in a steady-state model, but rather the predicted change in population over time.

Modelling farm nutrient losses

With the benefit of the preceding discussion, it is time now to ask how modelling can usefully help estimate farm nutrient losses. As no modelling approach is ‘right’ or ‘wrong’, the challenge lies in choosing and developing a model that is fit for the intended use.

To make tactical management decisions on the ground, a farmer might want a model to estimate and predict the rate of nutrient loss at a point on a farm at a daily or weekly timescale. Such a model would help identify the movement of nutrients throughout the entire farm system over a short time, allowing farmers to improve decision making to increase efficiency and minimise environmental impacts.

However, developing such a model that will work equally well on all New Zealand’s farms would require prohibitively large amounts of data and likely be very complex. It would also need to be tailored in its construction on a farm-by-farm basis to ensure that individual farm characteristics are taken into account, requiring significant expertise.

Simplifications and assumptions are needed if a model is going to be able to estimate farm nutrient losses from a wide range of farm systems and for a variety of purposes. This is Overseer’s ambition.¹⁹ However, before we can assess how well it achieves that, we need to understand the basic design of the Overseer model, how it is set up, and what it does.

¹⁸Another example could be if the rates of change varied over time (for example, as a function of population or climate).

¹⁹Other models (such as Agricultural Production Systems sIMulator (APSIM) and Soil Plant Atmospheric System Model (SPASMO)) are also used in New Zealand. Their development and intended use often confines them to research and site-specific investigations.



Source: Taranaki Regional Council

Figure 2.3 Many dairy farms now dispose of their shed effluent by applying it to land, reducing the need for fertiliser. This is a management practice that can be modelled.



3

The Overseer model

This chapter builds on the broad modelling approaches outlined in the previous chapter, and goes further to show that Overseer is a largely empirical, deterministic, and steady-state model. It also outlines key assumptions and sources of uncertainty in Overseer.

This description of the Overseer model is presented in three sections. The first section outlines key design features of Overseer. The second section provides a high-level description of how Overseer generates its estimates of greenhouse gas emissions, and nitrogen and phosphorus losses. The final section provides examples of what Overseer can and cannot do, given the model's evolution, design principles, calibration, and uncertainties.

Overseer: scope, design principles and uncertainty

What Overseer does: the basics

Put simply, Overseer is a model that describes nutrient flows on farms (Figure 3.1). Overseer takes nutrients that are present or introduced to the farm, models how they are used by plants and animals on the farm, and then estimates how they leave the farm and in what form.

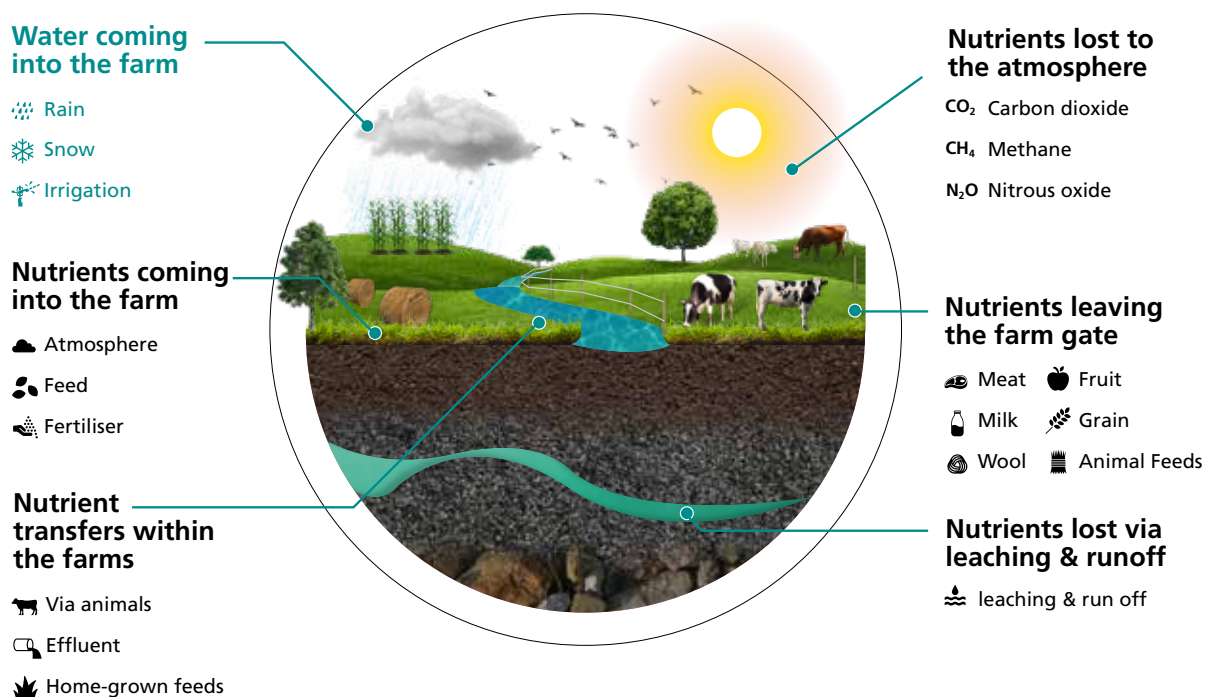


Figure 3.1 Nutrient flows on farms.

Some nutrients are already in the soil on the farm, and more nutrients are added as fertilisers and animal feed.

Nutrients end up in plants and animals, supporting their growth and the production of valuable products (such as crops, meat, milk, wool). Excess nutrients are excreted by animals as dung and urine, which are deposited on the soil or in farm structures, and are often reused on-farm as fertiliser.

Some nutrients leave the farm gate as farm products (e.g. meat, milk, crops, wool, and wine), while others are lost to the environment. How much is lost will depend on the local climate, management practices, and soil characteristics. Overseer estimates these nutrient losses from the farm, which includes gaseous emissions into the atmosphere, leaching through the soil, and run-off across the land surface.

Overseer estimates nutrient flows and provides a '*nutrient budget*' for seven nutrients: nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, and sodium. It also estimates soil acidity for paddocks under pasture. Sediment and pathogens, such as *E. coli*, fall outside the model's scope.

By modelling nutrient flows, Overseer can provide a farmer with estimates of what nutrients are in deficit and could be supplemented through fertiliser to maintain plant growth and production. This was the job Overseer was originally designed to do: improve the efficiency of fertiliser applications.

To help manage fertiliser application, Overseer had to estimate how much nutrient was *not* being captured in productive outputs but, rather, was being lost to the environment. These modelled estimates of nutrient losses helped farmers minimise their fertiliser bills. But the same estimates became useful for farmers and others interested in environmental pressures due to the loss of excess nutrients.

Overseer cannot estimate the environmental impacts of these nutrient losses, because these often occur far beyond the farm boundary in distant receiving waterbodies. However, Overseer-derived nutrient losses provide a good starting point for estimating environmental impacts, since nutrient loss is a major stress on the receiving environment.

The Overseer model is offered as a web-based application.²⁰ The latest version, OverseerFM, models seven land uses (i.e. management block types), thereby enabling nutrient losses from diverse land uses within a single agricultural enterprise to be quantified.²¹

The modelled land uses are:

- pasture
- crop
- fruit
- trees and scrub
- fenced wetland
- riparian
- house.

²⁰ The latest software interface, termed OverseerFM, was released in June 2018. The older software interface is now referred to as the Overseer legacy version.

²¹ OverseerFM website (<https://fm.overseer.org.nz/>). Accessed 3 October 2018.

It is worth noting that Overseer models pastoral land uses best (dairy systems in particular). The model outputs for the other land uses are more uncertain.²² This is due to the greater geographic coverage and investment in understanding processes that control nutrient flows in pastoral systems. Much of the discussion below focuses on Overseer's modelling of pastoral farming.

Key modelling principles

In relation to the broad modelling approaches outlined in the previous chapter, the general approach used by Overseer is steady-state, largely empirical, and deterministic in nature. This combination of approaches is largely tied to a key design principle that goes back to the model's origins – namely, that input data needed to run the model is readily available for the farms being modelled.

The following section highlights how the modelling approaches and design principles affect Overseer's performance.

Steady-state

The steady-state nature of Overseer means that the model assumes average and constant management and site characteristics. This allows on-farm nutrient flows to be compared over time. However, Overseer is less useful for modelling situations when farm management is significantly changing, which happens, for example, when a land use is changing or intensifying.²³

A secondary issue is climate variation. Farm management during a wet year is different from farm management during a dry year, which in turn is different from the long-term average climate that Overseer is based on. This means that farm inputs are not necessarily consistent with the long-term climate from either an annual or a monthly perspective.

²²Wheeler and Shepherd, 2013, p.19.

²³Overseer can be used to model two different farm systems (e.g. pre- and post-land use change). This modelling can be used to assess relative changes between the two farm systems.



Source: Rob Suisted/naturespic.com

Figure 3.2 The steady-state nature of Overseer means that the model assumes average and constant management and site characteristics. This makes Overseer less useful for modelling situations when farm management is significantly changing, for example, when a piece of land is converted from forestry to intensive dairy farming.

Farm inputs are consistent with production

The steady-state approach of Overseer is reflected in the principle that inputs are consistent with entered production.²⁴ The model assumes that entered production characteristics (e.g. crop yields or milk-solids production) can be achieved with the user-defined inputs, (e.g. management practices, and site characteristics).

Moreover, Overseer assumes that inputs are consistent with production irrespective of whether a farming system is viable or not. The ability to enter unrealistic inputs and create unrealistic farming operations is a clear drawback of this principle.²⁵

²⁴This is often referred to as inputs being in equilibrium with production. See Watkins and Selbie (2015, p. 29).

²⁵Over time, there have been some efforts to allow users to manually check aspects of the viability of farm systems. For example, in Overseer version 6, estimated pasture production was reported, which users can use as a feasibility check. In addition, some sensibility testing is embedded into OverseerFM (e.g. for pastoral blocks), as the software provides a suggested range for production, and can also generate error messages. OverseerFM website (<https://fm.overseer.org.nz/>). Accessed 16 October 2018.

Further, if a user changes one input, the model does not automatically update other inputs (or production). This means users need enough knowledge of farm systems to make adjustments themselves to ensure a farm system is viable.

On the upside, this principle combined with the reliance on readily available input data has made the model more accessible to a wider audience, in comparison with more complex dynamic models.²⁶

Semi-empirical nature of the model

Overseer is a largely empirical model, which has mechanistic components that have been fitted to match data that has been collected in the field. This means it relies on calibration – a process that fine-tunes its parameters using experimental data.

It is worth noting that variable amounts of research have contributed to the development of the different Overseer components. As a result, some parts of the model have been much better calibrated and tested than others. For example, pastoral blocks within Overseer are the most calibrated. In comparison, crop blocks in Overseer are based on a limited body of research, and not all crops grown by horticultural and arable enterprises are currently represented in the model.

It is not only the lack of calibration that limits the ability of Overseer to accurately represent cropping systems. It is also a consequence of the underlying steady-state modelling principle described above. Crops need to be rotated between different paddocks, meaning that block management frequently changes.

Furthermore, soil is cultivated and new crops are planted on a regular basis. This means that the decomposition of crop residues and nitrogen mineralisation are key processes in cropping systems. However, these processes are not well represented in Overseer, thereby introducing greater uncertainty into model outputs.²⁷

Table 3.1 summarises the extent of calibration undertaken across the land uses modelled by Overseer.

²⁶ APSIM is an example of a complex dynamic model, often used for research purposes.

²⁷ See Khaembah and Brown (2016). This study recommended revisiting the way these processes are modelled in Overseer, however, to-date these recommendations have not been taken up.

Table 3.1. Calibration extent of Overseer.²⁸

Source: Shepherd et al., 2015; Pers. comm. Richard McDowell, 2018.

Management block	Nitrogen calibration	Phosphorus calibration
Pastoral	Calibration (undertaken in 2012) used nutrient loss measurements from farmlot studies at eight locations. These were: Edendale, Southland (intensive beef); Tussock Creek, Southland (dairy); Kelso, Otago (dairy); Lincoln University Dairy Farm, Canterbury (dairy); Massey University Dairy Farm, Manawatū-Whanganui (dairy); Ruakura, Waikato (dairy); Scott Farm, Waikato (dairy); and Wharenui, Bay of Plenty (dairy). A recalibration exercise is currently underway.	Calibration (undertaken in 2005) used data from 23 sites: Canterbury (2), Otago (3), Southland (2), Manawatū (5), Northland (2), Waikato (4), West Coast (2), Wellington (1), Hawkes Bay (2).
Crop	Arable crops – very limited calibration (one Lincoln site).	Arable crops – none due to a lack of experimental sites. Forage crops – limited to 2 sites in Otago and 1 in Southland.
Fruit crop	None due to a lack of experimental sites.	None due to a lack of experimental sites.
Trees and scrub	None due to a lack of experimental sites.	None due to a lack of experimental sites.
Wetlands and riparian	Very limited calibration based on published studies.	Very limited calibration based on published studies.
House	Very limited calibration (based on one international study).	None.

²⁸For pastoral blocks (nitrogen) – see Shepherd et al. (2015). A re-calibration exercise is currently underway – pers. comm., Mark Shepherd (2018). For pastoral blocks (phosphorus) – see McDowell et al. (2005) and Gray et al. (2016). For crop blocks (nitrogen) – see Shepherd et al. (2015). For forage crop blocks (phosphorus) – see McDowell (2006), McDowell and Houlbrouke (2009), and McDowell and Steven (2008). For wetlands and riparian blocks – see Rutherford and Wheeler (2011), Gray et al. (2016) and McDowell et al. (2008). For house blocks – see Wheeler et al. (2010a) for details.

Model scales

Temporal scale

In keeping with Overseer's steady-state approach, inputs are time-averaged and the model provides annual average outputs.²⁹

Even though parts of the model operate at multiple time-steps (including daily and monthly) to better represent the processes, one of the key inputs – climate data – is supplied as a long-term (30 year) average.³⁰ This means that any extreme variations between years are smoothed out in the climate inputs. This can create a mismatch between annual farm management inputs and long-term climate inputs.³¹

Overseer has also been calibrated using long-term average data. For example, regarding nitrogen leaching, Watkins and Selbie note, "A research trial will likely produce different N leaching measurements in each year of a 5-year study... [However] the average N leaching is used (alongside other research trial data) to calibrate the model."³²

Spatial scale

Overseer is not concerned with what is happening at any single point in space. Instead Overseer takes a whole block (and a whole farm) view. This concept allows Overseer to simplify the complexity of some farm processes to more easily estimate nutrient loss from blocks and the whole farm.

For example, soils and grazing stock management are often spatially variable and complex. Different soils often occur within the same paddock, sometimes metres apart. Moreover, even within the same soil types, specific soil properties can differ.

While the real-time management of stock on a farm is quite complex, Overseer's approach reduces the need to specify exactly where animals are grazing. The model assumes that the animals are grazing *somewhere* on the block. This implies that excreta returned is also *somewhere* on each block.

²⁹ Wheeler et al., 2018.

³⁰For example, to simplify inputs, annual rainfall data in OverseerFM is automatically retrieved – from the 30-year average climate database from the NIWA Virtual Climate Station Network – based on the user-supplied location (Overseer Legacy version also allows for manual entry of annual or monthly rainfall data). However, the majority of processes in Overseer (in particular the drainage and nitrogen leaching model) operate at monthly or daily time steps, requiring annual rainfall to be distributed between months and days (Wheeler et al., 2018).

³¹Of particular importance is the term over which farm input data is entered. The NIWA Virtual Climate Station Network data captures the long-term average of climate, meaning that any extreme variations between years are smoothed out. In contrast, production and farm management varies year to year. There is unknown uncertainty with comparing annual average climate with actual annual production and farm management data to calculate a 'year-end' nutrient budget.

When Overseer is used as a predictive tool, rather than calculating a year-end nutrient budget, it is suggested by Overseer that five years' worth of actual farm data is used to create a long-term management average, which is more in line with climate data (Willis, 2018, p.15).

³² Watkins and Selbie, 2015, p.29.

Horizontally, the model stops at the farm boundary. In Overseer, a farm is divided into blocks, with blocks typically representing areas with similar physical characteristics and management practices (Figure 3.3).³³ While a block is spatial, it is not joined up to the blocks around it. In this way Overseer cannot be described as being spatially explicit in the normal sense of the words.³⁴ Also, Overseer does not require these blocks to be contiguous in nature, meaning that different farm elements can be spatially connected or not. A block could even be located in another catchment.

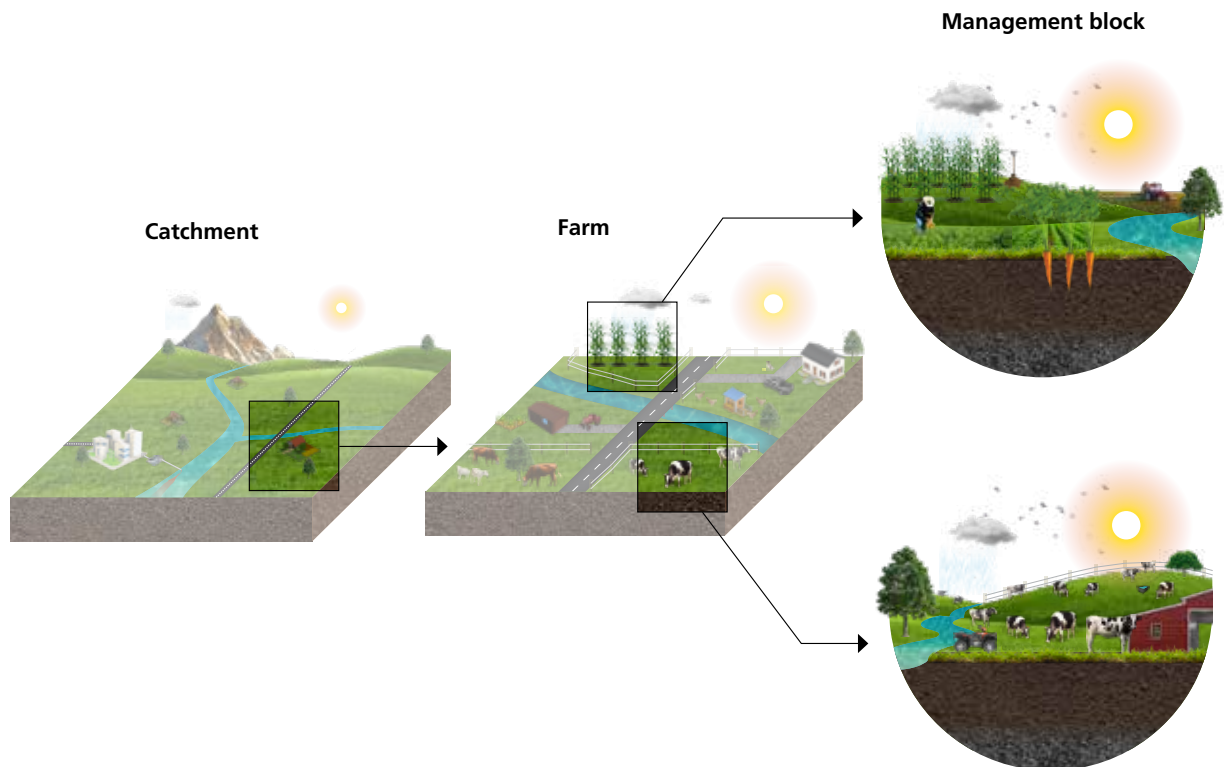


Figure 3.3 In Overseer, a farm is divided into blocks, with blocks typically representing areas with similar physical characteristics and management practices.

The way a farm is blocked can have an effect on the distribution of nutrients within the farm system and must therefore be carefully considered. For example, the ideal blocking of a farm to account for nitrogen losses may be different from that used for phosphorus losses, given the different relative importance of topography in influencing nitrogen and phosphorus loss.³⁵

³³But the sum of management blocks does not equal the farm. Overseer also accounts for nutrient transfers between blocks and farm structures such as a milking platform, feed pad, effluent pond, and lanes.

³⁴However, some spatial variability can be modelled as a result of the way a user divides a farm into blocks. In addition, OverseerFM 'starts to be' spatially explicit, by allowing users to draw blocks on a mapping interface. These blocks 'know' which climate and soil data to load.

³⁵McDowell, 2018.

One important consequence of Overseer not being strictly spatially explicit is that it has limited ability to identify critical source areas on a farm. Such areas can be significant contributors to nutrient losses from farms, especially for phosphorus. However, once identified, critical source areas can be modelled as separate blocks and managed accordingly.³⁶

Vertically, Overseer does not consider the leaching of nitrogen beyond the bottom of the root zone (which for pasture is assumed to be 60 centimetres). This means that the model provides no information about nitrogen transport and transformations between the root zone on a farm and a receiving waterbody.

Overseer also estimates emissions to the atmosphere of the three main agricultural greenhouse gases (carbon dioxide, methane, and nitrous oxide).³⁷

Assumptions

Assumptions are inevitable when developing a model. For example, all of the key modelling principles outlined above represent assumptions that have been made to simplify the farm system and make the model easier to use.³⁸ The combination of assumptions incorporated into the model play a significant role in what the outputs represent and how they can be used. For example, where there is limited or no data, Overseer is dependent on extrapolation beyond measured ranges and expert judgement.³⁹

Similarly, several assumptions reflecting good farming management practices are incorporated into Overseer, and the model produces outputs accordingly.⁴⁰ These assumptions include the following:

- effluent is stored in sealed structures (i.e. sealed non-leaky ponds)
- dairy cows use laneways to move from the paddock to the milking shed
- fertiliser is applied according to Fertmark⁴¹ and Spreadmark⁴² Codes of Practice (i.e. evenly at the time and rate stated, without any poor management).

However, if good management practices are not followed, environmental losses will in reality likely be higher than those estimated by Overseer.

³⁶Several spatially explicit models (e.g. MitAgator and Land Use Capability Indicator (LUCI)) have been recently developed that build on components or outputs of Overseer. For example, MitAgator allows critical source areas to be identified.

³⁷These emissions are estimated by using emissions factors. See Wheeler et al. (2008).

³⁸For example, assumptions include the use of long-term average climate data, spatial aggregation of soil data, that sample data sets used to develop relationships are representative, and that site characteristics are constant over time. In general, key assumptions built into Overseer have been publicly stated by model developers (e.g. Watkins and Selbie, 2015).

³⁹This is a well-established practice where there is a lack of empirical data from model parameterisation.

⁴⁰ Overseer assumes some specific good management practices are used, because not all processes can be adequately captured due to the model's steady-state nature. 'Good management practices' have also been termed 'best management practices' by Wheeler (2018a, p.19).

⁴¹Fertmark website (<http://fertqual.co.nz/understanding-the-marks/fertmark/>).

⁴²Spreadmark website (<http://fertqual.co.nz/understanding-the-marks/spreadmark/>).

By its nature, Overseer does not reflect day-to-day management. So it cannot capture any losses associated with a one-off incident such as an effluent spill. Nor can uneven fertiliser applications or applications too close to a stream be modelled in Overseer (even if a farmer has access to that data from GPS tracking).⁴³

While Overseer incorporates several assumptions reflecting good farming management practices, it can still model some instances of 'bad practice'. For example, it is possible to model over-stocking, the application of phosphorus fertiliser when run-off is likely, over-irrigating and winter applications of nitrogen fertiliser, as well as over-application of fertiliser for the required level of production.

Uncertainty in Overseer

Principles such as steady-state and the long-term averaging of Overseer raise an obvious question: how closely does the model approximate a real farm? This is a critical question. Users need to know that they are actually applying the right amount of fertiliser to meet their production targets, while also meeting environmental management goals.

The question might appear to be simply one of comparing model results with measured data. But it is not. Models are simplifications of complex systems and uncertainty is inescapable. Answering this question involves understanding the uncertainties inherent in any model.⁴⁴

As mentioned in chapter 2, there are two fundamental types of modelling uncertainty: uncertainty inherent in the model framework and uncertainty associated with model inputs.

A good example of *uncertainty inherent in the model framework* is Overseer's use of a 'typical' animal in a mob for its calculations of animal energy requirements.⁴⁵ The model assumes that using the mean characteristics of a mob to generate total energy requirements is the same as summing all individual animals in the mob. This approach creates uncertainty as not all animals are 'typical' – natural variability between animals is inevitable.

Poor record keeping is a direct source of *uncertainty associated with model inputs*. For example, a farmer might be unsure how much fertiliser or supplemented feed was used on the farm. An unreliable estimate of a key input increases uncertainty of the final outputs.

⁴³Overseer model developers have given some consideration to including the option of modelling nutrient losses if good management practices are not followed (e.g. effluent ponds are not sealed), although no changes to the model to allow this have been included to-date (Wheeler, 2018a, p.20).

⁴⁴United States EPA, 2009.

⁴⁵The term 'mob' is used by Overseer (Wheeler, 2018b), and represents the collective total of an animal type on the farm.

A more fundamental source of uncertainty is the limited availability of experimental field data of measured nutrient losses that can be used to calibrate the model. As previously discussed, Overseer is a semi-empirical model and relies on data to 'tune' or calibrate its parameters. However, the datasets of nitrogen and phosphorus loss measurements are quite limited (Table 3.1). Depending on whether a farm of interest has similar (or different) combinations of soils, rainfall, climate, and farming systems compared with the ones used for calibration, uncertainty can be small or large.

Model uncertainty is unavoidable, especially when modelling complex biophysical processes such as nutrient losses from farm systems, and one of the goals of the modeller should be to assess and communicate that uncertainty when reporting any outputs. Uncertainty analysis is used to quantitatively estimate the likelihood that the estimated values represent the real world values.

A related analysis, called a sensitivity analysis, is also used to improve the model and is often carried out alongside an uncertainty analysis. Sensitivity analysis helps determine which elements or parameters contribute the most to variations in results. The two analyses are used to improve model development.

It is worth noting that in Overseer, different uncertainties are associated with different outputs. For example, uncertainty associated with greenhouse gas estimates may not be the same as for nitrogen loss estimates.

No formal uncertainty analysis of Overseer as a whole has ever been conducted. The significance of this is discussed in chapter 4. Uncertainty estimates, however, exist for some elements of the model.

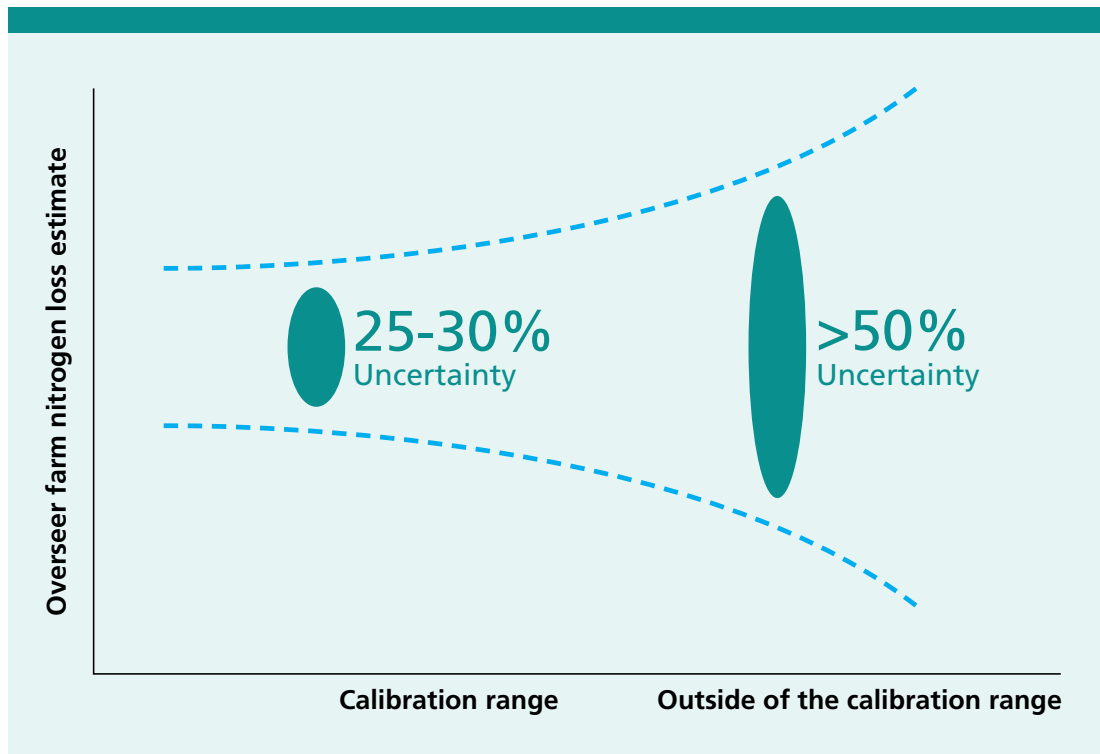
Uncertainty in nitrogen loss estimates

A simple uncertainty analysis for predicted nitrogen losses was undertaken in 2001 using an earlier version of Overseer (version 5).⁴⁶ This analysis (not publicly available, but widely quoted) indicated that the model uncertainty for predicted nitrogen losses (on farms that have characteristics similar to those from which field data has been gathered and used to calibrate the model) was about 25-30 per cent. Apparently, this estimate did not include errors associated with measurements, or uncertainty from data inputs, providing only part of the full picture of quantifying uncertainty.⁴⁷

According to Overseer's developers, a similar uncertainty range is likely to apply to the model's predictions of nitrogen loss using the current version (version 6). This of course, only applies to farms 'within the calibration range' – in other words, farms that have characteristics similar to those from which field data has been gathered and used to calibrate the model (Figure 3.4).

⁴⁶Ledgard and Waller, 2001.

⁴⁷Watkins and Selbie 2015, p.32.



Source: Watkins and Selbie, 2015, with data from Wheeler, 2018a, p.10.

Figure 3.4 Schematic description of uncertainty associated with nitrogen loss estimates.

Table 3.1 highlights that the locations used for the 2012 calibration of pastoral blocks were primarily from the Waikato and Southland regions. The sites had a limited range of soils types, a limited band of rainfall (between 600 millimetres and 1200 millimetres), and a limited range of management practices.

If farms of interest have characteristics that differ from those used for calibration, higher levels of uncertainty can be expected. It has been suggested that uncertainty in these circumstances is likely to exceed 50 per cent, but could be much higher still.⁴⁸

For example, in Canterbury, Overseer estimates of nitrogen leaching from dairy farms on light and poorly-drained soils could be anywhere from nearly 40 per cent below to 60 per cent above the actual leaching rate. A similar pattern was observed for sheep, beef, and deer enterprises.⁴⁹

⁴⁸ Wheeler, 2018a, p.10.

⁴⁹ These uncertainties were derived by experts with good knowledge of Overseer. The experts used an uncertainty elicitation framework (Sheffield Elicitation Framework) to estimate uncertainties of modelled nitrogen losses for each soil and land use groups, in the three management areas in the Waimakariri zone. See Etheridge et al. (2018) for more details.

Talking about uncertainty ranges in percentage terms is somewhat abstract. The sheer scale of uncertainty becomes more tangible when translated into nitrogen load estimates. For example, for one of the management areas in the Waimakariri Zone, the experts were 90 per cent confident that the estimated nitrogen loads were somewhere between 399 tonnes N/year to 910 tonnes N/year.⁵⁰ This variation is significant by any standard, although not surprising given the variability in nitrogen leaching rates seen under field conditions.⁵¹

Higher uncertainty will also apply to cropping systems due to a lack of experimental sites used for calibration.

Very little sensitivity analysis has been conducted on Overseer. However, a simple sensitivity analysis of nitrogen loss estimated by Overseer version 5 was undertaken in 2006.⁵² Drainage, animals, effluent management, fertiliser, crops, and imported feed were (qualitatively) identified as the key drivers of nitrogen loss in Overseer by a group of experts.⁵³

Uncertainty in phosphorus loss estimates

With regard to phosphorus, loss estimates, uncertainty, and sensitivity analyses were conducted in 2015. The uncertainty analysis indicated that for the 32 measured losses of phosphorus from small plots to catchments, uncertainty was up to 30 per cent.⁵⁴

A quantitative sensitivity analysis showed that estimated phosphorus losses were most sensitive to hydrological variables (e.g. rainfall or drainage class), followed by soil characteristics (e.g. slope and anion storage capacity), and then the type and rate of phosphorus applied.⁵⁵

⁵⁰In percentage terms, this 90% confidence interval translated into a range from -38% to +42% (Etheridge et al. 2018, p. 11).

⁵¹For example, one study found that measured N leaching varied by an order of magnitude (<10 to >100 kg N/ ha /year) over a 9-year study period because of variations in weather and farm management (Rutherford, 2018. p. 15).

⁵²See Power et al. (2006) for details.

⁵³This one-page summary was provided by Michael Keaney (Ballance Agri-Nutrients) and prepared with assistance from K. McCusker, I. Power, A. Roberts and D. Wheeler (Keaney, N.D.).

⁵⁴Mean uncertainty was determined as the standard error of the relationship between modelled and measured estimates (Pers. comm., Richard McDowell, 2018).

⁵⁵MitAgator, a spatial farm-scale tool, built using Overseer's core algorithms, was used for this exercise (McDowell et al., 2015a).

How Overseer generates its estimates

Overseer requires a wide range of inputs to be able to model farm nutrient loss and greenhouse gas emissions estimates (Figure 3.5).⁵⁶

Information about farm management is a core model input. Farm management information falls into two categories – farm-level and block-level inputs. These tend to reflect the scale of decision making. For example, decisions on land use, stock policy and farm structures (e.g. milking platforms or effluent ponds) are typically made at the farm level, whereas decisions about fertiliser application, irrigation, the choice of crops, or grazing management practices are made at the block level.

Information about the natural characteristics of the farm (i.e. soils and climate data) is also required. Here Overseer draws on climate and soil data that New Zealand’s research institutions have generated over many years. These are of varying comprehensiveness.^{57,58}

⁵⁶One of the model’s original development goals was the requirement for the information to be readily available to farmers and farm consultants or, where absent, the availability of suitable defaults.

⁵⁷As mentioned above, OverseerFM is able to draw on NIWA’s Virtual Climate Station Network to retrieve rainfall data from the 30-year average climate database (Wheeler 2018c).

⁵⁸Similarly, OverseerFM is able to retrieve soil information from S-map (a spatial soil database developed by Manaaki Whenua – Landcare Research). By supplying a block’s coordinates to S-map, OverseerFM is able to identify soils present on that block. These soils are automatically loaded into OverseerFM, and the user can then select up to three soils per block. The leaching result for a block is a weighted average of losses from each soil.

However, S-map does not cover the entire country. As of October 2018 it only covered 34% of New Zealand or about 63% of the productive land. Where S-map is not available, users have to use legacy soil maps – like Fundamental Soil Layers – which come with coarser resolution and more uncertain soil properties.

Technically, soil siblings are supplied by S-map. New Zealand soils are grouped into categories at five levels: order, group, subgroup, family, and sibling. As evident from above, soil sibling is the most detailed unit. Soil siblings are selected based on soil physical properties, like soil depth, texture, and stoniness. Information on soil siblings is available from the New Zealand Soil Classification website (<https://soils.landcareresearch.co.nz/describing-soils/nzsc/>).

Fundamental Soil Layers supply information on soil orders. The New Zealand Soil Classification has 15 soil orders, which cover all of New Zealand. These soil orders are: allophanic, brown, gley, granular, melanic, organic, oxidic, pallic, podzols, pumice, recent, semiarid, ultic, anthropic, and raw soils. Information on soil layers is available from the New Zealand Soil Classification, soil order website (<https://soils.landcareresearch.co.nz/describing-soils/nzsc/soil-order/>).

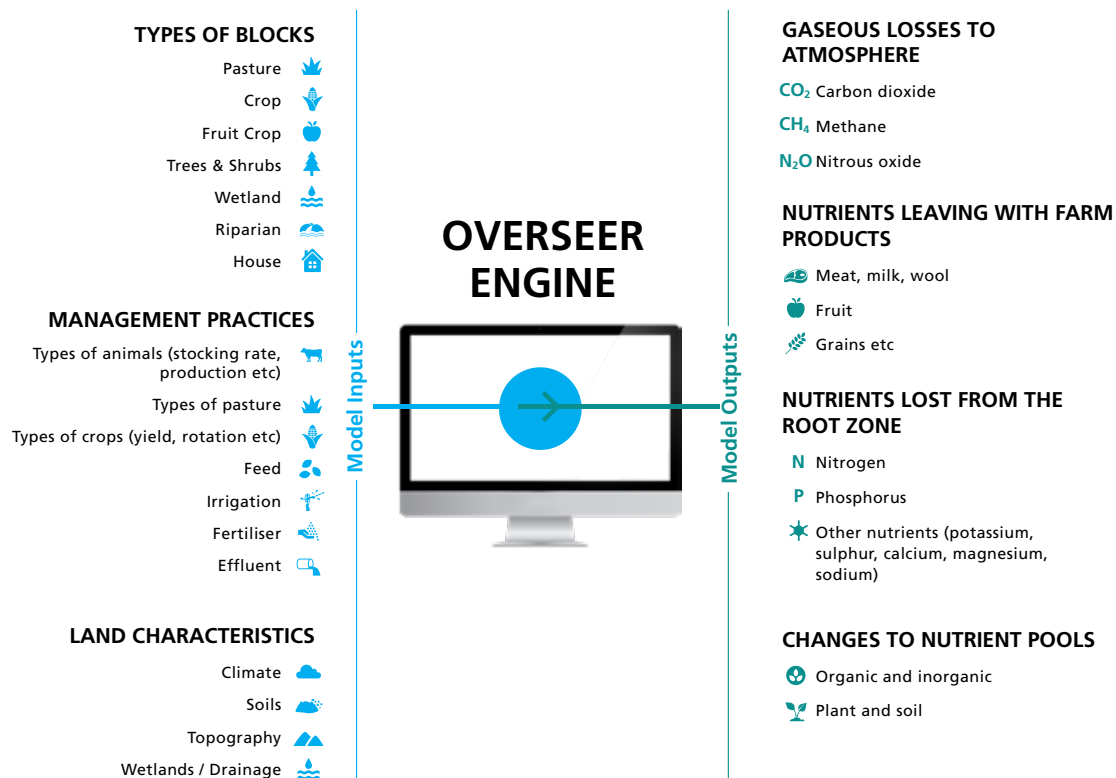


Figure 3.5 Conceptual diagram showing information required to set up Overseer (model inputs) and information generated by the model as a result (model outputs).

On the continuum between complex and simple models, Overseer sits somewhere in the middle.⁵⁹ This is largely due to complex interactions between relatively simple components. The 'engine' of the model (Figure 3.5) consists of over 30 sub-models (Table 3.2).

⁵⁹ Shepherd, et al., 2013, p.3.

Table 3.2. Sub-models in Overseer.

Source: Wheeler, 2018a.

Sub-model	Publicly available documentation ⁶⁰	Documentation not available publicly
Animal sub-model		
Animal model		Technical manual
Characteristics of animals	Technical manual	
Animal metabolisable energy requirements	Technical manual	
Intakes	Technical manual	
Subject-related sub-models		
Hydrology	Technical manual; Wheeler and Bright, 2015	
Climate	Technical manual	
Characteristics of soils	Technical manual	
Characteristics of fertilisers	Technical manual	
Characteristics of pasture	Technical manual	
Characteristics of crops	Chakwizira et al., 2011	Technical manual
Supplements	Technical manual	
Crop growth	Cichota et al., 2010	
DCD	Shepherd et al., 2012	
Wetland sub-model	Rutherford et al., 2008; Rutherford and Wheeler, 2011	
Riparian strip		
Specific enterprises		
Dairy goats	Carlson et al., 2011	
Outdoor pigs	Barugh et al., 2016, Wheeler et al. 2016	
Allocation procedures		
Supplement allocation	Technical manual	
Crop feeding		
Between-source and enterprise allocation		

⁶⁰A list of publicly available technical manuals can be found on the Overseer website (<https://www.overseer.org.nz/user-portal/science-model-information>).

Distribution of farm data to block scale		Technical manual
Effluent and pad management	Wheeler et al., 2012	Technical manual
Farm distribution		
Specific block sub-models		
Pastoral		
Fodder crop		
Cut and carry	Wheeler et al., 2010b	
Riparian strips		
Wetlands	Rutherford et al., 2008; Rutherford and Wheeler, 2011	
House blocks	Wheeler et al., 2010a	
Tree blocks		
Nutrient models		
Crop-based nitrogen sub-model	Cichota et al., 2010; Wheeler et al., 2011a	Technical manual
Urine patch sub-model	Cichota et al., 2012	Technical manual
Phosphorus (P)	Metherell, 1994; Metherell et al., 1995; McDowell et al., 2005; McDowell et al., 2008	
Sulphur (S) and potassium (K)		
Cations (calcium, magnesium and sodium)	Carey and Metherell, 2002	
Acidity	de Klein et al., 1997	
Reporting		
Constructing a nutrient budget	Selbie et al., 2013	
Constructing reports and indices	Wheeler et al., 2011b	
Greenhouse gas reporting		
Carbon dioxide, embodied and other gaseous emissions	Technical manual	
Calculation of methane emissions	Technical manual	
Calculation of nitrous oxide emissions	Technical manual	
Greenhouse gas reporting	Wheeler et al., 2008; Wheeler et al., 2011c, Wheeler et al., 2013	

Nitrogen losses in Overseer

An estimate of nitrogen losses is the final combined result of many calculations made in almost all sub-models except those dedicated to other nutrients and greenhouse gases. As a result, the quality of all of these sub-models matters.⁶¹

The urine deposited by grazing animals (sheep, cattle and deer) is the primary source of nitrogen losses on pastoral farms. Urine patches contain high concentrations of nitrogen (up to the equivalent of one tonne of nitrogen per hectare), which are much greater than the capacity of pasture to take it up. As a result, excess nitrogen is prone to losses, especially via leaching through soil.

In order to estimate nitrogen losses from animal urine and dung, Overseer uses a calculation sequence which starts with an animal – how much nitrogen was taken in by the animal, how much was retained in the product, and how much was excreted.

Overseer estimates animal feed intake from the net energy requirements of an animal and the energy content of the feed. It uses the nitrogen content of the feed to estimate total nitrogen intake. Nitrogen intake is then partitioned between animal products (e.g. milk, meat) and excreta (urine and dung). Most of the excreted nitrogen ends up in urine. Nitrogen leaching from urine patches and non-urine sources (fertiliser and effluent are the main non-urine sources of nitrogen losses) is then modelled separately.

The last step in calculations involves scaling up all the losses to the block and farm level, as this is the scale for which Overseer produces nitrogen loss estimates.

In the absence of animals, nitrogen fertiliser (e.g. urea) becomes an important source of nitrogen losses. In this case, Overseer estimates nitrogen losses as the net difference between inputs (fertiliser, soil, biological fixation by clover) and removals (uptake by plants, denitrification). In general, Overseer assumes that plants are relatively efficient at taking up nitrogen when not overwhelmed with excessive amounts of nitrogen from urine, so nitrogen losses on enterprises without animals are generally lower.

Phosphorus losses in Overseer

Overseer uses a separate sub-model to estimate phosphorus losses. This sub-model was developed in 2005 and has remained largely unchanged since then.⁶²

The main sources of phosphorus inputs within an agricultural system include soil itself, fertiliser, effluent, supplements, and excreted animal dung. Unlike nitrogen, the amount of phosphorus in animal urine is insignificant. Currently Overseer assumes that all phosphorus ends up in dung and none in urine.

⁶¹Not all sub-models have been documented. Even fewer have been peer-reviewed. Overseer model components that have been reviewed include: the use of soil parameters (Pollacco et al., 2014), greenhouse gas sub-models (Kelliher et al., 2015; de Klein et al., 2017), the metabolisable energy sub-model (Pacheco et al., 2016), the phosphorus loss sub-model (Gray et al., 2016), and the hydrology sub-model (this review was led by David Horne from Massey University, but it is not publicly available). However, the key sub-models for estimating nitrogen losses (e.g. urine patch and background nitrogen losses) have not been peer-reviewed.

⁶²Some minor modifications have been made to the phosphorus model, including the addition of other farming systems (e.g. deer). See McDowell et al. (2005) for the original description of the phosphorus sub-model, and Gray et al. (2016) for the peer-review.

The phosphorus sub-model within Overseer is calibrated to phosphorus losses to second-order streams due to run-off. In this case run-off includes surface run-off and sub-surface (leaching) flows, but excludes deep drainage to groundwater or mass movement.⁶³

Sitting behind the block- and farm-scale losses are estimates of different forms of phosphorus losses. These include incidental losses (recent soil phosphorus inputs with fertiliser, effluent, dung) and background losses from the soil (erosion or animal treading damage). The sum of both these losses is referred to as total phosphorus lost to water.⁶⁴

One limitation of the phosphorus sub-model is that not all types of erosion are included. For example, the sub-model can account for sheet flow and some gully erosion.⁶⁵ However, it does not estimate phosphorus that is lost in sediment associated with mass movement due to more extreme events such as earthflows or landslides.⁶⁶ In some topographical settings, particularly in the hill country, this can be a major source of phosphorus in some years.

As mentioned above, Overseer does not 'know' where critical source areas are. Critical source areas are minor parts of a paddock, farm or catchment that account for major proportions of water quality contaminant loss. For example, stock camps established on hill slopes have high concentrations of phosphorus that may be lost via run-off. However, as these critical source areas remain unknown to the model, Overseer has limited ability to help with targeting them and making mitigation options more cost-effective. However, if trained, a user could identify obvious critical source areas and include them as a separate block.

⁶³A first-order stream is a headwater, while a second-order stream results from the joining together of two first-order streams. While the model does not know where the second-order stream is, it is unlikely for a farm to be hydrologically isolated from a second-order stream.

⁶⁴The phosphorus loss in run-off includes both dissolved phosphorus and particles of phosphorus attached to eroded soil.

⁶⁵Sheet erosion is the uniform removal of soil in thin layers by the forces of raindrops and overland flow, and can cover large areas of sloping land.

⁶⁶Gray et al., 2016, p.32.



Source: Peter Scott

Figure 3.6 Heavy rainfall can lead to mass landslides on exposed hillsides. As well as being a costly loss of productive soil, landslides can add significant amounts of sediment and phosphorus into waterbodies. Overseer cannot model the occurrence or impact of such erosion events.

Greenhouse gas emissions in Overseer

As mentioned earlier, Overseer also estimates gaseous emissions from farms: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), all of which are significant greenhouse gases.⁶⁷

Within Overseer, the three greenhouse gases (GHG) are calculated using different approaches, accounting for differences in pathways and processes. Ten sources of greenhouse gas emissions are considered in Overseer.⁶⁸

⁶⁷Due to the increasing focus on greenhouse gasses (GHG) that has followed New Zealand's signing of the Paris Agreement and the development of the Zero Carbon Bill, several studies have been commissioned to investigate the underlying science used in Overseer when accounting for farm scale GHG losses (e.g. Kelliher et al. 2015; de Klein et al. 2017).

This work is in addition to the technical manual chapters (Wheeler, 2018d,e,f) and GHG reporting publications (Wheeler et al., 2008, 2011c, 2013) from Overseer that relate to GHGs. Furthermore, the potential role of Overseer in GHG reporting has been discussed by the Productivity Commission (New Zealand Productivity Commission, 2018) and the Prime Minister's Chief Science Advisor (Gluckman, 2018).

⁶⁸The sources include seven animal sources (dairy, dairy replacements, sheep, beef, deer, dairy goats, and others) plus horticulture, cropping, and export (Wheeler, 2018d,e,f).

The majority of carbon dioxide emissions come from direct emissions (e.g. fertiliser) and embodied emissions (e.g. electricity use and fuel).⁶⁹ Methane and nitrous oxide emissions (with the exception of fertiliser N₂O emissions) are related to animal processes and by-products, which in turn are governed by the animal's energy requirements.

Methane emissions come largely from processes in the animal's rumen (enteric processes) and the breakdown of dung.⁷⁰

Nitrous oxide is primarily produced as a by-product of soil nitrogen transformations from excreta (about 80-85 per cent) and fertiliser application. Nitrogen in urine and dung is estimated based on the nitrogen content of animal feed intake. The rate of nitrous oxide loss is then estimated using an emission factor for the different excreta. Emissions from fertilisers are calculated by multiplying the amount of nitrogen applied to a block by the emissions factor for fertiliser.

Overseer Legacy offers three different options for entering nitrous oxide emissions factors. They include: annual average emission factors, annual averages that are seasonally adjusted, and using farm-specific emission factors. Annual emission factors used by Overseer are largely the same as the New Zealand's Agricultural GHG Inventory model.⁷¹

While the ability to account for farm-specific factors for nitrous oxide has been noted by several authors as an important tool for accounting for on-farm GHG emissions, using farm-specific approaches can lead to erroneously high nitrous oxide emission estimates (compared to empirical observations and the use of annual average national emissions factors).⁷² As a result, it has been recommended to use the annual emission factors option rather than the farm-specific approach.⁷³

⁶⁹Embodied emissions are estimated as the sum of energy required to produce a good or service.

⁷⁰In Overseer, monthly dry matter intake is multiplied by a default enteric emission factor, with monthly values summed to produce an annual rate. The emissions factor varies based on the species of animal, and in the case of sheep by age. The default emissions factors used by Overseer are – by and large – the same as those used in the New Zealand's Agricultural GHG Inventory model, which have been generated from New Zealand-based studies. This research has also shown that the methane emission factor remains stable throughout the year and across locations. As a result, Overseer does not incorporate any seasonal variations in enteric methane emission factors. In addition, all feeds are currently assumed to have the same methane emission factor (Wheeler, 2018e).

⁷¹See Kelliher et al., 2015 for details. However, the use of farm specific emission factors is seen as desirable given that a primary driver of nitrous oxide emissions is thought to be soil water content (de Klein et al., 2017).

⁷²See de Klein et al. (2017) for details.

⁷³See de Klein et al. (2017) and Overseer Ltd. (2018a) Release notes for Overseer version 6.3.0. However, the ability to select the different input emissions factors for nitrous oxide does not appear to be currently present in the new interface (OverseerFM).

What Overseer can and cannot do

As a consequence of Overseer's purpose, design, history, evolution, and data availability Overseer CAN do the following:

- estimate farm (and block) nitrogen losses from the root zone and phosphorus losses to second-order streams
- estimate whole farm greenhouse gas emissions
- model seven nutrients (nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, and sodium) and greenhouse gases (carbon dioxide, nitrous oxide, methane)
- estimate maintenance fertiliser requirements
- model most common farming practices and mitigations to reduce the environmental footprint (e.g. lowering stock numbers, decreasing fertiliser application, irrigation management, types of feed and supplements)
- model proposed changes in the farm system (e.g. introduction of mitigations), and estimate nutrient losses and greenhouse gas emissions as a result of those changes⁷⁴
- model some instances of 'bad farming practice' (e.g. over-stocking, over-fertilising, over-irrigating and winter applications of nitrogen fertiliser, as well as over-application of fertiliser for the required level of production)
- model seven land uses or block types, with varying degrees of uncertainty.

By contrast, Overseer CANNOT:

- accurately model situations when farm management is changing, which happens, for example, when a land use has changed or intensified
- check if the inputs result in a farming operation that is realistic or not
- capture any variation in nutrient losses within a block
- capture patterns of nutrient losses at a shorter term (e.g. daily, weekly)
- be used to help make any day-to-day management decisions (e.g. when to irrigate)
- capture any losses associated with an incident (e.g. spill-over of effluent)
- model uneven fertiliser applications or applications too close to a stream
- model some novel farming practices and mitigations to reduce environmental footprint, such as urease inhibitors, pastures with plantain and chicory, use of dietary salt, and a full range of crops⁷⁵

⁷⁴This option allows farmers and consultants to test possible scenarios.

⁷⁵Wheeler 2018a, pp.18-19.

- produce accurate estimates outside calibration ranges
- provide the uncertainty associated with an estimate of nutrient loss or greenhouse gas emissions (e.g. Overseer does not provide a range of values within which an estimate could lie, or the level of confidence associated with the range)
- model sediment and pathogens (e.g. *E.coli*)
- model phosphorus lost with mass movement of sediment (i.e. slips and landslides) from large storms
- identify critical source areas on a farm (such as stock camps established on hill slopes) – unless these are modelled as separate blocks
- model impacts of the spatial layout of blocks or any spatial relationships between blocks
- provide information about what happens to nitrogen beyond the root zone (60 centimetres from the land's surface) or phosphorus beyond a second-order stream.



4

Overseer, regional councils and water quality

This chapter examines the way Overseer is being used by regional councils in support of policies designed to limit diffuse nutrient pollution.

It first examines the way Overseer is being used by regional councils in support of policies designed to limit diffuse nutrient pollution. It does not directly consider non-regulatory industry use of Overseer, except to acknowledge that such usage is widespread.⁷⁶

It then turns to some of the key issues councils face if they elect to use Overseer in managing nutrient loss. This section draws on guidance provided to councils in two reports: *Using OVERSEER in regulation*, prepared by Freeman Environmental Ltd in 2016 ('the Freeman report'); and *Using Overseer in Water Management Planning*, prepared by Enfocus Ltd in 2018 ('the Enfocus report').⁷⁷

This analysis is informed by the views of farmers, farming consultants, and regional council staff interviewed by the Parliamentary Commissioner for the Environment's (PCE) staff in the course of the investigation.

⁷⁶For example, Overseer nutrient budgets are produced by Fonterra for its farms under the 'Supply Fonterra' Nitrogen Programme, which was launched in 2012.

⁷⁷The Freeman report (Freeman et al., 2016) was commissioned by a number of regional councils, Ministry for the Environment, Ministry for Primary Industries and industry groups. The Enfocus report (Willis, 2018) was commissioned by Overseer Ltd.

Regional council use of Overseer

This section draws on a report commissioned by the PCE to examine the ways regional councils are currently using Overseer, and to ascertain what council staff see to be its advantages and disadvantages. The report is available in full on the PCE website.⁷⁸

Reference to Overseer in regional council and unitary authority regional policy statements and resource management plans

Seven councils do not explicitly reference Overseer in their regional policy statements or resource management plans (Table 4.1, column 2). However, even where councils do not explicitly reference Overseer in these documents, they may still use it. For example, staff at Greater Wellington Regional Council consider Overseer to be a valuable tool for catchment modelling despite no reference to the tool in the council's policies and plans.⁷⁹

Three councils include preparation of an Overseer nutrient budget as one of the requirements for permitted activity status for farming activities but impose no restriction on the amount of nitrogen leached (Table 4.1, column 3).

For example, under Environment Southland's Proposed Water and Land Plan, existing farming operations will be permitted activities provided the farmer prepares and implements a Farm Environmental Management Plan containing an Overseer nutrient budget and meets a number of other permitted activity standards.⁸⁰

The Overseer nutrient budget component of the Farm Environment Plan is intended to encourage good farm practice and provide the council, and the community, with an information base on which to make policy decisions regarding nutrient management when the catchment-by-catchment limit setting process begins in Southland.⁸¹ While the Farm Environment Plans are not subject to council approval, they must be provided to Environment Southland upon request.

Six councils go further than simply requiring preparation of an Overseer nutrient budget. These councils attach some regulatory consequence to the amount of nitrogen leached by a farm. In other words, they use Overseer as part of a framework that imposes *nitrogen loss limits*. Typically councils will require a retrospective 'performance' file displaying nitrogen loss rates based on actual farm data. Some councils also require a predictive Overseer file to show how a future nitrogen limit will be met (Table 4.1, column 4).⁸²

⁷⁸The report, commissioned from The Catalyst Group, is based on findings from a desktop review of the resource management plans of all 16 regional councils and unitary authorities (with the exception of Chatham Islands) and phone interviews with 31 staff from these councils. See The Catalyst Group (2018) available at www.pce.parliament.nz.

⁷⁹Pers. comm., Tony Faulkner, Greater Wellington Regional Council, 2018.

⁸⁰Farms below 20 ha in size are exempt from the requirement to provide a Farm Environmental Management Plan containing an Overseer nutrient budget. Other permitted activity standards relate to the altitude of the activity and practices relating to intensive winter grazing. Proposed Southland Water and Land Plan, Rule 20.

⁸¹Hearing Report: Proposed Southland Water and Land Plan Prepared under Section 42A of the Resource Management Act 1991, April 2017. The Council intends developing a Plan Change for freshwater objectives, limits and targets in Southland (that includes all Freshwater Management Units) to be notified by 2022.

⁸²Often plans allow for Overseer or an alternative approved model to be used.

In some cases, resource management plans contain activity status thresholds based on Overseer nitrogen loss estimates. For example, from June 2020 Hawke's Bay Regional Council will require farming properties in the Tukituki River catchment to obtain a resource consent should they exceed nitrogen leaching rates set out in the Regional Resource Management Plan.⁸³ The consent requirement will trigger a process for reducing nitrogen leaching from farms, through the implementation of progressively more stringent management practices.

In other cases, councils have avoided reliance on Overseer estimates for activity status, and have instead defined activity status with reference to the area used for specific activities. Environment Canterbury, for example, has used the area subject to irrigation and winter grazing to differentiate between permitted activities and those farming activities that require resource consents.⁸⁴ If a farm requires resource consent under these rules it will be subject to a nitrogen loss limit – and Overseer is used to monitor compliance – but the nitrogen loss limit is not the determinant of whether or not the farm requires resource consent.

The councils using Overseer as part of a framework imposing nitrogen loss limits (with the exception of Otago Regional Council) use Overseer in conjunction with farm plans that must be prepared as part of any application for a farming activity that needs a resource consent.

Implementation of the actions in these plans is then subject to monitoring and enforcement by councils. While the names used to describe these plans (e.g. farm environment plans, nutrient management plans etc.) and their specific requirements vary between councils, all need to be prepared by a certified person, and all must identify actions to reduce the risks of diffuse discharges of contaminants. The costs for most farm plans can be expected to fall within the range of \$2,200 and \$7,500.⁸⁵

For example, Bay of Plenty Regional Council requires a Nutrient Management Plan (NMP) as a condition of consent for farms in the Lake Rotorua catchment as part of Plan Change 10. The NMP must spell out mitigation actions to provide a pathway from a property's nitrogen leaching start point to its long term 'Nitrogen Discharge Allocation' to be achieved by 2032. Overseer is used to model the pathway (i.e. establish that the actions proposed will achieve the long term reduction in nitrogen loss).⁸⁶

⁸³Hawke's Bay Regional Council, 2015. Hawke's Bay Regional Resource Management Plan. Rule TT1 – Production land use, p.191A.

⁸⁴Environment Canterbury, 2016. Proposed Variation 5 to the Canterbury Land and Water Regional Plan. Rules 5.44A and 5.54A.

⁸⁵Note that in this study preparing Farm Environment Plans (FEPs) for Fonterra farms was much quicker due to Fonterra already having existing farm maps and Overseer files for their shareholder farms (AgFirst Waikato, 2016).

⁸⁶Section 42A Report for Proposed Plan Change 10: Lake Rotorua Nutrient Management. At the time of writing this plan change (Plan Change 10: Lake Rotorua Nutrient Management) was before the Environment Court.

Table 4.1 Use of Overseer in regional council and unitary authority regional policy statements and resource management plans

Council	Use of Overseer in regional policy statements or resource management plans		
	No regulatory use of Overseer	Regulatory – permitted activity standard	Regulatory – nitrogen loss limits
Auckland Council			
Bay of Plenty Regional Council			
Environment Canterbury			
Environment Southland			
Gisborne District Council			
Greater Wellington Regional Council			
Hawke's Bay Regional Council			
Horizons Regional Council			
Marlborough District Council			
Nelson City Council			
Northland Regional Council			
Otago Regional Council			
Taranaki Regional Council			
Tasman District Council			
Waikato Regional Council			
West Coast Regional Council			

Using Overseer to set nitrogen loss limits

Overseer is not only used in determining compliance with nitrogen limits (as described above) but is also used in *setting* nitrogen loss limits. This happens both at the level of the farm and catchment. These uses of Overseer are not always explicit in the regional policy statements or resource management plans themselves, so are discussed separately to the uses outlined in Table 4.1.

At the catchment scale, Overseer has been used as part of complex catchment-level modelling exercises. Overseer's role has been to estimate nitrogen losses from all the farms in a catchment while other models, accounting for nutrient transport and transformations, have been used to estimate the amount of nutrients finally entering receiving waterbodies. These catchment-scale modelling exercises have helped regional councils determine the scale of reduced nutrient leaching that will be needed to achieve desired water quality objectives.

One of the more sophisticated catchment-scale modelling exercises that has been undertaken concerns Lake Rotorua and the writing of Plan Change 10. Once an ‘acceptable water quality’ outcome for the lake was agreed, a target nitrogen load was determined. A catchment-scale model (which accounted for attenuation and groundwater time lags) was then used to determine the level of farm nitrogen losses consistent with achieving the target. Further discussion of catchment-scale issues is included in chapter 7.

Overseer plays a significant role in the setting of farm level nitrogen loss limits, also known as ‘allocations’. Broadly speaking, the approaches taken to date have been based either on what have been loosely termed ‘natural capital’ approaches (Otago, Horizons and Hawke’s Bay regional councils) or on approaches based, at least in part, on a farm’s previous nitrogen losses, known as ‘grandparenting’ (Waikato and Bay of Plenty regional councils and Environment Canterbury).

In the Horizons region, Land Use Capability (LUC) classes were used as a proxy for natural capital, with a maximum nitrogen leaching limit ascribed to each of eight classes. The limits for each LUC class were developed using hypothetical reference farms, which were modelled using Overseer.⁸⁷

In the Lake Rotorua catchment, the Bay of Plenty Regional Council used Overseer to model each farm’s historic nitrogen losses from 2001–2004. In order to achieve the reduction in the total nitrogen load to the lake sought by the council, a standard percentage reduction for each property based on the type of land use (dairy or dry stock) was applied. A further adjustment was made, where necessary, to bring a property within a range for that sector (this enabled the council to require the higher nitrogen leaching properties to reduce more).

As the above examples illustrate, Overseer has been used by some councils as a tool to determine a property’s leaching limit, but not to determine the approach taken to allocation. This is a decision made by councils, informed by political, social, economic and scientific considerations.

Overseer and phosphorus management

With respect to phosphorus, no council currently imposes phosphorus loss limits at the farm scale. However a number of councils require a nutrient budget that estimates phosphorus loss (in addition to nitrogen loss) as part of a farm plan. Council plans require Overseer, or an alternative approved model, to be used for this purpose.

⁸⁷The Land Use Capability (LUC) classes date back to a 1950s classification of the productive potential of land, with most LUC/NZLRI (New Zealand Land Resource Inventory) mapping taking place in the 1970s and 1980s. A number of concerns have been voiced by scientists about LUC’s fitness for the purpose of setting nitrogen limits. Main criticisms included: narrow focus on agricultural productivity (with the focus on arable cropping rather than pastoral land use), high variability of pastoral productivity within a LUC class, and limited correlation of LUC classes with nitrogen losses. See Lilburne et al. (2016) for details.

For example, in the Tukituki River catchment in Hawke's Bay, a Farm Environmental Management Plan (FEMP) must be prepared that contains a nutrient budget including phosphorus loss and nitrogen leaching rates for a farm. Farms in this catchment also need a specific Phosphorus Management Plan to be included in the FEMP. The plan identifies the inherent risks associated with phosphorus and sediment loss, the significance of those risks, and the management practices that will be implemented to avoid or reduce the risks.

Other methods to manage diffuse discharges

A variety of other mechanisms are used by councils to manage diffuse discharges alongside, or instead of, Overseer. Some of these mechanisms are voluntary, such as the riparian programmes utilised by the Taranaki Regional Council.⁸⁸ Others are regulatory, such as permitted activity standards that require stock exclusion from waterways, or standards for fertiliser use, irrigation, and effluent application to land.⁸⁹

Issues with Overseer application

In addition to the survey commissioned for this investigation, in-depth interviews were conducted with council staff, users and experts. From that body of evidence four key application issues emerge:

- data input uncertainty
- version change
- the inability of Overseer to represent farm systems in particular regions
- uncertainty in a compliance setting.

This is not an exhaustive list. During the investigation, other concerns were raised by council staff that merit further attention.⁹⁰ While the discussion that follows is from a regulator's perspective, the issues in question are also issues for farmers and the wider community.

Issue 1: Data input uncertainty

As mentioned in chapters 2 and 3, uncertainty associated with inputs is a key type of model uncertainty. With Overseer, input uncertainty can occur in a number of ways.⁹¹

Inadvertent errors can occur when someone enters a different value than the one they intended while recording farm data or setting up Overseer files.

⁸⁸However, Taranaki Regional Council is proposing to shift its riparian programme on the Taranaki ring plain from non-regulatory to regulatory. Taranaki Regional Council, 2015. Draft freshwater and land management plan for Taranaki. Rule 35(c) – Intensive pastoral farming p.66.

⁸⁹The Catalyst Group, 2018, pp.21–23.

⁹⁰For example, access to farm data in order to undertake catchment modelling to underpin plan development was a challenge for several councils. In some cases this data was held by industry organisations but not provided to the council e.g. because the data was not explicitly collected for that purpose. Other issues include dealing with sales (and new owners) and leased land.

⁹¹This list is based on the categorisation in the report by Enfocus (Willis, 2018).

Errors can also result from poor record keeping. For instance, a farmer might be unsure how much fertiliser or supplementary feed was used on the farm. An unreliable estimate of a key input increases uncertainty of the final outputs. Errors can also arise from simple misunderstandings or a lack of knowledge.

Uncertainties can also arise when users seek to ‘work around’ a problem because Overseer is not able to model a particular farm system. Workarounds are required in a range of circumstances, as outlined below.⁹²

- Some crop types grown in New Zealand are not modelled in Overseer. These are generally specialist vegetables or high value non-herbage seed crops.
- Double-sowing of crops (two crops sown during the same month) is not modelled in Overseer. For example, to increase winter grazing potential, growers often sow forage crops and clover seeds concurrently. In Overseer only one crop management option per month is allowed.⁹³
- Changes to paddock boundaries in the course of the year cannot be modelled in Overseer. Crops are often grown on small areas (e.g. 0.2 ha), with some variation throughout the year as space becomes available. However, Overseer is currently designed to model larger areas and even combine paddocks with common attributes and management into a single block.
- Uneven distribution of animals over a block that is being grazed cannot be modelled in Overseer. However, in reality forages and fodder crops are likely to be break fed. It can take five to eight weeks to break feed a crop like kale.



Source: pxhere.com

Figure 4.1 Overseer models a range of land uses. However, uncertainty can arise when Overseer cannot model a particular farm system (e.g. some crop types grown in New Zealand are not modelled in Overseer).

⁹²Hume et al., 2015.

⁹³It is anticipated that results from the ‘Forages for Reduced Nitrate Leaching’ project will enable enhanced forage crop options within Overseer.

As a consequence of these limitations, Overseer users have devised ways of representing farm systems in Overseer. Despite their best efforts there may still be significant (or at least unknown) differences between the actual farm and the farm as represented in Overseer. This can be problematic, especially if any workarounds are not explicit and are not applied consistently by different users.⁹⁴

Interpretation differences are another source of input uncertainty. For example, wetlands can be set up as separate wetland blocks or be included in other blocks (e.g. pasture) with very different results for estimated nutrient loss.

Finally, it is possible to deliberately manipulate Overseer outputs. For example, indicating that soil moisture is monitored using special sensors and that irrigation is only applied when soil moisture falls below a trigger point, will produce a lower nitrogen loss number compared with visual assessments or no assessments at all.

Setting up management blocks in another catchment in order to reduce the average nutrient loss estimated by Overseer is another example of deliberate manipulation. While, on paper, nitrogen leaching will be reduced, in reality no on-the-ground change in farming practice has occurred.

This investigation has not been able to find any published data quantifying the frequency with which any of these sources of input uncertainty occur, nor of any attempt to quantify the resulting impact on model uncertainty. However, data input uncertainty was raised as a key disadvantage of Overseer by regional council staff. In discussions with farmers, farm consultants and regional councils, numerous anecdotes of deliberate manipulation were reported, as were instances of workarounds, and interpretation differences.

A number of resources and practices are available to help overcome these problems. Several of them are described below.

Overseer Best Practice Data Input Standards

Overseer Best Practice Data Input Standards were first developed in 2013 by a group of technical expert users and model developers. The latest data input standards are designed for Overseer version 6.3.0 and were published in March 2018 by Overseer Ltd. The standards aim to reduce inconsistencies between different users and provide guidance on data inputs that “consistently achieve the most meaningful results”.⁹⁵

Use of the standards should, in particular, reduce interpretation differences. For example, as outlined above, wetlands can be set up as separate blocks or be subsumed within other types of blocks. According to the standards, if a wetland area is retired from grazing, then this area should be accounted for as a riparian block. This is

⁹⁴For example, Overseer Ltd publishes Frequently Asked Questions (FAQ) online which guide users on some ‘workarounds’ to known difficulties in selecting the most appropriate input parameters.

⁹⁵Overseer Best Practice Data Input Standards. Overseer Version 6.3.0, March 2018.

because expert knowledge on types of wetlands is currently required to correctly set up a wetland block.⁹⁶

The standards also provide useful advice on how to deal with some of the ‘workaround challenges’ described above. For example, if a particular crop is not represented in Overseer, the standards recommend choosing the most similar crop from the ones available.

The standards will not, however, in and of themselves reduce inadvertent errors, deliberate attempts to manipulate the final number, or improve record keeping. Further, in some instances, adherence to the standards may not provide the best representation of the farm. For example, the standards recommend the use of ‘occasional pugging’ for all soil types under dairy farms. However, not all dairy farms have the same level of pugging. Farm knowledge, user experience and training are vital to ensure accurate representation of a particular farm in Overseer.

As mentioned above, the standards aim to reduce inconsistencies between different users, and are useful to this end. For this reason they should be used by all those undertaking Overseer modelling when the results will be used to inform regulation. This is consistent with the recommendations of both the Freeman report and the Enfocus report.

Certification of farm advisors

As Overseer is a technical tool, it requires an operator who possesses a certain level of expertise to operate it in a way that minimises the various forms of input uncertainty described above. The Freeman report recommends, at a minimum, the possession of a Massey University Certificate in Advanced Sustainable Nutrient Management, an equivalent qualification, or extensive experience in a specific farming system and detailed understanding of Overseer. The Enfocus report recommends the Massey University Certificate in Advanced Sustainable Nutrient Management.

While the need for operators to possess appropriate qualifications seems generally accepted by regional councils, significant waiting periods have been reported in those regions where councils require farmers to prepare Overseer budgets for compliance purposes, highlighting a shortage of appropriately trained people.

Auditing of Overseer modelling

Where Overseer is used to set a farm nitrogen loss limit (for instance, one based on a farm’s historical losses) or determine compliance with nitrogen limits, there are significant incentives for the deliberate manipulation of Overseer modelling results.

The Freeman report identifies situations in which regional councils should require the audit of Overseer modelling by a qualified person not involved in the initial

⁹⁶However, it seems this issue is still not entirely resolved. The OverseerFM User Guide, which was published by Overseer Ltd since the latest standards, suggests that unfenced natural wetlands be entered using the Drainage/Wetlands tab. A photo guide produced by NIWA is accessible to users to help determine wetland type.

Overseer modelling exercise. Audit is recommended for determining resource consent compliance and in cases where the results may have particularly significant implications for regional plan development or determining a regional plan activity status. It provides a comprehensive list of factors that should be considered in an audit.⁹⁷

To be able to audit Overseer files, councils and auditors need access to the necessary information. In most situations the full Overseer XML file (the file which sets out the full suite of input and output data) is required to provide an independent auditor with sufficient information to ensure the robustness of a nutrient loss estimate. For example, Environment Canterbury requires the suite of inputs that go into generating an Overseer estimate so it can check the validity of the nitrogen loss output and recreate these estimates from time to time in the most recent version.⁹⁸

The auditor is likely to be 'off-site'. This means they will need a way of checking the input data using information from various sources such as annual taxation accounts showing opening and closing stock numbers, stock transactions or annual nutrient statements provided by the fertiliser company.

As noted in chapter 3, Overseer assumes that inputs are consistent with production irrespective of whether a farming system is viable or not, opening up the possibility of an operator entering unrealistic inputs and creating unrealistic farming operations.⁹⁹ The auditor needs to have the expertise to assess whether inputs and outputs are within the normal range for the farm system and location. The current shortage of qualified professionals outlined above is equally problematic for ensuring a robust audit system.

Secure receiving and storing of Overseer information

Councils need a secure way to store Overseer information and one that enables them to efficiently locate and uplift this data should it be needed in the future, such as for catchment modelling, auditing, or undertaking compliance activities.

Historically this would have required councils to build a secure system to collect and store the XML files used to generate Overseer estimates. However, in the new OverseerFM the centralised farm account replaces the XML files in the legacy product. Instead of providing an XML file to a council, the new software allows users to submit information to councils using the 'publication' button in the OverseerFM user interface. Overseer Ltd consider this will make sharing of information from farmer to council much more streamlined and improve councils' ability to audit Overseer files.

However, exactly what information regional councils will be able to extract, store and analyse remains unconfirmed. Several councils are concerned about the extent to

⁹⁷Freeman et al., 2016, Table 12, pp.82–84.

⁹⁸Pers. comm., Leo Fietje, Environment Canterbury, 2018.

⁹⁹Over time, there have been some efforts to allow users to manually check aspects of the viability of farm systems. For example, in Overseer Version 6.0 estimated pasture production was reported, which users can use as a feasibility check. In addition, some sensibility testing is embedded into OverseerFM (e.g. for pastoral blocks) as the software provides a suggested range for production, and can also generate error messages. OverseerFM website (<https://fm.overseer.org.nz/>), accessed 16 November 2018.

which OverseerFM may affect their ability to recreate or audit Overseer files and the potential for a property owner to refuse to share information (e.g. if threatened with enforcement action). Affected regional councils are currently in negotiations with Overseer Ltd on this issue.¹⁰⁰

The use of the best practice data input standards, certification, auditing and secure storage of Overseer files are practices generally accepted by regional councils.¹⁰¹

It should not, however, be assumed that implementing these practices is easy. There is a need for council staff to have a high degree of understanding of farm systems and expertise in Overseer to facilitate the auditing of Overseer results. Effective oversight of the process of receiving, auditing and storing Overseer files is likely to require significant staff time.¹⁰²

Issue 2: Version change

Overseer is updated fairly regularly. Some of these changes are to the model user interface, or relate to fixing minor bugs or adding some functionality. These changes may or may not impact on nutrient loss estimates.

However, once a year, more significant changes are made to the computational 'engine' of the model with consequences for nutrient loss estimates. For example, a substantial upgrade of the irrigation sub-model occurred in 2015 which resulted in significant changes to nutrient loss estimates from irrigated land.¹⁰³ The ongoing process of updating soil information in the S-map soils database also affects the model's output.

The Freeman report states there are potentially very significant policy, regulatory and implementation resourcing implications flowing from Overseer version changes. Version change was also highlighted by council staff as a major problem. The impact on farmers of version changes is potentially significant, and was frequently raised by farmers and farming consultants as a key concern.

For example, the use of nitrogen loss rates as consent thresholds in plan rules has meant that, simply due to model changes, farms in some regions have suddenly become subject to different and generally tougher consent requirements.¹⁰⁴ This creates uncertainty with respect to regulatory obligations and undermines farmer confidence in the model.

¹⁰⁰ Pers. comm., Waikato Regional Council and Environment Canterbury, 2018.

¹⁰¹ For example, where Overseer is used in a limit setting context all regional councils require the development of an Overseer Nutrient Budget that is calculated by a suitably qualified or accredited farm advisor in accordance with Overseer Best Practice Input Standards.

¹⁰² Pers. comm., Bay of Plenty Regional Council, 2018.

¹⁰³ OVERSEER® Release notes for version 6.2.0, April 2015.

¹⁰⁴ Freeman et al., 2016, p.50.



Source: Parliamentary Commissioner for the Environment archives

Figure 4.2 Farmers in the Manawatū-Whanganui region faced issues with Overseer version changes in 2012. Under Version 5.4 of Overseer, the council considered about 80 per cent of farmers in the region would be able to comply with nitrogen loss limits in the regional plan. Under Overseer Version 6, the council's position was that this figure was closer to 20 per cent, meaning that many more farmers would require a tougher resource consent to continue farming. Horizons Regional Council is still working through issues this version change caused for its regional plan.

That said, council staff also recognise the need for continuous and timely improvements to the model. Farmers also want improvements to Overseer that can better reflect their farm systems.

Some regional councils have responded as the pitfalls of particular planning approaches have become known. For example, nitrogen loss limits were used in the Canterbury Land and Water Regional Plan to define whether a farm's activity had permitted activity status. Farm nitrogen losses based on Overseer were revised upwards as a result of version updates. This resulted in many farms requiring resource consents despite no change in actual farming practices.

The council responded to this issue in a 2016 plan change. Instead of using Overseer estimates, it used the area under irrigation and winter grazing to differentiate between permitted activities and those farming activities that required resource consent. This approach (defining permitted activities using 'narrative' thresholds) avoided the issue of Overseer version changes in the regional plan.¹⁰⁵ However, the council still confronts the issue of Overseer version changes in its resource consent processes.

¹⁰⁵Environment Canterbury, 2016, Proposed Variation 5 to the Canterbury Land and Water Regional Plan, Rules 5.44A and 5.54A.

Bay of Plenty Regional Council's approach to version changes (in Plan Change 10) is to use the latest version of Overseer and specify a method (referred to as the 'Reference File' method) to maintain the proportionality of a property's nitrogen allocation relative to the rest of the sector. The rationale is that the proportionality of the initial nitrogen allocation is sound and should therefore be maintained into the future, across multiple version changes.¹⁰⁶

While there has been significant thinking about ways to address this challenge in recent years on the part of regional council staff, it is not clear that the issue of version changes can be considered 'solved' for any council using Overseer in a framework with nitrogen loss limits. Some of the approaches are yet to be tested, either in the Environment Court, or in on-the-ground implementation.

While the Freeman report states it is essential that councils clarify how Overseer version changes will be managed, and provides some useful ways to do this, it does not provide a recommended option, and in this sense may be of limited assistance to councils, particularly those preparing plans which refer to Overseer for the first time.

If there is to be more consistent and confident practice on the part of regional councils, central government will need to step forward and prescribe a best practice approach. Flexibility could be left to councils to depart from it on a case by case basis. With the release of OverseerFM and the move by Overseer Ltd to make the legacy version unavailable, the need for such advice is particularly urgent.

Issue 3: The inability of Overseer to represent farm systems in particular regions

As explained in chapter 3, Overseer is a largely empirical model. This means it relies on calibration – a process that fine-tunes its parameters using experimental data. Higher levels of uncertainty can be expected when Overseer is used to model farms with characteristics that differ significantly from those used for calibration purposes.

The locations used for the 2012 calibration of nitrogen losses from pastoral blocks were primarily from the Waikato and Southland regions. The sites covered a limited range of soil types, a limited band of rainfall (between 600 and 1200 millimetres), and a limited range of management practices. It follows, for example, that sites with high rainfall (>1400 millimetres) as well as those on shallow, free-draining soils (which are common in large parts of Canterbury) will have higher uncertainty. In addition, higher uncertainty will also apply to cropping systems, as the majority of the sites used for calibration were dairy farms.

Some regional councils with climatic conditions, soil conditions or farm systems which are not reflected in the calibration exercise have recognised the need to improve Overseer's calibration. Recognising that Overseer has not been calibrated for the high

¹⁰⁶For a full description of the reference file methodology see the Statement of Evidence of Alistair Charles MacCormick on Behalf of the Bay of Plenty Regional Council in the matter of Lake Rotorua Nutrient Management – Proposed Plan Change 10 to the Bay of Plenty Regional Water and Land Plan, 17 January 2017.

rainfall conditions in Rotorua, the Bay of Plenty Regional Council initiated calibration trials on two dairy farms in the Lake Rotorua catchment with AgResearch. Project funding came from the council, DairyNZ and AgResearch.

Environment Canterbury has expressed concern about the lower level of confidence in Overseer's ability to model arable and horticultural systems compared to its ability to model intensive pastoral systems which have had a greater level of calibration.¹⁰⁷

It is apparent that an inadequate range of calibration studies may significantly degrade the reliability of Overseer estimates in regions such as Marlborough, Tasman, West Coast, Gisborne, Taranaki and Northland. As soil information is one of the key inputs, areas with no S-map data will have less accurate results. Regions such as Northland, Taranaki, Gisborne and the West Coast have no or limited S-map coverage, and therefore the more generic 'Fundamental Soil Layer' option must be selected within Overseer.¹⁰⁸ This is a reason to give real priority to improved calibration trials and soil information to underpin regulator and farmer confidence.

Issue 4: Uncertainty of Overseer in a compliance setting

A key concern raised by council staff is that due to the uncertainty of Overseer's estimates, absolute outputs from Overseer could not be relied on for enforcement purposes. Enforcement refers to the broad range of actions taken by councils to respond to non-compliance with the Resource Management Act 1991 (RMA). These actions include negotiation, abatement notices, enforcement orders and, at the most serious end, prosecutions for offences under the RMA.

Prosecutions require that the elements of a criminal charge are proved beyond reasonable doubt. The concern is that Overseer cannot be used to prove non-compliance with a limit set in a resource consent – for example, proving that actual nitrogen leaching on a farm exceeds a given number of kgN/ha/yr. Councils relying on an Overseer derived estimate of nitrogen loss to trigger a requirement for resource consent face issues of a similar nature, albeit to a lower standard of proof.

We are not aware of any cases where a prosecution has been initiated in the Environment Court based on an Overseer estimate of nitrogen loss. In the absence of any case law, whether the model forms an adequate basis for prosecution remains a live issue for councils.¹⁰⁹

However, the RMA provides a number of enforcement mechanisms designed to ensure compliance with the statutory regime that do not require councils to meet the evidential test required in a criminal prosecution.

¹⁰⁷Pers. comm., Leo Fietje, Environment Canterbury, 2018.

¹⁰⁸Manaaki Whenua Landcare Research advises that as at October 2018, national S-map coverage was 34%; LUC 1-4 63% but LUC 5-8 was <25%; Waikato 72%; Bay of Plenty 59%; Canterbury 46%. Soil-map and S-map online website (<https://soils.landcareresearch.co.nz/soil-data/s-map-and-s-map-online/>).

¹⁰⁹The Catalyst Group, 2018, p.iv.

Some councils are satisfied that these other mechanisms (e.g. letters, abatement notices, enforcement orders) allow them to satisfactorily achieve compliance. For example, in one instance where a council received Overseer files which didn't match what it saw on the ground, it conducted formal interviews with the farm owner, farm manager and consultant. It emerged that some of the information was false and steps were put in place to rectify the situation.¹¹⁰

There are also ways to respond to Overseer's uncertainty in the design of planning provisions themselves.

First, there is the way councils design their 'compliance platform'. Bay of Plenty Regional Council's Plan Change 10 uses Nutrient Management Plans and the 'committed actions' set out in these Plans as the primary point of monitoring, and, if necessary, compliance, as opposed to the Overseer nitrogen loss estimate itself.

Second, expert opinion suggests there is a lower level of uncertainty when using models to describe relative differences, such as the increase or reduction of nitrogen leaching after a management change, rather than when providing the absolute values of leaching.¹¹¹

This principle is applicable to Overseer's nitrogen loss estimates – the science and model construction mean Overseer's estimate of the degree of change between two systems on the same soil with the same climate will be less uncertain than the absolute value.¹¹²

Because of this, the Enfocus Report suggests Overseer in a regulatory context is probably best regarded as a tool for assessing the relative change in nitrogen leaching between different points in time, rather than a model that attempts to estimate nitrogen leaching in absolute terms. The Report states: "... Overseer will be very good at assessing whether a (say) ten percent reduction in N leaching has occurred on a particular property (given a series of practices) over a prescribed (say) five-year period."¹¹³

An example of a council using Overseer to assess the relative change in nitrogen losses from a farm is Plan Change 10. Bay of Plenty Regional Council requires each property to reduce nitrogen losses by a specific percentage by 2032. It does this through the use of reference files.

While the planning provisions of some councils have been developed with Overseer's uncertainty and compliance challenges in mind, overall the approach by councils varies significantly and this issue remains a key concern of council staff.

¹¹⁰Pers. comm., Leo Fietje, Environment Canterbury, 2018.

¹¹¹Chicota and Snow, 2009, p.250.

¹¹²Statement of Evidence of David Mark Wheeler before the Board of Inquiry in the matter of the Tukituki Catchment Proposal, September 2013.

¹¹³Willis, 2018, p.16.

Conclusion

Some of the issues outlined above are partly within the power of regional councils to solve.

Councils are able to lessen the scope for deliberate manipulation of Overseer modelling through auditing Overseer files, and setting up robust systems to receive, store and retrieve them.

However, as this chapter notes, there is a need for council staff to have a high degree of knowledge of both Overseer and of farm systems in order to audit Overseer files. The shortage of qualified Overseer operators in the wider sector has been highlighted. This issue is even more pronounced among councils which, relative to industry, have few in-house qualified operators.

Planning provisions can be drafted in a way that reduces issues arising from Overseer's limitations, uncertainty and version changes, but the issue of version changes continues to pose a significant challenge to councils using Overseer in a framework with nitrogen loss limits.

If greater uniformity of practice and confidence in regulators is to be forthcoming, official guidance from central government setting out a best practice approach to managing version change and dealing with problems of model uncertainty in the design of planning provisions would be desirable.

The issue of some climatic conditions, soil conditions or farm systems not being reflected in the calibration studies for Overseer has led to some regional councils funding new calibration studies. However, these are multi-year, costly exercises that do not appear to be the subject of current strategic or prioritised investment.

Some issues associated with using Overseer in regulation are not within the power of regional councils to solve or improve – or councils may not have access to the information and resources required to address the issue.

Model uncertainty can only partly be addressed by councils. Councils have limited means of understanding where the most important sources of model uncertainty arise, or understanding the consequences of these sources of uncertainty on Overseer's outputs. Ultimately, this means Overseer's uncertainty cannot be fully acknowledged, quantified and carried through into risk analysis when councils are developing plans.

Furthermore, in the absence of an independent peer review of Overseer, councils have limited ability to reassure those they are seeking to regulate that the model is utilising the best available scientific information, and that it is incorporating it appropriately.

Understanding and addressing these issues requires a more fundamental look at the model itself. It requires an understanding of the scientific elements that should be assessed and the processes that should be followed, when judging whether a model can be used to support regulation making. That is what the next chapter deals with.



5

Assessing Overseer

This chapter has three main sections. The first section looks at how to judge a model's suitability for use in support of regulation. It notes that despite New Zealand's use of models in regulatory processes there is no official guidance to assist either regulators or those being regulated to make an informed judgment about whether a specific model is suitable and acceptable for use.

In the absence of New Zealand guidance, this section describes the United States Environmental Protection Agency's (EPA) framework for the evaluation of environmental models. This framework identifies scientific elements that should be assessed, and process steps that should be undertaken, when judging whether a model can be used to support regulation.

The second section assesses Overseer using the United States EPA's framework. It is not a formal, exhaustive evaluation. Rather, it provides a picture of the existence – or absence – of information that could help determine whether Overseer is of sufficient quality to serve as the basis for regulation making.

On the basis of this assessment, the third section poses the question of whether Overseer can be used in a regulatory context.

Judging a model's fitness to support regulation

The implementation of New Zealand's environmental policy drives the use of models in a range of domains. For example, the New Zealand Coastal Policy Statement 2010 requires coastal hazards risk, over at least 100 years, to be assessed.¹¹⁴ Similarly, the National Policy Statement for Freshwater Management 2014 requires regional councils to establish and operate a freshwater quality accounting system, which records information on contaminant loads and sources.¹¹⁵ In the air quality domain, the National Environmental Standard for Air Quality requires councils to determine the effect of a new air discharge application on ambient standards.¹¹⁶

Although not always explicitly stated, the above policy instruments necessitate the use of models in their implementation. Models are also commonly used to inform decision making throughout the consenting process under the Resource Management Act 1991 (RMA).¹¹⁷ In this sense Overseer can be seen in context as one of many models used for environmental regulatory purposes in New Zealand.

If a model is to be used in a regulatory setting, everyone – regulators and regulated alike – need to have confidence that it is fit for purpose.¹¹⁸ Despite New Zealand's use of models in environmental regulation, there is a lack of guidance on how to assess whether a specific model is acceptable for use. There is also no widely applicable guidance on what good practice looks like for those developing models for regulatory decision making.¹¹⁹

Fortunately, such guidance has been developed in other jurisdictions and in academic literature.¹²⁰ The United States National Research Council (NRC) 2007 report *Models in Environmental Regulatory Decision Making* and the United States EPA's 2009 report *Guidance on the Development, Evaluation, and Application of Environmental Models*

¹¹⁴New Zealand Coastal Policy Statement, Policy 24.

¹¹⁵National Policy Statement for Freshwater Management (2014) – amended 2017, Policy CC1.

¹¹⁶Resource Management (National Environmental Standards for Air Quality) Regulations 2004.

¹¹⁷Özkundakci et al. (2018) provides an overview of model use and the legal challenges that have been raised against them within a New Zealand context.

¹¹⁸For example, Özkundakci et al. (2018, p.1) outline that modellers and decision makers need to have a clear understanding of the purpose of the model, ensure transparency in the modelling process, acknowledge and minimise limitations and ensure that relevant best practices guidelines are followed. However, what modelling best practice looks like is sometimes difficult to define, as differences between scientific best practice and regulatory best practice vary with environmental domains.

¹¹⁹However, some domain specific guidance is available on the application of modelling in implementing environmental policy. Examples include guidance related to the National Policy Statement for Freshwater Management (e.g. MfE, 2016), New Zealand Coastal Policy Statement (e.g. MfE, 2017) and Resource Management (National Environmental Standards for Air Quality) Regulations 2004 (e.g. MfE, 2004). In addition, as discussed in the previous chapter, Freeman et al. (2016) provides some non-statutory guidance for regional councils on the use of Overseer. However, this report does not address the issues of model development and evaluation.

¹²⁰For example, Jakeman et al. (2006) outline ten steps in model development and discusses minimum standards for model development and reporting; Bennett et al. (2013) suggest a five-step procedure for evaluating the performance of environmental models, focusing on graphical and numerical methods; Tonitto et al. (2018) define a seven-step process for model selection and use; United States EPA (2009) provides guidance on the development, evaluation, and application of environmental models; and Queensland State Government's *Good Modelling Practice Principles* (Jakeman et al., 2018) sets out good water modelling practices and principles.

are particularly useful guidance documents.¹²¹ In these documents the term ‘model evaluation’ is used to describe the process of generating information that helps determine whether a model and its analytical results are of sufficient quality to serve as the basis for a regulatory decision.

These publications provide a list of scientific elements that should be assessed, and process steps that should be undertaken, when evaluating a model. They are applicable across a wide spectrum of environmental models, reflecting the United States EPA’s reliance on models in diverse settings – including atmospheric and indoor air models, groundwater and surface water models, exposure models, risk assessment models, and economic models.¹²²

Furthermore, these publications have been developed specifically for models used to inform regulatory decisions. This is in recognition of the fact that evaluation of regulatory models must interrogate a model differently, and address a more complex set of trade-offs, than research or other models used in the public or private sector for non-regulatory purposes.¹²³ This issue is expanded on later in this chapter.

In the absence of a New Zealand specific framework for evaluation of environmental models, this report uses the United States EPA’s evaluation framework to assess Overseer.

Elements of model evaluation

The United States EPA suggests twelve elements should be addressed in model evaluation. For this report, these elements have been grouped into four broad categories.

1. Is the model based on sound science?

- *Scientific basis*
- *Computational infrastructure*
- *Assumptions and limitations*
- *Peer review*

2. Is the model managed to ensure quality?

- *Quality assurance and quality control*
- *Data availability and quality*
- *Test cases*

¹²¹National Research Council (NRC), 2007 and United States EPA, 2009.

¹²²For examples of environmental models used by the United States EPA, see NRC (2007) Appendix C.

¹²³For example, the NRC (2007, p.2) states “Evaluation of regulatory models also must address a more complex set of trade-offs than evaluation of research models for the same class of models. Regulatory model evaluation must consider how accurately a particular model application represents the system of interest while being reproducible, transparent, and useful for the regulatory decision at hand. Meeting these needs may require different forms of peer review, uncertainty analysis, and extrapolation methods.”

3. Does the model's behaviour approximate the real system being modelled (including the tools and procedures necessary to make this judgment)?

- *Sensitivity and uncertainty analysis*
- *Corroboration of model results with observations*
- *Benchmarking against other models*

4. Is the model appropriate for a specific regulatory application?

- *Model resolution*
- *Transparency*

Model evaluation based on these elements not only helps determine whether a model is of sufficient quality to serve as the basis for a decision. It also helps identify potential areas for model improvement.

Importantly, the United States EPA recommends that evaluation is conducted over the entire life cycle of the model, starting early in the process and continuing throughout model development and application.¹²⁴

Tailoring model evaluation to the model's intended application

An evaluation of any model should be tailored to the task the model is being asked to perform. Because Overseer is used for a range of regulatory and non-regulatory applications, it is important to be very clear about the purpose for which the model is being used. Here are four different tasks a user might ask of the model.

- Task one: A farmer might use Overseer to optimise maintenance fertiliser requirements, to help maximise farm productivity and profitability.
- Task two: A farmer might use Overseer to explore ways to reduce a farm's environmental footprint, looking at how alternative farming practices affect the amount of nitrogen and phosphorus that leaves the farm. This use of Overseer might be required by a regional council in order for that farm to be considered a permitted activity, or could be undertaken voluntarily by a farmer.
- Task three: A researcher or regulator might use Overseer in a catchment modelling exercise to help determine the total nitrogen load reaching a waterbody (discussed more in chapter 7). This might ultimately inform limits set in a regional plan.
- Task four: Regulators might require the use of Overseer to estimate the amount of nitrogen that leaves a farm, for determining compliance with nitrogen limits.

¹²⁴United States EPA, 2009, p.19.

The assessment of Overseer in this chapter is based on Overseer's use as described in task four. However, we consider trust and confidence in Overseer to also be important for the uses in task two and task three, and the questions posed throughout the evaluation process are applicable to these uses. This is because these uses may still broadly be considered 'regulatory'. For example, where Overseer is used for catchment modelling, its use might ultimately inform a regulation or a specific policy approach by a council.

Evaluating a model in a regulatory context differs from evaluating the same model for research or private purposes. There are more complex trade-offs with regulatory use. For example, if we take *transparency* from the United States EPA's list, one aim in a regulatory setting will likely be enabling regulators and regulated alike to understand, and develop confidence in, how the inputs are transformed into model results. This usually favours a simpler model, as it is easier to communicate how the model works, how outputs change as inputs are varied, and how predictions match observations.

Where the science requires a complex model (as is often the case), it is very difficult to communicate the model workings to affected parties. In such situations, *transparency* involves building trust with affected parties through clear communication of a model's uncertainty backed up by details of quality assurance tasks.

Two pressures compete with the desire for simplicity as an aid to transparency. First, there is the desire to 'improve the science' which usually increases the complexity of the model (often by introducing additional parameters), requires more detailed input data, makes quality assurance more challenging, and makes it increasingly difficult for the layperson to understand the modelling.

Second, there is the desire by affected parties to 'expand the scope' of the model so that it addresses issues not envisaged when the model was first developed. Such trade-offs are certainly relevant to an evaluation of the use of Overseer.

Regulatory models also require more scrutiny of their accuracy and robustness as the use and consequences of erroneous outputs can have significant and uneven impacts on individuals and the wider community. As a result, the processes of *uncertainty analysis*, *model corroboration*, and *model implementation* are important.

For example, in circumstances where the use of an environmental model is for the purpose of protecting public health or environmental health, there may be significant consequences for the public, or the environment at large, if the model's result is erroneous. This is not to say there are no consequences of a non-regulatory model producing an erroneous result, but the nature of the risk is likely to be different. Again, this is relevant to the level of detail that an evaluation of the regulatory use of Overseer requires.

Regulatory models must also be evaluated within the applicable legislative environment, and need to be sufficiently 'robust' to be defended from legal challenges. For example, when a plan is prepared under the RMA, regional councils

must prepare a report which assesses the risk of acting or not acting if there is uncertain or insufficient information about the subject matter of the plan provisions.¹²⁵ The uncertainty associated with the use of Overseer in preparing plan provisions, and indeed the uncertainty of any alternative approaches, is relevant to such a report.

Assessing Overseer against the United States EPA guidance

The following section describes aspects of what is known and not known about Overseer, using the twelve elements suggested by the United States EPA as a series of questions.¹²⁶

This review was unable to make a comprehensive evaluation of Overseer because some information is not available in the public domain (e.g. aspects of the science behind the model, model calibration, corroboration, and robustness). This review does, however, identify what information exists to help determine whether Overseer is of sufficient quality to serve as the basis for regulatory decision making, highlight information that appears to be lacking, and recommend future review, analysis, and testing activities.

1. Is the model based on sound science?

Scientific basis

Evaluation of the scientific basis of a model is one of the most important factors to consider in model evaluation, as it underpins the conceptual framework from which a model is developed. Evaluating the scientific basis of a model can take many forms, but one approach is to consider the 'scientific pedigree' of a model. This refers to the history and quality of scientific theories used within the modelling framework and can apply to the model as a whole, or to sub-models.¹²⁷

For Overseer, although many of the underlying principles appear to be well grounded, there is no full, publicly available, comprehensive description of the scientific framework used by Overseer.¹²⁸ As a result, the scientific pedigree of the model as a whole is hard to assess.

A similar statement can also be made about the pedigree of the individual sub-model components, with some more easily assessed than others. For example, a sub-model for which the pedigree can be assessed with reasonable confidence is the metabolisable energy requirements of animals to calculate dry matter intake. The use of this approach is well accepted in the scientific community.¹²⁹ It also underpins New Zealand's Agricultural Greenhouse Gas Inventory.¹³⁰ By contrast, the limited publicly

¹²⁵Resource Management Act 1991, s 32(2)(c).

¹²⁶ United States EPA, 2009, pp.33–34.

¹²⁷NRC, 2007, p.71.

¹²⁸However, the model's generalised conceptual framework is described on the Overseer website (<https://www.overseer.org.nz/how-overseer-engine-works>).

¹²⁹Pacheco et al., 2016, p.1.

¹³⁰For example, see Pacheco et al., 2016.

available documentation surrounding another sub-model, the urine patch component of the nitrogen leaching model, makes its pedigree difficult to discern.¹³¹

Given the evolving state and pedigree of the scientific underpinning of some model components, well documented reasoning for the inclusion and use of particular scientific theories is essential if users are to have confidence in Overseer.

Computational infrastructure

Computational infrastructure refers to the way phenomena are related through mathematical relationships to produce a numeric result in a model. The translation of scientific principles into mathematical relationships is an important aspect of model development.

An evaluation of this translation is needed to ensure the mathematical relationships are appropriate and the model's behaviour approximates the system being modelled.

For Overseer, information on many of the mathematical equations used can be found in the technical manual chapters which accompany the individual sub-models and are publicly available. But for some aspects of the model these chapters are withheld by Overseer Ltd (e.g. the urine patch and background sub-models).¹³²

Some information can also be found in published journal articles and external reports written for Overseer. However, one thing that is sometimes missing from this documentation is information on the reason for equation and parameter choice where multiple options are available.¹³³

No part of the Overseer source code has ever been publicly available.¹³⁴

Without full access to the model structure, code and all supporting documentation, a comprehensive evaluation of the computational infrastructure of Overseer is not possible.

Assumptions and limitations

The important assumptions and limitations of a model, and the degree to which these are documented, are key pieces of evidence used to evaluate a model.¹³⁵

The communication of Overseer's assumptions and limitations affects the level of understanding users have and, in turn, can significantly affect the way regulators approach the use of Overseer.

¹³¹The Overseer website lists scientific papers, including some related to urine patch dynamics, but the related interactions within the full model are not described. Overseer scientific publications website (<https://www.overseer.org.nz/science-papers>).

¹³²See chapter 3.

¹³³See, for example, Pacheco et al., 2016, p.1.

¹³⁴There is one instance of the code being made available under a non-disclosure agreement for external examination, (Pers. comm., Harry Clark, 2018).

¹³⁵NRC, 2007; Özkundakci et al., 2018.

AgResearch has set out the key assumptions of Overseer in a useful document aimed at regional council staff.¹³⁶ While this provides a list of these assumptions, the scope of the document did not extend to describing just what these assumptions mean for the way regional councils should use the model.

This gap was targeted by two reports, the first by Freeman et al. in 2016 and a further report by Enfocus Ltd in 2018.¹³⁷ These reports provide information and advice to those using or considering using Overseer in the context of establishing freshwater objectives and limits under the National Policy Statement for Freshwater Management, and in resource consent processes.¹³⁸ In particular, Freeman et al. provides a useful table addressing the model's assumptions and limitations and what they mean for the use of Overseer in regulation.¹³⁹ The Enfocus report contains a broad discussion of similar issues in a more concise format.

These reports highlight that some of the fundamental assumptions made in the Overseer model affect its use in a regulatory setting. This emphasises the need for regulators to consider assumptions and limitations throughout a regulation making process. However, in the case of Overseer, this is made difficult by the limited available documentation and scrutiny that has historically been able to be applied to the underlying model.

Peer review

Peer review critically evaluates the adequacy and implementation of the scientific and technical components of a model. Such reviews should be undertaken by individuals who collectively have at least the same technical qualifications and experience as the model developers, but who are independent of those who performed the development work. However, consultation between developers and reviewers is likely to improve the review.¹⁴⁰

Defining the purpose and scope of a peer review is very important, as the framing of the review will have implications for the selection of appropriate reviewers, types of recommendations and the aspects of the model that are investigated.

The peer review process is not unidirectional, with the response to recommendations by model developers being as important as the independent review that is undertaken. As a peer review process is intended to improve model functionality, a review by itself does not achieve this. Once a peer review is completed, any issues and recommendations raised by reviewers need to be discussed with model developers, a consensus reached and any agreed changes that need to be made (or not made) need to be documented. Documentation should take the form of an acknowledgement of

¹³⁶Watkins and Selbie, 2015, pp.28–30.

¹³⁷Freeman et al. (2016) was commissioned by a number of regional councils, Ministry for the Environment, Ministry for Primary Industries and industry groups. The Enfocus report (Willis, 2018) was commissioned by Overseer Ltd.

¹³⁸Neither report examined the underlying model design. Rather, the reports considered how the model could be best used 'as is'.

¹³⁹Table 1 in Freeman et al., 2016, pp.13–16.

¹⁴⁰United States EPA, 2009, pp.23–24.

changes in release notes and a fuller explanation of changes in a published document of responses to reviewers' comments.

Several peer reviews of aspects of the Overseer model have been undertaken. Each review has focused on a specific sub-model, ranging from investigating the science available to support the use of the Overseer model conceptual framework to assessing the implementation of different components of the model.

Overseer model components that have been reviewed include: the use of soil parameters,¹⁴¹ greenhouse gas sub-models,¹⁴² the metabolisable energy sub-model,¹⁴³ the phosphorus loss sub-model,¹⁴⁴ and the hydrology sub-model.¹⁴⁵ Key themes raised by these reviews included the need to update the model to reflect the latest scientific understanding, the inclusion of new features, better documentation and increased transparency, the need for recalibration using expanded datasets, and the need to carry out uncertainty and sensitivity analyses.

Generally, the responses to recommendations and comments that have been made during the course of the peer reviews have not been documented (although some changes are noted in the release notes of model updates since Overseer Version 6.0). As a result, it is often unclear how and what review recommendations have been incorporated into the Overseer model.

The level of detail in the peer reviews of Overseer model components has varied. Difficulties in gaining access to aspects of Overseer that are not publicly available have been noted as a particular obstacle to generating a full picture of the model's functionality and implementation.

This has resulted in reviewers repeatedly highlighting the need for increased and improved documentation and transparency. This is often raised not only in the context of improving the ability of reviewers to assess the functionality of the Overseer model, but also to improve trust in modelling outcomes.¹⁴⁶

The potential benefit of peer reviews to the quality of the model is apparent from those few that have been conducted. For example, in 2014 model developers worked with the S-map team at Manaaki Whenua Landcare Research to understand how soil properties and categories were used in Overseer. The resulting review identified a number of opportunities to improve the description of soil processes within Overseer.¹⁴⁷

While reviews of the individual sub-models are important undertakings, a review of the entire model is needed to complement sub-model reviews. This whole-of-model peer review is particularly important in the case of Overseer, given its complexity,

¹⁴¹Pollacco et al., 2014.

¹⁴²Kelliher et al., 2015; de Klein et al., 2017.

¹⁴³Pacheco et al., 2016.

¹⁴⁴Gray et al., 2016.

¹⁴⁵This review was led by D. Horne from Massey University in 2014, but is not publicly available.

¹⁴⁶Comments from individual reviews are presented in chapter 3.

¹⁴⁷Pollacco et al., 2014.

the significant number of disciplines that interact within the model, and the range of different uses made of the model by different stakeholders (e.g. farmers and regulators). To date, such a whole model external review has not been undertaken.

2. Is the model managed to ensure quality?

Quality assurance and quality control

Quality assurance practices are designed to ensure that model implementation – and changes that are made to it – is robust, justified, and well documented. The level of quality assurance needed is dependent on model use and what model fitness-for-purpose looks like. Quality control, on the other hand, is designed to minimise the introduction of errors (e.g. coding errors) and ensure that the model is computationally fit for purpose. Both practices often include planning, documentation, assessment, and reporting of model functions and code development.

The implementation of quality assurance and quality control for the Overseer model was historically the responsibility of the model's scientific developers, AgResearch. Following the formation of Overseer Ltd, that company has taken over responsibility for quality assurance and quality control, with input from AgResearch.

For Overseer, quality assurance has largely taken the form of scientific developers ensuring that current scientific understanding has been included in the model and the commissioning of reports to investigate specific aspects of farm systems to be included in the future. Historically the inclusion (or not as the case may be) of elements into the model has fallen to a small number of developers, with the reason for changes to the model (beyond brief release notes) not always being made explicit.

Overseer Ltd is currently in the process of developing a science advisory panel to assess protocols and processes for the inclusion of new model elements and the revision of current elements.¹⁴⁸ An advisory group of this nature has the potential to provide more transparency about the model development process. However, good practice would be for any decisions made by Overseer Ltd (in response to recommendations from an advisory group) being made publicly available and open to scrutiny to ensure trust in the decision-making process. This is something that has been perceived to be lacking historically.

Since Overseer Version 6.0, communication of quality assurance practices has also taken the form of publishing release notes associated with version changes on the Overseer website. The release notes provide an outline and narrative of model and user interface changes. The level of detail in release notes may be acceptable if the intent is to communicate the types of changes that have been needed to ensure the model is functioning. But it will be insufficient to answer questions about exactly what changes have been made, and why, and how individual changes may cascade through the model operations.¹⁴⁹

¹⁴⁸Pers. comm., Caroline Read, 2018.

¹⁴⁹A comparison of the net effect of version changes on nutrient loss and greenhouse gas emissions has been reported in release notes since Overseer Version 6.2.1, by comparing model runs between the old and new versions using farm files held by AgResearch.

The release notes also encompass several elements of quality control, such as ensuring that the computational implementation of the model is fit for purpose. This includes information about descriptions of fixes to the code and dealing with known issues and errors. Other aspects of quality control (e.g. version control, user manual, information technology requirements for external parties such as S-map, and user issue reporting) are also documented and available in various locations.¹⁵⁰

Ultimately, quality assurance and quality control processes must contribute to trust and confidence in any model. Consolidating information into a single accessible repository that describes the processes that are currently implemented to ensure quality assurance and control would be beneficial for Overseer users.

Data availability and quality

This element of the framework is focused on the availability and quality of data that can be used for both developing model input parameters and assessing model results.

The three main aspects are:

- data used as default and user-defined inputs to the model
- data used to estimate values of model parameters
- data used for model evaluation.

The availability of input data depends on the type of input. For example, soil data from Manaaki Whenua Landcare Research's S-map and climate data from NIWA's Virtual Climate Station Network are available as default input data from the original providers. However, Overseer also requires user-defined farm management data. This data can be unreliable and difficult to obtain.¹⁵¹

Data used for model development and parameterisation is not readily available for peer review and the way the data has been used is unclear. Several coefficients in the Overseer equations need to be calibrated using empirical data. However, only a limited number of studies have been conducted (e.g. lysimeter studies at a small number of predominantly dairying sites in both the North and South Island measuring nitrogen leaching but not covering all soil types and rainfall regimes).¹⁵² While summary papers and research articles are often published at the end of experiments, actual datasets are often not. While Overseer developers have generally been able to access that data, the wider science community has not.¹⁵³

¹⁵⁰For example, aspects of quality control are described in Watkins and Selbie (2015) and on the Overseer website (<https://www.overseer.org.nz/>).

¹⁵¹However, Overseer Best Practice Input Standards advise users on appropriate input selection for user-defined data.

¹⁵²Best modelling practice recognises that collecting new data is a challenge, and recommends that modellers should build relationships with researchers and those responsible for collection of additional data to determine how such new data can guide model development (NRC, 2007, p.72).

¹⁵³For example, in order to calibrate Version 6 of Overseer in 2012, model developers have been able to access a range of farmlet datasets, including unpublished data from Manawatū and Lincoln University Dairy Farm (Shepherd et al., 2015).



Source: Parliamentary Commissioner for the Environment archives

Figure 5.1 Lysimeters have been developed to quantify nutrient leaching losses from soil by capturing all the water leaving a defined area of soil, which can then be analysed for its nutrient concentrations. This information can be used to improve Overseer model estimates.

Finally, a lack of available data has meant that a formal model evaluation hasn't been undertaken. Some informal or qualitative analyses (sensitivity testing or expert judgment) seem to have been undertaken, but these have not been publicly documented. This is despite the fact that Overseer's developers envisaged that model evaluation would be ongoing.¹⁵⁴

Test cases

Test cases help to determine whether the model software is working in a reliable and consistent way. This process involves a suite of software checks including the absence of 'bugs', stress testing and reasonableness checks.¹⁵⁵ The methods used and results obtained should be documented.

¹⁵⁴Shepherd et al., 2015.

¹⁵⁵NRC, 2007, p.74.

While test case comparisons are likely to have occurred at various stages of Overseer's development, the testing process followed by Overseer Ltd is generally not documented on the website or available in other materials.

Currently work is underway by Overseer Ltd to develop the software in a way that will allow the isolation of various components and sub-models of Overseer.¹⁵⁶ This will improve Overseer Ltd's ability to conduct test case comparisons on individual model components.

3. Does the model's behaviour approximate the real system being modelled?

Sensitivity and uncertainty analysis

Acceptance of model outputs, by the regulated and regulators alike, is ultimately dependent on confidence that the model represents the conditions that are being modelled.

Sensitivity analysis involves interrogating the model to determine how sensitive it is to changes in different elements and attributes.¹⁵⁷ Sensitivity analysis is normally undertaken by the model developer to help calibrate the model and quantify uncertainty, and also to guide further experimental and modelling work. It can also help users to understand the system being modelled and to build confidence in the model.

Uncertainty analysis builds on sensitivity analysis to quantify how natural variability, model framework uncertainty, and input uncertainty contribute to the likelihood that the model output truly reflects the real world (see chapter 2 and chapter 3 for more details).¹⁵⁸ Generally both analyses are undertaken in tandem.

Uncertainty and sensitivity analyses help parties make informed decisions and increase confidence that any decisions made using model outputs are appropriate. As such, these analyses are a critical aspect of model evaluation, both during the model's development and its use.¹⁵⁹ Within a regulatory context, failure to communicate and manage uncertainty in a meaningful way may also result in legal challenges.¹⁶⁰

¹⁵⁶Pers. comm., Caroline Read, 2018.

¹⁵⁷Sensitivity analysis is typically carried out by running a model a number of times, incrementally changing inputs around a single defined value (local sensitivity analysis) or across the entire feasible range of input values (global sensitivity analysis), and comparing inputs against outputs to understand the relationship between the two. Variability can either be assessed using one-at-a-time (varying each input individually) or all-at-a-time (vary all input factors simultaneously) methods. In general all-at-a-time methods provide a better characterisation of the sensitivity of the input factors.

¹⁵⁸There are different ways in which the estimate of uncertainty (i.e. the result from an uncertainty analysis) can be described. For example, uncertainty can be quantitatively described with mean and standard deviation, with a 95% confidence interval, risk probability (e.g. of exceedance) or qualitatively (e.g. level of confidence expressed as likelihood classes). The quantitative descriptions can be generated using approaches such as analytical (e.g. Taylor's Series approximation and other mathematical techniques), simulation-based (Monte Carlo methods, importance sampling), Bayesian, and non-probabilistic methods (e.g. fuzzy, interval). Qualitative descriptions can be generated using expert judgment of likelihoods.

¹⁵⁹NRC, 2007, pp.79-87.

¹⁶⁰Özkundakci et al., 2018, p.60.

Formal uncertainty and sensitivity analyses have not to date been carried out for Overseer. This is despite numerous calls for these analyses.¹⁶¹

Available literature on Overseer provides users with some basic understanding of the sources of uncertainty, and some guidance on how to reduce the level of uncertainty of input data.¹⁶² However, the absence of a formal uncertainty analysis for the whole model, or for component parts, is a significant shortcoming in the development of Overseer.

The justification for not undertaking a full uncertainty analysis has centred on the complexity of the Overseer model, the limited amount of data available for testing, and the difficulty of identifying and quantifying all sources of uncertainty in the model.¹⁶³ Limited studies focusing on parts of the model – often relying on expert judgment – have been carried out. However, the majority of these are outdated and some are not publicly available.¹⁶⁴

No model will ever be perfect and there will always be uncertainty associated with results. But, without an uncertainty analysis for Overseer, it is difficult for regional council staff to engage with interested parties about the level of certainty that can be attached to modelled nitrogen losses. In the absence of an uncertainty analysis, Environment Canterbury has used collaborative expert judgment analysis to estimate uncertainty of Overseer-derived nitrogen losses.¹⁶⁵ This highlights the desire of users to have access to uncertainty analysis in some form to support their engagement with interested parties and make better-informed decisions on appropriate limits.

Undertaking sensitivity and uncertainty analyses would improve transparency and increase trust in the model. It would also help improve the model by identifying elements in need of further research or elements that do not contribute substantially to model outputs.

Corroboration of model results with observations

Corroboration involves comparing model results with data collected in the field or laboratory to assess the accuracy and improve the performance of the model.

The approach may be quantitative (e.g. using statistics to estimate how closely the model results match measurements made in the real system), or qualitative (e.g. using expert knowledge to obtain understanding about a system's behaviour). The former approach may be appropriate in data-rich situations, while the latter approach may be preferred where data is scarce.¹⁶⁶

¹⁶¹For example, Polacco et al., 2014, Gray et al., 2016 and Freeman et al., 2016.

¹⁶²For example, Shepherd et al, 2013; Watkins and Selbie, 2015; Overseer web page (<https://www.overseer.org.nz/how-overseer-engine-works>).

¹⁶³Etheridge et al., 2018.

¹⁶⁴For example, Ledgard and Waller (2001). The need to undertake an uncertainty analysis is on Overseer Ltd.'s radar, with an initial proposal in development (pers. comm., Caroline Read, 2018).

¹⁶⁵Etheridge et al., 2018. This analysis was done for the Waimakariri Zone.

¹⁶⁶United States EPA, 2009, p.65.

Sometimes, the term ‘validation’ is used to describe this process. ‘Corroboration’ is a better term as validation implies a claim of truth, and no model is ever *truly* validated.¹⁶⁷

The previous chapter described another process in model development – ‘calibration’. This is the process of adjusting model parameters so that the resulting predictions give the best possible fit to the observed data. The reason it is relevant to this section is that the model calibration step can be linked with a corroboration step where a portion of the observations are used to calibrate the model, and then the calibrated model is run and results compared with the other portion of data to corroborate the model. The key point here is that a different data set is used for each process.

A full corroboration of the model has never been undertaken.¹⁶⁸

In respect to nitrogen leaching estimates, a calibration process took place in 2012 prior to the release of Overseer Version 6.0. A revised nitrogen pastoral grazing sub-model was calibrated against nitrogen leaching measurements.¹⁶⁹ During this process up to three parameters were adjusted to give reasonable agreement between modelled estimates and measurements from a limited set of data. Sensibility testing also took place. But this is not documented. A limited dataset of nitrogen leaching data meant there was insufficient data to both calibrate and formally corroborate the model.¹⁷⁰

Work is currently underway to recalibrate several sub-models used to estimate nitrogen leaching (the hydrology, urine patch and background nitrogen sub-models).¹⁷¹

Ongoing corroboration of all model components in line with best practice would be valuable. In addition, the procedure followed and results generated should be well-documented and publicly available.

Benchmarking against other models

Benchmarking compares one model with other similar models.

Over the years, researchers have made several attempts to compare nitrogen loss estimates generated by Overseer with a more complex mechanistic model called an Agricultural Production Simulator (APSIM). For example, in 2015 researchers compared nitrogen leaching estimates generated by the two models from well-drained soils under a dairy farm. Both models produced plausible estimates (i.e. within the same order of magnitude). However, some disagreements between the models were identified.¹⁷²

¹⁶⁷NRC, 2007, p.138.

¹⁶⁸Shepherd et al. (2015, p.5) note the need to calibrate and evaluate various model components.

¹⁶⁹The studies used for the 2012 calibration included (Shepherd et al., 2015): Ruakura dairy farm (Waikato, N rate and stocking rate trials); Scott Farm (Waikato, three farm systems and a range of soils types); Edendale (Southland, intensive beef, a range of N rates); Tussock Creek (Southland, duration of grazing and DCD (dicyandiamide)); Manawatū (effluent). Additionally, extra unpublished data was secured from Manawatū and Lincoln University Dairy Farm (covering Templeton and Eyre soils).

¹⁷⁰Shepherd et al, 2015, p.2.

¹⁷¹Pers. comm., Caroline Read, 2018.

¹⁷²Vibart et al., 2015.

A comprehensive effort to compare nitrogen loss estimates for crops derived from the same two models – Overseer and APSIM – was undertaken by Plant and Food scientists in 2016. The testing focused on Overseer’s crop module and aimed to identify discrepancies occurring between Overseer and APSIM. However, the scientists couldn’t interrogate the Overseer code – they could only compare whole model outputs. As a result, they couldn’t identify the exact reasons for any discrepancies, and recommended further areas for investigation.¹⁷³

Another example of benchmarking is the comparison of irrigation and drainage estimates from IrriCalc and a modified version of Overseer.¹⁷⁴ This comparison was undertaken in response to concerns about Overseer’s irrigation sub-model. The authors compared average annual estimates of irrigation and drainage for a range of soils and climates, and irrigation management regimes produced by IrriCalc and a modified version of Overseer. The comparison highlighted general agreement between the estimates from the two models. It also highlighted some differences in the estimates of irrigation depth for variable irrigation management scenarios. Further investigation to understand the causes behind discrepancies was suggested.¹⁷⁵

4. Is the model appropriate for a specific regulatory application?

Model resolution

Model resolution refers to the spatial or temporal scale at which the model operates. This is compared with the scale at which the model is going to be used.

Overseer operates at block and farm scales, and produces long-term annual average outputs. This spatial and temporal resolution stems from the model’s original application – helping farmers identify maintenance fertiliser requirements for pastoral blocks on farms.

As a result, much of the temporal and some of the spatial variability is averaged within Overseer. This means that although input information for a specific year can be added, the rate of nutrient losses represents the long-term trend, not necessarily the rate for that particular year. Setting aside attenuation beyond the root zone, Overseer’s long-term nutrient loss predictions are a better fit when the receiving body is also broadly sensitive to long-term impacts (e.g. aquifers and lakes). Conversely, rivers are more sensitive to fluctuations of nutrient inputs at shorter timescales, which Overseer does not predict.

¹⁷³Khaembah and Brown, 2016. Some discussion to address the recommendations raised has occurred since (pers. comm., Caroline Read, 2018).

¹⁷⁴IrriCalc is a web-based single-layer soil water balance model. It uses daily measurements or estimates of irrigation, rainfall, drainage, and actual evapotranspiration to calculate daily soil water content. The hydrology sub-model in Overseer is similar to IrriCalc in that it is also a single-layer soil water balance model that uses a daily soil water content calculation to estimate daily drainage. IrriCalc website (<http://mycatchment.info/>). For more discussion on the benchmarking exercise see Wheeler and Bright (2015).

¹⁷⁵Wheeler and Bright, 2015.

In contrast a dynamic model (for example APSIM) can describe nutrient losses at finer spatial and temporal scales (a point in a paddock, and on a daily time step).

However, dynamic models are often developed to be site-specific, require large amounts of input data, and greater expertise is typically required to run them. These factors limit the use of dynamic models to the research environment primarily.

The resolution of Overseer is broadly in line with some of the regional council requirements and goals (e.g. property scale). However, Overseer's resolution is not consistent with the need to manage nutrient impacts at the catchment scale (e.g. the combined impact of nutrient losses from a number of properties and other sources within a catchment). Trade-offs and compromises will naturally need to be made between model resolution, regulatory needs and the resources needed to review, improve and implement Overseer.

Transparency

Transparency refers to the ability of scientists (e.g. peer reviewers), affected parties and members of the public to comprehend the essential workings of the model and understand the processes followed in developing, evaluating, and applying a model.

For models used in environmental regulatory decision-making, high standards of transparency are important for a range of reasons. Most fundamentally, those affected by regulations have a right to understand the basis on which the regulations were made.

Greater transparency also allows independent experts to offer a constructive critique of model components, and could also result in the model being improved by third parties.

Previous sections have highlighted a number of key pieces of information about Overseer that need to be documented and made publicly available (e.g. the crop based nitrogen sub-model and the urine patch sub-model). This information should cater for both lay users of the model (farmers, regulators, and the public) and scientists.

Regulators, farmers, and the wider public need a working understanding of the model – that is, what the model can and cannot do and the level of uncertainty associated with its estimates. As non-scientists, these users need documentation that is clear and well-presented. The documentation should openly convey the strengths and weaknesses of the model. The *Technical Description of OVERSEER for Regional Councils* provides a comprehensive resource on these matters for regulators, farmers, and the wider public.¹⁷⁶

Scientists want more detailed information about a model's workings, particularly those peer reviewing a model, or using it for research purposes. For these purposes, documentation should state the underlying scientific principles, sources of data and equations used to build the model engine.

¹⁷⁶Watkins and Selbie, 2015.

Overseer Ltd currently documents this information in its technical publications. To its credit, the majority of Overseer sub-models or components have been documented in the form of publicly available technical manual chapters. However, several issues remain.

- A small number of model components, including those relating to crop growth and some allocation procedures, are not documented at all. In some instances there is a limited write up in the form of a manuscript from a presentation at the annual Fertilizer and Lime Research Centre Workshop, but this does not provide the same level of detail as a technical manual would usually provide.
- Several components of the model, including the animal model, the crop-based nitrogen sub-model and the urine patch sub-model, are documented in a technical manual chapter but the chapter is not publicly available (see chapter 3). These technical manuals are intentionally withheld under the Overseer Intellectual Property (IP) Policy.
- Technical manual chapters are lacking important details, such as the reasons behind the choice of equations or omission of components, which could be critical. In a 2016 review of the metabolisable energy requirements sub-model, many of the recommendations relate to the need to provide a clearer rationale for the choice of equations.¹⁷⁷

These issues mean scientists (e.g. catchment modellers) and users continue to be seriously limited in their ability to understand the workings of Overseer. Independent peer review is currently prevented for several components of the model where technical documentation is not available (including several components fundamental to estimating nitrogen loss) unless special access to Overseer documentation is negotiated.

Some scientific reviews will require greater detail about how the model works than the level of documentation currently available. Reviewers require a good scientific understanding of the processes being modelled. In addition, they need access to the source code to ensure that numerical algorithms have been correctly implemented in the software. Access to the code is also important for scientists hoping to improve the model (e.g. those wishing to conduct sensitivity analysis). However, the source code of Overseer is proprietary and Overseer Ltd is prevented from sharing it under the Overseer Ltd IP Policy.

There is only one instance where access to the source code has been provided to an external party. In this case, a small working group (including modellers, programmers and animal, soil, and system scientists) were granted permission to scrutinise the code, in order to review the choice and implementation of the equations for the animal sub-model and calculation of methane and nitrous oxide.¹⁷⁸ This work is being completed to standardise algorithms and equations between Overseer and the New Zealand Greenhouse Gas Inventory and allow Overseer to be used for farm-scale greenhouse gas reporting.¹⁷⁹ At the time of writing the resulting review was not yet published.

¹⁷⁷See Pacheco et al., 2016.

¹⁷⁸Pers. comm., Harry Clark, 2018.

¹⁷⁹de Klein et al., 2017, p.5.

Can Overseer be used in a regulatory context?

Overseer can provide farmers with valuable information when making judgments about farm management, and when working with fertiliser companies and farm consultants. However, using Overseer to estimate nitrogen loss to meet regulated limits changes the way its output is viewed – even if published guidance on how to use the model has been followed. The level of trust placed in modelled outputs is crucially dependent on what's at stake – who carries the risks of decisions being taken on the basis of the model's outputs? Farmers may be happy enough with the model as a decision support tool for farming purposes, but demand a much higher level of assurance when the consequences can be used to compel legal compliance.

Although Overseer has been accepted by the Environment Court for use by councils in regional plans to manage nitrogen losses, it has not been subject to the rigorous formal scrutiny necessary for regulators and regulated alike to have full confidence in its fitness for purpose.¹⁸⁰

The assessment undertaken in the section above revealed that a significant amount of information that is needed to assess Overseer's fitness for purpose is lacking. A comprehensive and well-resourced evaluation of Overseer should be undertaken. Initiating this will inevitably require access to the 'engine' of the model, which in turn raises important questions about the proprietary nature of Overseer. These issues are discussed in the next chapter.

It would be tempting to conclude that Overseer should not be used in regulation until such an evaluation is carried out. However the decision to use a model is not based only on scientific criteria. Public values, economic, social and legal considerations also contribute to the decision.

The National Policy Statement for Freshwater Management effectively requires councils to manage diffuse discharges of nitrogen. Councils can specify practices that are known to be beneficial in terms of reduced nutrient losses, although this can still be a resource-hungry process. In some cases ensuring farms are following good management practices, through a monitored and enforced farm plan programme, will be sufficient.

Where nutrient loadings in a catchment are clearly beyond anything that is consistent with safeguarding the life-supporting capacity of receiving waterbodies, councils need to determine what reductions are required across the whole catchment, and to know that specific, quantifiable reductions can be achieved on each individual property. There is a need to have a tool capable of quantifying nitrogen lost from farms. Overseer can fulfil this task.

¹⁸⁰For example, Overseer's use in managing nitrogen leaching from farming using Overseer-determined nitrogen discharge allowances for individual properties was first accepted by the Environment Court in its decision on Waikato Regional Council's Proposed Variation 5 to the Waikato Regional Plan. See *Carter Holt Harvey Ltd v Waikato Regional Council*, Environment Court, Auckland, A123/2008, 6 November 2008.

It appears from this investigation that most, if not all, of the regional councils currently using Overseer for determining compliance with nitrogen limits do so in this context – i.e. the severity of the nitrogen problem they face has led them to Overseer. Council staff acknowledge the tool is far from perfect, but blunter tools would be required if Overseer was not available.

This investigation has identified some important gaps and shortcomings in transparency, peer review, corroboration, uncertainty and sensitivity analyses, and the way the model has been documented. If Overseer is to continue to be used in a regulatory setting, these shortcomings need to be speedily addressed to provide confidence to the regulators and regulated alike. This is essential to building trust in its application and in the nutrient limits that are being set.

It should also be recalled that Overseer assumes good management practices are occurring on farms. To be able to have confidence in a regulatory framework using Overseer-derived nitrogen loss limits, regional councils must be satisfied that these practices are occurring. Regional councils therefore would do well to spend effort monitoring farms for compliance with these practices alongside any Overseer-based framework.



Source: Dr Mike Joy

Figure 5.2 Excess nutrients can promote unwanted algae and plant growth in streams and lakes, leading to low oxygen levels that affect fish like this kōaro (*Galaxias brevipinnis*) and other species. At extreme levels, nutrients can directly reduce the life-supporting capacity of waterways.



6

Ownership, governance and funding of Overseer

A history of ownership, governance and funding of Overseer

Overseer's roots date back to 1982 when the Ministry of Agriculture and Fisheries Fertiliser Advisory Service attempted to summarise all available fertiliser research and provide standardised advice on fertiliser application. The rationale for this advice was essentially economic.

The Ministry and the fertiliser industry's interest in understanding agriculture's impacts on freshwater and helping farmers to manage these impacts came later in the early-1990s. By then, publicly funded research on fertiliser application was in the hands of one of the new Crown Research Institutes, AgResearch Ltd ('AgResearch').

At the time, AgResearch was developing a model called "Outlook" – an econometric model that could calculate optimum fertiliser recommendations. The Ministry of Agriculture and Fisheries, along with the Fertiliser Association, wanted to develop a model that could help farmers, advisors, and industry staff understand nutrient balances better, both with respect to improved fertiliser use *and* to provide a better understanding of nutrient flows in an environmental context.

By combining the nutrient balance component from the Outlook model with the 'PKS Lime model' (a fertiliser decision support model that was also being developed at the time), AgResearch was able to provide a way forward. The resulting model became "Overseer" in 1999.

It was, from the outset, hampered by funding. The Ministry had only small amounts of funding to develop the model. However, the Fertiliser Association expressed an interest in contributing to the model's development. AgResearch offered in-kind contributions. From the Ministry's point of view, this provided both welcome resources and a continued collaboration with an organisation that had a ready network of farmers and farm advisors, and an organisation with research experience.

In the late 1990s, a Memorandum of Understanding (MoU) was drawn up between the Ministry of Agriculture and Forestry, the Fertiliser Association, and AgResearch establishing equal joint ownership of Overseer. The Ministry and the Fertiliser Association were to provide funds and AgResearch was to provide intellectual property. Total funding of approximately \$100,000 per year was secured.

Overseer's use in a regulatory setting first arose in 2005 when the Waikato Regional Council notified Variation 5 of its regional plan relating to the Lake Taupō Catchment. This was a high-profile water quality challenge involving an iconic water body. The first more generalised recourse to Overseer was made by Horizons Regional Council in its *One Plan*, notified soon afterwards in 2007.



Source: Parliamentary Commissioner for the Environment archives

Figure 6.1 Lake Taupō in the central North Island is valued for its scenery, clean water and internationally renowned trout fishery. Concerns with increasing nitrogen loading in the lake, particularly from intensive farming nearby, led the Waikato Regional Council to impose a nitrogen cap for land users in the catchment. Farm-scale nitrogen losses and targets were calculated using Overseer, although a key part of the approach was the establishment by the National Government of a fund to help buy properties in the catchment and retire them from pastoral farming.

In the same year, the New Zealand Government decided to establish an emissions trading scheme for greenhouse gases. A tool that could estimate greenhouse gas emissions from a farm was needed and Overseer was the only readily available option. The importance of accurate estimations for New Zealand's international reporting obligations under the United Nations framework convention on climate change (UNFCCC) provided some urgency to the task of a significant upgrade of Overseer. A funding boost from the three owners in 2007 provided Overseer with \$1.2 million per year for five years, its largest budget to date.

The owners recognised the need for a more formal ownership agreement to replace the MoU. That ownership agreement was signed in 2009. It confirmed the joint equal ownership of Overseer by the Ministry of Agriculture and Forestry, the Fertiliser Association, and AgResearch.

The essence of this ownership arrangement remains in place under an updated agreement signed in 2016. Today it is the Ministry for Primary Industries (MPI), the New Zealand Phosphate Company Ltd, and AgResearch that each own a one-third share in Overseer intellectual property.¹⁸¹

Within five years, it became clear that the growing demands on the model were outstripping the owners' capacity to develop the model to meet them. These demands included the requirements of regional councils, the need for wider stakeholder engagement, increased technical resourcing, and management systems to better control development of the model. In 2013, Overseer Management Services Ltd was established, with the appointment of a general manager to address these needs.

The owners also sought a new, financially sustainable structure for Overseer that would relieve the owners of the need to fund it indefinitely.¹⁸² In 2015, various different resourcing options were explored. These included: leveraging funding as joint ventures with primary sector agencies, introducing a user charge, and MPI redirecting funding from other programmes. The possibility of funding from regional councils was investigated, but ultimately this came to nothing.¹⁸³

The owners also concluded that Overseer's governance needed to evolve to introduce clear accountability, manage perceptions of conflicts of interest, and to limit their liability.¹⁸⁴ MPI, supported by AgResearch, initially favoured a discrete business unit within MPI. The Fertiliser Association did not support such an approach, preferring a limited liability company and the creation of a more commercially responsive management structure.¹⁸⁵

¹⁸¹The New Zealand Phosphate Company Ltd became an owner following assignment of ownership by the Fertiliser Association of New Zealand in 2016.

¹⁸²MPI, 2014, 2015a.

¹⁸³MPI, 2014, 2015b,c.

¹⁸⁴MPI, 2015d.

¹⁸⁵MPI, 2015b.

Agreement on a new governance model was reached in 2016. A limited liability company would manage the day-to-day running and development of the model, while the owners would retain existing and new intellectual property. This new company was incorporated in 2016 and named 'Overseer Ltd'.

The owners granted Overseer Ltd an exclusive licence to Overseer's intellectual property. The company's mission is to procure science and technical input, grow revenue sources, market Overseer, liaise with stakeholders, and manage and improve Overseer's intellectual property, *inter alia*.¹⁸⁶ The three owners agreed to contribute financially or in-kind to Overseer Ltd for three years.¹⁸⁷

Unlike the tripartite ownership of the intellectual property that Overseer represents, Overseer Ltd has just two shareholders, AgResearch and the New Zealand Phosphate Company Ltd. At the time of incorporation in 2016, Overseer Ltd's shares were held equally by the two shareholders.

The Crown restricts its shareholding in private companies. As a result, the Ministry for Primary Industries has no shareholding. However, it is granted all the rights and powers of shareholders under the shareholders agreement, such as the appointment of directors. Changes to the company constitution require the vote of the Ministry for Primary Industries appointed director, and shares in the company cannot be transferred to any other party unless there is written consent from MPI. The company constitution also prevents the payment of dividends to shareholders. Income is to be reinvested in the maintenance and improvement of Overseer and the business.¹⁸⁸

At this point, it is useful to explain the business of each of the three intellectual property owners.

The New Zealand Phosphate Company is a limited liability company trading as The Fertiliser Association of New Zealand Incorporated. The Fertiliser Association is a trade association representing and owned in equal shares by the two major New Zealand manufacturers of superphosphate and nitrogen fertilisers – Ballance Agri-Nutrients Ltd and Ravensdown Ltd. Both companies are farmer-owned cooperatives.

AgResearch is a Crown Research Institute (CRI) established under the Crown Research Institutes Act 1992. This Act requires CRIs to undertake scientific research for the benefit of New Zealand.¹⁸⁹ AgResearch's research focus is primarily pasture-based animal production systems, the products derived from these systems, and the environmental performance of these systems.¹⁹⁰ AgResearch is a Crown Entity

¹⁸⁶OVERSEER Ownership Agreement, clause 6, executed 29 March 2016.

¹⁸⁷For the financial year ending June 2017, the Ministry for Primary Industries funded Overseer Ltd \$1,000,000. The Fertiliser Association of New Zealand funded Overseer Ltd \$937,500 and AgResearch Limited provided \$500,000 of in-kind services to Overseer Ltd (Overseer Ltd, 2017).

¹⁸⁸Shareholders' agreement relating to OVERSEER Limited, executed 29 March 2016, and Constitution of OVERSEER Limited under the Companies Act 1993.

¹⁸⁹Crown Research Institutes Act 1992, section 5.

¹⁹⁰AgResearch's core purpose is to "enhance the value, productivity and profitability of New Zealand's pastoral, agri-food and agri-technology sector value chains, to contribute to economic growth and beneficial environmental and social outcomes for New Zealand. AgResearch website (<https://www.agresearch.co.nz/assets/Uploads/Statement-of-Core-Purpose.pdf>), accessed 3 December 2018.

Company under the Crown Entities Act 2004, which means its ownership must remain 100 per cent with the Crown. It must also generate an adequate rate of return on shareholders' funds, and operate as a successful going concern.¹⁹¹

The Ministry for Primary Industries is a government ministry, employing over 2,500 people. MPI's work includes policy development and regulatory responsibilities across the dairy, forestry, horticulture, viticulture, meat and wool, and seafood sectors. MPI is part of the multi-agency Freshwater Taskforce, based within the Ministry for the Environment and charged with freshwater policy.

The Overseer board is responsible for the overall corporate governance of Overseer Ltd. The chief executive is responsible for the day-to-day management of the company and conduct of the business. There are currently nine in-house roles (chief executive, business development, customer services, product manager, two developers, tester, administrator, communications). A science manager role is being investigated.

Overseer Ltd's major focus since its incorporation has been to place Overseer on a financially sustainable basis without ongoing recourse to the owners to fund the maintenance and further development of the model, and to accelerate development of the model.

Overseer Ltd has, from the outset, sought to ensure Overseer achieves its vision as "the trusted on-farm strategic management tool for achieving optimal nutrient use for increased profitability and managing within environmental limits." Despite the growing demands of regional councils to use the tool, at no stage has Overseer Ltd's vision been to create a regulatory tool.¹⁹²

Overseer Ltd's first business plan was approved by the shareholders and MPI in July 2017. The plan established a software-as-a-service business model, including a complete rebuild of the software, increasing customer support, and introducing charging. While the model has been available free of charge from its inception, the business plan proposed users would be charged to use the new software.

In early 2017 it became apparent that the business plan would not be successful without additional funding in the short term. New Zealand Phosphate Company Ltd and Overseer Ltd entered into a redeemable preference share (RPS) arrangement under which New Zealand Phosphate Company Ltd advanced funds to Overseer Ltd, subject to interest and an obligation on Overseer Ltd to redeem the RPS for cash (repaying the funds advanced) at the end of the specified period. If the funds advanced (plus accrued interest) are not repaid at the end of the period specified under the RPS arrangement, those redeemable preference shares will be converted to ordinary shares.¹⁹³

¹⁹¹ Crown Entities Act 2004, section 51.

¹⁹² Overseer Ltd, 2015.

¹⁹³ Under the Redeemable Preference Shares Subscription Agreement between Overseer Limited and New Zealand Phosphate Company Limited, \$550,000 had been paid by New Zealand Phosphate Company Limited at 30 June 2018 (Overseer Ltd, 2018b).

AgResearch Ltd has an option to subscribe for, in aggregate, up to half the number of fully-paid redeemable preference shares held by New Zealand Phosphate Company Ltd. AgResearch Ltd may exercise its option at any time prior to the redemption or conversion of New Zealand Phosphate Company Ltd's RPS. If AgResearch Ltd exercises its option to subscribe for the maximum number of RPS available to it, and both New Zealand Phosphate Company Ltd's RPS and AgResearch Ltd's RPS are converted to ordinary shares in Overseer Ltd, the proportion of ordinary shares held by each entity will remain unchanged.

The RPS are non-voting shares. As such, the issue of redeemable preference shares does not, on its face, change the governance of Overseer Ltd. The RPS arrangement entitles New Zealand Phosphate Company Ltd and AgResearch Ltd (if AgResearch Ltd exercises its option to subscribe for RPS) to a dividend, the result of which is that interest accrues on the funds advanced by each RPS holder to Overseer Ltd. Other than that dividend entitlement, the issue of RPS does not affect the requirement that profits are reinvested in the company.¹⁹⁴

More recently still, the Government announced further funding of \$1.25 million per year for four years to support improvements to Overseer.¹⁹⁵

The new software, 'OverseerFM', was released on a free-of-charge basis in June 2018, but an annual subscription per farm account will apply from January 2019. The amount of the subscription has yet to be confirmed.

The transition to a software-as-a-service model has enabled a major change in the way Overseer is accessed. This means farm data is stored centrally within a farm account. Farmers can submit information to councils and other organisations using the "publication" function from their farm account.

It is anticipated that the central repository of farm data will be a significant time saver. Once a baseline farm analysis is set up within a farm account, it can be reused and amended without having to create a new analysis from scratch.¹⁹⁶

The "user interface" – the part of the software people see and interact with – has been significantly overhauled with improved design and functionality. A report commissioned by Overseer Ltd to quantify the benefits of OverseerFM, estimated time savings of 25-50 per cent (between three to five hours) when generating a nutrient budget in OverseerFM compared to OVERSEER Nutrient Budgets version 6.3.0. A key factor in the time savings is the new mapping feature in OverseerFM.¹⁹⁷

¹⁹⁴Redeemable Preference Shares Subscription Agreement between Overseer Limited and New Zealand Phosphate Company Limited; and Redeemable Preference Shares Subscription Agreement between Overseer Limited and AgResearch Limited.

¹⁹⁵Parker and O'Connor, 2018.

¹⁹⁶Barber et al., 2018.

¹⁹⁷Barber et al., 2018.

Aligning ownership, governance and funding with the model's purpose

Chapter 5 described why transparency is important for a model like Overseer that is used in a regulatory setting: those affected by regulations have a right to understand the basis on which the regulations are made. This reasoning is rooted not in science but good public process.

Beyond that, there is a utilitarian argument that greater transparency expands the number of scientists and developers who are able to critique the model, and in doing so contribute to its improvement.

Chapter 5 concluded that gaps in publicly available information mean that Overseer falls short of the transparency required in a regulatory setting. This is equally true for the use of Overseer to determine compliance with nitrogen loss limits as it is for any potential future regulatory use to estimate greenhouse gas emissions.

As the following section argues, making Overseer transparent to render it fit for regulatory use, is inseparable from issues of ownership, governance and funding. This chapter explores these issues and proposes an alternative way forward.

How the intellectual property in Overseer came to be proprietary

As a starting point, it is worth reiterating that Overseer is a proprietary model. A model is proprietary if any component that is a fundamental part of the model's structure or functionality is not available to the general public, or not available without charge.¹⁹⁸ There is a range of ways a model can be proprietary. Currently Overseer has a proprietary source code and some proprietary algorithms and technical manuals, but the user interface is available freely. In 2019, the model will also have a proprietary user interface.¹⁹⁹

That Overseer today is a proprietary model is the end point of a long evolution that was not preordained from the model's early days. None of the Overseer owners have contributed on the basis that Overseer was valuable software that could earn its owners significant commercial returns. The prohibition in Overseer Ltd's constitution on the payment of dividends to shareholders, and the requirement that income is to be reinvested in the maintenance and improvement of Overseer and the business, are the evidence of that.

Overseer has evolved as it has largely in response to the way it has been funded. The owners did not set out to build a model for regulatory purposes. Consequently the Crown did not scope, then allocate, the investments needed to achieve that. Funds have been allocated by the Crown as pressures for nutrient or greenhouse gas emissions management pressed on the Government of the day.

¹⁹⁸NRC, 2007, p.111.

¹⁹⁹OverseerFM is currently available to the user for free, but in 2019 users will be charged. There is an intention that a research version of the model will be available freely for non-commercial research. (Pers. comm., Caroline Read, 2018.)

The fertiliser industry's interest has been in helping farmers and their advisors to make efficient use of fertiliser, and, in a social and political climate that has increasingly questioned farming's environmental impact, also understand nutrient losses. Retaining a social licence to operate through being able to demonstrate responsible practices provided an important motivation to remain engaged.

While AgResearch has been the source of much of the scientific and technical knowledge needed to develop the model, it has never regarded Overseer as a flagship for technology transfer through commercialisation. It has made the best of whatever resources it has been able to lay its hands on to develop a tool that has been understood as simultaneously advancing the institute's core business of improving the productivity of pastoral systems, and addressing concerns about their environmental sustainability.

The current move to a business model in which both the source code (and some algorithms and technical manuals) *and* the user interface are proprietary appears to have been driven by a desire on the part of the owners to secure a solid funding basis. There is recognition by the owners, that to effectively resource the various development and evaluation activities sought for the tool, significantly more funding is required. The owners' concern is that making the intellectual property freely available could undermine the company's ability to generate the revenue it needs.

The need for secure funding going forward cannot be emphasised enough. Historically, it has been the most important factor limiting model improvements. Following the release of OverseerFM, Overseer Ltd has estimated it will need to generate \$4 million per annum to continue to develop and maintain the tool.²⁰⁰ When this is compared with the \$1 million to \$1.5 million per annum the tool was receiving up until recently, the scale of the underfunding of the tool becomes apparent.

Would greater transparency undermine the interests of Overseer's owners and the model's future?

The Draft Intellectual Property Policy prepared by Overseer Ltd sets out the approach the company takes to Overseer intellectual property (IP).²⁰¹ The policy requires Overseer Ltd to protect Overseer IP to maximise the benefits from the owner's investment in Overseer IP and minimise risks. One of the risks identified in the policy is the development of competitive models by a third party. A competitor model could undermine Overseer Ltd's revenue from user subscriptions and thereby place at risk the future development of the model.

As a consequence of the IP policy, several technical manual chapters have been intentionally withheld from public release. There are limited examples of technical manuals being released under non-disclosure agreements to allow external review.²⁰² No part of the source code has ever been publicly available. In one instance the code was released under non-disclosure agreements for external review (see Box 6.1).

²⁰⁰Pers. comm., Caroline Read, 2018.

²⁰¹At the time of writing the IP Policy was in draft form, having been approved by the Board and awaiting approval of shareholders.

²⁰²For example the Animal Model technical manual chapter was shared in confidence to enable a 2016 review of the Metabolisable Energy Requirements Model (Pacheco et al., 2016).

Box 6.1 External review of the Overseer model code

In 2018, part of the Overseer source code was made available for external review under a non-disclosure agreement between Overseer Ltd and the reviewers. The review is focused on the choice and implementation of the equations for the animal sub-model and the calculation of methane and nitrous oxide emission estimates.

The foundations for this review were laid several years prior when the New Zealand Agricultural Greenhouse Gas Research Centre initiated a benchmarking exercise comparing greenhouse gas emission estimates by the New Zealand's Greenhouse Gas Inventory and Overseer models. Both models use the same underlying methodology.²⁰³

During this exercise, differences in estimates were found between the two models, attributed to Overseer's animal sub-model. However, as the researchers did not have access to Overseer's source code they could not be certain.²⁰⁴ Further studies followed in subsequent years and differences in estimates persisted. An error in Overseer's source code was identified.²⁰⁵

This work provided the basis for facilitating access to the animal sub-model code for review in 2018. At the time of writing the resulting review is not yet published, but the results of this study are expected to inform changes to the Overseer source code.²⁰⁶

Greater transparency could be addressed at two levels – publication of the model's algorithms and making the model's software open source. The consequences of these no longer being treated as proprietary are considered in turn.

Publishing the model's algorithms – the set of mathematical steps or procedures used to build the model engine – would be an important element in improving Overseer's transparency.

Currently it is impossible for anyone outside the model development team to know how Overseer generates nitrogen loss estimates. Making the algorithms available would of course make them available to any competing model developer. If they were published, they could supposedly be replicated in another model.

It is difficult to know how likely this would be. Any competitor model would presumably have to be funded privately and, if it was to compete with the use of Overseer in a regulation-making context, would be subject to the same transparency expectations recommended in this report.

²⁰³The underlying methodology for both models is based largely on the Australian feeding standards (CSIRO, 1990, 2007).

²⁰⁴Kelliher et al. 2015; Harry Clark, pers. comm., 2018.

²⁰⁵de Klein et al., 2017.

²⁰⁶Harry Clark, pers. comm., 2018.

Beyond the potential loss of revenue to Overseer Ltd, competing models would create a challenge for regulators. Councils would be required to store data across a range of model platforms, and the ability to integrate data (from, for example, farms in the same catchment using different models) could present a technical challenge.

The cost to farmers and industry if required to become proficient in using a new model, or several models at once for different purposes, is another consideration. There are also issues of quality control. In a world of multiple models, a regional council would need to ensure that not just one model, but multiple models were fit for their intended regulatory purpose. New Zealand is a small country with a small pool of modelling expertise, and focusing efforts on the development of one model to estimate diffuse nutrient losses may be a better use of these limited resources.

Beyond access to Overseer's algorithms, there is the question of the Overseer software source code – the programming language that tells the software how to function. Software can be associated with several licensing paradigms; the most important distinction is open source versus proprietary software. Generally speaking, software is open source if the source code is free to use, distribute, modify and study, and proprietary if the source code is kept secret.

The arguments for open-source software being used for environmental modelling in a regulatory context are essentially the same as those outlined earlier with respect to transparency. Open-source software facilitates those affected by a regulatory decision to understand the basis on which decisions are made. For this reason the United States Environmental Protection Agency has a preference for using non-proprietary software for environmental modelling.²⁰⁷

Open-source software also has the advantage of allowing third-party scientists and developers to freely critique and improve the model. While publishing the scientific basis of the model and the parameters, equations, and algorithms it uses would improve Overseer's transparency significantly, access to the source code is considered the gold standard for encouraging improvements to the models by the wider modelling community.

The Agricultural Production Systems sIMulator (APSIM) moved to an open-source platform in 2007 and remains open source for non-commercial use with its source code available on the web. The move to an open-source platform has encouraged developers outside the founding agencies to modify and enhance APSIM. In addition, the number of users and developers continues to grow, ensuring APSIM's longevity even after many of the foundation members have moved on.²⁰⁸

One of the concerns raised with open-source models, particularly those used for regulatory purposes, is a perceived lack of control over what is incorporated into the model. From conversations with modellers and model developers, it appears that this is

²⁰⁷United States EPA, 2009, p.31.

²⁰⁸Holzworth et al., 2018.

not an insurmountable challenge. The issue can be managed by an organisation acting as a gatekeeper to the official version of the model. That organisation maintains full control, having the ability to manage changes, and decide when an official release of a new version is desirable.

The groundwater model MODFLOW described in chapter 5 provides a case in point. Developed by the United States Geological Survey in 1984, the model's code is open source and the software can be used, copied, modified, and distributed without cost. The model is now used worldwide, including in a recent modelling exercise in the Ruamāhanga catchment.²⁰⁹ The United States Geological Survey has a "core" MODFLOW version at any one time. This is the version that is under active development and is often the most widely used and most thoroughly tested.

What would be the implications of making Overseer open source? As a starting point, it would be a significant change in terms of the public perception of the model, although the ability to scrutinise the source code would be unlikely to be of significant use to the broader public and stakeholders. However, the model is likely to acquire greater legitimacy with stakeholders because of the potential that is created for accountability on the part of regulators. Stakeholders would be able to seek independent third-party advice on whether the model's assumptions and simplifications were sound. In addition, making the engine of the model transparent creates an opportunity for scrutiny by independent experts.

The new opportunity for independent experts (i.e. those outside the model development team) to modify and enhance Overseer, is perhaps the greatest benefit of an open-source approach. As experience suggests with APSIM, the move to an open-source platform enabled a wider community of developers to modify and improve the APSIM model. Overseer Ltd's decision to release the source code of the animal sub-model under a non-disclosure agreement for external review illustrates the potential for improvements to Overseer when external experts have access to the source code (Box 6.1).

The other significant benefit of an open-source approach would be an enhanced usefulness of the model for research purposes and catchment modelling relevant to regional plan preparation. The closed nature of the algorithms and code within Overseer poses challenges to incorporating it within an interoperable modelling framework, the general intention of which is to have models and data that are open and freely available where possible.²¹⁰

An open-source Overseer would, however, create an additional management challenge. Increased transparency would be accompanied by a need to respond to questions, improvements and critique by stakeholders. Overseer's curators would need to have the resources and processes in place to do this.

²⁰⁹Blyth et al., 2018.

²¹⁰Sandy Elliott, pers. comm. May 2018.

What sort of ownership and funding model would be consistent with a model directed at achieving environmental improvements and one used for regulatory purposes?

Starting from the premise that maximum transparency is in the best interests of those subject to regulation, regulators themselves, and the research community on which they rely, a way needs to be found to support the maintenance and development of the model consistent with that premise.

A simple, blunt solution would be to require that when regional councils are seeking to manage nutrient losses in their plans, at least for pastoral farms, Overseer should be the only accepted model for this purpose. A national environmental standard or other regulation under the Resource Management Act 1991 could be used to mandate this. This would make official what has, in fact, been the approach of government throughout Overseer's development history.²¹¹

One concern with such an approach is that it would reduce the incentive for innovation. Central and regional levels of government would need to ensure that Overseer remained the subject of regular evaluation and improvement.²¹² On the other hand, the very nature of an open-source model encourages third-party innovation and improvement.

Another concern is that managing diffuse nutrients requires more than just dealing with pastoral farms. Other land uses can have significant nutrient losses. New markets are opening up in response to consumer concerns about climate change and other environmental impacts of farming, to products such as alternative proteins and synthetic meats. Given that there is likely to be an increasing diversity of crops grown, the Government needs to consider developing other models for non-pastoral land uses.

Establishing Overseer as the official model for regulatory purposes for pastoral farms would at least secure whatever revenue can legitimately be derived from subscriptions. But the extent to which subscriptions can be relied on to raise revenue requires further examination. It seems reasonable that land users should meet part of the costs of the regulatory system needed to manage their diffuse pollution. This would also recognise the private commercial benefits to be gained through use of Overseer such as efficiencies in fertiliser use and, potentially, the benefit to trade on the environmental credentials of the model.

Meeting those costs is a more reasonable burden to shoulder when complete transparency about the Overseer model enables land users and their advisors to interrogate the reasonableness of any limits or other regulatory requirements that are imposed.

²¹¹From the memory of staff involved from the early development phase, the Ministry for Agriculture and Forestry made a conscious decision not to fund any other models that were being promulgated. Consequently the Ministry for Agriculture and Forestry, and then MPI, supported only Overseer as a decision support tool for greenhouse gas and nutrient loss management (pers. comm., Penny Nelson, Ministry for Primary Industries, 2018).

²¹²Each of the elements of model evaluation set out in chapter 5 would need to be considered, and improvement and review activities identified and undertaken as a result. These include the soundness of the science underling the model, whether it is managed to ensure quality, the degree to which the model's behavior approximates the real system being modelled, and the appropriateness of the model for a specific regulatory application.



Source: pxhere.com

Figure 6.2 The majority of investment and development in Overseer has been focused on pastoral farming systems. However, as farms diversify in the face of changing consumer preferences and the impacts of climate change, it is an open question whether Overseer will be the best model for managing the environmental impacts of these new farming systems.

But even with greater transparency and all the gains that research-community access to the model could provide, it is doubtful whether subscriptions alone can provide the resourcing needed to support nutrient pollution management. This is because while the Overseer model itself requires approximately \$4 million per annum to be maintained, far more significant sums are required to fund the underlying empirical research needed to corroborate and calibrate the model.

The limited extent of these investments has been outlined in chapters 3 and 5. Upgrading our understanding of soils and innovative farm management practices will undoubtedly benefit the Overseer model. But the benefits are much more widespread. This is classic public-good research that is legitimately part of the Crown's public-good science investment. And to the extent that regional granularity is required, it is research that should be co-funded by regional councils and their ratepayers.

Making Overseer an open-source model, and one that is officially supported by the Government as the model of choice for estimating nutrient losses to water for pastoral farms, firmly embeds Overseer's purpose as one of importance to 'New Zealand Inc'. While there are private commercial benefits to be gained from the use of Overseer on farms, the purpose of Overseer becomes directed at achieving environmental improvements on farms to help achieve environmental policy objectives.

Overseer's ownership and governance need to align with this purpose. The most immediate question is whether it would be consistent with the Fertiliser Association's

current co-ownership of the intellectual property. The Fertiliser Association's significant contribution to Overseer over many years has kept the model afloat. Without its support we would not be where we are today. Opening up the model raises two questions: would it be fair to the Fertiliser Association (given its investments)? And would a clear public-good purpose be consistent with its continued ownership stake?

The answer to the first question depends on the extent to which a valuable asset is being devalued. This is not an assessment this review can make. Conversations with the Fertiliser Association suggest that the model's value to the fertiliser companies is rooted not so much in ownership as the link it enables them to maintain with farmers and farm advisors. An open-source model would not disrupt that. Neither would it prevent the companies developing value-added proprietary tools based on the Overseer model.

The second question comes down to this: is it appropriate for a trade association owned by the two major New Zealand manufacturers of superphosphate and nitrogen fertilisers – Ballance Agri-Nutrients Ltd and Ravensdown Ltd – to be part owners of an open-source model explicitly supported by the Government for use in managing diffuse discharges and maintained as a public-good instrument?

This is a question that should be directly addressed. If the answer is no, then it would be an option for the Government to buy the Fertiliser Association's ownership stake in the intellectual property. This would make the Overseer IP jointly owned by AgResearch and the Government. Given AgResearch's ultimate ownership by the Crown, and its statutory requirement to undertake research for the benefit of New Zealand, reaching agreement on open sourcing the model would be potentially more achievable.

Resolving the issue of intellectual property ownership is a separate matter from who develops and maintains the model. Since its incorporation in 2016, Overseer Ltd has developed significant in-house expertise in software development. Recently, model development has been brought "under one roof" by having software developers working full time in-house on Overseer. Overseer Ltd considers this will enable it to interrogate the implementation of the model and start to establish approaches for evaluation.

In the course of this investigation, it has become apparent that the company has built relationships with multiple stakeholders and has an in-depth understanding of the issues arising from the perspectives of councils, farmers, industry, and others.

A change in ownership would necessitate a fresh look at the governance of the Overseer model and whether a limited liability company remains the right vehicle to develop and maintain Overseer. If Overseer officially becomes the model of choice for regional councils seeking to implement property-level nitrogen limits in their plans, at least for pastoral farms, a regional council perspective on the governance board would make sense. Regardless of the specific governance arrangement arrived at, the existing expertise and institutional memory of staff at Overseer Ltd will be essential to retain going forward.



7

Beyond Overseer - understanding and modelling catchments

This chapter situates the use of Overseer in a broader catchment context. It has four sections.

The first section draws readers' attention to additional information needed to understand the impacts of excess nutrients on water quality. As mentioned earlier in this report, Overseer has been used as part of catchment-scale modelling exercises. Catchment-scale modelling and the steps involved are described in the second section of this chapter.

The third section talks about making better use of the information base we have, and provides examples of available datasets that can assist our understanding of nutrient transport across catchments. The final section makes a few concluding remarks.

Developing a better understanding of nutrient transport in catchments

For regional councils to be able to manage diffuse discharges as required by the National Policy Statement for Freshwater Management, they need a better understanding of sources and environmental impacts of excess nutrients on water quality. This goes beyond the scope of Overseer.

Overseer is designed to model nutrient inputs and losses from an individual farm. Losses of nitrogen are calculated where it leaves the root zone (60 centimetres below the paddock's surface) and for phosphorus, where it enters second-order streams. The environmental impacts of those losses, however, are felt at the level of catchments or sub-catchments.

Therefore, to understand the environmental impacts of excess nutrients on water quality, regional councils need to couple the farm-level estimates that Overseer generates with additional catchment-scale information.

In particular they need answers to these questions:

- How much of the nutrients leaving a farm actually makes it to a waterbody?
- What sort of waterbody do the nutrients end up in? How vulnerable is it?
- What other factors affect the impact the nutrients have, including contributions from other sources?

All of these factors need to be considered when thinking about how to manage nutrients to improve water quality. The following sections deal with each of these issues in turn.

From a farm to a waterbody

Excess nutrients from farms reach waterbodies through a number of pathways.²¹³ Being highly mobile in water, nitrogen tends to go with the flow – down into groundwater, laterally through soil closer to the surface, or travelling via surface water. Phosphorus, in comparison, is much less mobile and mainly enters waterways with soil and sediment, although losses into groundwater have been noted recently in a few cases.²¹⁴

The speed and form in which nitrogen reaches water bodies varies. Nitrogen changes its chemical form depending on the surrounding conditions and these forms have different fates. Nitrogen may stay in the water as mobile nitrate and be temporarily stored (e.g. taken up by annual plants that generally grow prolifically in summer and die back in winter and decay). Or microbes may turn it into gaseous forms and permanently remove it from the water by a process called denitrification. Climate, topography, hydrology, soils, and underlying geology all play a role in determining which of these processes occurs.

Collectively, processes that reduce the amount of nitrogen as it travels from the root zone to a waterbody are known as *attenuation*.²¹⁵ Depending on the conditions, the amount of attenuation can be trivial or can significantly reduce the amount of nitrogen reaching waterbodies.²¹⁶

For example, researchers at Massey University have shown that the rate of nitrogen attenuation varies between 30 per cent and 70 per cent across different sub-catchments in the Tararua Groundwater Management Zone (Figure 7.1).²¹⁷ Clearly, depending on where they are situated, the contribution of identical farms to water quality degradation will differ significantly.

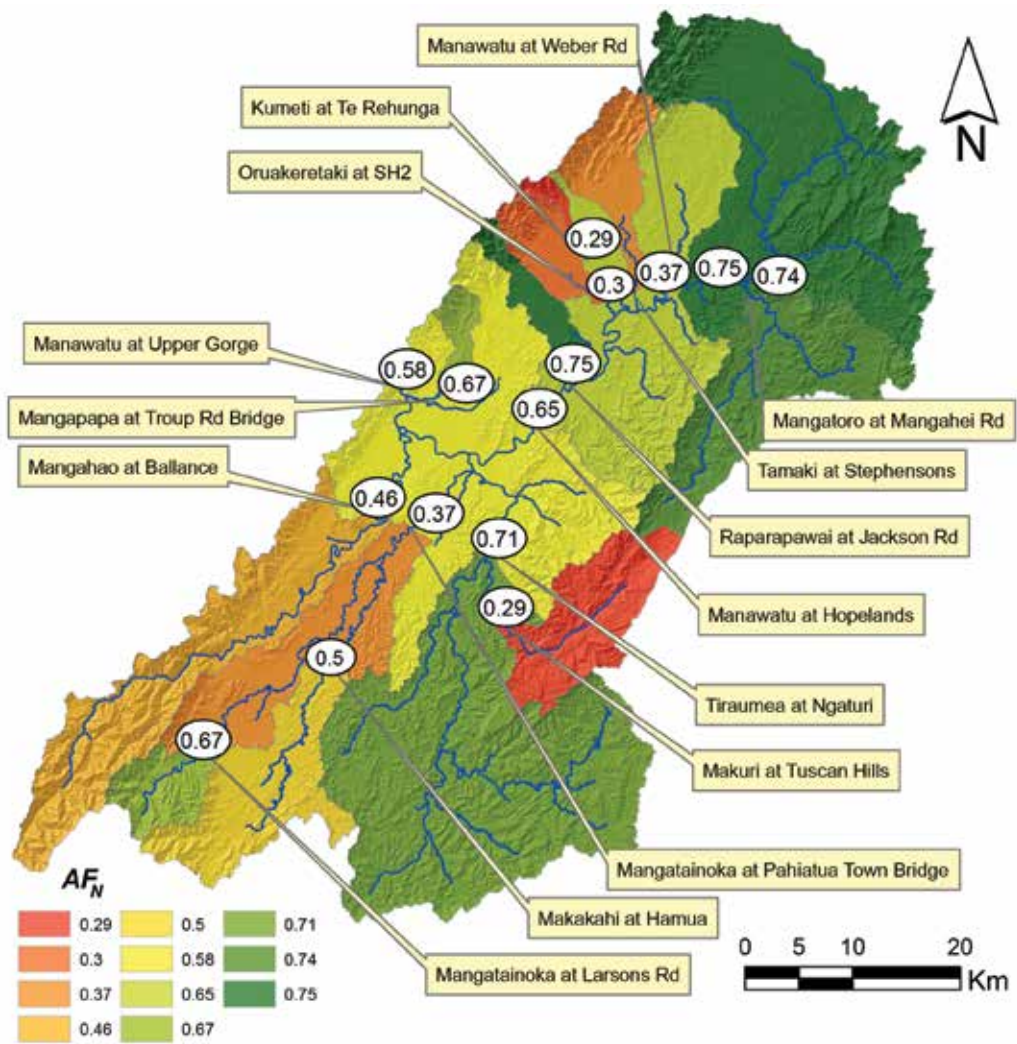
²¹³Broadly speaking, more rainfall means more water is available to move contaminants both over the surface and down through the soil into groundwater. Topography (slope) determines the pathway water takes. The interconnectedness of the different soil and subsoil layers determines the ease and speed with which contaminants can travel from farm paddocks to rivers, lakes, and aquifers.

²¹⁴McDowell et al., 2015b.

²¹⁵To *attenuate* means to make something smaller, thinner, or weaker.

²¹⁶Some phosphorus leaching into groundwater can also be attenuated. McDowell et al., 2015b.

²¹⁷Elwan et al., 2015.



Source: Elwan et al., 2015

Figure 7.1 Variable nitrogen attenuation rates across the Tararua Groundwater Management Zone. AF_N stands for nitrogen attenuation factor, which is calculated as a loss of nitrogen between where it leaves the farm and where it affects a receiving waterbody.

The vulnerability of the receiving waterbody

The impact of nutrient pollution is significantly dependent on the natural characteristics of the waterbody where the nutrients end up.²¹⁸

- Generally, lakes and estuaries are more vulnerable than rivers. Lakes and estuaries can act like sinks, accumulating pollutants that can in turn favour algal blooms and nuisance plant growths.
- How much water there is in a river or stream, how fast it moves, whether it is shallow or deep, shady or open, and the variability of its flow will all affect its vulnerability.
- Aquifers are, in effect, underground reservoirs that are fed by water soaking through the ground. How vulnerable an aquifer is to dissolved pollutants depends on how accessible it is to water from the surface (which depends on the subsoil), and how quickly water moves through the aquifer.

When different nutrients reach a waterbody is also important. For example, rivers and streams are usually most vulnerable to nutrients in summer. Algae and aquatic plants generally grow more prolifically in summer because lower rainfall results in higher temperatures, lower flows, fewer flushing flows, and higher concentrations of nutrients. There is also more sunlight in summer, resulting in more photosynthesis.



Source: Brian High

Figure 7.2 Algae and aquatic plants generally grow more prolifically in summer because lower rainfall results in higher temperatures, lower flows, fewer flushing flows, and higher concentrations of nutrients. There is also more sunlight in summer, resulting in more photosynthesis.

²¹⁸PCE, 2013.

What other factors determine the impact nutrients have?

Nutrient concentrations themselves do not generally have negative impacts on the health of waterbodies, although nitrogen can be directly toxic to aquatic species and people at high concentrations.²¹⁹ Rather, high concentrations have indirect effects through the promotion of excess plant growth, which can lead to the smothering of habitat, dangerous oxygen depletion, and pH changes causing changes in the structure and functioning of freshwater communities.

However, these relationships are not always easy to predict.

For example, studies of the relationships between nutrients and algae show a fairly clear relationship in lakes, but weaker direct relationship in streams and rivers.²²⁰ This is because lakes are more likely to provide the warm, stable conditions algae need to build up. In comparison, flow in streams and rivers can be highly variable. When a high flow or flood occurs, algae will be washed away and a new community will begin to establish itself until the next high flow occurs. Any analysis of the relationship between nutrients and algae in streams and rivers must therefore include information on flow levels.²²¹

Similarly, modelling exercises found that while increasing nitrogen concentrations have negative impacts on stream invertebrate communities, the physical characteristics of the site and the amount of fine sediment had an even greater influence.²²²

This discussion has highlighted the complex relationship between nutrients entering the land and the effects that they can ultimately have. However, understanding nutrient sources is only one (albeit important) piece of the puzzle.

Modelling catchments

Understanding how nutrients travel through catchments requires a picture in three physical dimensions, plus a fourth: time. The water cycle is continually refurbishing flows across, through, and under the land on the way to lakes, aquifers, and, ultimately, the sea.

We cannot physically measure nutrient flows through catchments in such detail that we have a perfect understanding of what ends up where, and with what effects. Instead, we need to turn once again to models for help.

²¹⁹In recognition of this fact, standards have been set to limit nitrate concentrations in drinking water to protect human health, and for natural waterbodies to protect aquatic species. For human health see Table 2.2, Maximum acceptable values for inorganic determinands of health significance, in *Drinking Water Standards for New Zealand 2005 (Revised 2008)* on the Ministry of Health's website (<https://www.health.govt.nz/system/files/documents/publications/drinking-water-standards-2008-jun14.pdf>).

For waterbodies, see nitrate toxicity limits for rivers in Appendix 2 of the National Objectives Framework in the National Policy Statement for Freshwater Management 2014 (revised in 2017). Available from the Ministry for the Environment website (http://www.mfe.govt.nz/sites/default/files/media/Fresh%20water/nps-freshwater-amended-2017_0.pdf).

²²⁰For example, Smith et al., (2016) found a positive relationship between chlorophyll-a concentrations (as a measure of algal growth) and total nitrogen and total phosphorus in the surface water of Lake Rotorua between 2001 and 2015.

²²¹Snelder et al., 2014.

²²²Clapcott and Goodwin, 2014.

Catchment-scale modelling exercises consist of three key steps:

1. quantifying the total loss of nutrients from all sources in a catchment
2. quantifying the nutrient load that reaches a waterbody
3. assessing the impact of nutrients on the waterbody.

Each of these is discussed in greater detail below.

Step one: quantifying total nutrient losses

Root zone nutrient losses from individual farms can be used to help determine the total amount of nutrients entering waterbodies in a catchment.²²³

The total agricultural diffuse nutrient losses can be estimated as the sum of modelled losses from individual farms in a catchment using actual Overseer farm files. A good example of this was the modelling exercise undertaken to inform a plan change to improve water quality in Lake Rotorua.²²⁴ Detailed 'benchmarking' data for the majority of farms in the Rotorua catchment collected by the Bay of Plenty Regional Council formed the basis of such modelling.²²⁵

However, obtaining Overseer nutrient loss estimates for actual farms in a catchment can be challenging. Overseer may not be used by all farmers in a catchment of interest or Overseer data may not be available to regional councils due to privacy concerns.²²⁶ In this case "proxies" – estimated nutrient losses for generic farms – can be used instead. The Waikato Regional Council used proxies to inform the Healthy Rivers/Wai Ora plan change due to a lack of actual farm-level data from Overseer.²²⁷

It is also important to quantify the contribution of nutrients from other sources within the catchment.²²⁸ While the great majority of nitrogen entering waterways comes from livestock urine, and most phosphorus comes with soil and sediment, the contribution of nutrients from point sources can be significant at specific times and places.

For example, point sources of phosphorus from wastewater treatment plants in the Upper Manawatū River are very significant for a good portion of the year. About half

²²³Total amount of nutrients also includes diffuse nutrient losses from other non-agricultural land, urban areas, natural sources and point source discharges.

²²⁴At the time of writing this plan change (Plan Change 10: Lake Rotorua Nutrient Management) was before the Environment Court.

²²⁵See Rutherford, 2016, p.15 and Palliser et al., 2018.

²²⁶However, such farm data may be held by farming industry organisations (e.g. Fonterra and DairyNZ).

²²⁷Nutrient losses from diffuse sources were calculated as a function of land use and the source yields associated with these land uses. The source yields for pastoral and horticultural land uses in the Waikato and Waipā River catchments were derived from Overseer. However, report authors recommended that Overseer-derived diffuse source yields should be reassessed due to large uncertainties and model limitations (Semadeni-Davies et al., 2015).

²²⁸For example, contributions from point sources (septic tanks, geothermal inputs, and sewage) in the Rotorua catchment were also estimated and used in the catchment-scale modelling (Rutherford et al., 2009, pp. 31-32).

the phosphorus entering the river from spring to autumn comes from point sources. By contrast, in winter, higher rainfall washing in more sediment and manure reduces the share of point-source phosphorus to less than a quarter.²²⁹

Step two: quantifying nutrient load that reaches a waterbody

The second step is to quantify the nutrient load that reaches a waterbody. A number of catchment-scale models have been developed internationally for this purpose.

The term *catchment model* is a broad term that can include modelling of groundwater and surface water, erosion and sediment, nutrients and pathogens. Catchment-scale models come in all shapes and sizes, and can be designed to model changes over a range of timescales, from daily to long-term, multi-year averages.

For example, the Soil and Water Assessment Tool (SWAT) developed for the United States Department of Agriculture, Agricultural Research Services, is a catchment-scale model that attempts to quantify the impact of land management practices on river flow and water quality.²³⁰ In New Zealand, SWAT has been used to model water, sediment, and nutrient fluxes in the Puarenga Stream catchment near Rotorua.^{231,232}

While international models often come with extensive databases, local values are needed for the model to correctly reflect local conditions. A lack of local data for required parameters has proved to be a barrier to using international models in New Zealand catchments.²³³ In addition, international models often come with a set resolution (i.e. the grid size), which might make modelling highly variable terrain challenging.²³⁴

As a result, several simplified hybrid models, which include mechanistic components that are empirically calibrated, have been developed. CLUES (see Box 1) and ROTAN are examples of New Zealand-developed hybrid models.

²²⁹Ledein et al., 2007, pp. 23-26.

²³⁰SWAT is a catchment-scale model used to simulate the quality and quantity of surface and groundwater, and predict the environmental impact of land use, land management practices, and climate change. The model uses topography, soil types, land use, climate/rainfall, crop and land management properties to generate water and contaminant flux, yield, and state for various spatial (hydrologic response unit, sub-catchment, reach, catchment) and temporal (daily, monthly, yearly) levels. SWAT website (<https://swat.tamu.edu/>).

²³¹Me et al., 2015.

²³²Another example of a complex dynamic suite of models is an integrated hydrologic modelling system MIKE, developed by the Danish Hydrological Institute (DHI). MIKE SHE, which is one model in the suite, is an integrated model for groundwater, surface water, recharge, and evapotranspiration. The core of the model is based on a hydrological cycle, but it can quickly become rather complex due to links with other MIKE models and add-ons (e.g. rainfall run-off simulations, contaminant dispersion, and sediment transport). MIKE website (<https://www.mikepoweredbydhi.com/>).

²³³Tuo et al. (2015) compared five catchment-scale mechanistic models (including SWAT), and concluded that data availability was a crucial factor in evaluating model results and uncertainty in these models. Moreover, in many situations models were difficult or impossible to implement due to the limited available data.

In addition, NIWA used the selection criteria outlined by Tuo et al. (2015) and concluded that none of the available mechanistic models were well suited for application in catchments like Rotorua, Taupō and Tukituki where limited data is available for model calibration (Rutherford, 2018, p.24).

²³⁴For example, for application of the MIKE SHE model in the Selwyn catchment, a grid cell size of 1 km² was used, which meant small-scale variations could not be modelled even though they may have been important (Rutherford, 2018, p.27).

ROTAN was used as part of the aforementioned modelling exercise in the Lake Rotorua catchment. Firstly, Overseer was used to estimate nitrogen losses from farms in the catchment.²³⁵ Secondly, ROTAN was used to model transport of these losses from within the catchment to the lake Rotorua. Three delivery pathways (quick flow, groundwater and stream flow) were conceptualised, and different attenuation and groundwater time-lags were taken into account.²³⁶ The authors predicted nitrogen loads to Lake Rotorua, however, they found that uncertainty was lowest for total catchment loads, higher for loads from individual sub-catchments, and very high for individual farms.²³⁷

Box 7.1 Surface water modelling – Catchment Land Use for Environmental Sustainability model (CLUES)

Catchment Land Use for Environmental Sustainability model (or CLUES) is often used for catchment-scale water quality modelling in New Zealand. Developed by NIWA, this hybrid, steady-state model is an amalgamation of existing modelling and mapping procedures. CLUES provides mean annual loads and median concentrations of contaminants (nitrogen, phosphorus, sediment and *E. coli*). While the model is simple to set up and run, it does not capture day-to-day variations.

The components of CLUES include: a simplified version of Overseer, SPASMO, SPARROW and CLUES Estuary, as well as simple socio-economic indicators.²³⁸

- Overseer is used in a simplified way to estimate mean annual loads of nitrogen and phosphorus from pastoral land uses as a function of enterprise type, stocking rate, soil drainage class, rainfall and region. Overseer is run for each land use within each sub-catchment. While individual farms are not represented, different land uses are represented based on land cover and AgriBase information.²³⁹
- SPASMO is used to estimate nitrogen losses from horticultural and cropping land uses.²⁴⁰
- SPARROW is used to estimate *E. coli*, sediment, nitrogen and phosphorus from all other (i.e. non-agricultural) sources. In addition, SPARROW is used to estimate downstream transport of various contaminants. SPARROW estimates

²³⁵Nitrogen losses were estimated over a period from 1900 to 2015. The authors reported that uncertainty in nitrogen losses averaged $\pm 50\%$. This was due to changes in survey methods, reporting only at district scale, limited information about historic land use, and uncertainty in Overseer itself. See Palliser et al. (2018) for more details.

²³⁶See Rutherford et al., 2018 for more details.

²³⁷Rutherford, 2018, p. 27.

²³⁸Elliott et al., 2016

²³⁹AgriBase is a national spatial database which holds information on approximately 142,000 current New Zealand farms. It is administered by AstoreQuality. AgriBase website (<https://www.asurequality.com/our-solutions/agribase/>).

²⁴⁰SPASMO (Soil Plant Atmosphere System MOdel) has been developed in New Zealand by Plant and Food Research. The model estimates the transport of water, microbes and solutes through soils by integrating variables such as climate, soil, plant water uptake, and other factors affecting environmental processes and plant production.

attenuation rates from observed in-stream concentrations of nutrients at monitoring sites in the catchment.²⁴¹

- CLUES Estuary takes CLUES estimates of catchment loads of nitrogen and phosphorus, and represents how these are mixed in an estuary to determine estuarine water quality.

Since its development in 2006, CLUES has been used to estimate the loads of nutrients, sediment and *E. coli* in research studies, and to support catchment policy and planning. The model has been applied to assess potential impacts of land use change in single catchments (e.g. Upper Waikato River Catchment) as well as the entire country. It has also been applied to assess the efficacy of mitigation measures (e.g. stock exclusion and conservation planting) on sediment loads into Kaipara Harbour.²⁴²

Several aspects of CLUES' structure and functioning can affect the accuracy of the model:

- CLUES is a surface water model, which means it assumes all contaminants are transported via a network of streams and rivers, rather than via groundwater.
- For each sub-catchment, the proportion of the area within each of the 19 land use classes used in CLUES is specified. However, the precise location of the land use within the sub-catchment is not represented explicitly. This limits the spatial resolution of the model.
- The default land use dataset provided with CLUES is for the baseline year of 2008. Because New Zealand doesn't have a comprehensive, robust, land use dataset, up-to-date land use information is difficult to obtain. Currently, land use is inferred from land cover information (derived from the Land Cover Data Base, last updated in 2012) in combination with other often proprietary databases (like AgriBase).
- The simplified version of Overseer accepts a limited set of inputs (stocking density, pastoral enterprise type, rainfall, soil order, and topographic slope class) compared with the full detailed version. It has been suggested that assumptions within the simplified Overseer model may need to be re-examined as little sensitivity to stock rate intensification was observed.²⁴³

As the level of uncertainty of Overseer estimates is largely unquantified, it is difficult to conduct formal uncertainty analysis of the overall catchment-scale estimate. In addition, every time Overseer is significantly updated, other components of CLUES (namely SPARROW) need to be recalibrated to compensate for such changes. Uncertainty in Overseer and the implications for other model parameters remains of concern.

²⁴¹SPARROW (SPATIally Referenced Regressions On Watershed attributes) has been developed by United States Geological Survey. The model estimates the amount of a contaminant transported from inland catchments to larger waterbodies by linking monitoring data with information on catchment characteristics and contaminant sources. The term 'watershed' is synonymous to 'catchment'.

²⁴²Elliott et al., 2016.

²⁴³Elliott et al., 2016.

Nutrient transport through different parts of the landscape is usually modelled using separate models. For example, CLUES (see Box 7.1) is used for modelling surface water (streams and rivers), and MODFLOW for modelling groundwater (see Box 7.2).

Box 7.2 Groundwater modelling – MODFLOW

Developed by the United States Geological Survey, MODFLOW is a dynamic model that simulates saturated groundwater flow. As the model's code is open source and free to use, the model is now used worldwide. A modular structure is the key feature of MODFLOW, which allows for new packages to be added and the model's scope to be expanded. While anyone with the necessary skills can write a customized component and suggest improvements to the model, the United States Geological Survey maintains official releases.

MODFLOW has several companion models, including:

- MODPATH – to track particle paths
- MT3DMS – to simulate contaminant transport in the saturated groundwater
- RT3D – to simulate chemical reactions
- UZF – to simulate unsaturated zone flow
- SRF – to simulate shallow and surface hydrologic processes.

Currently MODFLOW only models deep groundwater and does not model 'quick flow' (viz. overland flow and shallow interflow) in detail, and requires nitrogen losses in drainage to be specified (e.g. based on Overseer).

In New Zealand, MODFLOW is one of the models regularly used by GNS Science. For example, MODFLOW was one of the models used in a recent modelling exercise in the Ruamāhanga catchment.²⁴⁴

Integrating models across surface water and groundwater domains is a complex technical task, often requiring collaboration between modellers and organisations.²⁴⁵ Several key water models used in New Zealand are not open source and are developed by different organisations.²⁴⁶ These issues contribute to integration challenges.

An attempt to integrate various models has recently been made under the umbrella of the *Our Land and Water – Toitū te Whenua, Toiora te Wai – National Science Challenge*. A *model interoperability* project is aiming to construct a framework of nationally applicable open-source models that draw on national datasets. The

²⁴⁴Blyth et al., 2018.

²⁴⁵For example, an integrated catchment water quality model of the Ruamāhanga catchment was developed as collaboration between Greater Wellington Regional Council, Jacobs, GNS, NIWA, Waikato University and Aqualinc. It's envisaged that this model will help guide the freshwater limit setting required under the National Policy Statement for Freshwater Management.

²⁴⁶Examples of closed source models include: Overseer, CLUES, ROTAN.

modelling framework is envisaged to be suitable for integrated and spatial assessment of the economic, production, and environmental implications of land use and land use change at farm to catchment scales.²⁴⁷ This builds on one of the recommendations arising from a catchment modelling workshop held almost a decade ago: namely the removal of intellectual property restrictions on data and models to facilitate both the uptake of models and collaboration in model development.²⁴⁸

Limitations of catchment-scale modelling

Catchment models are valuable tools. They allow land managers to understand and test relationships between land use practices, interventions, and environmental outcomes, and make better-informed decisions when proposing policies and rules.

However, catchment models, by their nature, also have to make a number of simplifying assumptions. For example, CLUES assumes all contaminants are transported via a network of streams and rivers – groundwater is out of the model's scope.

Models also make assumptions about attenuation rates. For example, a model might assume that attenuation of nitrogen is uniform across a sub-catchment. However, as we have seen from the Massey University research (Figure 7.1), the attenuation potential of land can be highly heterogeneous. Differences even metres apart can cause attenuation to differ significantly. Models can account for this by using measurements from within the catchment to provide estimates of attenuation rates.²⁴⁹ However, the accuracy of these calibrations will depend on how many sites have been monitored – the greater the number of sites, the better and more finely scaled the estimates.²⁵⁰

It is important that any model assumptions and uncertainty are well communicated and factored into risk assessments and policy decisions, as they are present in all models.

There is an opportunity to improve catchment models by expanding current monitoring networks, investing in new field instruments, and striving for real-time, continuous water quality measurements. This approach could also facilitate adaptive management – adjusting policy targets and actions on the ground on the basis of the state and trends of receiving environments.

²⁴⁷Elliott et al., 2017., p.6.

²⁴⁸The 2009 workshop also recommended that guidelines on project conceptualisation, model selection and calibration should be developed (Fenton, 2009, p.16). However, almost a decade later, this recommendation is still outstanding.

²⁴⁹However, any measurements will also have a degree of uncertainty due to natural variability which will affect any estimated rates.

²⁵⁰It is often not only the number of sites that is an issue, but also the length of time that measurements have been collected.

Improvements can also be made by:

- better understanding and keeping a record of land use practices in the long-term (including historical knowledge). Such information can help identify and predict lag times in a catchment
- better understanding of spatial and temporal variability of surface water and groundwater interactions
- improving the resolution of land use information to make better use of datasets (e.g. matching decisions on land use practices with the resolution of weather forecasts).²⁵¹

Step three: assessing the impact of nutrients on the waterway

Quantifying the quantity of contaminants that reach waterways is not enough in itself. It is influencing the quality of water that is the object of policy makers. They need an understanding of the impact excess nutrients have on a waterbody. The relative importance of addressing excess nutrients depends on the state of the waterbody, and the values the community wants to protect. In terms of the Resource Management Act, these values can be thought of in terms of a waterbody's life-supporting capacity.²⁵²

A catchment model would ideally be able to provide information on the impact of excessive nutrients on the life-supporting capacity of a waterbody. Currently, individual catchment models are limited in this regard – CLUES can provide estimates of the loads and concentrations of nutrients in waterbodies, but does not model resulting algal biomass or the effects on aquatic invertebrates. To model such outcomes, different and often more complicated models are required, or the results from a catchment model are fed into other models designed for such a purpose.

There are a number of models developed to describe the relationships between nutrients and other stressors, and water quality outcomes. These have been used to explain what drives particular outcomes, and predict where management actions may be effective. Examples of this approach include identification of the impacts of sediment on catchments in the Manawatū-Whanganui region, recent work looking at the impacts of nutrient concentrations and site characteristics on stream invertebrate communities, and modelling the impacts of nitrogen and phosphorus loads on ecosystem health in Lake Rotorua.²⁵³

²⁵¹Pers. comm., Richard McDowell and Ken Taylor, 2018.

²⁵²Section 5 of the Resource Management Act 1991.

²⁵³For example, a model called SedNetNZ was used to assess the impact of the Sustainable Land Use Initiative in the Manawatū-Whanganui region on river sediment loads (Dymond et al., 2014).

Clapcott and Goodwin (2014) examined the cause-and-effect relationships between land cover and associated land-use impacts and the Macroinvertebrate Community Index.

For information ecosystem health in Lake Rotorua see Rutherford et al. (2009), Rutherford et al. (2011) and Rutherford (2016).

The models used to investigate these relationships often rely on data from a wide range of sites and sources. Therefore, while they may help identify key mechanisms or processes, they may be less useful for working out what interventions are required in a specific catchment or sub-catchment. However, such investigations can help to parameterise models such as CLUES for individual catchments, or can identify key management interventions – such as the need to specifically target erosion rates,²⁵⁴ or increase shading through a streamside replanting programme.

Making better use of the information base we have

As is always the case with modelling, the physical information needed to calibrate catchment-scale models poses a challenge. But New Zealand does not start from a blank slate.

Decades of taxpayer and ratepayer investment have resulted in numerous datasets being generated that can assist our understanding of nutrient transport and transformations across catchments. Over the years, several attempts have been made to document the available resources.

In preparation for the State of the Environment reporting in 2012, Statistics New Zealand characterised environmental datasets and information across multiple domains. In collaboration with the Ministry for the Environment (MfE) and the Department of Conservation (DOC), data gaps were identified and *Environment Domain Plan 2013* was developed to fill those gaps.²⁵⁵

Building on this effort, recent State of the Environment reports have documented available indicators and datasets across domains alongside key information gaps. For example, *Our land 2018* and *Our fresh water 2017* provided useful stocktakes across land and water domains.²⁵⁶

Some of the gaps these reports reveal are significant. For example, it has been estimated we only understand the structure of about 30 per cent of the aquifers in New Zealand.²⁵⁷ Soil databases are also patchy in scale, age and quality. As of October 2018, the S-map coverage of New Zealand was 34 per cent, although this is 63 per cent of productive

²⁵⁴A recent report by Snelder (2018) produced for the Horizons Regional Council demonstrated strong statistical evidence of regional improvement in the water quality measures (*E. coli*, clarity, suspended sediment, turbidity) over the past decade in the Manawatū-Whanganui region. In addition, this analysis provided strong statistical evidence of water quality improvements associated with upgrading point source discharges throughout the region. Moreover, weak but statistically significant positive associations were observed between improving trends for all water quality variables and the proportion of catchment area involved in Sustainable Land Use Initiative (SLUI) farm plans.

The Sustainable Land Use Initiative was founded by the Horizons Regional Council in 2006 to limit the effects of large-scale hill erosion and prevent silt building up in rivers in the region. The focus of this voluntary initiative has been on completing whole-farm plans, which identify areas for erosion control on a farm-by-farm basis, and undertaking works on farms once the plans are complete. The SLUI programme is funded by central government, ratepayers, and landowners. For more information see Cooper and Roygard (2017).

²⁵⁵See Statistics New Zealand, 2012, and Statistics New Zealand, Ministry for the Environment, Department of Conservation, 2013.

²⁵⁶MfE and Stats NZ, 2017, 2018.

²⁵⁷Pers. comm., Chris Daughney, GNS, 2018.

land.²⁵⁸ It is important that such gaps in data and understanding are prioritised and incrementally closed.²⁵⁹ Without that, models will remain poorly calibrated, with higher levels of uncertainty in some settings.

Another stocktake of existing land and water models, alongside data sources to support modelling, was undertaken as part of the proposal for the development of an interoperable modelling system.²⁶⁰

A key finding of the stocktake exercises is that while numerous datasets exist, they are maintained by a variety of different organisations, and come in various states of comprehensiveness and age (Figure 7.3). Also, funding for their maintenance and development has not been driven by any clearly defined national objectives.

Furthermore, these datasets are not 'joined up' in the most useful way to gain a better understanding of nutrient transport across catchments. In a number of cases, the datasets are also not easily accessible due to proprietary ownership arrangements.²⁶¹ This is hard to justify given that taxpayers have funded the creation of these datasets in the name of public-good science.

²⁵⁸S-map coverage as of October 2018. (<https://soils.landcareresearch.co.nz/soil-data/s-map-and-s-map-online/>). In addition, while the older soil datasets (Fundamental Soil Layers) is non-proprietary, the newer, more detailed S-map is proprietary for commercial use.

²⁵⁹Recommendations to prioritise the data gaps identified in *Our land 2018*, and make an investment case to incrementally close them, have already been made to the Secretary for the Environment and the Government Statistician. See *Our land 2018* commentary available at www.pce.parliament.nz.

²⁶⁰Elliott et al., 2017, Tables 7-3 and 7-4, pp.42-49 and pp.56-64.

²⁶¹For example, information on water features (e.g. stream networks) requires permission to access, as it is linked to river reaches and is part of the River Environment Classification provided by NIWA. Similarly, Virtual Climate Station Network administered by NIWA, is also proprietary. New Zealand also does not have a single, comprehensive, robust, nationally representative dataset that characterises land use, and how it is changing spatially and temporally. Current estimates are based on data from a variety of sources, including Land Cover Data Base (LCDB) and AgriBase (which provides some information on land use class and stocking rates. However, coverage is incomplete and the database is proprietary).

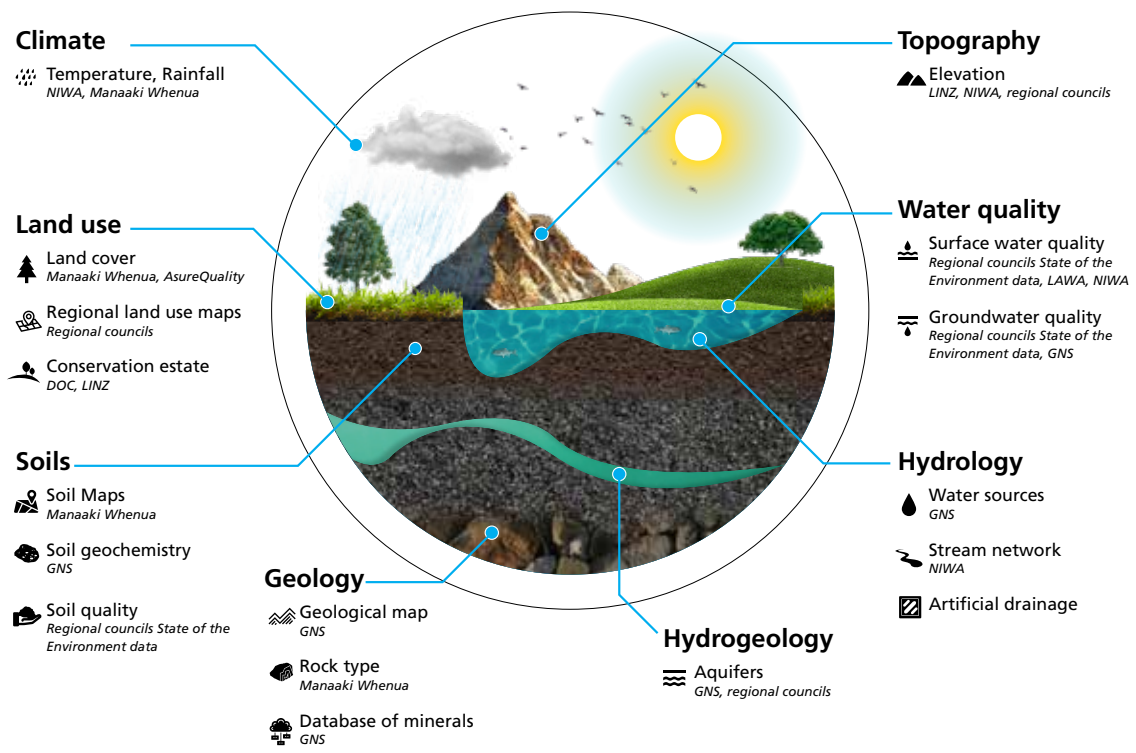


Figure 7.3 Existing datasets – and their curators – that can assist the understanding of nutrient transport across catchments.

It is important to collect new data and keep expanding existing datasets. However, it is equally important to advance our understanding by extracting extra value from existing information and data – for example, by joining up datasets across domains, rethinking existing conceptualisations and designing new ones (see Box 7.3). A comprehensive rethink of the public-good purpose of these datasets, their funding, and accessibility is overdue.

Box 7.3 Novel approaches

The *physiographic approach* is an example of a novel approach to mobilise existing datasets. The focus on water is a key feature of this approach – it is water rather than land that lies at the heart of this framework.

At its core, a physiographic approach involves systematically mapping the constituent biophysical characteristics of a landscape (like climate, topography, hydrology, soils, and underlying geology) to identify key processes that influence water quality. Importantly, land use with its nutrient pressure on water quality is not included as an inherent landscape property. As a result, the integrated classification system of physiographic units and zones can provide useful information about the vulnerability of the land. It can then be used predictively to help indicate appropriate land use and management.

The physiographic approach is still being developed, and initial trials have been conducted in Southland, and more recently Northland at a regional scale, and in the Waituna catchment on a catchment-scale.²⁶²

High-resolution catchment-scale mapping can lead to targeted actions to improve water quality (e.g. see the high-resolution physiographic maps for the Waituna catchment). However, they often need new data to be collected, and the quality and resolution of existing data will affect the spatial accuracy of the physiographic units.

Another novel approach is the *land use suitability approach* that attempts to build on existing models and datasets. It looks to develop an enhanced understanding of 'land suitability', by assessing the land in terms of both its productive potential and its environmental constraints.²⁶³

A land use suitability approach tries to assess a piece of land based on a combination of the following attributes:

- productive potential – the inherent capacity of a land parcel to deliver primary production
- risk to receiving environments – the inherent capacity of the land to attenuate contaminants on their way to receiving environments. How 'leaky' is a land parcel?
- constraints on receiving environments – given a particular limit or a water-quality objective, what is the maximum acceptable load of contaminants for a receiving environment? Is it already exceeded or not?

²⁶²Southland: Rissmann et al., 2016, Hughes et al., 2016; Northland: pers. comm. Clint Rissmann, 2018; Waituna: Rissmann et al., 2018. High-resolution physiographic units for the Waituna catchment can be found on the Land and Water Science website (<https://www.landwaterscience.co.nz/living-water>).

²⁶³McDowell et al., 2018.

This approach has also been recently trialled in Southland, where a few models (such as Overseer and SPARROW), as well as several datasets (such as land use information, soil maps, drainage, river environment classification, and physiographic zones), were combined and mapped to inform the three attributes mentioned above.²⁶⁴ Like the physiographic approach, the quality and resolution of existing data and models will affect the spatial accuracy of the land use suitability approach.

Importantly, new conceptualisations like those described above could help match land use to inherent landscape features, inform targeted efforts to improve water quality, and minimise impacts of agricultural production on receiving environments.

Conclusions

Overseer estimates on their own are rarely enough to make decisions about managing water quality in a catchment. Additional information about the biophysical characteristics of the entire catchment is often required. This includes information on nutrients leaving farms as well as any other non-farming sources, and their transport and transformations on the way to distant receiving environments.

While the above task is beyond the scope of Overseer alone, the information the model can provide is a good, quantitative, starting point for understanding the stress that nutrient loss is imposing on the receiving environment. However, estimates produced by Overseer are only estimates, and will always be accompanied by some degree of uncertainty. Overseer estimates are not the only source of uncertainty though – catchment-scale modelling efforts bring further uncertainty.

Uncertainties in model estimates and complexities in the underlying science are not reasons for inaction. While the impact of nutrients on water quality can vary, it is clear that if nutrient loads increase significantly, so does the stress on water quality.²⁶⁵ The state of water quality in many intensively farmed catchments is *prima facie* evidence of the need to reduce that stress. But to accurately quantify the likely environmental impact of reduced nutrient loss, and then link that to monitored water quality outcomes, requires a much better understanding of catchment-scale dynamics.

While nutrient transport and transformations through catchments is complex, a wide variety of datasets and models is available to help understand and manage catchments. Their coverage and management is fragmented. Depending on the locality, the contribution they can make to modelling and decision making will vary

²⁶⁴Pers. comm., Richard McDowell, 2018.

²⁶⁵PCE, 2013, p. 62.

significantly. Dataset coverage can also inject significantly different levels of uncertainty into both Overseer and catchment-scale models.

Large public investments have been made in both models and databases. The public-good nature of these investments suggests their accessibility should not be constrained by the ownership interests of the institutions that host them. This in turn demands a careful examination of the way their maintenance and future development is funded.

A joined-up view of catchment-scale environmental outcomes, and the goal of protecting 'the life-supporting capacity of air, water, soil and ecosystems', suggests that a collaborative approach to setting priorities and investing in these databases is required. This should embrace Crown Research Institutes, regional councils, and other science providers.

As with the estimates from Overseer itself, the outputs of catchment models can have significant on-the-ground consequences for farmers and other businesses. As a result, catchment-scale models must also meet the key criteria for use in regulatory settings. Given the range of catchment-modelling approaches that can be used, best practice guidance on when and how such models should be used in policy and plan making would be valuable.



8

Conclusions and recommendations

Conclusions

Overseer provides farmers with valuable information in making judgments about farm management. This is the purpose for which it was initially designed, and for which it has been managed and resourced.

But using Overseer's output is also useful to regional councils who are required, under the National Policy Statement for Freshwater Management, to do something about farm nutrient losses, which are seriously compromising water quality. The same model that optimises nutrient use for farmers, mechanically estimates nutrient loss from the root zone of a paddock.

Of course, there are plenty of practices councils can specify that are known to be beneficial in terms of reduced nutrient losses. And in some cases, ensuring that farms are following good management practices through monitored and enforced farm plans will be sufficient to achieve water quality outcomes.

But where nutrient loadings in a catchment are well beyond anything that is consistent with safeguarding the life-supporting capacity of receiving waterbodies, councils need to know that specific, quantifiable reductions are being achieved. There is a need for a tool capable of quantifying nutrients loss from farms.

It is scarcely surprising that some regional councils, grappling with unsustainably high nutrient leaching, have turned to Overseer, since it provides estimates of the very environmental pressure they are charged with managing.

But using the tool privately, and using it to estimate limits and enforce compliance are two very different things. Farmers may be happy enough with the model as a decision-support tool for farming purposes, but demand a much higher level of assurance when the consequences can be used to compel legal compliance. The level of trust placed in modelled outputs is crucially dependent on how those outputs are being used.

Although Overseer's farm and user-based focus make it attractive for use in regulatory decision making, it has not been subjected to the rigorous formal scrutiny that those who are being regulated might expect.

The assessment contained in this report has revealed that a significant amount of information needed to confirm Overseer's use in a regulatory setting is lacking. For this reason, a comprehensive and well-resourced evaluation of Overseer needs to be undertaken, if both councils and farmers are going to be able to feel confident that the model is fit for purpose. Initiating this will inevitably require access to the engine of the model, which in turn raises important questions about the proprietary nature of Overseer.

This conclusion raises an immediate question: what should happen in the meantime? As this report has described, Overseer currently underwrites a number of regulatory approaches that are either in force or in the process of being implemented. The approaches of some regional councils represent a considerable amount of 'learning by doing'.

It appears to me that most if not all the regional councils currently using Overseer to determine compliance with nitrogen limits do so because of the nature of the challenge they face. Overseer, in conjunction with catchment-scale modelling, provides a defensible quantitative basis for charting a pathway towards a lower environmental nutrient burden. And Overseer, by itself, provides a defensible basis for engaging land users on how they can, in a quantifiable way, reduce their share of that burden.

I should also observe that in these heavily over-allocated settings, if councils were to step back from trying to quantify limits, they would have to turn to much more aggressive input or land-use controls. I am not sure farmers would be any happier with that. They have consistently resisted input controls, such as limits to stocking rates, fertiliser application, cropping practices, and the amount of imported feed, on the basis that these sorts of regulations would be inflexible and stifle innovation on the farm.

Those concerns have and should continue to be taken seriously. Land-use controls will have a role in some situations, but trying to make an effects-based regime work, in which farming activity is limited by its environmental impact, is in my view worth the effort. After all, it focuses everyone on the issue we are trying to address: degraded water quality.

The best way forward is to speedily address important gaps and the shortcomings in transparency, peer review, corroboration, uncertainty and sensitivity analysis, and model documentation raised in this investigation. This will provide confidence both to regulators and farmers that uncertainties associated with the model are within acceptable bounds. This is essential to building trust in its application and in the nutrient limits being set.

It should also be recalled that Overseer assumes that good management practices are occurring on all farms. To have confidence in a regulatory framework using Overseer-derived nitrogen-loss limits, regional councils must be satisfied that these practices are occurring on all farms. Key instances where farms may not be compliant with these practices, based on our interviews, relate to storage and application of effluent on farms, and irrigation practices. Regional councils would therefore do well to ensure they are monitoring farms for compliance with these practices alongside any Overseer-based framework.

Recommendations

It is not enough for me to conclude that Overseer can be used in a regulatory context, subject to the matters I have identified as needing to be remedied. The Government itself has to decide if it wishes to see Overseer used to help manage water quality. All my detailed recommendations should follow from that.

While modelling nutrient loss using Overseer is just one tool in the water quality toolbox, if it is going to be used, it must be able to command a wide degree of confidence. Further, if modelling is going to be used to measure farm-level nutrient loss, then it should be used in a way that is nationally consistent. Only the Government can bring the parties together to ensure that best practices find their way into plans.

In making that high-level judgment, the Government can, in addition to this report, draw on a wide range of analyses, reviews, and guidance documents. But after a multi-decadal process of model development, and the elapse of more than ten years since Overseer was first used to set nitrogen discharge limits in Lake Taupō, it would be helpful if the Government were to clearly outline the regulatory uses of Overseer that are appropriate, and then establish steps to support that view.

1. I recommend that the Minister for the Environment and the Minister of Agriculture indicate if they wish to see Overseer used as a tool in the regulation of water quality and, if so, clearly identify what additional steps and actions may be required to support that use.

The recommendations that follow are made on the basis that Ministers are prepared to endorse Overseer's use in a regulatory context and direct officials accordingly.

The use of models in decision making and regulation calls for a higher level of scrutiny and transparency than is needed when using a model for research or non-regulatory purposes.

Currently there is a lack of guidance on the development, evaluation, and application of environmental models within the New Zealand environmental policy context. In its absence, this report used the elements of model evaluation developed by the United States EPA.²⁶⁶

The development of 'good' or 'best' practice environmental modelling guidance could go a long way to alerting model developers and users alike to the processes and requirements that need to be considered throughout model development, evaluation and application.²⁶⁷

2. I recommend that the Minister for the Environment task his officials to develop best practice guidance for the development, evaluation, and application of environmental models in regulation, drawing on international experience.

Given that the original development of Overseer did not envisage its current regulatory application, and that its use and ambitions have evolved organically over time, it is perhaps not surprising that more formal elements of model evaluation were neglected, at least in the early days.

That said, Overseer has been used to support regulation since 2005. If that is to continue, important gaps and shortcomings in transparency, peer review, corroboration, uncertainty and sensitivity analysis, and model documentation must now be addressed to provide confidence to councils and farmers.

²⁶⁶As noted in chapter 5, some domain-specific guidance is available on the application of modelling when implementing specific environmental policy, but there is a lack of guidance on the development and evaluation of environmental models for regulatory purposes.

²⁶⁷A distinction is often made between 'good' and 'best' modelling practices. The term 'good' is used to represent a general consensus, whereas the term 'best' is often used to represent a clear and common understanding of what modelling practices should look like. Ultimately the decision will be up to the authors of the guidance document.

3. I recommend that the Overseer owners and Overseer Limited ensure that a comprehensive and well-resourced evaluation of Overseer is undertaken. In particular:

(a) a whole-model peer review should be undertaken by technical experts independent of those who performed the development work.

A peer review of the whole Overseer model has never been carried out, nor have peer reviews of several key sub-models (such as the nitrogen leaching suite). Ongoing peer reviews are important for assurance that Overseer is of sufficient quality to serve as the basis for regulation making and to ensure the model's quality is maintained.

(b) a formal uncertainty and sensitivity analysis should be undertaken for the Overseer model.

Formal uncertainty and sensitivity analysis has not been carried out for Overseer. Understanding model uncertainty is important when models are used as the basis of policies and regulations. Quantifying and communicating uncertainty may not be an easy task for those managing Overseer, but it is necessary in some form to improve confidence and transparency in the model outputs.

Uncertainty analysis is also of importance when Overseer is used in interoperable modelling frameworks as part of catchment-modelling studies. Currently these studies are limited in their ability to understand Overseer's contribution to overall modelling uncertainty.

A better understanding of Overseer's uncertainty reduces the risk of discussions being derailed by how much modelled outputs diverge from the real world and will help focus thinking on how it can be most effectively used.

(c) In the interests of greater transparency, the following information should be documented and made publicly available:

- **the collated data used to calibrate and test the model**
- **the underlying scientific principles for all model components**
- **the algorithms, equations and parameters for all model components**
- **the source code.**

4. I recommend that Overseer owners make Overseer an open-source model.

An open-source model provides the transparency needed for Overseer to be used in regulation with greater legitimacy. Stakeholders would be able to seek independent third-party advice on whether the model's assumptions and simplifications were sound. In addition, making the engine of the model transparent creates an opportunity for scrutiny and improvement by independent experts.

An open-source approach is in conflict with the business model that has been adopted by Overseer Ltd. A way would need to be found for Overseer Ltd to support the ongoing maintenance and development of Overseer as an open-source model.

5. I recommend that the Minister of Agriculture and Minister for the Environment seek advice on ownership, governance and funding arrangements that would:

- **enable Overseer to be mandated as the 'official' model for estimating diffuse nutrient pollution for water management purposes where that is appropriate; and**
- **secure the ongoing resources to maintain and develop the model.**

6. To provide long-term funding stability, I recommend that the Minister of Agriculture and Minister for the Environment direct officials to conduct a strategic review of the:

- **resourcing needed to maintain and develop the model**
- **level of ongoing costs appropriately attributable to Overseer users in a regulatory setting**
- **level of public-good investment needed to build trust in the model through better corroboration and calibration using a greater number of sites throughout the country**
- **basis on which regional councils should contribute to regionally specific research to support use of the model.**

A comprehensive evaluation of Overseer and a move to making Overseer an open-source model would take time. In the meantime, regional councils have to work with the model under current arrangements. I have raised the need for guidance on managing version change and undertaking compliance in relation to Overseer estimates.

While these are key areas that need addressing, they are not exhaustive and there will be others. In all cases, regional councils need to ensure that plans are drafted in a way that can incorporate model-driven changes without disrupting farmers trying to comply with their obligations.

Official central government guidance should be provided to assist council planners to design plan provisions where councils have decided to use Overseer in regulation. This guidance should build on the Freeman report and the Enfocus report but could go further, setting out preferred approaches and, equally, those that are not recommended.²⁶⁸

The guidance should be accessible to planners without significant experience in using Overseer, and should be linked with other advice produced to support the implementation of water quality policies and objectives, including the National Policy Statement for Freshwater Management.²⁶⁹

7. To this end, I recommend that the Minister for the Environment direct officials, in consultation with regional council staff, scientists, and expert planners, to prepare guidance for councils designing plan provisions that use Overseer as part of a framework involving nitrogen-loss limits.

8. I further recommend that the Minister for the Environment direct officials to initiate a working group including representatives from each regional council and unitary authority, scientists, and Overseer Ltd to undertake a strategic review of:

- **those circumstances where regionally specific research is needed to support use of the model (e.g. field trials to be used in calibration or corroboration)**
- **the mechanisms to fund this research**
- **ways of ensuring that the outputs of this research are fit for purpose (e.g. the trial duration is long enough) and can be subsequently used in Overseer's modelling.**

²⁶⁸The Freeman report (Freeman et al., 2016) was commissioned by a number of regional councils, Ministry for the Environment, Ministry for Primary Industries and industry groups. The Enfocus report (Willis, 2018) was commissioned by Overseer Ltd.

²⁶⁹For example the guidance should augment the *Draft Guide to Limits under the National Policy Statement for Freshwater Management 2014 (as amended in 2017) (MfE 2018)* and *Draft Guide to Communicating and Managing Uncertainty When Implementing the National Policy Statement for Freshwater Management 2014*. (MfE 2016).

Overseer estimates on their own are rarely enough to make decisions about managing water quality in a catchment. Additional information about the biophysical characteristics of the entire catchment is required. In addition to nutrients leaving farms, this includes nutrients from non-farming sources, and their transport and transformations on the way to distant receiving environments.

While nutrient transport and transformations through catchments is complex, a wide variety of datasets and models is available to help understand and manage catchments. Their coverage and management is currently fragmented. Depending on the locality, the contribution they can make to modelling and decision making will vary significantly. Dataset coverage can also inject significantly different levels of uncertainty into both Overseer and catchment-scale models.

Large public investments have been made in these models and databases. The public-good nature of these investments suggests that their accessibility should not be constrained by the ownership interests of the institutions that host them. This in turn demands a careful examination of the way their maintenance and future development is funded.

9. I recommend that the Minister for Science and Innovation, in consultation with the Minister for the Environment, reviews the ownership, use, and development of the many models and databases that inform our understanding of catchment-scale dynamics, to ensure that water quality managers have access to the best possible understanding of nutrient transport and transformation.

10. I recommend that the Minister for Science and Innovation ensures that the Crown's ongoing investment in these models and databases is made in a joined-up way, with the express aim of contributing to the goal of protecting 'the life-supporting capacity of air, water, soil and ecosystems'.

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