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Research Briefing: Revealing the impact of predictive models as decision support tools in environmental planning

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Contents

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From the WRC research it became clear that there were important implications in relation to decision making in the urban context and as a result this research project has been designed to further interrogate those issues.

Executive Summary

Predictive modelling is commonly used to support decision-making in planning. This paper investigates the use, reliability, and effect of this to better understand the ways in which models influence planning policy, practice, and outcomes. The methods comprise of a literature review, model scoping phase, and a systematic analysis of case law.

The paper demonstrates the importance and reach of predictive modelling as a DST in planning and how processes and outcomes are influenced by multiple pressures across the science-policy nexus. These pressures can be classified as *scientific practices*, *political imperatives*, and the *spaces in-between,* such as the practices of communication and translation.

First, the analysis identifies a range of issues which may affect the quality of the evidence base relied upon for decision making. These issues largely relate to the substance of models including their scientific components, evaluative techniques and modes of application. Adoption of rigorous scientific method and techniques of model evaluation are identified as strengthening the evidence base, as is clear communication of model limitations to model users and decision makers. Second, consistency, clarity and communication of key terms underpinning a predictive model are vital to effective planning decisions. Third, reduction in qualitative assumptions and connection of model development to statutory mandates and policy contexts may also increase integrity of the evidence and avoid models assuming de facto decision-making power or interfering with the role of decision makers. Fourth, modelled evidence should not be viewed in isolation but in the context of the wider environment, cumulative effects and the intent of the policy settings.

The paper provides the foundation for ongoing research with stakeholders who develop, use or analyse predictive models as decision support tools in urban planning. The next stage interrogates more deeply the key themes identified in this interim report, such as model fitness for purpose, reliability, the operation of different logics and hidden power, and the policy interface and translation of predictions.

1 The importance and reach of Decision Support Tools

Contemporary decision making in planning for urban environments is aided by an eclectic range of decision support tools (DST), from population projections, to cost-benefit analyses, to complex traffic models. DSTs may be defined as: "a method or framework that can be used to assist with analysis/assessment of information required for the decision-making process or to assist with the decision-making process itself" (Envirolink, 2012). Essentially models are constructed, selective, and simplified representations of reality designed to gain insights into parts of a complex system. This research, developed as part of *National Science Challenge: Building Better Homes, Towns and Cities,* is designed to investigate the influence and limitations of predictive modelling as a DST in the context of building better homes, towns and cities. In instances where environments are not well studied, and/or new technologies are employed predictive modelling may constitute the majority of the evidence base. However, more commonly predictive modelling is but one element of the evidence base and is supported by additional sources such as non-modelled expert evidence, photographs, and site assessments. Modelling may also be incorporated within other DST such as Cost Benefit Analysis and Geographic Information Systems.

Within this decision making context, DSTs can be understood as relating to two broad areas: *strategic planning*, and *development control*. From a strategic perspective their roles are to understand systems and predict states and impacts with a view to informing policy and decision-making (Wallace, 2017). For example, in providing this evidence base, DSTs influence decisions about the use, protection and development of land and resources (Schmolke et al., 2010; Özkundakci et al., 2018), such as via trends in population or consideration of the impact of expansion of urban boundaries on traffic or the existing environment. DSTs are also used to support the construction of objectives, policies and methods in plans prepared under the Resource Management Act 1991 (RMA) or policy under the Local Government Act 2002 (LGA). From a development control standpoint they frequently support impact assessments in consenting processes and the development and application of consent conditions, such as

with regard to traffic, parking, or noise. They are also used to support compliance, monitoring and enforcement. Together these various DST elements exert significant influence upon the nature of our buildings, towns, and cities in a complex manner.

While this initial categorization of *strategic planning* and *development control* provides a useful means to appreciate the scale and variety of DSTs in shaping development, their role goes well beyond that of an objective tool used by a 'decision-maker'. They also exert influence between each other. For instance, DSTs concerning population growth or employment projections will in turn feed into DSTs relating to infrastructure provision or future zoning for housing, which in turn may influence DSTs connected to design criteria at the site level. Other DSTs then feed into the process of decision making at the site scale, such as development feasibility studies or traffic impact assessments.

The development of policy is also closely interwoven with model use and development. For example, models can become embedded in planning policy and shape regulatory methods, such as with nutrient discharge models like OVERSEER® Nutrient Budgets (OVERSEER) and land use policy (Waikato Regional Council Proposed Plan Change 1). Conversely, statutory mandates, planning policy and criteria can become embedded in models through inferences, assumptions and parameters employed in model development and application (Pascual et.al., 2013). In addition, statutory mandates and directions together with the objectives, policies and rules of subordinate planning instruments determine outcomes in planning decisions, including the weight or acceptability of expert evidence based on modelled predictions (*Okura Holdings Limited v Auckland Council* [2018] NZEnvC 87).

So while it may be expected that DSTs should be designed to support planning and policy the relationship operates in a much more complex and less visible manner. DSTs can also influence each other, so there are models built upon models and assumptions built upon assumptions. Further, the availability and usefulness of data means they can actually help create the policy, and the policy settings they help create can also influence the weight attached to DSTs within any decisions.

2 Pressures along the Science-Policy Nexus

To provide added complexity, the importance and reach of predictive modelling as a DST in planning is influenced by multiple pressures across the science-policy nexus. It is affected by *scientific practices*, *political imperatives*, and the *spaces in-between*. The first of these is a rational, technical perspective related to the need for sound 'evidence-based planning'. It is well understood that making good policy decisions is dependent upon robust information and further that the limitations of the information should be understood (Gluckman, 2013: 10). Moreover, as planning is inherently future-oriented there is a need for projection and conjecture in accurately determining future states and actions (Özkundakci et al., 2018; White, 2013). From this perspective, DSTs are therefore a scientific means to simplify, codify, and make sense of complex human systems and potential futures (O'Neill, 2001).

Turning to politics, while DSTs may appear scientifically objective, research is beginning to reveal their hidden logics and powers. For example, there is a political choice involved concerning the selectivities of when, where and which DSTs to use, and for what purpose (Haughton and White, 2017). Significantly, they are also useful as they provide a means to enable decisions to be defended. Here, DSTs with a focus on quantification or cost-benefit analyses can distil scientific complexity down to simple forms of spatial representation or economic justification that have been useful in helping to determine policy choices, or mitigate potential legal challenges or future liability claims (White and Haughton, 2017). These 'calculative practices' of decision making are associated with the need to make complex systems, such as those associated with housing, governable (McAllister et al., 2016; Miller, 2001). More broadly with regard to predictive modelling in planning, this literature is related to how practices of quantification, such as via economics, does not merely describe or explain, but also actively shapes cognitive structures, designs markets and influences decisions (Boldyrev and Svetlova, 2016; Mackenzie, 2006; McAllister, 2013). Due to the association of DSTs with accuracy they can also serve to exclude other voices or data, and in doing so exert power over real world outcomes (Denis et. al., 2006). As such, evidence such as predictive modelling has a performative nature in building better homes, towns, and cities, that can assume a level of epistemic authority, condition housing agents, and privilege certain

outcomes in a largely hidden manner (Christophers, 2014; Murphy, 2014). Put simply, their influence is fundamental–they influence objectives, policy, practices, and outcomes.

In addition, the literature identifies significant issues connected to the spaces in-between science and policy, and scientific literacy of decision makers. Most notably, this concerns aspects related to the effective translation of science to policy and decision-making, and the ability for practitioners to understand model quality evaluation and the underpinning data (e.g. Schmolke et al., 2010; Council for Regulatory Environmental Modeling, 2009; Fisher et al., 2010; Pascual et al., 2013). These issues point to the need for planners and decision makers to be familiar with the tool, understand its functions and limitations, including the assumptions and data that sit behind the outputs, and importantly to be apprised of the mechanisms for model quality evaluation in order to appreciate the robustness, balance evidence, and assign weight. The literature further identifies the importance of best modelling practice to support interpretation and provide a reliable evidence base (e.g. Jakeman et al., 2006). However, incorporation of best practice is uneven, and in New Zealand it is not subject to any regulatory control or administrative oversight. These are issues we will discuss in more depth later in the research.

Due to its predictive nature, and the influence of both epistemological and ontological uncertainty, modelling is recognised as inherently uncertain. The Supreme Court recently adopted the insightful observation "…all models are wrong, but some models are useful" (*Sustain our Sounds Inc. v New Zealand King Salmon Company Ltd* [2014] NZSC 40 at [132]). This quote provides a good way to summarise this research. Simply put, the aim is to try and make predictive modelling evidence more useful with regard to building better homes, towns and cities. We do this in two ways. First, by interrogating the influence of modelling in planning decisions and, second, the potential vulnerability of planning decisions and policy reliant upon modelled outputs and the measures available to support robust decision-making. The research is therefore designed to contribute to both good modelling practices and good decision practices across the science-policy nexus, from the construction of models, to their political impact on policy, to their influence on outcomes. Although the study has a New Zealand focus, given the prevalence of DSTs in planning decisions around the world, we anticipate that these findings will be relevant internationally.

3 Methodology

The research approach combines literature review, scoping study, and legal decision review of model use and development in the context of planning decisions. This section provides an accessible overview, a more technical and detailed description will be provided in the final report after the second phase of research. The literature review involved examining texts connected to predictive modelling, decision making and the science-policy interface. The scoping study developed an inventory of the most critical DSTs used in urban planning, particularly from a housing perspective. To interrogate these matters more deeply in the New Zealand planning context, a review of legal decisions was undertaken. This is a tested technique to review predictive modelling in planning decisions (Wallace 2017; Özkundakci et al., 2018) as the level of scrutiny provided in this arena is consistently the most robust available within the planning field. This paper is an interim output and reports back on the findings of the review of legal decisions. The next phase of research involves interviews with key stakeholders to better understand the issues raised and analyse how the use of DSTs in decision making may be reconfigured to help build better homes, towns, and cities.

The main body of evidence we draw upon relates to the review of New Zealand legal decisions. We do this in order to examine systematically the representation and application of predictive modelling as a DST in an urban context, and analyse whether particular characteristics or uses of models influence evidential reliability in decision-making. Drawing upon previous technical and legal studies concerning modelling and best practice, we developed an approach that allowed us to investigate process and substantive challenges. This provides an insight into both current practice and best practice. It targeted recent decisions (1 January 2015 to 15 June 2018) relevant to urban concerns. The Westlaw NZ database was used for the search. A range of search pathways were applied with the following settled upon as producing a reasonable balance of relevance and comprehensiveness: Environmental cases, Free Text (model! & urban! OR residential) AND Judgment Date (Between 01/01/2015 AND 01/02/2018) AND Jurisdiction (NZ).

The search produced 155 documents, consisting of 85 potential decisions, which were then ordered by decision-making level, with the majority being decisions of the Environment Court. The highest courts were examined first, due to the dominance of points of law and the doctrine of precedent. All decisions of the Environmental Protection Authority (EPA) from 1 January 2015 in relation to Resource Management Act 1991 (RMA) proceedings were also the subject of a separate search using the same coding due to their likely relevance to modelling in urban environments.

The analysis screened in excess of 85 New Zealand environmental decisions (plus 2 separate Board of Inquiry decisions located in the EPA database) and then analysed in depth 17 of those decisions identified as of particular interest in terms of modelling practice.

In legal terms, a challenge is directed to the ways that the model generates expert evidence and to the purpose to which it is applied. A challenge can be made to the substance of a model. These 'technical disagreements" may involve the scientific components, the evaluation process used to test validity/review or the application of the model. Alternatively, where a regulatory context requires a specific process for model development, a challenge may be directed to failings in that process termed 'process challenge' (USEPA; Council for Regulatory Environmental Modeling, 2009). We have drawn upon these categories in this analysis with a particular focus upon substance challenges, due to the absence of regulatory control of the modelling process in the context of the RMA or LGA.

In addition to these classifications, we also examined how models may be challenged, made vulnerable or strengthened in terms of value of the evidence. In New Zealand the admissibility of evidence is governed by whether the fact-finder is "likely to obtain substantial help" from the expert's opinion (s 25 Evidence Act 2006). So in this context, challenges to predictive modelling will depend upon if the decision maker finds the evidence to be substantially helpful, or not. Drilling down into this further, the notion of 'substantial help' concerns three aspects common to judicial systems and scrutiny of evidence: relevance, reliability and probative value. The Court of Appeal decision *Vero Insurance New Zealand Ltd v Morrison* [2015] NZCA 246 at [24] was used a baseline for determination of these matters, and from there the study set of decisions was analysed to detect challenges or observations made in

relation to the relevance, reliability or probative value, as well as classification according to the USEPA study.

3 Findings and Discussion

The number and type of appeals

In relation to the screened decisions (n.87 including Board of Inquiry decisions) the analysis reveals that a wide range of predictive models are employed in supporting decisions about the urban environment, which helps explain the scope and complexity of the contests engaged in, and the nature of decisions to be made regarding both strategic planning and development control (Figure 1). The modelling under scrutiny was largely undertaken in the context of resource consents or plan appeals, but also extended to an interim enforcement application in relation to a multi-unit staged subdivision. Commonly, the models were employed to predict the character, scale and/or intensity of development impacts such as noise, odour, discharge dispersal, or flood hazard in disputes between developers, local authorities and neighbours (e.g. *Sabatier v Auckland Council* [2018] NZEnvC 60, *Vipassana Foundation Charitable Trust Board v Auckland Council* [2017] NZHC 1457, *Pierau v Auckland Council* [2017] NZEnvC 90, *Friends of Michaels Avenue Reserve Inc v Auckland Council [*2016] NZEnvC 5, *Quieter Please (Templeton) Inc v Christchurch City Council* [2015] NZEnvC 167.

Disputes at the more strategic scale were also highlighted, characterised largely by conflicts concerning Auckland metropolitan urban limits, urban growth, zoning and the Proposed Auckland Unitary Plan (*Okura Holdings Limited v Auckland Council* [2018] NZEnvC 87, *Self Family Trust v Auckland Council* [2018] NZEnvC 49, *Albany North Landowners v Auckland Council* [2017] NZHC138).

Figure 1 shows the wide influence of DSTs and also the relative influence of particular areas. For example, we can see how DSTs relating to transport and traffic are by far the most frequently screened. Note that the reference to number of decisions does not equate to the 87 decisions screened (including 2 Board of Inquiry) as some decisions were excluded due to

the sense of the reference 'model' and other decisions contained reference to more than one model in the proceedings.

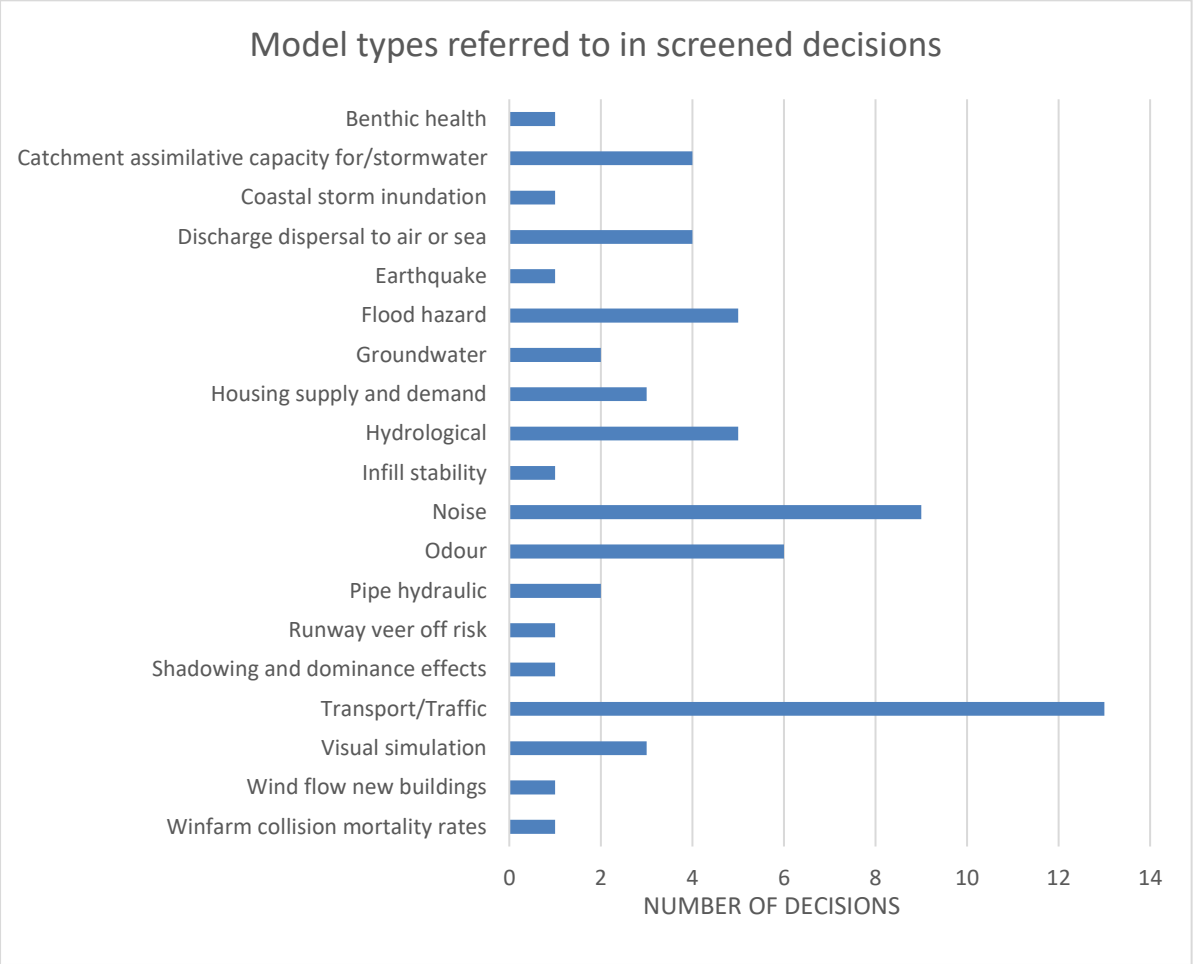

Figure 1: Model types challenged or referred to in screened decisions

The results of the analysis are consistent with prior reviews of legal challenges to modelled predictions (CRE, 2009; Wallace, 2017; Özkundakci et al., 2018) yet reveal additional findings relevant to the urban context. Dominating the challenges were matters concerning the scientific components of models. Quality of input data and associated assumptions and parameters featured commonly, highlighting the criticality of rigorous science as a key modelling success factor. A further success factor was the extent of evaluative techniques applied in model development. The adoption of processes of independent peer review and validation techniques, expert agreement and consistency in approach are indicated as strengthening the evidence base for decision making. The historical success of a model has bearing in this regard as well. The final scientific component, model application, is also of

relevance. Applying a model out of context, for instance in a different geographical location to where it was developed, for a different system, season, time frame or species, may make it vulnerable to challenge in relation to both the relevance and reliability of predictions.

Leading on from this, the next section pulls out additional key decision making issues identified through the screened decisions in the context of making decisions for building better homes towns and cities.

1. Clarity and Consistency of Key Terminology

The critical importance of clarity and consistency of terminology in model development, and the nexus to the policy and decision making context was highlighted by the research. Three decisions demonstrated how variance in key terms when predicting development capacity can result in stark differences to the evidence presented to decision makers (*Appealing Wanaka Inc. v Queenstown Lakes District Council* [2015] NZEnvC 139; *Albany North Landowners v Auckland Council* [2017] NZHC138; *Self Family Trust v Auckland Council* [2018] NZEnvC 49). Significantly, the decision in *Albany North Landowners v Auckland Council* [2017] NZHC138 at [37] recounts how Auckland Council in the development of its Unitary Plan had relied on 'theoretical capacity' enabled by the Unitary Plan, rather than on the measure of capacity that takes into account physical and commercial feasibility, also known as 'feasible enabled capacity'.

This seemingly simple definitional issue had a considerable impact upon planning outcomes. It led to a shortfall of nearly 200,000 dwellings in projections for housing capacity in contrast to subsequent 'extensive analytical work and modelling' required by the Independent Hearings Panel responsible for determining the final form of the Plan. As a result of the additional scrutiny of predictive modelling evidence provided by the legal process, the planning scheme for densification set out in the proposed Auckland Unitary Plan was revisited and altered. The Council was obliged to file in evidence revised objectives, policies and rules for residential zones that enabled significantly greater housing capacity. In turn this led to legal challenges concerning the scope of these revisions and their legitimacy within the planning process.

In addition to demonstrating the importance of clear definition of key modelling terms, the decision highlights how effective scrutiny of modelling process and outcomes may not be applied until a legal process imposes that scrutiny. And further, that the imposition may only arise where a party or a decision maker queries that particular strand of evidence. There may be other definitional issues in decision making across New Zealand that have an effect on building better homes, towns and cities, which are not uncovered due to the difficulty in interrogating the science.

These decisions underscore the importance of experts unpacking the key terminology, methods and assumptions that sit behind modelled predictions, in a manner that is visible to and testable by decision makers (Pascual, 2013). Essentially, it also traces a line from confusion in production of evidence to confusion in policy and decision-making, and points to the importance of peer review of modelled evidence, expert conferencing, or other means to translate science to policy. It also supports the need for caution in adapting or repurposing a model developed for one particular purpose to a different application.

2. Lack of Detail Concerning the Type of Development.

The type and numbers of housing has a major effect on the impacts of development and also other aspects of planning, such as infrastructure, amenity, or public transport. However, it was observed in *Okura Holdings Limited v Auckland Council* [2018] NZEnvC 87 at [478] that the detail of the 'dwelling make up' may be absent or unknown at the time projections are made, thus making evidence less reliable. For example, accurate traffic assessments would be reliant on such detail. Therefore, the decision emphasises how without detail concerning the specific construction of the urban environment the predictive modelling relating to the proposal may not be particularly useful for aiding decision making. Again, it was only the scrutiny offered by this more stringent legal process that revealed this issue.

3. Lack of Integration.

This leads on to the next observation, and the critical importance of not viewing modelled evidence in isolation, but instead, recognising the interconnected nature of both

development and the natural and physical environment, as well as the potential for cumulative effects. In *Okura Holdings Limited v Auckland Council* [2018] NZEnvC 87 at [293] when assessing the impact of urban development upon benthic biota, the Court, despite considerable conservatism being built into the modelling, recognised the degree of uncertainty "about how cumulative effects and other (undefined) stressors might impact on these modelled results". This finding contributed to the final decision not to allow changes to the metropolitan urban boundary. The issue also demonstrates the importance of moving out of siloes by combining modelled evidence with other sources of evidence to support robust decision-making.

4. Importance of Clear Policy Direction.

Related to the prior finding is the vital influence of statutory mandates and the policy context in making decisions that involve predictive modelling, and the ability of policy settings to 'tip the balance' as to the reliability and weight of evidence. Modelling is recognised as inherently uncertain. A range of mechanisms exists to manage uncertainty, including adaptive management mechanisms, but the adequacy of the evidential foundation must be carefully scrutinised to determine, for instance, whether a precautionary approach requires prohibition of the activity (*Sustain our Sounds Incorporated v New Zealand King Salmon Company Ltd* [2014] NZSC 40 at [129]). Recently, the decisions in *Okura Holdings Limited v Auckland Council* [2018] NZEnvC 87 and *Self Family Trust v Auckland Council* [2018] NZEnvC 49 have underscored the significance of strong objectives and policy in protecting environmental values in the urban environment. Part of this significance stems from the lens forged from the policy context through which predictive evidence will be assessed:

> *[375] In our section on marine benthic ecology we found that while the sediment and heavy metal discharge modelling was very conservative and the effects of the modelled discharges on the benthic biota were well within agreed thresholds, there remained a degree of uncertainty about how cumulative effects and other (undefined) stressors might impact on the modelled results. Whether this uncertainty had the potential for the effects of discharges to cause the benthic health of the*

> *Estuary to reach a tipping point and consequently whether a precautionary approach should apply was arguable. We added that what may well tip the balance for us was the significance of the Estuary with its importance being formally recognised by a number of instruments including its Marine Reserve status and the SEA provisions of the Unitary Plan (Okura Holdings Limited v Auckland Council [2018] NZEnvC 87).*

Put simply, if decisions are occurring in a policy vacuum, or in a weak directive environment, then predictive modelling evidence may take on greater weight in shaping outcomes. This may foster a disconnected siloed urban environment, rather than effectively deliver integrated and strategic planning goals. It also emphasises how strong policy objectives are a good way to manage uncertainty and complexity; as uncertainty is rife strong political objectives can more easily shape the outcomes, rather than authority being given to technical decisions.

5. Hidden Assumption of Power

The data revealed how the development and application of models may mean that they can assume political power in a hidden fashion. Modelled predictions heavily reliant upon assumptions and inferences, particularly of a qualitative nature, present a particular challenge to decision makers. Not only are they less reliable than direct observation/longitudinal studies, but the modelling process determines the 'relative treatment' of information as model inputs. As such, they may interfere with, or supplant, the role of the decision-maker in weighing the evidence (*West Coast Environmental Network Inc. v West Coast Regional Council and Buller District Council* [2013] NZEnvC 47 at [220]; Özkundakci et.al 2018). This may be understood as a case where the ways in which a model is developed and treats information means that it can effectively assume administrative or regulatory power.

Further issues may also arise where criteria employed in the development of model parameters, assumptions, and inferences are inconsistent with or unconscious of regulatory schema. In a regulatory vacuum, decisions made in the construction of modelled evidence may embed assumptions (for example, in the employment of assessment criteria in the

absence of regulatory controls) that by its adoption, has the effect of embedding de facto policy. Therefore DSTs can create policy in a way that circumvents political processes. This finding also points to the value of strong, directive policy in planning instruments, and further, the critical importance of the translation of policy settings to model development, and clear documentation of model limitations in the application of modelled outputs to decisions.

6. Lack of Best Practice

The research demonstrated both the wide variety and complexity of modelling types, but significantly their variance in quality and fitness for purpose. Despite their importance in building better homes, towns and cities, overall there was a lack of scrutiny, which tended to operate in an ad-hoc fashion. Key aspects of decision making best practice, for example, consistency, quality or robustness, were applied in an uneven manner and there was a general difficulty in applying effective administrative oversight due to the position of the area between science and policy.

Reference to 'high level modelling' in an instance where evidence was produced without quality controls, such as sensitivity analysis, indicates the ability of the judiciary to test and discriminate in assessing modelled predictions (*Sabatier v Auckland Council* [2018] NZEnvC 60). The decision in Final Report and Decision of the Board of Inquiry into the Ruakura Development Plan Change (2014) at [701] also reveals growing judicial awareness of the elements of best modelling practice in the production of reliable modelled evidence. In a legal challenge, the scrutiny is high. The decision makers have the benefit of cross-examination of expert witnesses, the expert evidence of opposing parties, expert codes of conduct requiring methodological clarity (e.g. Environment Court Practice Note) and expert conferencing. In the Environment Court, this may also be augmented by the presence of Planning Commissioners as decision makers expert in the matters the subject of the evidence. Yet only a fraction of planning decisions are legally challenged and as a result, many important decisions will be made at administrative levels without the benefit of this form of scrutiny.

Taken together, these six issues do not show how every decision is subject to each of these problems, but rather how the processes and practices of decision making means that difficulties may not be uncovered unless an appeal is lodged, which effectively ensures a higher level of scrutiny is reached. More broadly, the research provides insights into the difficulty in effectively translating science to policy and practice, particularly where it encompasses expert technical knowledge. The research uncovered issues of particular relevance to the use of modelled evidence in decision making for the urban environment.

The problems uncovered by the research are wide ranging and will be investigated in more depth via qualitative research aimed at stakeholders across the science-policy nexus. The key questions relate to the substance of models, the ways that they are developed, relationships to the policy settings and political language, and the power that they can exert over outcomes. The difficulty in evaluating models within the decision making process was evident and there were issues with fundamental considerations, such as the weight, relevance, or reliability of the evidence. The decisions point to 'modelling success factors' including the application of rigorous science in development of the model, effective evaluation techniques, and the use of the model in context.

It is important to note that the absence of some of these factors does not necessarily make models 'useless', it just means that they can be assigned an appropriate level of reliability, weight, and confidence. There will always be assumptions and parameters, or particular choices of data input, that will affect confidence levels, the key is the ability to quickly and clearly interpret this across the science-policy interface. This also highlights the importance of the adoption of best modelling practice at the outset of the development, careful documentation of the modelling process, and the clear communication of model limitations to those who will rely upon and apply the predictions. It further suggests the need to develop administrative practices which support consistency in adoption of best practice. For example, the confidence in a model's output can be supplemented by additional evidence or techniques, such as expert peer review or other management mechanisms directed at the science-policy interface. This confidence should be expected to increase the more critical the decision may be on the ground.

4 Conclusion

Planning policy and decision-making is closely interwoven with model use and development. Models can be embedded in planning policy and applied in support of regulatory methods. Conversely, statutory mandates, planning policy and criteria can be embedded in models through terminology, inferences, assumptions and parameters employed in model development and application. In addition, statutory mandates and planning instruments determine outcomes in planning decisions including the weight or acceptability of expert evidence based on modelled predictions. It is clear that DSTs play a pivotal role in building better homes, towns, and cities, beyond the provision of objective evidence.

The analysis identified a range of issues relating to the substance of models, including their scientific components, evaluative techniques and modes of application. Aspects include the quality of input data and associated assumptions and parameters, the adoption of processes of independent peer review and validation techniques, expert agreement, consistency in approach, application in context and the historical success of a model. Consistency, clarity and communication of key terms underpinning a predictive model are vital to effective planning decisions, as shown by the example of strategic planning for development capacity in the Auckland and Queenstown urban environments. Reduction in qualitative assumptions and connection of model development to statutory mandates and policy contexts may also increase integrity of the evidence and may avoid models assuming de facto decision-making power or interfering with the role of decision makers.

Models are inherently uncertain and the policy context is strongly determinative, indicating the value of directive and informed policy in this respect. Modelled evidence should not be viewed in isolation but in the context of the wider environment, cumulative effects and the intent of the policy settings. When casting decisions for the future the value of predictive modelling is clear, but so too is the importance of rigorous scrutiny of the outputs and clear communication of limitations to decision makers. The next phase of research will analyse and evidence these issues further.

5 Supplementary Information

Key Legal Decisions

Albany North Landowners v Auckland Council [2017] NZHC138

Appealing Wanaka Inc v Queenstown Lakes District Council [2015] NZEnvC 139

Craddock Farms Ltd v Auckland Council (2016)19 ELRNZ 390

Final Report and Decision of the Board of Inquiry into the Northern Corridor Improvements Proposal 2017

Final Report and Decision of the Board of Inquiry into the Ruakura Development Plan Change (2014)

Findlay v New Zealand Transport Agency [2016] NZEnvC 39, [2016] NZRMA 183

Findlay v Waipa District Council [2017] NZEnvC 96

Friends of Michaels Avenue Reserve Inc v Auckland Council [2016] NZEnvC 5

New Zealand Transport Agency v Architectural Centre Inc. [2015] NZHC 1991, 19 ELRNZ 163

Okura Holdings Limited v Auckland Council [2018] NZEnvC 87

Pierau v Auckland Council [2017] NZEnvC 90

Quieter Please (Templeton) Inc v Christchurch City Council [2015] NZEnvC 167

Re Queenstown Airport Corporation Ltd [2015] NZEnvC 222

Re Waiheke Marinas Ltd [2015] NZEnvC 218

Sabatier v Auckland Council [2018] NZEnvC 60

Self Family Trust v Auckland Council [2018] NZEnvC 49

Sustain our Sounds Inc. v New Zealand King Salmon Company Ltd

Sustainable Matatā v Bay of Plenty Regional Council [2015] 18 ELRNZ 620

Vero Insurance New Zealand Ltd v Morrison [2015] NZCA 246

Vipassana Foundation Charitable Trust Board v Auckland Council [2017] NZHC 1457

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