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Research

Evaluating water quality regulation as a driver of farmer behavior: a social-ecological systems approach

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ABSTRACT. Water quality policy for agricultural lands seeks to improve water quality by changing farmer behavior. We investigate farmer behavior in three water quality regimes that differ by rule structure to examine the fit and interplay of each policy within its social-ecological context, important aspects for improving water quality. Vermont, USA's practice-based policy requires the adoption of specific practices, whereas New Zealand's Lake Taupo and Lake Rotorua performance-based policies require farmers to meet a numeric limit for nutrient loss on their farm. Across the three regions we interviewed 38 farmers to elicit mental models of nutrient management changes. We utilized the social-ecological systems (SES) framework to guide mental model elicitation, drawing on farmers' perceptions of the SES to identify salient aspects for behavior. Mental models were grouped by region and analyzed using network analysis. Farmers in all regions self-report high levels of behavior change and cite the policies as key drivers of behavior. This suggests that each policy fits in that it is achieving desired behavior change. However, different behavioral patterns emerged across the regions that we hypothesize have implications for biophysical fit: structural changes dominate in Vermont (e.g., buffers) and system changes in Taupo (e.g., switch from dairy support to beef cattle). The interplay of the policy in each setting, such as with incentive programs in Vermont and a market for nitrogen in Taupo, contributed to the different behavioral patterns. Additionally, access to capital in some form is required for farmers to achieve changes associated with higher biophysical fit. The social fit of the policies also varied, evidenced by dramatic upheaval in Taupo to mostly neutral perceptions of the policy in Vermont. We conclude that regions considering a shift to water quality rules for farms should carefully consider behavioral dynamics in policy design to achieve water quality goals.

Key Words: *environmental regulation; farmer decision making; mental models; social-ecological systems; water quality*

INTRODUCTION

Water quality policy targeting agricultural nonpoint source (NPS) pollution strives to improve water quality by changing farmer behavior across the landscape. Despite the pervasive impact of agricultural NPS pollution to freshwater systems, little is known about the social, economic, and political dynamics that contribute to the persistence of the problem, including the role of mandatory NPS pollution policy in changing farmer behavior (Carpenter et al. 1998, McDowell et al. 2016, Rissman and Carpenter 2015). The types of land management changes farmers make on their land and the drivers that influence these behaviors are signals of whether water quality will improve and if behavior is changing as intended. The mental models farmers hold with respect to the motives for their nutrient management behavior can help identify underlying mechanisms driving behavior (Jones et al. 2011, Saldaña 2015). Understanding farmers' mental models can in turn shed light on the fit of a water quality policy within the broader watershed context, and social and ecological outcomes.

For water quality policy to achieve the desired outcome it must fit well within the social-ecological context and have good interplay with the pre-existing institutions that structure interaction and behavior in a given setting (Goodin 1998, Young et al. 2008). Institutions refer to the rules, strategies, or norms that constrain human interaction and behavior (North 1990, Ostrom 2005). Policy or institutional fit refers to the ways in which institutions fit "ecosystem dynamics, our priorities concerning these, and what rules "fit" these issues," but importantly, also the way in which an institution shapes human action (Vatn and Vedeld 2012). As Vatn and Vedeld (2012) describe, "No regime can fit a resource...if the regime is unable to create the actions wanted or needed."

Because of challenges in measuring and monitoring agricultural NPS pollution (Meals et al. 2010), it is difficult to assess the ecological fit of a water quality policy through water quality trends. Instead, we can identify links between the policy and actions of interest that drive NPS pollution trends, i.e., farmer behavior change, to assess the fit of the policy with the biophysical system. In particular, we focus on the type of behavior changes being made on the land to assess biophysical fit because not all nutrient management changes will have the same ecological impact long term. We can assume that a reversible management change in the amount of fertilizer applied will have a lower effectiveness on improving water quality in the long term than a farm system transition from a high nutrient loss system, like a dairy farm, to a lower nutrient loss land use, like forestry.

Alongside the biophysical fit of the policy, we can look to farmer perceptions to examine the social fit of the policy, or "how well institutions match human expectations and local behavioral patterns" (DeCaro and Stokes 2013) to understand institutional acceptance of a policy. With the typically slow movement of nutrients in the landscape, it is difficult for farmers to see a cause-and-effect relationship between behavior changes induced by a policy and water quality improvement. Therefore long-term buy-in and acceptance of the policy as legitimate is critical (DeCaro

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and Stokes 2013). With farmer behavior and mental models we can assess qualitatively the social and biophysical fit of a water quality policy.

We investigate farmer behavior in three agricultural NPS pollution policies in Vermont, USA and Taupo and Rotorua, New Zealand (NZ), targeting the same biophysical challenge: the reduction of water quality due to runoff of nutrients from agricultural landscapes. In each policy, farmers have a set of "choice rules," which specify what a farmer "must, must not, or may do" (Ostrom 2005:200). These mandatory policies represent two different types of choice rules: practice-based and performance-based. Under Vermont's practice-based policy, farmers must implement a series of practices or structures to be in compliance (VAAFM 2018). In the NZ performance-based policies, farms must stay under a performance limit for modeled nutrient leaching, but they can choose any suite of strategies to achieve the standard (WRC 2011*a*, BOPRC 2016). The Taupo policy has been in operation since 2011, Vermont since 2016, and the Rotorua process is yet to be implemented and therefore represents a policy signal, i.e., requirements of policy are known but not yet enforced.

We present a novel methodology, integrating the social-ecological systems (SES) framework and mental models analysis, to address three key research questions: (1) What types of nutrient management behavior changes do farmers report making? (2) What do farmers perceive as the drivers of their nutrient management changes? And (3) what are the perceived individual and watershed outcomes of behavior changes and the NPS pollution policy? The aim of this analysis is to identify and assess the behavior changes induced by policies developed to improve water quality and the social and ecological factors driving behavior, both important components of policy fit and interplay (Young et al. 2008, Vatn and Vedeld 2012, DeCaro and Stokes 2013). We did not attempt to assess the effectiveness of policy to achieve water quality improvement because not enough time has passed to see marked improvements in water quality.

Theoretical framework

Ostrom's SES framework (2009) considers the way in which interactions between governance systems, users, resource systems, resource units, and system outcomes exist within broader social, economic, political, and ecological dynamics. Typically in applications of the SES framework researchers use a diversity of metrics (Cox 2014, McGinnis and Ostrom 2014, Leslie et al. 2015), but rarely include perspectives of individual actors. Here we draw on farmers' perceptions of dynamics in the SES, i.e., mental models, to identify the most salient aspects of the system to behavior as a basis for examining policy fit and interplay, given that the aim of agricultural NPS pollution policy is to improve water quality through changing farmer behavior. As Ekstrom and Young (2009) note, identifying institutional fit at the system-wide scale requires incorporating the "full suite of institutions relating directly or indirectly to a socioecological system." In our case studies, we look to farmers to identify the suite of institutions they perceive as causal drivers of their behavior.

Exploring farmer mental models within the context of a water quality policy can provide important insight into how farmers make decisions that ultimately impact water quality (Carley and Palmquist 1992). A mental modeling approach has been employed to understand a broad range of environmental behavior, including irrigator water-use decisions (Douglas et al. 2016), definitions of sustainable agriculture (Hoffman et al. 2014), weed management decisions (Jabbour et al. 2014), and climate change beliefs (Zia and Todd 2010). Furthermore, we group mental models by region into regional mental models to examine "collective knowledge and understanding of a particular domain held by a specific population of individuals" (Hoffman et al. 2014:13016).

Study site descriptions

Rotorua and Taupo, NZ and Vermont, USA have each implemented agricultural NPS pollution policy that regulates nutrient loss from farms. The three regions are agriculturally dominated landscapes that have seen recent agricultural intensification associated with decreases in water quality (Rutherford et al. 1989, Mcdowell et al. 2009, Quinn et al. 2009, Smeltzer et al. 2012, Smeltzer 2015; see Fig. 1). Note that in Figure 1 we show one watershed in Vermont, the Missisquoi watershed to represent land use in Vermont at a similar scale to Taupo and Rotorua, but the policy in Vermont is state-wide and therefore at a much larger scale. Table 1 gives a description of each of the three case study regions using the high-level SES categories.

Taupo, NZ

The Lake Taupo watershed, on NZ's North Island, is dominated by pastoral agriculture, with approximately 113 sheep and cattle farms and seven dairies, and has a spatial extent of 2865 km² (J. Palmer 2020, WRC, *personal communication*). Approximately 19% of the Taupo watershed is in pastoral agriculture, 23% is in forestry, 56% is indigenous vegetation or undeveloped land, and 2% is in developed land uses (Barnes and Young 2012). With declining water quality, the Waikato Regional Council proposed "Variation No. 5" of the Waikato Regional Plan in 2005 to clean up Lake Taupo (WRC 2011*a*). The policy, which became operational in 2011, is a performance-based cap-and-trade program for nitrogen. Under the policy, farm nitrogen leaching was capped at historical levels. Each farm was allocated a nitrogen discharge allowance based on their highest modeled annual nitrogen loss between 2001 and 2005 (WRC 2011*a*). A public fund managed by the Lake Taupo Protection Trust was established to permanently reduce nitrogen losses in the watershed by 20% and achieve the environmental goal of restoring the lake to 2001 water quality levels by 2080. The NZD$80 million endowment to the Trust was an equal contribution from local, regional, and national government (Kerr et al. 2015). Additionally, a nitrogen market was established to provide flexibility to farmers in how they met their regulated individual discharge allowance while also achieving the overall basin cap. Farms are monitored annually to ensure compliance with their nitrogen discharge allowance and pay an annual fee (WRC 2011*b*).

Rotorua, NZ

Lake Rotorua watershed is located about 80 km northeast of Lake Taupo and is also dominated by pastoral agriculture, but more concentrated: the watershed features 407 farms, including 107 dairies, and has a spatial extent of 500 km² (The Rotorua Lakes Protection and Restoration Action Programme 2009; D. Smeaton 2020, *personal communication*). Approximately 42% of the Lake Rotorua watershed is in pastoral agriculture, 18% is in forestry, 21% is indigenous vegetation, and 19% is in developed land uses

Table 1. Social-ecological system description of the three case study regions.

Case study policy regions	Taupo, Waikato Region, New Zealand	Rotorua, Bay of Plenty Region, New Zealand	Vermont, United States
Resource units	Nitrogen	Nitrogen	Phosphorus
Resource system	Mostly extensive pasture-based beef and sheep farms with some dairy operations	Mixture of pasture-based dairy operations and sheep and beef operations	Mixture of full and semiconfinement dairy, semiconfinement cattle, vegetable, and other diversified farm systems
Governance System	Variation 5 of the regional plan: performance-based cap-and-trade	Rule 11 and Proposed Plan Change 10 of the regional plan: performance-based cap-and-trade	Act 64 and the Required Agricultural Practices: practice-based regulation
Users	Farmers	Farmers	Farmers
Social, economic, political setting	• No subsidies for agriculture (Quinn et al. 2009) • International export-based market (Quinn et al. 2009) • Public pressure on agriculture, and dairy in particular, to reduce water quality impacts (Holland 2015) • National Policy Statement for Freshwater in 2011/2014 mandates water quality limits across country by 2025 (MftE 2014[†]) • Taupo was the first nonpoint source (NPS) trading program in the world (Kerr et al. 2015)	• No subsidies for agriculture (Quinn et al. 2009) • International export-based market (Quinn et al. 2009) • Public pressure on agriculture, and dairy in particular, to reduce water quality impacts (Holland 2015) • National Policy Statement for Freshwater in 2011/2014 mandates water quality limits across country by 2025 (MftE 2014) • Rotorua early adopter of water quality regulation for agricultural NPS (behind Taupo and some other regions)	• Many agricultural subsidies, including incentives and programs to adopt conservation practices (McDowell et al. 2016) • Most agricultural products are sold out of state, with less exposure to international markets than NZ farmers (Wironen et al. 2018) • Public finger pointing at dairy as the problem for water quality in Lake Champlain and other waterbodies throughout the state (Smith et al. 2008, Flagg 2015)

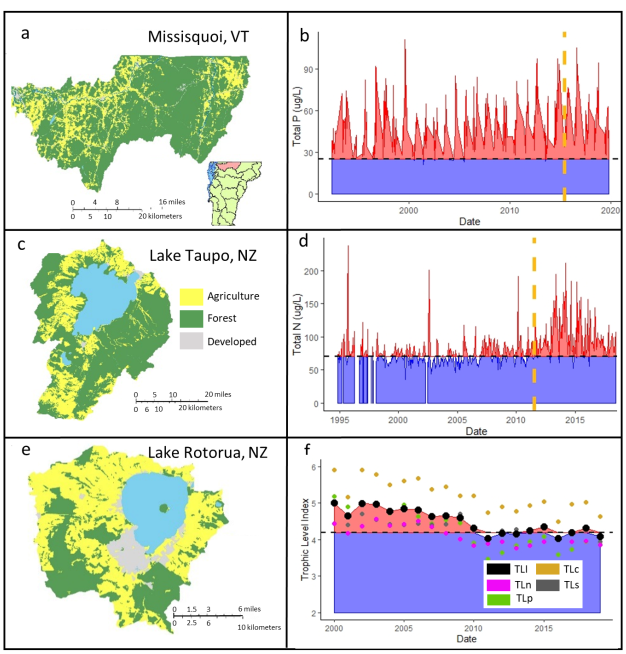
[†] The National Policy Statement for Freshwater Management was further amended in 2017 but at the time of the interviews only the 2014 version of the National Policy Statement was in effect.

(BOPRC 2016). With declining water quality in the Rotorua Lakes, the Bay of Plenty regional council passed Rule 11 of the region's Water and Land Plan in 2005. The water quality goal in the plan is based on the Trophic Level Index (TLI), a composite index comprising total nitrogen, total phosphorous, chlorophyll *a*, and Secchi depth (Burns et al. 2009). The target TLI for the watershed is 4.2. Reductions in total nitrogen and total phosphorous loads to the lake are needed to achieve this TLI. Rule 11 put a "line in the sand" and capped farm nitrogen and phosphorous discharges at their current levels. Further rules, the focus of this study, Proposed Plan Change 10 (to the Bay of Plenty Regional Natural Resources Plan), were notified in February 2016. These rules managed activities that contribute nitrogen to Lake Rotorua with an aim to reduce the overall amount of nitrogen leaching in the watershed from its current load of 755 tN/yr to its sustainable load of 435 tN/yr (BOPRC 2016). As of August 2020, the rules are still not yet operational, but will likely be in late 2020. Proposed Plan Change 10 is a performance-based cap-and-trade program for nitrogen and includes a nitrogen discharge allowance for each farm. An incentive scheme complements Plan Change 10, which features a NZD$40 million fund set up to buy nitrogen off landowners who want to permanently lower their nitrogen discharge. The goal of the scheme is to purchase 100 tN by 2022, which is 13% of the current watershed N load (Rotorua Te Arawa Lakes Programme 2014). Unlike Taupo, Rotorua farmers must make mandatory reductions in their nitrogen leaching rates to achieve an additional 140 tN reduction.

Vermont, USA

The state of Vermont is located in the northeastern USA on the border with Canada and has a spatial extent of 23,871 km² (U.S. Census Bureau 2010). Vermont's water quality policy is state-wide, but it was motivated by the phosphorus-driven eutrophication of Lake Champlain. Water quality in Lake Champlain has been on the decline for decades because of agricultural intensification and urban development (USEPA 2016). Vermont's agricultural industry includes over 6500 farms, made up of dairy, cattle, and vegetable farms, with over 800 dairy farms dominating agricultural land use and economic output (VDPC 2015, USDA-NASS 2017). Approximately 20% of Vermont is in agriculture, 78% is in forestry, and 2% is in developed land uses (University of Vermont Spatial Analysis Laboratory 2019). In 2015, the Vermont legislature passed Act 64, which requires farms to comply with the Required Agricultural Practices (RAPs) to reduce phosphorus runoff from farms (VGA. 2015). The RAPs include mandatory practices, such as writing nutrient management plans, cover crop requirements for highly erodible soils, manure spreading bans, and 25 foot (7.5 meter) buffers between farm fields and surface waters (VAAFM 2018). Under the new rules, farms were required to register with the state, pay

Fig. 1. Land use maps and water quality trends in Missisquoi watershed, Vermont, Lake Taupo, and Lake Rotorua watersheds. Figures (a), (c), and (e) shows land use split between agriculture, forest, and developed land in (a) Missisquoi watershed, Vermont (Multi-Resolution Land Characteristics Consortium 2016), (c) Lake Taupo watershed, New Zealand, and (e) Lake Rotorua watershed, New Zealand (Landcare Research New Zealand Ltd 2015). Note that the Vermont policy is implemented at the state level across all watersheds (see subset of Vermont state in Figure a), but for the purpose of land use, we show one Vermont watershed, the Missisquoi, here at a similar scale to the Taupo and Rotorua watersheds. Figures b, d, and f show corresponding long-term water quality trends, by the regionally relevant management metric, in (b) Missisquoi watershed, Vermont (Vermont Department of Environmental Conservation 2020), (d) Lake Taupo watershed, New Zealand (Verburg and Albert 2019), and (f) Lake Rotorua watershed, New Zealand (BOPRC 2020). The black dashed lines represent upper water quality thresholds for desired water quality, with the red portion of the plot representing the water quality above the threshold (BOPRC 2018, LCBP 2018, WRC 2011). Note that plot (b) is total phosphorus, the nutrient of concern in Vermont, plot (d) is total nitrogen, the nutrient of concern in Lake Taupo, and plot (f) is the Trophic Level Index (TLI) in the large black points for Lake Rotorua. Lake Rotorua manages to the TLI, a composite measure of total nitrogen (TLn), total phosphorus (TLp), secchi depth (TLs), and chlorophyll *a* (TLc), with each of these converted to the same scale via the trophic level equation. The gold lines represent the date at which policy in each region became operational, as the Rotorua policy is not yet operational, there is no gold line in plot (f).



an annual fee, and are monitored for compliance with the RAPs. Monitoring frequency is dependent on farm size: every year for large farms (> 700 dairy cows or equivalent, e.g., 1000 beef cattle), every three years for medium size farms (< 700 and > 200 dairy cows or equivalent), and every seven years for small farms (< 200 dairy cows or equivalent) (VAAFM [date unknown]).

METHODS

Data collection

We completed a total of 38 semistructured interviews with farmers in Vermont and NZ (Table 2) between 2016 and 2018. The number of interviews in each region is fairly balanced, but the number of farmers interviewed in Vermont represents a much smaller proportion Vermont's farming population compared to the NZ samples. An interview protocol was used as a basis for the semistructured interviews, which included questions about the farm system, nutrient management changes, drivers of changes, and perceptions of the broader water quality and policy in the watershed (see Appendix Table A1.1 for interview protocol). Interviews ranged between 30 minutes and 3 hours, and each was recorded and transcribed. This study received exempt certification from the University of Vermont's Institutional Review Board.

Farmer participants were selected using maximum variation sampling to purposely interview participants that represented a diversity of farm types and sizes (Collins 2010). We identified an initial list of potential participants in each region with assistance from agricultural extension agents and regional government employees. We then used snowball sampling to recruit additional participants and, in Vermont only, recruited via a government agriculture newsletter and the Vermont Farm Bureau. By farm size, the sample is skewed toward smaller farms in Vermont, which is representative of farm size distribution across the state (USDA-NASS 2017). Alternatively, farm size distribution in the Taupo and Rotorua samples is skewed toward larger farm sizes, according to Vermont's size definitions as noted below Table 2. This, however, is only meant to be used as a point of comparison because in general, NZ's farms are larger than Vermont's. The average number of dairy cows on a farm in Vermont is 155 (VDPC 2015), whereas the average number of dairy cows on a farm on the North Island of NZ is 352 cows (LIC and DairyNZ 2018).

Data analysis

Content analysis

Interview transcripts were analyzed using directed, i.e., theory-driven, qualitative content analysis (Hsieh and Shannon 2005) in NVivo 12 (QSR International Pty Ltd 2018), followed by network analysis to identify themes (Pokorny et al. 2018). We used Delgado-Serrano and Ramos's (2015) definition of the SES framework as a starting point for the content analysis. We also allowed for subcategories to emerge in the coding process. See Appendix Table A1.2 for the full codebook used in the analysis.

To capture farmers' nutrient management behavior as an indicator of institutional fit between the aims of the policy and the behavioral actions needed to achieve those aims, we coded any self-reported change in nutrient management in the last 5–10 years or planned changes to occur in the next two years. We categorized nutrient management behavior into one of three categories: management, structural, or system changes (Table 3).

Table 2. Interview sample across regional policy contexts

Farmers interviewed	All	Region		
		Vermont	Taupo	Rotorua
Total	38	16	11	11
By farm type				
Dairy	23	11	3	9
Beef, sheep, or deer	14	4	8	2
Vegetable	1	1	0	0
By farm size[†]				
> 200 dairy cows or equivalent	11	11	0	0
< 700 and > 200 dairy cows or equivalent	12	4	4	4
> 700 dairy cows or equivalent	15	1	7	7

[†]Farm size categories are based on Vermont's designation (VAAFM [date unknown]). Dairy cow equivalents refer to the equivalent of other species in the units of dairy cows, for example, 700 dairy cows is equivalent to 1000 beef cattle. New Zealand farm size designations are typically reported in hectares. Because animal units were recorded in the interviews, it serves as a common unit of comparison.

These categories reflect a spectrum in capital expense and time commitment required to make the changes, as well as the reversibility of the changes, e.g., management changes are generally less capital/time intensive and more reversible compared to structural, and structural less than system. The spectrum also captures variation in the potential reduction in nutrient losses that one would expect to see from a nutrient management change.

As noted in Table 1, the case study sites differ in their focal nutrient of concern, i.e., Vermont's rules address phosphorus and NZ's rules address nitrogen. Differences in nutrient cycles have implications for management: phosphorus's main transport pathway off a farm is through runoff via soil erosion and overland water flow, whereas nitrogen's is through leaching into groundwater and subsurface flow (Carpenter et al. 1998, Mcdowell et al. 2009). The categorization of behaviors shown in Table 3 was designed to capture a range of behaviors appropriate for both nitrogen and phosphorus management. Additionally, we would expect the trends in capital investment, reversibility, and potential nutrient reduction associated with the different categories of nutrient management changes to hold true regardless of nutrient.

Regional mental model network analysis

We grouped interviews by region and used NVivo 12's matrix query tool to export three regional aggregate, weighted, nondirectional adjacency matrices. Following methods adapted from Hoffman et al. (2014) and Pokorny et al. (2018), adjacency matrices for each region were imported into R version 3.5.1 (R Core Team 2018) and analyzed as regional mental model network graphs using the igraph package (Csardi and Nepusz 2006). The adjacency matrices report the co-occurrence of drivers, behaviors, and outcomes in the grouped interviews for a region. In the aggregate matrices for each region each node represents a concept, i.e., SES driver, behavior, or outcome, the link between them represents a connection between those concepts, and the weight of the link represents the number of participants in a region who made a connection between the two concepts.

Regional mental model networks were analyzed using network node statistics: occurrence probability and strength. The occurrence probability of a node represents the likelihood that a node is included in the network, and therefore the extent to which a node resonates across a regional sample. It is calculated as the ratio of farmers that mentioned the node to the total number of farmers in a region's sample (Hoffman et al. 2014). Strength reflects both the breadth and prominence of a node, combining the occurrence probability and the number of nodes that a node is connected to, i.e., the "degree," in a single metric: the sum of the weights of links for all links connected to a node (Csardi and Nepusz 2006). Finally, to examine which SES subcategories were most influential in driving nutrient management behavior, we analyzed a subset graph with only drivers and behaviors, i.e., no outcomes. In this subset graph, we ranked drivers in each region by node strength. The network visualizations for each of the three regions are in Appendix Figures A1.1 to Figure A1.6.

RESULTS

Behavior changes

Farmers across all regions reported making behavioral changes to decrease nutrient loss on their farms. On average, farmers in Vermont made 5.8 behavioral changes each, farmers in Taupo made 4.6 behavioral changes each, and farmers in Rotorua made 3.6 behavioral changes each (Table 4). Farmers across all three regions made management changes, but Taupo farmers favored system changes (versus structural changes), whereas Vermont farmers favored structural changes. Rotorua farmers did not show a preference for structural versus system changes.

Some behaviors are specific to each region and agricultural systems. These practices include soil sampling (VT), no-till (VT), manure spreading (VT), installing a new barn or updating barn structures to mitigate runoff (VT), and grazing animals off pasture or farm for a period time to reduce nutrient leaching (NZ).

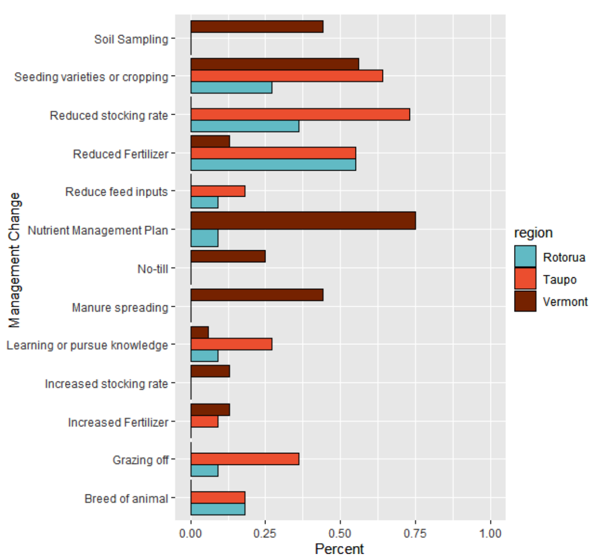
Table 3. Categories of nutrient management behavior changes on farms.

Category	Definition	Examples of changes in category
Management	Changes to crop or animal types, plus practices related to soil and animal management	Includes changes in timing and amount of fertilizer applied, changes in the cropping rotation, stocking rate of animals, type and amount of animal feed, and grazing animals on or off farm.†
Structural	Farm physical or infrastructure changes	Includes edge-of-field and riparian buffers, stock exclusion from waterways, new milking parlor, new effluent system, water retention bunds, and animal stand-off pads.
System	Change in overall farm dynamics, including type of product and expansion or contraction of land base	Includes transition in farm type, e.g., between dairy, beef, and sheep, sheep milking, and forestry, transition to organic or grass-based system, land retirement, purchase of new land, and sale of land.

†Grazing animals on or off the farm involves moving animals in order to protect wet pasture from damage.

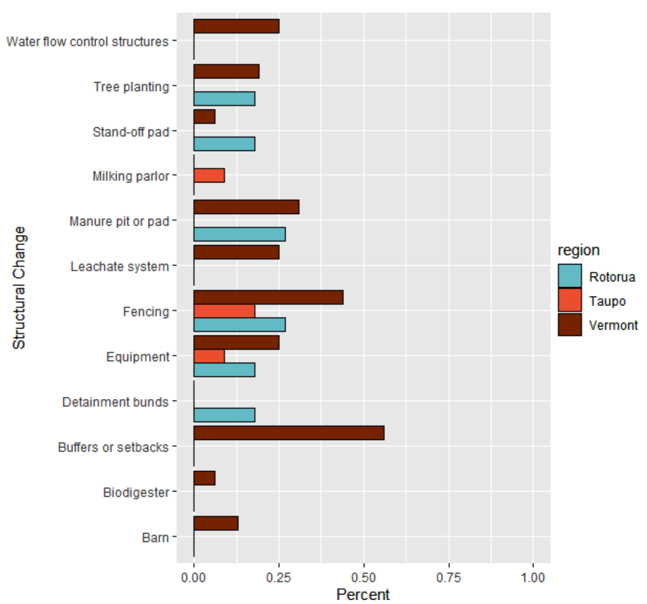
Management changes
The top two management change categories for all three regions were seeding varieties/cropping changes and fertilizer changes (Fig. 2). Reduced animal stocking rate was a relatively common management change in Taupo and Rotorua, but no farmers in Vermont reduced their animal numbers. Only Vermont farmers and one Rotorua farmer started nutrient management planning and soil sampling. Across all three regions a small number of farmers engaged in pursuing nutrient management knowledge. All of the behaviors noted thus far would be considered behaviors that would be expected to reduce farm nutrient losses. However, there were two categories of behavior reported where nutrient losses would be expected to increase: increased fertilizer use and increased stocking rate. In Taupo and Vermont, one and two farms respectively increased fertilizer use, and two farms in Vermont also increased their stocking rate, i.e., the number of animal units on their farm.

Fig. 2. Percentage of sample reporting management changes by region.



Structural changes
Vermont farmers made the most structural changes on average (Fig. 3). The structural changes in common across the three regions were fencing and purchasing new equipment, e.g., more efficient irrigator. The top structural changes for Vermont were buffers and setbacks, manure pit or pad upgrades, leachate systems, and water flow control structures. In Rotorua, manure pits or pad upgrades were the top structural change. In Taupo, relatively few structural changes were made, but the few included milking parlor upgrades, equipment upgrade, and fencing.

Fig. 3. Percentage of sample reporting structural changes by region.



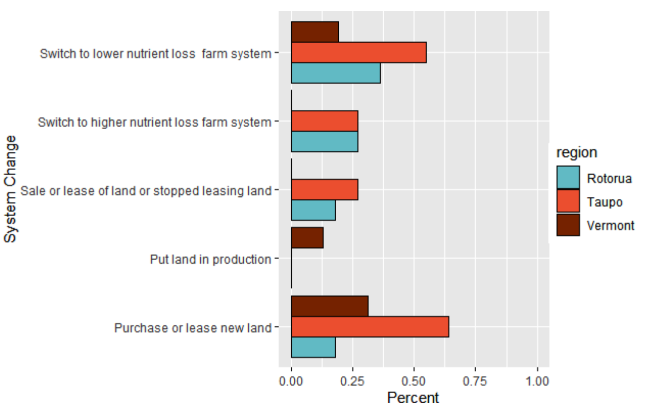
System changes
The top system changes across all three regions were switching to a lower nutrient loss farm system and the purchase or lease of new land (Fig. 4). In Vermont, three farms transitioned to systems with lower nutrient losses, i.e., grass-fed or organic dairies. In

Table 4. Count of nutrient management changes and average number of behavior changes per person by region.

Behavior change	Vermont (n = 16)		Taupo (n = 11)		Rotorua (n = 11)	
	Count	Average (std. dev.)	Count	Average (std. dev.)	Count	Average (std. dev.)
Management changes	46	2.9 (1.0)	33	3.0 (1.8)	19	1.7 (1.4)
Structural changes	40	2.5 (1.7)	4	0.4 (0.6)	14	1.3 (1.2)
System changes	10	0.6 (0.7)	19	1.7 (0.6)	11	1.0 (1.0)
Total changes	93	5.8 (2.5)	50	4.6 (1.5)	40	3.6 (1.9)

Rotorua, four farms were converted to forestry or transitioned from dairy to sheep and beef cattle grazing. Finally, in Taupo, six farms converted to exotic forestry (pine) or native forest or transitioned from dairy support or cattle breeding systems to beef finishing systems. Taupo and Rotorua farmers reported some land was sold or no longer being leased, but Vermont farmers did not. Although it should be noted that two of the three farmers who sold farm land in Taupo also purchased other farm land in the watershed. So, these farmers did not exit farming in the watershed. Importantly, there were three instances in Taupo and Rotorua where farmers shifted to a higher nutrient leaching farm system, including transitions to dairy, sheep milking, and cattle breeding operations. Similarly, in Vermont there were two cases in which a farmer transitioned from forestry into agricultural production.

Fig. 4. Percentage of sample reporting system changes by region.



Behavioral drivers

Overall, Taupo and Vermont farmers referenced 19 different SES subcategories as behavioral drivers, whereas Rotorua farmers referenced 16 (see Appendix 1 Table A1.3 and Table A1.4 for all driver node statistics). Not all SES subcategory drivers were present in each of the regions. However, in general, farmers in each region referenced many of the same drivers (Table 5). We define key drivers as those drivers that ranked in the top five drivers by strength in at least one region.

Governance drivers

Water quality policy is the top ranked behavior driver in Taupo and Rotorua, and the second in Vermont. In both Taupo and Rotorua, the occurrence probability is 100%: every farmer interviewed referenced water quality policy as a driver of behavior. In Vermont, there was also a very high occurrence probability of 94%. The following three quotes, one from each region, demonstrate the influence of each region's water quality policy on behavior:

> *Some of my land, I'm on the early spreading ban. Due to the new Required Agricultural Practices, I got to hit them [with manure spreading] in the midsummer, so we're changing the way we got to do things, a little bit. We'll see in a few years. Hopefully, it'll benefit.* Vermont Farmer

> *But when Rule 11 came in ... we [got rid of] 230 cows and 2 full time jobs. That was a result of [the water quality policy] because we were leasing land. We were leasing land and then with the [the water quality policy] we needed to get out of the catchment, which we've done*. Rotorua Farmer

> *We bought the farm and farmed it for a couple of years and through [the] consultation process, it was pretty obvious that it was going to be capped, and it might be worse than that, we weren't sure what was going to come out of that ... So we decided after a lot of soul-searching that we would sell*. Taupo Farmer

In Vermont, instead of water quality policy, government agency assistance had the highest strength rating and an occurrence probability of 88%. In Rotorua, government agency assistance was also relatively influential, ranked fourth amongst drivers with an occurrence probability of 45%, however, in Taupo, it ranked 10th, with an occurrence probability of only 18%. Farmers in Vermont reported government agency assistance mainly from the U.S. Department of Agriculture's (USDA) Natural Resources and Conservation Service (NRCS) programs that give financial assistance for adopting, upgrading, or installing new practices/structures on the farm, as well as technical assistance. In Rotorua, farmers referenced some financial assistance from the Regional Council to install physical structures on their farms such as fencing or water detainment berms, as well as funding to write farm management plans. The following quote represents the strong influence that NRCS played in driving behavior change for many Vermont farmers in the sample:

> *So, [the NRCS agent] just stopped in one day and they're nonregulatory. It was just a total social visit and I said, "Well, I've got some concerns" ... So, he really listened to me and said, "Yeah, let's go for it. Let's do it." So,*

> *[the USDA NRCS' Environmental Quality Incentives Program] project is maxed out at $250,000.00 at the time. Well, we maxed it out.* Vermont Farmer

NGOs and other organizations ranked third amongst behavioral drivers in Vermont, sixth in Rotorua, and 11th in Taupo. Seventy-five percent of farmers in Vermont referenced technical assistance from the University of Vermont (UVM) agricultural extension and organic certification programs, or financial assistance from watershed programs and land trusts. One Vermont farmer noted a sentiment about UVM Extension, which was shared by many in the Vermont sample: "They're really, really helpful." In Rotorua, only 36% of farmers cited NGOs and other organizations as drivers, but they included similar categories of organizations, such as land trusts, research organizations like AgResearch, and industry extension like DairyNZ. The other two governance nodes, other government policies and participation in a farmer group, were not listed in the top five of behavioral drivers in any region.

Actor drivers
Actor economics was an important driver across all three regions. This driver represents a farm or farmer's economic situation as opposed to broader market considerations like price. Aside from actor economics, no other actor subcategory drivers were listed amongst the top five behavioral drivers in any region. These other actor drivers include ethics, flexibility, leadership or entrepreneur, lifestyle, past experience, social attributes, and technology.

Actor economics, in terms of node strength, ranked second in Taupo with a 91% occurrence probability, second in Rotorua with a 64% occurrence probability, and fifth in Vermont with a 50% occurrence probability. Actor economic drivers were phrased in similar language across all three regions. One Vermont farmer, while describing a transition from forested land into agricultural land, said, "the biggest driver is getting the most out of every dollar." In Rotorua, when explaining reduced use of nitrogen fertilizer, a farmer stated, "it was just around maximizing profit." Finally, in Taupo, one farmer described their reason for leasing out their land as "money, money, and money."

Resource system and resource unit drivers
Ecological drivers, such as drought, flooding, and erosion, were ranked as top five drivers across all three regions. In Rotorua ecological drivers were ranked third, including protecting native species, minimizing runoff, and reducing erosion. In Vermont, ecological drivers were ranked fourth including soil health, minimizing runoff, stabilizing streambanks, concerns over water quality, and controlling erodible soils. Last, In Taupo, ecological drivers were ranked fifth, with many farmers referencing the influence of multiple years of drought. Farm production needs were not listed as a key behavioral driver in any of the three regions.

Nitrogen and phosphorus attributes were ranked relatively higher in Rotorua (fifth) and Taupo (eighth) than Vermont (12th). Only one farmer interviewed in Vermont referenced attributes of phosphorus as driving behavior, i.e., the specifics of nutrient cycling. In contrast, a small subset of farmers in Rotorua and Taupo cited a sophisticated understanding of nutrient dynamics as driving behavior change.

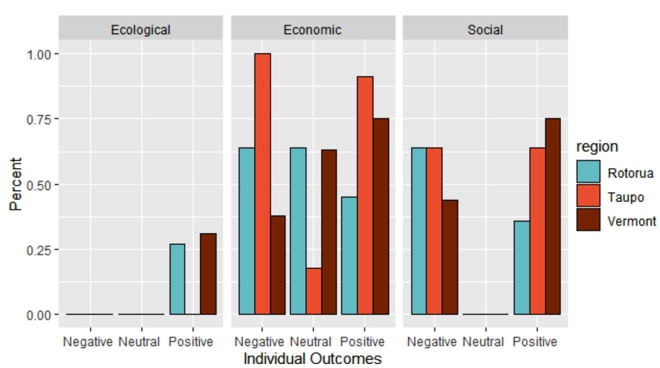
Social, economic, and political setting drivers
The nitrogen market subcategory was very influential in Taupo. This code was specific to the existing voluntary nitrogen market in Taupo that was established as a part of the water quality policy. The nitrogen market is ranked third as a behavioral driver in Taupo, with an occurrence probability of 82%. One farmer in Rotorua referenced concrete plans to sell nitrogen in the newly formed nitrogen market in Rotorua. There is no current market for nitrogen or phosphorus in Vermont.

Broader economic and market drivers, such as price, market access, and competition were ranked fourth as a behavioral driver in Taupo and eighth in Vermont and Rotorua. The other four drivers in this category, including social context, industry, or consultant advice, demographic shifts, and carbon market, were ranked relatively low across the three regions.

Outcomes

Individual outcomes
At the individual level, Taupo farmers reported more negative and as well as more positive economic outcomes on average than Rotorua and Vermont farmers in the sample (see Fig. 5). Across the regions these included compliance costs, farm viability, financial impacts, and impacts to farm economic flexibility. One Vermont farmer referenced a negative financial impact related to requirements under the water quality policy, when they said, "The biggest problem I have is we have to put a leachate system in. Ugh. It's an $81,000 project, which I don't think is even needed," but later clarified that they wouldn't pay the full cost of the project. Some positive outcomes included improved farm viability, beneficial financial impacts, better farm economic flexibility, and access to new markets. One Taupo farmer said, "To me it's been a windfall. We bought land cheaper. We made some very clever smart moves, so it's opened up huge opportunities for me as a person." Several farmers in Vermont and Rotorua mentioned that the water quality policy had neutral impact compliance costs for their farm.

Fig. 5. Percentage individual outcomes by region.



In terms of individual social outcomes, Vermont farmers on average reported more positive outcomes than Taupo and Rotorua and fewer negative outcomes than Taupo and Rotorua. Farmers reported increased knowledge and awareness, nonfinancial benefits such as pride, and recognition for environmental stewardship. For negative individual social outcomes, farmers mentioned distrust in regulation, nonfinancial

Table 5. Key behavioral driver node statistics. Key drivers are those that are ranked by strength in the top five of drivers in at least one of the three regions. Lack of statistics for a node in a region means that a node was not mentioned in the region.

	Node description	Node statistics	Taupo	Vermont	Rotorua
Water quality policy (governance)	The specific water quality policy in each region (i.e., Taupo's Variation 5, Vermont's Act 64 and the RAPs, and Rotorua's Rule 11 and Proposed Plan Change 10)	Rank	1	2	1
		Strength	88	58	42
		Occurrence probability	100%	94%	100%
Government assistance (governance)	Technical or financial assistance from a government agency/entity	Rank	10	1	4
		Strength	9	74	14
		Occurrence probability	18%	88%	45%
Economics (actor)	Microeconomic considerations tied to a farm or farmer's economic situation, e.g., income, debt, and economic efficiency of farm	Rank	2	5	25
		Strength	49	21	2
		Occurrence probability	91%	50%	64%
Ecological (resource system)	Existence, mitigation, or prevention of erosion, runoff, drought, flooding, etc.	Rank	5	4	3
		Strength	31	31	17
		Occurrence probability	45%	44%	55%
Nitrogen market (social, economic, political setting)	Purchase or sale of nitrogen in Taupo's nitrogen market or future purchase or sale in Rotorua's nitrogen market	Rank	3	-	10
		Strength	42	-	2
		Occurrence probability	82%	-	9%
NGOs or other organizations (governance)	Interactions with nongovernmental entities including extension, watershed programs, land trusts, and research organizations, and universities	Rank	11	3	9
		Strength	7	48	6
		Occurrence probability	9%	75%	36%
Economics and markets (social, economic, political setting)	Macroeconomic and market dynamics including prices, market access, and competition	Rank	4	8	8
		Strength	40	9	5
		Occurrence probability	82%	44%	9%
Nitrogen and phosphorus attributes (resource units)	Attributes of nitrogen and phosphorus and the movement of these nutrients in the landscape and farm system	Rank	8	12	5
		Strength	16	2	11
		Occurrence probability	27%	6%	27%

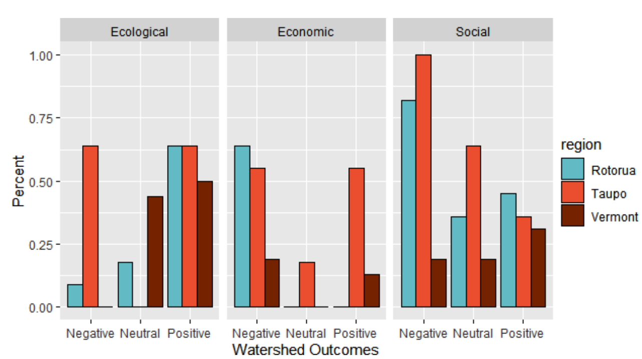
costs like time, stress, and mental health impacts, uncertainty in the future of their farming livelihoods, and a few farmers in Rotorua mentioned feeling like they were unfairly impacted by the water quality policy at a personal level.

No negative ecological outcomes at the farm scale were reported in any region as a result of their behavior changes or the water quality policy. However, a few farmers in Vermont and Rotorua, but not Taupo, referenced positive ecological change on their farms in terms of pasture or soil quality, and water quality.

Vermont watershed outcomes

Vermont farmers generally perceived more positive and neutral watershed level outcomes than negative (see Fig. 6 for comparison across regions). Vermont farmers mentioned increased community awareness, community well-being, and fairness as positive social outcomes, but few reported negative community well-being. One farmer described the impact of the water quality policy on a neighbor: "And, I think it's too bad. He gets really upset about it. He's done a really good job farming all his life ... they're basically forcing him out of business." Only a few Vermont farmers noted negative or positive economic impacts. On the negative side farmers cited challenges to the agricultural community operating with regulation and low product prices, while on the positive side farmers cited financial viability with cost share assistance and flexibility in the water quality policy regulations.

Fig. 6. Percentage watershed outcomes by region.



Eight Vermont farmers perceived positive watershed ecological outcomes, seven neutral, and none mentioned negative ecological outcomes. Vermont farmers in the sample appeared split as to whether management changes were being made, and some farmers said they do not see changes. One Vermont farmer said, "I go by some of the other farms that do some of the things they do, I go, "What the heck? How do they get away with that?"" Other farmers were optimistic in their outlook for water quality improvements from land use changes. Another Vermont farmer said, "I see the bigger farms, a lot of them are doing cover crops where they never did before." Most of Vermont farmers' ecological outcome reflections related to farming management changes on the landscape and not broader land use changes.

Taupo watershed outcomes
In the Lake Taupo watershed, farmers' perceptions were polarized, with high numbers of positive and negative outcomes. Socially, every farmer mentioned at least one negative outcome of the water quality policy, mostly in terms of fairness of the policy or community well-being. Reflecting on the policy process, one farmer said the "uncertainty emotionally and mentally [was] shocking ... a lot of farmers were depressed because they didn't see a lot of hope." Many farmers mentioned other farmers selling their farm and leaving the catchment during the policy process. For the large number of comparatively underdeveloped, relatively low-nitrogen leaching Māori farms in the catchment, farmers expressed that the policy was unfair. Except for freehold land purchased by Māori individuals, Māori generally cannot sell land. One farmer said: "And being a lot of Māori-owned land they went overly heavy about it because it sort of hindered what they could do with their land further down the track." Neutral watershed social perceptions included acceptance of the policy, a desire to "just get on with it." Positive social outcomes included the flexibility from allowing nitrogen trading and the ability to sell nitrogen to the trust. Selling nitrogen was seen as a positive outcome for Māori farms because it allowed them to liquidate capital without selling their land.

Perceptions of watershed economic impacts in Taupo varied greatly amongst the farmer sample, with six farmers mentioning positive and negative economic impacts and two neutral. One farmer explained how the policy limits their farm's economic potential: "Essentially, under this process we can't grow any more meat per hectare, our livestock numbers are capped at 2004 levels, and costs inexorably keep growing." Conversely, on the positive side, one farmer said, "the beauty about farming in here is that you've got a resource that comes in for 25 years. Now, I'd argue that there is nowhere in NZ that you've got a license to farm for 25 years."

Taupo farmers were split equally between negative and positive perceptions of the ecological outcomes. Farmers perceived the policy technically as a success, purchasing nitrogen out of the catchment, changing land use to reduce nitrogen leaching, and capping nitrogen in the watershed, and, in some cases, farmers thought the lake was clearing up. However, some farmers reflected negatively upon the fact that new dairy farmers were able to come into the watershed under the policy and intensify by purchasing nitrogen discharge allowances through the market. Additionally, many farmers reflected negatively upon the transition of land from pastoral agricultural to forestry under the water quality policy. As one Taupo farmer reflected, "All that now is getting developed ... That should never ever be put into trees, and it is going to end up having trees. That is wrong."

Rotorua watershed outcomes
In Rotorua, farmers in the sample perceived more positive ecological watershed outcomes, split social impacts and only negative economic impacts of the water quality policy process. Economically, seven farmers reported that the policy process has resulted in a steep decline in investment in farming in the watershed and the perception that "financially, it's not doable" to achieve the nutrient reductions required. Nine farmers perceived negative social impacts at the watershed scale including impacts on community well-being and perceived fairness of the policy. According to one Rotorua farmer, the policy process has been emotionally difficult: "So, I think - but it's like grievance; this - this phase is the angry phase, and then acceptance might come because that's what happened ... in the Taupo catchment like I say." Rotorua farmers reported that the policy is unfair toward farmers and that the urban share of the burden is being overlooked. Furthermore, Rotorua farmers expressed frustration that previous actions to reduce phosphorus runoff they have undertaken voluntarily have not been given enough credit under the new policy, i.e., because the policy focuses on nitrogen reduction. Four farmers noted positive social outcomes while another four farmers noted negative social outcomes. One farmer said that as a result of the policy community awareness and well-being has risen: "I think that probably the biggest plus out of it is actually talking to your neighbor, and working with your neighbor, and seeing what they're doing."

Seven Rotorua farmers perceived positive ecological outcomes, with two neutral and just one negative. On the positive side, one farmer suggested that the policy halted further land use intensification: "there might have been a few more farms convert to dairy ... had [the water quality policy] not been there." In some cases, farmers reported that "most farmers have done small changes to improve areas" whereas others perceived that "the land use change in the catchment, has been minor." Although a number of Rotorua farmers noted positive ecological outcomes, similar to Vermont, the outcomes focused on management changes, not land use change.

DISCUSSION

Behavioral patterns and institutional fit
Farmers in the sample reported changing nutrient management behavior mostly to reduce nutrient losses from farms, i.e., intended direction of the policy, and the actions of these farmers are expected to improve water quality over time to meet the goals of the policy. This suggests that all three regions demonstrate a reasonable degree of biophysical fit, in which the aim of the policy, i.e., to change farmer behavior to improve nutrient outcomes, is resulting in the human actions desired. However, we do see important differences in the types of behaviors enacted under the different rule structures, which are likely to have differential impacts on water quality improvement.

First, management changes are the clear low-hanging fruit. Management changes are relatively inexpensive, more reversible, and do not necessarily require major time or financial investments. If perceived as ineffective in the short-term, e.g., because of the slow ecological pace of water quality improvement, these behaviors could be easily reversed. Therefore management changes do not provide strong assurance for long-term water quality impacts. As a consequence, it is not surprising that farmers across all three regions reported a number of management changes.

There are markedly different patterns in structural and system changes between the regions that are likely to have implications for biophysical fit due to differential water quality. Farmers reported more structural changes in Vermont and more system changes in NZ, whereas in Rotorua, farmers reported lower levels of both. In most cases, structural changes adjust nutrient movement pathways on the farm rather than the overall amount of nutrients used, e.g., fertilizer use, feed use, and/or animal numbers. System changes, as we see dominating in Taupo, conversely, typically impact the overall quantity of nutrients used on the farm through changing the amount required for farm production needs. Thus, it is likely that system changes represent a greater potential for reducing nutrient losses and for improved biophysical fit for the policy. Although we hypothesize there is a differential impact of these behaviors on nutrient load, ultimately this is an area where further research is needed to better understand the relationship between these structural and system changes and water quality improvements in each specific biophysical context.

Interplay of water quality policy with the SES in the regional mental models

Through examining drivers and outcomes, we find differences in the interplay between the policy and the SES context in each region's mental models. These differences are likely driving the dominance of structural versus system changes in Taupo and Vermont, as well as have implications for the social fit of the policy.

Vermont farmers described an incentive-based SES context that supports farmers with financial and technical assistance to adopt new structural practices with a regulatory backstop. Vermont's policy takes advantage of the path dependence of the cost-sharing approach to conservation in USA agri-environmental policy: the policy adds a regulatory mechanism that requires change, but still allows for financial assistance to farmers in changing behavior. In this sense, the policy is, as Ekstrom and Young (2009) state, "benefit[ing] from [the] stickiness" of pre-existing institutions, rather than working against them. Notably, because of this strong interplay, Vermont is the only region in which the water quality policy is not reported as the main driver of behavior. The design of the practice-based policy, requiring specific practices on farms, also aligns with the program structure of NRCS and other programs that pay farmers to adopt conservation practices. We hypothesize that this is the reason for very few farm system changes in the Vermont sample. Further, the heavy role of incentives in the SES context shapes the outcomes for farmers with very few negative social and economic impacts noted, alluding to high degree of social fit. However, farmers expressed mixed perceptions about whether the policy is actually having an effect ecologically and leading to long-term water quality improvements. This suggests that the policy may be trading off short-term social fit for long term biophysical fit. This may also be a symptom of broader issue of spatial fit (Galaz et al. 2008) in the Vermont policy: without farm-scale nutrient limits, there is no direct link in responsibility between the water quality at the watershed scale and individual farm contributions, making it difficult to enable and enforce systemic changes (Vatn and Vedeld 2012).

In Taupo, farmers described polarized experiences at the interplay of regulatory requirements and market dynamics that drive systemic change for the profit of some and marginalization of others. Taupo's policy regulates modeled nutrient reduction rather than the practices that reduce nutrient losses. Within this performance-based policy, structures do not "count" in the policy in the same way they do in Vermont. Furthermore, there are not the programs to assist farmers in purchasing or upgrading infrastructure. To adapt to the nutrient cap, famers in our sample were able to sell nitrogen to the voluntary nitrogen market and used the capital to change their farm system. In Taupo, both actor economics and broader economics and markets are important drivers, reflecting a challenging interplay between regulating nitrogen at the watershed scale and allowing farmers to remain competitive in the global agricultural market (Vatn and Vedeld 2012). This results in two polarized experiences: (1) many farmers are at the margin economically and struggle to offset new risks and exposure and (2) some farmers were able to take great economic advantage of the policy to further improve their economic situation. For many in the first situation, the new policy fostered entrepreneurship and innovation in a way that was not seen in the other two regions. For example, farmers were experimenting with new farm system types, like sheep milking, and new branding/marketing strategies to make up for their inability to intensify their production system. Similarly, Taupo farmers report polarized social impacts suggesting a lower degree of social fit. However, Taupo farmers did reflect some institutional acceptance through a desire to simply "get on with" the new policy.

Finally, in Rotorua, our study captured a time of high uncertainty with a strong policy signal. Rotorua's farmers cited fewer drivers than the other two regions and fewer behavioral changes. However, the water quality policy was reported as the top driver of behavior change in the region, suggesting that even though just a policy signal, i.e., the policy was not yet operational, the proposed rules were perceived as changing behavior. The strength of actor economics in driving management changes reflects that farms are pursuing the "low hanging fruit," while evaluating the potential economic impact of future changes. Like Taupo, this reflects the challenging interplay between global economics and regional nitrogen policy, exacerbated here by the policy uncertainty at the regional scale. Unlike Taupo, the regional council in Rotorua has played a role in providing cost share funding and technical assistance to farms to install some structures, mainly fencing and detainment berms on farms in the past 10 years. However, there is no cost share available for practice adoption under the new policy. As a result, farmers in our sample expressed highly negative social and economic outcomes, alluding to a very low degree of social fit at the time of the interviews. Interestingly, some farmers reported positive ecological outcomes as a result of land management changes, but again like Vermont, these were not perceived as broad landscape changes and therefore likely reflect lower biophysical fit as well.

Opportunities for fit and interplay

Comparing across the three regions, a key takeaway is that farmers needed access to finance or financial assistance to achieve the structural and/or system changes that we hypothesize are associated with higher biophysical fit. In Vermont, farmers used financial assistance to make structural changes, in Taupo farmers sold nitrogen to enable system change, and in Rotorua, without a functioning nitrogen market or extensive financial assistance options, there were much lower levels of structural and system change. Without access to capital, our results suggest that farmers are unlikely to undertake any changes beyond management changes. Water quality policy can take advantage of interplay with pre-existing conservation schemes, like in Vermont, or design new market structures, like in Taupo, to enable structural and system changes.

Ecological drivers across the three regions played a role in nutrient management decisions under the policies. It appears as though an important part of behavior change is the alignment of nutrient management changes with ecological functioning on farm, such as drought tolerance or reducing erosion. This intuitive result can aid in promoting adoption and compliance through highlighting the biophysical fit of the behavior with both the water quality in the watershed and the functioning of the farm system.

Overall, our study presents a novel integration of the SES framework with farmer mental models to contribute four key insights for policy fit and interplay. First, the mandatory water quality rules for farms in the three regions are perceived by farmers as causally changing their behavior, suggesting that there is a fit between each policy and its aims. Second, however, the different rule structures are resulting in different patterns of nutrient management changes on the landscape, which we hypothesize will have implications for biophysical fit and effectiveness of the policy, i.e., water quality improvement, over the long term. Specifically, we hypothesize that system changes, as seen in Taupo, present greater opportunity for long-term water quality improvement as opposed to structural and management changes, and we highlight this as an area for future research. Third, although all three regions have or are implementing mandatory rules, farmers' experience of the outcomes of these policies demonstrate varying degrees of social fit, lowest in Rotorua, highest in Vermont, with some evidence for trade-offs between biophysical and social fit. Finally, the regions are each challenged by different issues of fit and interplay. Interplay with pre-existing institutions is driving behavior in Vermont, but challenging social fit in Taupo and Rotorua, and the overall spatial misfit of Vermont's policy may be driving the potential trade-off in social and biophysical fit.

CONCLUSION

Farmer behavior change is critical to improve water quality and reduce agricultural NPS pollution. In this study, we evaluated farmers' experiences and perceptions in three regions facing mandatory rules to curb agricultural NPS pollution using a novel integration of the SES framework and farmer mental models to assess policy fit and interplay. As more regions consider mandatory water quality rules to address nutrient pollution from farms, our analysis suggests that rule selection should consider (a) explicitly matching the biophysical aims of the policy with the types of behavior changes needed in the landscape to achieve the desired nutrient reductions, such as enabling system changes to improve nutrient load reduction as needed; (b) the interplay between policy rules and the current social, economic, ecological, and political drivers for nutrient management on farms, such as broader market integration that may hinder behavior change or threaten social fit; and (c) potential enablers that can interact with mandatory rules to further policy aims, such as financial incentives or support. To this last point, we find that access to capital in some form is required for farmers to achieve changes associated with higher biophysical fit. The use of this novel methodology, combining mental models analysis with SES framework-based policy analysis allows for a closer examination of the processes through which policy is changing behavior and the experienced impacts of policy change. For regions considering a shift to mandatory rules for nutrient pollution from farms, we suggest that policy design should carefully consider driver-behavior-outcome dynamics to achieve long-term water quality policy fit.

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/12034

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Data Availability:

The data that support the findings of this study are available on request from the corresponding author, CRHW. None of the data are publicly available because of their containing information that could compromise the privacy of research participants. Ethical approval for this research study was granted by the University of Vermont Institutional Review Board protocol number CHRBSS:16-612.

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Appendix 1

Table A1.1. Interview protocol question for farmers

Interview protocol questions
How long have you or your family been farming in the watershed?
Could you tell me a bit about your farm system?
Can you run me through what a week on your farm looks like?
In the last 5-10 years, have you made any changes to your farm system or the management of your farm business? What was the driver for these changes?
What are the costs of these changes? Benefits?
Are you planning to make any changes to your farm system in the next 2 years?
Can you tell me a little about your experience with the water quality policy process?
Has the capping of nutrients changed the face of the watershed?
How fair do you think the policy is/was?
Would you have done anything different to manage water quality in the lake?

Table A1.2. Full codebook with descriptions and representative quotes

Nodes	Description	Example Quote
drivers		
Actor		
A_economics	funding, debt, efficiency, other sources of income, dependence on farm	*"I think, ultimately, its profitability. The most decisions we've made are on profitability. And so, the smaller, environmental changes – well, there's benefits as well. So, applying nutrients on lower rates more often, if we don't waste the nutrients, it makes more sense. So, most of those changes, we hope, eventually, help profitability as well."*
A_ethic	stewardship or land ethic, love of learning, aesthetic, price of being a "good farmer"	*"And we did a lot of those things because we were under a lot of pressure. But that's not the whole story. We are an environmental organization. So, it's sort of part of our mission to be good. So, it wasn't like we didn't want to do them. It's what we're supposed to do."*

A_flexibility	convenience, steady supply, lifestyle, flexibility in running the farm system	*"Yeah it was about giving us more flexibility in our system, and to help try and drought proof, yeah to - for the lake issue was, it was about being capped, effectively capped. That is a way of still being able to improve and maximize. But it also gave us another block of land that is separate if we ever wanted to sell something or anything like that."*
A_leadership or entrepreneur	Actor themselves represented leadership and entrepreneurial spirit to drive change, or actor received advice or followed path of leader or entrepreneur. For personal, the actor should mention something about trying something new, being on the cutting edge, taking a risk, taking leadership or being an entrepreneur. For receiving advice, the actor should mention a figure or figures that influenced their change.	*"Two and a half years ago we made the decision that we were sick of dealing with dairy farmers, and that we were really really keen to support [a new business initiative led by local farmers]. So we went and saw them to see what they needed and how it would work."*
A_lifestyle	this includes ease of management	*"So really I make the decision based on what I want to do, what I think is going to be more profitable, what suits the way I farm as well and my lifestyle."*
A_past experience	past experience with policy/state/regional government	*"So the decision had been made by then that they were going to benchmark and that we knew. So I knew how the farming system was going to work [because of experience with the policy process and previously owning land in the catchment]. I probably knew it better than anybody, I'd say. So that's why I was more comfortable in getting back in."*

A_social attributes	family life, succession	*"Well, I had a son and daughter both milking cows for someone else and then would come home and crutch lambs. So, I was left in the muck and getting no time off because there's only one main unit. And so, we thought if we could buy the dairy unit, we'd employ more staff and hopefully be able to get on the roster and get some time off."* *"No incentive and stuff, but the other thing with the lake is it's the taonga for the Maori. So it's their treasure. They were very keen to protect it anyway, and they'd made decisions around the lake to protect it way before Environment Waikato started."*
A_technology	availability of specific technology	*"We've modeled land use change [to make a farm diversification plan]."*
Governance		
G_gov assistance	technical or financial assistance from a government agency	*"The guy I've been working with through NRCS, he keeps me pretty informed. I'm pretty good friends with him, so he keeps me quite informed on everything and we go over stuff. I had a couple spots that I had to change things but other than that we've been pretty – we pretty much knew what was going on."*
G_ngos or other	Interactions with non-governmental entities, these include organic, extension, watershed programs, land trusts, housing and conservation board, industry group requirements or best practices, and research organizations/universities	*"As far as the rules for organic are so strict that these new laws on the water quality and watershed, we've already been having to follow since we went organic. The stream setbacks and all that are already in there for organic."*
G_other gov policies	Central, regional or local government policies that impact nutrient management, such as conservation policies	*"Well, we were up for resource consent, so it was – as far as the effluent upgrade, it helped us get a longer resource consent, and it kept us compliant."*

G_farmer group	participation in a group representing farmer interests	*"I probably got a little bit involved in [the farmer group] as to see how [the policy] was going to work more for my own selfish reasons because most of the farms around here are managed by farm managers, and I thought well if it's going to turn to shit I'd really want to be the first one to get out but if I could see some opportunities I wanted to stay"*
G_water quality policy	cap, state, regional policy	*"And the interesting thing was that when they brought the new rules into the catchment, the big businesses that owned those farms, sold the farms in the catchment straight away."* *"Some fields flood. Some of my land, I'm on the early spreading ban. Do with the new [water quality policy]. I got to hit them in the midsummer, so we're changing the way we got to do things, a little bit. We'll see in a few years. Hopefully, it'll benefit."*
Resource_system		
RS_ecological	erosion, runoff, endowment, improve ecosystem, nutrients, drought, flooding	*"I bought a manure truck, so I had to do it myself, now... Well, doing it myself, I'll do it more times per year, less each time, and try to minimalize runoff and get on when the land needs it. When the land can use it."*
RS_farm production	animal needs, increase/decrease, quality of product, pasture integrity	*"Originally the country that went into pines was the lower producing areas, but the nitrogen is sort of considered to be across the whole farm. So by taking out the lower producing areas it meant we could farm the better areas a little bit more intensively which gave us options, but then they sold more nitrogen and now we don't have a lot of options."*
Resource_units		
RU_n p attributes	attributes of N & P and the movement of these nutrients in the landscape and farm system	*"I'm doing it as a cover crop and I'm gonna crop it. I'm gonna do it as a forage so we're gonna chop it. We're gonna try it because the soil will pull up a lot of phosphorus out of the soil. Really, every time you plow and see the field, you're releasing that phosphorus that's*

		bound because phosphorus doesn't move in the soil. "
Social economic and political settings		
S_industry or consultant		*"So, we actually did a feasibility study. We got consultants to do a feasibility study, put the whole thing together, talked to the accountant, and then went to the bank and the regional council on the condition that – the last condition for doing it for buying the farm was that the pond was that we got the consent for the whole thing."*
S_ c market	Carbon Market as a driver	*"[Did you get carbon credits on that?] On the pines that they planted yes... So when [the farm] sold the nitrogen, Mighty River Power generate energy out of the lake. They've got the dams in the river. So they put a deal that they wanted carbon so they tied the two together."*
S_demographic shifts	For example, people going out of farming without a successor	*"I was renting these places – I had my milkers – and, I was renting places for my heifers. And, I had my heifers over at this farm, over here. This [neighbor 1] – that I told you he only milked 35 cows – he had sold his cows; he had retired from farming. And, I had my heifers way over at [neighbor 2's], at a different farm. And, [neighbor 2] came to me, and said, "Do you want to rent my pastures?" And so, I rented them, and it was a lot of fence, because it was a hexagon, so it was a big area."*
S_economics and markets	competition, profit, efficiency, prices broader than the watershed dynamic, carbon credit opportunities	*"The main reason why we came back in and bought here was location. Secondly, different land use in the future. And thirdly, land prices. Land prices had dropped by thirty or forty percent, so it made it economic to get back in again."*

S_n market	Nitrogen market as a driver	*"We planted about 40 hectares of pine trees, production pines, but no, the size didn't change at all. And that was partly because we'd sold some nitrate credits, once we got our cap sorted out, we had plenty so we sold it down."*
S_social context	Neighbor complaints	*"I tell my friend, I said "Farming is a hostile environment right now. It's hostile." I mean, the environment that we're in is hostile. Not only do we have pressure from regulators, we have regulations, we have pressure from intolerance from the community."*
outcomes		
Individual Outcomes		
IO_negative economic		
IO_Neg_compliance	compliance costs related to policy	*"But it's just got to the point where I might actually have to get a little bit more involved with it, because they just sent me a monitoring bill that was huge and I've just wrote a letter to them and said that I'm not going to pay that because that's 153 percent increase on last year's bill."*
IO_Neg_farm viability	Reduction in ability for farm to remain solvent and profitable, survive as a business	*"Well, just for the very reason – if you can't grow your business then you can't survive. So, we had to shift. So, we decided we would reduce our operation in the catchment, and increase our operation outside of the catchment."*
IO_Neg_financial	Reduction in profit, payoff, funding, reduced earnings, compliance, property value, new revenue streams including new products, new markets, diversification	*"Well, there are direct financial costs and there are also social costs, I think. The direct cost to you is these physical costs like building detainment berms and putting effluent ponds and buying upgraded irrigators and things like that."*

IO_Neg_flexibility	Loss of flexibility in farm management	*"And before the rules, you could do whatever you wanted to do. Now, you can probably make changes as long as you stay within the rules. So, I suppose, yes. We started cropping in the summer to develop those pellets to improve the quality of grass. And that's not going to happen. So, that hasn't changed in a way. Although, I don't know think we expected to do it for long anyway, did we? It's just an option that we don't have anymore."*
IO_negative social		
IO_Neg_distrust in regulation	Frustration or distrust with regulation or agency implementing the regulation, or in the monitoring (Overseer)	*"Oh, I just don't contact [the Regional Council]. Because I don't have enough respect or trust in them to be able to do that."*
IO_Neg_fairness	Perceived that situation is unfair in individual position	*"We planted trees on steep land to stop erosion. And we did flood control work. And I can show you that on the photos that I've got. And those things all worked really well, but the annoying thing is that now that doesn't count towards what we're doing. So, what we've done is, we've harvested the trees, and we haven't replanted. Because we need to have more grass to try and keep our cow numbers up. It's stupid. It's stupid that they're not recognizing environmental benefits that were done in the '90s and the '80s."*
IO_Neg_non-financial costs	time, depression, involvement with community	*"It was tough, man it was tough. Because we were all farming. We used to joke and say man this would be great if this was your day job. Because A) you are on a salary, B) You are really interested, C) you haven't got any skin in the game, and it's just really interesting stuff. But we were all trying to hold down, I had two little babies, trying to hold down farms, and businesses, and represent people and communicate and try and forge our way through this process, it was incredibly hard."*

IO_Neg_uncertainty in future	Uncertainty in the future of the farm system and what will be possible	*"Well, we won't have a business. Because they're looking for a 30 percent reduction. So, instead of having 230 cows, we'll have 160 cows. That just won't work. Just like if you're salary got cut by a third, it would certainly change your perspective as well."*
IO_neutral economic		
IO_Neu_compliance	Compliance with policy is a negligible cost	*"So, you know I mean the RAPs I mean definitely yes we've had to make some adaptations to our management here and all, but they haven't really impacted us detrimentally. It hasn't been a big burden or impact on us as a farm."*
IO_positive ecological		
IO_Pos_environmental quality	specific resource not specified	*"No. No benefits. Apart from environmental benefits, that's about it. Certainly no financial benefits."*
IO_Pos_soil quality	improvements in individual's soil and pasture quality	*"And all that where the brook is, it's not mud now, its grass. And going over the years, it's not just grass, it's nice grass – nice, and lush grass; and, I only pasture it, maybe, three or four times a year."*
IO_Pos_water quality	improvements in water quality at the farm-scale level, or due to farm-scale level behaviors	*"So, I think we must – so, if water quality is improving in [the] Bay… Something is happening. Some of these practices are – and I don't know whether that has to do with it or not. I just think we've done so much – that it's useful. It's proven that it works."*
IO_positive economic		*"Yeah, so that's what I'm trying to say. If I'd kept running a similar number of stock my nitrogen output would have dropped but the policy changes allowed me to improve the farm's productivity without breaching my nitrogen cap."*
IO_Pos_farm viability	improvements in ability for farm to remain solvent and profitable, survive as a business	*"Well, the NMP plan is a chance to save money, there, because we know for over fertilizing. With the first one we did, the comprehensive one, we found out that we were putting almost double manure on the grassland than we should've been. You can put too much. It's all there is to it. You put too much. That's a good thing to save money, if you can."*

IO_Pos_financial	Improvement in profit, payoff, funding, increased earnings, compliance, property value, new revenue streams including new products, new markets, diversification	*"Yeah there were benefits. For people like me that had very, very high NDAs, to have sold a few off the top. Like I sold down to a reasonable level and that would have been good if we hadn't lost the extra 1300. So there were benefits in yeah any very, very high NDA farms - could get part of their capital out. It was like selling part of your farm, but actually not losing the farm."*
IO_Pos_flexibility	Improvement in flexibility in farm management	*"Pretty much, like we sold down the cattle and replaced those cows with trading stock and they were winter grazers, so it didn't really alter the figure too much, it just gave us more management flexibility."*
IO_Pos_new markets	Accessing new markets, marketing, pricing, supply chain changes	*"We're certainly producing the product, but we haven't had a decent product to sell, which has been the biggest issue. We've tried cheese and yoghurts. We have been exporting frozen milk to our cheese maker in Aussie for the last few years. But the last 18 months we've taken on a [new] partner and they're powdering it and take it to China. That's been a pretty amazing leap forward, and it's given us a solid market with reasonable returns."*
IO_positive social		
IO_Pos_awareness	improved understanding of farm system, nutrient dynamics	*"So those sort of things, yeah, you're very aware of - we talk a whole new language now in terms of nitrogen discharge allowance, NDAs and things like that. Yeah and we're conscious of those things. We live in a different world here now."*
IO_Pos_non-financial benefits	new opportunities, involvement with community, sense of pride in work, reduces burden of work	*"Oh, I sleep easier at night. Yeah, to keep compliant with the old pond, I did some stuff that I wasn't very proud of. But he had to do it to stay compliant really. Yeah, so now all that's gone now. Easier management and all that sort of stuff is, yeah."*

IO_Pos_enviro recognition	Received recognition for environmental stewardship/sustainability of farm system	*"Then we won the [environmental award], now is the moment when the dollars profit per KG of nitrogen came together. We've been testing, the [farm system] thing is just a big experiment. We've measured ourselves against other farmers through the [award]."*
watershed outcomes		
WO_negative ecological		
WO_Neg_environmental quality	specific resource not specified	*"Well, we're back again to the nitrogen, phosphorus/biodiversity. Because if you look at what the Regional Council's job is, it's not only nutrients, its biodiversity. It's protecting native bush. Its pests. There are a lot of things. But it's only actually PC 10 hasn't taken into consideration any of those other things that actually the Regional Council is in charge of implementing, or controlling."*
WO_Neg_land use patterns		*"That was all taken out of farm land and they were farming conservatively anyway. They were having no effect on the lake over there at all because they all had sheep. But that's all in trees now."*
WO_Neg_water quality		*"So this trading of nitrogen also creates another problem of what they call hotspots. Some people don't want to know about it but of course it makes a difference. Put it this way; if I put this tea towel on the bench and I get two glasses of water, one I just sprinkle lightly everywhere, it hardly sinks through, the other one I just pour it right here, you're going to find a big puddle here that's going to run over here. In effect this nitrogen cap thing has done exactly that."*
WO_negative economic		

WO_Neg_farming viability	Reduction in ability for farming in the watershed to remain solvent and profitable, survive as a business/industry	*"That's just what happens. The – yeah, they're a lot of farms that are – it's kind of a perfect storm situation too, where I think the number of farms is like 750 farms left in the state... Somebody said the other day that they read from the agency that they could see 150 to 200 more farms go out this year. A lot of that's like – milk price, and then regulations at the same time."*
WO_Neg_financial watershed	profit, payoff, funding, reduced earnings, compliance, property value, new revenue streams including new products, new markets, diversification	*"Farmers have made a real stand in this catchment to say, 'We can do this, what's required by 2022, whatever the percentage top is. But what's required after 2032 is not doable. Financially, it's not doable.'"*
WO_negative social		
WO_Neg_well-being	community involvement, depression, community members leaving	*"So, I think – but it's like grievance; this – this phase is the angry phase, and then acceptance might come because that's what happened for us in the Taupo catchment like I say."*
WO_Neg_fairness	perceived fairness of the policy process/policy outcomes	*"When grandparenting was on the table, who was going to miss out? [Maori land], big time. And as owners of the lakebed, and individually owners of the farms, a lot of farms especially down in the Western area, 55% of the landholding, they had a really big series of interests to try and weigh up. And they had voluntarily retired a whole heap of their own land... And so when grandparenting came out, these guys were severely penalized. There is no recognition of those environmental benefits from having already given. So you can understand why they are pretty pissed off."*
WO_neutral ecological		
WO_Neu_lack of changes	Not sure whether there is a positive or negative impact on water quality or other environmental indicators at the watershed scale	*"The land use, land use change, in the catchment, has been minor."*
WO_neutral economic		

WO_Neu_economic impact	Perception that policy has had neutral economic impacts	*"But actually, well, I've personally found it pretty easy, it hasn't been too bad at all. Most of the farms down here are large Maori owned blocks, and when I talk to the other managers, they've pretty much found the same thing. There's a couple on lower benchmarks that sort of get a little bit - the farms were probably not as developed, so that's probably limited how much they can develop their farms. But in general, I don't think it has affected things too much."*
WO_neutral social		
WO_Neu_acceptance		*"But, you know, it's something that I've been involved with for 30 years of farming and so it's been a major cost to farms definitely, which everybody seems to have just – just get on with it."*
WO_Neu_well-being		*"Socially, some people who are really unhappy have gone. Which is good they've sold, probably still not happy but they were able to exit. Some of the angst around that was that the trust stood on the market and paid what private valuations, but some of those people still say that wasn't enough."*
WO_Neu_fairness	Policy is both fair and unfair	*"Everybody's got to do their share. Are they picking on us? No, I don't think so. Some people think they are, but I think everyone's gotta do their part. I think there's certainly been room for improvement; I think it runs you know. I only see something no one's – nothing's gonna change."*
WO_positive ecological		
WO_Pos_land use patterns		*"I think there would be a lot more dairy farms [without the policy], particularly on Maori lands down the bottom of the lake, which is just beautiful land. There would have been more development, yep. So, it met its purpose. I think the lake is improving too."*
WO_Pos_management changes		*"I see the bigger farms – a lot of them are doing cover crops where they never did before."*

WO_Pos_water quality		*"So – so, yeah, so, – but we want the lake to get – to get better as well and we – we – we think we're seeing that so there's a – we – we do think there is a balance in things, but – but then the financial imperative sort of seasonal; these are making some good decisions anyway, unfortunately."*
WO_positive economic		
WO_Pos_farming viability		*"And that is one of the best thing that has actually happened in this catchment, is that we have, we can trade effectively. So it doesn't lock someone in forever and gives people flexibility and things like that. A lot of people wouldn't actually realize that or use that or whatever, but that is huge flexibility. You've got to have that flexibility if you want to go ahead."*
WO_Pos_financial	profit, payoff, funding, reduced earnings, compliance, property value, new revenue streams including new products, new markets, diversification	*"So for the Maori incorporations the benefits were huge. They could take capital out of land but they can't sell it. So Maori land can't be sold. So if it was me, I owned this land and I couldn't sell it and someone was going to give me a whole lot of money for that land and I owned it, I'd have planted the whole thing in trees...So it allowed them to release capital out of their land holdings, retain their land because they can't sell it and then they've taken that money out and my incorporation have treated it as capital."*
WO_positive social		
WO_Pos_awareness	awareness of water quality, farm dynamics and environmental footprint	*"Well, farmers have become aware of the environmental impacts that farming has on the waterways and the lakes."*
WO_Pos_well-being	community involvement, depression, community members leaving	*"So, yeah. Actually, I think that probably the biggest plus out of it is actually talking to your neighbor, and working with your neighbor, and seeing what they're doing."*
WO_Pos_fairness	perceived fairness of the policy process/policy outcomes	*"Yes, I do, absolutely. I think we have a workable proposition, a workable nitrogen constraint."*
Recent nutrient management behavior		
Management change		

M_change breed	Change in animal stock, part of the physical stock of the farm, not something that can be changed on a day to day management basis.	*"Basically, change the breed really. As I say, they were very high maintenance. We had dry seasons and the following year they didn't perform very well. So we got a hardier, bit more robust sheep on board, but they don't produce quite as much, but they cost - the cost of running them has dropped as well, so - and that was to fit with putting milking on it, sort of changed the dynamics of the farm, so just that fit with the whole system."*
M_reduced fertilizer	changes in the application of fertilizer timing and/or amount, including manure	*"Just, I suppose, I have changed from putting the fertilizer on in the autumn to putting it on in the spring. Or late spring, probably, more than early spring. Due to, probably, a bigger loss would occur in the autumn."*
M_grazing off	Began or changed grazing off of livestock, or wintering off, including dairy support	*"What we've done instead of winter cropping and wintering on the farm, we've taken more animals off the farm during the winter. It also helped that the grasses that were growing now provide feed over a wider part of the season. But it's both continual productivity improvements that has come to help in the situation."*
M_increased fertilizer	increase in the application of fertilizer	*"And then, in the last few years, we've found that we haven't really had enough manure on the closer fields, and it costs a lot more to get it to the further fields, so the last few years, we've been putting more commercial fertilizer on the further fields, and sometimes no manure, and putting more of that manure on the grass ground during the summer and definitely putting more – or, enough – on the corn ground that's close by."*
M_increased stocking rate		*"Yeah, chicken as well, so it's kind of a quick background. I guess I'd say also we've grown the flock a little bit –"*
M_pursue knowledge	Actively pursue knowledge to better understand nutrient dynamics (engage in research)	*"We've actively pursued knowledge by engaging in research trials."*

M_manure spreading	Changes in the application of manure timing, amount or pattern, also changes in location of manure stacking	*"I bought a manure truck, so I had to do it myself, now. I'm gonna do – rather than hiring somebody to come in and mainly want the pit empty, so just put it on as heavy as they can put it on because they're only coming in once or twice a year. Well, doing it myself, I'll do it more times per year, less each time, and try to minimalize runoff and get on when the land needs it. When the land can use it. That way, absorption is better and I'd like to hit it as soon after cropping and pray for doing it the day before a rain, that way it gets incorporated in."*
M_notill	Switch to no-till	*"Then, as for fields, the last few years we've been – we've been kind of experimenting with no till for about 20 years, and probably six or seven years ago we went halfway no till and four years we got to 100 percent no till –"*
M_nutrient management plan	Began or revised a nutrient management plan or overseer plan	*"That was my first effort at writing my NMP, yeah. We had a different contractor doing it for us initially the first year or two. Even back then, we were already at $4,500.00, $5,000.00 then and we didn't have the land base that we have now."*
M_reduce feed inputs	Changes in purchased feed or other inputs (non-fertilizer)	*"Yeah we also bring in palm kernel at this stage. Yeah we have cut down - well we're trying to do at the moment because it is not worth losing money on using it. "*
M_seeding or cropping	Began, changed or stopped seeding varieties or cropping patterns	*"Yeah, yeah. We're gonna seed more, now. We always like our corn but we used to plant 300 acres and now we're down to 180."*
M_soil sampling	Began or changed soil sampling	*"Talking with USDA, I'm trying to reseed to improve my pastures and so I'll be doing some soil testing. I didn't do that when I went to the [nutrient management class], but I will now just so that I better understand."*
M_stocking rate	Changed number of animal units	*"No, there's no reduction in – well, actually it did come with a reduction in stocking rate as well. I think I've mentioned that we reduced from about 3.4 down to 2.9."*

Structural change		
St_barn	Change or construct barns	*"Then we're actually building a barn to bring these animals home because that contract grade is – they're doing a nice job raising them, but that's – we can more than pay for a barn."*
St_biodigester		*"[Q: When did you guys put in the biodigester?] 2008... Yup. It was something we decided to do."*
St_ buffers	Change or construct buffers or setbacks on rivers, streams or ditches	*"right, yeah, and some ditches and with buffers I think was the last project we did a while back was maybe 30 feet and then they came and planted trees and they help even compensate us a small amount for the land that we lost because our fields did go right down to those areas."*
St_detainment bunds	Change or build detainment berms to control flow of water, slow flow of water and runoff of nutrients	*"Obviously where we pug ground up is another issue, we are always conscious of that, but we've also put in a lot of detainment berms, if you can imagine this farm is elevated it's got quite a big catchment and all the water eventually is coming down into the lake. It's going to get there one way or the other. These detainment berms, so far we have done about seven with the regional Council to reduce or to mitigate the flow of water that comes through, especially when we have these big downpours."*
St_equipment	Purchase or change farming equipment	*"We have adopted the best management practice advice in terms of effluent and disposal. We put in a new storage system. A rubber-lined storage system. It – to have best practice for effluent and disposal. We brought new land application irrigators to meet the application requirement."*
St_fencing	Change or construct fences	*"We had to fence up the swamps because there are some wetlands on the backside of a couple of our fields that we had to fence out. Water quality. Like I said, it all makes sense. It makes you more money in the long run. Cows aren't gonna make milk standing in the mud."*

St_leachate system		*"The biggest problem I have is we have to put a leachate system in. Ugh. It's an $81,000.00 project, which I don't think is even needed because our bunker are – well, they're 100 feet from the brook and they're 50 feet from the road."*
St_manure pit or pad	Change or construct manure pit	*"By getting manure on the land – we put in a manure pit – by getting the manure on the land, we went – our tonnage of feed multiplied by four times in two years, per acre. It's huge. That's all money in your pocket because you're not purchasing that extra feed."*
St_milking parlor	change or construct milking parlor	*"We've been going about eight or nine years. Eight years, yeah. It didn't actually take that long, built a shed, a purpose built milking shed and pretty much within 12 months we were producing milk."*
St_stand-off pad	Change or construct stand-off pad	*"We still have no – on our own, we put in a cement pad to feed the cows on. We're still dealing with – we kind of get a nice bedded pack built that's dry, and then we get six inches of snow on top of it –"*
St_tree planting	Plant trees to restore banks or native bush (not pine plantation - that is a system change)	*"Apart from fencing off gullies and planting them in natives, rather than productions trees, that's about it."*
St_water flow control structures	add or change culvert, put in drains to divert water	*"Some of our diversion water goes through a culvert underneath this pushway. I didn't wanna pour concrete there, so what I did is I added onto the culvert on both sides and just built it up, so now the dirt is much higher than our concrete pushway, and when she came back, she said that was fine."*
System change		
Sy_purchase or lease land	Purchase new land for agriculture within the policy region	*"Well, we just barely purchased some more land. We're up to 280 acres. We rent another 100 acres of crop land."*

Sy_put land in production		*"Then there was a white pine stand that we wanted to cut and reclaim for pasture and we wanted to clear all that junk wood, and then we wanted to drastically thin out the hemlock out of the sugar bush..."Yep, he gave me approval." I said "Can we start?" "Yeah, go ahead. Get started." We start. Clear cut 20 acres here, and clear cut a bunch here, and do a bunch of work, and we only did, probably 25 percent of what we wanted to do –"*
Sy_sale or lease of land	Sale of agricultural land	*"So we decided after a lot of soul-searching that we would sell."*
Sy_switch to higher intensity	Transition to or from dairy, sheep, beef, vegetable, other, pine plantation, dairy support. Note that many farms can be multiple different farm systems at once, and may take up additional system types, for example a dairy may retire some land and plant a pine plantation. Switch from breeding operation to purchasing stock included as well, or reverse, switch from purchasing to breeding	*"Well, one would be put the sheep milking unit on...So basically, we've put that on and it has changed the dynamics a little bit. And then we've sort of intensified that area, the sheep milking area, quite a bit. Mainly with the sheep, but it hasn't changed our nutrient output a hell of a lot, I don't think."*
Sy_switch to lower intensity	Transition to or from dairy, sheep, beef, vegetable, other, pine plantation, dairy support. Note that many farms can be multiple different farm systems at once, and may take up additional system types, for example a dairy may retire some land and plant a pine plantation. Switch from breeding operation to purchasing stock included as well, or reverse, switch from purchasing to breeding	*"Really, since we went grass fed – this is recent – we've had to – we're still trying to figure out how this is changing our – last summer was the first summer we were 100 percent grass fed."*

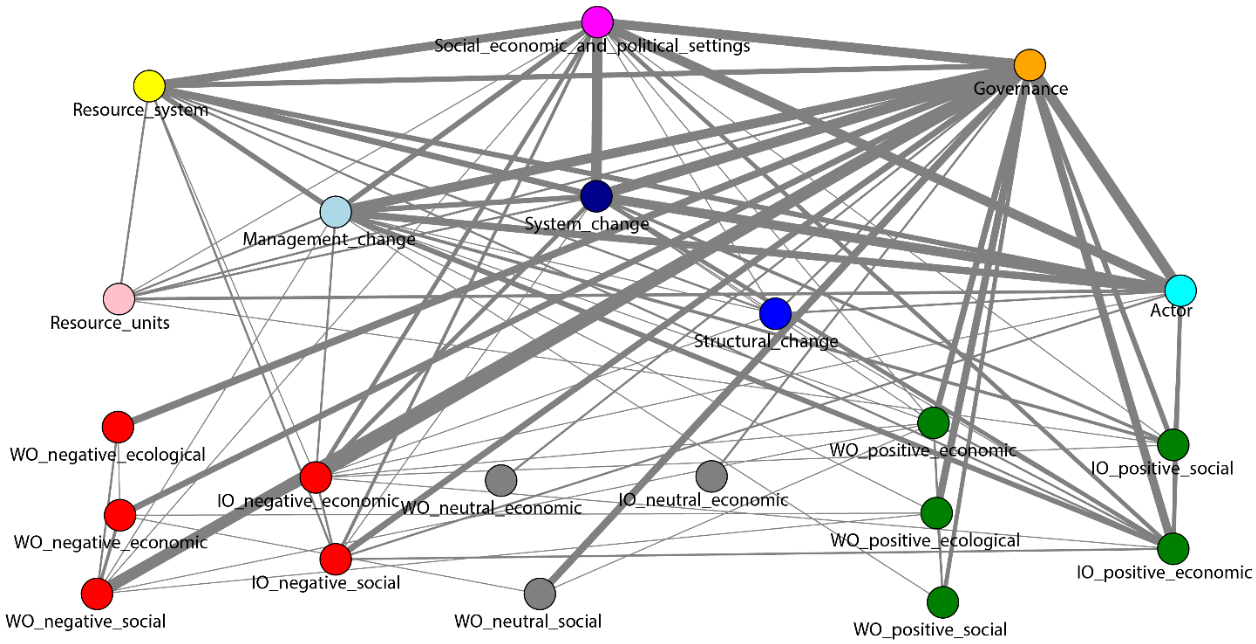

Figure A1.1. Network graph representing group mental model of Taupo farmers' watershed social-ecological system. The arrangement of nodes mimics the structure of the SES Framework in Error! Reference source not found. **above. Color of node represents the category of node: driver nodes are orange (governance), magenta (social, economic and political settings), yellow (resource system), cyan (actor), and pink (resource system); behavior nodes are light blue (management), blue (structural) and navy (system); watershed (WO) and individual (IO) outcomes nodes are red (negative), grey (neutral) and green (positive).**

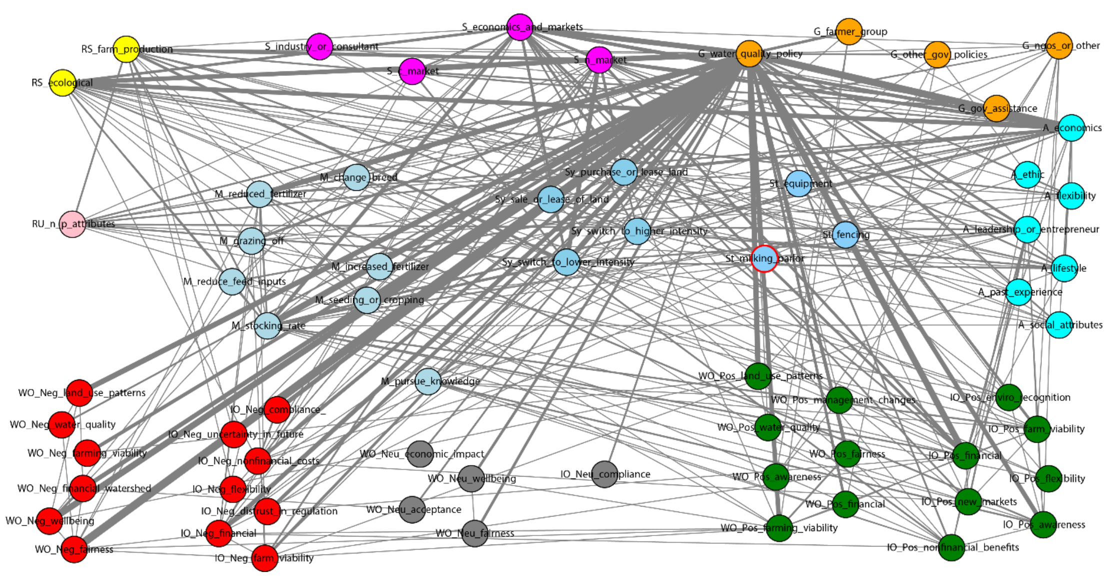

Figure A1.2. Taupo SES sub-category group mental model network.

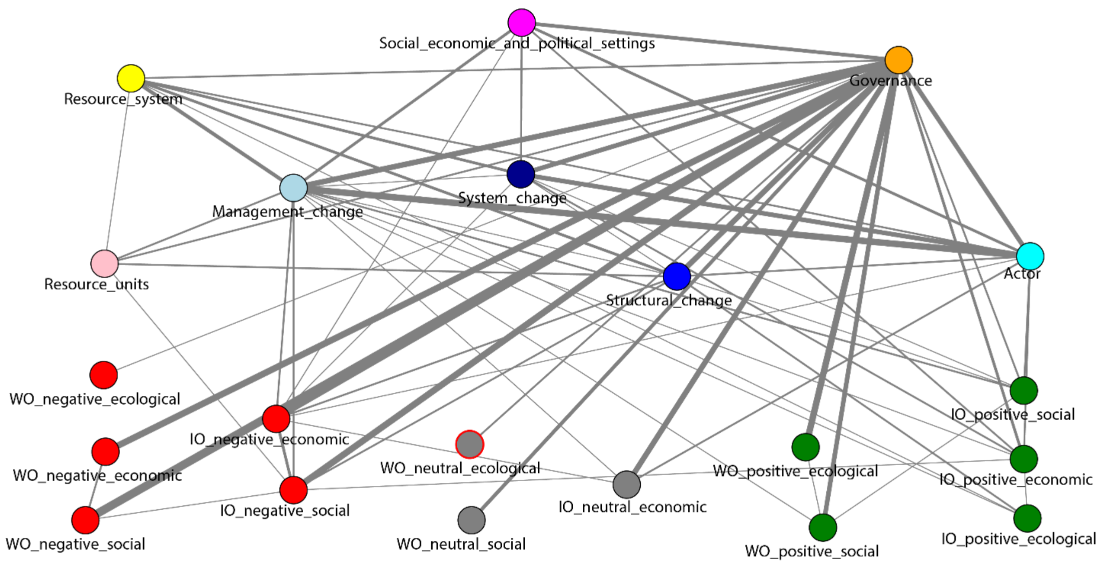

Figure A1.3. Rotorua SES Category group mental model network

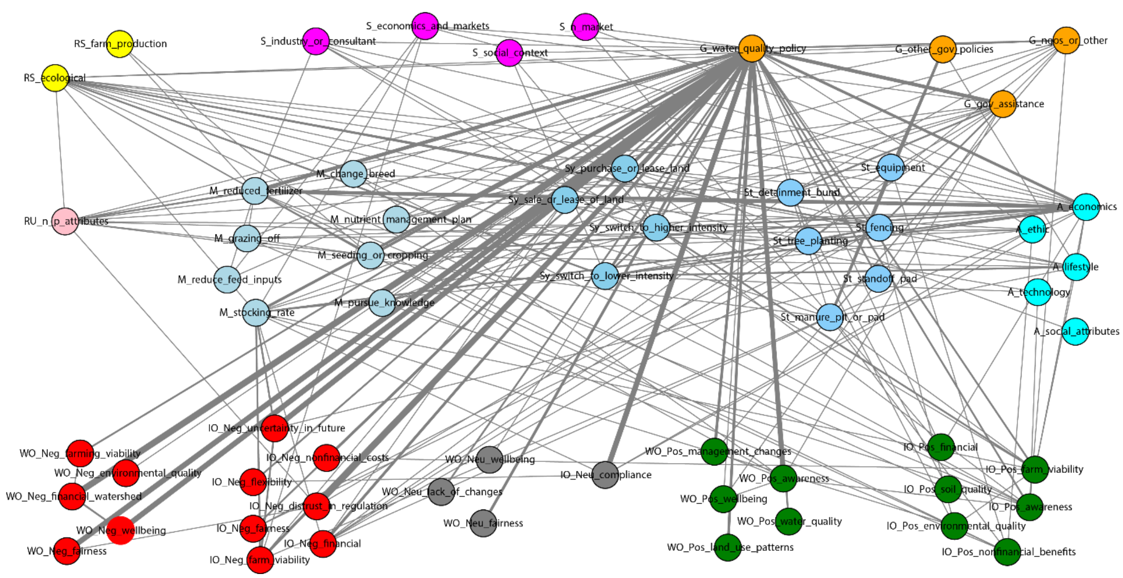

Figure A1.4. Rotorua SES sub-category group mental model network

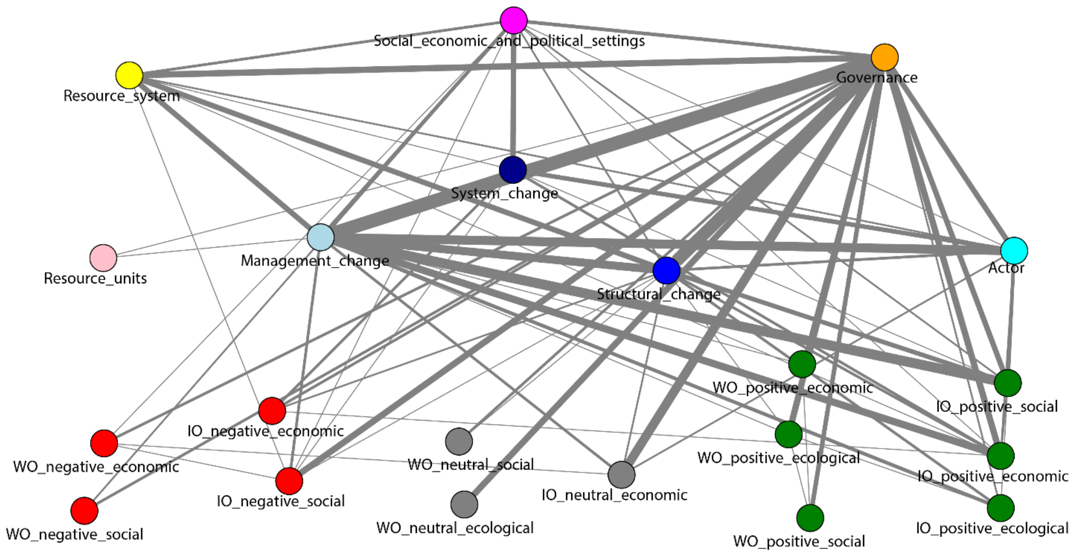

Figure A1.5. Vermont SES Category group mental model network

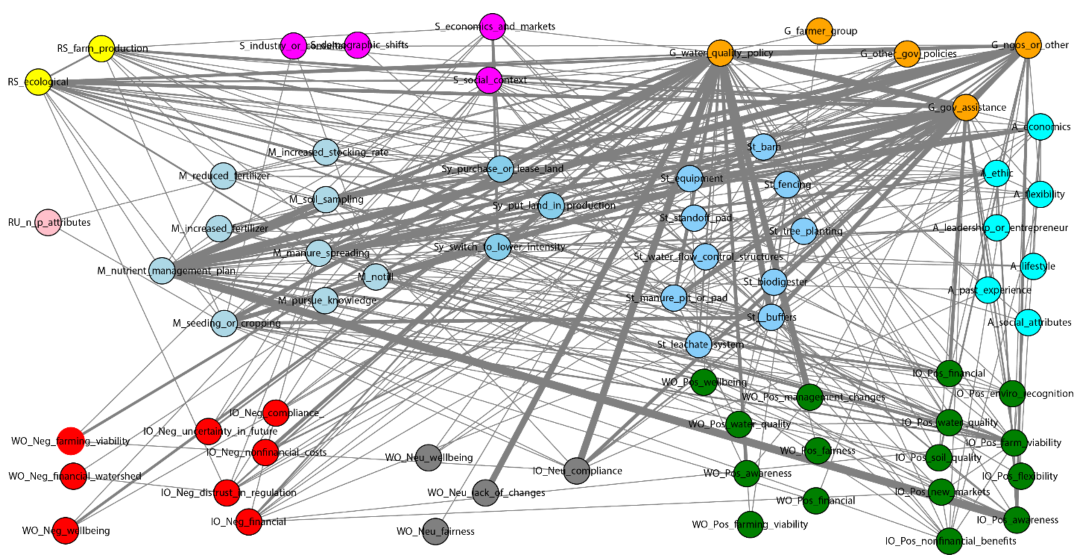

Figure A1.6. Vermont SES sub-category group mental model network.

Table A1.3. **Driver node statistics by region in Driver-behavior sub-network. Rank reflects the descending rank of strength (high to low). The data driving these ranks is from the Driver-behavior sub-network so ranks do not reflect influence on outcomes.**

	Taupo (n = 11)				Vermont (n = 16)				Rotorua (n = 11)			
Sub-category node	rank	strength	degree	occurrence probability	rank	strength	degree	occurrence probability	rank	strength	degree	occurrence probability
A_economics	2	49	23	91%	5	21	13	50%	2	25	16	64%
A_ethic	14	2	2	9%	6	17	15	38%	8	5	5	18%
A_flexibility	10	9	7	18%	9	8	8	13%	-	-	-	-
A_leadership_or _entrepreneur	7	17	12	27%	10	4	3	13%	-	-	-	-
A_lifestyle	8	16	11	27%	11	3	3	6%	6	9	8	36%
A_past_experience	12	5	5	9%	10	4	3	13%	-	-	-	-
A_social_attributes	10	9	8	27%	12	2	2	6%	11	1	1	9%
A_technology	-	-	-	-	-	-	-	-	10	2	2	9%
G_farmer_group	12	5	3	27%	13	1	1	6%	-	-	-	-
G_gov_assistance	10	9	7	18%	1	74	25	88%	4	14	9	45%
G_ngos_or_other	11	7	7	9%	3	48	22	75%	6	9	8	36%
G_other_gov_policies	13	4	3	27%	10	4	4	13%	7	8	5	27%
G_water_quality_policy	1	88	28	100%	2	58	26	94%	1	42	25	100%
RS_ecological	5	31	18	45%	4	31	18	44%	3	17	15	55%
RS_farm_production	6	23	14	64%	6	17	13	31%	10	2	2	9%
RU_n_p_attributes	8	16	11	27%	12	2	2	6%	5	11	10	27%
S_c_market	9	11	7	18%	-	-	-	-	-	-	-	-
S_demographic_shifts	-	-	-	-	13	1	1	6%	-	-	-	-
S_economics_and _markets	4	40	18	82%	8	9	6	44%	8	5	5	9%
S_industry_or _consultant	13	4	4	9%	10	4	4	6%	8	5	5	18%
S_n_market	3	42	18	82%	-	-	-	-	10	2	2	9%
S_social_context	-	-	-	-	7	15	13	19%	9	3	3	9%

Note: The one letter prefix of the driver sub-category node name represents the overall driver category that the node belongs to: A = Actor, G = Governance, RS = Resource System, RU = Resource Units, S = Social, economic and political setting.

Table A1.4. Drivers ranked by strength across each region. Note that data driving these ranks is from the Driver-behavior sub-network so ranks do not reflect influence on outcomes. The one letter prefix of the driver sub-category node name represents the overall driver category that the node belongs to.

Rank	Taupo	Vermont	Rotorua
1	G_water_quality_policy	G_gov_assistance	G_water_quality_policy
2	A_economics	G_water_quality_policy	A_economics
3	S_n_market	G_ngos_or_other	RS_ecological
4	S_economics_and_markets	RS_ecological	G_gov_assistance
5	RS_ecological	A_economics	RU_n_p_attributes
6	RS_farm_production	A_ethic	A_lifestyle
		RS_farm_production	G_ngos_or_other
7	A_leadership_or_entrepreneur	S_social_context	G_other_gov_policies
8	A_lifestyle	S_economics_and_markets	A_ethic
	RU_n_p_attributes		S_economics_and_markets
			S_industry_or_consultant
9	S_c_market	A_flexibility	S_social_context
10	A_flexibility	A_leadership_or_entrepreneur	A_technology
	A_social_attributes	A_past_experience	RS_farm_production
	G_gov_assistance	G_other_gov_policies	S_n_market
		S_industry_or_consultant	
11	G_ngos_or_other	A_lifestyle	A_social_attributes
12	A_past_experience	A_social_attributes	
	G_farmer_group	RU_n_p_attributes	
13	G_other_gov_policies	G_farmer_group	
	S_industry_or_consultant	S_demographic_shifts	
14	A_ethic		