Nowell, P., Muller, C., Stephens, T., Kpodonu, T., Patel, M., and N. Brown, 2023. Accounting for change: A pioneering approach to optimised catchment action planning using the Freshwater Management Tool. In: *Diverse Solutions for Efficient Land, Water and Nutrient Use*. (Eds. C.L. Christensen, D.J. Horne and R. Singh). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 35. Farmed Landscapes Research Centre, Massey University, Palmerston North, New Zealand. 14 pages.

ACCOUNTING FOR CHANGE: A PIONEERING APPROACH TO OPTIMISED CATCHMENT ACTION PLANNING USING THE FRESHWATER MANAGEMENT TOOL

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Introduction

As a unitary authority, Auckland Council (AC) has responsibility for regulating land use activities under the Resource Management Act (RMA) and managing for the protection of water resources under the Local Government Act (LGA) (Department of Internal Affairs, 2002, Ministry for the Environment, 1991). Effective management of water as it moves through the hydrologic cycle is fundamental to integrating both acts and achieving wellbeing outcomes, adapting to climate change, managing urban growth, mitigating the effects of rural land use on freshwater ecosystems, and reversing biodiversity loss.

Auckland Council's most recent long-term plan (2018–2028) set aside $452 million for targeted water quality improvement, including the reduction of contaminants received by urban and rural waterways. To ensure this investment contributes to optimal water quality outcomes with greater efficiency through targeted action, Auckland Council's Healthy Waters Department (HW) is developing the Freshwater Management Tool (FWMT)—an accounting and management decision-making tool which guides feasible, effective actions for freshwater water quality outcomes on a least-cost basis.

While used to inform water quality management overseas (USA, Canada), the FWMT's pioneering approach to optimised action planning and freshwater accounting is new for Aotearoa New Zealand. The FWMT is comprised of two established US-EPA models (the Loading Simulation Program in C++, or LSPC, and the System for Urban Stormwater Treatment and Analysis Integration, or SUSTAIN; United States Environmental Protection Agency, 2004; United States Environmental Protection Agency, 2014) that have been adapted specifically for application in New Zealand (i.e., for policy requirements, biophysical conditions, meteorological and climate variation, land uses, and interventions).

The FWMT approach (LSPC + SUSTAIN) is innovative for enabling detailed geospatial assessment[1] of:

- Present and future water quality (under altered land management, land use, climate, or combination thereof)
- Feasible, effective, and least-cost actions (for an objective or to ensure greatest environmental return on investment).

[1] In and between catchments, for a range of rural and urban activities, biophysical conditions, and water quality objectives.

The FWMT is continuous, process-based, and fully integrated across Auckland's rural and urban landscapes (5,465 catchments, 100+ land types, 15-minute dynamic output). The tool simulates hydrology, physicochemical condition, and six major contaminants across various forms (nitrogen, phosphorus, sediment, *E.coli*, copper, and zinc—total, oxidised, and reduced).

The tool's process-basis, continuous time series output (15–minute), and cost-optimisation approach are direct responses to an outcome-focus and management purpose linked to Auckland Council's unitary status, with combined regulatory and implementation (investment, action) responsibilities under the National Policy Statement for Freshwater Management 2020 (NPS-FM, Ministry for the Environment, 2020). Simpler statistical and lumped models are fundamentally unsuited to defining a critical condition (i.e., the precise period, sources, and load of contaminant needed to be managed to achieve an objective). Nor are they suited to identifying those targeted actions needed to treat critical conditions and which lead to fundamental changes to instream conditions beyond that which any existing statistical correlation can identify. For instance, water quality might exceed some target value for only some brief period or critical time, at some critical place(s), or due to some corresponding critical source(s). The combination of all three critical criteria is the basis of targeted management using the FWMT—defining the options, from any feasible mix of actions linked to particular sources and places, that are able to target those critical weather, activity, and biophysical conditions.

The focus on water quality outcome (instream, in-lake, or to coast/estuary), actions needed (type, location, scale, cost), and the notion of a critical condition are innovations arising from the FWMT approach—providing the scope for decision-making tools to direct targeted effort (investment, regulation) within and between individual catchments while reflecting differences in critical conditions and treatment options.

Due to the novel nature of the FWMT approach, the tool is supported by a decadal programme of continuous improvement and application, drawing on a robust evidence base drawn from advanced geospatial and data generation/analysis techniques, applied research, and literature (including State of the Environment monitoring, device efficiency information, and complete 50-year lifecycle costings). An external peer-review panel has also been established to scrutinise both the tool as well as its long-term development programme (Hamilton *et al.* 2021).

The FWMT development programme represents a significant investment in knowledge acquisition, data generation, relationship building, guidance development, and management scenario testing in response to the operational requirements of recently introduced national policies (e.g., NPS-FM, the National Environmental Standards for Freshwater [NES-F]), RMA reform, and 3 Waters reform. This suite of outputs is focused on supporting the implementation requirements of operators, industry sectors, landholders, remediation programmes, communities, and mana whenua across Tāmaki Makaurau; some of these outputs are highlighted below:

- Healthy Waters and primary industry sector organisations are undertaking farm mitigation trials to establish evidence around feasibility/opportunity, costs, and event-based effects.
- Healthy Waters, Horticulture NZ, and Perrin Ag are improving the FWMT's horticultural land use activity information (including the understanding of baseline and mitigated water quality and economic footprints for commercial vegetable production—see Nowell *et al.* 2023).
- Healthy Waters and NIWA are exploring coupled FWMT-ecological modelling (macroinvertebrates, fish, algae).

- Healthy Waters and DHI are exploring integrated freshwater-coastal modelling (see Kpodonu *et al.* 2022).
- Healthy Waters, University of Waikato and Limnotrack are exploring coupled FWMT-lake process modelling.
- Healthy Waters, NIWA, and University of Otago are exploring improvement to metal simulation and toxicity reporting.
- Healthy Waters, NIWA, and HAL are developing novel climate time-series for representative concentration pathways for future scenario modelling.
- Healthy Waters, Puhoi Stour, and Aquanet are developing a novel model-targeted monitoring programme to improve model calibration and validation.

This paper will focus on how the FWMT can support those involved in freshwater farm planning, from primary industry organisations to rural professionals and farmers and growers.

The Freshwater Management Tool programme

The FWMT programme integrates a suite of digital tools to determine actions to achieve water quality outcomes—actions that will change the underlying processes, contaminants, flow regimes and broader physicochemical conditions instream, in-lake, or to-coast. From these, the tool can supply costs and detailed geospatial guidance on what effort is required to invest where for targeted treatment of land use activities.

By examining actions for feasibility, impact, and cost, the FWMT delivers valuable information for informing regulatory design, responding to regulatory notification, securing investment, and guiding both freshwater farm planning and integrated catchment management—as well as assessing outcomes.

Six key questions guide the FWMT's action planning purpose and outcomes-focus.

What?

Freshwater Management Tool baseline outputs tell a comprehensive story of water quality across 5,465 modelled sub-catchments at 15-minute intervals over a 15-year simulation period (2003–2017). A 'grading' period of 2013–2017 is used for the instream water quality attribute state analysis, reflecting NPS-FM requirements.

Daily hydrological and contaminant time-series (both to-edge-of-stream loads and in-stream concentrations for dissolved and total nitrogen and phosphorus; total copper and zinc; total suspended sediment including clay, silt and sand fraction; and *E.coli*) have been peer reviewed by Hamilton *et al.* (2021) and are presented in part in Brown *et al.* (2021).

Calibrated using SoE water quality data and hydrometric flow data, the FWMT baseline outputs provide valuable 'catchment context' information on both chronic and acute conditions (Figure 1) and contaminant sources (see Figure 6). These outputs can help to guide actions that target the 'critical' times and locations where a numeric attribute is likely to exceed a target threshold.

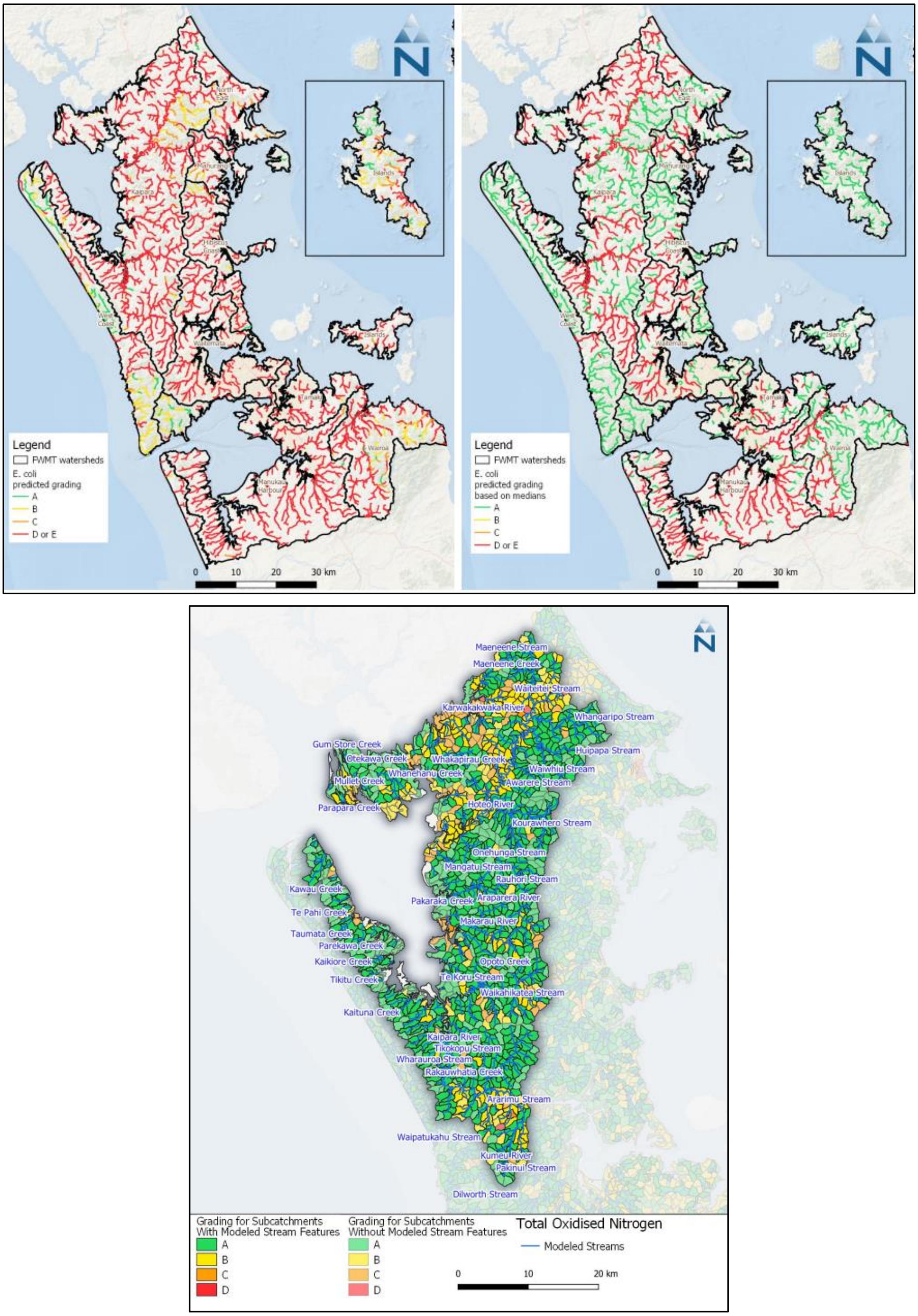

Figure 1: Top—Predicted stream grading for *E.coli* based on the worst performing numeric attribute state (left) and median concentration (right) (2013–2017). Bottom—Predicted sub-catchment grade for total oxidised nitrogen (TON) based on the worst performing numeric attribute state (2013–2017). Grading based on the NPS-FM (2020).

Why?

Taking action to improve water quality requires actors to understand not only the effect (e.g., in-stream contaminant concentration) but also the cause. Freshwater Management Tool outputs are simulated by applying a dynamic climate (i.e., a rainfall time-series) over one of 106 distinct 'land surface types' (Figure 2). Each land surface type represents key geophysiochemical (e.g., soils, slope, climate, land cover) and anthropogenic (e.g., imperviousness, land use) factors that influence variation in water quality across the Auckland region (grouped into 'hydrologic response units,' or HRUs).

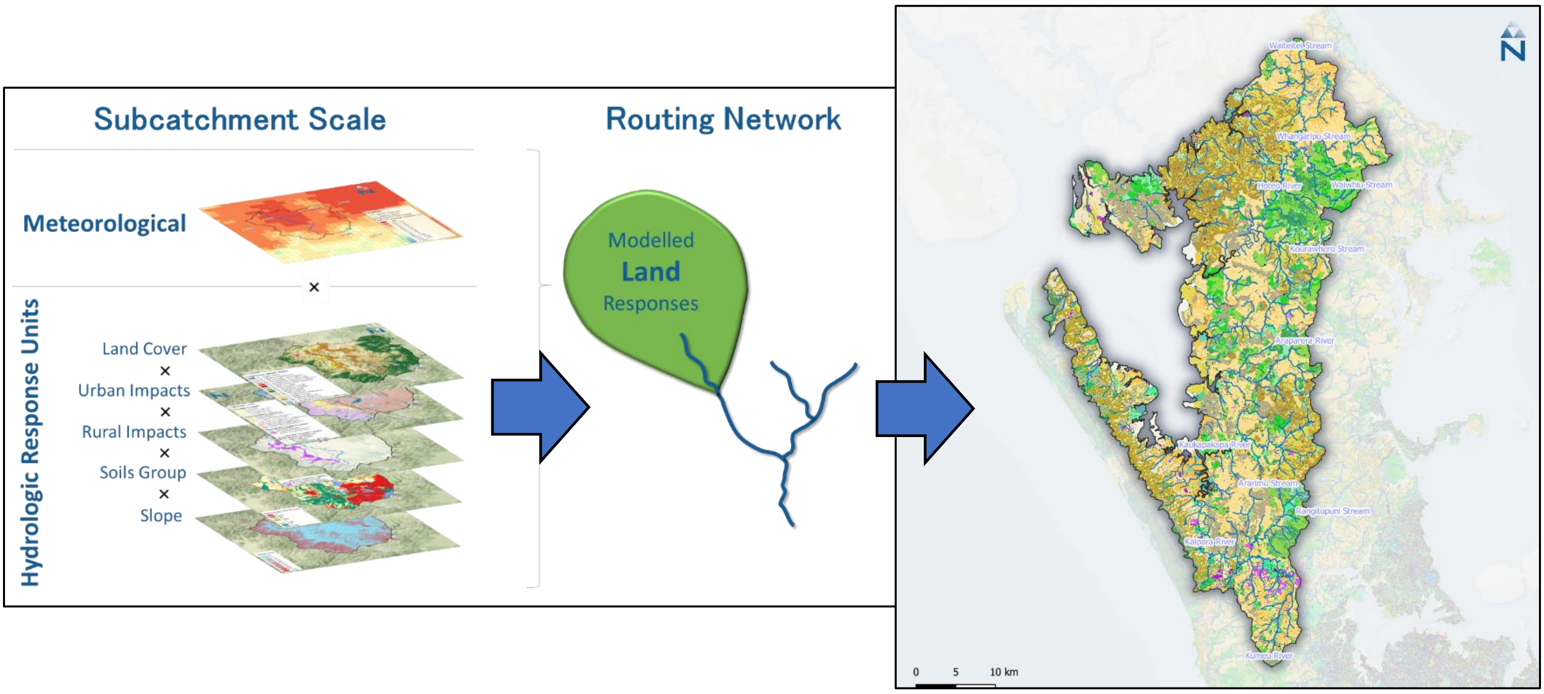

Figure 2: The FWMT's 'hydrologic response units' allow for the attribution of in-stream water quality state to sub-catchment landscapes and are defined at a 2x2 m resolution across the model domain.

Modelled land responses are routed downstream integrating both rural and urban sources and their combined effects—providing a full 'mountains to sea' view of contaminant generation, transport, and fate. Once entering the stream network, various instream processes then alter the form and availability of contaminants including processes for stream erosion which respond to stream hydrology and differences in channel composition (i.e., varying contaminant concentrations and form throughout journey from mountain to sea).

The process-bases of the FWMT allows actors, including freshwater farm planners, to not only understand the effect on receiving environments (e.g., the ecosystem response to contaminant loading), but the causes of water quality state. The interaction between hydrology—runoff, interflow, and groundwater—and contaminant sources, as well as the effect of flow on the distribution of loads (i.e., flow/contaminant direction and accumulation) and concentrations en-route (i.e., in-stream concentrations), underpin the FWMT's ability to attribute in-stream contaminant footprint to land activity status.

For primary industry land uses, the FWMT represents pastoral, horticultural, and forestry across two slope[2] and five soil drainage categories, providing land managers with detailed, objective information on catchment state, pressures, and risks at the sub-catchment (~100 ha) scale.

What if?

For land managers, industry bodies, network operators, funding providers, and regulators a key question for water quality improvement programmes is: *What if catchment land use or land management change (whether by regulation or investment)?* The ability to test scenarios and attribute real costs and benefits to both in-field/edge-of-field devices and practice-based change is made possible by the FWMT's 'mitigation library' (Figure 3) a robust database of feasible actions available to achieve a given water quality objective.

Mitigations are characterised by their effect on both hydrology and contaminant generation and/or transport (i.e., inclusive of both hydrologic and contaminant benefits) as well as full 50-year life cycle costs (Stephens *et al.* 2021). Costings are unique for New Zealand in that they are inclusive of land purchase (urban) and opportunity (rural) costs, ensuring fairness when determining where the required investment falls (e.g., ratepayer, developer, or landholder). As costs are also HRU-specific, farm system-specific differences in the costs and benefits of actions are accounted for (e.g., differences in opportunity costs across dairy, sheep and beef, and horticultural farm system types).

Choices for dairy & sheep and beef farm systems:

- Bundled **Good Farming Practices** (three levels of increasing GFP adoption)
- **Riparian** (stock exclusion, grassed or planted)
- **Detainment bunds**
- **Wetlands** (natural, constructed)
- **Soil conservation** (space-planting, retirement)

- Identification of feasible action location & extent
- Treated areas (upstream) are unique to each mitigation type.

- Sustainable costs (50-yrs)
- Outlay + maintenance + renewal + opportunity costs (specific to HRU type)

Figure 3: The FWMT's scenario modelling ability is underpinned by a detailed library of mitigation benefits, a geospatial representation of mitigation 'opportunity,' and full 50-year lifecycle costs. Opportunity mapping details the explicit location of all feasible interventions (e.g., those areas suitable for wetland remediation, of higher risk of mass wastage, or suitable for riparian management).

[2] Slope classes define the slope-based relationship parameter values underlying hydrological and contaminant processes within the model; however, the specific LiDAR-derived slope of each 2 x 2 m HRU raster cell is used to drive the process relationships.

However, scenario testing is not limited to mitigations. Hydrologic response unit and climate swapping allows for the determination of future, or predicted, state under changing climatic conditions, urban growth, changes in rural land use patterns, or all three.

Who, where, and how?

The final set of questions relate to actions. The questions of where and how to act 'optimally' in the landscape are fundamental to achieving targeted water quality improvement efficiently. The FWMT's current state assessment, process-basis, and mitigation library all combine to enable 'optimised action planning' (Figure 4)—a unique combination of feasible actions to achieve a water quality target or spend given an amount of investment, at least-cost or for greatest benefit, respectively. Once the *where* and *how* questions are answered, the question of *who* is required to act for any given action plan is made clear due to the HRU-specific mitigations within action plans (i.e., actions are explicitly linked to land use activity types).

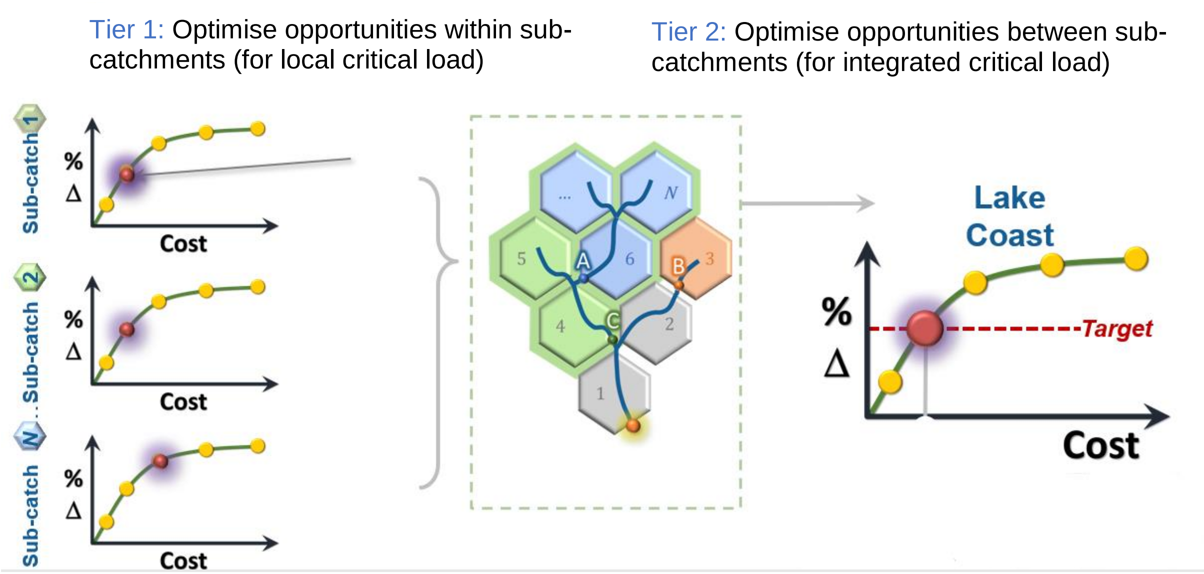

Figure 4: The FWMT's two-tiered optimisaiton routine ensures the greatest impact for investment while achieving desired outcomes both locally and at downstream assessment points. This approach ensures cumulative effects do not threaten the achievement of water quality targets.

For industry organisations, FWMT action plans provide an evidence base that can be used to seek additional investment. For rural professionals, farmers, and growers, optimised action plans link actions to catchment context information, a key input for freshwater farm planning, and provide direction on which on-farm devices or practice-based changes will have the greatest impact on sub-catchment water quality. Actions link water quality state with pressure, supporting targeted, consistent on-farm risk assessment across the region. Action plans also identify more efficient catchment-based mitigations that may cross farm boundaries or treat larger upstream catchment areas compared to farm-by-farm approaches that may favour local impact at the expense of a broader downstream objective or result in action redundancy—leading to decreased efficiency and increased spend for the same reduction in contaminant load to stream.

As optimisation can be constrained by HRU, mitigation type, contaminant, or geographic location, questions can be asked and assumptions tested regarding the fairness of costs across different actors, the relative importance of differing mitigation strategies (e.g., focusing on GFP vs. edge-of-field devices), the effect of prioritising one contaminant over another, or the impact of focusing on a specific receiving environment (e.g., streams require a concentration-based critical condition vs. lakes and coast where load defines the critical condition governing water quality state). Understanding the consequences of prioritisation approaches can help to ensure clarity of action and reduce implementation costs.

Case Study: The Mahurangi East Land Restoration Project

The Mahurangi East Land Restoration Project (MELR) is a $5 million, 5-year targeted remediation programme to improve health of the Mahurangi Harbour by reducing the amount of sediment eroding from land and waterways. Auckland Council and Ngāti Manuhiri Settlement Trust have partnered to design and deliver the programme, which is funded by the 'Jobs for Nature' Ministry for the Environment's (MfE) fund.

Optimised action plans are sought for each of six key sub-watersheds reflecting different communities and extension (Figure 5). The combined area of 12,308 ha represents 131 individual sub-catchments of ~40-100 ha each, with an optimised action plan computed for each prior to integration at six final assessment points. Action planning is informed by the FWMT's understanding of the current state of sediment loss to watercourses within the catchment as well as the sources of that sediment (Figure 6).

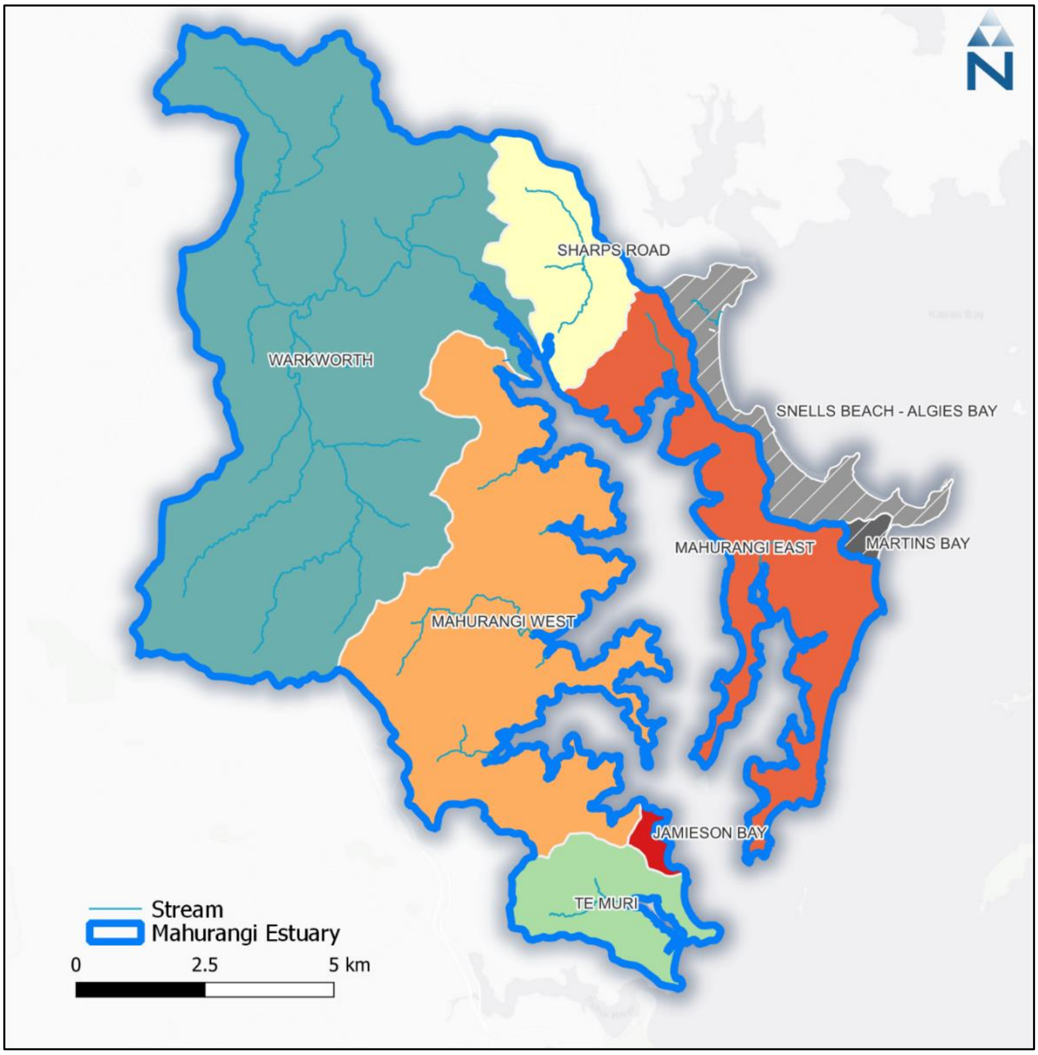

Figure 5: The Mahurangi East Land Restoration Project targets the loss of sediment to watercourses to improve the Mahurangi harbour.

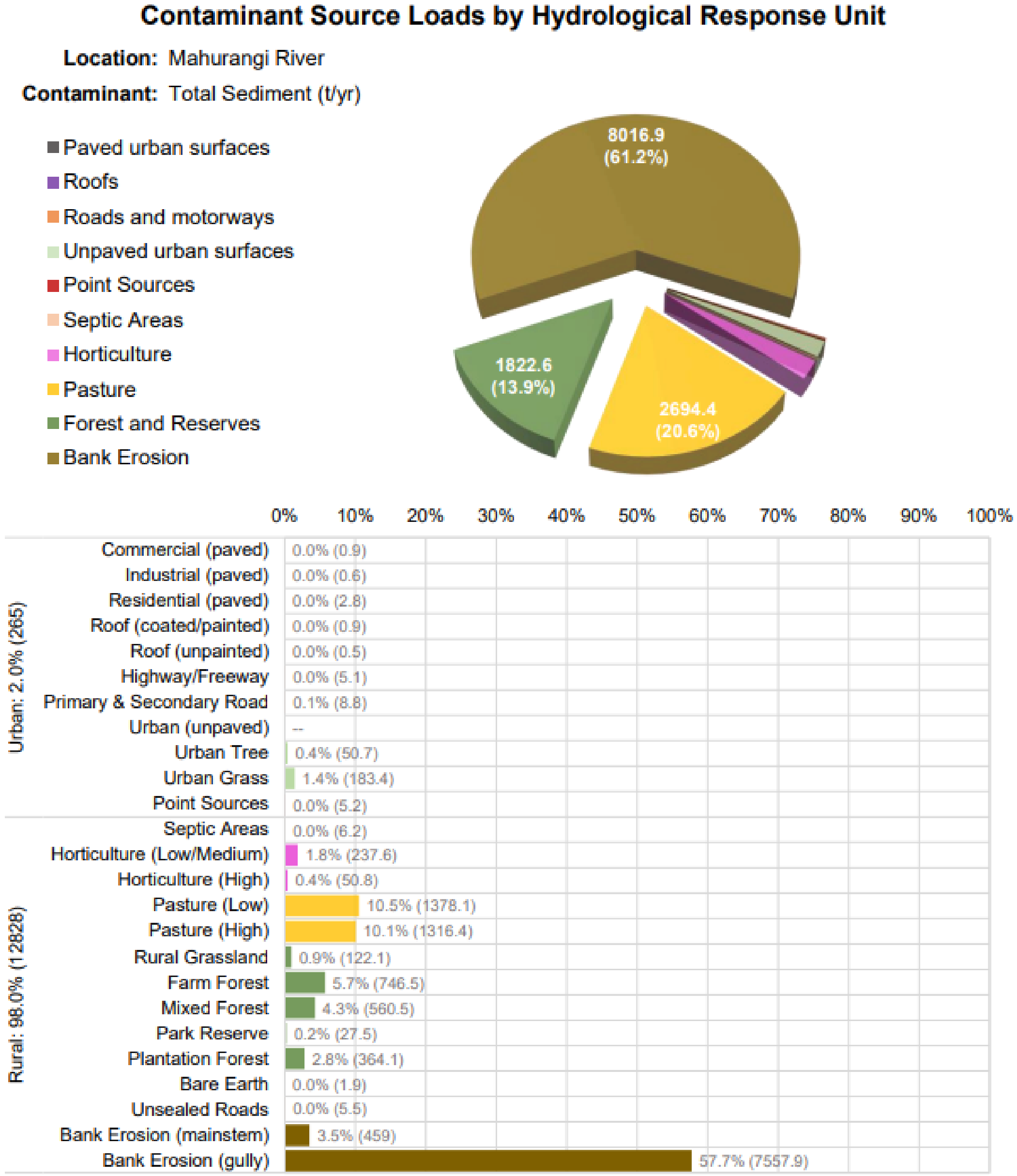

Figure 6: Total sediment loss (t/yr) by source (HRU) for the Mahurangi River Catchment. Note that not all the MELR project area falls within the Mahurangi River Catchment.

The combined optimised action plan was developed to guide investment within the catchment using the following criteria:

- Targeted contaminant: sediment (with co-benefits then modelled and reported for N, P, and *E.coli*)
- Assessment point: six terminal freshwater reaches (optimised outcome for sediment delivered to coast)
- Critical condition: annualised sediment load (all sediment discharged over 5-year baseline period; returned as an annual average reduction)
- Cost-optimised investment: $3.7M (shared 50:50 between MELR and landholders)[3]
- Available actions: wetlands, riparian management (one option: fenced—5-m setback—and native planted—10,000 stems per ha), highly erodible land management (one option: space-planted poplar at 70 stems per ha—opportunity limited to areas of highly erodible land on pasture[4])

The resulting optimised action plan (Figure 7 and Table 1) identified a spread of actions to achieve a maximum reduction in annualised sediment loads to coast from land and streams for a given total acquisition cost. That optimal spend of ~$3.7M (TAC) is simulated to achieve a ~9.8% reduction in the amount of sediment reaching the Mahurangi Harbour.

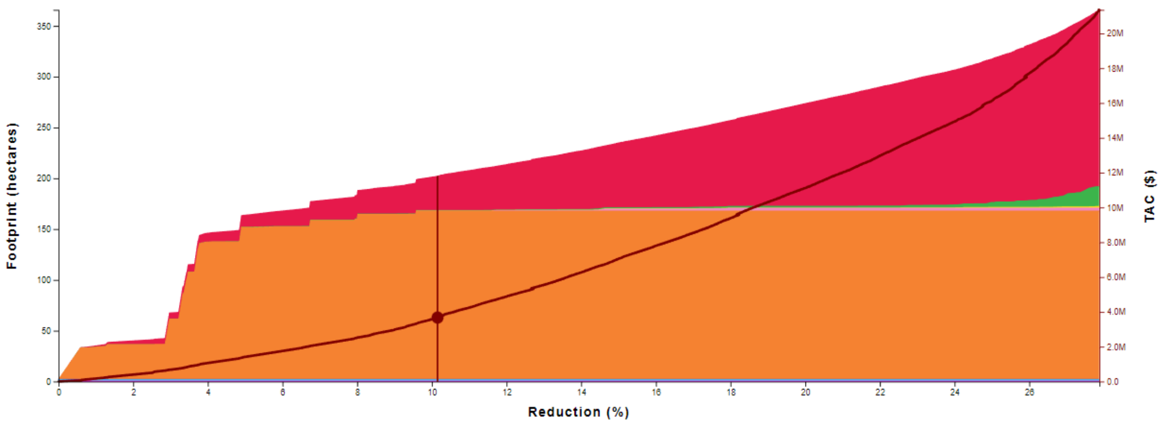

Figure 7: The FWMT's optimised action plan for MELR as represented in a single graph. The curved line represents the suite of 'least-cost' actions to achieve a given % reduction in sediment to coast. The vertical line is the single 'optimal action plan' that will achieve a ~9.8% reduction in sediment to coast for ~$3.7M TAC. The colours represent the area (footprint) for the various mitigations, or actions, within the action plan. A 9.8% reduction in sediment requires ~179 ha of space-planted poplar (orange) and ~34 ha of riparian planting (red, at 5-metre setback). Note the area of space-planted poplar plateaus at around the 10% reduction mark as most of the available opportunity for space-planting has been taken up by this point.

[3] While the reduction in sediment was optimised to reduce the total 50-year lifecycle cost, the figures reported represent the initial cost of implementation, or 'total acquisition costs' (TAC) exclusive of maintenance or renewal. TAC is the equivalent of those up-front costs for which MELR offers co-funding. See Stephens *et al.* (2021) for costing information.

[4] Highly erodible land was defined using Donovan's (2022) modelled land erosional yields derived for the Our Land and Water National Science Challenge—taking the 5% highest-yielding areas and intersecting with pastoral land cover to limit opportunity for highly erodible land management in the FWMT.

Table 1: Breakdown of total acquisition costs and area footprints by intervention type for the MELR optimised action plan.

Intervention type	Cost (TAC)	Footprint (ha)
Highly erodible land management (space-planted poplars)	$0.21M	179
Riparian management (5-m setback, native planted at 10,000 stems per ha)	$3.44M	34
Wetland (naturalised—fenced and planted, minimum earthworks)	$0.03M	0.34
Total	**$3.68M**	**213**

While the optimised action plan has helped Auckland Council and Ngāti Manuhiri Settlement Trust to prioritise programme funding, the geospatially explicit outputs (Figure 8) also provide direction to fund administrators on which catchments to target outreach and support field advisors to determine where actions will have the greatest impact on-farm.

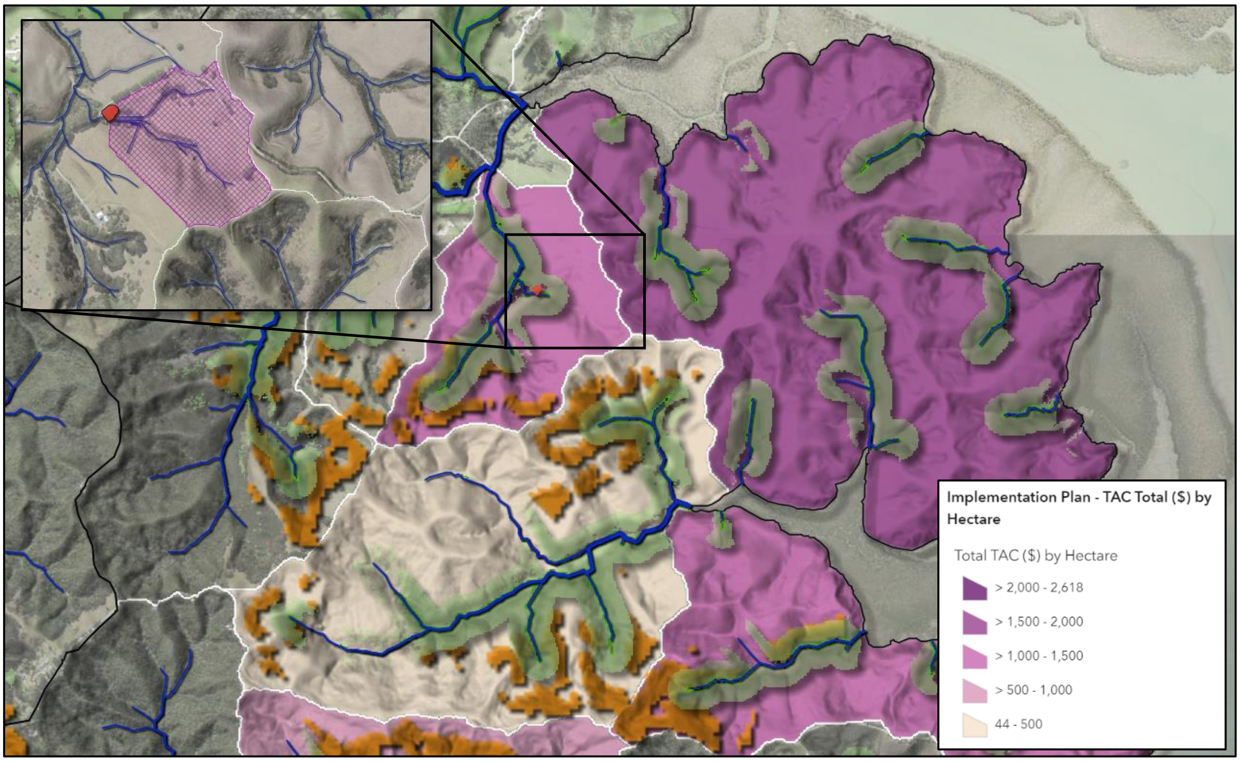

Figure 8: Geospatial FWMT outputs are produced to help direct on-farm action. In the above graphic, catchments are shaded purple to show the degree of spend (TAC) per ha required to achieve a targeted reduction in sediment to coast for least cost. Green areas represent chosen riparian planting opportunities, while orange areas represent the chosen space-planted poplar opportunity. The small red polygon represents a wetland opportunity. Inset shows wetland opportunity and corresponding treated catchment area.

Implications for targeted action planning

The FWMT approach is novel in New Zealand with no other decision-support tools linking a continuous, process-based understanding of water quality state at such high resolution (~100 ha sub-catchments, 15-minute time-series, 100+ land types, distributed stream network) to intervention and lifecycle-cost optimised modelling. The FWMT programme is nearing its full first stage (v1) completion of both baseline, scenario (future Auckland growth), and optimised action planning (for urban and rural water quality outcomes).

This paper frames some of the new innovative decision-support the FWMT programme now offers regionwide in Auckland and which is separately under development in watersheds within the Northland and Bay of Plenty regions.

The FWMT's focus on critical conditions, the generation of opportunity maps, and the development of optimised geospatial and costed action plans is a powerful new advance in how NZ Inc. delivers on aspirations for no further degradation and future improvement of water quality against a backdrop of historic, ongoing, and likely future pressures from resource use.

Notably, new projects are underway within the FWMT programme to develop the country's first high-resolution forecast climate time-series (2 km mesh, 15-minute time-series for rainfall intensity and other meteorological variation; NIWA and HW). Output from this work will permit decision-making for targeted actions not only for existing climate but equally for forecast future climate-driven changes in biophysical processes.

The FWMT produces guidance to the sub-catchment (~100 ha) scale, but with information resolved within each sub-catchment on mitigation opportunities, costs, and activity types. The combination of process-based (causative) understanding of water quality and available actions to a representative scale (sub-catchment, sub-watershed, watershed, region) is now informing the targeted investment of Crown and rate-payer funds to deliver greater water quality outcomes. Equally, the outputs are being explored for use in aiding primary industry farm-environment decision-making, regulatory regional planning, and integrated catchment planning and operations. Healthy Waters is now keen to examine use of the FWMT to guide and account for freshwater farm planning—helping to direct actions to best achieve water quality objectives and importantly, to assign benefits to actions (past, present, and future) taken by farmers and growers. Rewarding landholders with transparent, objective estimates of how actions in freshwater farm plans will improve water quality is seen as key to driving meaningful change.

Accounting, or the act of assigning a forecast benefit to actions, is likely to become an essential part of New Zealand's adaptive management response to the NPS-FM. The FWMT supports adaptive management by overcoming monitoring and empirical modelling constraints, particularly where action implementation is expected to take years to decades and the resultant effects in receiving environments are then likely to be delayed longer still before being detectable with current monitoring approaches (e.g., subject to marked response delays, hysteresis instream, unable to disaggregate individual freshwater farm plan benefits on contaminants and environmental flows). Consider the timeframe for root and canopy development to occur following space-planting to stabilise an area of mass wastage (Phillips *et al.*, 2020) and longer period still, for eroded material instream to be discharged before some new improved state is achieved.

As the rural sector looks to fully implement the Government's *Essential Freshwater* package, this paper has demonstrated how the FWMT's lifecycle optimisation and intervention modelling can be used to derive least-cost strategies for remediating catchments. Combined with its use as an accounting tool, the FWMT offers farm environment planners, farmers and growers more direction on actions to prioritise and credit for action taken. Accounting for change—now and into the future.

The FWMT team encourages collaboration. If you would like to know more about the FWMT or see a use for the tool in your work, the FWMT team would like to hear from you: fwmt@aukclandcouncil.govt.nz.

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