CURRENT AND FUTURE STATE OF AUCKLAND'S WATERSHEDS: STAGE 1 FRESHWATER MANAGEMENT TOOL

Dustin Bambic (Paradigm Environmental), Tom Stephens, Coral Grant, Tom Porter and Nick Brown (Auckland Council Healthy Waterways Department), Caleb Clarke (Morphum Environmental)

ABSTRACT

Auckland Council (AC) is responsible for the management of freshwater quality and quantity in the Auckland region. The National Policy Statement for Freshwater Management (NPS-FM) has driven an array of studies, programs, and policy considerations by AC. Regarding the hydrology and water quality in our streams and rivers, a key technical element of AC's process to set freshwater objectives, establish limits, and propose methods for achieving objectives is the Freshwater Management Tool (FWMT). The Wai Ora-Healthy Water programme is currently developing the FWMT, a regionwide dynamic modelling system to simulate water quality current state and evaluate future state under a range of interventions (e.g., structural devices, good practices and diversified land use).

The FWMT is built using open-source, process-based, continuous simulation models developed by the U.S. EPA – the current state model is the Loading Simulation Program – C++ (LSPC) and the future state model is the System for Urban Stormwater Analysis and Integration (SUSTAIN). Continuous simulation is an important component of the approach, as management of freshwater quality requires prediction of the frequency, duration and magnitude of contaminant events, both for grading state and better determining appropriate interventions. Longer-term contaminant loading and concentration under steady-state can equally be estimated by the FWMT, at varying spatial scales from sub-catchment to catchment or harbour.

At the 2018 Stormwater Conference, we shared preliminary data processing for initial FWMT set-up. At the 2019 Conference, we will present FWMT Stage 1 LSCP output:

- Current state outputs regarding the region's hydrology and water quality (sediment, nutrient and metals concentrations);
- Calibration process and example output for current state, based on flow and water quality data across State of the Environment monitoring and end-of-pipe data;
- Evaluation of current monitored and modelled state to national and regional freshwater guidance, emphasizing greater regional modelled representation; and
- Next steps in finalization of FWMT Stage 1 development due for completion of current state capability by mid-2019.

We will describe the FWMT Stage 1 SUSTAIN (future state) model development, including long-term vision for how the FWMT will support AC decisions, policy, planning and stakeholder engagement for the NPS-FM. Combined, both FWMT model elements will enable robust scenario-testing of changes in contaminant generation, transport and interception into the future from targeted, optimized strategies for devices, practices and land use, whether to freshwater or coastal.

KEYWORDS

water quality, stormwater, contaminants, modelling, hydrology, national policy statement for freshwater management,

1 INTRODUCTION

Auckland Council is responsible for the management of freshwater quality and quantity in the Auckland region. Since 2011, the National Policy Statement for Freshwater Management (NPS-FM; MfE, 2017a) has driven an array of studies, programs, and policy considerations by Auckland Council into improved freshwater resource management. Amendments to the NPS-FM in 2014 introduced greater reporting requirements across a diversity of attributes (water quality parameters), at increased numeric and spatiotemporal resolution, to ensure water quality can be more rigorously maintained or improved (the National Objective Framework – NOF). Now since 2017, the NPS-FM has set ambitious goals for improved recreational water quality nationwide across freshwater management unit and especially moderate-sized waterways (e.g., 4th order rivers, lakes >1500m circumference; MfE, 2017b).

Auckland Council is uniquely positioned to implement the NPS-FM, with support from a $452M targeted rate for water quality over the next decade. This targeted rate funds activities such as rehabilitation of waterways, stormwater contaminant removal and wastewater upgrades (AC, 2018). The need to make generational and costly changes in freshwater quality under the NPS-FM, urgently under the targeted rate (AC, 2018), demands considerable strategic investment and decision-making capability from Auckland Council. The basis of that decision-making is complex, a catchment accounting framework able to resolve differences in contaminant loading, processes and intervention opportunities, spanning the entire region from harbour to sub-catchment: the Freshwater Management Tool (FWMT).

The FWMT is a continuous simulation, process-based model able to simulate the contribution and behaviour of contaminants in runoff, interflow and active groundwater from rainfall (e.g., Grant et al., 2018). By determining the regional spread in current state, not simply for generalized conditions but for periodic runoff events, through a distributed network of streams (spanning the entire region and resolved to sub-catchment scale), the FWMT can determine evidence-based regional objectives for water quality. For instance, changes in hydrology and/or contaminant loading required to support agreed, future water quality outcomes.

The FWMT also enables scenario-testing. Opportunities for devices or interventions are determined from device performance and landscape constraints (e.g., for reticulated stormwater management: the upstream drainage catchment area, distance to stormwater offtake, slope of device area). Alongside general "source control" reductions in contaminant (either independent of hydrology or tied to gradients in rainfall-runoff), strategies can be determined for improved future water quality. That exercise can be scaled across sub-catchments, catchments and harbours to optimize outcomes by cost, for both instream and downstream outcomes.

The FWMT thereby delivers on two requirements of improved freshwater management by Auckland Council: (1) refined understanding of current freshwater quality state (i.e., highly resolved in space and time); and (2) the ability to determine future possible changes therein, as well as strategies to achieve future freshwater quality outcomes. *Region-wide*, that is with calibration and planning responses geared at regional rather than catchment-specific use.

Managing contaminants through an integrated whole-of-catchment approach, inclusive of sensitive coastal receiving environment, is a key requirement of the NPS-FM. Modelling the likely future freshwater quality state hand in hand with interventions required thereof, provides Auckland Council with a powerful infrastructure and regulation planning tool for the NPS-FM.

2 APPROACH & STRUCTURE OF FWMT

2.1 Staged build

An overview of Auckland Council's ongoing process to develop and apply the FWMT for its dual requirements is provided in Figure 1. The FWMT being developed in the near-term, leading up to full scenario planning for primary contaminants, is referred to as the FWMT Stage 1. These contaminants include: total nitrogen (TN), dissolved inorganic nitrogen (DIN), total phosphorus (TP), dissolved reactive phosphorus (DRP), total copper (TCu), total zinc (TZn), total suspended sediment (TSS) and *E.coli*.

Future stages are envisioned to incorporate improved datasets, expanded scope of processes and increased diversity of interventions in the rural and urban landscape. Such an iterative approach was chosen to rapidly progress regional planning for the NPS-FM and support engagement with peers and stakeholders early. The approach also enables future changes heralded by the Government to the NPS-FM to be incorporated readily into the FWMT Stage 2 (e.g., MfE, 2018).

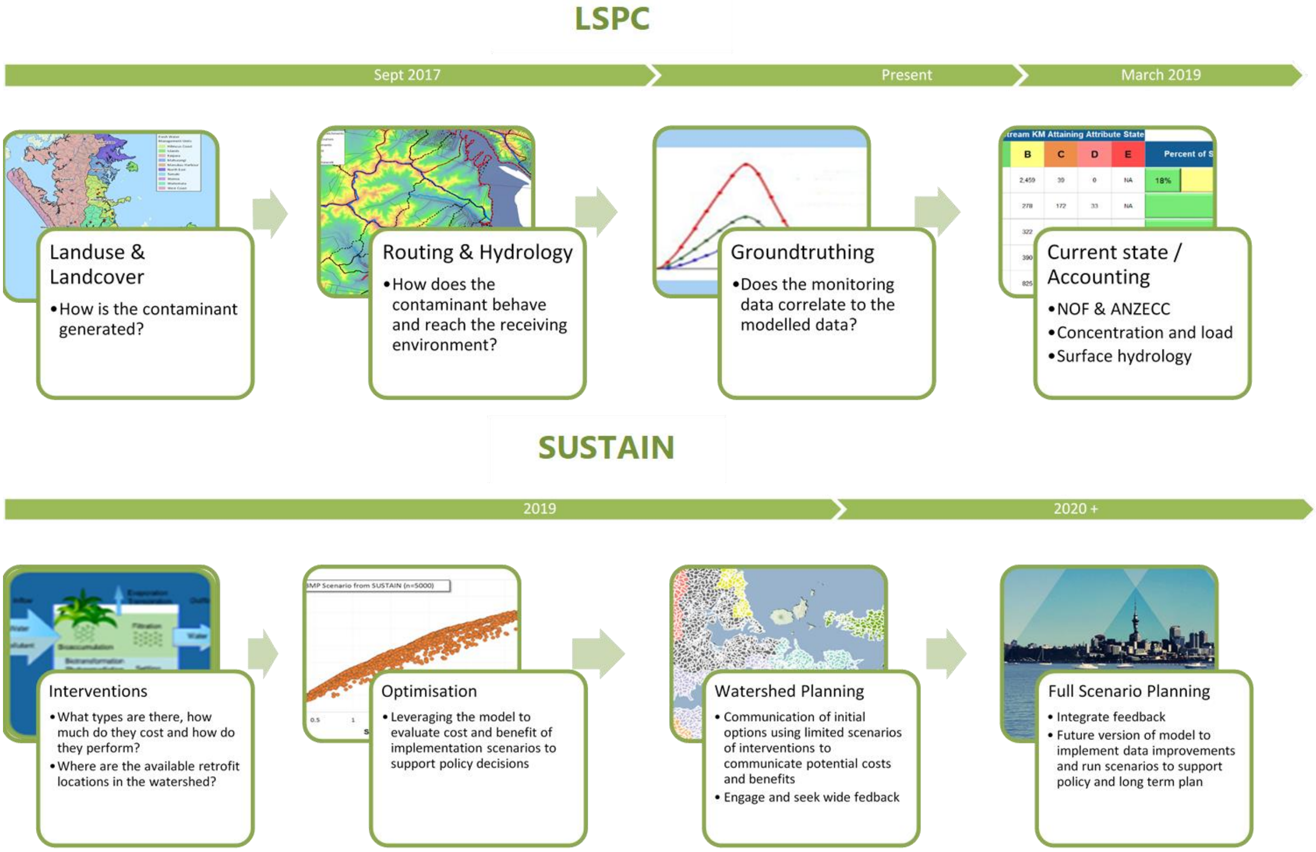

Figure 1. Near-term process for FWMT development to support NPS-FM implementation.

2.2 Modelling framework

The FWMT is comprised of two components: (1) a distributed hydrology and water quality model for primary contaminants (Loading Simulation Program – C++ [LSPC]; and (2) an intervention optimisation model to simulate the effects of structural devices and more generalized, source-control linked to management practices or land use (System for Urban Stormwater Treatment and Analysis INtegration [SUSTAIN]) (Figure 2).

In line with recommendations for best-practice modelling and environmental decision-making in Ozkundaci et al. (2018), both FWMT model components are free, open-source, public-domain models which have been subject to extensive peer review and continued application over two decades since their development for the US-EPA national total maximum daily load toolbox (link) (Figure 3). The LSPC-SUSTAIN modelling system has been used for a variety of watershed-scale implementation strategies in the U.S. inclusive of peer and statutory review (e.g., Los Angeles, San Diego, and San Francisco Bay Area [Black and Veatch et al., 2016; City of Calabasas et al., 2016; Ch2m et al., 2016; MWH et al., 2016; Dominguez Channel Watershed Management Area Group, 2016; Larry Walker Associates et al., 2016]).

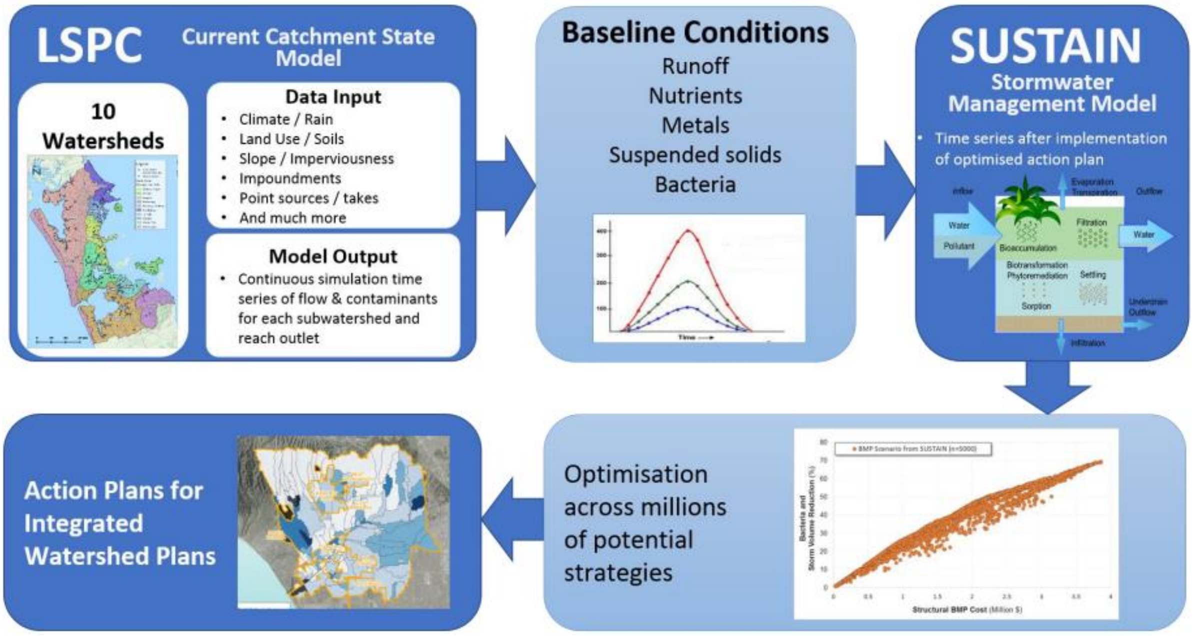

Figure 2. The FWMT is comprised of two modelling components developed by the US-EPA (LSPC and SUSTAIN) to determine current and optimized future freshwater quality state.

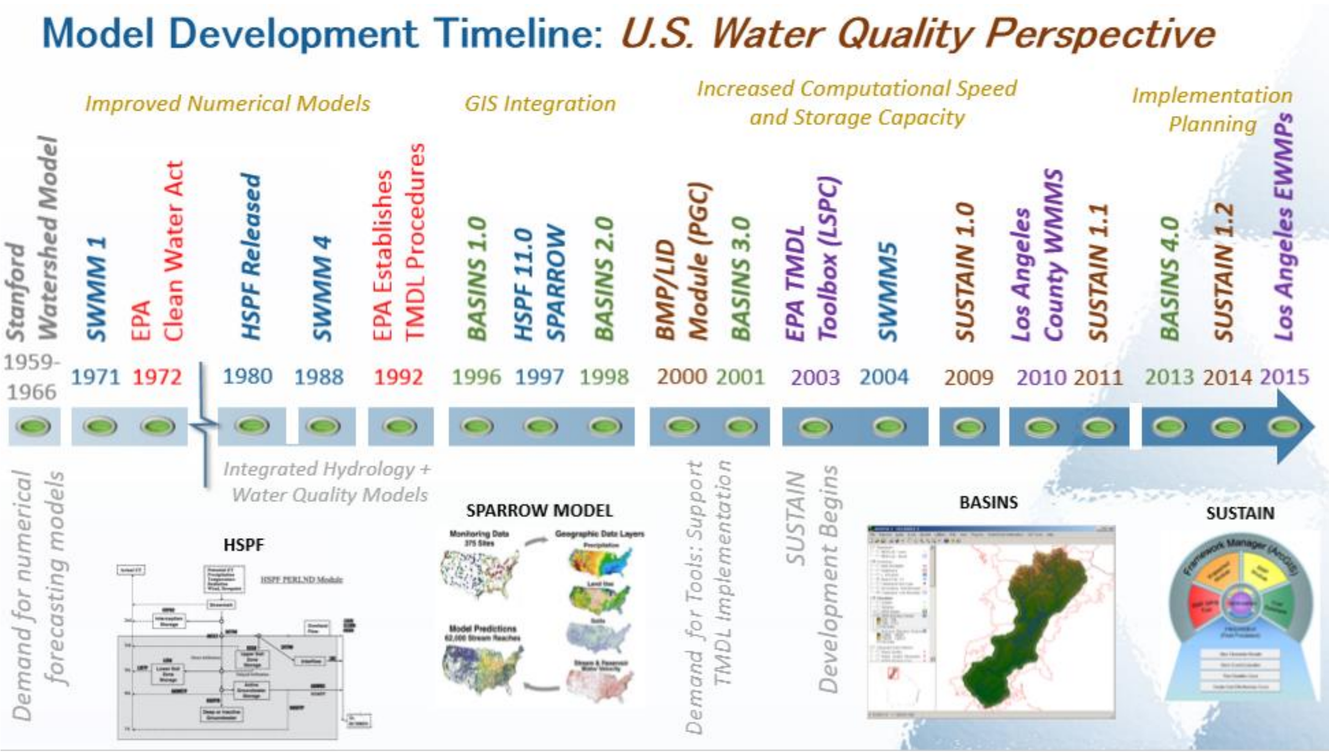

Figure 3. Evolution of the U.S. water quality models including LPSC and SUSTAIN.

2.3 Current State: LSPC Components

LSPC continuously simulates rainfall-runoff dynamics, including interflow and active groundwater components of streamflow and detention devices (e.g., water supply dams, stormwater ponds). The FWMT applies LSPC in a large-scale (whole of region), high-resolution build that simulates over 3000 km of modeled stream network and ~5,400 sub-catchments (Figure 4).

Baseline conditions in LSPC are derived from NZ datasets on: land cover, intensity of use and extent (Agribase, LCDB4); urban impervious area type and extent (LINZ, Auckland Council and NZTA datasets); vegetation layers and height (Auckland Council); soil order (S-MAP); rainfall, evaporation and temperature (Auckland Council point gauges and NIWA VCSN[1]); digital elevation model-estimated stream network and slope (LiDAR); stream network profile and composition (Auckland Council); and stormwater and wastewater network, including point source discharges and Type 1 and 2 overflow locations (Watercare, Auckland Council[2]). On-site wastewater contributions were approximated through a risk-based approach, limited to sub-catchments not served by reticulated wastewater networks and based on roofing extent.

Land cover, intensity of use, soil order and slope are combined into classes marking shifts in each factor's response to rainfall and/or gradient in contaminant generation, to create a matrix of ~120 "hydrological response units" (HRU). Each HRU is parameterized with key build up and wash-off parameters that allow for continuous simulation of runoff and contaminants, whereby concentrations depend on instantaneous and antecedent weather conditions. The yield (or response) of each HRU depends on its location and corresponding weather through time. This fundamental mechanistic approach represents a major advance in contaminant modelling capability for Auckland Council, which previously relied upon annualized unit-area yields that varied only by land cover rather than by rainfall, nor wider land attributes. The process-based simulation of contaminants within the FWMT will provide the ability to analyze a variety of conditions of varying duration and intensity, from average annual load to rainfall-based or flow-based event equivalents, throughout the stream network for primary contaminants. Note, model scope has grown to include processes related to dissolved nutrient species (DIN, DRP) whereas output is presented here from application of a mass-balance filter to TN and TP (i.e., determining contributions of modelled dissolved to total nutrient mass based on the ratio of observed dissolved to total nutrient mass at SOE stations region-wide, for 2013-2017, that were uniformly applied to each modelled TN or TP time-step).

The HRUs comprise the building blocks for each of the ~5400 sub-catchments, whose discharge and contaminant masses are routed by LSPC through the stream network. Each receiving reach segment can then be assessed for contaminant state, in terms of national or regional guidance (e.g., percentile annualized or event-based exceedance of a concentration or load threshold).

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[1] Auckland Council is implementing rainfall time-series from Auckland Council radar datasets to enhance resolution of rainfall-runoff variation in space (<4km), which could be used in future model builds.

[2] Auckland Council has generated wastewater overflow time-series for three major service areas (Mangere, Warkworth, Rosedale) that have been applied to 391 overflows as point-sources with 15-yr, 15-minute timesteps to generate wastewater overflow concentrations entering the freshwater receiving environment.

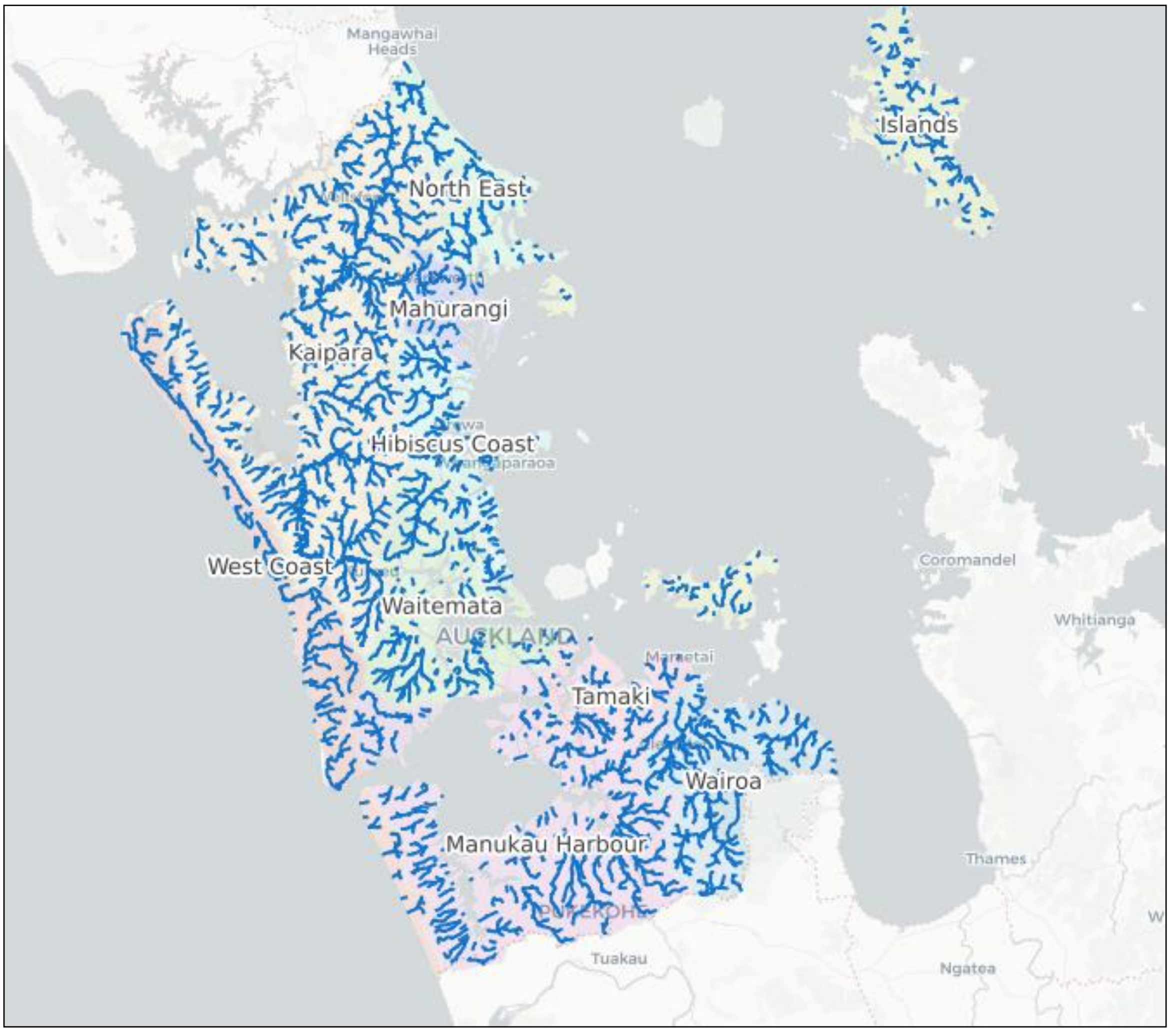

Figure 4: FWMT Model Stream Network in Auckland Council with LSPC

2.2 Future State: SUSTAIN components

The future state output of the FWMT is generated with the SUSTAIN model, developed by the USEPA to support practitioners in developing cost-effective management plans for municipal stormwater programs and, evaluating and selecting best management practice (BMP) to achieve water quality goals (USEPA, 2009).

SUSTAIN was originally developed as a decision support system for selection and placement of structural devices at strategic locations in watersheds (e.g., for contaminant interception). It includes a process-based continuous simulation BMP module for representing flow and pollutant transport routing through various types of interventions, providing the primary application of SUSTAIN – continuous simulations of stormwater device performance.

As a component of the FWMT build, SUSTAIN is being expanded to allow for evaluation of non-structural control measures such as improved management practices (e.g., riparian, land, nutrient and effluent management practices) and land use diversification (e.g., shifting underlying land uses within sub-catchments). The latter simulating reduced contaminant loading at source ("source-control"). Improved management practices can also be tied to devices and/or to urban HRUs to simulate improved "treatment-trains" (e.g., GD01 – AC, 2017). Collectively, representing both interception and source control on urban and rural HRUs, to support the regionalized use of the FWMT Stage 1.

A secondary application of SUSTAIN is simulating cumulative effects of interventions, practices and/or land use change, for optimal cost-benefit of achieving contaminant targets. The SUSTAIN model includes a cost database (and earlier efficacy database). SUSTAIN identifies opportunities based on "decision variables" that constrain devices, mitigation practices or land use change. As device sizes and locations change, so do cost and performance. SUSTAIN uses an optimization engine to iteratively generate a cost-effectiveness curve comprised of millions of possible scenarios at watershed-scale. From these, SUSTAIN identifies mitigation strategies applied to HRUs and/or stream/piped networks, for cumulative sub-catchment or catchment outcomes on hydrology and contaminants (e.g., concentrations and loads - see Figure 5).

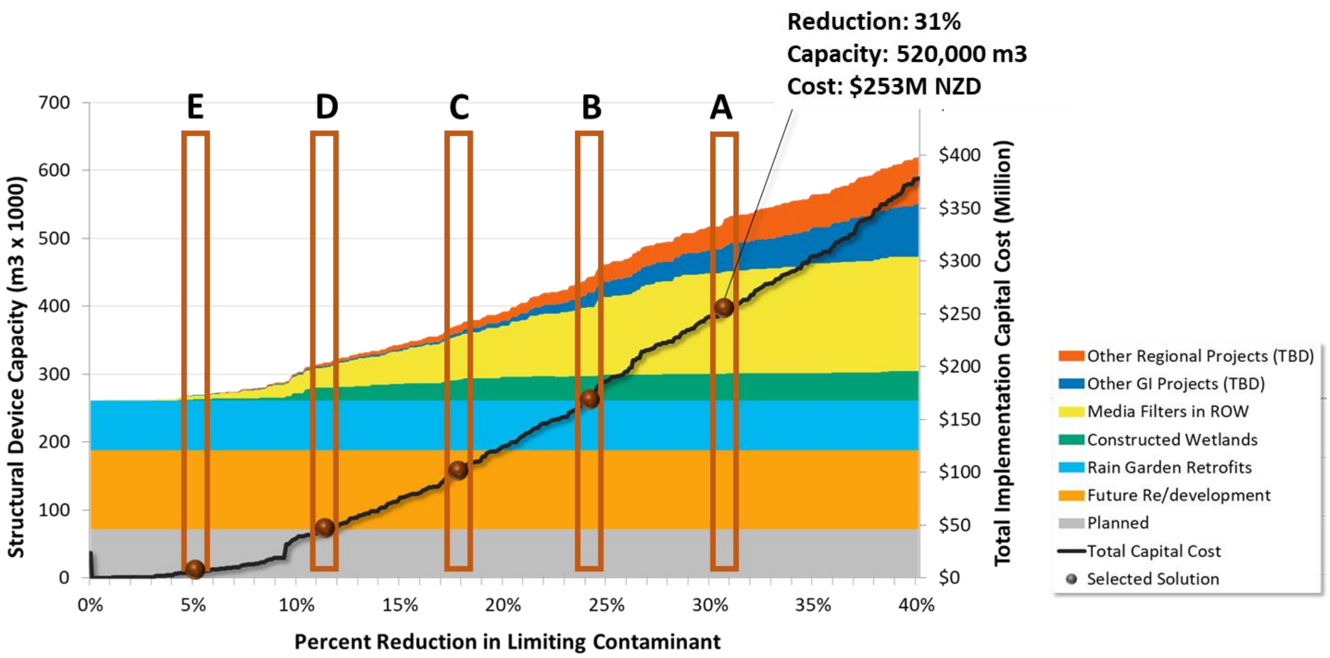

Figure 5: Hypothetical illustration of SUSTAIN output from the FWMT (integrated across sub-catchments) to assess the cost and benefit of strategies to achieving contaminant reductions for NPS-FM attribute states outcomes. Note the expanded capability on earlier US applications, to incorporate practiced-based and land use-change based options. Device capacity is read from height of coloured bars, cost from black line.

The SUSTAIN model build for the FWMT is in early development. Key considerations facing AC include the range and choice of devices or source-control to simulate, the constraints and performance assigned to these (e.g., requirements, cost, efficacy) as well as the locations to optimize for (e.g., river mouth, 4th order streams). Nonetheless, Figure 5 illustrates how SUSTAIN outputs can evaluate the cost-benefit and mix of strategies to achieve improved water quality under the NPS-FM. The FWMT will also help identify where constraints otherwise preclude attribute states (i.e., improvement to "A" grading might not be possible to attain within constraints of devices or source-control).

3 INITIAL CONFIGURATION AND CALIBRATION OF FWMT CURRENT STATE

The FWMT Stage 1 LSPC model has utilized a variety of datasets for configuration and a calibration approach focused on State of Environment (SOE) river stations – monitoring locations utilized for assessment of regional state and trend of water quality and quantity across rivers, with typically monthly resolution of flow and contaminant concentration.

3.1 Configuration of the LSPC Model

The Stage 1 LSPC model required formatting of wide-ranging datasets noted in Section 2.3, configured for the period 2013-2017[3] across climate, land use, wastewater/stormwater and soils. Output from configuration is summarized in Table 1, resulting in ~5400 sub-catchments of ≥40Ha, with approximately one model stream segment per sub-catchment. Modelled area excludes several islands in the Hauraki Gulf.

The delineation of the stream network and sub-catchments required intensive processing to identify the pipe network and impoundments (e.g., location, direction of flow, gradient and capacity). Major point sources including wastewater overflow and stormwater discharge points are incorporated (e.g., network piping >300mm discharge points). Piped channels were represented as natural stream flow-paths except for sub-catchments where the entire model flow segment was piped, in which case they were delineated as artificial, piped flowpaths (e.g., sub-catchments with mix of natural stream channel and culverts, represented throughout as stream flow-path). Major takes with dedicated, telemetered flow-series were included as abstractions on flow, and only wastewater effluent directly discharged to freshwater was included as a point source (e.g., Wellsford; all others discharging to land or marine environments excluded). Overflow points include exit of pipes as point-sources for the Warkworth, Waiuku, Rosedale, Pukekohe, Mangere and Army Bay networks only.

Stream channel geometry was determined from watercourse assessments and otherwise from relationships to drainage area within the watercourse dataset. Note the LSPC model includes 3,000km of streams and does not explicitly represent many of the lowest order streams in the region. For instance, the estimated total permanent and intermittent stream network in Auckland is approximately 23,760km, of which 3,634km span all third to seventh order streams (i.e., 100% of >3rd and 70% of 3rd order streams included; Storey and Wadhwa, 2009)[4]. This resolution offers a compromise between computational demands and the Auckland Unitary Plan's focus on intermittent and permanent streams.

Sub-catchments were assigned a representative rainfall time-series from an AC operated rainfall station if the latter centroids were within 5km of corresponding station, and if not, from interpolation of the NIWA Virtual Climate Station Network (VCSN) to those sub-catchment polygon centroids.

Along with representation of physical features, the configuration of LSPC Stage 1 involved populating the model database with initial process parameters derived from several sources, including previous calibrated versions of the LSPC model (United States), modelling literature (NZ, international), prior regional modelling (Contaminant Load Model and CLUES), and contractor reports for Auckland Council (e.g., end-of-pipe, pervious and impervious surface stormwater data from URQIS, RIMU and HW).

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[3] LSPC has been configured with stationary HRUs, meaning HRU boundary and types were held constant in space from 2013-2017 to represent current state. Further configuration is occurring for future state LSPC output, revising rainfall and HRU distribution to reflect future scenarios.

[4] FWMT includes <40Ha contaminant yields in accounting, representing their build-up and wash-off explicitly but routing this direct to the sub-catchment of >40Ha and associated stream segment.

Table 1: Stage 1 LSPC Segmentation and Explicit Point Sources and Takes for FWMT

Watershed	Model segmentation			Distribution of HRU (km^2)			
	Sub catchments	Total area (km^2)	Stream length (km)	Developed	Horticulture	Pasture	Forest
Hibiscus coast	373	256	157	33.4	4.2	90.7	65.1
Islands	442	386	160	2.8	5.2	70.6	212.2
Kaipara	1,417	1,406	1,041	9.0	23.6	914	256.2
Mahurangi	140	129	70	3.0	2.4	70.9	26.9
Manukau Harbour	1,060	918	529	76.8	58.3	446.8	146.5
North East	278	241	130	2.5	4.9	133.7	49.0
Tamaki	294	190	97	47.0	0.9	40.4	40.3
Wairoa	419	420	365	2.6	4.8	251.1	103.0
Waitemata	607	434	252	100.0	9.3	94.8	122.7
West Coast	435	409	262	8.1	7.1	123.1	203.3
Total	5,465	4,788	3,064	285	121	2,236	1,225

3.2 Calibration of the LSPC Model

Calibration of the FWMT Stage 1 LSPC model is an iterative process, whereby model performance is regularly gauged and improved over time with additional data. That includes within Stage 2, targeted monitoring to better resolve and improve performance along gradients of physical, climatic or instream process, contaminant and device.

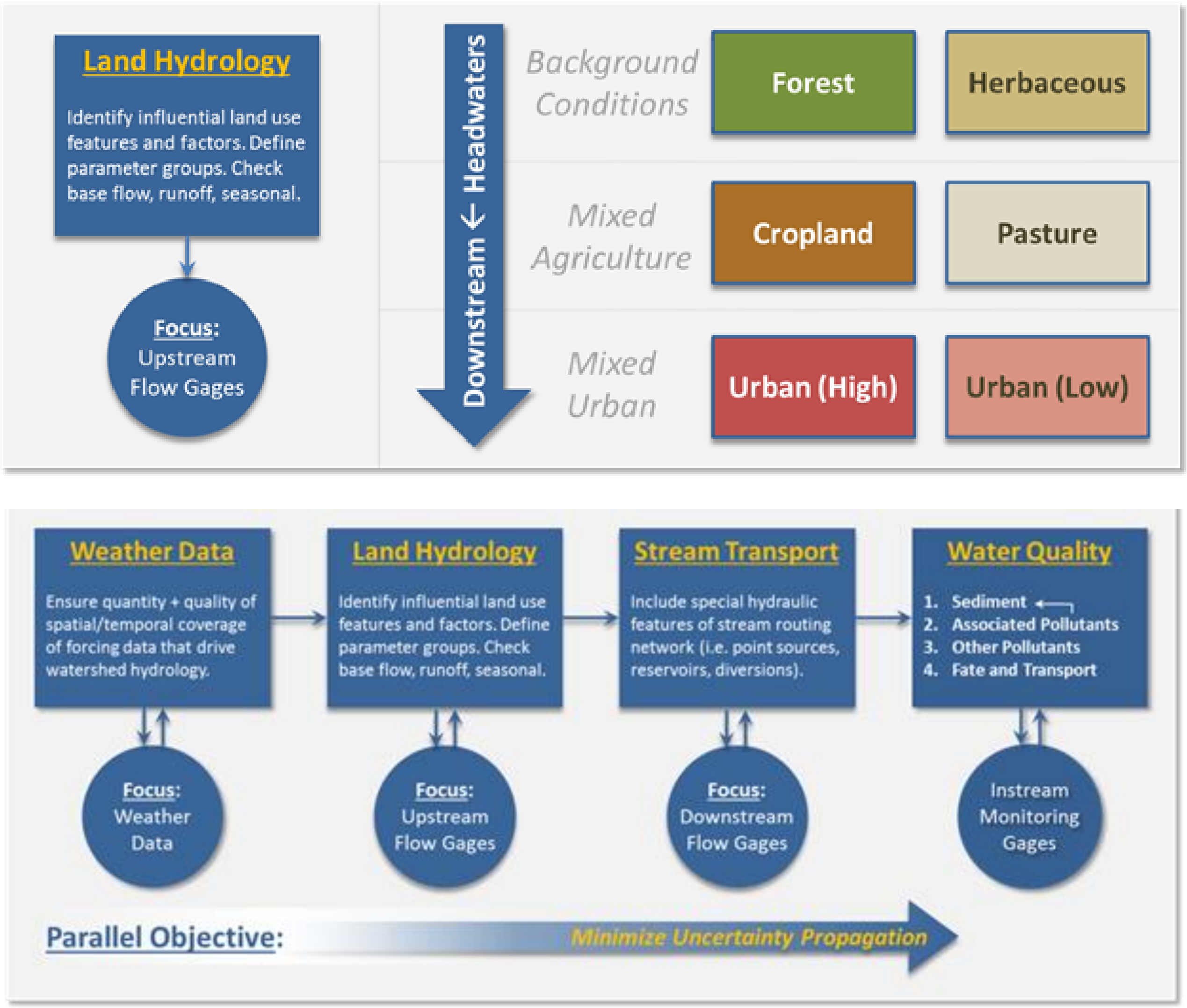


Figure 6. Illustration of baseline calibration process considering land use (top) and uncertainty of boundary condition data (bottom)

The FWMT Stage 1 LSPC calibration has used a process designed to address error and uncertainty (Figure 6). The process generally follows from upstream to downstream, both in terms of land use (from headwaters to terminal watershed outlets) and boundary conditions (from precipitation data to instream contaminant concentrations). The hydrology and water quality calibration has leveraged from SOE river monitoring, largely for the period 2013-2017 (but extending to 2003-2017 at some stations). Of the 36 SOE river stations with hydrometric data, 23 were utilised after filtering to exclude those with infrequent, unrepresentative and/or inconsistent data. The 23 flow-calibration stations covered a broad range of HRU, sub-catchment area and hydrographic conditions.

Calibration has focused on the most recent 5 years of observations (2013-2017), to align model performance with the underlying, "static" land cover and intensity assumed by LSPC (note: the LSPC model can time-vary land cover and intensity, but that functionality is not being utilised in the FWMT Stage 1 build.)

For each SOE river station, a detailed set of statistical performance metrics were generated. The performance metrics for hydrology are shown in Table 2, which are defined from LSPC applications for the USEPA on continuous simulation model performance. These metrics would be considered conservative in prior LSPC builds (Lee et al., 2012; Riverson et al., 2012; Chen et al., 2014), more so for the FWMT, where calibration is performed at regional scale (i.e., process behaviour cannot vary between streams of equivalent HRU composition but can vary across the 106 HRU types and respond to varying rainfall and stream geomorphology within sub-catchments). However, this reflects the NPS-FM requiring detailed understanding of event-based and continuous contaminant effects on freshwater quality.

Table 2: Example quantitative metrics for hydrologic calibration assessment

Model Component	Very Good	Good	Fair	Poor
Error in Total Volume	< 5%	5-10%	10-15%	> 15%
Error in 50% Lowest Flow Volumes	< 10%	10-15%	15-25%	> 25%
Error in 10% Highest Flow Volumes	< 10%	10-15%	15-25%	> 25%
Error in Storm Volumes	< 10%	10-15%	15-25%	> 25%
Winter Volume Error	<15%	15-30%	30-50%	>50%
Spring Volume Error	<15%	15-30%	30-50%	>50%
Summer Volume Error	<15%	15-30%	30-50%	>50%
Fall Volume Error	<15%	15-30%	30-50%	>50%
R^2 Daily	>= 0.8	>= 0.7	>= 0.6	<0.6
R^2 Monthly	>= 0.85	>= 0.75	>= 0.65	< 0.65
NSE annual	>= 0.75	>= 0.5	> 0.25	<= 0

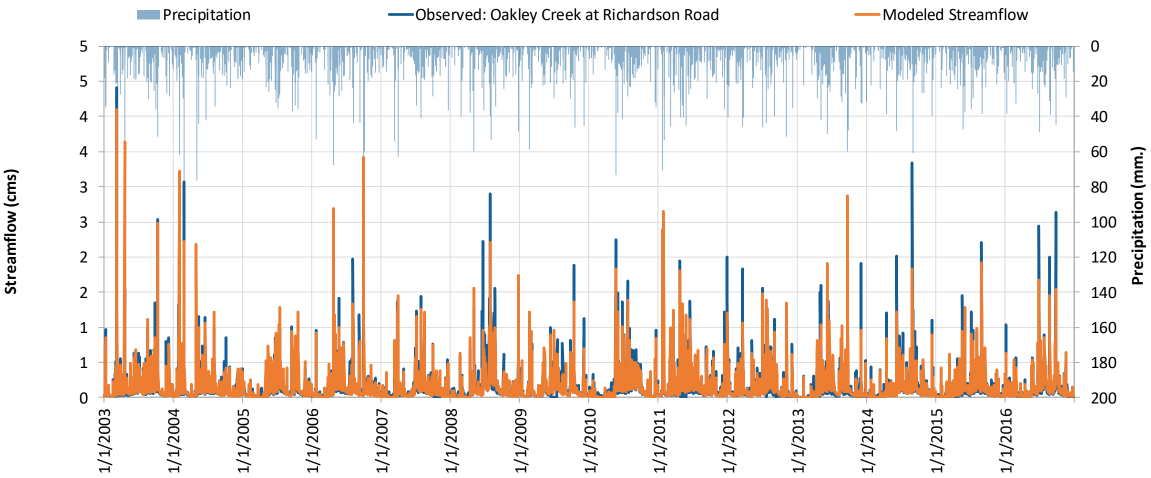
Figure 7 and Table 3 shows an example hydrologic calibration panel for one of 23 SOE river stations used in flow calibration. Given the continuous simulation capability, performance of the FWMT Stage 1 LSPC model is assessed throughout the flow-hydrograph (Table 3). Generally, each SOE station offers in the range of 45,000 discrete observed hourly flows (2013-2017) and 60 water quality grab sample over the last 5 years (2013-2017). Note that Table 3 is tentative as continued, iterative calibration is occurring. Nonetheless it indicates areas where further calibration can improve knowledge of current state. Namely at baseflow, which is expected given the complex hydrogeology in Auckland.

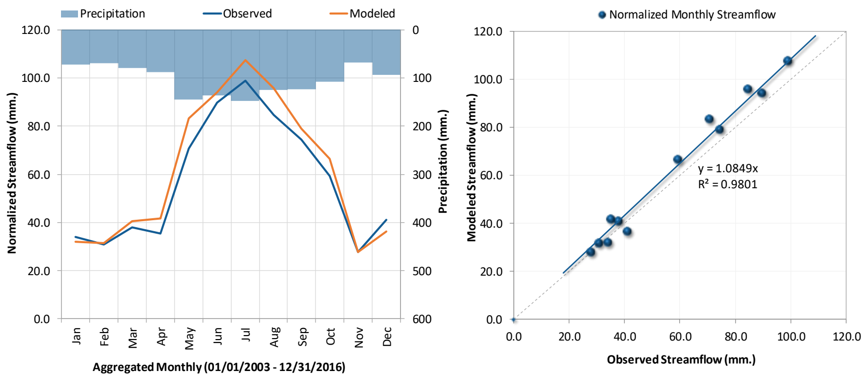
The initial water quality calibration is being conducted for TN, TP, TSS, TCu, TZn and *E. coli*, and ongoing. Further changes are expected to indicative output below, from that and also expansion of primary contaminants to include DIN and DRP and better discrimination of bankside from overland-delivered sediment.

Water quality calibration is constrained by the availability of monthly water samples (e.g., n=60 at monthly intervals, for 2013-2017). Hence, equivalent statistics (RMSE, R2, NSE) will be applied to coarser bins either in space or time, to avoid diminishing power from increasingly less numerous observations than for hydrologic calibration (i.e., for flows greater than median n is likely to be <30). Calibration performance statistics will be produced on water quality concentration and load, for annual periods (average, median, 95th%), flows greater and lesser than the median, stormflows and baseflows. Exploration of calibration further back into time than 2013, for stations with limited underlying land cover or intensity changes to the period 2013-2017, is also being made to enhance opportunity to better explore these performance envelopes without losing statistical power from reduced samples therein.

Table 3: Summary of regionwide hydrologic calibration assessment across 23 SOE hydrology river stations in the Auckland Region (2013-2017). Calibration is ongoing.

Attribute:	Number of Sites Attaining Attribute State				Percent of Sites Attaining Attribute State
	Very Good	Good	Fair	Poor	
Total Annual Volume	11	3	7	2	48% / 13% / 30% / 9%
Highest 10% of Flows	9	5	9	0	39% / 22% / 39%
Lowest 50% of Flows	7	3	2	11	30% / 13% / 9% / 48%
Annual Storm Volume	9	5	8	1	39% / 22% / 35% / 4%
Summer Storm Volume	9	10	3	1	39% / 43% / 13% / 4%
Annual Baseflow Volume	5	5	9	4	22% / 22% / 39% / 17%
Baseflow Recession	8	4	7	4	35% / 17% / 30% / 17%
Nash-Sutcliffe E (Annual)	7	14	2	0	30% / 61% / 9%





Calibration Metrics (01/01/2003 - 12/31/2016)	Relative Mean Error	Recommended Error Criteria			
		Very Good	Good	Fair	Poor
Total Annual Volume	4.7%	≤ 5%	5 - 10%	10 - 15%	>15%
Highest 10% of Flows	-5.1%	≤ 10%	10 - 15%	15 - 25%	>25%
Lowest 50% of Flows	-1.9%	≤ 10%	10 - 15%	15 - 25%	>25%
Annual Storm Volume	-4.8%	≤ 10%	10 - 15%	15 - 25%	>25%
Summer Storm Volume	-2.2%	≤ 15%	15 - 30%	30 - 50%	>50%
Annual Baseflow Volume	15.1%	≤ 10%	10 - 15%	15 - 25%	>25%
Baseflow Recession	3.1%	≤ 3%	3 - 5%	5 - 10%	>10%

Calibration Metrics (01/01/2003 - 12/31/2016)	Relative Mean Error				
	Annual	Winter	Spring	Summer	Fall
Seasonal Total Volume	4.7%	7.8%	-1.9%	1.1%	6.9%
Seasonal Storm Volume	-4.8%	-5.2%	-6.8%	-2.2%	-4.4%
Seasonal Baseflow Volume	15.1%	19.7%	3.5%	6.0%	20.3%
Seasonal Baseflow Recession	3.1%	0.8%	2.0%	6.2%	2.6%
Nash-Sutcliffe Efficiency (E)*	0.78	0.79	0.82	0.88	0.65

* E = 1 Perfect match of modeled to observed
E = 0 Model predictions as accurate as observed mean
E > 0.5 Indicator of acceptable model fit
E < 0 Observed mean better predictor than model

Performance Metrics

Very Good	Good
Fair	Poor

Figure 7. Example LPSC hydrologic performance assessment for a calibration station for period 2013-2017. Note output will be generated for 23 SOE stations, generally spanning 45,000 observations of flow.

For illustrative purposes, an example water quality calibration output is shown in Figure 8 for 7 SOE stations (combined). The water quality calibration assessment for Stage 1 will eventually incorporate performance metrics based on percent difference of observed and simulated values across all 23 SOE river stations, in time for the conference presentation.

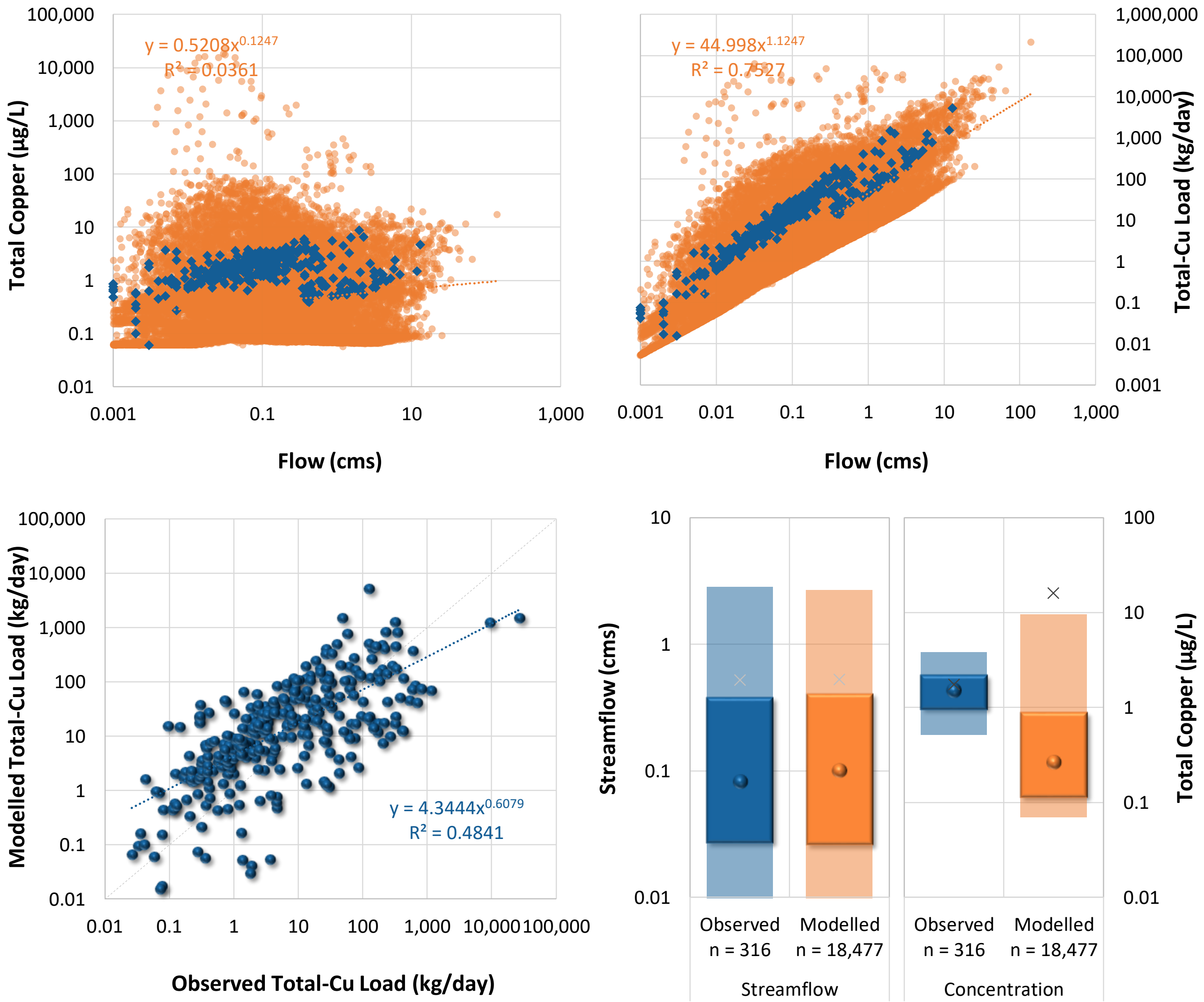


Figure 8. Indicative LPSC water quality performance assessment for Total Copper across seven SOE river Stations (regional water quality calibration is ongoing). Blue are observed, orange predicted observations. Calibration is ongoing to encompass all 23 SOE river stations.

4 CURRENT STATE

The assessment of current freshwater quality state under the NPSFM for Auckland's watersheds will leverage both actual monitoring data and predicted outputs from the FWMT, for the period 2013-2017. The SOE river monitoring network provides comprehensive (monthly, multiple indictor) datasets for 36 stations across the region (of which 13 were excluded from calibration for incomplete, inconsistent and/or unrepresentative datasets).

The SOE river stations receive runoff from approximately 15% of the entire regional watershed and therefore, potentially unrepresentative. A key objective for the FWMT is improved regional coverage of waterway types for better, more representative reporting of freshwater quality state than possible from SOE monitoring alone.

Please note that the following represents preliminary water quality state output (as of February 2019) and will be updated through the ongoing calibration of additional SOE river stations for flow (see above).

4.1 Monitoring-based water quality state

Assessment of current state (2013-2017) monitored at 36 SOE river stations was conducted using an approach based on both regional and national guidance. Table 4 summarises observed datasets and Table 5 the corresponding reporting guidance. Only information on E.coli, dissolved Cu (DCu), dissolved Zinc (DZn), nitrate-nitrogen (NO3N), and ammoniacal-nitrogen (NH4N) is presented below.

The National Objective Framework (NOF) was developed to support consistent national reporting for the management objectives of the NPS-FM, whose attributes correspond to different values (effects on human and ecosystem health) and use a variety of metrics and durations (e.g., annual median, 95^{th}%, % exceedance, minima, maxima – percentiles estimated by Hazen method and 95^{th}% only if ≥10 samples). Methods for attribute state determination closely followed guidance from MfE except that total oxidized nitrogen was conservatively reported as NO3N (Table 5). However, DCu and DZn were reported from regional guidance for ecosystem health, undergoing peer-review assuming hardness of 30 g/m3 CaCO3, without adjusting for dissolved organic carbon (Gadd et al., in review). Wider SoE reporting is available from Auckland Council, results here are for comparative purposes only (see Bishop et al., 2015).

Table 4: SoE locations and Sample Counts for Current State Assessment

Watershed	Site	SiteId	Start Date	End Date	Sample Count								
					E.coli	TON	Ammonia	DO (continuous)	Copper (soluble)	Copper (total)	Zinc (soluble)	Zinc (total)	TSS
Hibiscus Coast	Nukumea @ Upper	7171	1/9/2013	12/11/2017	60	60	59	0	60	60	60	60	54
	Okura Creek	7502	1/9/2013	12/11/2017	60	60	59	0	60	60	60	60	54
	Vaughn Stream	7506	1/9/2013	12/11/2017	60	60	58	656	60	60	60	60	54
	Waiwera Stream	7104	1/8/2013	12/5/2017	60	60	59	0	60	60	60	60	54
	West Hoe Stream	7206	1/9/2013	12/11/2017	60	60	59	774	0	0	0	0	54
Islands	Cascades @ Whakanewh	74701	2/7/2013	12/13/2017	58	58	58	0	0	0	0	0	52
	Onetangi @ Waiheke R	74401	2/7/2013	12/13/2017	58	58	58	0	0	0	0	0	52
Kaipara	Kaukapakapa @Taylors	45415	1/8/2013	12/5/2017	60	60	59	785	0	0	0	0	54
	Kumeu River	45313	1/8/2013	12/5/2017	60	60	59	0	60	60	60	60	54
	Makarau @ Railway	45505	1/8/2013	12/5/2017	60	60	59	0	60	60	60	60	54
	Riverhead Stream	45373	1/8/2013	12/5/2017	60	60	58	0	60	60	60	60	54
Mahurangi	Mahurangi River FHQ	6811	1/8/2013	12/11/2017	60	60	59	0	60	60	60	60	54
	Mahurangi River WS	6804	1/8/2013	12/11/2017	60	60	59	0	60	60	60	60	54
Manukau Harbour	Ngakaroa Stream	43829	1/9/2013	12/6/2017	60	60	60	784	0	0	0	0	54
	Papakura @ Alfriston	1043837	1/9/2013	12/6/2017	59	59	59	0	58	58	57	58	53
	Papakura Stream	43856	1/9/2013	12/6/2017	59	60	60	0	60	60	59	60	54
	Puhinui Stream	43807	1/9/2013	12/6/2017	60	60	60	766	60	60	59	60	54
	Waitangi Falls Br.	43601	1/9/2013	12/6/2017	60	60	60	0	0	0	0	0	54
	Whangamaire Woodhous	438100	1/9/2013	12/6/2017	60	60	60	0	0	0	0	0	54
North East	Matakana River	6604	1/8/2013	12/11/2017	60	60	59	0	59	59	59	59	54
Tamaki	Omaru @ Maybury	8249	1/25/2013	12/21/2017	60	60	59	0	60	60	60	60	54
	Otaki Creek	8219	1/25/2013	12/21/2017	59	59	57	0	59	59	59	59	53
	Otara Ck East Tamaki	8214	1/25/2013	12/21/2017	60	60	58	0	60	60	60	60	54
	Otara Ck Kennel Hill	8205	1/25/2013	12/21/2017	60	60	59	0	60	60	60	60	54
	Pakuranga Ck Botany	8217	1/25/2013	12/21/2017	60	60	59	0	60	60	60	60	54
	Pakuranga Ck Greenmt	8215	1/25/2013	12/21/2017	60	60	59	0	60	60	60	60	54
Wairoa	Wairoa @ Caitchons	8568	1/9/2013	12/6/2017	60	60	60	0	0	0	0	0	54
	Wairoa River	8516	1/9/2013	12/6/2017	60	60	60	769	60	60	59	60	54
Waitemata	Avondale Stream @ Sh	8019	1/9/2013	12/21/2017	60	60	59	0	60	60	59	60	54
	Lucas Creek	7830	1/9/2013	12/11/2017	60	59	58	0	60	60	60	60	54
	Oakley Creek	8110	1/9/2013	12/21/2017	60	60	58	0	60	59	59	58	54
	Opanuku Stream	7904	1/8/2013	12/5/2017	60	60	59	700	0	0	0	0	54
	Oteha Stream	7811	1/9/2013	12/11/2017	60	60	59	0	60	60	60	60	54
	Parrs Cross	7955	1/28/2016	6/6/2017	18	18	16	0	18	18	18	18	18
	Rangitopuni River	7805	7/6/2016	12/5/2017	18	18	18	677	0	0	0	0	12
West Coast	Cascade Stream	44603	1/8/2013	12/5/2017	60	60	59	0	0	0	0	0	54

Table 5: NOF Attribute States used for Current State Assessment of Rivers

Numeric Attribute State used for Current State Analysis	FRESHWATER CONTAMINANTS FOR RIVERS SUBJECT TO CURRENT STATE ANALYSIS											
	E. coli[2]		Dissolved Copper[1,2,4,8]		Dissolved Zinc[1,2,4,9]		Nitrate[2,5]		Ammonia[6]		Dissolved Oxygen	
	Statistic	Value (MPN/ 100 mL)	Statistic	Value (ug/L)	Statistic	Value (ug/L)	Statistic	Value (mg/L)	Statistic	Value (mg/L)	Statistic	Value (mg/L)
A	% over 540	< 5 %	Annual Median	≤1	Annual Median	≤2.4	Annual Median	≤1.0	Annual Median	≤0.03	7-day mean min	≥8.0
	% over 260	< 20 %										
	Median	≤130	95th percentile	≤1.4	95th percentile	≤8	95th percentile	≤1.5	Annual Maximum	≤0.05	1-day min	≥7.5
	95th percentile	≤540										
B	% over 540	5 - 10 %	Annual Median	>1 and ≤1.4	Annual Median	>2.4 and ≤8	Annual Median	>1.0 and ≤2.4	Annual Median	>0.03 and ≤0.24	7-day mean min	≥7.0 and <8.0
	% over 260	20 - 30 %										
	Median	≤130	95th percentile	>1.4 and ≤1.8	95th percentile	>8 and ≤15	95th percentile	>1.5 and ≤3.5	Annual Maximum	>0.05 and ≤0.40	1-day min	≥5.0 and <7.5
	95th percentile	≤1000										
C	% over 540	10 - 20 %	Annual Median	>1.4 and ≤2.5	Annual Median	>8 and ≤31	Annual Median	>2.4 and ≤6.9	Annual Median	>0.24 and ≤1.30	7-day mean min	≥5.0 and <7.0
	% over 260	20 - 34 %										
	Median	≤130	95th percentile	>1.8 and ≤4.3	95th percentile	>15 and ≤42	95th percentile	>3.5 and ≤9.8	Annual Maximum	>0.40 and ≤2.20	1-day min	≥4.0 and <5.0
	95th percentile	≤1200										
D	% over 540	20 - 30 %	Annual Median	>2.5	Annual Median	>31	Annual Median	>6.9	Annual Median	>1.30	7-day mean min	<5.0
	% over 260	>34 %										
	Median	>130	95th percentile	>4.3	95th percentile	>42	95th percentile	>9.8	Annual Maximum	>2.20	1-day min	< 4.0
	95th percentile	>1200										
Bottom Line or E	% over 540	> 30 %	Annual Median	2.5	Annual Median	31	Annual Median	6.9	Annual Median	1.3	7-day mean min	5
	% over 260	> 50 %										
	Median	>260	95th percentile	4.3	95th percentile	42	95th percentile	9.8	Annual Maximum	2.2	1-day min	4
	95th percentile	>1200										
Reference	NPSFM, 2017		ANZECC 2000 & AC, Development of Copper and Zinc as Auckland Specific Attributes[3]		ANZECC 2000 & AC, Development of Copper and Zinc as Auckland Specific Attributes[3]		NPSFM, 2017		NPSFM, 2017		NPSFM, 2017[7]	

Shown in Table 6 is the regional assessment of Auckland's current water quality state from SoE river monitoring data (2013-2017) for three national and two regional attributes. The assessment demonstrates varying freshwater quality current state between contaminant. For example, 34 of 36 SOE river stations achieved A or B states for NO3N, while 30 of 36 received grade E for *E. coli*.

Table 6: Monitoring-based current state assessment for Auckland's 36 SoE river stations (2013-2017). Note E.coli incorporates four metrics, and is graded conservatively to the lowest scoring.

	Number of Sites Attaining Attribute State					
Attribute:	A	B	C	D	E	Percent of Sites Attaining Attribute State
Ammonia (n= 2,038 samples, 36 sites)	21	8	6	1	NA	58% / 22% / 17%
Nitrate (n= 2,069 samples, 36 sites)	29	5	1	1	NA	81% / 14%
Zinc * (n= 1,452 samples, 25 sites)	10	4	7	4	NA	40% / 16% / 28% / 16%
Copper * (n= 1,453 samples, 25 sites)	12	6	6	1	NA	48% / 24% / 24%
E.coli (n= 2,069 samples, 36 sites)	1	5	0	0	30	14% / 83%

4.2 Model-based water quality state

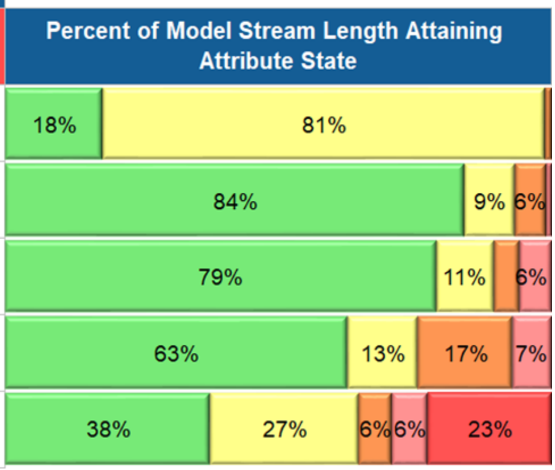
Preliminary calibrated FWMT output has been applied to equivalent national and regional guidance in Tables 4 and 5, to generate an equivalent modelled regional assessment of water quality state (2013-2017).

For each modelled stream reach, each daily average concentration was processed to generate a current state assessment in Table 7[5]. The summary represents over 3000km of modeled stream network, with each stream segment being assessed with 1825 daily time-step concentrations (2013-2017). When compared to the monitoring-based assessment, the regional predictive output generally indicates lesser degradation than the monitored water quality assessment (with the exception of NH4N-toxicity).

With calibration ongoing, it would be premature to comment on whether monitoring networks are less representative and/or likely to lead to unrepresentative assessment of freshwater quality (i.e., any differences in modelled and monitored state could correspond to greater error and/or spatiotemporal resolution in modelling). However, with the greater spatiotemporal resolution of the FWMT, the regional predictive model clearly highlights the challenges facing Auckland Council in reporting on current state let alone the secondary objective for the FWMT, of determining future improved state from various mitigation and device strategies. Likewise, Figure 9 demonstrates the engagement capability of the FWMT linked to its comprehensive HRU and routing network: a dynamic map viewer is in development to represent state outcomes (mitigation and device opportunities), on a stream segment (sub-catchment) basis.

Table 7: Early draft regional predictive current state assessment for Auckland region. Number of locations sum to 3,044 with equal sample number (monthly for 2013-2017 to be comparative).

	Total Stream KM Attaining Attribute State				
Attribute: (1,825 samples/site, 3,044 km)	A	B	C	D	E
Ammonia	546	2,459	39	0	NA
Nitrate	2,560	278	172	33	NA
Zinc	2,399	322	146	177	NA
Copper	1,910	390	527	217	NA
E.coli	1,148	825	188	195	687



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[5] Alternative analysis methods are being explored for processing of the FWMT time series. Auckland Council is uniquely challenged through the FWMT by the need to resolve how to compare 15-minute resolved contaminant concentration or loads, at thousands of instream locations, against national guidance developed for monthly sampling of considerably fewer locations, to deliver equivalent output (e.g., knowledge of current likely state).

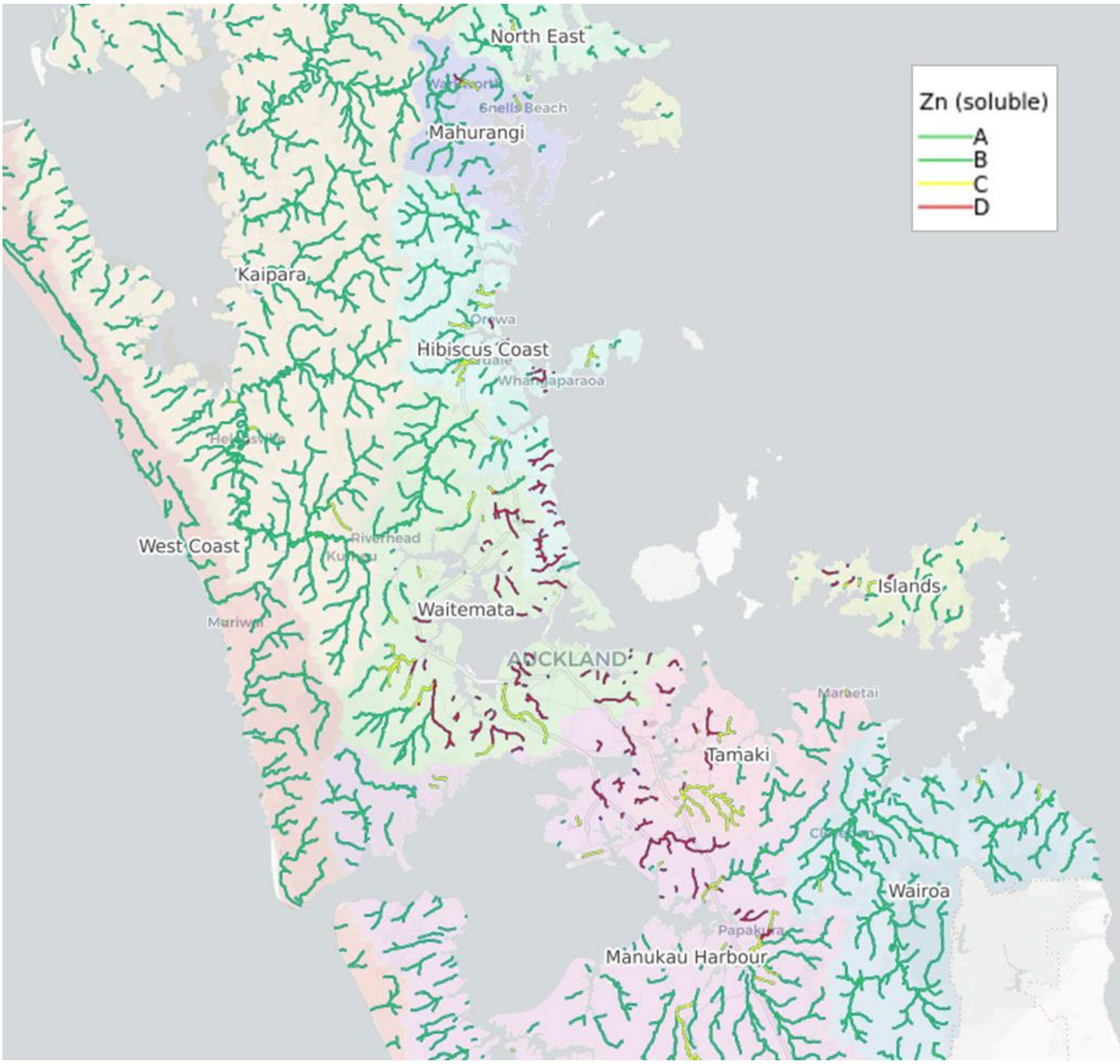

Figure 9: Screenshot of Map Viewer Showing Current State Assessment for Zinc using an Early Draft Regional Predictive Approach. Green is A or B, Yellow is C and Red is D under provisional regional guidance (Gadd et al., in prep).

5 CONCLUSIONS

The FWMT represents a paradigm shift in reporting and strategic decision-making capability for water quality in Auckland Council, from 10's of monitored to 1000's of modelled locations, from monthly to hourly or finer intervals. The combination of a process-basis with comprehensive land typology (n ~106) and flow network (3,000km including piped network, overflow and point-sources), is already generating impressive output, albeit of preliminary status.

Development of the FWMT Stage 1 LSPC model will be completed by mid-2019 (e.g., calibration of the current freshwater quality state). Development of the FWMT Stage 1 SUSTAIN model is ongoing, to enable high-resolution time-series of contaminant concentration and load to be determined region-wide following structural and non-structural interventions (e.g., good management practice; land use change). The FWMT Stage 1 SUSTAIN model is anticipated to be complete during 2019.

The capability to determine likely future freshwater quality state and consequent changes therein from optimized, landscape-constrained and costed intervention strategies, at regional-scale provides a much-needed evidence-basis for strategic decisions on Auckland's future. The challenge remains the accuracy and limitations thereof, recognizing these impose constraints on how model output should be used in decision-making for regional planning outcomes on the NPS-FM and water quality targeted rate.

Model expansion is now occurring to deliver high-resolution, robust information on both primary contaminants (TN, TP, TZn, TCu, TSS, *E.coli*) as well as dissolved nutrient contaminants (DIN, DRP) and better resolution of bankside from overland sources of sediment (for the FWMT Stage 1 LSPC model). Exploration is also ongoing to couple the FWMT with in-lake process models to represent outcomes of external contaminant loads.

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