SAFESWIM AT A CROSSROADS: NEXT STEPS FOR NEW ZEALAND'S WORLD LEADING PROGRAMME

A. Schollum & M. Neale (Puhoi Stour Ltd), H. Foreman & N. Brown (Auckland Council, Healthy Waters)

ABSTRACT

In July 2021, the Safeswim programme was cited as an exemplar of global best practice by the World Health Organisation in its updated guidance on recreational water quality monitoring and communication.

From March to October 2017, Healthy Waters collaborated with Watercare Services Limited, Surf Life Saving Northern Region, and the Auckland Regional Public Health Service to overhaul the Safeswim programme. This involved:

- introducing predictive water quality modelling and targeted sampling to the programme alongside longitudinal monitoring,
- integrating data from continuous monitors on the wastewater network,
- enabling water network managers, public health experts, and surf life saving professionals to raise hazard alerts manually, and
- presenting this information to the public in real time through a dedicated website.

After five years' of evolution, Safeswim now provides a fully integrated system for water quality and beach safety monitoring, management, and communication from Cape Reinga to Port Waikato. In addition, from late 2022 Surf Life Saving New Zealand adopted Safeswim as the preferred platform for public safety communication at all lifeguarded beaches around New Zealand.

This paper provides an overview of the Safeswim system, explains the framework that underpins its approach to water quality assessment and communication, describes the predictive models and system architecture that underpin the system, and presents the results of independent investigations, including by Audit NZ, into the accuracy of Safeswim's predictive models.

The limitations of recreational water quality monitoring programmes based on weekly monitoring were illustrated across New Zealand this summer with beaches being 'closed' based on 'out of date' monitoring results that no longer represented actual conditions. Conversely, in the United Kingdom people routinely swim unawares in water contaminated by overflows from wastewater networks.

As New Zealand's institutional arrangements for water management evolve, Safeswim's accurate, transparent, user-focused, and world-leading approach provides an alternative to current programmes based solely on weekly monitoring, which is not capable of telling swimmers what they want to know – where is it safe to swim now?

KEYWORDS

Water quality, technology, engagement, operations, industry capability

PRESENTER PROFILE

Andrew Schollum began his career importing organic foods and natural medicines before retraining in environmental management and industrial ecology. Since 2004 Andrew has held senior policy roles in regional and central government, managed a consenting team for an electricity generator, worked as a senior advisor to the Chair of the Land and Water Forum, and established a 'natural resources' service line at Martin Jenkins and Associates. In 2017 Andrew co-founded the consultancy Puhoi Stour, which provides strategic science advice to clients across public, private, and NGO sectors.

1 BACKGROUND

New Zealand's beaches are central to our culture and a key part of our national identity – we expect to be able to swim in clean water and to be safe at the beach. It is widely recognised, including by the World Health Organisation, that public agencies should develop predictive water quality models to provide beach users with information on the current state of water quality – thereby allowing them to manage their own risk of exposure to contaminated water.

In October 2016, immediately following the news of the water quality crisis in Havelock North, Auckland Council staff commissioned an independent review of their recreational water quality monitoring programme to make sure Auckland Council was doing everything it reasonably could to ensure the safety of people swimming at Auckland's beaches.

The independent review found the council's recreational water quality monitoring programme was generally complying with national guidelines, but that those guidelines were out of date and the programme had failed to keep pace with advances in science, technology, and practice since they were published in 2003. The review noted that the health risk posed by faecal contamination in recreational waters has traditionally been assessed in New Zealand by taking weekly samples of Faecal Indicator Bacteria (FIB) during the summer swimming season, comparing the results with published thresholds, and making the results available on council websites and/or the Land and Water Aotearoa Website (LAWA).

If designed and implemented effectively over a sustained period, weekly monitoring can reveal general trends in water quality and can be used to grade the quality of water at a swimming location. Relying on the results of weekly monitoring is not, however, an effective way to manage the public health risk from recreating in contaminated water. There are two critical limitations of programmes that rely on weekly monitoring alone:

- It takes 48 hours or longer before samples are sent to the lab, processed and results returned to the council. It can take longer for these results to be made publicly available. This means management actions based on monitoring results are always retrospective and can only be implemented several days after beach users have potentially exposed themselves to contaminated water.

- Contamination events in coastal water are typically short, with most lasting less than 24 hours. In general terms, this means weekly monitoring programmes have at best a one-in-seven chance of detecting a typical contamination event.

In accordance with the recommendations of the independent review, Auckland Council conducted a pilot study of potential alternatives to weekly sampling. The first step was to implement a targeted programme of high frequency sampling in the Waitemata Harbour

from Pt Chevalier to St Heliers[1] to develop a reliable baseline of actual water quality. This involved taking samples at three locations at each beach, three times a day, in a range of conditions (i.e., following rain events of differing intensities). These findings were compared against the results of the weekly sampling programme and the predictions of an untrained water quality model developed by DHI for a project commissioned by another council department for another purpose. Weekly sampling identified only 4 percent of guideline exceedances observed by the targeted sampling programme, while the untrained DHI predictive model accurately identified 72 percent.

This pilot study graphically demonstrated the shortcomings of weekly monitoring and highlighted that the current programme perpetuated a false sense of security and created a public health risk at Auckland's beaches. Council staff became aware of this health risk in late December 2016. By February 2017, staff had secured political support and funding to integrate predictive water quality modelling into Auckland's recreational water quality monitoring and reporting programme, and by October 2017 the new Safeswim system was launched. In 2021, after four years of operation, Safeswim was cited as a global exemplar of best practice by the World Health Organisation in its updated guidelines on recreational water quality (World Health Organisation, 2021).

In 2017 (Milne et al) and 2019 (McBride et al), in reports commissioned by the Regional Council Sector, NIWA recommended that councils develop predictive water quality models for recreational swimming locations. New Zealand's regional councils have been extremely slow, however, to implement these recommendations. Predictive water quality models have only been developed and implemented by Auckland Council (in 2017), Greater Wellington Regional Council (in 2020), and Northland Regional Council (in 2021).

2 THE SAFESWIM SYSTEM

2.1 SYSTEM ARCHITECTURE

In simple terms, Safeswim is a method for generating data, a data warehouse for synthesizing and feeding data through location-specific predictive water quality models, a website back-end for manual alerting, and a website front-end for presenting data to the public in real time. Safeswim has been designed to be flexible, allowing partners to use a data warehouse administered by Healthy Waters or to provide information direct to the Safeswim website from their own data warehouse (see Figure 1).

Safeswim's water quality predictions are produced using three typologies of model which differ in sophistication, functionality, and information needs. The model type used at any location reflects the information available and characteristics of each location to ensure the best possible health risk advice is provided to beach users.

- 'White box' mechanistic models, which provide numerical forecasts of FIB based on a contaminant load model and a hydrodynamic harbour model that simulates contaminant movement, dispersion, and pathogen die-off.

- 'Black box' regression models, which provide numerical forecasts of FIB based on statistical relationships between previous FIB results and environmental predictor variables.

[1] This area covers many of the city's most used swimming spots and its beaches are some of Auckland's most vulnerable to sewage overflows.

- 'Criteria' models, which provide a relative water quality score based on rainfall triggers, previous FIB results and time of day, the expert judgment of network managers and input from a panel of independent public health experts.

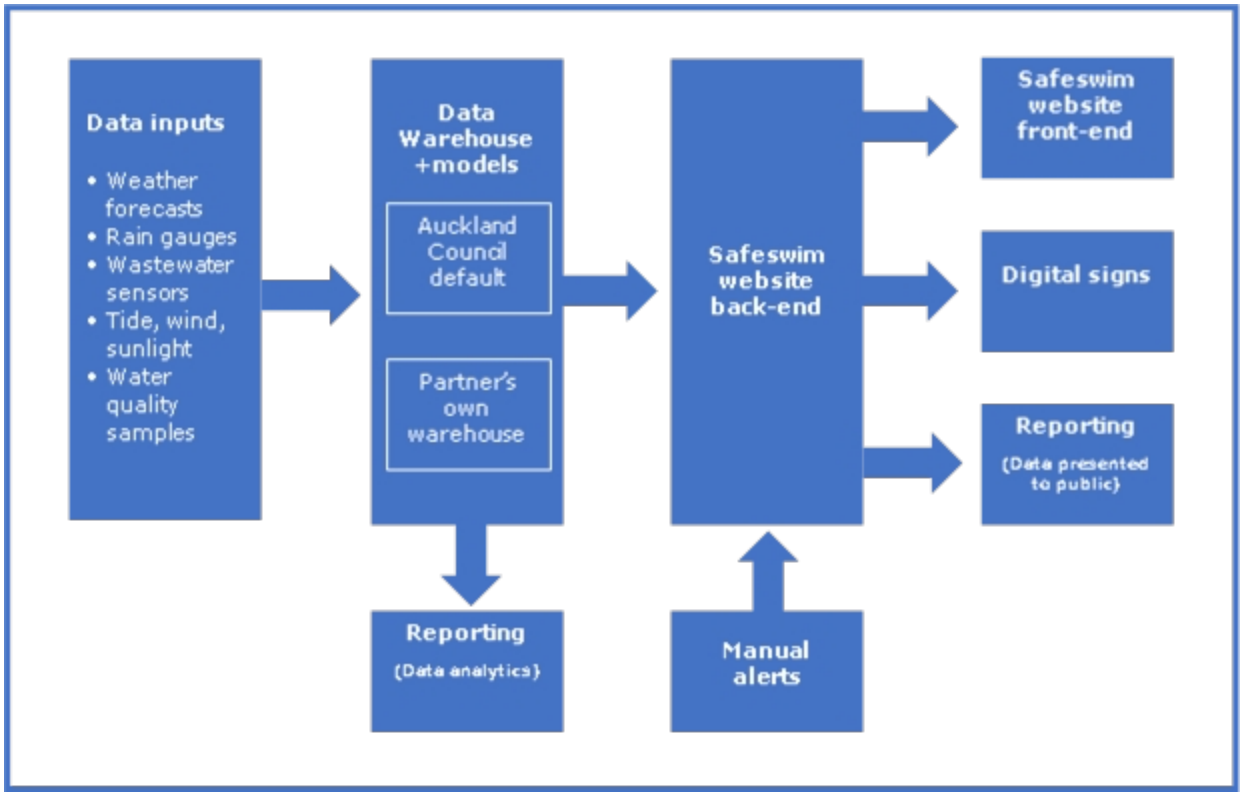

Figure 1: Safeswim system architecture

2.2 SAFESWIM'S PREDICTIVE WATER QUALITY MODELS

Safeswim's models are built using the historical record of data from weekly sampling programmes and trained and validated using the results of targeted sampling[2] undertaken during or shortly after rain when water networks come under stress and are likely to experience contamination. The combination of historic monitoring and targeted sampling data provides a picture of water quality specific to each location.

In addition to incorporating water quality data from longitudinal and targeted sampling, Safeswim's predictive water quality models consider weather forecasts, observed rainfall (intensity, duration, and location), tidal conditions, wind speed and direction, and sunlight. This allows Safeswim's models to account for the movement, dispersion, and breakdown of contaminant plumes once they reach the water.

Data from rain gauges are also factored into water quality predictions every 15 to 60 minutes, depending on the model, to ensure predictions reflect observed rainfall and to correct for inaccuracies in weather forecasts (i.e., should predicted rain not occur or should it rain unexpectedly). Safeswim is currently working to integrate rain radar into its system.

Alarms on data inputs automatically alert system operators if information appears stale (i.e., if a continuous monitor isn't returning a signal at its normal frequency, indicating a

[2] Samples are taken in accordance with World Health Organisation Guidelines at places where people are likely to swim and at a range of distances from likely sources of contamination (e.g., stormwater outlets, engineered overflow points on wastewater networks and at the mouth of urban streams feeding onto beaches).

malfunction) or if readings exceed reasonable thresholds (i.e., if a rain gauge records more than 30mm of rain in 10 minutes). These alarms prompt investigation and could result in manual changes to Safeswim predictions to correct for errors in data feeds.

Safeswim is committed to continual improvement and an ongoing programme of periodic sampling – building on the previous weekly sampling programme – is used to validate and refine model predications. Ongoing sampling allows Safeswim to deliver both beach surveillance and beach grading as required under New Zealand's Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas. Overall, the Safeswim programme's sampling team in Auckland takes two to three times more water quality samples per year than prior to the programme's overhaul in 2017.

New Zealand has been slower to adopt environmental models than the United States and Europe, and there is still widespread public misunderstanding and distrust of model outputs. Unfortunately, Healthy Waters was not able to support the deployment of Safeswim's predictive water quality models with a public education campaign, and after the overhaul some commentators advocated publicly for reallocating the money spent on developing models and taking more samples instead.

Sampling is time consuming and expensive, and even if it were financially possible to take daily samples at all beaches on the Safeswim programme, the lab results would not be available for 24 hours or more after they were taken – management actions would still be retrospective and people would still find out that water was contaminated after they had swum in it. Regardless, Healthy Waters commissioned an independent assessment of the relative accuracy predictive models versus perceived alternatives of daily sampling and an 'inactive' approach whereby the council simply advised people against swimming for 48 hours after heavy rain. The Safeswim models were comfortably more accurate than both perceived alternatives (see Table 1).

Measure	**Safeswim model**	**Daily monitoring**	**Inactive approach**
Accurate	15 of 17 = 88%	9 of 17 = 53%	12 of 17 = 71%
Accurate or precautionary	16 of 17 = 94%	15 of 17 = 76%	12 of 17 = 71%
False negatives (i.e., high risk)	1 of 17 = 6%	4 of 17 = 24%	5 of 17 = 30%
Guideline exceedances detected	4 of 5 = 80%	1 of 5 = 20%	0 of 5 = 0%

Table 1: *Results of comparative assessment of Safeswim models versus alternatives*

For a new predictive model to be brought onto the Safeswim platform, it must meet benchmarks for overall accuracy, sensitivity (ability to predict exceedances) and specificity (ability to predict compliances). Safeswim has adopted standards from the United States Geological Survey (USGS) for models of the type employed in the Safeswim system. The USGS requires 80% overall accuracy, 50% sensitivity and 80% specificity.

The accuracy and reliability of model predictions is assessed annually against these performance standards. Models performing at the lower end of the scale are targeted for additional sampling to generate the data necessary to refine the model and improve its performance.

In 2022, for the third successive year, Audit NZ investigated the performance of Safeswim's predictive models and found them to comfortably exceed performance thresholds (e.g., average overall accuracy of 89%) and concluded no changes were required to the programme.

2.3 MANUAL AND AUTOMATIC FAILSAFE AND HAZARD ALERTING FUNCTIONS

A model can only predict predictable circumstances, but sometimes unpredictable events cause water quality to breach guidelines. A network fault or maintenance issue can, for instance, cause wastewater to overflow from sewage networks in dry weather conditions. Extreme weather events, like those experienced in Auckland in February 2023, can cause slips that damage water network and cause significant and persistent contamination that is beyond the capability of models to predict. For this reason, Safeswim draws on data from continuous monitors (sensors) at pump stations and engineered overflow points at key points on wastewater networks, and automatically displays icons denoting poor water at affected sites if these sensors detect overflows that are likely to risk public health.

The location of these sensors is agreed with the relevant network operator as are the thresholds that trigger an automatic water quality alert on Safeswim – proximity to the beach and the duration or volume of overflow – and these parameters are reviewed and approved by an independent panel of public health experts.

Credentialed staff at participating water utilities and public health authorities can use Safeswim to manually upload water quality alerts and pop-up messages to the website. This gives operational staff the power to change predictions shown on the website should a member of public or contractor alert the network operator to an overflow in an area not serviced by continuous monitors (sensors). Safeswim also allows network managers to upload photos and explanatory notes, inform the public of risks and hazards arising from extreme weather events, and provide updates on the status of remedial works. These functions were used extensively through the COVID-19 pandemic to clarify the nature of restrictions in place at Auckland's beaches, and in the wake of the flooding caused by Cyclone Gabrielle.

Safeswim can also be used by 'environmental health' and 'pollution response' departments at participating councils to manually upload water quality alerts advising the public of a range of contamination events not covered by Safeswim's models (i.e., oil spills or chemical discharges). This feature was used, for example, to alert the public of risks due to contaminated water being flushed to the sea from the basement of the Sky City Convention Centre following the rooftop fire during construction.

An important feature of Safeswim is that water quality information is complemented by advice from surf lifesaving organisations and public health agencies on other safety hazards. Credentialed users from these organisations, including lifesaving patrol captains, can manually upload public advisory notices, alerting the public to hazards such as dangerous wind or wave conditions, rip currents, dangerous marine life, or other pollution events.

3 EVOLUTION OF SAFESWIM

3.1 FIRST CYCLE OF EVOLUTION – DEVELOPING SAFESWIM

Safeswim was developed in seven months from March to September 2017 in time for deployment over the 2017/18 summer. This involved: developing a partnership with other agencies that have responsibilities for beach management (Surf Life Saving Auckland Region) and public health (Auckland Regional Public Health Service), building models for 92 locations around Auckland, redesigning the council's water quality sampling programme,

developing model performance benchmarks, obtaining meteorological data and routing it to a data warehouse along with water quality sampling results and data from continuous monitors and rain gauges, training and validating model predictions, modifying the operational protocols of water utilities to ensure staff and contractors provided information to Safeswim, designing and building a standalone user-focused public-facing website and manual alerting system, connecting outputs from the data warehouse to the website, conducting beach hazard assessments, and testing and deploying the system.

The short timeframe for development and large scope of work forced the project team to focus on core functions, in the knowledge that further refinement would be required immediately after deployment.

3.2 SECOND CYCLE OF EVOLUTION – EMBEDDING SAFESWIM

The 2018 and 2019 calendar years were spent enhancing the reliability and usability of the system (adding automatic alerts, improving the speed and reliability of data transfer through the system, improving the user-interface for backend administrators and frontend users) and lifting the performance of models (ongoing training to improve accuracy, and replacing 'criteria' models with 'black box' regression models as more data became available).

During this period staff from Auckland Council's Healthy Waters Department also worked closely with council communications staff to assuage their initial concerns regarding the presentation of more accurate water quality in real time, which they felt would undermine the reputation of council as an environmental manager and Auckland as an attractive destination. Healthy Waters staff also worked closely with staff from Watercare Services Limited and other departments to assuage concerns that Safeswim would create performance expectations they could not meet within existing budgets, forcing them to discontinue planned projects and reallocate resources to address issues highlighted by Safeswim.

In 2018, citing Safeswim, the Mayor of Auckland proposed to raise a targeted rate of approximately $450 million over ten years to fund improvements in water quality aiming to address the issues highlighted by the programme. Over 67 percent of Aucklanders who submitted on the proposal registered their support, while 74 percent registered support or partial support – an unprecedented response to a proposal to increase rates.

Since Safeswim's deployment in 2017, Watercare Services Limited has become a staunch supporter of the programme – embracing its culture of innovation, transparency, and accountability, and coming to use Safeswim as a key tool for public communication. Healthy Waters and Watercare routinely collaborate to find and fix the cause of poor water quality identified by Safeswim's monitoring and modelling, and use the number of 'swimmable days' at Auckland's beaches as a performance benchmark to assess the effectiveness of their interventions.

3.3 THIRD CYCLE OF EVOLUTION – EXPANDING SAFESWIM

Despite the disruption caused by the COVID-19 pandemic, water quality sampling in the Auckland region increased in frequency from 2019 to 2023, allowing for the development of additional water quality models. There are now 132 location-specific predictive models operating at beaches, rivers, and lakes across the Auckland region.

During the same period, Northland Regional Council undertook a successful trial of Safeswim in the Northland Region and, in the lead-up to the 2022/23 swimming season, Safeswim was extended to 72 additional locations throughout Northland.

Safeswim currently provides a fully integrated system for water quality and beach safety monitoring, management, and communication at 204 locations from Cape Reinga to Port Waikato, and has been adopted by Surf Life Saving New Zealand as the preferred platform for web-based public safety communication at all 92 lifeguarded beaches around New Zealand.

4 WHAT NEXT FOR SAFESWIM?

From its launch in October 2017 to April 2023, the Safeswim website has attracted 1,215,000 unique users and every summer 180,000-350,000 users visit the site in 300,000-500,000 sessions, with numbers fluctuating in response to how rainy or dry the conditions are. Awareness and usership of Safeswim continues to grow and, given the programme has recently become Surf Life Saving New Zealand's preferred platform for public beach management and communication, its popularity is likely to increase further.

Independent audits of the Safeswim programme, including by Audit New Zealand, have confirmed the accuracy of Safeswim's predictive water quality models and the website has demonstrated its flexibility as a tool for public communication through the COVID-19 pandemic and following Cyclone Gabrielle. The programme's success and the degree of public engagement with its outputs has encouraged Healthy Waters to continue to fund Safeswim's development. The Safeswim project team are currently working to convert Safeswim into a 'native application', making it easier for users to customise their experience and tailor notifications to suit their interests. On the technical side of the programme, the team is working to integrate rain radar into the platform – further increasing the accuracy of model predictions which will no longer rely on weather forecasts and rain gauges which, while widespread, are not located at every beach on the programme.

The limitations of recreational water quality programmes based on weekly monitoring were illustrated across New Zealand this summer with public frustration at beaches in the South Island being 'closed' because of monitoring results that were 'out of date' and no longer represented actual conditions. Similarly, in the United Kingdom, in the past year the mainstream media has run several campaigns highlighting weaknesses in the public monitoring and reporting of water quality, and aiming to make people aware they are routinely swimming in water contaminated by overflows from wastewater networks.

Northland Regional Council's decision to develop predictive water quality models and communicate them via the Safeswim website has demonstrated the ease and cost-effectiveness of the programme – perhaps more councils will follow Northland's lead? If councils are reluctant to use the Safeswim system's architecture but wish to use the Safeswim website as a communication channel, the system is designed to facilitate this. Greater Wellington Regional Council, the one council south of Auckland that has adopted predictive water quality models, chose to build and operate their own models in-house following a similar approach to Safeswim, but only communicate their data via LAWA. Northland Regional Council and Auckland Council use both Safeswim and LAWA. This option is available to all councils.

Environmental models are good at making sense of data, at filling gaps in time and space, and at forecasting future conditions. But models and monitoring must work together – "without data, models are fantasy, without models, data are chaos" (Crill, 2014). Councils know that weekly monitoring alone misses many guideline exceedances, creates a false sense of security and increases public health risk. The public inquiry into the Havelock North drinking water quality incident has established clearly that, if councils are aware of system risks and failures, they have a duty of care to address them. Reports from NIWA in 2017 and 2019 for the regional sector recommended councils develop predictive water

quality models and, in 2021, the World Health Organisation has cited Safeswim – a platform built around a combination of predictive models, targeted sampling, and longitudinal monitoring – as a global exemplar of best practice. Surf Life Saving New Zealand is advocating for predictive water quality models to be implemented at all lifeguarded beaches. It cannot be too long now until more New Zealand councils develop predictive water quality models for recreational swimming locations.

5 CONCLUSIONS

Prior to overhauling Safeswim in 2017, Auckland Council's weekly water quality monitoring programme, which broadly complied with national guidelines, was identifying as few as 4 percent of guideline exceedances. Safeswim's models have been independently audited and found to be nearly 90% accurate on average. Prior to the 2017 overhaul, perhaps 3,000 people visited Auckland Council's beach water quality page every summer, for around 10,000 sessions.[3] This summer (2022-23) 357,000 users visited the Safeswim website for 810,000 sessions. Safeswim is clearly far more accurate and far more effective at reaching people than the previous system.

Safeswim played a pivotal role in lifting awareness of water quality issues and changing the conversation around water management in Auckland, ultimately helping to secure unprecedented levels of support for a targeted rate generating $450 million over ten years to find and fix the cause of contamination at Auckland's beaches. The general public's reaction to Auckland Council 'owning up' to a legacy of water quality issues has been overwhelmingly positive and the data generated by Safeswim and the communication platform it offers have helped Healthy Waters and Watercare work together effectively to find issues, while giving people the best possible information to manage their own health and safety until those issues can be fixed.

Councils have known since 2016 that the methods and approach underpinning New Zealand's 2003 'microbiological water quality guidelines for marine and freshwater recreational areas' are no longer fit for purpose. In a world where environmental problems are becoming more complex, resources and money more scarce, and the health risks associated with contaminated water more acute – we have a duty of care to improve public systems that perpetuate a false sense of security.

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[3] Accurate user data are not available.