Waikato Dynamic Models

Background document for prioritisation

Prepared for Waikato River Authority

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Executive summary

A recently-completed WRA co-funded project "Waikato/Waipaa River Modelling Framework" proposed a set of dynamic models for water quality, quantity and ecology at the scale of the entire Waikato/Waipa freshwater system to support Te Whaimana o te Awa o Waikato (Vision and Strategy), with emphasis on identifying model outputs to predict Report Card taura attributes.

This report outlines modelling investment options in a form that can assist with prioritisation. The report will inform two facilitated workshops (one Iwi-centred), which will aim to identify priority projects and funding pathways.

To assist with prioritisation, each of the 13 model components identified in the previous report has been summarised using a consistent set of headings. The headings relate to factors that might be used to justify a modelling project, such as the need, benefits, limitations, data needs, indicative costs, dependencies, and time-frame for the proposed work.

This report also presents overarching project components that are proposed to serve one or more model components. There are also some overall considerations such as the general benefits of the modelling initiative, and limitations and risks in the overall set of models.

This report lays the foundation for the prioritisation workshops, which will be followed by documenting the workshop findings, and making recommendations for initiating the modelling and associated data collection process.

1 Introduction

A recently-completed Waikato River Authority (WRA) co-funded project "Waikato/Waipaa River Modelling Framework" proposed a set of dynamic models for water quality, quantity and ecology at the scale of the entire Waikato/Waipa freshwater system to support Te Whaimana o te Awa o Waikato (Vision and Strategy), with emphasis on identifying model outputs to predict Report Card taura attributes. A key principle for the proposed modelling approach is to develop a co-owned set of models with open access in a collaborative way. A tentative, ambitious work plan and indicative costing was reported (Elliott 2020). A range of model types and associated data collection activities and training were also identified. There is now a need to focus the model development programme into a series of high-priority projects with specific workplans and agreed funding pathways.

This report outlines modelling investment options in a form that can assist with prioritisation. The report will inform two facilitated workshops (one Iwi-centred), which will aim to identify priority projects and funding pathways. The intention is to include decision-makers and model users in the workshops, rather than just modellers. This will be done to ensure that the workshops will address a range of objectives, not just the technical modelling requirements. Following the workshops, written summaries of the workshop proceedings will be prepared, including agreed funding priorities and pathways. It is anticipated that this process will lead to the development of specific, targeted work briefs and associated project workplans.

This report identifies:

- A set of modelling options and associated data collection/collation activities based on the “Waikato/Waipaa River Modelling Framework” report.
- The types of question that could be answered if a particular modelling option is implemented, and Report Card Taura addressed.
- Benefits and costs of the options, including data collection.
- Risks associated with implementing each option.
- Overarching considerations such as data housing, governance, and model dependencies.

Several stakeholders and potential funding contributors that have an interest in the models, each bringing their priorities and goals. This report does not anticipate their priorities, but rather leaves prioritisation to the workshops.

2 Description of the main modelling components and associated data

To assist with prioritisation, each of the 13 model components identified in the previous report has been summarised using a consistent set of headings. The headings relate to factors that might be used to justify a modelling project, such as the need, benefits, limitations, resourcing, dependencies and time-frame for the proposed work. We provide an assessment of whether the project is 'low-hanging fruit' – a loose term intended to indicate whether the model is easy to implement, data are available, that the work could be done in a short time and is likely to have high value for the effort expended.

Apart from the model components, there are other overarching project components that are proposed to serve one or more model components (see Section 3). There are also some overall general considerations such as general benefits and of the modelling initiative, and limitations in the overall set of models, which are presented in Section 4.

[the description of the first model component begins on the next page]

Component 1. Contaminant generation

Brief description

Generates loads and concentrations of contaminants entering streams or groundwater over time as a function of climate, soils, land use, and land management.

Questions addressed

- How will changes in land management affect contaminant inputs to the rivers and lakes?
- Where are the key places where contaminants are generated, and where shoudl land use interventions be targeted?
- How will water quality in tributaries be affected?
- How quickly will changes in inputs occur?
- How will climate change affect contaminant loading?

Uses

- Regional plans
- Limit setting
- Assessing impacts of rehabilitation
- Assessment of large consents

Taura addressed (Plus economics)

Kai, Water quality, Experience, Ecological Integrity

Software

SWAT

Limitations

- Difficult to represent effects of individual farm management plans
- Erosion model will need improvement to represent slips
- Not all management/mitigation measures can be represented
- River model is limited (e.g., eutrophication aspects, sub-daily dissolved oxygen)
- Doesn't represent deep aquifer without coupling to aquifer model

Model dependencies

- None

Dependent models

- Groundwater quality
- Reservoir water quality
- Mainstem water quality
- Taupo water quality

Data

- Climate
- Land use and management
- Soils
- Water quality monitoring (monthly)
- New storm monitoring
- Point source discharge timing

Risks: and their management

- Coupling with groundwater may be demanding computationally: use high-performance computing or model simplification
- Mass erosion may be difficult to incorporate: leverage other research on dynamic erosion modelling
- Difficulty linking to farm plans and details of farm system management: use as complement to budget/overseer models, not as full replacement

Alternatives

- Contaminant budget models (don't address dynamics)
- eWater Source (not as sophisticated)
- HYPE (SWAT preferred)

Capacity and Capability

- Capability in NIWA, internationally.

Cost: Modelling, including application, training, development (preliminary estimate)

$450k

Cost: New data acquisition (preliminary estimate)

$640k

Other Costs (in addition to students, data platform, management)

- Erosion model development

Development timeline

2-5 years

Possible stages and sub-projects

- Nutrients and E.coli; groundwater; enhanced erosion

Low-hanging fruit? (Low is good)

Medium

Component 2. Groundwater quality and quantity

Brief description

Determines groundwater levels and quality, subsurface flow pathways, and discharge to streams. Quantity model could be used alone if only flows are of interest.

Questions addressed

- How does groundwater storage affect baseflow inputs into the river?
- How does groundwater affect the timing (including lags) and amount of nitrogen inputs to the river?
- How do groundwater takes affect river low flows?

Uses

- Regional plans
- Assessment of large consents
- Assessing impacts of nitrogen loss mitigation, including spatial aspects
- Improving water resources models, especially low flow prediction

Taura addressed (Plus economics)

Kai, Water Quality, Experience, Ecological Integrity, Water security

Software

MODFLOW and MT3D

Limitations

- Limited and spatially-uneven knowledge of hydrostratigraphy, denitrifications locations and rates.
- Time-consuming to run models with fine spatial detail
- Don't model near-surface processes well
- May not be fine enough to represent groundwater-dominated inflow to small lakes well

Model dependencies

- Recharge quantity and nitrogen losses to the groundwater system

Dependent models

- Mainstem water quality
- Mainstem flows
- If flows only are of interest, then water qualtiy aspects of groundwater could be ignored.

Data

- Groundwater geology
- Groundwater denitrification conditions
- Groundwater monitoring (quality, ages, levels)

Risks: and their management

- May be too complex to set up and couple with other models: Use high-performance computing. Possibly use meta-models or simplified models for faster run times.
- Models limited by knowledge of subsurface conditions, resulting in high uncertainty: leverage research on uncertainty of GW models

Alternatives

- Some proprietary alternatives are available, but not necessarily superior.

Capacity and Capability

- Considerable capability and capacity in NZ

Cost: Modelling, including application, training, development (preliminary estimate)

$450k

Cost: New data acquisition (preliminary estimate)

$0k

Other Costs (in addition to students, data platform, management)

Development timeline

2-5 years

Possible stages and sub-projects

- Focus on areas with greatest influence of GW

Low-hanging fruit? (Low is good)

Medium-high

Component 3. Runoff generation and routing to rivers for normal flows and floods

Brief description

Determines runoff to streams and recharge to groundwater over time and spatially as a function of soil and land use/management. May also route flows down small streams. Emphasis on normal flows and flood flows, but can be extended to low flows if the model is appropriate.

Questions addressed

- What mechanisms are responsible for generation of flows into the river system and tributaries?
- How are flood sources affected by land use?
- What are the risks of flood flows under future climate change?
- What will be the inflows into the river system for flood forecasting?

Uses

- In conjuction with flow routing in mainstem and rivers: Flood risk assessment
- Consideration of land use change on normal and high flows
- Flood forecasting
- Design of management responses to flood risks, including implcications of climate change

Taura addressed (Plus economics)

Water Security [Kai][Ecological Integrity].

Software

D-Hydrology (WFLOW)

see SWAT for water quality

see WEAP for water resources

Limitations

- Model developed for medium and high flows may not be well suited for low flows.
- Limitations in rainfall inputs.

Model dependencies

- None

Dependent models

- Mainstem flood routing.
- Habitat suitability in lower river
- Flood forecasting

Data

- Soils
- Flow records
- Climate
- Topography and stream network

Risks: and their management

- Capabilities of WFLOW models in NZ not clear : conduct a pilot project before committing to full implementation.
- Choice of particular WFLOW model not clear: pilot project

Alternatives

- DHI NAM (proprietary)
- TopNet (proprietary)
- SWAT (daily, limited to CN hydrology)

Capacity and Capability

- Generally good experience with hydrology models, but knowledge of WFLOW models limited.

Cost: Modelling, including application, training, development (preliminary estimate)

$450k

Cost: New data acquisition (preliminary estimate)

$0k

Other Costs (in addition to students, data platform, management)

Development timeline

3 years

Possible stages and sub-projects

- Initial pilot project

Low-hanging fruit? (Low is good)

Low-Medium

Component 4. Flow routing in mainstem and reservoirs

Brief description

Calculates flow rates and water levels throughout the river network given the inflows to the river system. Takes account of rules relating water levels and release rules to flow rates.

Questions addressed

- What will be the flood flows in the river and risk of flooding?
- How does reservoir operation affect the flows in the river? Can this be managed?
- Can flood infrastructure be managed better?
- Can reservoirs be operated better to provide environmental flows?
- Can storage be added to manage flows better?
- What will the water levels be over time?

Uses

- Flood infrastructure planning
- Refining reservoir operation rules for flood management
- Land use planning (large vegetation changes)
- Reservoir operation to improve recreational and environmental flows

Taura addressed (Plus economics)

Kai, Experience, [Ecological integrity], Water Security

Software

Dflow-1D (initially SOBEK)

Limitations

- Dflow is not yet available: In the interim, use SOBEK 2.6
- 1-D flow routing does not predict inundation and hydraulics accurately, but can use 2D capability of Dflow
- Only likely to be able to have approximate representation of real-live reservoir operation
- Dependent on quality of rainfall-runoff models

Model dependencies

- Rainfall-runoff model (SWAT or D-Hydrology)
- Groundwater model (for improved version)

Dependent models

- River water quality
- Hydraulic habitat in lower river
- Flood forecasting
- Fish habitat creation

Data

- River cross-sections
- River flow rates
- Flood infrastructure operation rules
- Hydro reservoir operation rules.

Risks: and their management

- Planned release of Dflow may be delayed or might not occur: Deltares have confirmed intentions to open-source 1-D calculations. Alternative avenues such as research agreements are possible, and can use proprietary version in the interim.
- May not be able to obtain suitable reservoir/generation rules: include generation companies in the collaborative group.
- Limited knowledge of flood infrastructure operation: build model incrementally, add targeted information. Include regional council and TLA in the collaborative group.

Alternatives

- MIKE 11/MIKE HYDRO River(proprietary, expensive but already some existing models).
- HEC-RAS (free, closed source)

Capacity and Capability

- Good capability and capacity for flood models in NZ, although not so much for Deltares products (more for DHI)

Cost: Modelling, including application, training, development (preliminary estimate)

$150k

Cost: New data acquisition (preliminary estimate)

$0k

Other Costs (in addition to students, data platform, management)

Development timeline

2 years

Possible stages and sub-projects

Low-hanging fruit? (Low is good)

Medium

Component 5. Mainstem water quality

Brief description

Caculates water quality in the river mainstem given contaminant inputs. Used in conjuction with flow routing.

Questions addressed

- How do inputs of nutrients and microbes, and associated mitigation, affect mainstem river quality?
- What are the risks of algal blooms?
- Can reservoir operation be modified to reduce risks of blooms?

Uses

- How do inputs of nutrients and microbes, and associated mitigation, affect mainstem river quality?
- How will flow abstractions affect water quality?
- How does imported water affect water quality?
- What are the risks of algal blooms?
- Can reservoir operation be modified to reduce risks of blooms?

Taura addressed (Plus economics)

Water quality, Experience, Ecological Integrity, Water Security

Software

D-Water Quality (initially SOBEK)

Limitations

- D-Water Quality is not yet available for 1-D. In interim use SOBEK
- May not be suitable for small tributaries due to complexity and computational expense

Model dependencies

- Contaminant generation.
- Rainfall-runoff
- Flow routing (but do not need accurate flood flows)
- Reservoir models desirable.

Dependent models

- Reservoir water quality models (for best representation of algae).
- Shallow lake models for best representation of lower river.
- Taupo 1-D model for best representation of long-term climate change risks

Data

- State of Environment monitoring
- River algae monitoring
- High resolution stream/river water quality data
- River channel sections
- Reservoir operating rules
- Point source data

Risks: and their management

- Not used previously in NZ leading to delays and possible unforseen difficulties or limitations: The model is used widely internationally so has undergone testing by others; Conduct pilot project before committing to full implementation.
- Planned release of Dflow may be delayed or might not occur: Deltares have confirmed intentions to open-source 1-D calculations. Alternative avenues such as research agreements are possible, and can use proprietary version in the interim. Enter collaborate projects with Deltares.
- Unsure whether capability for adding custom process libraries is functioning properly: collaborate with Deltares, and intially work with standard libraries

Alternatives

- MIKE HYDRO River with ECO lab (proprietary).
- Various alternatives investigated in scoping report.

Capacity and Capability

- Limited capability and capacity for dynamic river water quality modelling in NZ.

Cost: Modelling, including application, training, development (preliminary estimate)

$300k

Cost: New data acquisition (preliminary estimate)

$600k

Other Costs (in addition to students, data platform, management)

- Combined data platform

Development timeline

2-5 years

Possible stages and sub-projects

- Pilot project

Low-hanging fruit? (Low is good)

Medium

Component 6. Reservoir water quality

Brief description

Caculates water quality in reservoirs given the inflows and flow rates and climate. Used in conjuction with reservoir hydrodyanmic models. Can account for stratification and longitudinal variation of water quality.

Questions addressed

- How do the reservoirs affect algal proliferations in the lower river?
- What are the risks of conditions being suitable for cyanobacterial blooms?
- Can reservoir operation be modified to reduce risks of blooms?
- Would aeration be a means of reducing risks of blooms?
- What are the risks of reservoir stratification and de-oxygenation? Can that be managed?
- What are the risks of excessive macrophyte growth, and can that be managed.

Uses

- River rehabilitation
- Limit setting (quality and flow)
- Refining reservoir operation regimes
- Large consents
- Forecasting water quality (with an additional forecasting model)

Taura addressed (Plus economics)

Water quality, Experience, Ecological Integrity, Water Security

Software

Delft3D FM and D-Water Quality

Limitations

- Delft3D FM and D-Water Quality currently only beta release
- Computationally expensive, so HPC likely required, and marginally suitable for decadal simulations
- Models for macrophytes are not well-developed, so it may not be feasible to model macrophytes accurately.

Model dependencies

- Mainstem water quality and its dependencies

Dependent models

- Mainstem water quality (for best representation of algae).

Data

- Reservoir stratification, dissolved oxygen, and algal dynamics
- Reservoir hydrodynamics
- Wind data
- Lake morphometry
- Reservoir operation rules

Risks: and their management

- Not used previously in NZ leading to delays and possible unforseen difficulties or limitations: The model is used widely internationally so has undergone testing by others; Conduct pilot project before committing to full implementation.
- Only available currently as beta version: NIWA has research agreements, and there is roadmap for full public release.

Alternatives

- Various alternatives investigated in scoping report.

Capacity and Capability

- Limited capability and capacity for 3D lake modelling in NZ.

Cost: Modelling, including application, training, development (preliminary estimate)

$300k

Cost: New data acquisition (preliminary estimate)

$600k

Other Costs (in addition to students, data platform, management)

Development timeline

2-5 years

Possible stages and sub-projects

- Pilot project

Low-hanging fruit? (Low is good)

Medium

Component 7. 1-D Lake models

Brief description

Calculates lake stratification, mixing, water quality, and optionally ecological components in lakes, given the inflows and climate. Does not account for lateral variations in water quality.

Questions addressed

- How will lake water quality and ecological status (including macrophytes) respond to reductions in external contaminant loading and in-lake rehabilitation measures, and over what time-scales?
- What are climate change risks to shallow lakes and, at a coarse level, Taupo?
- What contribution do the lakes make to water quality degradation in the lower river?
- What will lake quality be like in the near future, what are the risks of cyanobacterial blooms?

Uses

- Contaminant load limit setting
- Forecasting algal blooms
- Predicting response to rehabilitation measures

Taura addressed (Plus economics)

Water quality, Experience, Ecological Integrity

Software

GLM-PCLake+

Limitations

- Difficult to predict ecological responses (e.g., macrophytes, fish)
- Difficult to model releases from lake bed (internal loading)
- Difficult to measure and model loading from the catchment due to limited monitoring and uncertain catchment area

Model dependencies

- Contaminant and flow inputs models

Dependent models

- Could contribute to lower mainstem models

Data

- Lake morphometry
- Lake water quality observations
- Lake ecological observations
- Stratification and DO monitoring

Risks: and their management

- Lake Taupo buoy future is uncertain: address this as part of model/data procurement

Alternatives

- DYRESM-CAEDYM (discontinued)
- AEM3D (proprietary, 3D)

Capacity and Capability

- Limited capability and capacity

Cost: Modelling, including application, training, development (preliminary estimate)

$450k

Cost: New data acquisition (preliminary estimate)

$400k

Other Costs (in addition to students, data platform, management)

Development timeline

2-5 years

Possible stages and sub-projects

- Model key lakes only

Low-hanging fruit? (Low is good)

Medium

Component 8. Taupo 3D model

Brief description

Calculates mixing, water quality, and optionally ecological components in lakes, given the inflows and climate, in three dimensions and over time.

Questions addressed

- What are risks of climate change to Taupo water quality (clarity, DO, stratification?)
- What are the risks of algal blooms, and their location?

Uses

- Managing land use
- Forecasting algal blooms

Taura addressed (Plus economics)

Water Quality, Experience

Software

D-Flow-3D and D-Water Quality

Limitations

- Does not model abundance and location of high-value fish species.
- Not suitable for long-term simulations.
- Unlikely to be able to forecast algal blooms accurately
- Will not be sufficiently spatially-resolved to model mixing of discharges such as sewage spills

Model dependencies

- Rainfall-runoff and contaminant generation

Dependent models

Data

- Wind observations or model predictions
- Nearshore and lake-centre water quality, currents, temperature and DO profiles
- Remote observations of optical quality of water

Risks: and their management

- Lake Taupo buoy future is uncertain: address this as part of model/data procurement

Alternatives

- AEM3D (proprietary, 3D)
- AED/AED2 (relatively new, limited user interface)

Capacity and Capability

- Limited capability and capacity

Cost: Modelling, including application, training, development (preliminary estimate)

$275k

Cost: New data acquisition (preliminary estimate)

$500k

Other Costs (in addition to students, data platform, management)

Development timeline

2-5 years

Possible stages and sub-projects

- Establish 1-D model first

Low-hanging fruit? (Low is good)

High

Component 9. Water availability and allocation (water resources model)

Brief description

Combines rainfall-runoff models, water demand models, water allocation, reservoir operation and abstraction rules to determine water availability and reliability over time and through a catchment. Some forms optimise water use allocations.

Questions addressed

- Where is water being used, and what is the relative contribution of different takes to stream flow depetion?
- How secure is the water supply for the future, including climate change?
- Can storage be managed better or added to improve flows, and other uses of the river?
- What are the implications of setting alternative water use rules?
- Are there options for increased take of water? When?
- Can water takes be allocated more effectively?

Uses

- Development of water management options, including participatory approaches
- Regional plan and rule development
- Basis for assessing large-scale consents
- Possible coupling with economic optimisation programs (GAMS)

Taura addressed (Plus economics)

Water Security. [Water Quality]

Software

WEAP (Water Evaluation And Planning) (preliminary decision)

Limitations

- Proprietary (although not expensive)
- Coarse spatial representation (not each small water user)
- Simplified representation of groundwater, although can be coupled with MODFLOW
- Not designed for short-term forecasting
- Hydrological basis not the same as other hydrological models
- Difficult to represent hydro generation demand
- Not open source.
- Limitations in input data (e.g., rainfall, lake evaporation)
- Environmental flows need to be specified, rather than an output

Model dependencies

- Population projections

Dependent models

Data

- Water consumptive use (unsure if this is available)
- Hydro operation rules
- Standard flow gauge data
- Historical and future climate
- Soil maps
- Land use maps
- Irrigation maps

Risks: and their management

- A fairly new class of model for NZ which may introduce delays and inforseen difficulties or limitiations: there is ample international precendent, and this class of model is well-established

Alternatives

- Write a custom package
- Use other hydromics software not targeted at water resources (e.g., SWAT, TopNet)
- eWater Source (not open source, less targeted at water resources)

Capacity and Capability

- Some capability development, because there is not much experience with this type of model in NZ.

Cost: Modelling, including application, training, development (preliminary estimate)

$450k

Cost: New data acquisition (preliminary estimate)

$0k

Other Costs (in addition to students, data platform, management)

- Data provision by councils and hydro companies
- Small software cost

Development timeline

2 years for the initial project, 4 years with refinement

Possible stages and sub-projects

- Can build up from simple models, add sophistication and coupling later

Low-hanging fruit? (Low is good)

Low-medium

Component 10. Habitat suitability mapping in lower river

Brief description

Combines hydrodynamic calculations (which calculate the distribution and timing of water depths and velocities given inflows and tides) with bathymetry, vegetation and river-bed substrate information to determine availabilty of suitable habitat for selected species and life-stages.

Questions addressed

- What suitable hydraulic habitat will there be for ecological needs such as whitebait spawning?
- What are the benefits from riparian vegetation management in lower river?

Uses

- Flow management to achieve hydraulic habitat goals

Taura addressed (Plus economics)

Kai. Ecological Integrity.

Software

D-Flow and mapping

Limitations

- Only some aspects of habitat suitability are related to hydraulics and substrate/vegetation.

Model dependencies

- Rainfall-runoff and flow routing

Dependent models

Data

- Bathymetry
- Measured flows and salinity for calibration
- Vegetation
- Substrate

Risks: and their management

- Salinity influence may be difficult to model (frontal mixing dynamics)

Alternatives

- DHI 3-D hydraulic models

Capacity and Capability

- Existing capability from coastal modellers.

Cost: Modelling, including application, training, development (preliminary estimate)

$150k

Cost: New data acquisition (preliminary estimate)

$0k

Other Costs (in addition to students, data platform, management)

- Assume sufficient hydrography from previous study
- May need additional vegetation survey

Development timeline

2-4 years

Possible stages and sub-projects

Low-hanging fruit? (Low is good)

Medium

Component 11. Operational forecasting for flood flows and water quality

Brief description

Uses rainfall-runoff, contaminant generation, flow routing and water quality models driven by climate forecasts to predict water and microbiological quality in near future.

Questions addressed

- How low will the river be in the near future (up to a week)?
- What re the risks of flooding in the near future?
- What will be the risks of poor microbial water quality and of algal blooms?
- Can short-term management of the river alleviate these risks?
- Will it be safe to swim now or in the near future?

Uses

- Management of recreational activities
- Reservoir and flood management to reduce risks
- Warning of flood risks
- Pollution event management

Taura addressed (Plus economics)

Water Quality. Experience. Water Security.

Software

FEWS

Limitations

- Model forecasts are uncertain
- Models need to be fast enough to run and deliver results when required, which may not be feasible with detailed models
- Access to weather forecasts and real-time observations may be limited
- Coupling models with expert knowledge about effective interventions may be difficult

Model dependencies

- Depends on a chain of models. The particular models (and data) needed are conditional on the variables that are being predicted (flood versus water quality).

Dependent models

Data

- Weather forecasts
- Telemetered flow observations
- Telemetered water quality observations (actual parameters or proxies)

Risks: and their management

- Need robust model deployment, data acquisition, and processes: use high-quality specialist forecasting software and institutions with operational forecasting experience.
- Models developed may not be compatible with forecasting technology: use a flexible forecasting framework.
- Models may be too computationally-demanding for real-time predictions: Use HPC where necessary, and meta-modelling (approximate representation of pre-run scenarios).

Alternatives

- Cylc (Open source, used by NIWA and internationally, no visualisation, https://cylc.github.io/software)
- MIKE Operations (proprietary)

Capacity and Capability

- Some existing capability for hydrological forecasting, but not with FEWS. Forecasting specialists needed for high-quality robust operational predictions.

Cost: Modelling, including application, training, development (preliminary estimate)

$600k

Cost: New data acquisition (preliminary estimate)

$0k

Other Costs (in addition to students, data platform, management)

- Real-time water quality and flows
- Weather forecasts
- HPC resources

Development timeline

2-5 years

Possible stages and sub-projects

- Flow forecasts before water quality simulation
- Statistically-driven water quality before simulation

Low-hanging fruit? (Low is good)

Medium once base models established

Component 12. Cyanobacteria

Brief description

Predicts concentrations of cyanobacteria in the water column (and optionally toxins) from water quality, flows, hydraulics and mixing conditions, and meteorological conditions.

Questions addressed

- What are the risks of cyanobacterial blooms under different flow and water quality conditions, in a long-term risk perspective and for short-term forecasting?
- Will these be of toxic species?
- What are the implications of climate change for cyanobacterial risks?

Uses

- Assessing risks for recreational use of water (long-term and forecasting)
- Assessing options for reducing risks of blooms
- Assessing risks for water treatment needs
- Assessing implications of nutrient load reductions
- Improving reservoir operation to reduce risks

Taura addressed (Plus economics)

Algal species and toxin observations with accompanying environmental observations or models.

Software

Machine learning model in R or Python

Limitations

- A data-heavy approach
- Predictions will be uncertain
- Statistical models are not always valid outside the conditions to which they have been calibrated
- Prediction of toxic forms and toxin levels entails considerable uncertainty

Model dependencies

- More sophisticated models will use flow, stratification, weather, and water quality models.

Dependent models

- Forecasting models

Data

- Algal species and toxin observations with accompanying environmental observations or models.

Risks: and their management

- Statistical models may not be sufficiently powerful to be useful: conduct pilot project.

Alternatives

- Mechanistic simulation models of algal species (entails considerable uncertainty regarding processes and parameters).

Capacity and Capability

- Good statistical expertise and expert knowledge of cyanobacterial available, although concentrated in two organisations.

Cost: Modelling, including application, training, development (preliminary estimate)

$225k

Cost: New data acquisition (preliminary estimate)

$0k

Other Costs (in addition to students, data platform, management)

- Collation of existing algal data (currently in hard-copy)

Development timeline

2-4 years

Possible stages and sub-projects

- Could do an initial model based solely on observations and weather.

Low-hanging fruit? (Low is good)

Low for initial versions. Medium for more sophisticated versions that rely on other models.

Component 13. Fish habitat creation by floodgate modification

Brief description

Predicts depths and duration of ponding areas, and the associated water quality in response to flow control structure manipulation and floods.

Questions addressed

- Can suitable ponding areas for fish be created behind flood infrastructure?
- Would water quality considerations preclude the use of ponding areas (e.g., low dissolved oxygen)?

Uses

- Assist with designing habitat creation meausures

Taura addressed (Plus economics)

Kai, Ecological Integrity

Software

D-Flow, D-quality and mapping

Limitations

- Water quality modelling of ponded water may be difficult
- Improvements of fish abundance associated with habitat creation will not be quantified

Model dependencies

- Flow, water quality, and hydraulic models

Dependent models

Data

- Detailed topography of ponding areas.
- Detailed knowledge of current flood infrastructure.
- Data needs for other models.

Risks: and their management

Alternatives

- Trial and error habitat creation (no modelling).

Capacity and Capability

- Required expert modelling.

Cost: Modelling, including application, training, development (preliminary estimate)

$300k

Cost: New data acquisition (preliminary estimate)

$50k

Other Costs (in addition to students, data platform, management)

Development timeline

Defer for medium-long term

Possible stages and sub-projects

- Feasibility/options scoping for habitat creation.

Low-hanging fruit? (Low is good)

High

3 Overarching project components

The initial model scoping project identified several workstreams that are associated with each sub-model, such as documentation of the model (datasets, parameterisation, performance) and providing training.

Several overarching projects, which form part of a broader infrastructure, were also identified. These are described below.

3.1 Data platform and hosting

Several of the proposed models will use common data, so it would be best to collate and deliver such data in a structured and organised way. Also, model results could be stored in a structured way, so that they can be retrieved and displayed by multiple parties.

Accordingly, a workstream associated with collating and hosting datasets is proposed, as a way to effectively and efficiently organise and deliver datasets.

Part of this workstream will entail collecting and curating datasets. It is anticipated that WRC will provide input to this project, as they have some of the necessary data science capability and infrastructure.

A further consideration is the actual housing of datasets on storage devices, with associated mechanisms for data retrieval. While a distributed architecture could be used for that purpose, it would be desirable to maintain an authoritative reference dataset.

A nominal budget of **$200k** is suggested for this task, although the required funding will depend on the number of datasets, the degree of co-funding by other organisations, and details of decisions such as data hosting and standards.

3.2 Students and building capacity

The proposed set of models will require people to build and apply models. It is envisaged that capacity will need to be extended to provide the necessary skillset in the long term. Considering that advanced skillsets are required, we consider that it would be desirable to fund university students to conduct research on model development and application. A particular desire is to enhance Iwi capability and capacity in modelling, so a targeted student position is envisaged.

Nominal funding of **$350k** is suggested for two PhD students (50k per student-year, 2 students at 3.5 years each).

This training is additional to training and documentation provided for each of the models.

3.3 Model hosting

Some cost will be associated with data licences, software licences for some proprietary models, and software support. Nominal funding of **$200k** is suggested for this item, but the amount will depend on the number of models and the particulars of the licences needed. This could be managed by the managing organisation (see the next section). By funding in this way, it is anticipated that some cost savings will be achieved, compared with each party having separate licences.

3.4 Governance, hosting, and management

Specific institutional arrangements will be required to address roles such as co-ordinating and managing workstreams, contracting and managing delivery, providing technical system-level leadership, organising training, managing steering groups and technical workshops, and providing communication about the project such as aims, progress and outcomes. There are various ways this could be set up, such as assigning these roles to a key model provider, funding an independent consultant, or establishing a separate entity with dedicated resources and responsibilities.

As a separate matter, the modelling initiative should have a governance group, to provide overall supervision, steering, and to assist with resolution and co-ordination between the collaborating parties. We also see a need for a dedicated funding stream for an Iwi representative, to ensure that the modelling is accessible, fit for use, and meaningful for Iwi interests. An allowance of 3 FTE over a 5-year period is anticipated, although this will depend on the scope and range of models selected, with a nominal funding of **$900k**.

4 Further considerations

4.1 Model dependencies

Some of the model components depend on other models, as indicated by model dependencies listed for each of the model components. For example, operational flood forecasting needs a runoff generation and flow routing model. These dependencies are shown schematically in **Figure 4-1**. These dependencies will help with decisions regarding choice of a package. The overarching project components such as model hosting are shown at the bottom of the diagram, with open-ended arrows indicating that the overarching components relate to most of the modelling components.

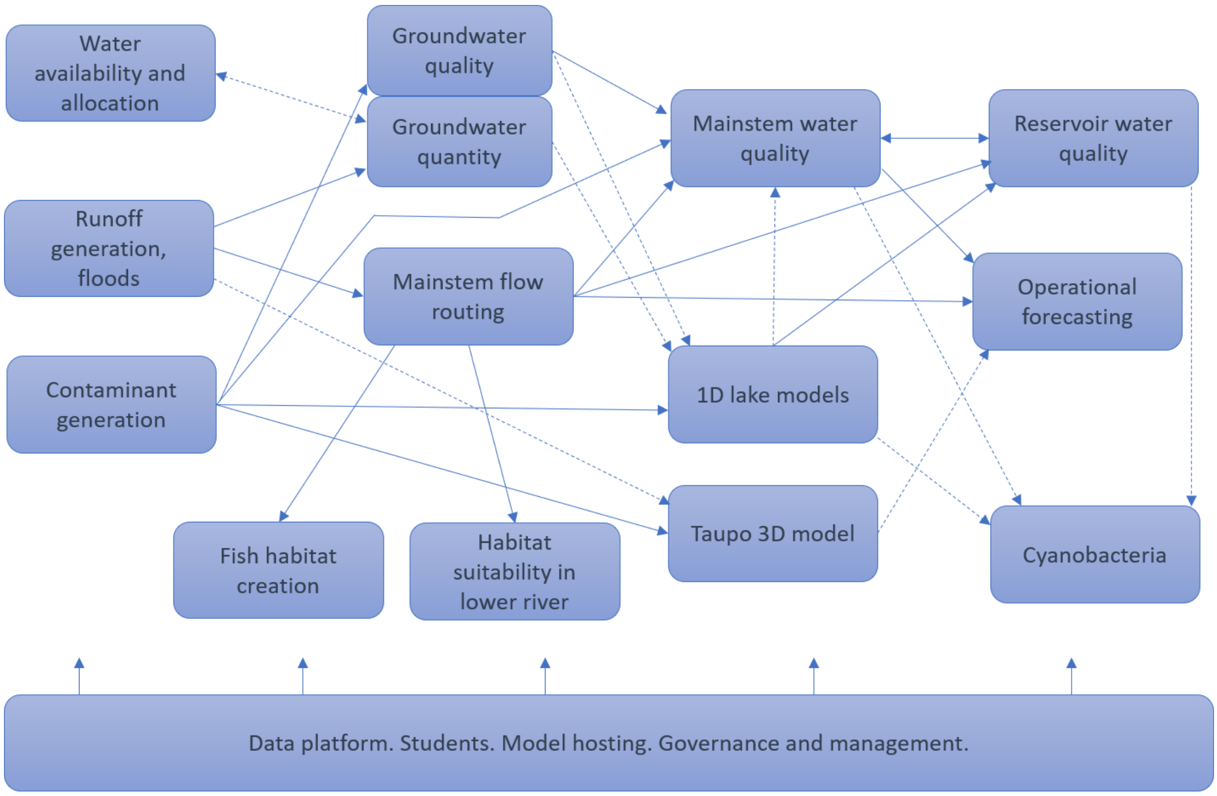

Figure 4-1: Approximate representation of model dependencies. Dashed arrows indicate where the model is partly dependent or optional.

4.2 General benefits of the modelling initiative

Many of the candidate modelling projects will provide benefits that go beyond the individual model. These benefits, which provide further justification for funding the overall project, include:

- Contributing organisations will be seen to contribute to the health of the river, which will enhance their mana and standing.
- A collective modelling approach will reduce costs to individual contributing organisations, because costs are shared.

- By sharing models there will be less duplication of effort, competition between parties will be reduced, and increased collaboration will allow more to be achieved overall.
- Collation of data required for modelling will have multiple benefits beyond providing inputs to models (for example, facilitating data visualisation and reporting activities external to the modelling process); in return, modelling provides additional justification for data collection and dissemination.
- The use of free software where appropriate means that a wider range of parties can engage in model development and applications.
- The use of open-source software means that there is the potential for a range of parties to extend and adapt the model for their particular needs, and for research students to be engaged with model development. Open source software lends greater confidence in the model due to transparency and enables leveraging the expertise of a broader modelling community.

4.3 Limitations of the set of models

During initial model scoping, **some model types were excluded** from consideration, and this is a limitation on what the overall set of models can achieve. Some examples of excluded models (gaps in the set of models) are:

- Fish abundance and movement models were excluded, due to fundamental limitations on quantitative understanding of factors driving fish behaviour, and data limitations.
- Dynamic land use evolution models were excluded. We note, however that WRC does have a dynamic evolution model, WISE, available for such forecasting (for example, anticipated patterns of land use development).
- The proposed set of models does not include an economic component. Rather, the models and model outputs are seen as potentially contributing to economic assessments (for example, flood risks, or effectiveness of scenarios of land development and mitigation measures that would be costed separately).
- River biogeomorphology (how river morphology develops over time, including the role of vegetation).
- Mechanistic modelling of toxic algal species.

Despite the emphasis on using free and open-source software, there are still **costs associated with training and support** for software, which is often best provided through the software developers. A limitation of some free software is that the user interface may not be as polished as for fully commercial software. In some cases (e.g., water resources models) we have recommended low-cost software rather than free options, because we could not find good free alternatives. Finally, although models may be free, input data may need to be licenced at a cost, and in some cases there will be costs for running models on high-performance computing infrastructure.

The **spatial resolution** of the proposed set of models is limited, due to the need to represent the full catchment. For example, we do not anticipate linking spatial details of farm plans explicitly in the models.

We also anticipate the need for **simple time-average budget models** to complement dynamic models. Such models: enable scenarios to be set up and run easily, can be linked to other models such as Overseer, and are generally easier to understand, use, and run compared with dynamic models. However, budget models have limitations, such as poor representation of algal growth dynamics and reservoir operation. Hence, we propose a dual-pronged approach whereby both dynamic and static models are established. This report only addresses the dynamic modelling.

There has been little mention of **uncertainty quantification** of the proposed set of models. Some models will be time-consuming to run, in which case it will be difficult to undertake multiple runs to assess the implications of uncertainty in model parameters. Hence, we do not consider that it is appropriate to insist on uncertainty analysis for all potential model components. Some models will be relatively, so that uncertainty analysis will be feasible, and for statistical/empirical models uncertainty analysis should be conducted. We propose that quantification of uncertainty be re-considered at the procurement stage, depending on the choice of models.

4.4 Overall risks

Risks associated with each modelling component have been identified in Section 2. There are some broader risks though, which will need to be managed during the project life.

One risk is that existing **data will not be readily available** when required, due to IP considerations. For example, forecasting would need rainfall forecasts, which are usually made available under strict conditions. If data cannot be obtained, the models cannot be run. This risk will be managed by a) allowing a budget for data access; b) including some key data providers in the modelling consortium; c) having a governance group; and d) defining management of data contracts as part of the model co-ordination workstream.

The proposed work programme is ambitious and resource-intensive. There is a risk that some key parties will **reduce funding part way through** implementing the set of models or at the point where development and implementation of models need to be continued beyond the initial 5-year timeframe. This risk will be managed in part by a) sharing costs to reduce the onus on any one party; b) including parties on a governance and steering group to ensure that the work remains relevant and targeted and c) prioritising and staging work with intermediate deliverables.

The proposed set of models is slanted towards **software provided by Deltares**, because they have generally committed to a free and open-source approach, with a track record of releasing some models to date. However, currently not all their models are open-source, which seems to be in part due to limited capacity and funding. The Deltares funding approach relies in part on providing services for advice and trouble-shooting, model application consulting, specific adaptation and extension of base software, training services, and international aid. Early access to models that are currently in beta stages of development can be achieved through collaborative agreements which entail mutual exchange of information and engagement. It is envisaged that the modelling consortium would enter into such an agreement, and that specific co-funded model trialling and extension projects would be done. Some allowance has been made for software service agreements, and once decisions on funding priorities have been made, the interested parties would enter discussions with Deltares.

4.5 Process for prioritisation

Two planned workshops which will follow the distribution of this report will identify priority projects and identify a potential pathway for funding. The prioritisation process will enable the different parties to identify sub-projects that are of greatest interest for their organisation and collectively. Factors relating to prioritisation will be refined at the workshop, but may consider:

- Are there any projects representing low hanging fruit (can be done relatively easily, in a short time-frame, with low risk, and with high benefit at low cost)?
- What are projects with overlapping/common benefits?
- Which projects are best value for money?
- Are there any starter projects that are required before others, and lay a platform for other models (e.g., basic hydrology models)?
- Are there any projects that are high-cost and low interest?
- Are there any essential projects?
- Are any projects too risky?
- Is a project desirable but best deferred, until more information is available or foundational projects are secured?
- Are there projects with serious impediments in terms of capability and capacity?
- Does a project answer a critical question?
- What are the most cost-effective projects (high benefit to cost ratio)?
- Is a sub-project (staged, pilot, exploratory, proof-of-concept) useful?
- Is a project seen as desirable, but more refined information is required before decisions can be made (e.g. model choice, costing)?

Workshop participants will be provided with this report before the workshop and asked to consider the priorities of their organisation and overall priorities before attending the workshops.

The facilitated workshops will also help identify any remaining critical gaps and will help identify funding pathways.

5 Summary

This report has presented information on several modelling alternatives (some of which are inter-dependent) in a consistent form that will assist with prioritisation and selection of models to be funded. Also, some overarching considerations applying to the set of models have been presented. This information will be provided to participants in the two model prioritisation workshops, which pave the way to refinement and procurement of selected projects.

6 References

Elliott, S. (2020) Dynamic models for the Waikato River system: Scoping study. Prepared from the Waikato River Authority. National Insititute of Water and Atmospheric Research. *NIWA Client Report*: 2020171HN.