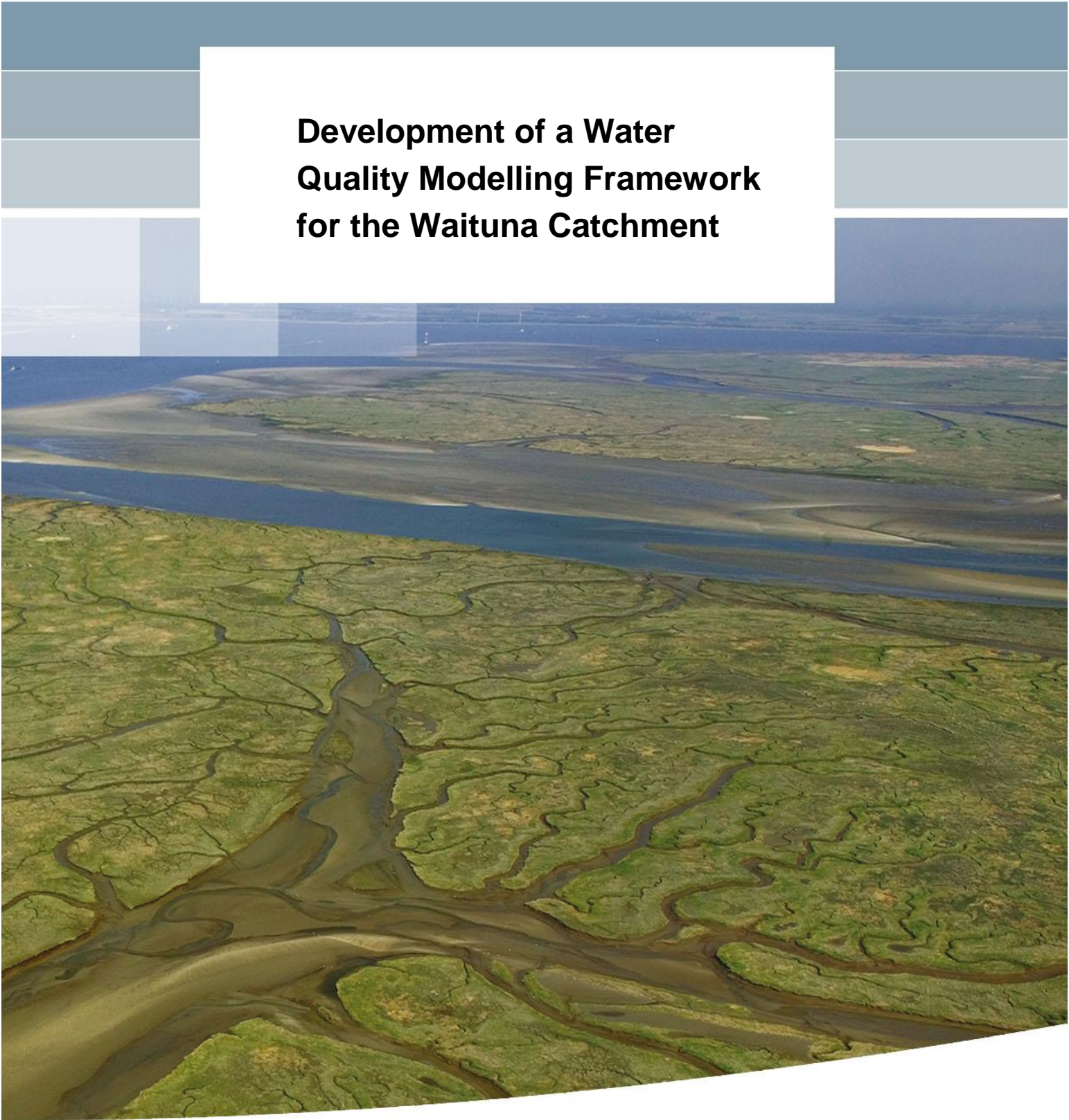


**Development of a Water
Quality Modelling Framework
for the Waituna Catchment**



Development of a Water Quality Modelling Framework for the Waituna Catchment

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Title

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Summary




In this study a catchment flow and nutrient load modelling framework was set up, applied and validated for the Waituna Lagoon catchment in Southland, New Zealand. The modelling framework spatially accumulates individual farm-generated nitrogen and phosphorus loads down the drainage network of each sub-catchment to provide an estimate of current baseline seasonal (3-monthly) nutrient inputs to the lagoon after attenuation (decay).

This report describes the setup of the hydrological and water quality model framework and its application as a potential catchment management planning tool for the Waituna Lagoon.

This study also provide learnings towards the development of a spatially refined and generic catchment water quality modelling framework to assist future catchment limit setting processes across other agricultural catchments in New Zealand.

References

Roovaart J.C. van den, E. Meijers, N. Goorden, D.F. Burger. 2014. Development of a Water Quality Modelling Framework for the Waituna Catchment. Deltares report 1209710-000.

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1 Introduction

1.1 Background

The Waituna Lagoon in Southland, New Zealand is an intermittently closed and open coastal lake or lagoon (ICOLL) system and RAMSAR site and is highly significant for its ecological, cultural and recreational values. Large scale development of the catchment (area 20,000 ha) commenced in the 1960s as part of central Government land development projects. Dairying and other pastoral land uses now represent more than 70% of the total catchment land area. Dairying, sheep and beef and dairy support businesses now contribute significantly to the local and regional economy. Lagoon water levels have been artificially managed since 1908, initially for recreation and more subsequently to maintain adequate drainage and prevent flooding of agricultural land in the lower part of the catchment.

Lagoon ecological health has declined over recent years due to increases in water column nutrient concentrations and a decrease in macrophyte cover and biomass. The risk of a regime shift to a turbid, algal dominated state is considered highly probable if further actions to improve water quality are not implemented (Waituna Lagoon Technical Group, 2013). This includes the likely need for a further reduction in nutrient loading from the catchment through the implementation of mitigation measures on and off farm.

A better understanding of catchment nutrient loading to the lagoon is required to allow different management options to be identified and fully evaluated. Assessment of the nutrient balance should take into consideration the spatial variability of individual nitrogen and phosphorus sources across the catchment as well as the seasonal variability in discharges to the lagoon.

The application of hydrological and water quality modelling tools calibrated against existing monitoring data can provide an effective way of quantifying total catchment nutrient loads to the lagoon. The complete model framework could then be further applied as a management tool to help evaluate the collective impacts of potential strategies for reducing nutrient inputs to the lagoon and steer future management objectives.

1.2 Study aims and objectives

The primary aim of this study was to develop a water quality modelling framework for the Waituna catchment to:

1. Quantify total catchment nitrogen and phosphorus loads discharging from each river sub-catchment to the Waituna Lagoon after attenuation
2. Visually identify critical load areas across the catchment as well as the accumulation of nutrient loads through the river network
3. Provide a framework for assessing the impacts of a range of mitigation scenarios on the total catchment load together with land owners and water managers
4. Provide learnings towards the development of a spatially refined and generic catchment water quality modelling framework to assist future catchment limit setting processes across other agricultural catchments in New Zealand.

A catchment flow and nutrient load modelling framework was set up, applied and validated for the Waituna catchment based on open source software. The modelling framework spatially accumulates individual farm-generated nitrogen and phosphorus loads down the drainage network of each sub-catchment to provide an estimate of current baseline seasonal (3-monthly) nutrient inputs to the lagoon after attenuation (decay).

Within this framework, the WFD Explorer water quality model has been used for the catchment load and surface water quality modelling, combined with the WFLOW water quantity model for the water balance. Both WFLOW and the WFD Explorer are available free of charge, while the WFLOW module is also OpenSource (as part of the Deltares OpenStreams package www.openstreams.nl).

This report describes the setup of the hydrological and water quality model framework to the Waituna catchment. This study is underpinned by a detailed analysis of catchment-wide nutrient sources which will be reported elsewhere by DairyNZ.

The application of the model framework to assess and make recommendations on possible solutions for the long term management of the catchment and lagoon will also be reported in a subsequent report.

1.3 Study activities

The following activities were undertaken as part of the current study:

- 1 Set up, calibration and validation of a 1D distributed hydrological model framework to compute daily discharges to the Waituna lagoon (WFLOW).
- 2 Coupling of the hydrological model to a data, workflow and visualisation framework (Delft-FEWS).
- 3 Extension of the hydrological framework to include real time control options to provide additional capabilities to access and drive operational water level management in the lagoon (RTC-Tools).
- 4 Set up of a catchment water quality model framework to estimate seasonal nitrogen and phosphorous loads to the lagoon (WFD Explorer).
- 5 Implementation of spatially refined catchment nutrient sources into the water quality model schematisation.
- 6 Coupling of hydrological model output to the water quality modelling environment.
- 7 Calibration and final quantification of total nitrogen and phosphorus loads to the lagoon after attenuation.
- 8 Application and testing of the complete modelling framework as a management tool for assessing the impacts of potential mitigation scenarios.
- 9 Provide recommendations and requirements for the possible expansion of the modelling framework to complex catchments elsewhere.
- 10 Reporting and model handover, including a user guide on how to run the model, update input information and apply management scenarios.

1.4 Report outline

Chapter 1 provides an introduction to the study and its key aims, objectives and research activities. Chapter 2 provides an overview of the modelling approach applied, and describes the various sub-models which make up the final model instrumentation.

The setup, calibration and results of each model are described in Chapters 3 (WFLOW hydrological model) and 4 (WFD Explorer water quality model). Chapter 5 tests the application of the model framework to run management scenarios while Chapter 6 describes the extension of the hydrological model to include the lagoon water balance and water level control tools. A summary of the study, recommendations for further model refinement and expansion and overall conclusions are provided in Chapter 7. Supplementary background information about the model framework is documented as appendices.

2 Modelling Framework

2.1 Requirements

The main purpose for applying a catchment water quality modelling framework to the Waituna Lagoon catchment was to (a) quantify total catchment nitrogen and phosphorus loads discharging from each sub-catchment to the lagoon after attenuation and (b) provide an integrated management tool which can be applied to explore possible management solutions to reduce nutrient loading together with land owners and water managers.

For the modelling tool to be effective, the following functionalities were desired:

- A spatially refined approach which allows farms and other load sources to be implemented individually in the model framework. This is to capture the large differences observed in nutrient losses from individual farms, for example due to differences in stocking rates, system type, soil type and other variables.
- An integrated catchment load management tool which can be applied to test a wide range of possible scenarios targeting different load sources, locations, soil types, land use types and activities.
- The ability to generate and visualise spatial output of stream nutrient concentrations and loading.
- Rapid model run times to allow scenarios to be simulated and analysed quickly together with land owners and stakeholders.
- An adaptable and flexible approach which allows more complex model functionalities, for example groundwater and in-stream processes, or other substances to be added in future without the need to reconfigure the existing set up and approach.
- Open-source software or freeware, to ensure that the model could be applied by anyone to any catchment without constraints. This improves model applicability and transparency and helps understand the capabilities and limitations of the model.
- A framework which could potentially be expanded to other agricultural catchments in New Zealand, irrespective of catchment size and complexity.

As the overall objective of the model is to assist catchment management planning, the main requirement of model output is mean, steady-state seasonal load estimates.

2.2 Selected modelling approach

To meet the specified requirements for the model, a framework based on the following individual sub-models was applied:

1. A 1D distributed catchment hydrological model for the simulation of rainfall runoff and sub-surface flows on a daily time step and 25 x 25 m spatial resolution (Deltares WFLOW).
2. A data, workflow and visualisation platform to serve as a user interface for the hydrological model and to assist data management and the result mapping (Delft-FEWS).
3. A coupled real-time control tool to simulate the lagoon water balance and assess and drive operational water level management (RTC-Tools).
4. A lumped, steady state catchment water quality model to quantify catchment nutrient loading after attenuation and conduct nutrient management scenarios (Deltares WFD Explorer).

A schematic overview of the complete modelling framework and individual sub-models is shown in Figure 2.1. Each individual model is described in more detail in the following sections.

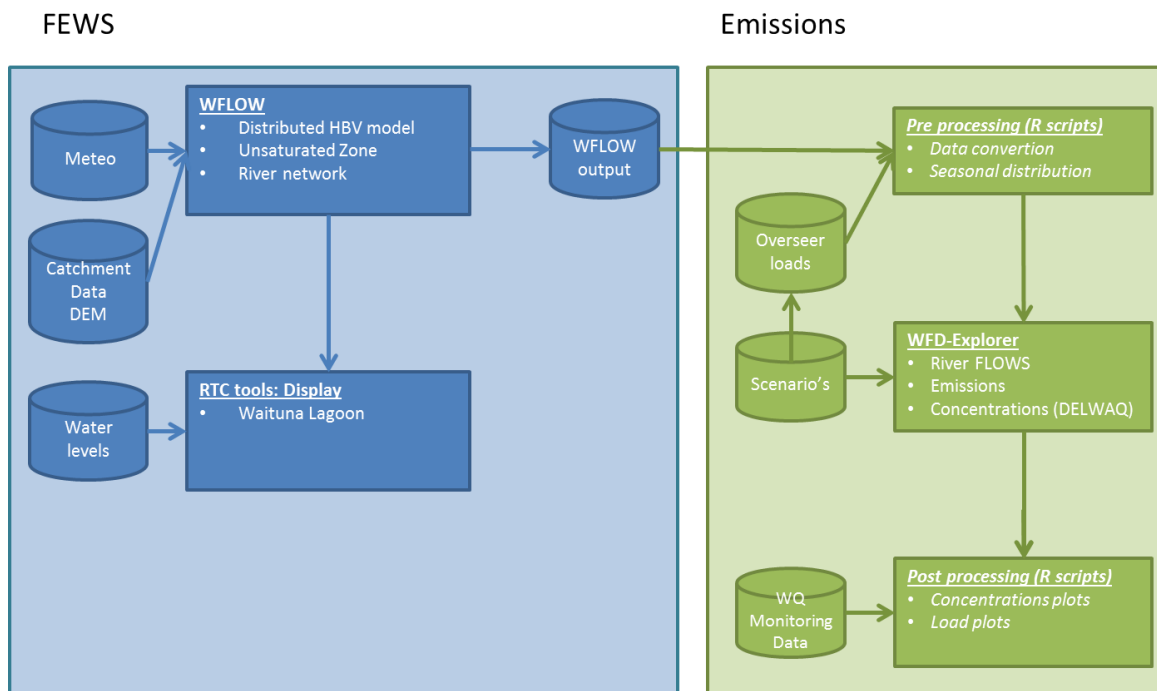


Figure 2.1 Schematic overview of the complete modelling framework as applied to the Waituna Catchment. The framework consists of two parts: the left part (blue) is the part for which the data handling is done by FEWS, the right part (green) covers the emissions with the WFD Explorer as core of the framework.

2.3 WFLOW hydrological model

WFLOW is a process-based distributed hydrological model developed by Deltares (Appendix A). Conceptually WFLOW is based on the HBV-96 model (Bergström, 1995). Hydrological processes are simulated at the spatial scale of model elements, which in the case of WFLOW are cells on a square grid. The model is programmed in a dynamic GIS environment based on PCRaster (Burrough et al., 2005), a dynamic programming language especially developed for spatial grid computations.

WFLOW incorporates the most important processes of the hydrological cycle as schematized in Figure 2.2. Different components of the hydrological cycle are modelled through a combination of sub-models nested in the model code, including:

1. Rainfall interception schematized by the Gash model (Gash, 1980, 1995).
2. Channel and overland flow modelled with the kinematic wave model.
3. Soil processes schematized by the HBV-96 model (Bergström, 1995). Alternatively, soil processes can be modelled with the TOPOG_SBM model concept (Vertessy and Elsenbeer, 1999).
4. Unsaturated zone.
5. Saturated zone.

The WFLOW model solves the governing equations for the surface and subsurface flow routines using the finite difference scheme. The equations are solved in time for each grid cell, providing continuous simulated values for the hydrological state variables (runoff volumes,

saturation etc.) for each cell. Channel flow processes are simulated using the kinematic wave model. The model output can be visualized as a sequence of spatial maps (gridded raster data) of hydrological variables. For selected locations across the catchment, time series of hydrological variables such as discharge or soil saturation can be generated.

WFLOW has been developed to simulate surface and the shallow sub-surface flow paths. Deeper, regional groundwater flows are not modelled and therefore ignored.

A detailed description of the WFLOW model is provided in Appendix A.

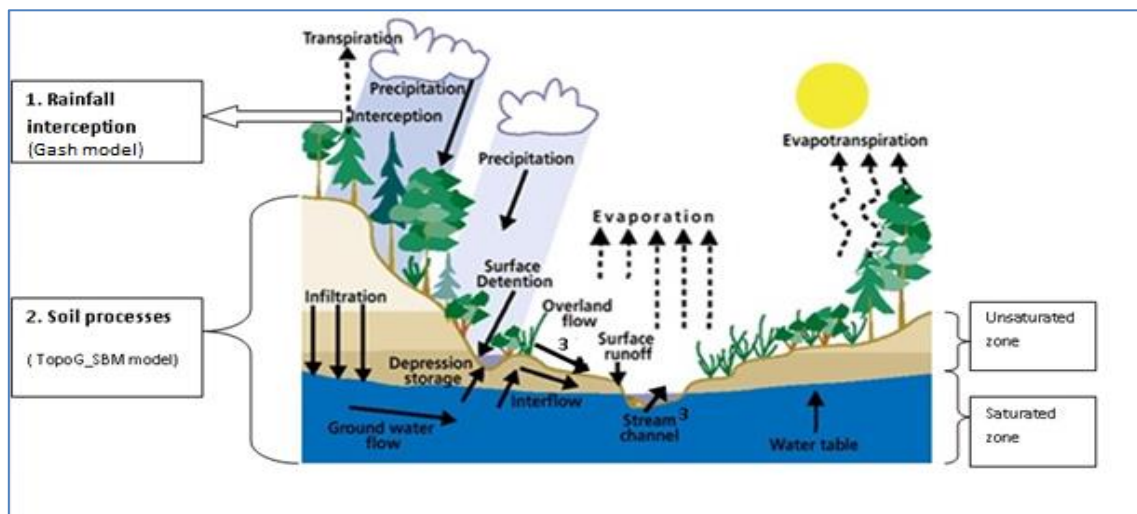


Figure 2.2 The basic components of the hydrological cycle represented in the WFLOW model.

2.4 FEWS platform environment

WFLOW was applied in combination with Delft FEWS as the hydrological model does not have a user-interface, making it difficult to run and analyse model results or demonstrate output to end users in an interactive way. This approach means that FEWS acts as the WFLOW user-interface as well as a data management system for importing and retrieving model inputs and outputs.

Delft-FEWS is an open software environment utilized for the application of various modelling tools built around a central database. A set of standard tools related to data handling are also incorporated, including modules for importing and exporting data, validating and interpolating data (both temporally and spatially) and transforming data (aggregation, disaggregation and transformation).

The philosophy of Delft-FEWS is to provide an open system to allow a wide range of existing models to be used. This concept is supported by the provision of a General Adapter module, which allows communication to external modules using an open, XML based, published interface. The XML published interface in combination with the General Adapter effectively enables “plugging-in” of any module to Delft-FEWS. A module adapter will typically be required to convert the published interface files to the native module data formats.

The module adapter will also need to be aware of specific requirements of the external module. A module adapter is the only requirement to get any external module to be used in Delft-FEWS. A module adapter can be made by any third party. Such adapters are already available to support a wide range of hydraulic and hydrological models, including WFLOW.

The concept of Delft-FEWS is schematically shown in Figure 2.3. The WFLOW model linked to FEWS follows the same approach as all other models linked to FEWS:

1. Forcing data is imported into FEWS, in this case measured precipitation and potential evapotranspiration as required for the hydrological model;
2. Data is exported to the WFLOW model in a defined format (Published Interface - PI). For the WFLOW model the defined format is PCRaster “map”-files;
3. Model runs are complete using the native format of the model code;
4. Data is imported from the model in the same defined format (PI).

More background information about Delft-FEWS model can be found on the Deltares wiki site (<http://publicwiki.deltares.nl/display/FEWSDOC/Home>).

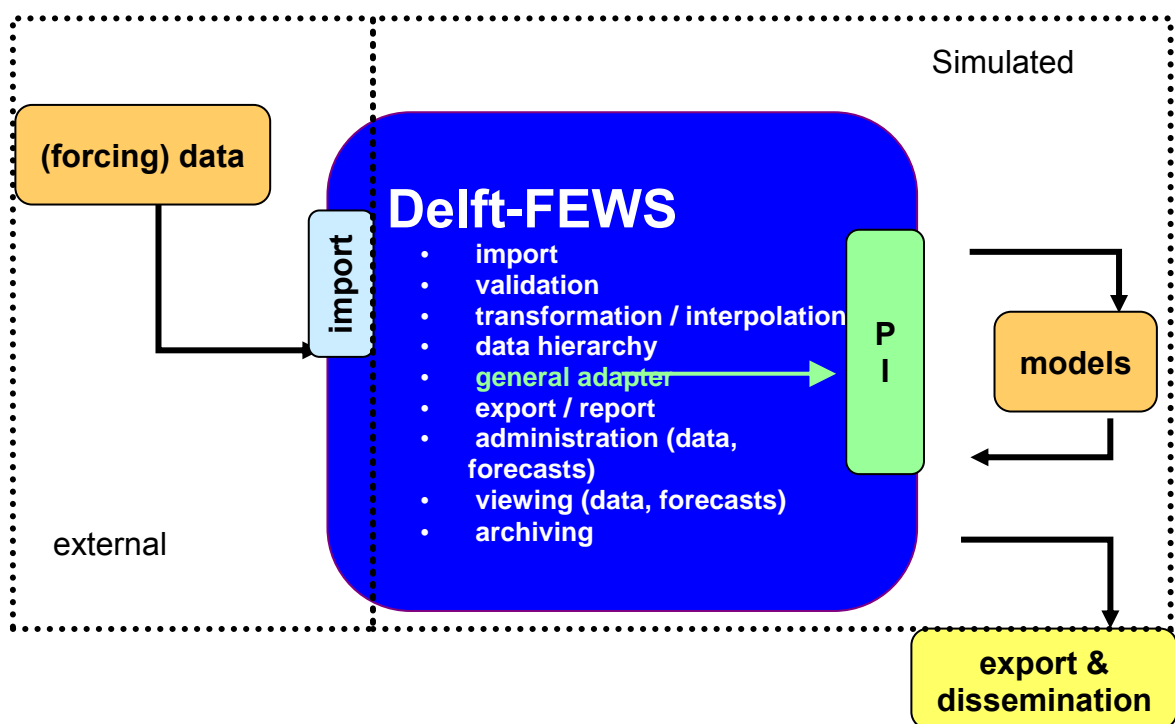


Figure 2.3 Concept of Delft FEWS.

2.5 WFD Explorer model

The WFD Explorer is a lumped, steady state model developed to support catchment water quality management (Fig. 2.4). The model was initially developed in response to modelling requirements for the Water Framework Directive (WFD) in the European Union. The WFD requires water managers to improve the chemical and ecological status of many degraded water bodies. The chemical and ecological status of a water body is defined by so-called EQRs: ecological quality ratios.

The EQR includes metrics based on concentrations of total nitrogen (TN), total phosphorus (TP), chlorophyll-a, and species composition and/or abundance of phytoplankton, macro fauna, macrophytes and fish.

To improve the chemical and ecological status of water bodies, water managers define sets of mitigation strategies. However, it is often not clear to what extent the strategies identified will improve the EQR of a water body. As mitigation measures are expensive, having prior insights on the likely effectiveness and cost efficiency of different mitigation scenarios is extremely helpful as part of the catchment management planning process.

The WFD Explorer has been developed to support water managers in making decisions on what measures should be implemented to improve the chemical and ecological functioning of a water body. Moreover, the WFD Explorer is also extremely useful as a communication tool to assist stakeholders with identifying different management options and outcomes in an interactive way. The WFD Explorer consists of a water balance, a substance balance, an ecological module and a mitigation module (including a cost module) (Fig. 2.4). In short, the WFD Explorer works as follows: the water balance constructs a water flow through a network of water bodies, for example ditches, streams and lakes. The water balance is then used as input for the substance balance, which transports the substances over the network. Next, information on nutrient concentrations together with characteristics of the water body (e.g., sheet piling, weirs) is used in the ecological module.

Mitigation measures can be inserted into the WFD Explorer at any substance or ecological level. The WFD Explorer generates output in the form of tables and maps. These outputs contain information on substance concentrations and chemical and ecological EQRs.

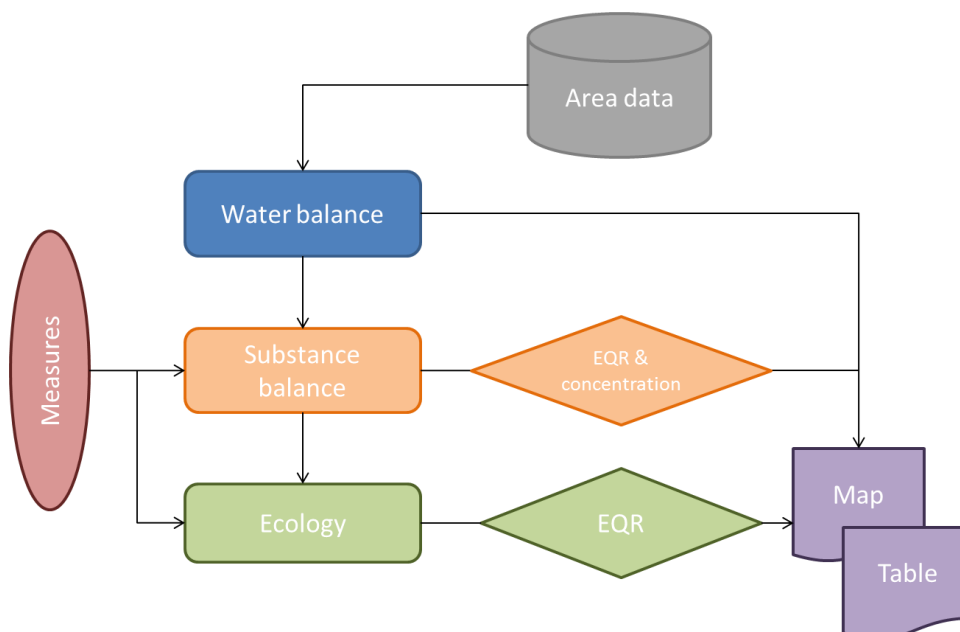


Figure 2.4 Flow chart of the WFD Explorer.

2.6 RTC-TOOLS

RTC-Tools is an open source, modular toolbox developed by Deltares for real-time control (RTC) of hydraulic structures such as weirs, pumps, hydropower, water intakes, etc. This module can be coupled to any of the existing Deltares hydrological models, including the WFLOW hydrological model, as applied in the current study.

2.7 Final model workflows

The final model workflows can be summarised as follows:

FEWS:

1. The Catchment hydrology is computed with WFLOW for the unsaturated zone and the river network.
2. The WFLOW model is fed by both static data concerning the description of the land surface (e.g. a Digital Elevation Model, land use parameters and soil parameters), and dynamic data, represented by the hydro-meteorological forcing of the model.
3. The WFLOW output is generated and manually transferred to the WFD Explorer.
4. The RTC model is automatically fed by WFLOW output and imported time series of the sea level. Model output is visualised in a dedicated display in FEWS.

Emissions:

1. Pre-processing scripts convert the WFLOW data to WFD Explorer format, including spatial and time aggregation and convert the load sources to WFD Explorer format, including a seasonal distribution.
2. The WFD Explorer interface imports data from the pre-processing script, combines the individual farm loads with the loads of other sources and calculates the nutrient concentrations for the schematized parts of the river network.
3. Within the WFD Explorer different emission scenarios are defined and calculated, either by varying the load input files or manipulation of the loads related to specific farms, land use, soil type or geographical location of the farms.
4. Post processing scripts combine measured and computed values for nutrient concentrations and loads, generate maps with loads per farm or per hectare, and present overviews with the contribution of the flows from the different sub-catchments to the lagoon.

3 Catchment hydrological model set up, calibration and results

3.1 Introduction

The goal of the hydrological model is to produce spatially distributed estimations of rainfall runoff from the Waituna catchment to the Waituna Lagoon through the drainage network. This information, including water balances generated for each individual farm title in the catchment, are subsequently used as input to the water quality model to simulate river water quality and contaminant loads to the lagoon.

This Chapter describes the setup of the hydrological model to the Waituna Lagoon catchment, including data inputs, model parameterization, calibration and results. A detailed introduction to the WFLOW model is provided in Chapter 2.

3.2 Model inputs

The input data required to execute a simulation in WFLOW can be separated into *i)* static data concerning the description of the land surface, and *ii)* dynamic data, represented by the hydro-meteorological forcing of the model.

Table 3.1 reports the key data requirements for the model and their respective sources as used for the current application.

Table 3.1 WFLOW data requirements and data sources.

Static Data	
Digital elevation model (DEM)	Topography data from LiDAR (airborne laser scanning) collected by NZ Aerial Mapping (NZAM).
Soil physical parameters	Southland Topoclimate soil layer (1:50 000 scale).
Land use	Environment Southland GIS database updated based on 2013-2014 DairyNZ survey information.
Dynamic data	
Precipitation and potential evaporation	NIWA Virtual Climate Station Network (VCSN) output (daily meteorological data on an interpolated grid 0.5 km x 0.5 km)
Discharge data (for calibration and validation)	Environment Southland daily discharge data Moffat Creek at Moffat Road, Waituna Creek, at Marshall Road and Carran Creek at Waituna Lagoon Road.

3.2.1 Digital elevation data and river network

Elevation data was based on a catchment-wide LiDAR (Light Detection and Ranging) survey carried out by NZ Aerial Mapping for Environment Southland in March 2012. Terrain analysis software was used in combination with a digital terrain elevation model (DEM) of the study area to determine sub-catchment boundaries, land areas and topography. The original DEM resolution of 1 x 1 m was disaggregated to a final resolution of 25 x 25 m to reduce the computational effort to run the WFLOW model over extended periods. The catchment river network was derived from a GIS layer provided by Environment Southland (Fig. 3.1).

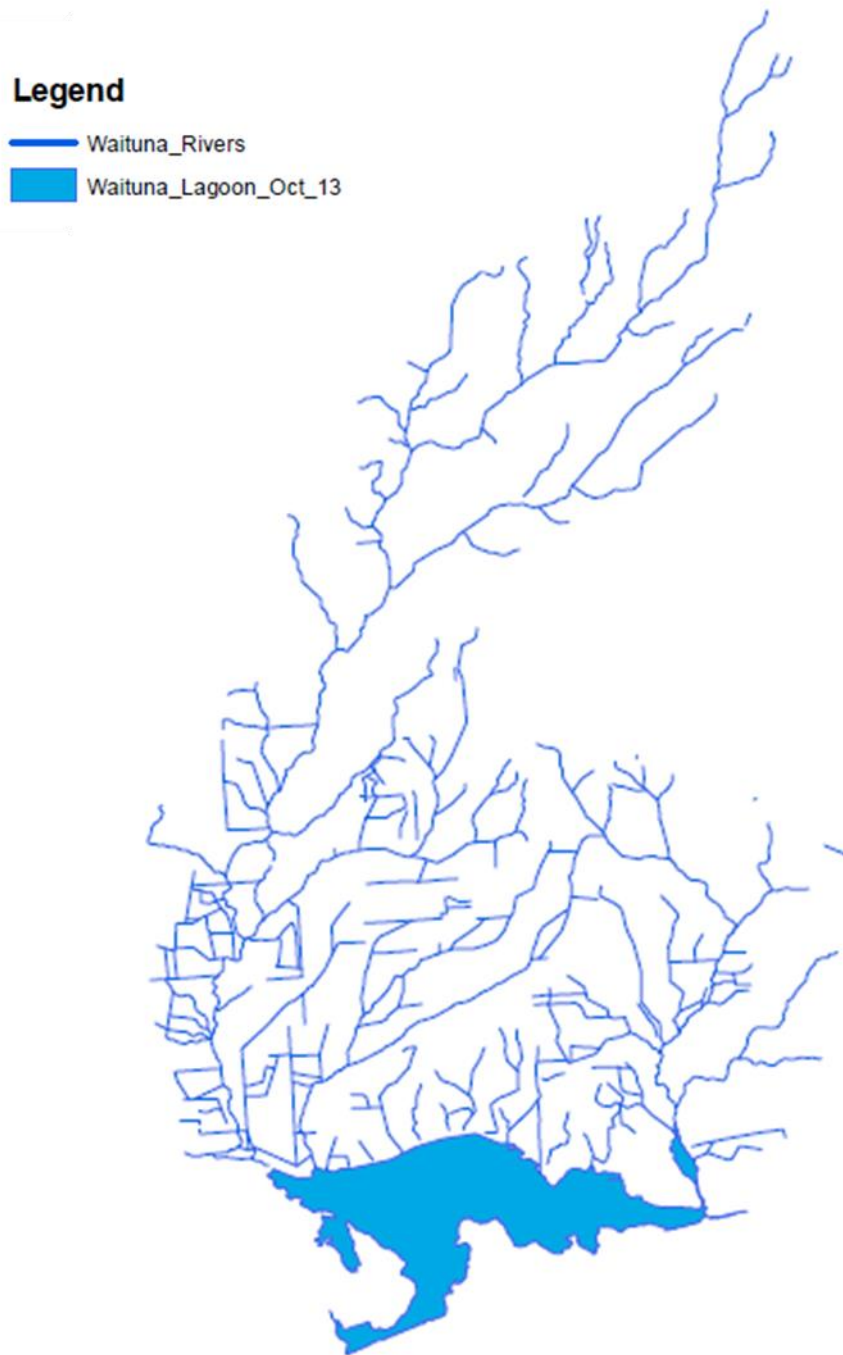


Figure 3.1 Waituna Lagoon Catchment river network (GIS layer from Environment Southland).

3.2.2 Land use type

Catchment landuse, used by the model to estimate surface runoff and evapotranspiration, was based on output from the Environment Southland landuse database. This information was updated with 2013 farm survey data collected by DairyNZ. The final landuse map provides an accurate estimation of current (2012-13) landuse class at the individual property scale (Figure 3.2). The main land use types in the Waituna catchment are Dairy, Dairy Support and Drystock, which collectively represent more than 70% of the total catchment land area. The landuse information was rescaled to a spatial resolution of 25 x 25 m to align with the final hydrological grid resolution.



3.2.3 Soil type

Catchment soil type, used by the model to determine soil water holding capacity and water storage depth, was derived from Environment Southlands Topoclimate database. This data represents a soil map across the Southland region on a scale of 1:50,000. Soil type in the Waituna catchment consist predominantly of organic soils in the south, brown soils in the north and a combination of intergrade soils (organic, gley and podzol) in the middle reaches of the catchment (Figure 3.3).


3.2.4 Precipitation and potential evapotranspiration

Precipitation, the principal forcing variable for the hydrological model, was derived from the NIWA Virtual Climate Station Network (VCSN, see <http://www.niwa.co.nz/climate/our-services/virtual-climate-stations>). The VCSN consists of a grid of 11491 virtual climate stations located across New Zealand, each of which provide a daily estimate of meteorological condition based on the interpolation of measured data from surrounding monitoring stations. The grid point separation of the network is 0.05 degrees latitude and longitude, which equates to approximately 5 km. Each station has daily interpolated values of wind speed, maximum and minimum temperature, relative humidity, MSL pressure, potential evapotranspiration, soil moisture content, 10cm soil temperature and global solar radiation. Precipitation and evapotranspiration data from 16 VCSN stations available across the Waituna catchment were used as input to the hydrological model (Figure 3.4). Precipitation was available from 1960 to 2014 and evapotranspiration from 1972 to the present.

Legend

-  Waituna_Rivers
-  Waituna_Lagoon_

Waituna Land Use

-  <all other values>

Category

-  Dairy
-  Dairy Support
-  Drystock
-  Forestry
-  Lifestyle
-  Mine
-  Res/Com
-  Wetland

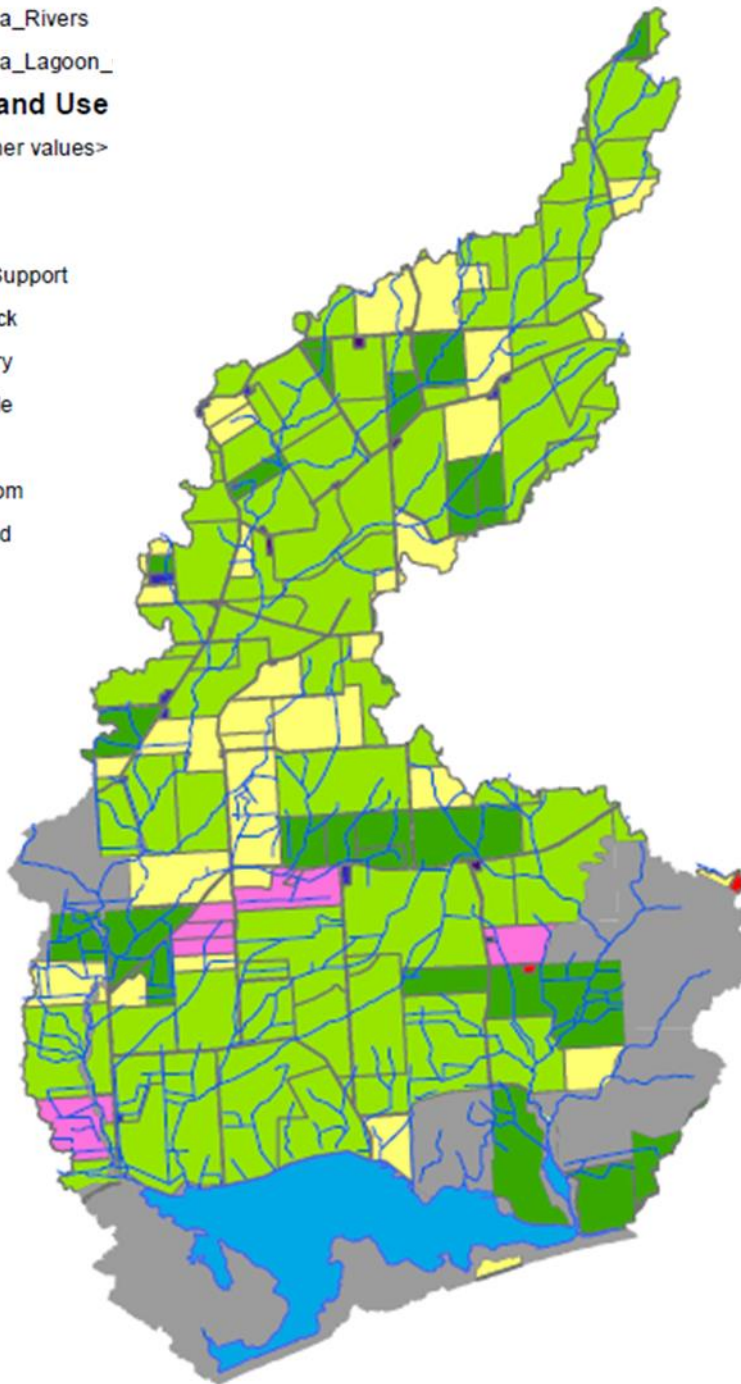


Figure 3.2 Waituna catchment land use type (from Environment Southland and DairyNZ).

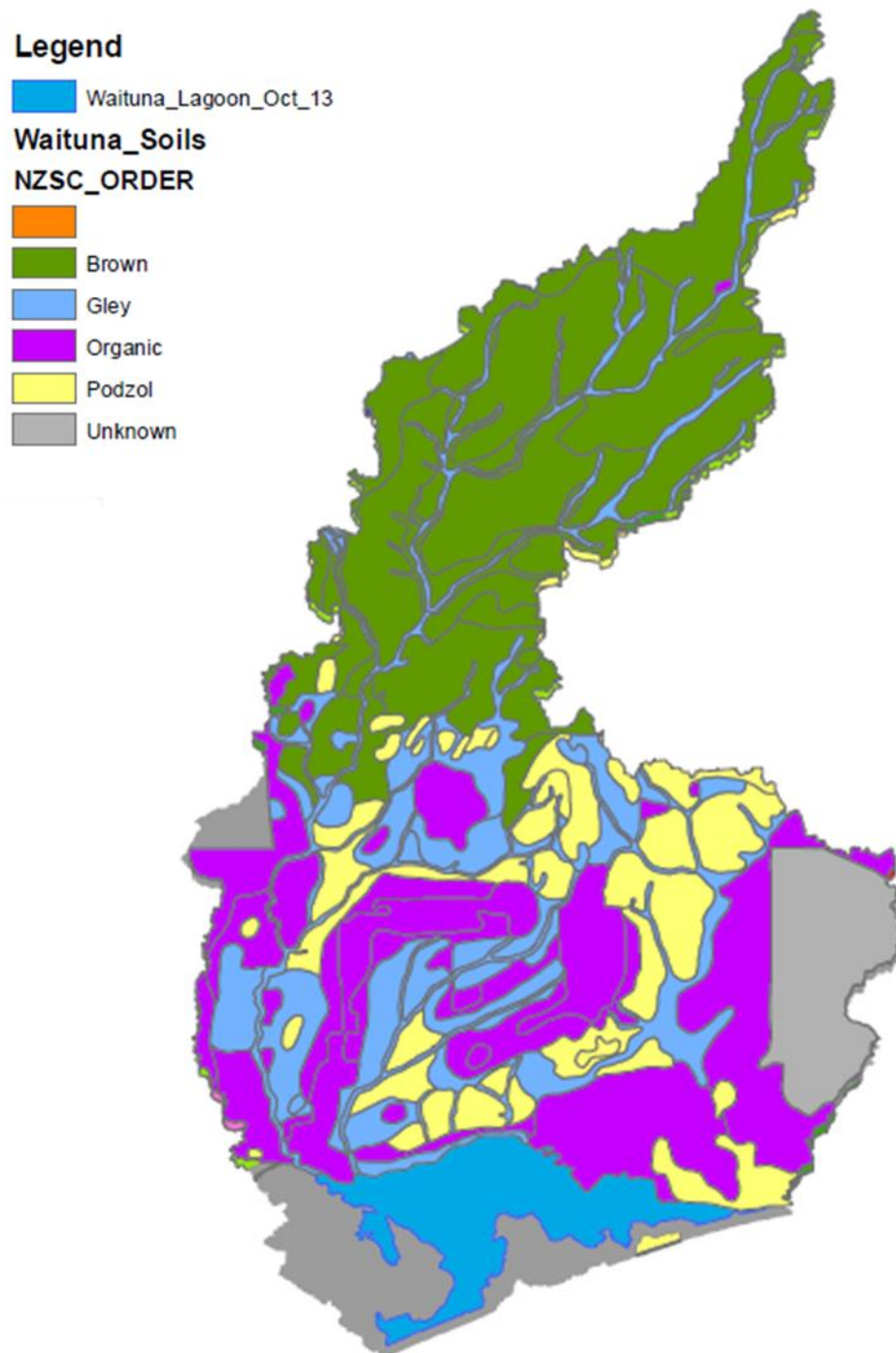


Figure 3.3 Waituna catchment soil type (from Environment Southland).

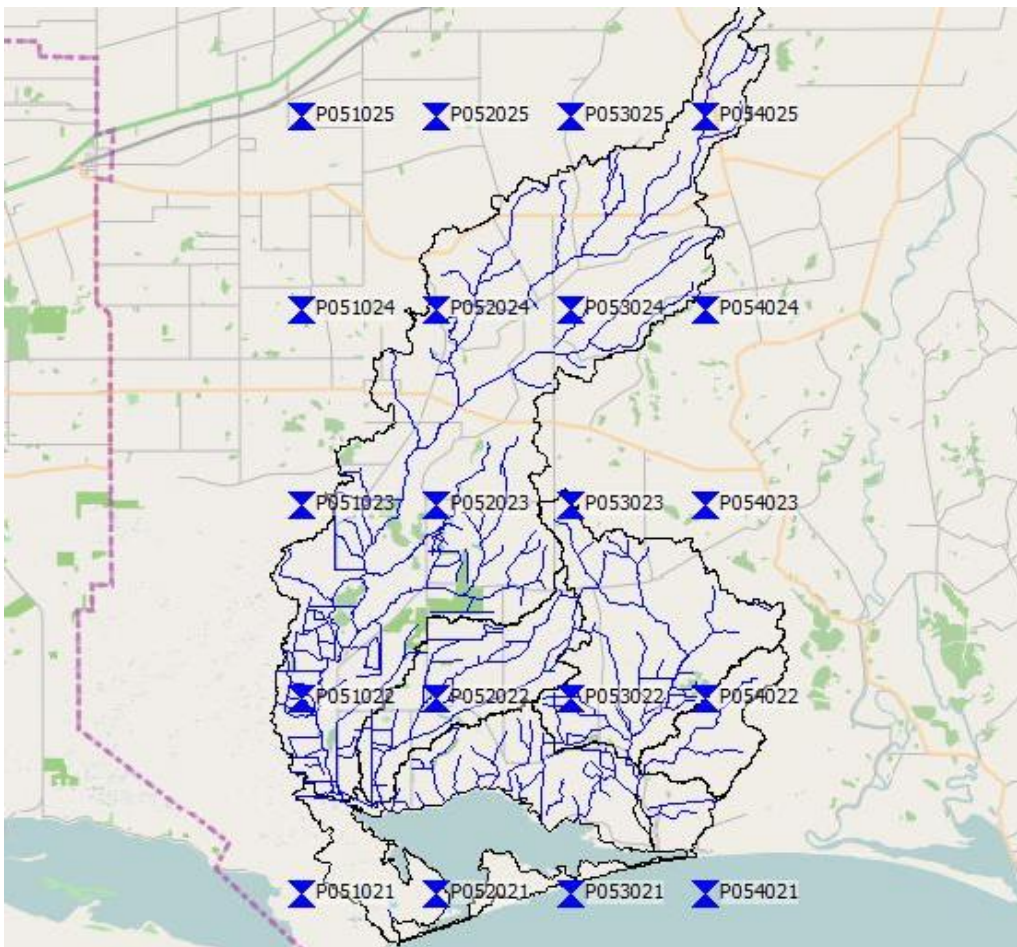


Figure 3.4 NIWA VCSN station names and locations used to derive meteorological forcing data for the WFLOW model.

3.3 Model parameterisation

3.3.1 Model coefficients

Model coefficients used to prescribe water storage and runoff in the unsaturated and free surface water routines of WFLOW were specified for each landuse type based on default settings and expert judgment (Table 3.2). Of the coefficients assigned, the fraction of compacted area per grid cell (PathFrac) and the rooting depth of the vegetation (RootingDepth) are variable across different landuse types.

Additional coefficients used by the unsaturated and saturated zone WFLOW soil routine were assigned for each specific soil type present in the catchment (Table 3.3). Values of soil-specific saturated conductivity were prescribed based on supplementary information recorded in the TopClimate Soils database after verification with Environment Southland soil scientists. All values assigned are considered to represent a best estimate for each soil type in the absence of more detailed soil information.

Table 3.2 Parameters used in WFLOW for the different land use types in the Waituna catchment.

	PathFrac	Rooting Depth [mm]	N [s/m ^{1/3}]	N_river [s/m ^{1/3}]
Dairy	0.01	100	0.1	0.04
Dairy Support	0.01	100	0.1	0.04
Drystock	0.01	100	0.1	0.04
Forestry	0.01	750	0.1	0.04
Lifestyle	0.01	100	0.1	0.04
Mine	0.2	0	0.1	0.04
Res/Com	0.4	30	0.1	0.04
Road Transport	1	0	0.1	0.04
Wetland	0	700	0.1	0.04

Description of parameters:

- PathFrac: Fraction of compacted area per grid cell
- RootingDepth: Rooting depth of the vegetation [mm]
- N: Manning overland flow [s/m^{1/3}]
- N_river: Manning N parameter for the Kinematic wave function [s/m^{1/3}]. Higher values dampen the discharge peak.

Table 3.3 Parameters used for the unsaturated zone of the Waituna catchment in WFLOW.

	FirstZone Capacity [mm]	FirstZone Min Capacity [mm]	FirstZone KsatVer [mm/day]	InfiltCap Soil [mm/day]	InfiltCapPath [mm/day]	theta R	theta S	M
Brown	2000	500	700	200	5	0.05	0.15	100
Gley	2000	500	50	200	5	0.05	0.15	100
Organic	2000	500	50	200	5	0.05	0.15	100
Podzol	2000	500	50	200	5	0.05	0.15	100

Description of parameters:

- FirstZoneCapacity: Maximum capacity of the saturated store [mm]
- FirstZoneKsatVer: Saturated conductivity of the store at the surface [mm]
- FirstZoneMinCapacity: Minimum capacity of the saturated store [mm]
- InfiltCapSoil: Infiltration capacity [mm/day] of the non-compacted soil fraction (unpaved area) of each grid cell
- Infiltration capacity: Infiltration capacity [mm/day] of the compacted soil (or paved area) fraction of each grid cell
- ThetaR: Residual water content
- ThetaS: Water content at saturation
- M: Soil parameter determining the decrease of saturated conductivity with depth

3.3.2 Model time step

A daily model computational time step was selected to reflect the temporal resolution of the available meteorological forcing data. The model can be run on a much finer time step (e.g. minutes) but in the absence of more temporally refined input data this would not improve model accuracy.

3.3.3 Integration into FEWS

Rainfall and potential evaporation derived from the VCSN stations (Fig. 3.4) was re-projected to NZGD 2000 – NZ Transverse Mercator to allow this information to be imported into FEWS. The existing VCSN grid (0.5 x 0.5km grid resolution) was downscaled to 25x25m grid cells by using nearest neighbour interpolation and conversion to the standard map format utilised by WFLOW (Fig. 3.5).

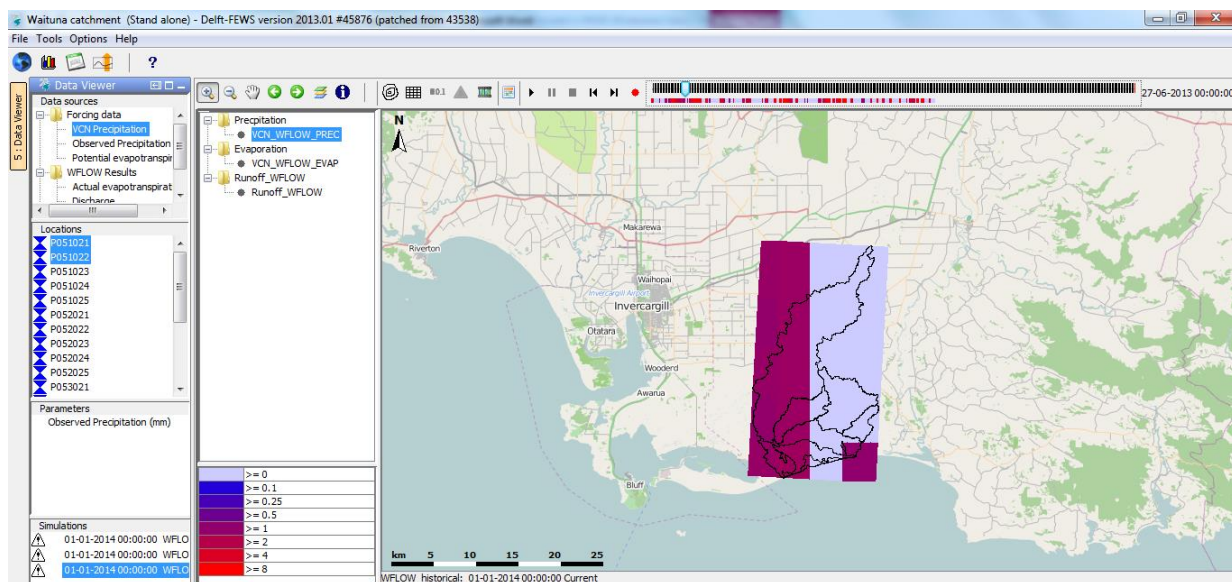


Figure 3.5 Screen shot of the grid-rainfall at 27-6-2013 of the Waituna catchment presented in the “Spatial Data” display of FEWS.

3.4 Model calibration and validation

3.4.1 Calibration process

A hydrological model needs to be calibrated to ensure optimal performance in terms of discharge simulation. Calibration is a process in which the model parameters used to describe the behaviour of the different soil store entities are adjusted until the model is able to optimally reproduce the behaviour of the stores over a selected period. Overall model performance is evaluated by comparing simulated discharge against measured discharge at downstream monitoring locations.

Discharge measurements were available from Environment Southland for all major tributaries discharging to the lagoon (Waituna, Moffat and Carran Creeks, Fig. 3.6).

Discharge in the Waituna Creek at Marshall Road has been measured continuously at 10-minute time intervals since August 2001. Moffat Creek has been monitored continuously since September 2007 and Carran Creek in November to December 2011 and from December 2012. In addition, monthly discharge measurements collected as part of Environment Southland's water quality monitoring program are available from 1995 for Waituna Creek, and from 2001 for Carran Creek, Carran Creek Tributary and Moffat Creek.

WFLOW was calibrated over a one-year simulation period (2011) focusing on Waituna Creek, which represents the largest contributor of discharge to the Waituna Lagoon. Model output was subdivided into sub-catchments in order to simulate discharge at each of the four monitoring locations (Fig. 3.6). In the first instance model daily output was compared against the continuous flow measurements recorded. Model performance was then further examined by comparing the computed seasonal (3-monthly) average of model output with measured observations. This time interval was selected to reflect the seasonal computational time step of the WFD explorer emissions model. The model was then validated over a 1.5-year period from April 2012 for all tributaries

3.4.2 Calibration results and adjustment of model input parameters

The results of uncalibrated model output against measured discharge in Waituna Creek are shown in Figure 3.7. These results indicate that the initial model setup underestimates discharges under base flow conditions. During the calibration phase it became apparent that the saturated hydraulic conductivity coefficient was the most sensitive parameter in the model. The original saturated conductivity was set to 50m/day for all soils except brown soil, which was set to 350m/day. By increasing this parameter two-fold, which is still within the range given by the Topoclimate soil database, the model performs much better, especially under base flow conditions.

The average and median seasonal (3-monthly) observed and modelled discharge are compared in (Table 3.4). These results show that the uncalibrated model underestimates mean flow conditions but the results are improved with calibration due to the higher simulated base flow (Table 3.4). Despite this improvement, the model still underestimates peak flows at times, as evident by the improved result when median values are compared instead of the mean.

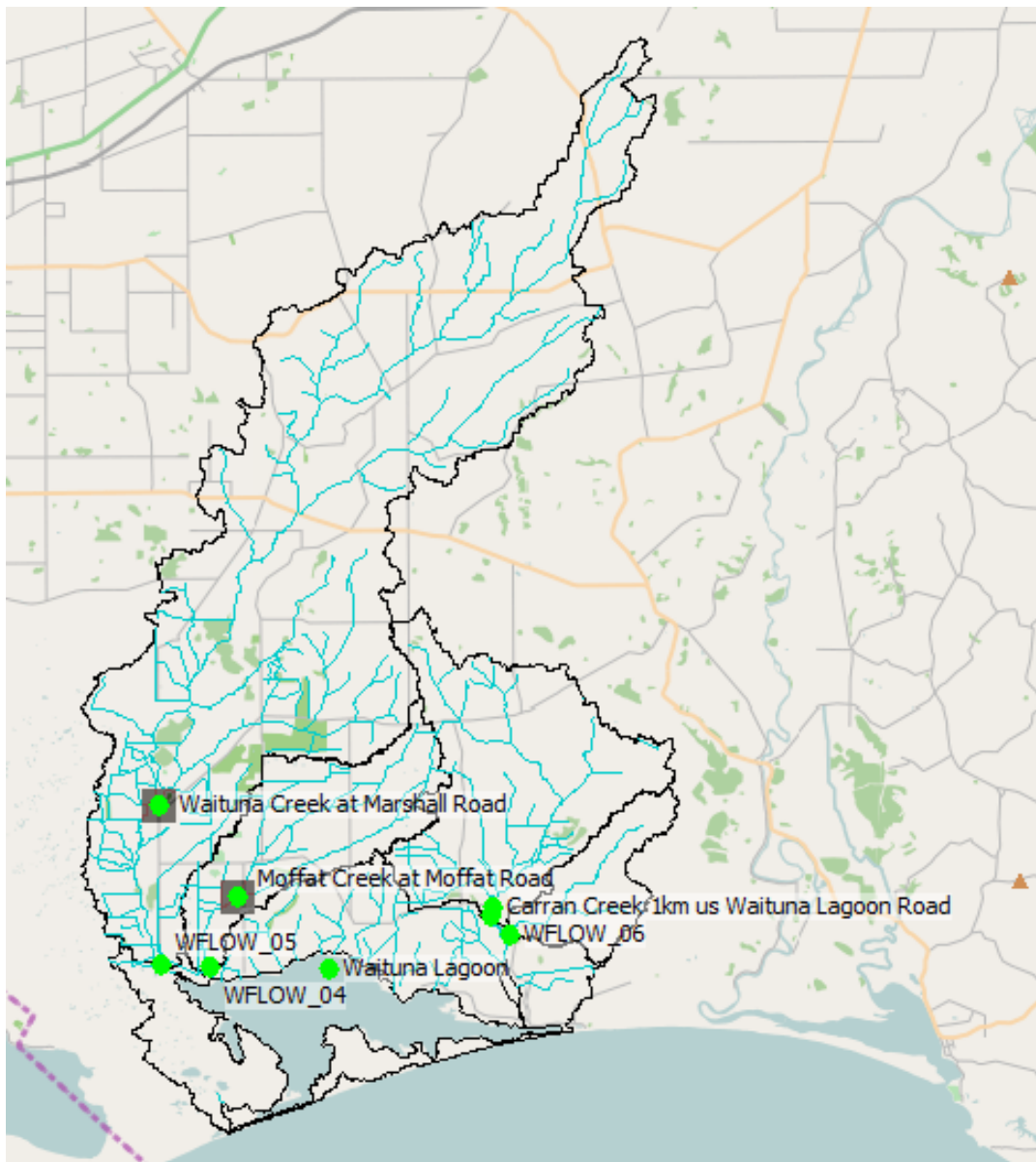


Figure 3.6 Environment Southland monitoring locations and WFLOW calibration sub-catchments.

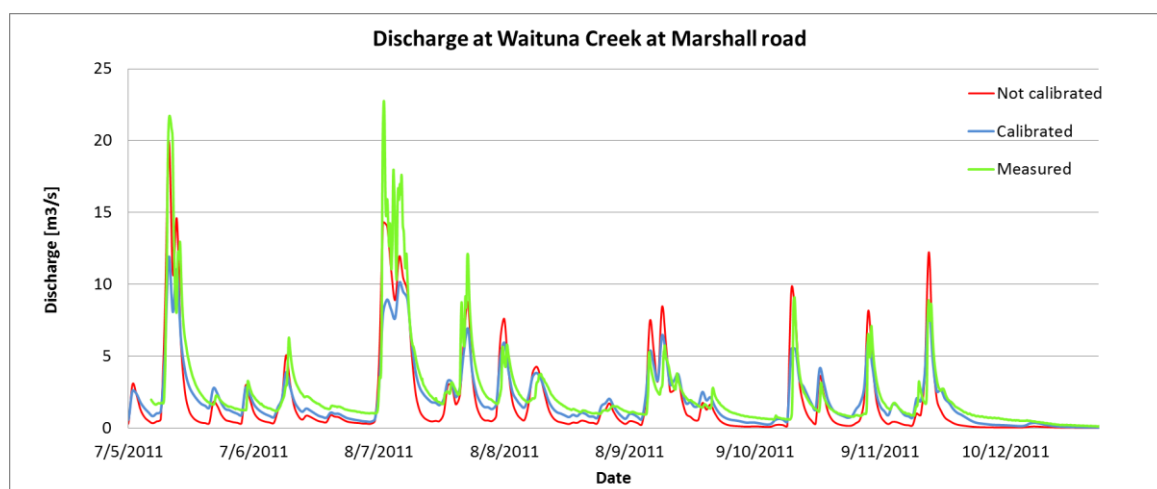


Figure 3.7 Observed, uncalibrated and calibrated model discharge at Waituna Creek for the year 2011.

Table 3.4 Simulated and observed mean and median seasonal discharge, Waituna Creek 2011.

	Period	Simulated runoff [m ³ /s] Original	Simulated runoff [m ³ /s] Ksat Calibrated	Observed runoff [m ³ /s] Measured
Mean	Quarter 2 2011 (13/05/2011-30/06/2011)	2.05	2.22	3.18
	Quarter 3 2011 (01/07/2011-31/09/2011)	2.58	2.71	3.37
	Quarter 4 2011 (01/10/2011-31/12/2011)	0.95	1.26	1.39
Median	Quarter 2 2011 (13/05/2011-30/06/2011)	0.73	1.35	1.81
	Quarter 3 2011 (01/07/2011-31/09/2011)	1.10	1.87	2.08
	Quarter 4 2011 (01/10/2011-31/12/2011)	0.20	0.67	0.9

3.5 Hydrological model results

The calibrated model was validated for each major tributary over a 1.5-year time step from April 2012. Model output was visually compared against the available flow measurements for each inflow (Figs. 3.8-3.10). A further and more quantitative analysis was made by comparing the seasonal (3-monthly) mean of model output against measured discharge (Table 3.5). The results for each inflow are discussed in detail in the following sections.

3.5.1 Results Waituna Creek

Figure 3.8 shows the final discharge results for the Waituna Creek at Marshall Road. This is the largest inflow to Waituna Lagoon, with discharge peaks of almost 25m³/s over the simulation period. Peak discharges are at times underestimated by the WFLOW simulation. While this could be improved by further refinement of the WFLOW input parameters, more information is required in order to undertake this. However, in general the timing of discharge peaks and base flow conditions are well represented by the model.

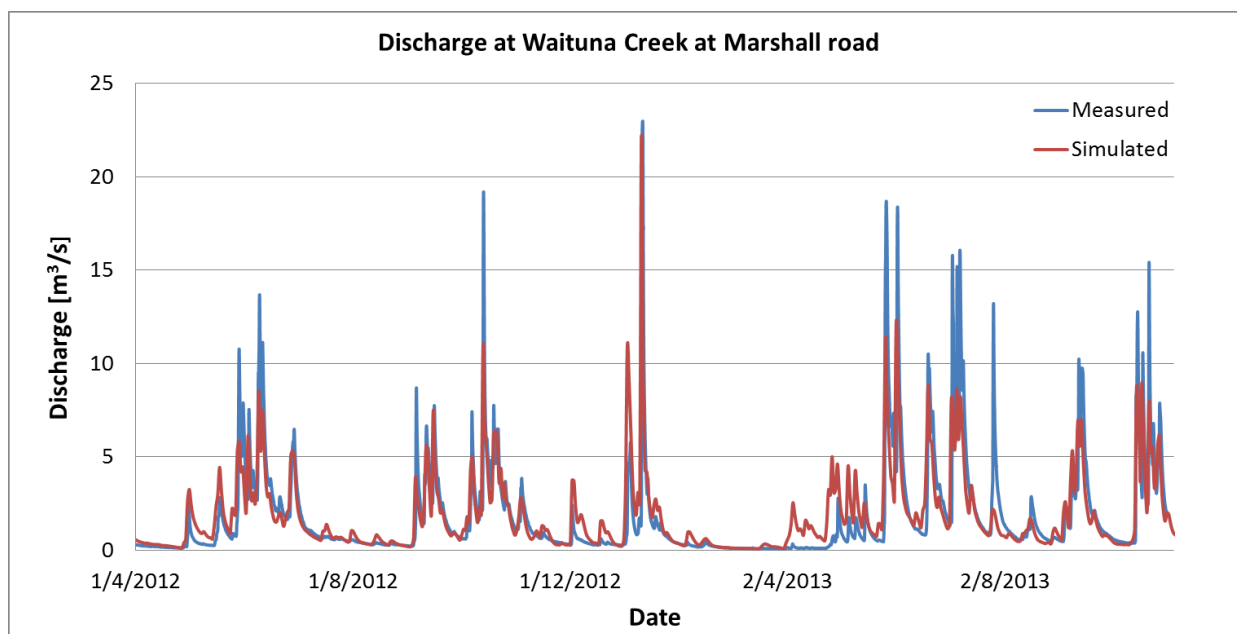


Figure 3.8 Measured and simulated discharge from June 2011-December 2013 at Waituna Creek at Marshall Road, 2012-2013.

Table 3.5 compares model output with measured data as seasonal means. Between April 2012 and January 2013 the model performs very well with an average discrepancy of only 1.6%. The model overestimates discharge in the first and second quarter of 2013, with an average difference of 31% between model output and measured data. It is suggested that a more detailed comparison of the VCSN model forcing data and rainfall measurements collected in the catchment is undertaken to evaluate the cause of the model discrepancies further.

Table 3.5 Mean seasonal discharge at Waituna Creek at Marshall Road, Moffat Creek and Carran Creek, 2012-2013.

Discharge	Period	Mean simulated discharge [m ³ /s]	Mean measured discharge [m ³ /s]
Waituna Creek	01-04-2012 - 01-07-2012	1.97	1.96
	01-07-2012 - 01-10-2012	1.13	1.18
	01-10-2012 - 01-01-2013	1.76	1.62
	01-01-2013- 01-04-2013	1.34	0.93
	01-04-2013 -01-07-2013	2.61	2.20
Moffat Creek	01-04-2012 - 01-07-2012	0.14	0.13
	01-07-2012 - 01-10-2012	0.17	0.10
	01-10-2012 - 01-01-2013	0.21	0.23
	01-01-2013- 01-04-2013	0.28	0.41
	01-04-2013 -01-07-2013	0.28	0.31
Carran Creek	01-01-2013- 01-04-2013	0.30	0.15
	01-04-2013 -01-07-2013	0.70	0.51

3.5.2 Results Moffat Creek

Figure 3.9 compares simulated and observed discharge in Moffat Creek at Moffat Road over the period April 2012 to December 2013. The simulated discharge peaks and base flow conditions are generally underestimated by the model. However, mean seasonal discharges compare well to the measurements (Table 3.5). The results suggest that the saturated soil conductivity is set too low in the model parameterization, as simulated discharge recedes slowly in comparison to the measurements. Increasing this parameter is also likely to increase magnitude of discharge peaks.

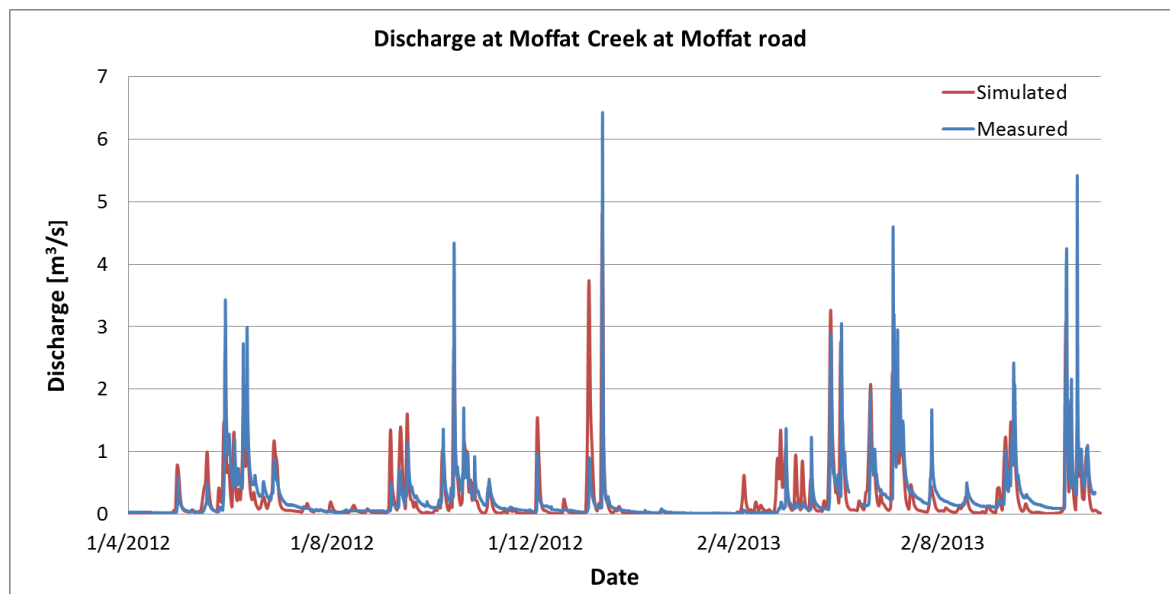


Figure 3.9 Measured and simulated discharge from April 2012-December 2013 at Moffat Creek at Moffat Road.

3.5.3 Results Carran Creek

The results of simulated and observed discharge in Carran Creek are presented in Figure 3.10. Measurements were not available for 2012 (except December). Discharge patterns are similar to Waituna Creek at Marshall Road, although total flows are substantially lower. Simulated discharge generally captures the observed trends, although some flow peaks are overestimated by the model. Table 3.5 compares the seasonal mean of observed and simulated discharge. The results show an overestimation of the WFLOW discharge, however, mean discharge is extremely low and therefore this has only a minor impact on the total catchment water balance.

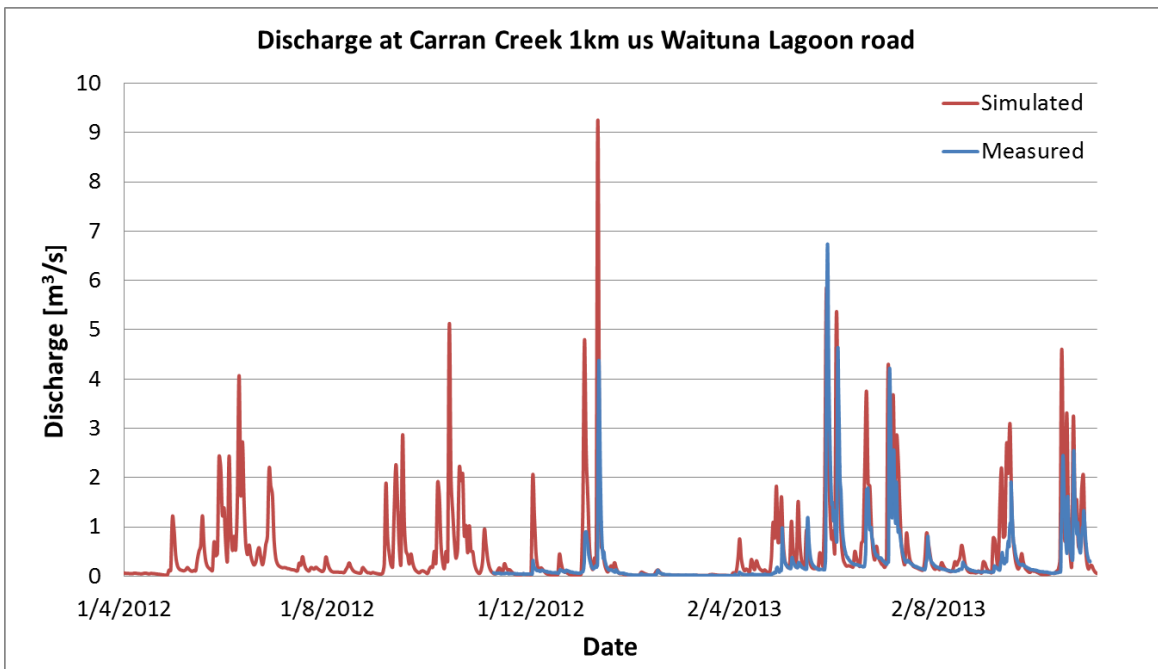


Figure 3.10 Measured and simulated discharge from April 2012-December 2013 at Carran Creek 1km upstream of Waituna Lagoon Road.

4 Catchment water quality model set up, calibration and results

4.1 Introduction

In this study the WFD Explorer water quality model was applied to quantify total nitrogen and total phosphorus loads discharging from each river sub-catchment to the Waituna Lagoon. The WFD Explorer is a lumped, steady state model developed to support catchment water quality management (Chapter 2). In this project the WFD Explorer model was applied by coupling a water balance model to a water quality model on a seasonal (3-monthly) time scale.

The catchment water balance was driven by runoff estimated on a 25 x 25m spatial resolution using the WFLOW hydrological model (see Chapter 3). The water quality model then adds emission values for all individual farm properties in the catchment as well as additional loading associated with other sources. The results of the model include flows of water through the river network, estimates of in-river nutrient concentrations and total nutrient loads as contributions to the lagoon by each sub-catchment. The complete model framework can be applied as a management tool to evaluate the impacts of different mitigation scenarios on catchment nutrient loading.

4.2 Setup of the WFD Explorer schematization

A WFD Explorer model schematization consists of three elements. These are:

- Basins, representing the catchments as a lumped area
- Surface water units, representing stretches of river network
- Links between the Bas and Surface water units.

The modelling process as applied to the Waituna catchment is shown in Figure 4.1.

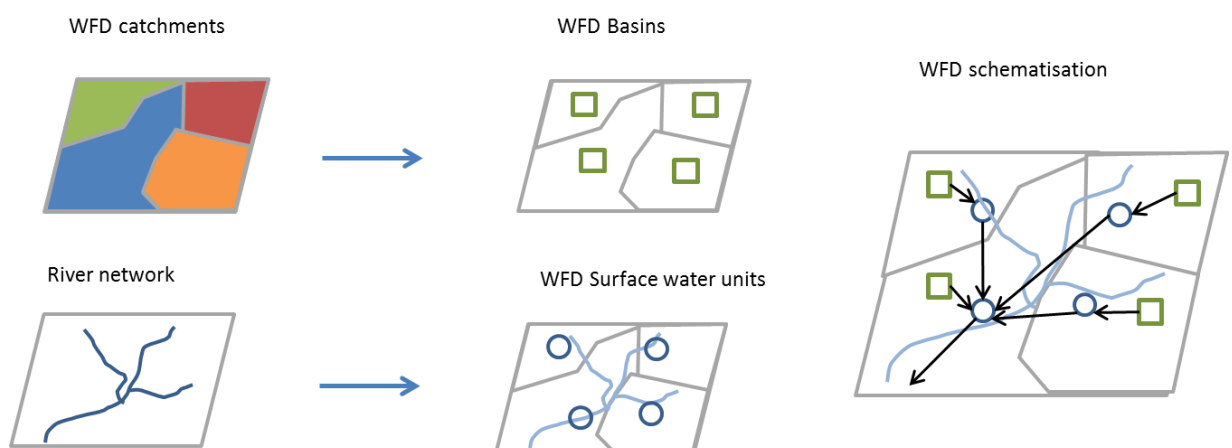


Figure 4.1 WFD Explorer model schematization as applied to the Waituna Catchment.

4.2.1 Basins

Each farm in the Waituna catchment was represented as an individual basin in the WFD model schematization. Farm boundary information as well as landuse type and land area were derived from a GIS layer supplied by Environment Southland, updated based on more recent farm survey information by DairyNZ (Figure 4.2). Roads were removed from the Farm title polygon layer and are treated separately in the model.

Several additional attributes (see Table 4.1) were also included in the GIS layer to make it ready for importing in the WFD Explorer.

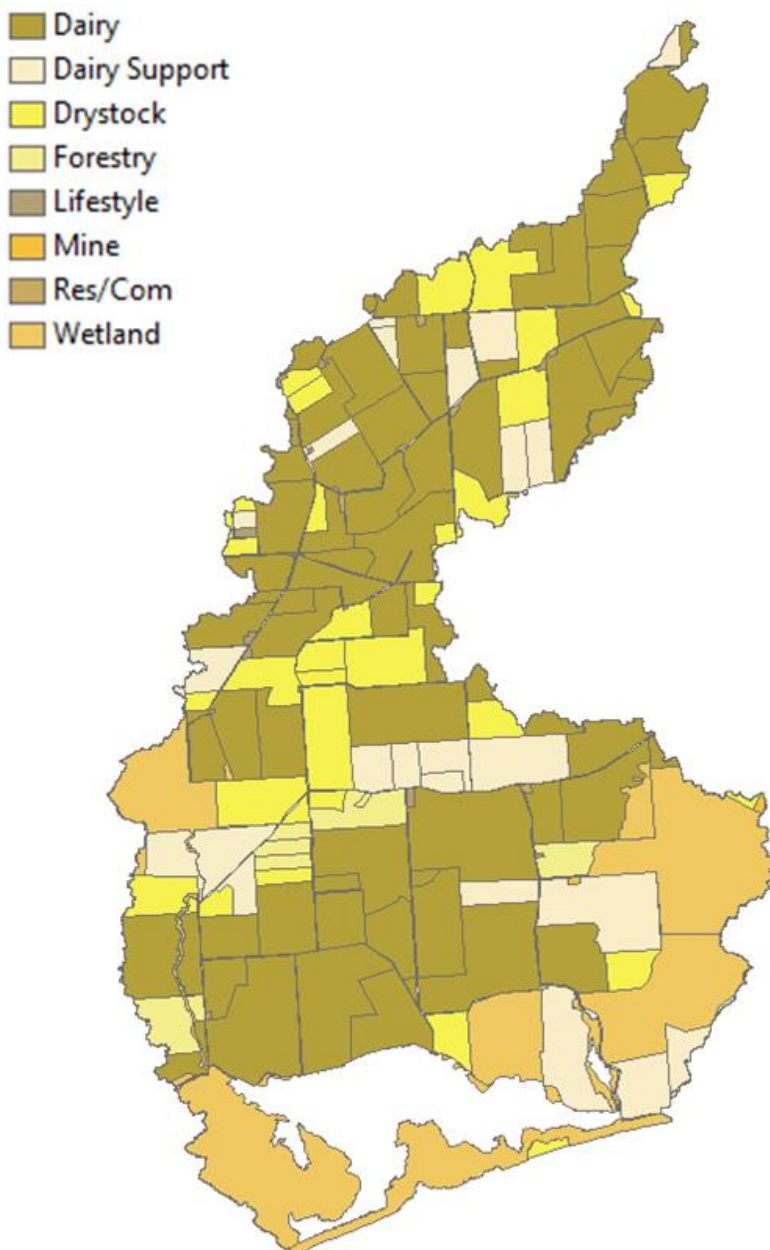


Figure 4.2 Farm boundary and landuse type GIS layer (from Environment Southland and modified by DairyNZ). This layer is used to generate the Basin nodes of the WFD Explorer schematization.

Table 4.1 Attributes added to the Farm tile GIS file.

Attribute	Type	Remark
ID	text	Node ID for WFD Explorer. In this case the "Code2" field from the Farm tile GIS file is used.
Name	text	Name of the Basin
Tag	text	Attribute to add some visibility options and filtering in the WFD Explorer. In this case the "Category" field from the Farm tile GIS file is used.
WATERHSURF	float	Horizontal Water surface, set to a default value of 100 m2. Not yet taken into account by the WFD Explorer.
WATERVOL	float	Volume of the basin/surface water node, set to a default value of 100 m ³ . In this case we do not use the water volume to compute the hydraulic residence time for the removal of nutrients.

4.2.2 River Network:

A river network map of the entire catchment was derived from Environment Southland (see Figure 3.1). Additional processing was required before implementation into the WFD Schematization. River reaches were first buffered to a polygon to enable presentation of concentration results in the WFD Explorer. Furthermore intersects were made to create unique stretches of river within each individual Farm title. In total 339 different stretches of river were implemented into the model framework (Figure 4.3).

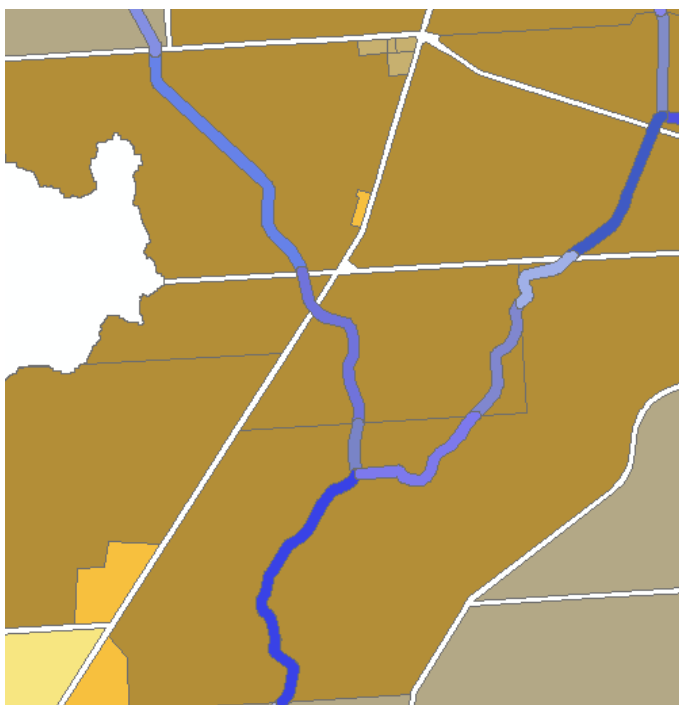


Figure 4.3 Part of the Waituna catchment river network. The unique stretches of river are shown in different shades of blue.

4.2.3 Links and flows

All Basins and Surface water units were linked to each other in the model schematization. As there is a free flow from upstream to downstream, the river routing was quite clear to implement in the WFD Explorer. Two steps were taken to generate the complete routing of the model.

First, the river routing was setup. These links were labelled with a tag "River". All River links have a 100% routing of the outflowing water to the next downstream node.

Secondly, the Basins were connected to the river network. During this procedure a GIS intersect was made between the river layer and the Farm title layer. A mapping table was made to relate each individual farm title to one or more adjacent river reaches. When a farm title is connected to several (n) river reaches, the outflow of the farm is distributed evenly across all river reaches (100% outflow/n river stretches). These links are labelled "FarmTile_River" in the WFD Explorer. Figure 4.4 depicts an example of a Farm tile – River connection. Not all farm titles intersected with the river network. These cases were added manually in the GUI of the WFD Explorer.

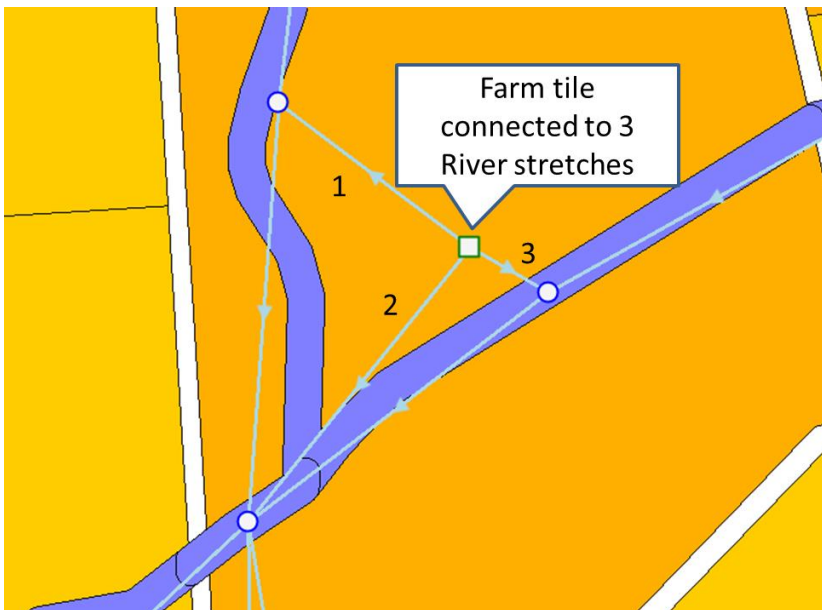


Figure 4.4 Farm tile – river connection.

4.3 Nutrient sources and coupling with WFLOW

4.3.1 Sources of emissions

Nutrient load sources were applied as diffuse loads to basins in the WFD Explorer schematization. Five types of load sources were implemented in the model framework:

1. Farm nutrient losses – Losses of total nitrogen and total phosphorus to the root zone for each individual farm, as estimated based on individual farm Overseer® nutrient loss estimations (DairyNZ unpublished data).
2. Non-agricultural landuse losses – nutrient loading associated with non-productive land use types in the catchment (wetlands, forestry, lifestyle blocks and residential/commercial).
3. Roads – nutrient loading associated with areas of land designated as landuse type roads.
4. Septic tanks – loads derived from household septic tanks located in the catchment.
5. Additional sources:
 - a. Birds – loading associated with water fowl and other bird species directly to the lagoon.
 - b. Bankside erosion (for P).

All nutrient load information for the catchment was provided by DairyNZ (unpublished data). The different loads were summarised in an xls file and converted to the WFD Explorer input using an R-script. This script converts the load values to WFD Explorer input format.

4.3.1.1 Farm loads

All farm-specific nutrient load information was provided by DairyNZ (unpublished data) and will be published in more detail elsewhere. In brief, total annual nitrogen and phosphorus losses were estimated for 70% (by land area) of all Waituna Catchment dairy, dairy support and dry stock farms based on individual farm nutrient budget generated using OVERSEER® (Overseer) (Agresearch, 2014) for the 2012-2013 dairy year (1 June to 31 May). Loading associated with different soil types (organic, gley, brown, podzol) and landuse activities (pasture, cropping, non-effective) within each farm were recorded separately (Table 4.2).

Nutrient losses associated with farms for which no information existed were estimated based on the mean of all equivalent enterprise types within the same geographical zone (top, middle of bottom of catchment, to reflect differences in soil type). Loads associated with farms located on the catchment boundary were reduced to reflect only the area of land inside the catchment.

Farm loads represent losses to the root zone (N and P) or overland flow (P) prior to any attenuation processes which may take place before discharge to surface waters or groundwater.

Individual farm load sources were also implemented individually in the model schematization to allow management scenarios targeting different sources to be carried out (Table 4.2).

Overseer computes farm nutrient losses as an annual load. Due to the importance the seasonal distribution of nutrient loading to the lagoon from a management perspective, annual loads were proportioned to a seasonal load based on the observed seasonal distribution of nutrient concentrations in Waituna Creek. The final fractions of the annual N and P loads applied to each season are given in Table 4.3.

Table 4.2 Different sources of N and P losses as estimated using individual farm Overseer nutrient budgets.

Load name	Load source
Pastoral Peat/Podzol/Brown/Gley	Pastoral activities/animals on Peat, Podzol, Brown and Gley soils, respectively.
Crop Peat	Crops on organic soils
Crop Sedimentary	Crops on Podzol + Brown + Gley soils
Bush and scrub	Bush and scrub land not used for grazing
Stock excluded	Other land not used for grazing
Wetland	Wetland area not used for grazing
Additional	Additional sources not associated with specific land types (i.e. runoff from lanes on the farm)

Table 4.3 Fractions applied for the seasonal distribution of annual farm nutrient losses .

Season	WFD Explorer Period	Factor Total N	Factor Total P
Jun/12 - Aug/12	1	30%	20%
Sep/12 -Nov/12	2	40%	55%
Dec/12 -Feb/13	3	10%	5%
Mar/13 -May/13	4	20%	20%

4.3.1.2 Non-agricultural landuse loads

Nutrient loading associated with non-agricultural landuse types were estimated based on a uniform aerial loading rate for each landuse type (DairyNZ, unpublished data). Landuse types were classified into wetland, forestry, lifestyle blocks and residential/commercial land areas. Land areas were derived from Environment Southland's GIS database. Nutrient loads were assumed to be constant through time irrespective of season.

4.3.1.3 Roads

Land areas designated as roads were treated separately to the non-agricultural landuse loads as individual GIS polygons extended over several sub catchments. Accordingly these were distributed proportionally to the length of the perimeter of the surrounding Farm tiles. Annual nutrient loads associated with this land use type were estimated based on area and a uniform aerial loading rate based on non-effective landuse types (DairyNZ, unpublished data).

4.3.1.4 Septic tanks.

Mean annual N and P loading associated with septic tanks were estimated based on population statistics and emission explainable variables (DairyNZ, unpublished data). The total catchment load was proportioned to individual locations across the catchment based on distributions in population density. The loads are given in Table 4.4. Loads were distributed evenly over the four seasons.

Table 4.4 Septic tank loads.

Code	River catchment	Easting	Northing	Load N (kg/yr)	Load P (kg/yr)	Basin
SP01	Waituna Creek	2175512.904	5413397.981	156.8	24.5	WA18
SP02	Waituna Creek	2177775.096	5416295.174	98.56	15.4	WA83
SP03	Waituna Creek	2174481.027	5410699.225	268.8	42	WA62
SP04	Waituna Creek	2170948.832	5408754.534	174.72	27.3	WA40
SP05	Waituna Creek	2173012.586	5407722.657	62.72	9.8	WA07
SP06	Waituna Creek	2169043.829	5408357.658	89.6	14	WA42
SP07	Waituna Creek	2170988.520	5404428.588	201.6	31.5	WA71
SP08	Moffat Creek	2175235.091	5404150.775	53.76	8.4	WA80
SP09	Carran Creek	2176187.593	5399189.827	161.28	25.2	WA73
SP10	Moffat Creek	2171583.834	5399586.703	161.28	25.2	WA30
SP11	Waituna Creek	2168289.765	5401293.269	224	35	WA24

4.3.1.5 Additional loads

In addition to loads associated with farms, non-agricultural landuse types, roads and septic tanks, two other emission sources were added to the model.

Total annual nitrogen and phosphorus loads associated with water fowl and other bird species were added as a direct input to the surface area of the lagoon. Loading rates were computed based on bird population statistics and estimates of mean daily excretion rates for individual species using a bird-specific nutrient load modelling tool (Water Birds V1.1) developed by the Netherlands Institute of Ecology (Bauer and Hahn, 2007). The final nutrient loads implemented in the model are provided in Table 4.5 (DairyNZ unpublished data).

During the model calibration phase it became apparent that an important source of phosphorus was missing in the Waituna Creek (see Section 4.4). The missing source was assumed to be related bank side erosion. A recent sediment finger printing study by McDowell et al. (2013) suggested that up to 95% of the sediment load in the lower Waituna Creek was derived from stream bank erosion associated with bank collapse and drain cleaning. Although phosphorus loads associated with erosion have not been measured, it is likely that part of the P load unaccounted for in the catchment nutrient balance is derived from this source. Accordingly, an additional P source associated with bankside erosion was implemented in the model framework immediately upstream of the Waituna Creek at Marshall Road monitoring location (Table 4.5). This load was distributed evenly over the four seasons.

Table 4.5 Other loads in the Waituna Catchment

Model NodeID	Location	Load type	Total N (kg/yr)	Total P (kg/yr)
900	Direct on lagoon surface area	Birds	4326	668
370	Upstream of WCMR	Bank erosion	0	4700

4.3.2 Coupling with WFLOW

Runoff computed by the WFLOW model (Chapter 3) was used directly in the WFD Explorer based on the workflow described in Figure 4.5. The grid output data of the WFLOW model was aggregated in time and space to fit the lumped schematization of the WFD Explorer using scripts to automate the process.

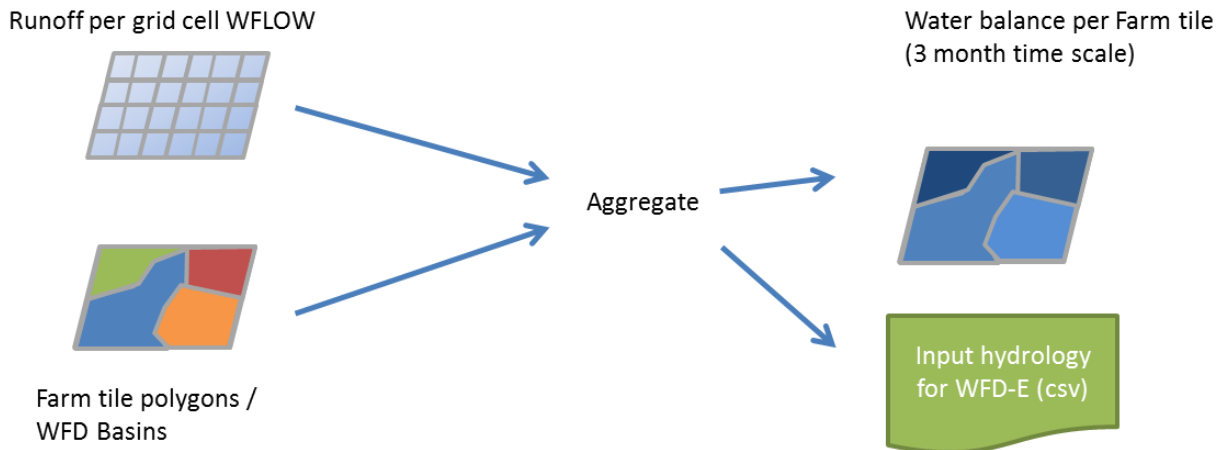


Figure 4.5 Coupling WFLOW grid data to the WFD Explorer schematisation.

4.3.3 Simulation period

Catchment water quality model simulations were conducted over the period June 2012 to May 2013 based on a seasonal time step (Table 4.6). During this period, the actual WFLOW output data was used to derive the catchment water balance.

Table 4.6 Simulation periods defined in the water quality model schematisation.

WFD Season	WFLOW Date	Emission Year
1	Jun/1/2012 – Aug/30/2012	2012
2	Sep/1/2012 – Nov/30/2012	2012
3	Dec/1/2012 – Feb/28/2013	2012
4	Mar/1/2013 – May/31/2013	2012

4.4 Validation of coupled flow model schematisation

The WFD Explorer computes flows at every link in the model schematization based on the input from WFLOW. In the first instance the results of the two models were compared to ensure that the results were comparable. The seasonally averaged discharges may differ slightly, as the connection between farm tiles and river stretches may intersect across different sub catchments.

Appendix C contains the comparison of WFLOW with WFD Explorer results for the water balance. In general at the Waituna Creek and the Moffat Creek both models have comparable outputs. At the Carran Creek however, the simulated flows do not match. Probably this is connected with the overestimation of some flow peaks by the WFLOW model (see Section 3.5.3). Further investigation to clarify this situation is suggested.

4.5 Calibration of the nutrient model

4.5.1 Calibration approach

Calibration of the catchment modelling framework is essential in order to accurately estimate the nutrient loading to the lagoon after attenuation processes have been accounted for. Nutrient inputs associated with individual farms, non-agricultural landuse types and septic tanks to the model all reflect loading prior to attenuation. The actual loads discharged to the surface drainage network and lagoon is likely to be lower after attenuation processes are accounted for. Attenuation rates are generally greater for N than for P, as N loads mostly represent losses to the root zone and groundwater whereas P loads also reflects losses through overland flow pathways. Overland runoff enters the surface waters more rapidly and therefore the potential for attenuation to occur is reduced.

During the calibration process two different calibration factors were used. First, the removal efficiency (or retention factor) was applied. Secondly, the seasonal distribution of the annual N and P load was tuned to calibrate the model result.

Calibration of the model output was targeted at total sub-catchment load and in-stream concentration. Loads are important from a management point of view as they represent the total mass entering the system. The observed loads were derived for four water quality monitoring locations from the measurement data available at individual monitoring stations between June 2012 and May 2013 (see Figure 4.6, Table 4.7). First the flow weighted mean concentration (FWMC) was computed for each season. The concentration was then multiplied by the online flow recorder data for that location. Measured loads were also compared to the sum of all source loads upstream of the measurement location within each sub-catchment (Table 4.8). Finally the measured concentration of TN and TP were compared with the modelled concentrations at the same locations.

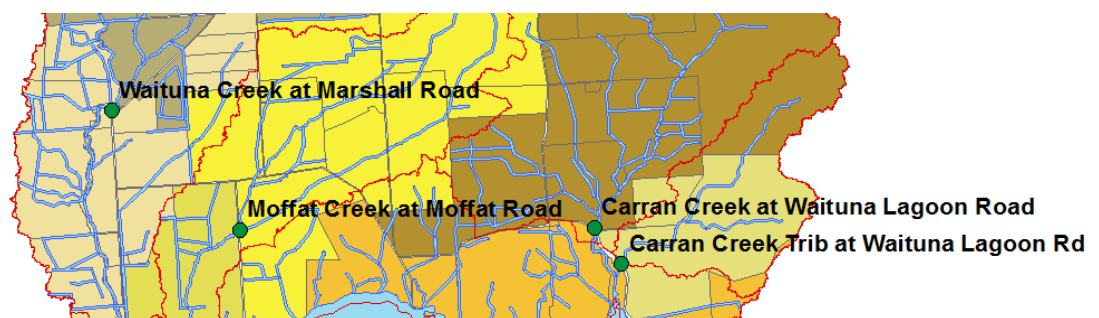


Figure 4.6 Calibration locations.

Table 4.7 Available water quality observations for each sub-catchment, June 2012 - May 2013.

River	Season	WFD Explorer Period	# Total N samples	# Total P samples	# Flow recorder samples
Waituna Creek	Jun/12 - Aug/12	1	8	8	8
	Sep/12 -Nov/12	2	6	6	6
	Dec/12 -Feb/13	3	3	3	3
	Mar/13 -May/13	4	17	17	17
Moffat Creek at Moffat Road	Jun/12 - Aug/12	1	8	8	8
	Sep/12 -Nov/12	2	7	7	7
	Dec/12 -Feb/13	3	4	4	4
	Mar/13 -May/13	4	4	4	4
Carran Creek at Waituna Lagoon Road	Jun/12 - Aug/12	1	8	8	n.a.
	Sep/12 -Nov/12	2	7	7	n.a.
	Dec/12 -Feb/13	3	3	3	n.a.
	Mar/13 -May/13	4	4	4	n.a.
Carran Creek Tributary at Waituna Lagoon Road	Jun/12 - Aug/12	1	6	6	n.a.
	Sep/12 -Nov/12	2	6	6	n.a.
	Dec/12 -Feb/13	3	3	3	n.a.
	Mar/13 -May/13	4	4	4	n.a.

Table 4.8 Total estimated nutrient loading to the area of catchment directly above each monitoring location.

Location	Total N (ton/y)	Total N %	Total P (ton/y)	Total P %
Waituna Creek at Marshall Road	267.1	71%	4.6	43%
Waituna Creek - downstream MR	17.0	5%	0.8	7%
Moffat Creek at Marshall Road	27.9	7%	1.4	13%
Moffat Creek - downstream MR	2.2	1%	0.1	1%
Carran Creek Trib at Waituna Lagoon Rd	1.3	0%	0.0	0%
Carran Creek at Waituna Lagoon Road	47.4	13%	3.1	29%
Direct to Lagoon	12.1	3%	0.7	7%
Total	374.8	100%	10.8	100%

4.5.2 Calibration results

A detailed analysis comparing measured loads with uncalibrated modelled loads in the Waituna Creek shows a good match after applying a 20% decay factor for TN (Figure 4.7). The measured P load was significantly higher than the modelled P inputs, indicating that an important source of P was missing in the model framework.

The retention rate of TN in Moffat Creek is estimated to be approximately 30% when simulated and measured loads are compared (Figure 4.7). It is plausible that no important N sources are missing from the model. For Phosphorus the observed loads match the model output, indicating that all important sources are likely to be represented and the attenuation factor is zero.

For Carran Creek measured flow data was not available and therefore it was not possible to compute the observed loads based on measurements. However, modelled flows were used with measured water quality concentrations to estimate observed loads in this stream. The resulting comparison of the approximated observed load with the simulated load suggests a retention rate of 30% for TN, and 25% for TP. As measured TP loads do not exceed the estimated upstream source load it is likely that all major load sources are represented in the model.

A similar analysis (simulated flow and measured water quality to derive observed load) for Carran Creek tributary again shows that the observed load is higher than the computed source load for both TN and TP. The main cause of this is suggested to be the small catchment size and associated difficulty to correctly address the loads towards this sub-catchment. However, the total loads generated by this sub catchment are extremely small in comparison to the discharges from the other sub-catchments.

As a result of this analysis a final removal factor of 20% was applied to all TN sources in the model to represent attenuation between source and measured in-stream loads. No attenuation factor was applied to TP, and instead an additional TP load was applied to represent potential bankside erosion (See Section 4.3). This load was distributed evenly over the four seasons.

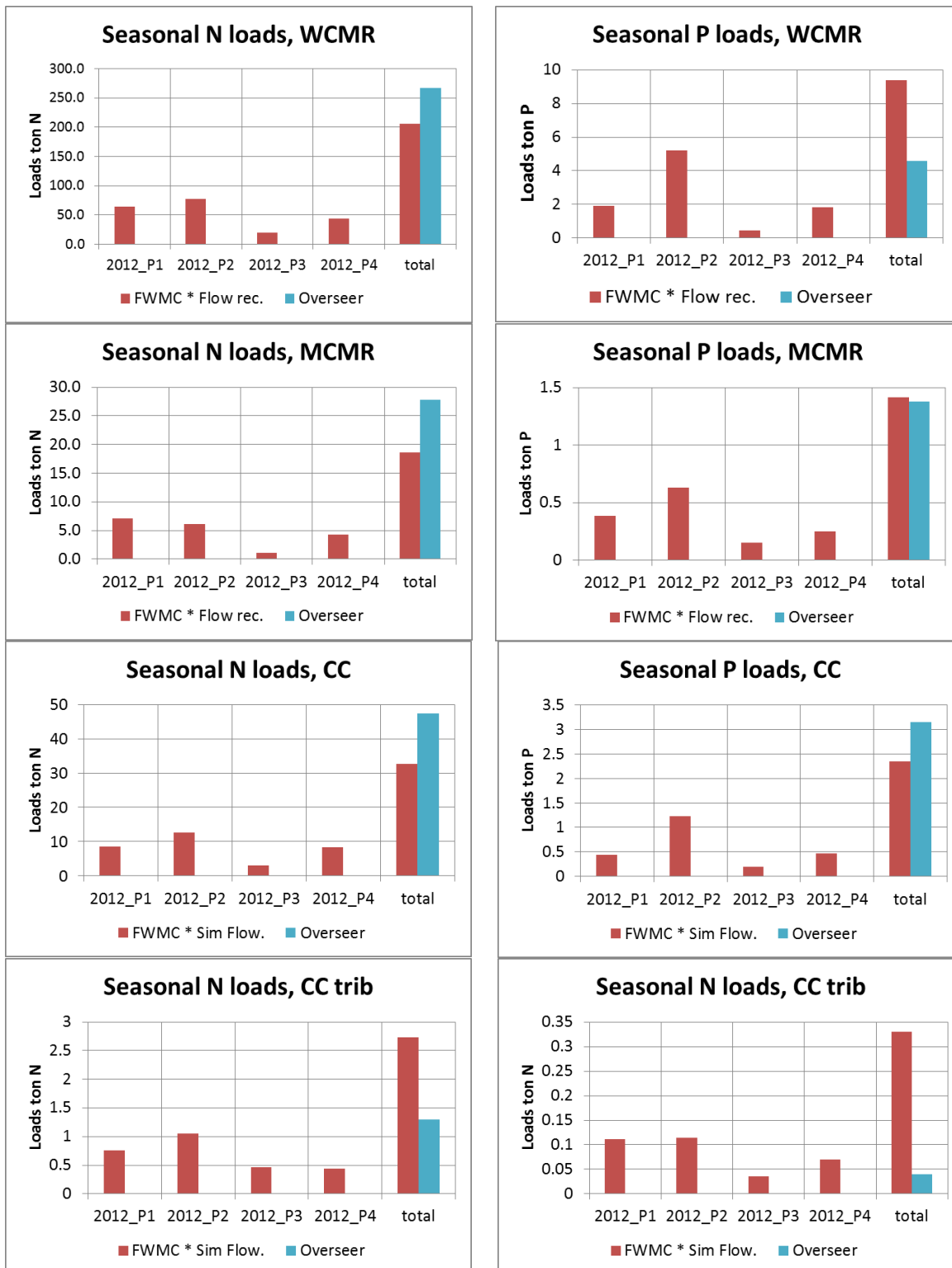


Figure 4.7 Observed (FWMC* flow) seasonal N and P loads compared to the total annual (2012-2013) estimated load upstream of each monitoring location (Overseer) for Waituna Creek at Marshal Road (WCMR), Moffat Creek at Moffat Road (MCMR), Carran Creek (CC) and Carran Creek tributary (CC trib).

4.6 Final calibrated water quality model results

4.6.1 Water quality Waituna Creek

Overall the model results compared well to the measured loads and concentrations after model calibration. Discrepancies did exist for some seasons, especially in the smaller tributaries, however, large seasonal variations also exist within the measurement data and when the mean, median and FWMC of the measured concentrations are compared. Figure 4.8 shows the computed loads for TN in the Waituna Creek at the Marshall Road monitoring location. There is a strong agreement between modelled and measured loads and the seasonal distribution is also correctly modelled.

Phosphorus loads were more difficult to model correctly (Figure 4.8). During the first and last quarter, modelled and measured loads are comparable. The model underestimates the measured load in spring and overestimates the load in summer. This is probably due to the fact that bank side erosion, which is assumed to represent up to 50 % of the total river P load, and is distributed evenly over all seasons in the model framework. There were no further measurements available to better estimate the contribution of this emission source.

Figure 4.9 shows simulated TN concentration at WCMR, which is comparable with the actual measurement data at this location. Variations within the measurements were quite high, with observed values ranging from 1 mg N/l to 6 mg N/l. The observed median concentration is lower than the mean concentration, due to a small number of samples with a high concentration. The FWMC values are very high compared to the mean and median concentration. Since the FWMC is used to derive the observed loads in the river, the loads may be overestimated if the computed flow ranges are assumed to be correct. Investigation of other methods to derive the loads in the river system might be useful.

The modelled concentrations follow the pattern of the measurements. The modelled concentration should be comparable to the FWMC when there is a perfect agreement between modelled and observed flows, which they do not (see Section 4.4), however, the model represents the measured values quite well.

Total phosphorus concentrations are shown in Figure 4.9. The measurements have similar characteristics as TN, including:

- Large variations in time, with values ranging between 0.05 mg P/l and 0.2 mg P/l and peak values of about 0.5 mg P/l;
- Median concentrations are lower than mean concentrations; and
- Rather high FWMC compared to the measurements.

The model gives results in the same order of magnitude as the observed mean values, as well as the FWMC for most seasons. The summer season shows the biggest (relative) difference compared to the measurements. Bank side erosion, which is assumed to be a constant load over the year, may overestimate P loading over the summer season.

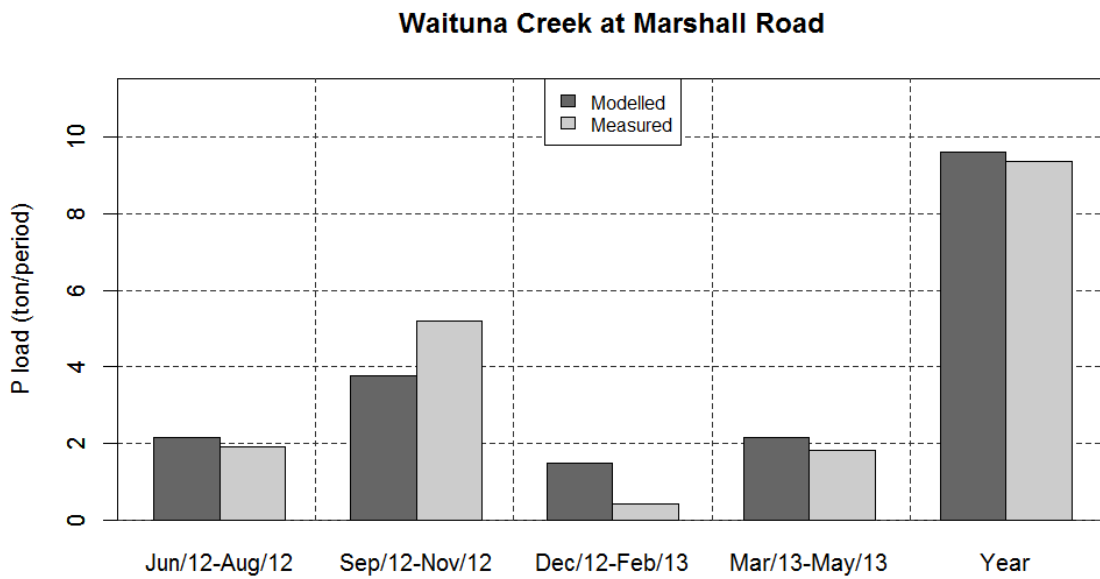
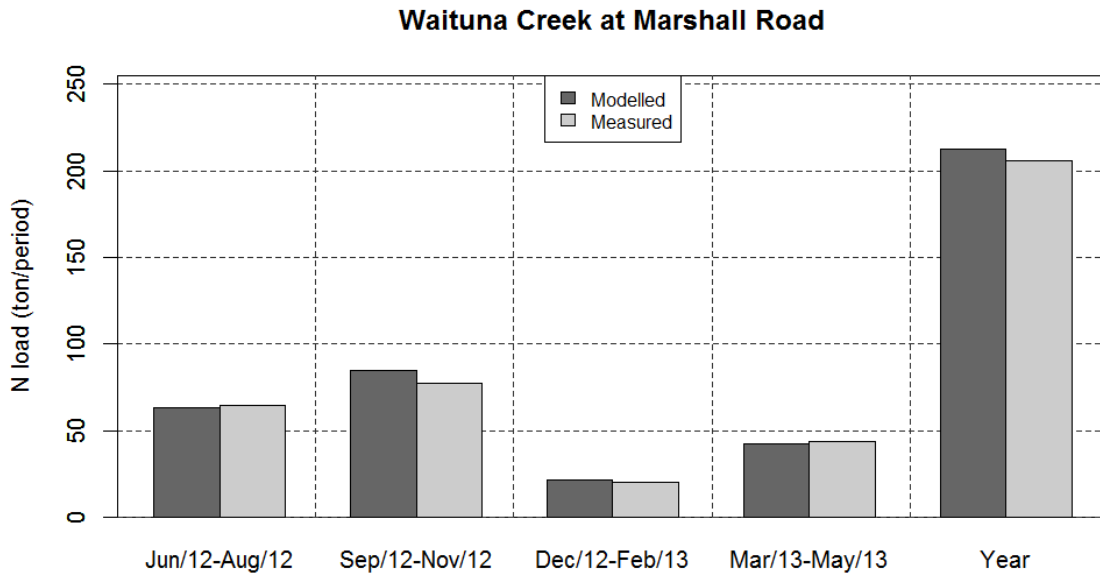


Figure 4.8 Modelled and observed total nitrogen (top) and total phosphorus (bottom) loads, Waituna Creek at Marshall Road, June 2012- May 2013.

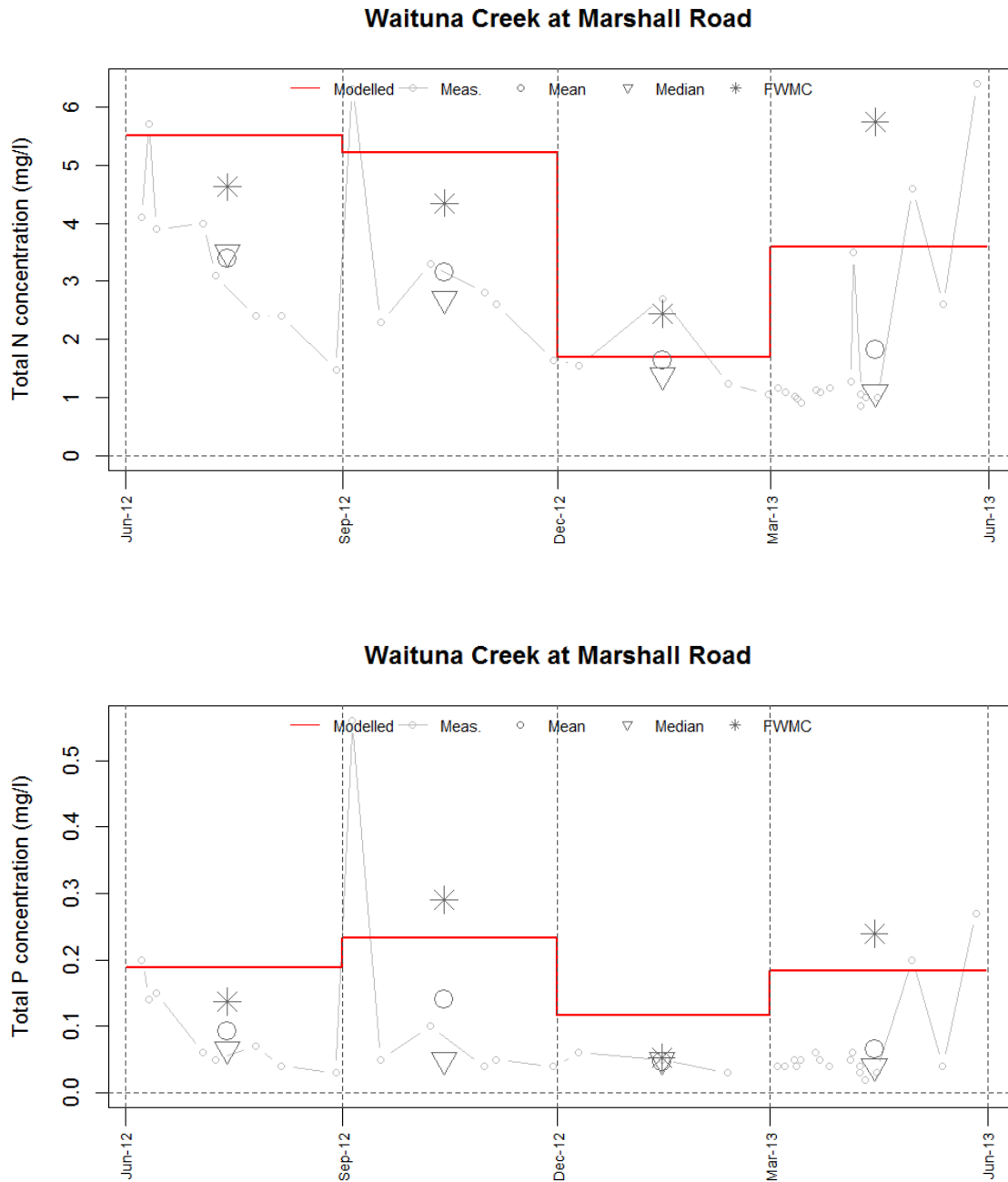


Figure 4.9 Modelled and observed (Meas) mean, median and flow-weighted mean concentration (FWMC) for total nitrogen (top) and total phosphorus (bottom) concentrations, Waituna Creek at Marshall Road, June 2012- May 2013.

4.6.3 Moffat Creek at Moffat Road

Total nitrogen loads in Moffat Creek are shown in Figure 4.10. The model represents the total annual loads quite well, despite differences within seasons. During winter the model underestimates the N load. In spring and summer the model slightly overestimates the load. The TP load is also underestimated by the model (Figure 4.10), with an annual total load is approximately 20% lower than the measured load.

Figure 4.11 shows the modelled and observed TN concentrations. The graphs show the same pattern as Waituna Creek, with measured concentrations showing a high degree of variability (range 1 mg/l to 5 mg/l) and high FWMC compared to the mean and median concentration. The model results follow the seasonal trend for the FWMC, however, in autumn there is a large mismatch between the two variables.

Modelled TP concentration mostly reflects trends in the measurements, although during summer and autumn the model underestimates the concentrations. One of the main reasons is overestimation of the discharges at Moffat Creek (see Section 4.4). As a direct result, P loads are more diluted resulting in lower in-stream concentrations.

4.6.4 Carran Creek and Carran Creek Tributary

Measured loads were not available for Carran Creek and Carran Creek Tributary and therefore a comparison between modelled and observed loads was not possible. These locations do, however, have water quality measurements. These were used to compare the concentration results of the WFD Explorer computation (Figs. 4.12 and 4.13).

The model results are slightly above the observed mean concentrations at both locations for TN. From previous locations we see that the FWMC was higher than both the mean and median concentration.

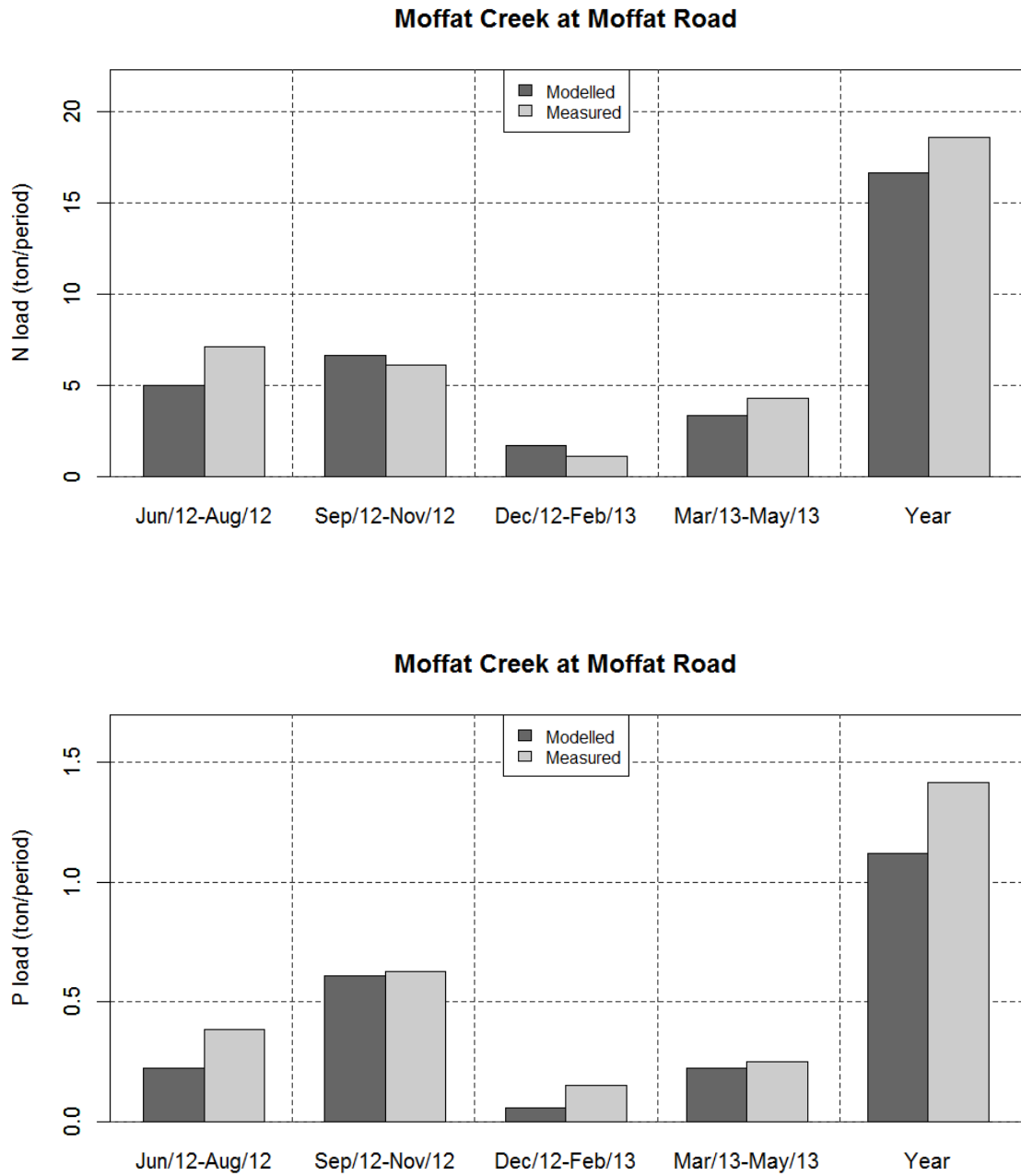
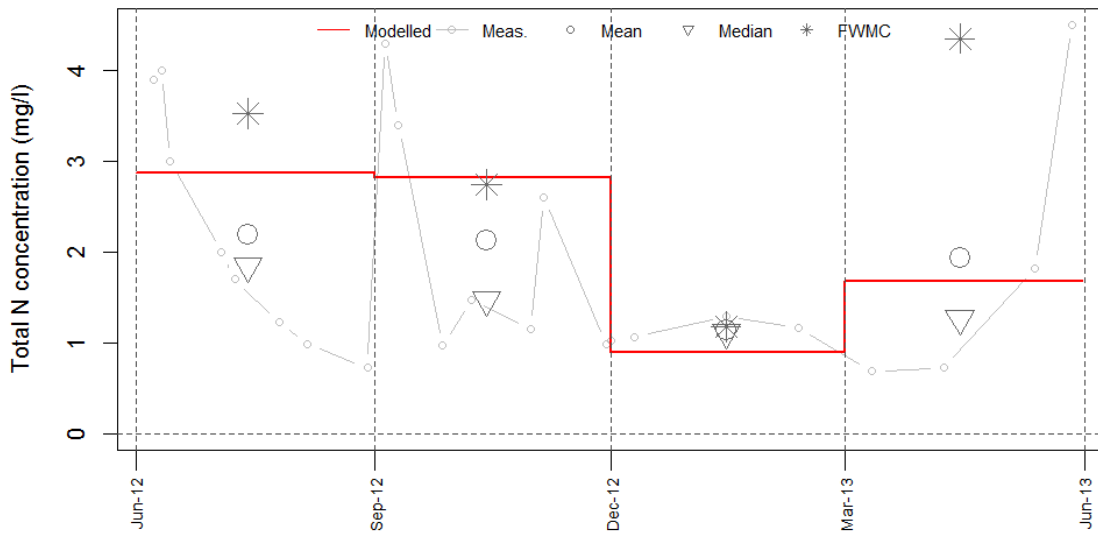


Figure 4.10 Modelled and observed total nitrogen (top) and total phosphorus (bottom) loads, Moffat Creek at Moffat Road, June 2012- May 2013.

Moffat Creek at Moffat Road



Moffat Creek at Moffat Road

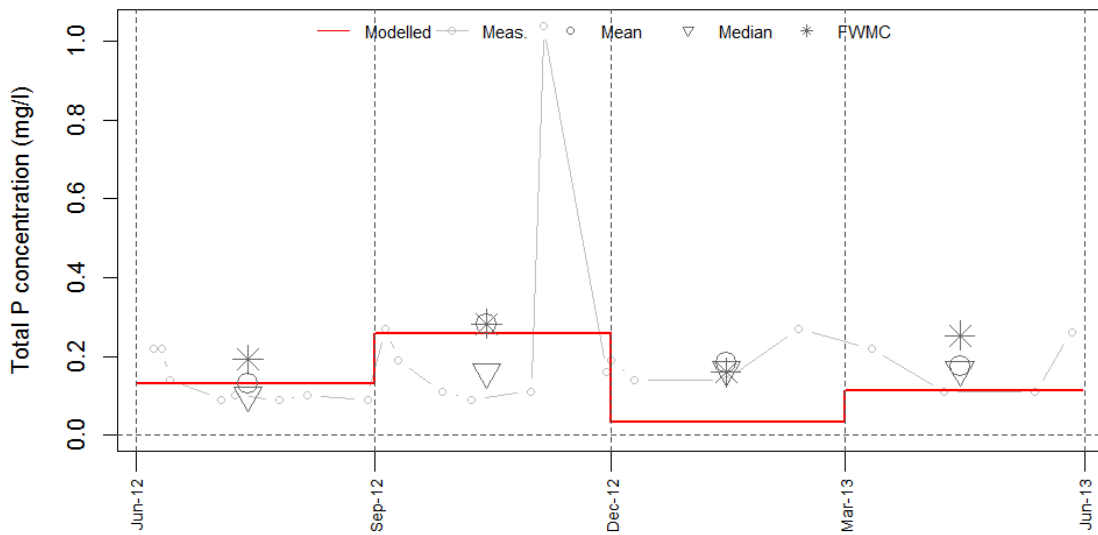


Figure 4.11 Modelled and observed (Meas) mean, median and flow-weighted mean concentration (FWMC) for total nitrogen (top) and total phosphorus (bottom) concentrations, Moffat Creek at Moffat Road, June 2012- May 2013.

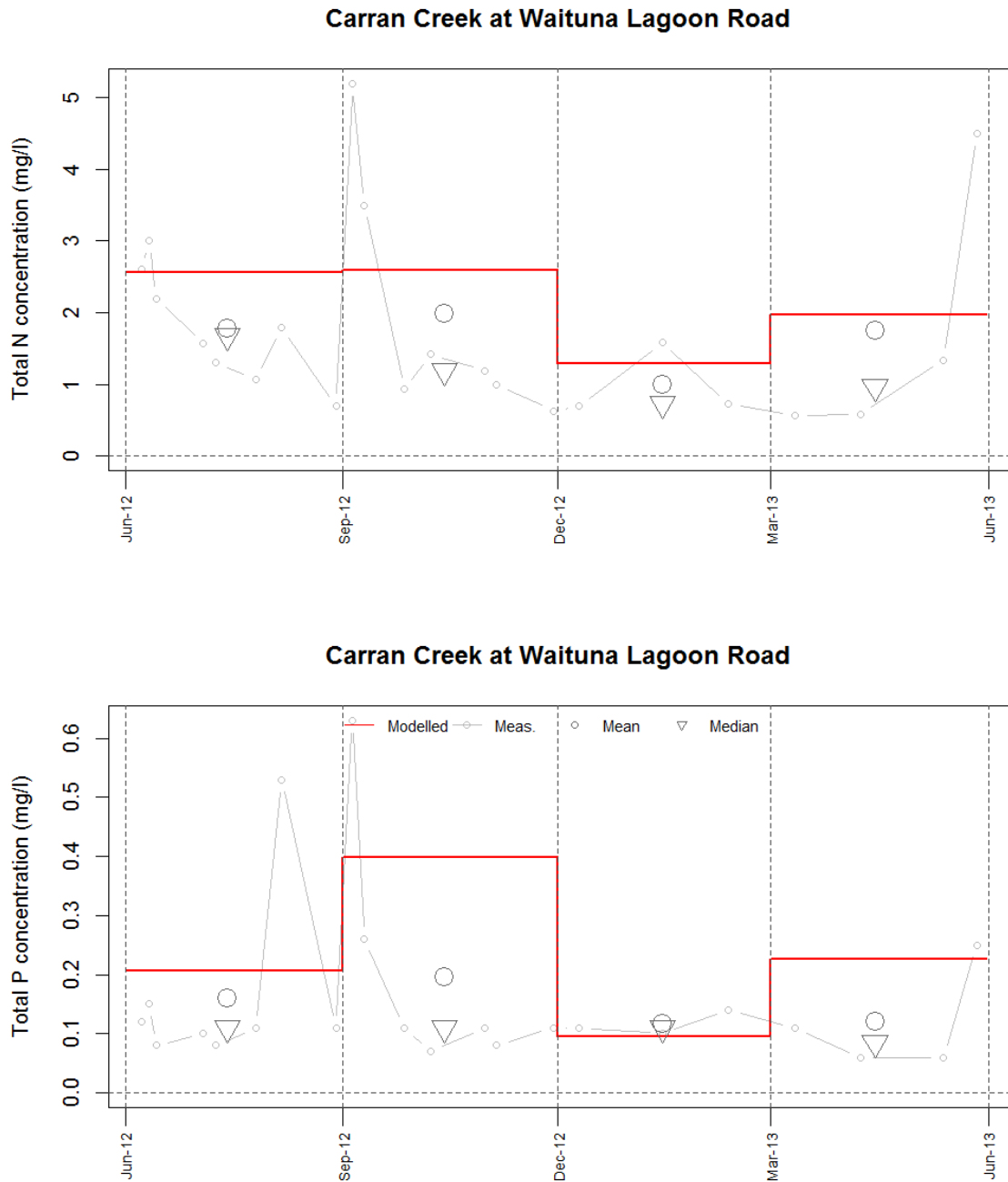


Figure 4.12 Modelled and observed (Meas) mean, median and flow-weighted mean concentration (FWMC) for total nitrogen (top) and total phosphorus (bottom) concentrations, Carran Creek at Waituna Lagoon Road, June 2012- May 2013.

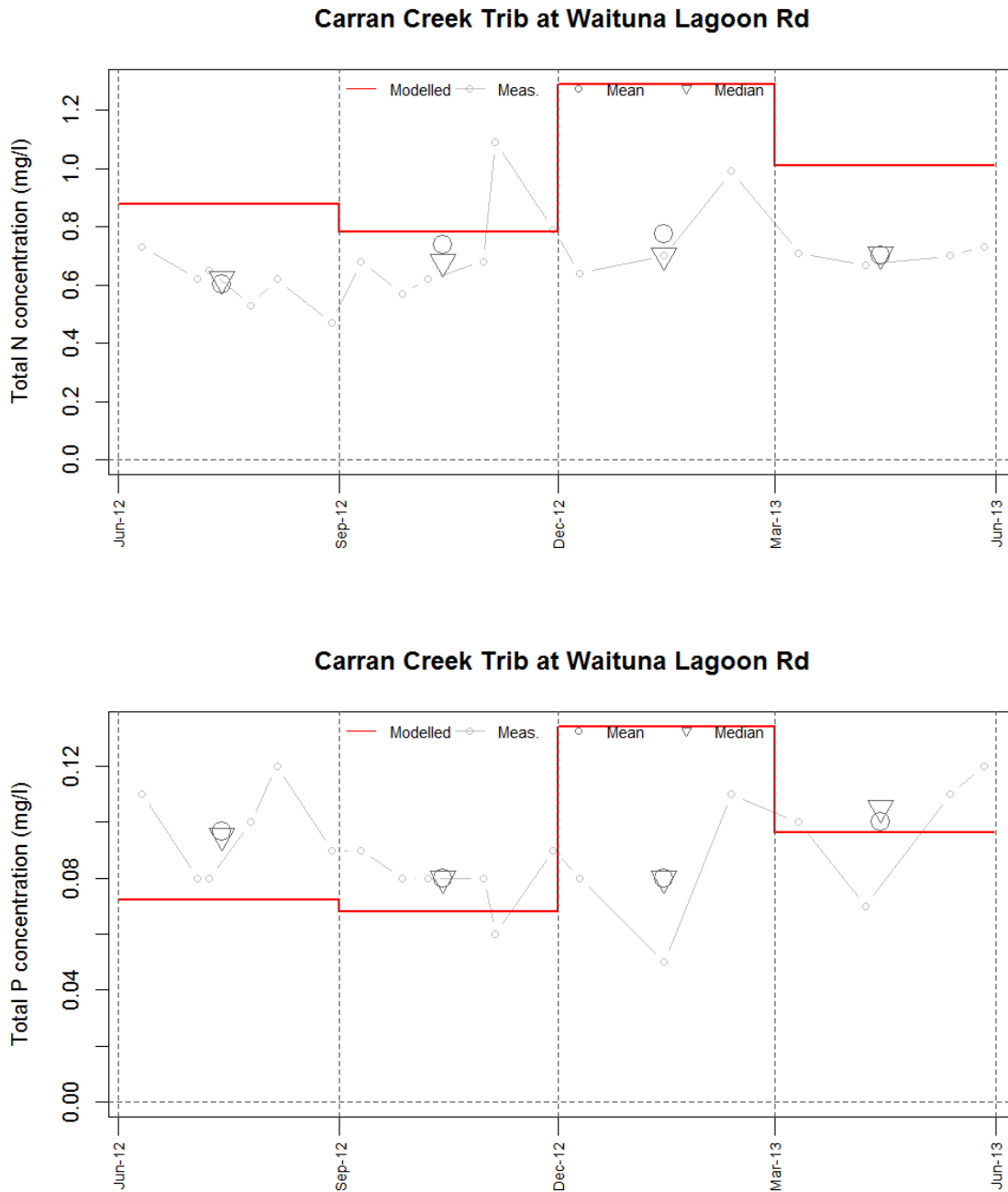


Figure 4.13 Modelled and observed (Meas) mean, median and flow-weighted mean concentration (FWMC) for total nitrogen (top) and total phosphorus (bottom) concentrations, Carran Creek Tributary at Waituna Lagoon Road, June 2012- May 2013.

4.7 Loads to the Lagoon

For management purposes it is useful to know the contributions of each sub-catchment to the total N and P load of the Waituna Lagoon. This information can be extracted from the model after a simple post processing step.

Total modelled nitrogen and phosphorus loads to the Waituna Lagoon from all sources after attenuation are estimated to be 302 tonnes TN/year and 16,5 tonnes TP/year, respectively (Figs. 4.14 and 4.15). Figure Waituna Creek is the main source of N to the lagoon, contributing about 75% of the total annual load. Other important sources according to the model are the direct contribution to the lagoon, followed by Carran Creek. Waituna Creek is also the most dominant source of P (Fig. 4.15) contributing 65% of the total annual load, followed by Carran Creek. Crows Creek, Moffat Creek and direct contribution to the lagoon all represent minor sources of P in comparison.

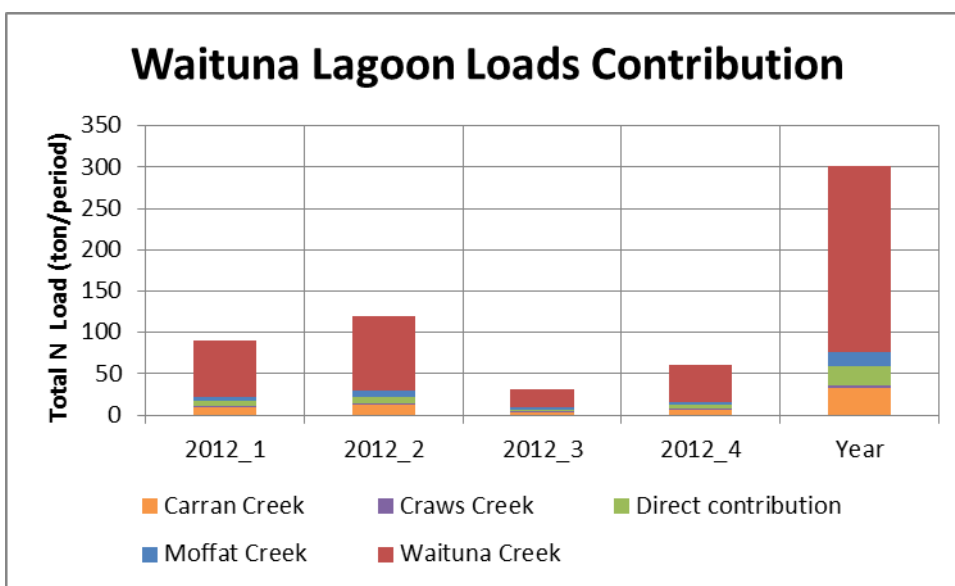


Figure 4.14 Modelled annual total nitrogen loads to the Waituna Lagoon from each sub-catchment, June 2012 - May 2013.

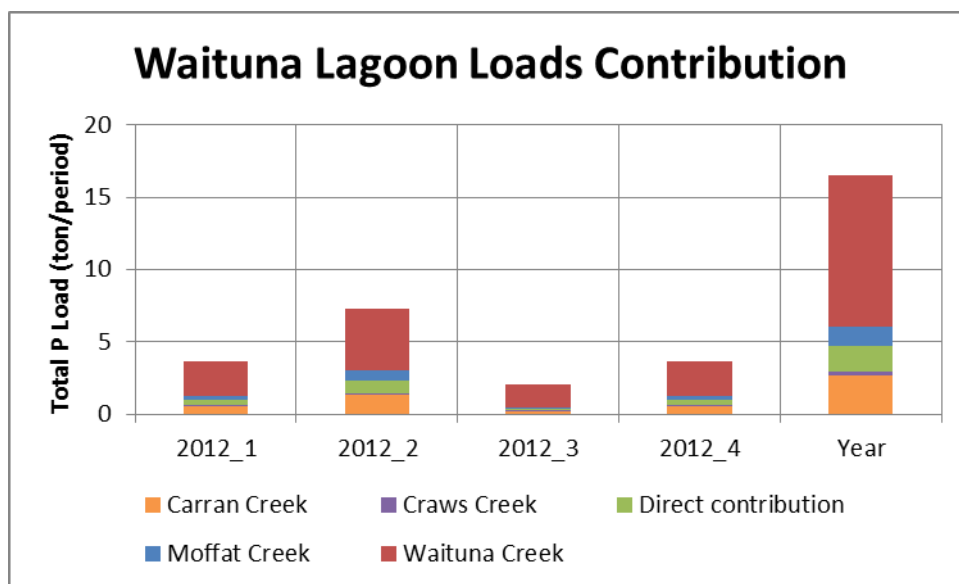


Figure 4.15 Modelled annual total nitrogen loads to the Waituna Lagoon from each sub-catchment, June 2012 to May 2013.

An overview of modelled concentrations of TN and TP is given in Figures 4.15 and 4.16, showing the gradient of concentrations in the river network and reaches where higher nutrient concentrations occur.

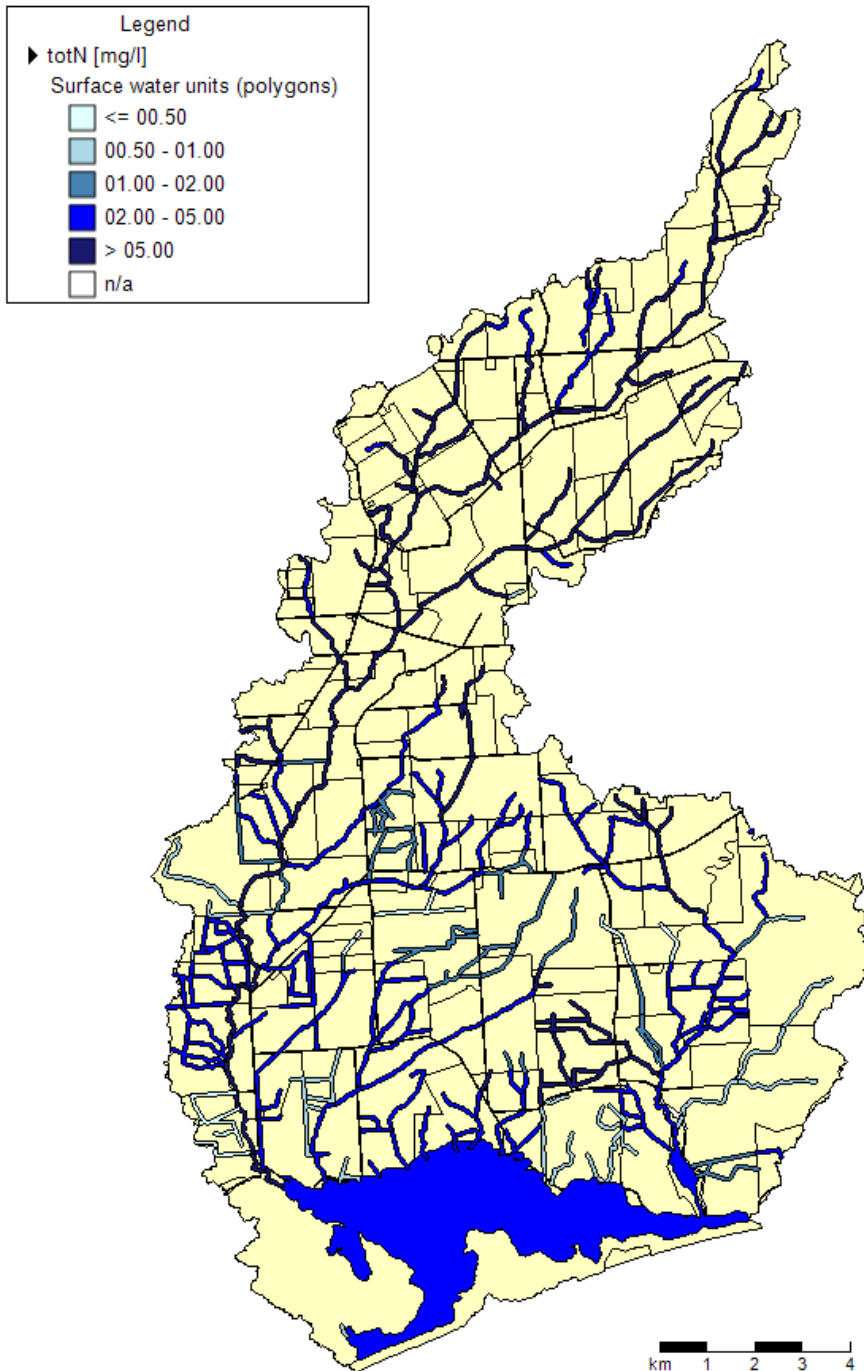


Figure 4.15 Modelled summer average concentrations TN per surface water unit.

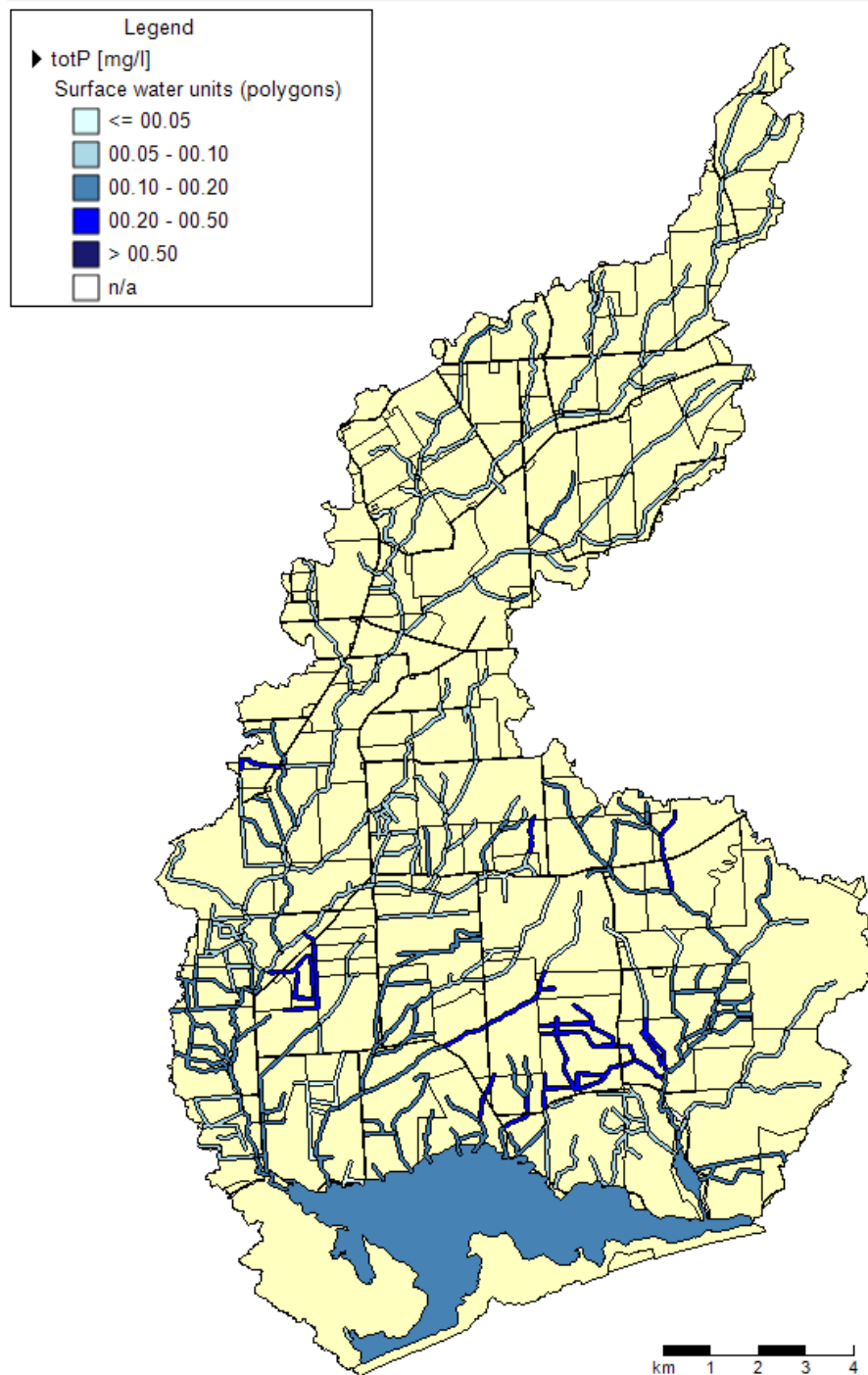


Figure 4.16 Modelled summer average concentrations TP per surface water unit.

5 Application of model framework to evaluate possible manage scenarios

5.1 Introduction

The complete modelling framework has been designed as a management tool which can be applied to help evaluate the impact of different management strategies for reducing nutrient inputs to the lagoon. The method of load implementation used in the model schematisation means that scenarios can be targeted at different soil types, land use practices or location in the catchment. The model can therefore be used as an integrated catchment management tool to help find a sustainable solution for farming and lagoon health.

In this Chapter the model is utilised to run a number of mitigation scenarios to understand and test how the model can be applied as a catchment planning tool. The scenarios applied and their results are intended as a demonstration only, and a more detailed evaluation is required in order to test these options and potential alternatives further, including a cost-benefit analysis which takes into consideration farm economic impacts.

While the current water quality model has been applied to the period June 2012 to May 2013, which reflects the existing input load information, any historical or future period can be simulated as long as measured or estimated meteorological and load information are available. The existing flow model simulation currently extends from 2002 to 2013.

5.2 Possibilities for scenario calculations and implementation

Management scenarios can be carried out using any one or a combination of the following approaches:

- Hydrological scenarios (in WFLOW) - adjustment of the meteorological input data to reflect a specific historical year or period, e.g. simulating a dry or wet period.
- Emission scenarios (in WFD Explorer):
 - Adjustment of farm-specific Overseer load inputs, as prescribed in the WFD Explorer import file.
 - Manipulation of load sources in the WFD Explorer schematisation, including the addition, elimination or modification of specific or collective load types.

The adjustment of farm-specific Overseer load information is an approach suited to situations where there have been significant changes to the operation of an individual farm, leading to large changes in farm N and P losses. Loads can be adjusted for individual farms or all farms where new or modified Overseer output is available.

Modification of loads through the WFD framework is a suitable approach for testing mitigation scenarios targeted across the entire catchment. This approach can be applied without the need to regenerate individual farm nutrient budgets using Overseer. Loads can be altered for a specific source (e.g., an individual farm), enterprise type (e.g. all dairy farms), soil type, geographical location or specific land use activities (e.g. cropping). Loads can also be partially reduced through adjustment of the removal efficiency (or retention factor) for each specific load source.

5.3 Testing of scenario framework

Within this project two different scenario calculations were carried out; (1) a scenario in which the WFD Explorer import file was modified to reflect a reduction in nutrient losses associated with individual farms located in the southern part of the Waituna Catchment, and (2) a scenario in which specific load sources were adjusted through the WFD Explorer. In the following sections, the different scenarios are described.

5.3.1 Implementation of Scenario 1: adjusted load import file

The basic goal of this scenario was to model an example of land de-intensification in the lower catchment, adjacent to the Waituna Lagoon. Emissions associated with six farms were reduced to zero for both TN and TP. The scenario was implemented by editing and importing a different loads file to the WFD Explorer.

5.3.2 Implementation of Scenario 2: emission reduction in the WFD Explorer

In this scenario N and P losses associated with crop blocks on organic soil on individual farms in the lower part of the catchment were reduced to zero. This scenario was implemented directly into the WFD Explorer by setting all farm N and P loads for Crop Peat values in the southern part of the catchment to zero using the model user interface.

5.4 Scenario results

The results of the scenario testing demonstrated that the model framework is highly suitable for use as a catchment management planning tool. As the focus of the current report was on the model set up and development, the results of the individual scenarios are not presented here. Instead, these will be addressed in a subsequent report by DairyNZ.

6 Extension of the WFLOW model water balance to include Waituna Lagoon

6.1 Introduction

The WFLOW hydrological model described in Chapter 3 was specifically set up to help simulate the transport of loads from the catchment to the lagoon. The model framework applied excludes a water balance of the lagoon, as the focus of the model was to simulate in-stream flows. Operational management of lagoon water levels represents a possible strategy to mitigate lagoon water quality concerns in addition to in-catchment measures. The WFLOW-FEWS framework has been used extensively as a decision-support system for operational water level and flood management in other studies through the integration of real-time control tools.

This Chapter describes the extension of the WFLOW model framework to include also the lagoon water balance and real time control options. The final model provides additional capabilities which can be utilised to assess and drive operational water level control.

The model extension includes only the hydrological components of the model, and not water quality.

6.2 Background

Water levels in Waituna Lagoon have been artificially managed since 1908. Management was initially carried out to enhance recreational fishing, and more recently to manage high water levels and its associated impacts on surface and sub-surface drainage of agricultural land in the lower catchment. Openings also have a positive impact on lagoon water quality (water column N and P concentration), but at certain times of the year, a negative impact on macrophyte (*Ruppia*) biomass. *Ruppia* is considered a key indicator of lagoon ecosystem health and total *Ruppia* biomass and cover has declined significantly over recent years for which monitoring data is available.

While *Ruppia* has a high tolerance to salinity, one of the two species present in the lagoon requires a spring-summer freshwater environment to ensure germination. While lagoon openings are carried out manually (using earth moving equipment), closing of the lagoon occurs naturally and is dependent on weather conditions and tidal forces (i.e. marine gravel beds are slowly deposited in the opening). If lagoon opening is carried out at the wrong time of the year (for example in summer), than natural closing may not occur that year, meaning that the lagoon stays open for an extended period which has implications on *Ruppia* germination and growth.

The rehabilitation of the Waituna catchment ultimately requires a combination of on and off-farm nutrient load reduction together with clever management of the lagoon opening and closing. This means looking for other solutions to close the lagoon, including the construction of a diversion channel to an adjacent river, or a weir to the sea. The extension of the catchment hydrological model to include lagoon water levels and operational control capabilities would provide an ideal management tool to explore lagoon opening and closing options further.

6.3 Implementation of RTC-tools in the FEWS/WFLOW system

The real time control model RTC-Tools (see Chapter 2) was integrated into the existing FEWS/WFLOW-system of the Waituna catchment. To represent the opening and closing of the lagoon, a weir is modelled in the mouth of the lagoon (Figure 6.1).

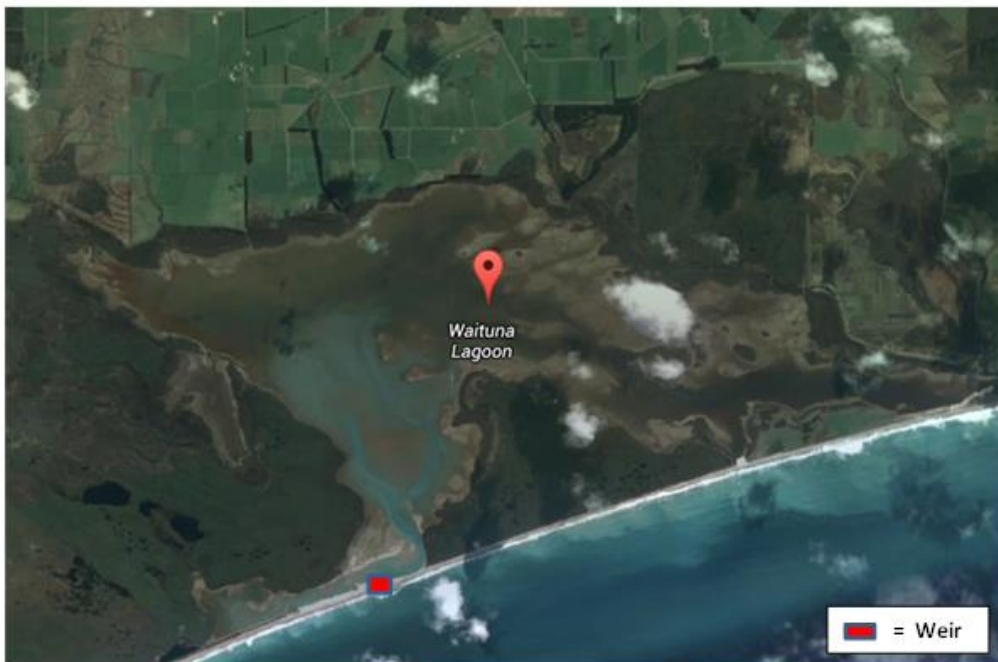


Figure 6.1 Location of the simulated weir at the mouth of the Waituna lagoon.

6.4 Operation of the weir in RTC-Tools

The operation of the system is steered by a user-defined water level for the lagoon. The user can define this water level within 10-minute time steps. This time step was selected because the input data for the sea level was available over the same period. Once the water level has been defined, the RTC-Tools model will calculate the optimal behaviour of the weir in order to meet the water level criteria set in the lagoon.

Weir operation in the model is explained in more detail in Figure 6.2. Every hour the RTC-Tools model check whether the water level of the lagoon is higher or lower than the user-defined water level. This is then compared to sea level outside the weir, which governs whether the weir can be operated at that time or not. Discharges from the lagoon cannot occur when outside sea level is equal to or exceeds lagoon level. All possible operation options of the weir in the model framework are described in Figure 6.2.

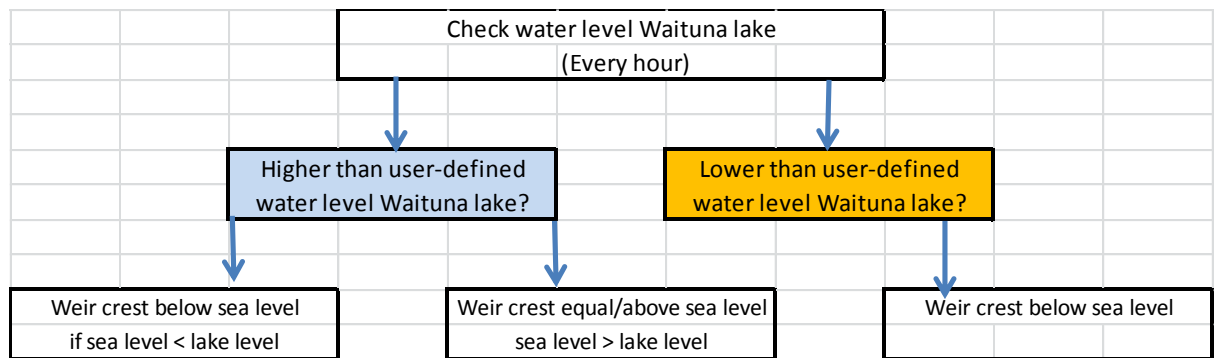


Figure 6.2 Operation of the weir steered on the user-defined water level of the lagoon.

6.5 Optimization of the lagoon water level and weir operation

Waituna lagoon water level management was optimised within RTC-Tools based on the following approach:

1. Calculation the mass-balance of the lagoon:

$$\text{Mass_balance_lagoon} = \text{Inflows_to_lagoon} - \text{Outflows_from_lagoon} + \Delta\text{storage_Lagoon} = 0$$

Where:

$$\text{Inflows_to_lagoon} = \text{Inflows_from_Waituna_catchment (WFLOW output)} + \text{Inflow_from_sea (using weir formula)} + \text{Precipitation}$$

$$\text{Outflows_from_lagoon} = \text{Evaporation} + \text{Seepage} + \text{Outflow to sea (using weir formula)}$$

$$\Delta\text{storage} = \text{Change in storage of water in the lagoon}$$

Calculation of the discharge over the weir

To calculate the discharge over the weir, the **weir formula* is used. The dimensions of the weir are set to: width=105m, height =3m. The loss coefficients are set to zero.

2. Calculation of the water level of the lagoon using storage-level relation:

With the level-volume relation of the Waituna lagoon (Fig. 6.3) and the calculated storage change (see mass balance), the water level of the lagoon can be calculated.

3. Optimization of the lagoon level and controlling of the weir

Every hour RTC-tools sets the crest level of the weir which is steered on the stipulated lagoon water level. The optimization of the lagoon water level and crest level of the weir is solved in a sequential explicit mode.

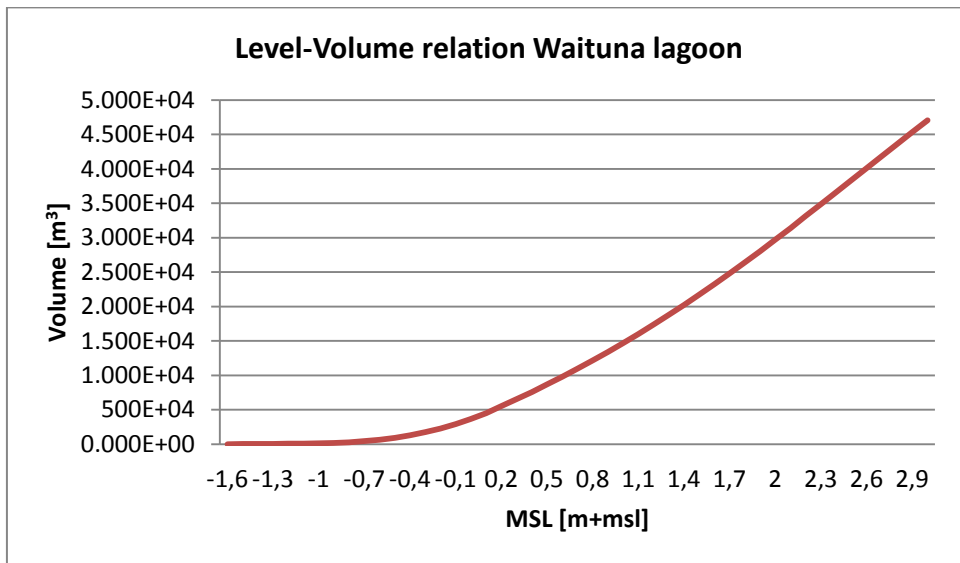


Figure 6.3 Level-Volume relation of the Waituna lagoon.

6.6 Test results

To test the operation of the model, the following scenario was implemented in FEWS. The target level of the lagoon was set to a constant value of 1.1m, as indicated by the red line (H.req user) in Figure 6.4. The dark blue line represents the simulated water level of the Waituna lagoon. The light blue line shows the sea level and the brown line presents the height of the weir, which changes every hour. The discharge over the weir is represented in the discharge graph below.

Figure 6.4 shows that from 14-9-2013 8:00 until 15-9-2013 2:00, the desired water level of the Waituna lagoon was higher than actual level (red line =1.1m) and therefore water must be discharged to sea. However, because the sea level is higher than the lagoon level at this time, the weir stays closed and discharge remains zero. At 15-9-2013 2:00, the sea level is below the simulated lagoon level and the weir crest is dropped below lake level to enable water discharge to sea.

The model framework was also extended to include a visualisation tool displayed in the FEWS user interface. This display provides a historical or live view of water balance and level results in an illustrative way. This information is updated every 10 minutes and includes information on the lagoon, including water fluxes in [m³/s] and the water level of the lagoon and sea in [m] (Fig. 6.5).

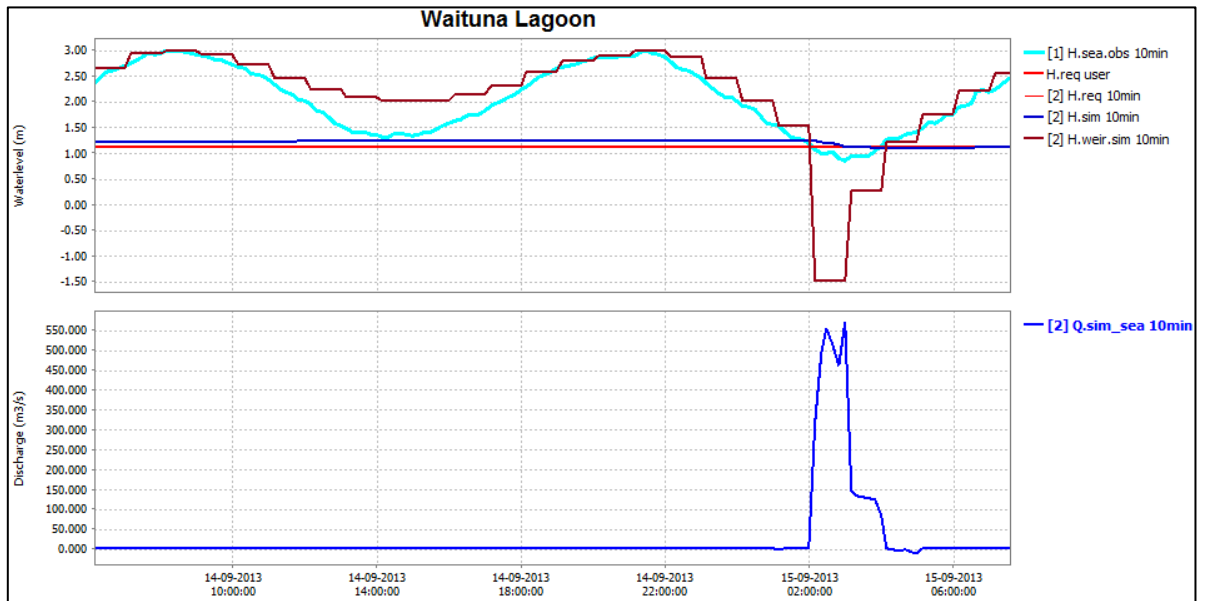


Figure 6.4 Graph showing the result of FEWS wherein the target level of the lagoon set to 1.1 m (Red line), the blue line is the simulated water level of the Waituna lagoon, the brown line is the optimal weir height simulated by RTC-tools and the discharge over the weir is presented by the blue line in the bottom graph.



Figure 6.5 Schematic Status Display of Waituna lagoon water levels and discharge information.

7 Summary

7.1 Summary

The aim of the current study was to develop a water quality modelling framework for the Waituna lagoon catchment to quantify total catchment nutrient loads discharging to the Waituna Lagoon. The final framework, which integrates a distributed hydrological model with seasonal loads model, provides a complete catchment management tool which can now be applied to explore possible management options to reduce nutrient loading at the catchment scale together with land owners and water managers.

The use of individual farm nutrient-load information in the model framework greatly improves the spatial resolution of the load estimates and provides much greater flexibility to investigate different management options. This approach reflects the substantial differences in nutrient loading observed across different farms, due to differences in intensity, wintering practices and development stage and location. Scenarios can be targeted at specific landuse types, soil types, geographical locations or different land use activities on individual farms.

The modelling approach taken is based on open-source software and, given the availability of input data, can easily be replicated to other catchments across New Zealand. This project has therefore provided significant learnings towards the development of a spatially refined catchment water quality modelling approach to assist future catchment limit setting processes in agricultural catchments

7.1.1 Modelling framework

The water quality modelling framework applied to the Waituna catchment has been set up over a relatively short time frame based on existing freeware software. The hydrological component of the framework and the RTC-tools application of the Waituna Lagoon run under the Delft-FEWS user interface and data management platform. This has been coupled to the WFD Explorer user interface and associated framework components using R-scripts.

The final framework enables the user to simulate the hydrology for the catchment on a detailed spatial scale, to define the farms as separate emission sources, to add additional point and diffuse emissions to the system, to estimate water quality concentrations in the river network and to calculate the contributions of the different sub catchments to the total nutrient load to the lagoon. Scenario calculations can be made using either modified Overseer input files or by applying detailed emission reductions on specific farms, emission types and soil types within the WFD explorer framework.

The project can be seen as a pilot study to test out a spatially refined modelling approach for wider application to other catchments in New Zealand. Considerations for further development of the conceptual framework and optimisation of model data input and model parameterisation are described in Section 7.2.

7.1.2 WFLOW hydrological model

The WFLOW model simulates discharge associated with surface runoff and shallow subsurface flows.

The contribution of deeper regional groundwater flow to the catchment water balance is not modelled and was therefore ignored in the current approach. Groundwater transit times in the Waituna Catchment are suggested to be reasonably rapid (months) and the water quality model is suggested to reflect mean annual loads in a steady-state environment.

Most of the data required to construct a high quality hydrological model was available on a fine spatial scale for the catchment. Parameter values used to prescribe water storage and runoff in the unsaturated and free surface water routines of the model for different land use types were estimated based on expert judgement and could be improved should more data become available. The parameter values for the different soil types, except for the saturated conductivity which was considered to represent the most sensitive parameter, were also estimated.

An extended calibration of the WFLOW model framework beyond the initial 1.5-year time period was not performed due to the short time frame of the project. Model calibration focussed on improving the saturated conductivity parameter settings which resulted in a more realistic discharge pattern. The model generally captured the timing and magnitude of flow peaks well, although mean flow conditions were underestimated over some seasons, in part due to rapid return to base flow after storm events whereas actual flows receded more gradually.

For Waituna Creek, the model performs well for three of the five seasons simulated, with flows overestimated over the remaining seasons. For Moffat Creek the simulated discharge peaks and base flow conditions are generally underestimated by WFLOW, potentially due to the saturated conductivity of the soil being set too high. Flows in Carran Creek are also overestimated by the model, however, as the average measured discharge is very low, this has only a small impact on the total flow to the lagoon.

A further analysis of the VCSN data relative to actual measured rainfall data collected from a station located in the catchment is considered important to further evaluate model performance and uncertainties. An extended calibration and more information on the WFLOW parameter settings for the catchment should also be undertaken. Finally, it is uncertain to what extent the extensive tile drain networks present in the catchment affect the flow results derived from the model.

Overall, the model framework and results generated are suggested to be reliable and fit for the purpose of calculating catchment nutrient loads on a seasonal time scale.

7.1.3 Water Quality Model WFD Explorer

A detailed model schematization comprised of basins (the farms), river segments and associated linkages was developed to represent the spatial distribution of catchment load sources. By combining the WFLOW hydrology with emissions from different sources, river water quality could be calculated by the WFD Explorer. From this data the contribution of nitrogen and phosphorus loads to the lagoon from the individual sub-catchment flows could easily be derived.

Nutrient loads used as input to the WFD Explorer reflected sources related to specific agricultural land uses. Different types of land uses were defined in the WFD Explorer as separate emission types.

Nutrient losses for individual farms were based on Overseer nutrient budget estimates. The Overseer model computes annual loads and these were distributed seasonally based on an optimal fit with the measured loads.

A comparison between the WFLOW and the WFD Explorer results for water flows suggested that in general both models have comparable outputs at the Waituna Creek and the Moffat Creek monitoring locations. At Carran Creek, however, the simulated flows did not match, and further investigation is needed.

Calibration of model output against measured water quality suggests the attenuation rate between source and downstream discharge is 20% for TN and 0% for TP. Total measured loads of phosphorus in Waituna and Carran Creeks were significantly higher than the estimated P inputs from agricultural and other landuse sources. This implied that either existing P loads associated with farms were underestimated, or a source of P was missing from the catchment, possibly attributed to bankside erosion. The magnitude of the additional P load is expected to be greater than the existing measurements once loading associated with storm events are also taken into consideration.

A recent sediment finger printing study by McDowell et al. (2013) suggested that up to 95% of the sediment load in the lower Waituna Creek was derived from stream bank erosion associated with bank collapse and drain cleaning. Although phosphorus loads were not measured as part of this study, it is likely that part of the P load unaccounted for in the catchment nutrient balance is derived from this source. Underestimation of farm nutrient loads should also not be discounted, however, the difference between computed input loads and the measured load is suggested to be much greater than the uncertainty range associated with Overseer P calculations. Further evaluation of this potential additional source is therefore important.

Accordingly, an additional P source associated with bankside erosion was implemented in the water quality model framework. In the absence of detailed measurements it was assumed that this source was equivalent to the difference between sub-catchment inputs and the measured loads, distributed uniformly over the year. This approach may have impacted the observed differences in modelled and measured P loads and concentrations over some seasons. At Moffat Creek annual TP loads were underestimated by 20% suggesting that bankside erosion could also be an important source of P from this sub catchment.

Overall the model results compared well to the measured loads and concentrations after calibration. Discrepancies did exist for some seasons, especially in the smaller tributaries. However, large seasonal variations also exist within the measurement data and when the mean, median and FWMC of the measured concentrations are compared. The existing monthly sampling program is generally conducted in dry-weather conditions and this variability is expected to be even greater should storm events also be considered.

7.1.4 Load reduction scenarios

Two different load reduction scenarios were simulated using the model framework to demonstrate and test the functionality its end use as a management planning tool. Of course numerous different measures targeting loads at specific locations (downstream or upstream, high or low, individual farms), specific soil types or specific land use or combinations of these can be applied.

7.1.5 Extension of the WFLOW model water balance to include the lagoon:

The WFLOW model framework was extended to include also the lagoon water balance and real time control options. This enables the model to simulate a flexible weir between the Lagoon and the sea based on 10-minute time series of the sea water level and the water level in the lagoon, driven by flows coming from the upstream catchment. The final model therefore provides additional capabilities which can be utilised to assess and drive operational water level control.

7.2 Recommendations for further model refinement

One of the objectives of this study was to provide learnings towards the development of a spatially refined catchment water quality modelling framework which could be applied to assist the catchment limit setting process in other New Zealand agricultural catchments. This Section makes a number of suggestions and recommendations for improving the Waituna Modelling framework, either with respect to the model input data or the model schematisation. In addition, options for a more modelling comprehensive framework incorporating also groundwater inputs and in-stream processes are described.

7.2.1 Recommendations Waituna model framework

The following recommendations are made with respect to the existing model framework as applied to the Waituna catchment.

Model data inputs and parameterisation

- An extended model calibration over a time period which is longer than the 1.5 years applied in the current study should be considered to fine-tune model accuracy of peak and base flow. This is to ultimately improve the simulated nutrient loads from the farms to the lagoon, which depends on the discharge.
- A detailed analysis of the NIWA VCSN rainfall and precipitation data within the Waituna catchment should be conducted. The model utilises daily rainfall generated from the VCSN network to prescribe a degree of spatial variability in the inputs. It is uncertain how representative this information is relative to actual measurements in the catchment. A more detailed analysis and calibration of the rainfall inputs could have a large beneficial impact on the performance of the WFLOW-model. This is to improve the modelled discharge with WFLOW and consequently the nutrient modelling
- The large difference between measured in-stream P loads and upstream Overseer inputs in some sub-catchments indicated that a large P source is missing from the nutrient balance. It is likely that this additional source is attributed to bankside erosion, however, this should be verified through sampling of sediment P concentration.

Model framework

- Model output of catchment load sources and in-stream nutrient concentrations are currently generated through a number of post-processing steps. Integration of the WFD Explorer model output into the FEWS environment could be considered to provide a single framework for displaying and analysing flow and water results.
- To improve the base flow simulations, a groundwater flow model (MODFLOW) for the Waituna catchment could be considered. This groundwater model has to be coupled with WFLOW within FEWS. This action requires a good understanding of the geology of the Waituna catchment.

- The current model framework is focused on generating mean seasonal loads to the lagoon. While a global attenuation rate to represent retention and attenuation has been fine-tuned and applied through the calibration process, specific in-stream attenuation processes were not examined. Direct coupling of WFLOW to Delwaq could be considered to provide a dynamic WQ computation which includes all degradation processes, including denitrification, sedimentation, and uptake by aquatic plants. Alternatively the first order retention process in the WFD Explorer could be applied to further define a decay rate and the volume and in- and outflow of the river segments. The decay rate constant can be prescribed for each substance individually and can be made temperature-dependent. Hydraulic model(s) for lakes and estuaries (2D/3D) could be connected to the existing framework to perform more detailed spatial information about surface flooding in the lower part of the catchment during periods of high lagoon water level.
- The mitigation cost module in the WFD Explorer could be applied to help provide a cost-benefit analysis of the most cost effective measures or scenario packages.

7.2.2 Extension of model to more complex catchments

The model configuration applied to the Waituna catchment was aimed at replicating seasonal, steady-state loading conditions. Due to the assumed relatively rapid time scales between groundwater recharge and discharge (months), deep, regional ground water inputs were ignored. As the catchment is small and river reaches short, specific in-stream processes were also neglected and represented by a global attenuation-retention factor. Should the current model framework be applied further to much larger catchments, groundwater inputs and in-stream processes will need to be considered.

The integration of the modelling framework into the FEWS environment provides significant flexibility to apply and couple different model configurations. FEWS is very suitable for data management, data conversions and standard workflows. The WFD Explorer GUI is an instrument which can be used interactively during stakeholder processes for evaluating scenarios.

Two options for expanding the model framework to address more complex situations have been identified. The first option extends the existing framework with a groundwater and 1D river network models, to better simulate more complex water balances and stream features (backwater curves, structures etc.) (Fig. 7.1). Although the groundwater model and the 1D river Network must be converted into appropriate inputs for the WFD explorer schematization, overall processes within the existing water quality model stay the same. If desired, the water quality model can also be expanded to include in-stream processes.

Option 1:

Advantages	Disadvantage
<ul style="list-style-type: none"> • Added modelling, covering more dimensions. 	<ul style="list-style-type: none"> • Increased complexity of the coupling with the Emission toolbox.

Option 2 provides more options and flexibility for automating pre and post processing steps within the existing model framework (Fig. 7.2). By including these steps in FEWS, all input and output files are generated automatically. In this approach FEWS also becomes the interactive tool for visualisation of the results. An extra option could be to directly incorporate access to the computational cores of the WFD Explorer. Standard computations and scenarios can then be run within FEWS environment. In future, the WFD explorer steady state tools could also be expanded with dynamic tools and full water quality processes (Delwaq dynamics).

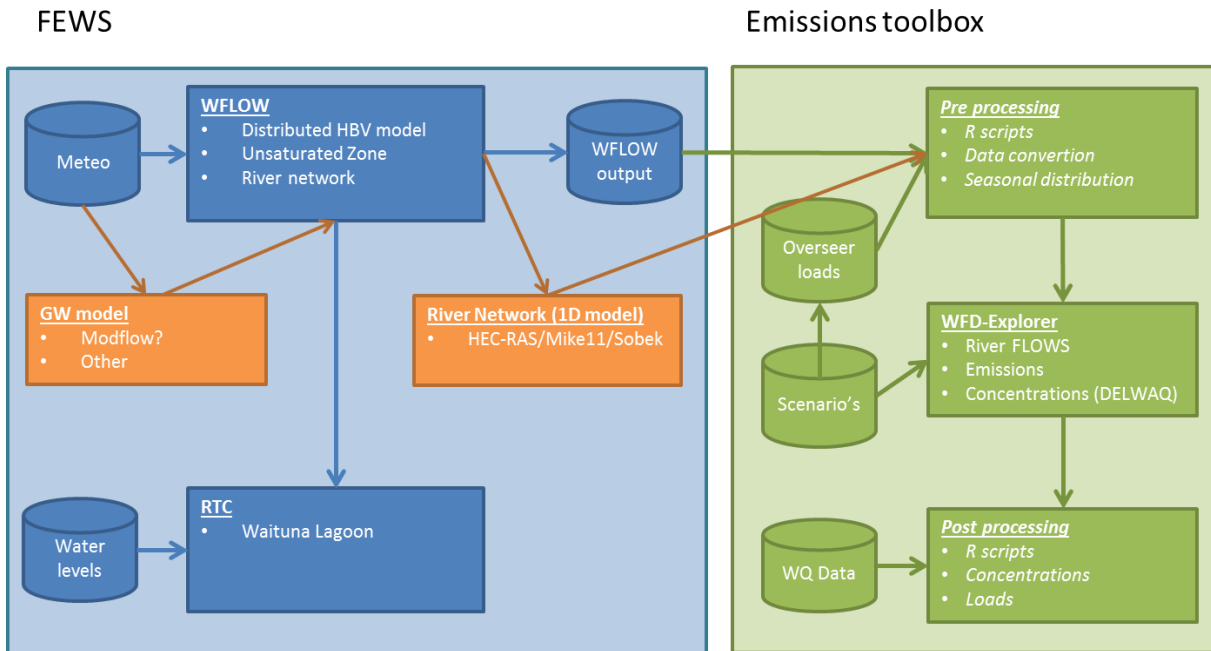


Figure 7.1 Option 1: extension with groundwater and 1D river network model.

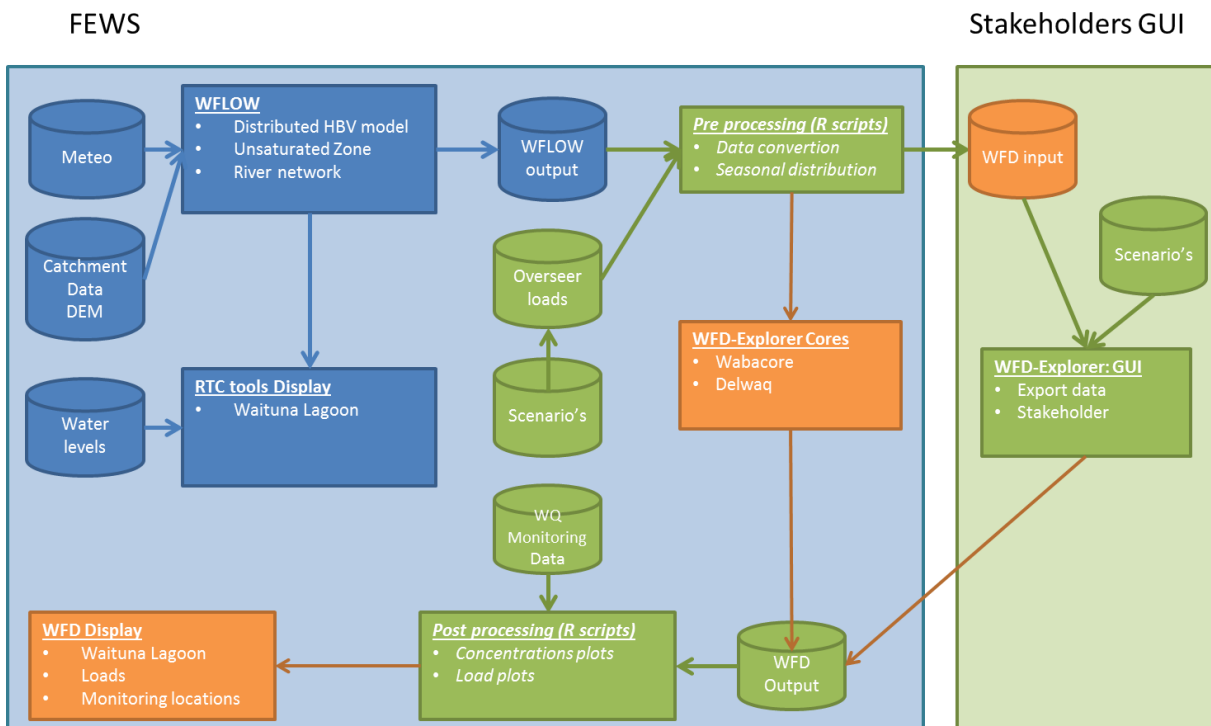


Figure 7.2 Option 2: extensions in FEWS.

Option 2:

Advantages	Disadvantages
<ul style="list-style-type: none"> • Further automation of the workflows. Less manual actions required. • Interactive scenarios are still possible with the Stand-alone WFD Explorer GUI • Standard display of WQ results. 	<ul style="list-style-type: none"> • More expensive to implement • Increased complexity of the FEWS system

7.3 Conclusions

The current study provides an integrated catchment water quality tool for the Waituna Lagoon catchment which can now be applied to explore possible options for achieving a sustainable solution for lagoon water quality and existing landuse activities. The model contains spatially refined source load information and therefore provides great flexibility to investigate different management options. Scenarios can be targeted at specific landuse types, soil types, geographical locations or different land use activities on individual farms. The model has also identified a critical gap in our understanding of existing catchment P sources, with a large source of P unaccounted for in two of the four sub-catchments modelled. This is either due to an underestimation of farm nutrient loads by Overseer, or more likely, additional P loading associated with bank side erosion processes.

The modelling framework applied offers a flexible approach which can easily be applied to other catchments in New Zealand. The framework allows for the simulation of water quality and pollutant loads on finer timescales in future applications through the DELWAQ water quality model included in the WFD Explorer framework. The WFLOW and WFD Explorer models can potentially be coupled with Overseer output files to provide a fully integrated system for the storage, management and environmental modelling of farm nutrient loss data through the open source Delft-FEWS software platform. Such a system could either be deployed in a stand-alone, manually driven or fully automated and distributed client-server environment.

This study can be seen as a pilot project towards developing a robust, nationally applicable and spatially refined (farm-scale) catchment modelling approach for the assessment of wide-scale water quality and water allocation issues over the long term.

8 Literature

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A Description of the WFLOW distributed hydrological model

A.1 Introduction

Conceptually, the WFLOW model is based on the HBV-96 model (Bergström, 1995). The details of the HBV model structure can be accessed in the scientific literature.

WFLOW is a distributed hydrological model. Distributed models remain in contrast to lumped-conceptual models, which merge entire sub-catchment areas into a set of model stores. In WFLOW the landscape is discretized into a model grid, which can have different spatial resolutions. The model grid is obtained by performing a flow drainage analysis on the raw DEM, executing pit-filling and obtaining a consistent drainage map with catchment delineations and a flow direction map, as shown in Figure A.1.

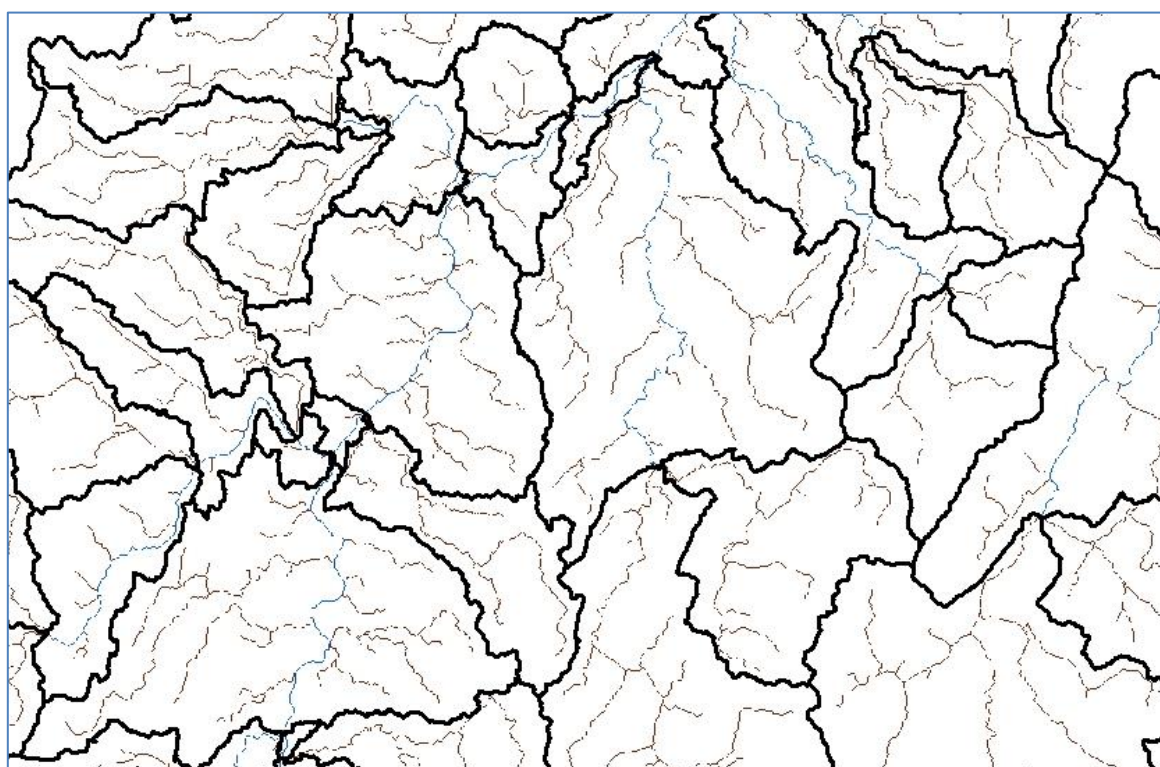


Figure A.1 Example of a drainage map obtained from the elaboration of a raw digital elevation map.

A.2 Model structure

The model structure is based on the design of the HBV-96 stores, whereby the structure is applied for each grid cell. Some modifications have however been introduced in the distributed HBV structure of the WFLOW model as described next.

First, the hydrological routing represent in HBV by a triangular hydrograph has been removed. Instead, the kinematic wave function is used to route the water downstream. All runoff that is generated in a cell in one of the HBV conceptual reservoirs is added to the kinematic wave reservoir at the end of a time step. There is no lateral connection between the different HBV cells in the model. Wherever possible, all functions that describe the distribution of parameters within a sub-basin have been removed, as this is not needed in the distributed WFLOW application.

A river basin is subsequently divided into a number of grid cells. For each of the cells individually, daily runoff is computed through application of the HBV-96 model. The use of the grid cells offers the possibility to turn the HBV modelling concept, which is originally lumped, into a distributed model.

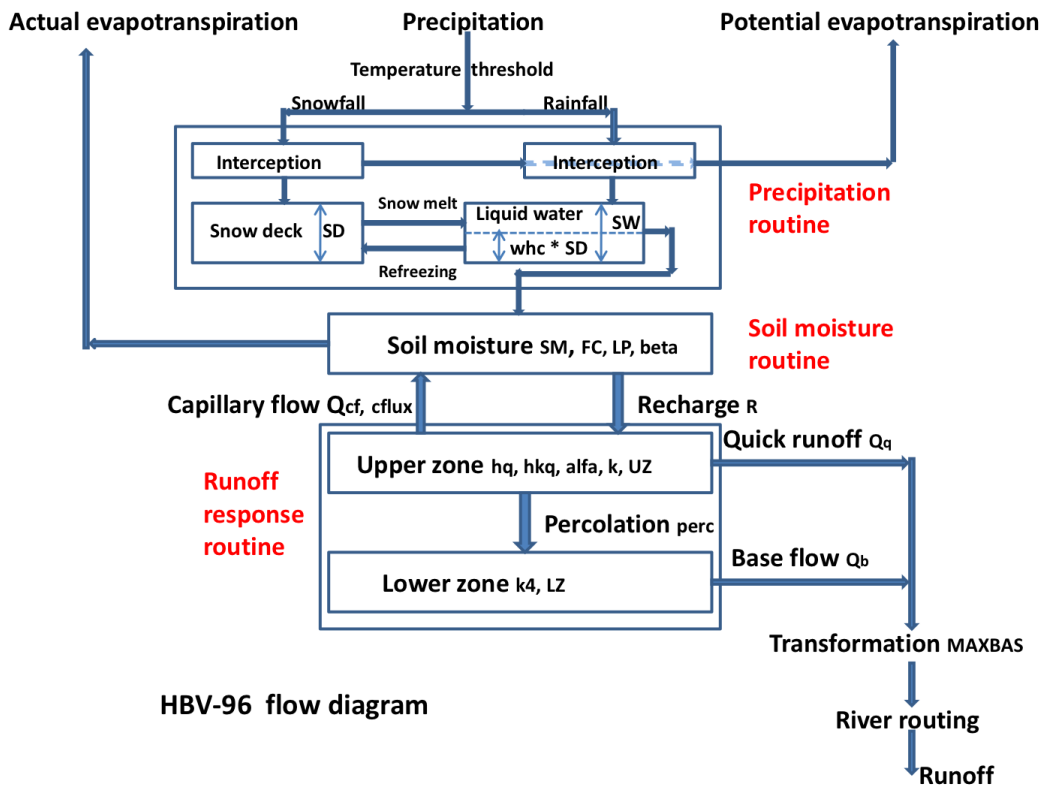


Figure A.2 Schematic view of the relevant components of the HBV model as implemented in WFLOW.

Figure A.2 shows a schematic view of hydrological response simulation with the HBV-96 modelling concept. The land-phase of the hydrological cycle is represented by three different components: 1) a snow routine, 2) a soil routine and 3) a runoff response routine. Each component is discussed separately below.

A.3 The snow routine

Precipitation enters the model via the snow routine. If the air temperature, T_a , is below a user-defined threshold TT ($\sim 0^\circ\text{C}$) precipitation occurs as snowfall, whereas it occurs as rainfall if $T_a \gg TT$. Another parameter, TTI , defines how precipitation can occur partly as rain or snowfall (see Figure A.3). If precipitation occurs as snowfall, it is added to the dry snow component within the snow pack. Otherwise it ends up in the free water reservoir, which represents the liquid water content of the snow pack. Between the two components of the snow pack, interactions take place, either through snow melt (if temperatures are above a threshold TT) or through snow refreezing (if temperatures are below threshold TT). The respective rates of snow melt and refreezing are:

$$Q_m - cfmax * (T_a - TT); T_a > TT$$

$$Q_t - cfmax * (TT - T_a); T_a \leq TT$$

where Q_m is the rate of snow melt, Q_t is the rate of snow refreezing, and cf_{max} and cf_r are user defined model parameters (the melting factor [mm/ C°] and the refreezing factor respectively).

The air temperature, T_a , is related to measured daily average temperatures. In the original HBV-concept, elevation differences within the catchment are represented through a distribution function (i.e. a hypsographic curve) which makes the snow module semi-distributed. In the modified version that is applied here, the temperature, T_a , is represented in a fully distributed manner, which means for each grid cell the temperature is related to the grid elevation.

The fraction of liquid water in the snow pack (free water) is at most equal to a user defined fraction, WHC , of the water equivalent of the dry snow content. If the liquid water concentration exceeds WHC , either through snow melt or incoming rainfall, the surplus water becomes available for infiltration into the soil:

$$Q_{in} = \max \{(SW - WHC * SD); 0.0\}$$

where Q_{in} is the volume of water added to the soil module, SW is the free water content of the snow pack and SD is the dry snow content of the snow pack.

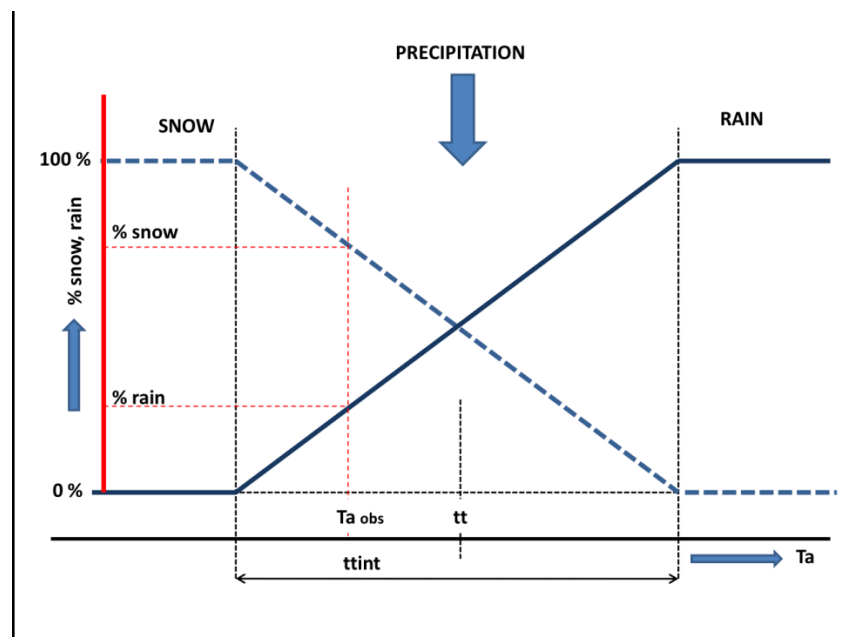


Figure A.3 Schematic view of the snow routine as implemented in WFLOW.

A.4 Potential Evaporation

The original HBV version includes both a multiplication factor for potential evaporation and an exponential reduction factor for potential evapotranspiration during rain events. The $CEVPV$ factor is used to connect potential evapotranspiration to specific land-use classes. In the original version the $CEVPFO$ is used and it is used for forest land-use only.

A.5 Interception

The parameters $ICF0$ and $ICFI$ introduce interception storage for forested and non-forested zones respectively in the original model. Within our application this is replaced by a single ICF parameter assuming the parameter is set for each grid cell according to the land-use.

In the original application it is not clear if interception evaporation is subtracted from the potential evaporation. In this implementation we do subtract the interception evaporation to ensure total evaporation does not exceed potential evaporation. From this storage evaporation equal to the potential rate ET_p will occur as long as water is available, even if it is stored as snow. All water enters this store first, there is no concept of free throughfall (e.g. through gaps in the canopy). In the model a running water budget is kept of the interception store:

- The available storage (ICF -Actual storage) is filled with the water coming from the snow routine (Q_{in}).
- Any surplus water now becomes the new Q_{in} .
- Interception evaporation is determined as the minimum of the current interception storage and the potential evaporation.

A.6 Soil routine

The incoming water from the snow and interception routines, Q_{in} , is available for infiltration in the soil routine. The soil layer has a limited capacity, F_c to hold soil water, which means if the field capacity F_c is exceeded, the abundant water cannot infiltrate and, consequently, becomes directly available for runoff (see Figure A.4).

$$Q_{dr} = \max \{(SM + Q_{in} - F_c); 0.0\}$$

where Q_{dr} is the excess soil water (also referred to as direct runoff) and SM is the soil moisture content. Consequently, the net amount of water that infiltrates into the soil, I_{net} , equals:

$$I_{net} = Q_{in} - Q_{dr}$$

A part of the infiltrating water, I_{net} , will runoff through the soil layer (seepage). This runoff volume, SP , is related to the soil moisture content, SM , through the following power relation:

$$SP = (SM / F_c)^\beta I_{net}$$

where β is an empirically based parameter. Application of this equation implies that the amount of seepage water increases with increasing soil moisture content. The fraction of the infiltrating water which doesn't runoff, $I_{net} - SP$, is added to the available amount of soil moisture, SM . The β parameter affects the amount of supply to the soil moisture reservoir that is transferred to the quick response reservoir. Values of β vary generally between 1 and 3. Larger values of β reduce runoff and indicate a higher absorption capacity of the soil (see Figure A.5).

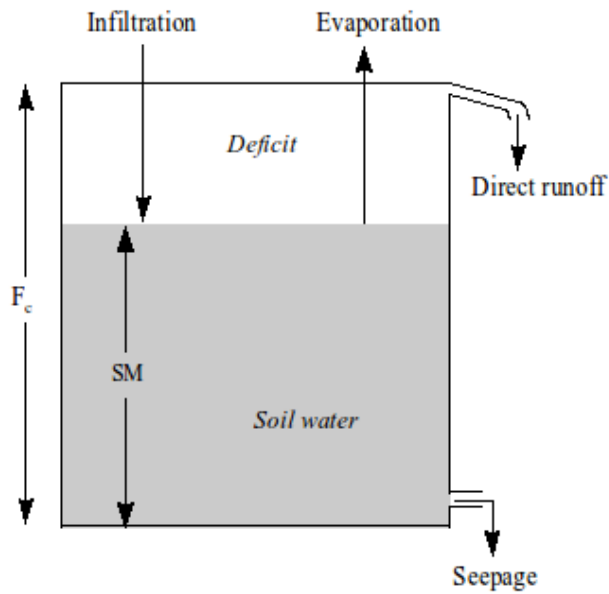


Figure A.4 Schematic view of the soil moisture routine.

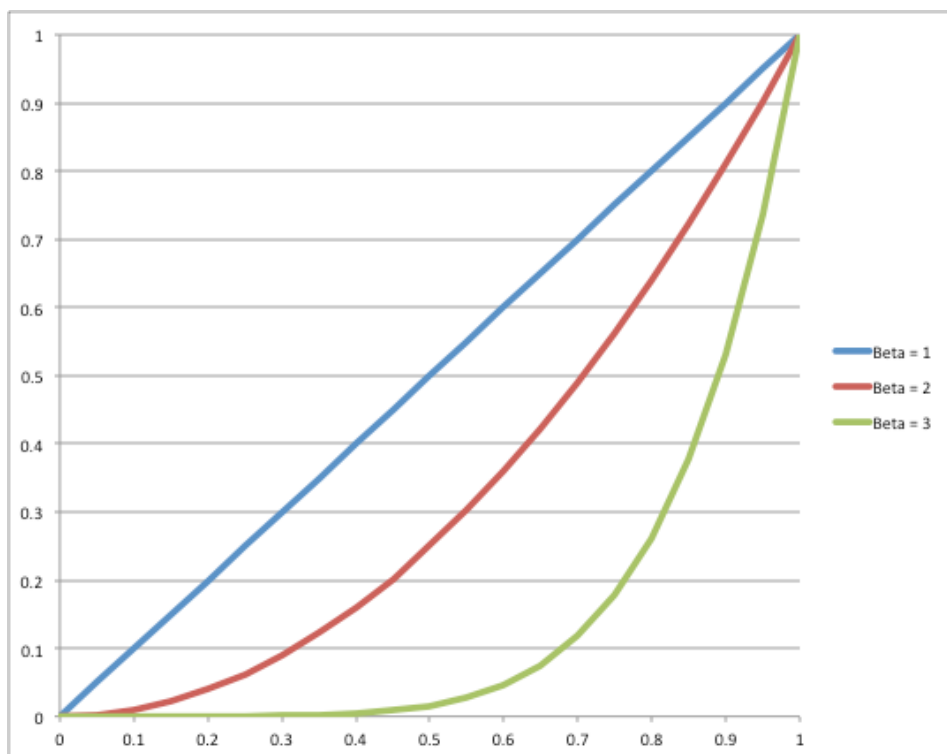


Figure A.5 Relation between SM/F_c (x-axis) and the fraction of water running off (y-axis) for three values of β : 1, 2 and 3.

A percentage of the soil moisture will evaporate. This percentage is related to the measured potential evaporation and the available amount of soil moisture:

$$E_a = SM/T_m E_p; SM \leq T_m$$

$$E_a = E_p; SM > T_m$$

where E_a is the actual evaporation, E_p is the potential evaporation and $T_m (\leq F_c)$ is a user defined threshold, above which the actual evaporation equals the potential evaporation. T_m is defined as $LP * F_c$ in which LP is a soil dependent evaporation factor ($LP \leq 1$).

In the original model (Berglöv, 2009) a correction to is applied in case of interception. If E_a from the soil moisture storage plus E_i exceeds $ET_p - E_i$ (E_i is equal to the interception evaporation) then the exceeding part is multiplied by a factor $(1 - ered) \leq 1$, where the parameter $ered$ varies between 0 and 1. This correction is presently not included in the WFLOW model.

A.7 The runoff response routine

The volume of water which becomes available for runoff, $S_{dr} + SP$ is transferred to the runoff response routine. In this routine the runoff delay is simulated through the use of a number of linear reservoirs.

Two linear reservoirs are defined to simulate the different runoff processes: the upper zone (generating quick runoff and interflow) and the lower zone (generating slow runoff). The available runoff water from the soil routine (i.e. direct runoff, S_{dr} , and seepage, SP) in principle ends up in the lower zone, unless the percolation threshold, $PERC$, is exceeded, in which case the redundant water ends up in the upper zone:

$$\Delta V_{LZ} = \min\{PERC; (S_{dr} + SP)\}$$

$$\Delta V_{UZ} = \min\{0.0; (S_{dr} + SP - PERC)\}$$

where V_{UZ} is the content of the upper zone, V_{LZ} is the content of the lower zone and Δ means increase of. Capillary flow from the upper zone to the soil moisture reservoir is modelled according to:

$$Q_{cf} = cflux * (F_c - SM) / F_c$$

where $cflux$ is the maximum capillary flux in mm/day and F_c is the field capacity. The Upper zone generates quick runoff (C_q) using:

$$Q_q = K * UZ^{(1+\alpha)}$$

here K is the upper zone recession coefficient, and α determines the amount of non-linearity. Within HBV-96, the value of K is determined from three other parameters: α , KHQ , and HQ [mm/day]. The value of HQ represents an outflow rate of the upper zone for which the recession rate is equal to KHQ . If we define UZ_{HQ} to be the content of the upper zone at outflow rate HQ , the following holds:

$$HQ = K * (UZ_{HQ})^{(1+\alpha)} = KHQ * UZ_{HQ}$$

If we eliminate UZ_{HQ} we obtain:

$$HQ = K * (HQ/KHQ)^{(1+\alpha)}$$

Rewriting for K results in:

$$K = KQH^{(1-\alpha)} HQ^{-\alpha}$$

The lower zone is a linear reservoir, which means the rate of slow runoff, Q_{LZ} , which leaves this zone during one time step equals:

$$Q_{LZ} = K_{LZ} * V_{LZ}$$

where K_{LZ} is the reservoir constant. The upper zone is also a linear reservoir, but it is slightly more complicated than the lower zone because it is divided into two zones: 1) a lower part in which interflow is generated and 2) an upper part in which quick flow is generated (see Figure A.6).

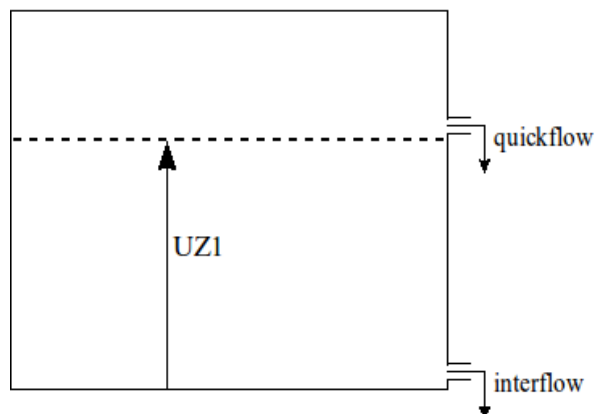


Figure A.6 Schematic view of the upper zone.

If the total water content of the upper zone, V_{UZ} , is lower than a threshold value $UZ1$, the upper zone only generates interflow. On the other hand, if V_{UZ} exceeds $UZ1$, part of the upper zone water will runoff as quick flow:

$$Q_i = K_i * \min \{UZ1; V_{UZ}\}$$

$$Q_q = K_q * \max \{(V_{UZ} - UZ1); 0.0\}$$

Where Q_i is the amount of generated interflow in one time step, Q_q is the amount of generated quick flow in one time step and K_i and K_q are reservoir constants for interflow and quick flow respectively.

The total runoff rate, Q , is equal to the sum of the three different runoff components:

$$Q = Q_{LZ} + Q_i + Q_q$$

The runoff behaviour in the runoff response routine is controlled by two threshold values P_m and $UZ1$ in combination with three reservoir parameters, K_{LZ} , K_i and K_q . In order to represent the differences in delay times between the three runoff components, the reservoir constants have to meet the following requirement:

$$K_{LZ} < K_i < K_q$$

B Running WFLOW in FEWS

The WFLOW model runs in FEWS by opening the tab: "Tools" and then clicking on the "Manual Forecast". You have to choose the workflow: "WFLOW historical". This workflow calls the WFLOW adapter which runs the WFLOW model. The T0 presented in the screen is the end time of the WFLOW simulation. You can edit this yourself. Furthermore you can choose whether you want to run the model for a cold or warm situation by selecting the tab: "Select initial state". By clicking the run button you can start the WFLOW simulation. The result maps and time series are automatically loaded into your FEWS system.

A screenshot of the simulated discharge of WFLOW imported in FEWS at 11-3-2005 is presented in the figure below (Figure B.1).

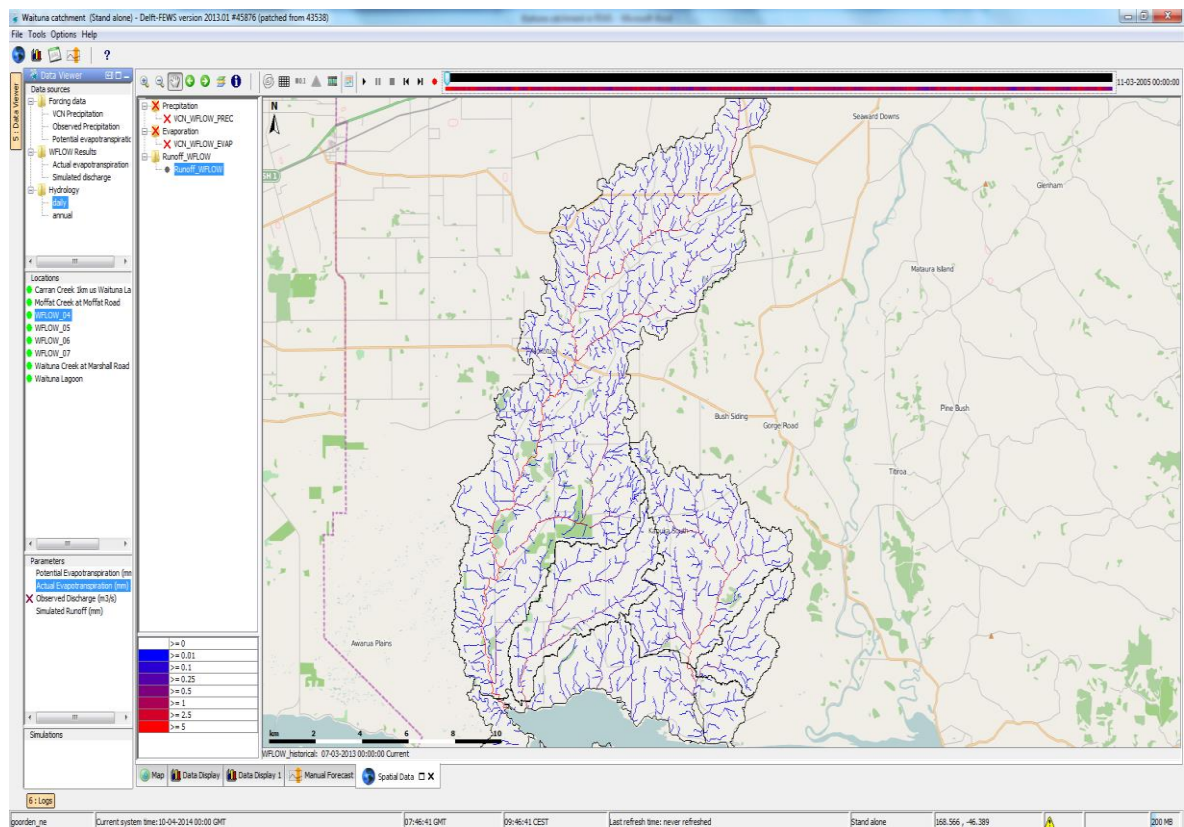


Figure B.1 Example simulated discharge in FEWS for 11-3-2005.

C WFLOW versus WFD Explorer FLOWS

Figure C.1 shows the discharges from the WFLOW model and the WFD Explorer mode for the 2012-2013 dairy year (1 June to 31 May). The observed discharges are also presented in the graph. There is a solid agreement between the WFLOW and WFD Explorer model. In the first period, the WFD Explorer will cover about 95% of the WFLOW flow.

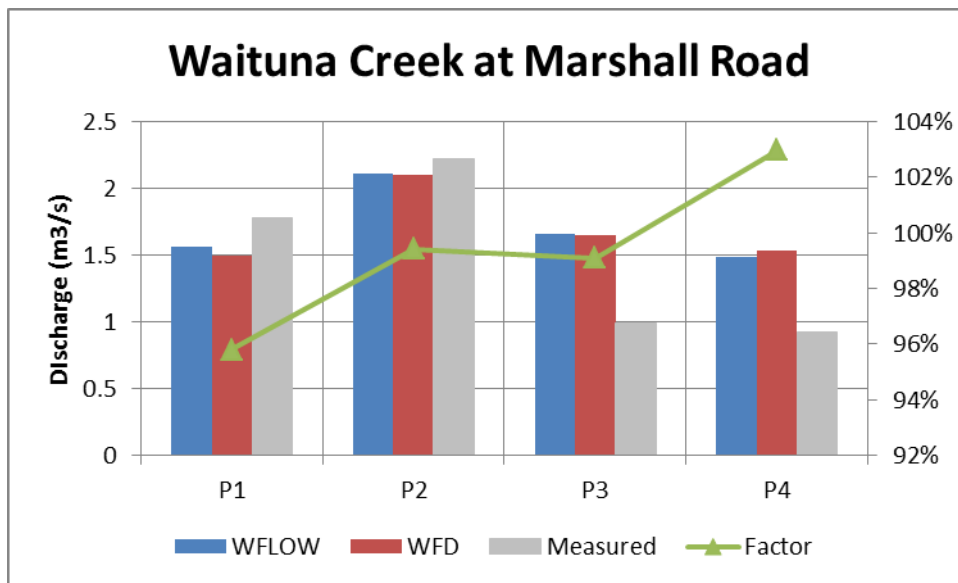


Figure C.1 Discharges at Waituna Creek at Marshall Road.

At the Moffat Creek location the discharges match quite well, although the difference is greater compared with Waituna Creek. The WFD Explorer receives about 90% of the water from WFLOW at this location. The reason is the catchment size, leaving it more vulnerable to mistakes due to sub catchments errors.

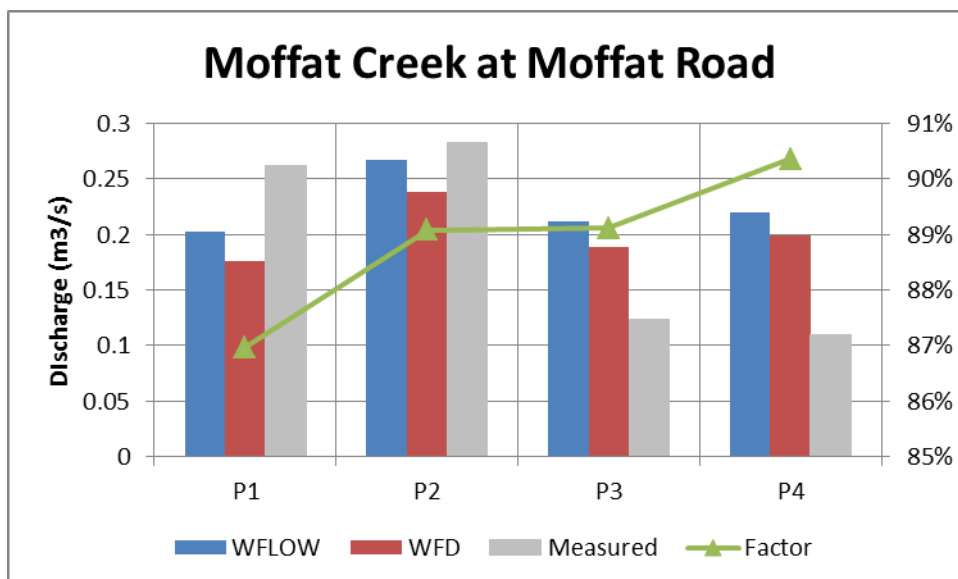


Figure C.2 Discharges at the Moffat Creek at Moffat Road.

For Carran Creek there is a huge mismatch between the WFLOW and WFD Explorer model output.

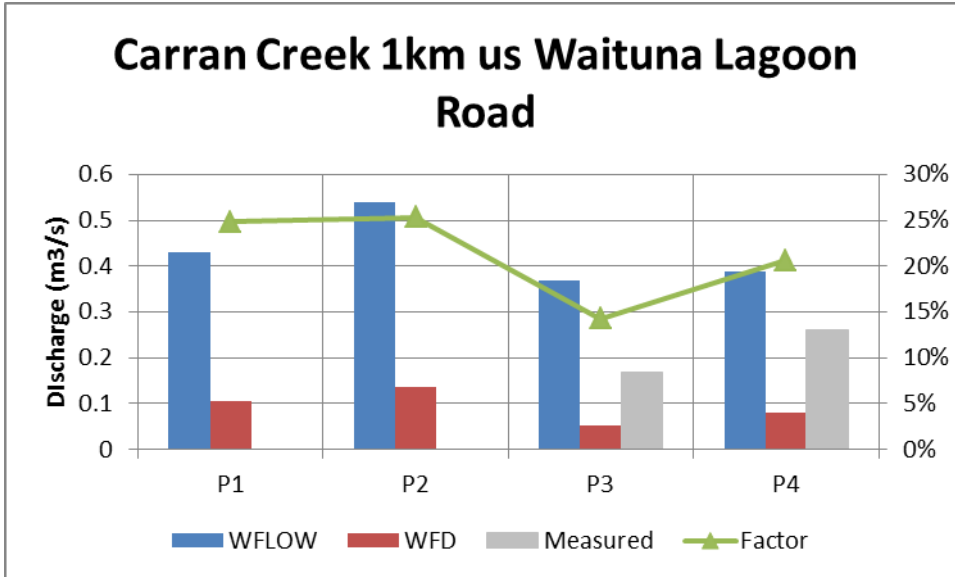


Figure C.3 Discharges at Carran Creek.

D User manual WFD Explorer R-scripts used in the project

For the Waituna WFD-Explorer schematization two R-scrips are available:

- 1 Pre-processing
- 2 Post-processing

Both scripts can be run in R in command line. Required is an installation of R, preferable a version equal or higher than R-3.0.2.

The general workflow of the two scripts is described below.

D.1 Pre-processing

The script can be run by the preprocessing.cmd. Basically, this is a batch file which will run the preprocessing script:

```
set R= "C:\Program Files\R\R-3.0.2\bin\R" --no-restore --no-save
%R% < "R/CreateFilesWFD-E.R" > PreProcessing.log --args Control_WFDEplorer.inp
```

During pre-processing three steps are taken:

- 1 cnWFLOW() → converts WFLOW results to WFD input
- 2 crtLoads(Scenario) → converts loads to WFD input
- 3 combineDifLoads(Scenario) → Combines WFLOW and loads input

The pre-processing part can be visualized as follows. A control file will contain basic settings for the pre-processing phase. The R script will read those files, locations and settings and will prepare WFD Explorer input.

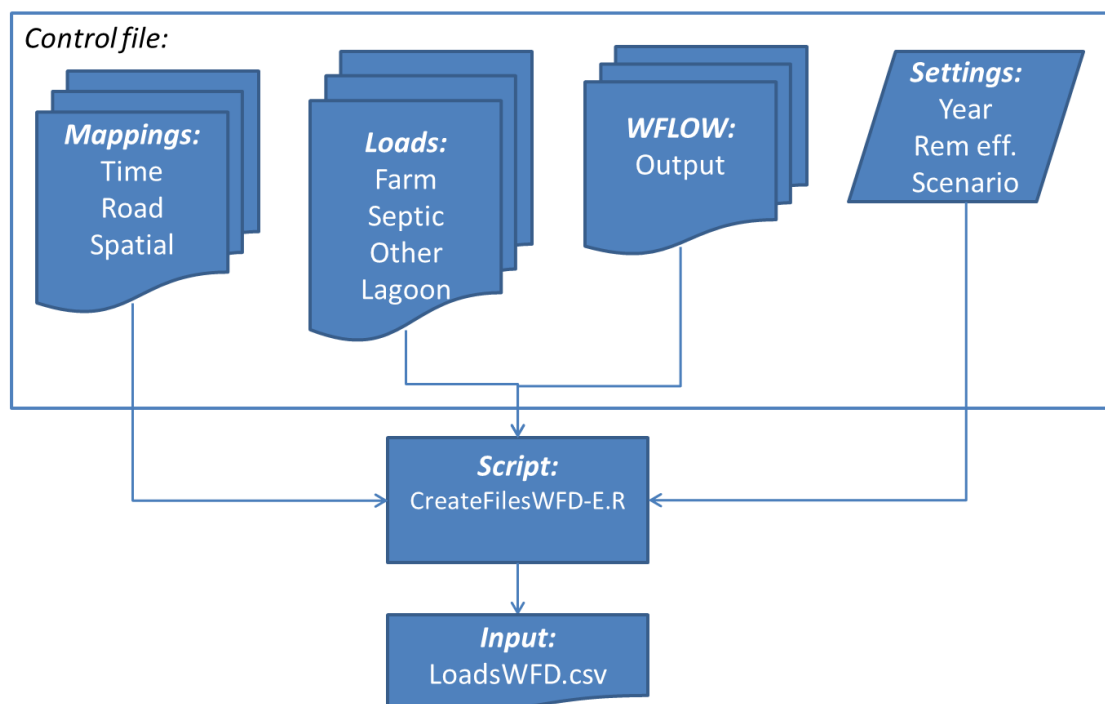


Figure D.1 Structure of the pre-processing script.

D.2 Post-processing

The post-processing procedure can be run in similar way as the pre-processing script.

```
set R= "C:\Program Files\R\R-3.0.2\bin\R" --no-restore --no-save
%R% < "R\CreatePlots.R" > Postprocessing.log --args Control_WFDEplorer.inp
```

During pre-processing three steps are taken:

- 1 combineResults() → will combine N and P exports in one file
- 2 crtConPlots() → will create line plots of concentrations at several locations
- 3 crtLoadPlots() → will create barcharts of loads at several locations

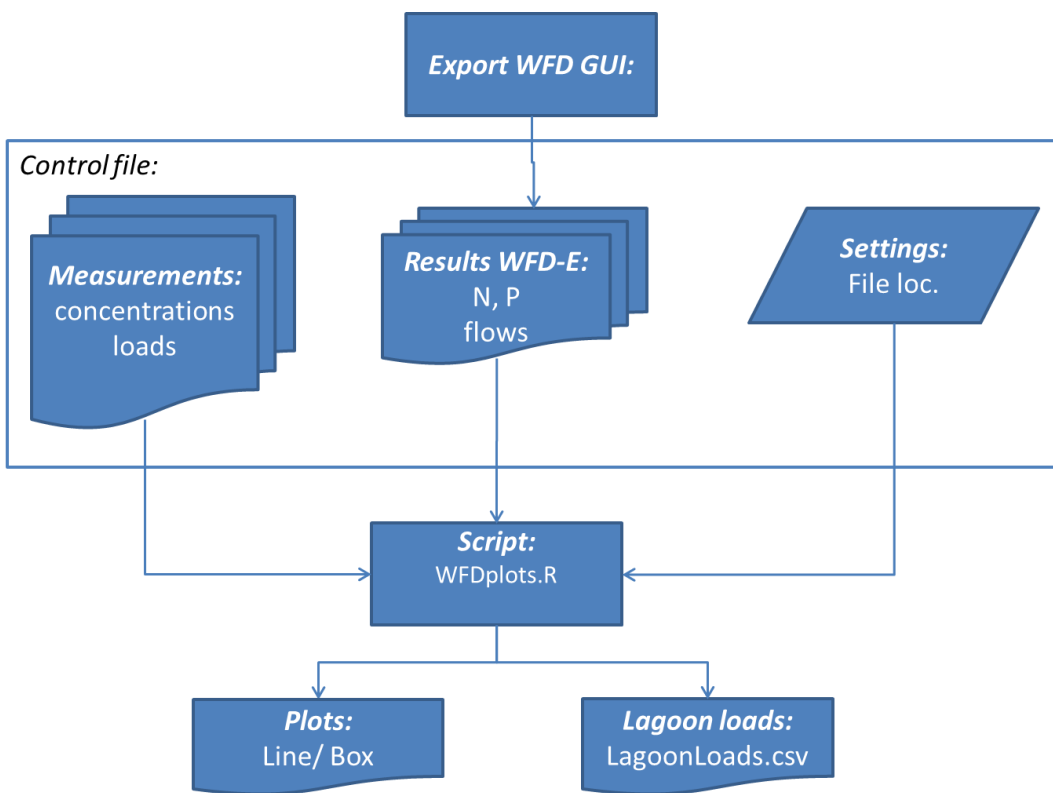


Figure D.2 Structure of the post-processing script.

D.3 Control file

In the control file, all relevant data can be set by the user, such as file locations, removal efficiencies, etc. The contents of the file are presented in Table D.1.

Table D.1 Control file content.

* Controlfile Waituna WFD Explorer model		
* July 2014 Erwin Meijers		
*-----		
* Loads Settings		
*	User definable value	Explanation
*-----		
Year	2012	# WFD-year for loads
fnLoads	Output/loadsWFD.csv	# Output name Loads
OtherLoads	EmissionData/LoadFiles/Otherloads.csv	# Additional loads
FarmLoads	EmissionData/LoadFiles/FarmLoads.csv	# Farm loads
SepticLoads	EmissionData/LoadFiles/Septic.csv	# Septic tank loads
LagoonLoads	EmissionData/LoadFiles/Lagoon_Banks.csv	# Lagoon loads and Bank side erosion
fLRmap	EmissionData/Mapping/Roads_Farms_relation.csv	# Roads Farms relation table
fLTmap	EmissionData/Mapping/T_Farm.csv	# Time mapping loads
LoadsScenario	FALSE	# Loads Scenario (TRUE/FALSE): If TRUE, Farmloads_Sen file is used, ouput
FarmLoads_Sen	EmissionData/LoadFiles/FarmLoads_scenario_nocr op.csv	# Farm loads - scenario
fnLoads_Sen	Output/loadsWFD_sen.csv	# Output name Loads scenario
Rem_eff_N	20	# Removal percentage for all N loads
Rem_eff_P	0	# Removal percentage for all P loads
*-----		
* WFLOW Settings		
*	User definable value	Explanation
*-----		
folWFin	WFLOW/WFLOWfiles/	# Input folder WFLOW
fWFSmap	WFLOW/Mapping/S_mapping.csv	# Spatial mapping
fWFTmap	WFLOW/Mapping/T_mapping.csv	# Time mapping
fWFLOW	WFLOW/Mapping/Wflowfiles.csv	# WFLOW filenames
outpWater	Output/WFDE_water.csv	# Output file
*-----		
* WFD Files		
*	User definable value	Explanation
*-----		
folWFDResults	WFDresults/Input/	
difSources	Output/Dif_loads.csv	# Difuse Sources file
difSources_sen	Output/Dif_loads_scenario.csv	# Difuse Sources Scenario file
fFlows	WFDresults/Input/wbout	# Basic name flows output

fResults	Output/results.csv	# Results file combined WFD Results
folPlots	Output/Plots/	
fFlowMap	WFDresults/Mapping/FlowMap.csv	# Flow mapping file relating WFD flows to measurement locations
fFlowMapLagoon	WFDresults/Mapping/FlowMap2.csv	# Flow mapping file relating WFD flows to Lagoon
fResLoads	WFDresults/Output/ComputedLoads.csv	# Loads Computed by WFD Explorer
fResLagoon	WFDresults/Output/LagoonLoads.csv	# Loads Computed by WFD Explorer to the Lagoon
*-----		
* Measurement Data Files		
*	User definable value	Explanation
*-----		
fMeasMeasurements	MeasurementData/Input/WaitunaRiverWQ3.csv	# Measurements file
fFWMC	MeasurementData/Input/FWMC.csv	# Flow Weighted Mean Concentrations file
fMeasMapping	MeasurementData/Mapping/Sites_mapping2.csv	# Sites Mapping
fDateMapping	WFDresults/Mapping/Date_mapping.csv	# Date mapping with WFD results
fBoxplot	MeasurementData/Mapping/Boxplot.csv	# Date mapping
fLoads	MeasurementData/Input/loads.csv	# Observed Loads on measurement locations

E User manual RTC-Tools

E.1 RTC-Tools optimization implementation for Waituna Lagoon

A RTC-Tools reservoir optimization model has been added to the FEWS New Zealand configuration. To be able to run the RTC-Tools optimization model, the Delft-FEWS configuration has been extended to perform all necessary preparatory steps.

E.1.1 Data import

As a first step, relevant time series are needed in Delft-FEWS. Four time series have been prepared and are imported from CSV files. The data needs to be placed in the following directories:

- \Import\CSV\Evaporation\Evaporation_flow_Daily_WFLOW_08.csv
- \Import\CSV\Lagoonlevel\Lagoonlevel_instantaneous_WFLOW_08.csv
- \Import\CSV\Precipitation\Rainfall_Daily_WFLOW_08.csv
- \Import\CSV\Sealevel\Sealevel_instantaneous_WFLOW_08.csv

The provided time series are daily values, or non-equidistant, instantaneous values. After the import, the time series are interpolated and converted to a regular 10 minute time step. In this module, an initial time series for the target lagoon level is created with a default value of 1.10 m +MSL. However the user can easily edit this target lagoon level within FEWS.

The import can be initiated from the Manual Forecast display (Import gauge-data Waituna) and can be inspected in the Data Display by selecting the right filters in the Data Viewer in the RTC-Tools Waituna Lagoon group (Figure E.1).

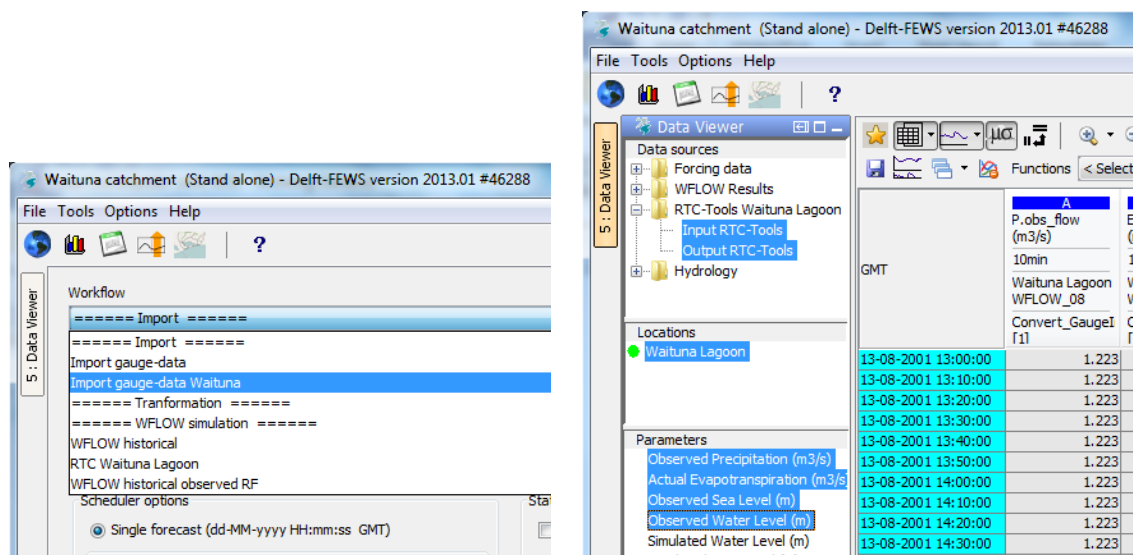



Figure E.1 Screenshot RTC-Tools Data Display.

E.1.2 Target lagoon level

The operator can modify the target (setpoint) time series for the Lagoon Level: In the dataviewer, select RTC-Tools Waituna Lagoon -> Input RTC-Tools with location Waituna Lagoon and parameter "Setpoint Water Level".

Open the table view and press  (Data Editor). The values of the time series identified by the qualifierId “user” and moduleInstanceId “User_Input” can now be modified. When finished, save the changes:

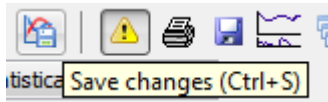


Figure E.2 Screenshot RTC-Tools Save Changes.

Please note that the RTC model has currently be set up to only run for 10 days (-10days – T0). This means that only modified lagoon level setpoint values will be taken into account.

E.1.3 Run RTC Optimization model

In order to run the RTC-Tools optimization, the following input time series have to be available for 10days with respect to T0 (-10days – T0) at the location WFLOW_08:

- Observed Water Level [m] (H.obs)
- Observed Precipitation [m³/s] (P.obs_flow)
- Actual Evapotranspiration [m³/s] (ET.act_flow)
- Observed Sea Level [m] (H.sea.obs)
- Setpoint Water Level [m] (H.req)
- Simulated Discharge [m³/s] (Q.sim)

A T0 that is suitable is e.g. 30-10-2013 00:00:00.

The workflow to run the RTC Optimization can be initiated by selecting “RTC Waituna Lagoon” in the Manual Forecast Display (see Figure E.3).

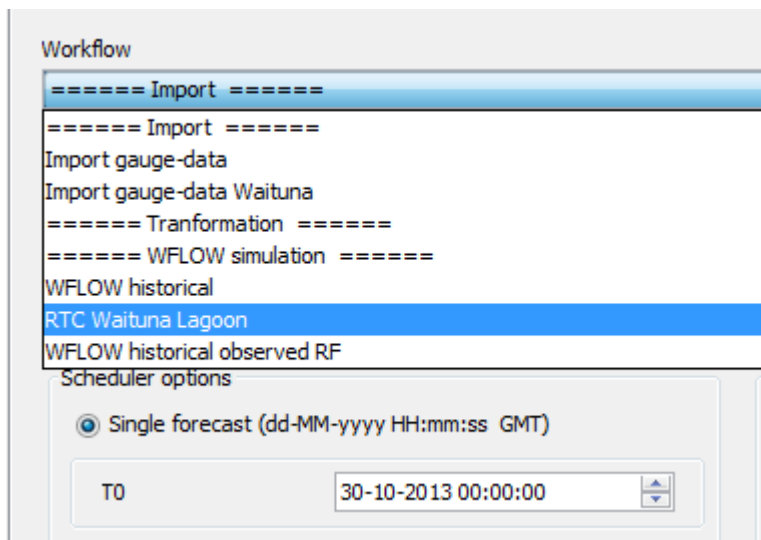


Figure E.3 Screenshot RTC-Tools Manual Forecast Display.

First a preprocessing step takes place, in which the modified lagoon target levels are consolidated and the WFLOW Historical model results are disaggregated and linearly interpolated to a 10 min time step.

After this, the General Adapter exports all necessary time series and state values (e.g. initial lagoon level, which is set to the value of the observed lagoon level at model start time) and the RTC model is run in the following directory:

\\Modules\rtc-tools\Waituna_Lagoon\Optimization\

E.1.4 RTC-Tools Optimization setup

All optimization inputs and results for Waituna Lagoon and the Sea have the locationid WFLOW_08 as a placeholder location. In RTC-Tools, the lagoon and the sea have been modelled as nodes. They are connected by a weir with a flexible crest.

The following modelling principles have been used:

- The RTC model runs at a 10 min time step
- The control action (weir crest movement) should occur every hour
- Inflows into the lagoon are provided by FEWS as 3 flow time series (m^3/s): Evapotranspiration, Rainfall, WFLOW simulation
- A barrier loss (m^3/s , dependent on lagoon level) is not implemented
- A sea level (m MSL) is provided by FEWS
- The model aims maintain the lagoon level at setpoint (user defined time series) by moving the crest height for a weir of 105m wide (min level -1.6m MSL, max level +3.0m MSL)
- Flow over the weir may occur in 2 directions. Flow from sea->lagoon and lagoon->sea affects lagoon level, but sea level is not affected by the flow (the sea level should just be the provided time series)
- A rate of change constraint aims to minimize the crest movements

RTC-Tools outputs, which are imported back into FEWS at 10min time steps are:

- Simulated Discharge to/from Sea [m^3/s] (Q.sim_sea)
- Simulated Lagoon Volume [m^3] (V.sim)
- Simulated Water Level [m] (H.sim)
- Simulated Weir Level [m] H.weir.sim

E.2 Schematic Status Display for the Waituna Lagoon

The Waituna Schematic Status Display (SSD) tab opens automatically when the FEWS system starts, it can be found next to the map tab. Additionally an icon was added which enables the user to open the SSD from the button bar (see Figure E.4).

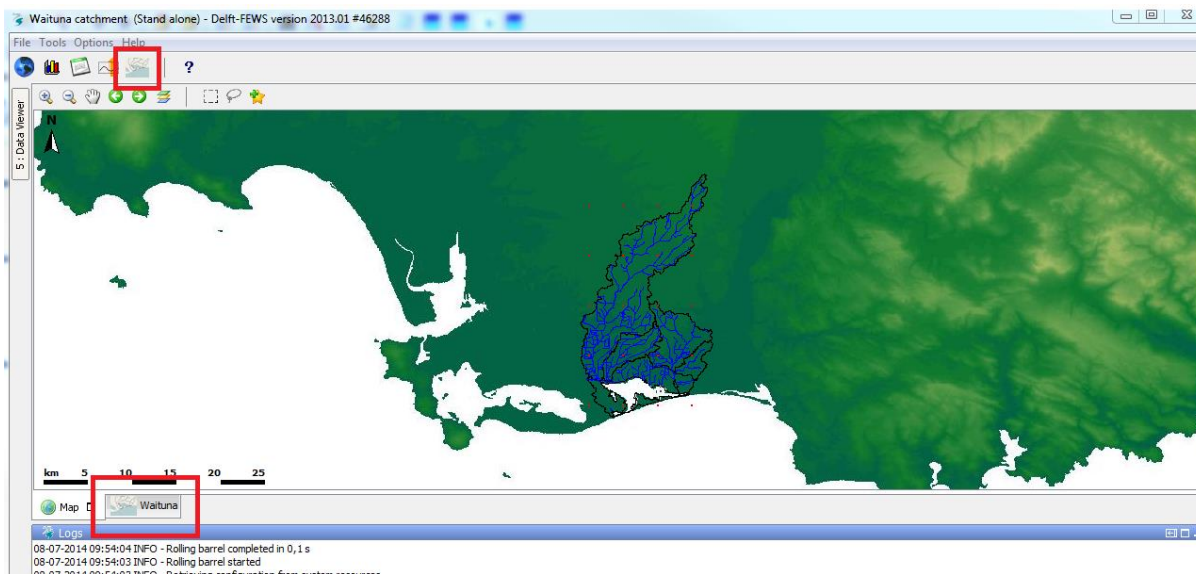


Figure E.4 Screenshot RTC-Tools start screen.

E.2.1 Schematic Status Display Waituna

A Schematic Status Display (SSD) was added to the configuration to present the results from the RTC-Tools reservoir optimization model. In the figure below a screenshot of the SSD screen is given, the meaning of the different objects and colours can be found in the legend.



Figure E.5 Screenshot RTC-Tools Schematic Status Display.

The SSD is based on time series with a time step of 10 minutes. In the SSD map overview (Figure above) only the most recent value of these time series is shown. The following principles have been included in the SSD:

- The water level of the Waituna Lagoon is the simulated (RTC) water level. Clicking on this value results in a graph where both the simulated and the originally observed water levels are shown.
- Clicking on the values and arrows in the SSD results in a graph containing the corresponding time series.
- Clicking on the weir structure (map and side view) results in a graph containing the simulated weir levels. The discharge time series shown next to the weir is always positive, it gives the current discharge in the direction of the arrow.
- The arrows appear when there is a discharge. A green arrow indicates flow towards the Waituna Lagoon; a red arrow indicates flow out of the lagoon (to the sea).
- Additional calculations needed for the values in the water balance are done in the postprocessing module of the RTC_Waituna_Lagoon_Optimization workflow. The water balance is calculated per 10 minutes..
- The side-view of the weir contains the time series of the observed sea level and the (RTC) simulated weir level and Waituna Lagoon level. The 'objects' move within a range using the values from the time series. The range of these objects can be found in the table below:

Table E.1 Range of objects in RTC-Tools for the Waituna Lagoon.

Time series	Minimum (m)	Maximum (m)
Waituna water level (sim)	-1.5	4
Sea water level (obs)	-1.5	4
Weir	-1.5	3

Important:

In the RTC optimization the discharge at WFLOW_08 was used as inflow from the catchment, in the water balance this value is shown. However, in the map the individual discharges for WFLOW_04:WFLOW_07 are shown. The sum of these values is not completely similar to the WFLOW_08 value.

Currently the water balance is incomplete due to missing seepage data. If this time series is added the total outflow and change of storage can be calculated.

E.2.2 Post-processing RTC-Tools module

The post-processing module is added to the workflow RTC_Waituna_Lagoon_Optimization. This module contains transformations for the calculation of the Waituna Lagoon water balance. The result of these transformations is shown in the water balance of the SSD. Additionally the output discharge time series of the RTC model is separated in a time series for discharge to (from the sea) and from the Waituna Lagoon. These time series are used for the discharge arrows in the SSD screen.

Config File:

- ..\Config\ModuleConfigFiles\Postprocess_RTC_Waituna_Lagoon_Optimization.xml

E.2.3 SSD for Waituna Lagoon

Map:

The SSD "map" is a SVG-file which can be found in the ReportImageFiles. In this SVG-file several objects and names have an Id (Note: In the SVG-file the properties can be found by right clicking on an object).

In the XML file Waituna.xml these properties are linked to the corresponding time series.

Config File:

- ..\Config\DisplayConfigFiles\Waituna.xml
- ..\Config\ReportImageFiles\Waituna.svg

Changing colour of arrows:

The arrows in the SSD show the direction of the flow when there is a discharge. The arrows will be green when water flows towards the lake and red when it flows out of the lake. In order to make this possible the following files were added to the configuration.

- ..\Config\TresholdValueSets.xml
- ..\Config\Tresholds.xml
- ..\Config\TresholdWarningLevels.xml