Envirolink Medium advice grant - 1964-MLDC149

Development of a Wairau Aquifer groundwater level forecasting tool

Memo prepared for the Marlborough District Council

Prepared for: Peter Davidson

Written by Dr. Thomas Wöhling

Task 1. Update Wairau Plains Modflow model: extending time series (NIWA-VCS, river, spring flows, groundwater head data, extending the spatially distributed Rushton model and Modflow model inputs.

The MDC provided an extended VCSN data set trough NIWA for the time period ending April 30, 2019. Computer simulations with the previously developed and calibrated Modflow model (Wöhling et al. 2018) were extended until this date. In preparation of the model inputs, the meteorological data was used and downscaled to run the spatially distributed (200x200m grid) land surface model for the entire Wairau Plains area.

Selected outputs of the model such as groundwater levels at key observation locations, Spring Creek flows, river-groundwater exchange fluxes, and the simulated cumulative travel time distribution for Spring Creek water is depicted in the graphs in Appendix A. The comparison with corresponding observations of groundwater levels and rated Spring Creek flows shows a good agreement between the new data and the model simulation, thus confirming the good predictive performance of the calibrated model. Uncertainty estimation around the best-fit model simulations was performed in previous work and was not part of this contract.

Task 2. Setup individual Eigenmodels for wells 3009 and 3821. Model calibration, model evaluation, uncertainty analysis. Test with independent data to assess predictive performance.

The Eigenmodel code was implemented in Matlab and adapted for the specific conditions conditions of the two groundwater wells 3009 (Wratts Rd) and 3821 (Conders 2). The model inputs consist of Wairau River flows derived from the MDC data server (Hilltop), rainfall and potential evapotranspiration for the Wairau Plains as derived from the VCSN and the Marlborough Research Centre, and groundwater abstraction for irrigation as estimated by the distributed land-surface model. The meteorological data are used to run a spatially lumped soil-water balance model for irrigated and non-irrigated land. The river recharge to the aquifer is described as a function of Wairau River flows and determined by fitting a parametric function to the net-exchange flows simulated with the numerical, 3D spatially distributed Modflow model. Uncertainty bounds for this function were estimated too and later used in the Eigenmodel simulations.

The Eigenmodels for the two wells were calibrated using Markov chain Monte Carlo sampling techniques that results in a maximum likelihood (best-fit) solution but also in a posterior distribution describing the parameter uncertainty. The models performed well for the calibration period and for the test with independent data (overall Nash-Sutcliffe Efficiency values >0.85) and uncertainty bounds generally encompassed the observed groundwater levels.

Model forecasts should be developed for the case that the Wairau River is in recession, i.e., that no further rain occurs in the Wairau River catchment. For that purpose, historic flow recession data was analysed and a master flow-recession curve (including uncertainty bounds) was developed. This function is then used for forecasting river flow recession starting from any flow level. Further, no rainfall on the land and historic levels of groundwater abstraction are assumed in the 30-day forecasting period. The model was re-tested on the historic recession data of different magnitude. These hindcasts showed a satisfactory coverage of all events tested. The corresponding simulations are depicted in Appendix B for the summer recession periods between 2012 and 2019.

Task 3. Develop spatial interpolation schemes to derive groundwater storage from groundwater level.

Groundwater storage is related to groundwater levels. The geometry of the hydrogeological layers of the upper Wairau Plain Aquifer has been investigated previously (Wilson, 2017). Using this data together with the Modflow model geometry yields a good estimate of the total storage in the aquifer. Aquifer storage is computed from the groundwater surface computed at each time step by the Modflow model. Aquifer storage can also be computed for each combination of heads measured for the wells 3009 and 3821. A functional relationship between head levels at these two wells and aquifer storage is derived using multiple regression techniques.

Thus, aquifer storage can be computed form groundwater levels. For convenience, storage is represent as deviation from the mean storage of the past decade. An example is given in Appendix C for a hindcast of the summer recession 2018-2019.

Task 4. Integration into a prototype of AquiferWatch tool: development of the program code, the input interfaces, automatic simulation, automatic compilation of results, and visualisation.

AquiferWatch is already fully operational. A modelling platform based on Matlab software has been set up for the model simulations and hosted at the TU Dresden Centre for Information Services. Pre- and postprocessing tools are implemented and a webserver was setup and is now operating at TU Dresden, where the results can be directly accessed 24/7 at the website `http://aquiferwatch.hydro.tu-dresden.de`.

The model simulations are running automatically every day for a forecast period of 30 days (with the assumptions for river flow recession as described above). Results are also updated at the website daily.

The pre-processing tools automatically access and download flow and meteorological data up to the current date off the web (MDC Hilltop Server, Marlborough Research Centre) and assemble the input files for the model simulations. The models are run several 100 times to account for the uncertainty in the master flow-recession curve, the parametric uncertainty of the Eigenmodels and the uncertainty pertaining to the functional relationship between the Wairau River flows and the aquifer recharge rate.

Postprocessing involves mainly the assembling of the model simulations, the computation of uncertainty bands and the visualization of these model results. Corresponding graphics are updated and copied to the webserver where they are available as the updated forecast.

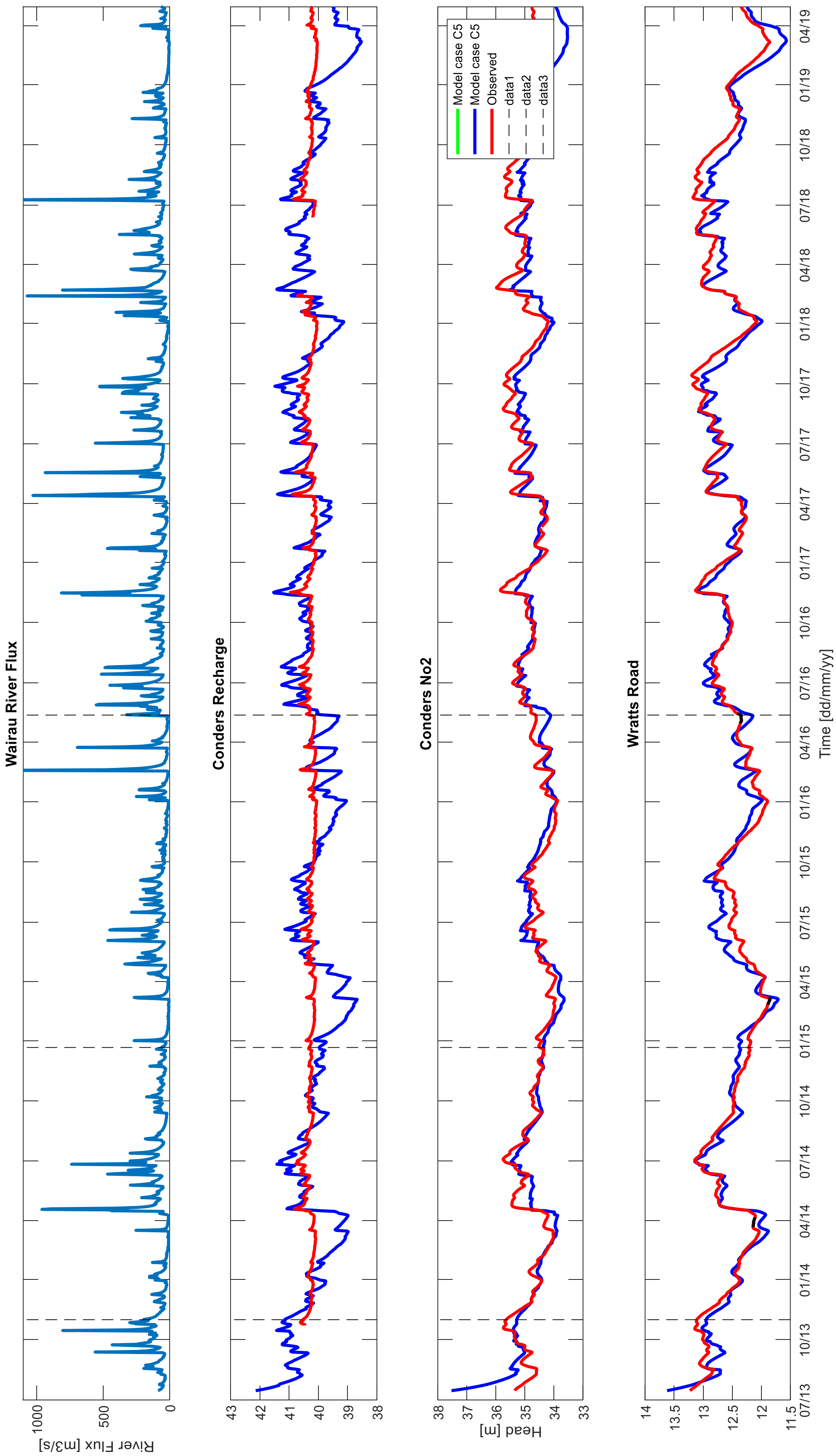
Task 5. Demonstration of the AquiferWatch prototype to LAL and MDC staff.

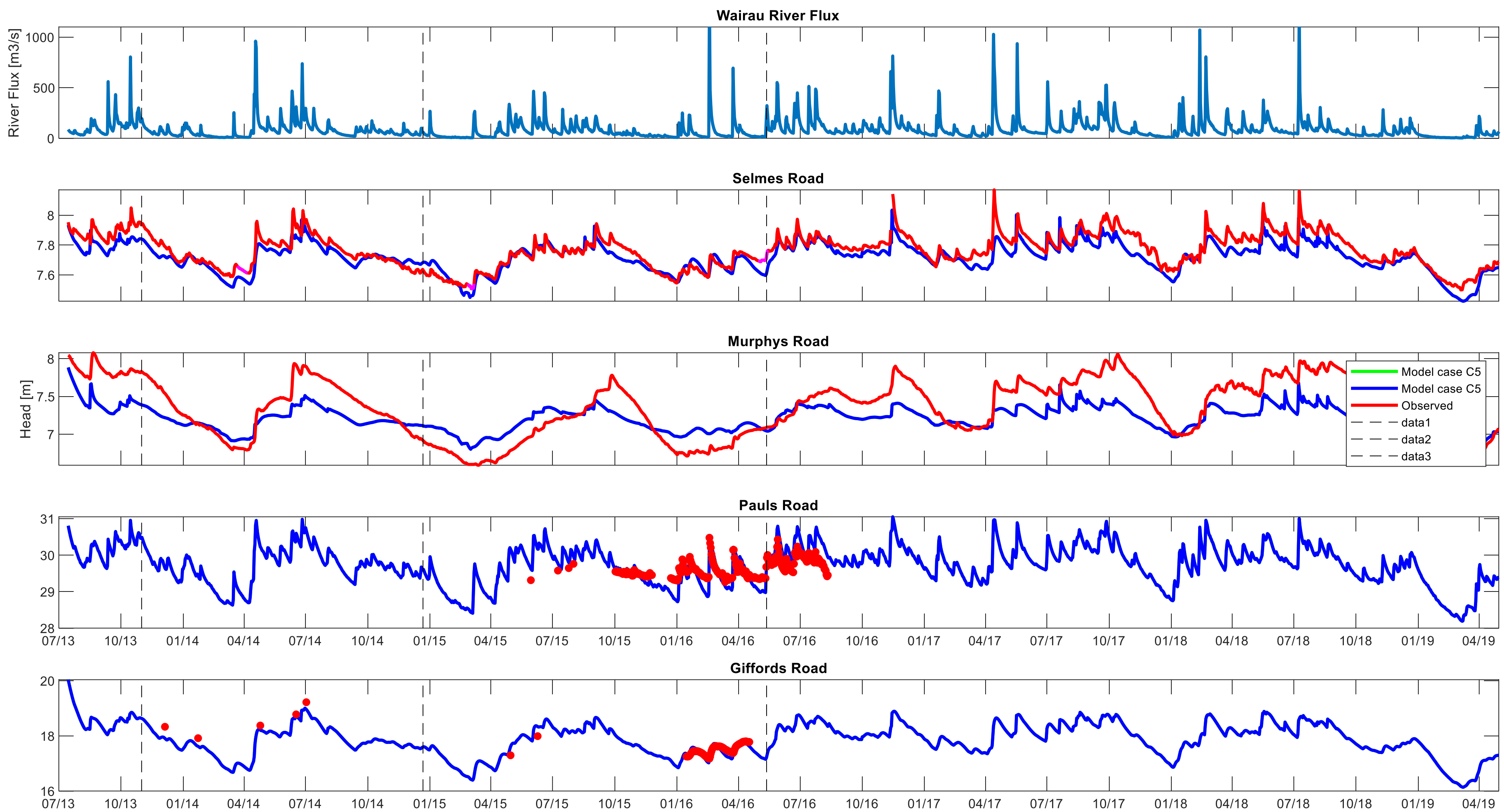
AquiferWatch was presented at the Annual Symposium of the Hydrological Society of New Zealand on 3 Dec 2019 and to MDC staff in Blenheim on 9-10 Dec.

Task 6. Development of the implementation plan.

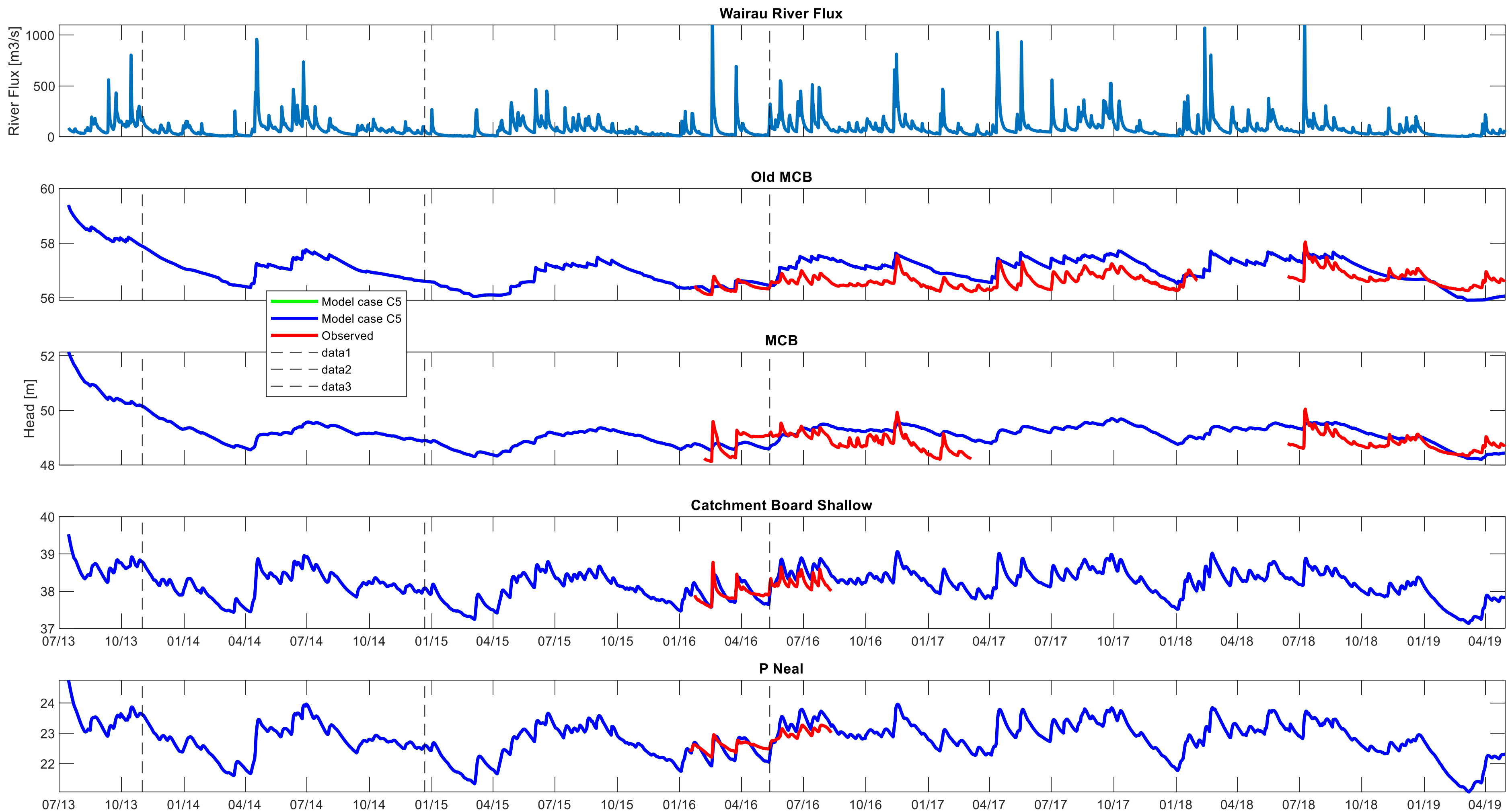
Since AquiferWatch is already fully operational, the implementation is practically completed. The AquiferWatch website can be simply linked to from the MDC websites. This is to be discussed with the MDC IT staff on 9-10 Dec.

Appendix A: extended Modflow Model Simulations

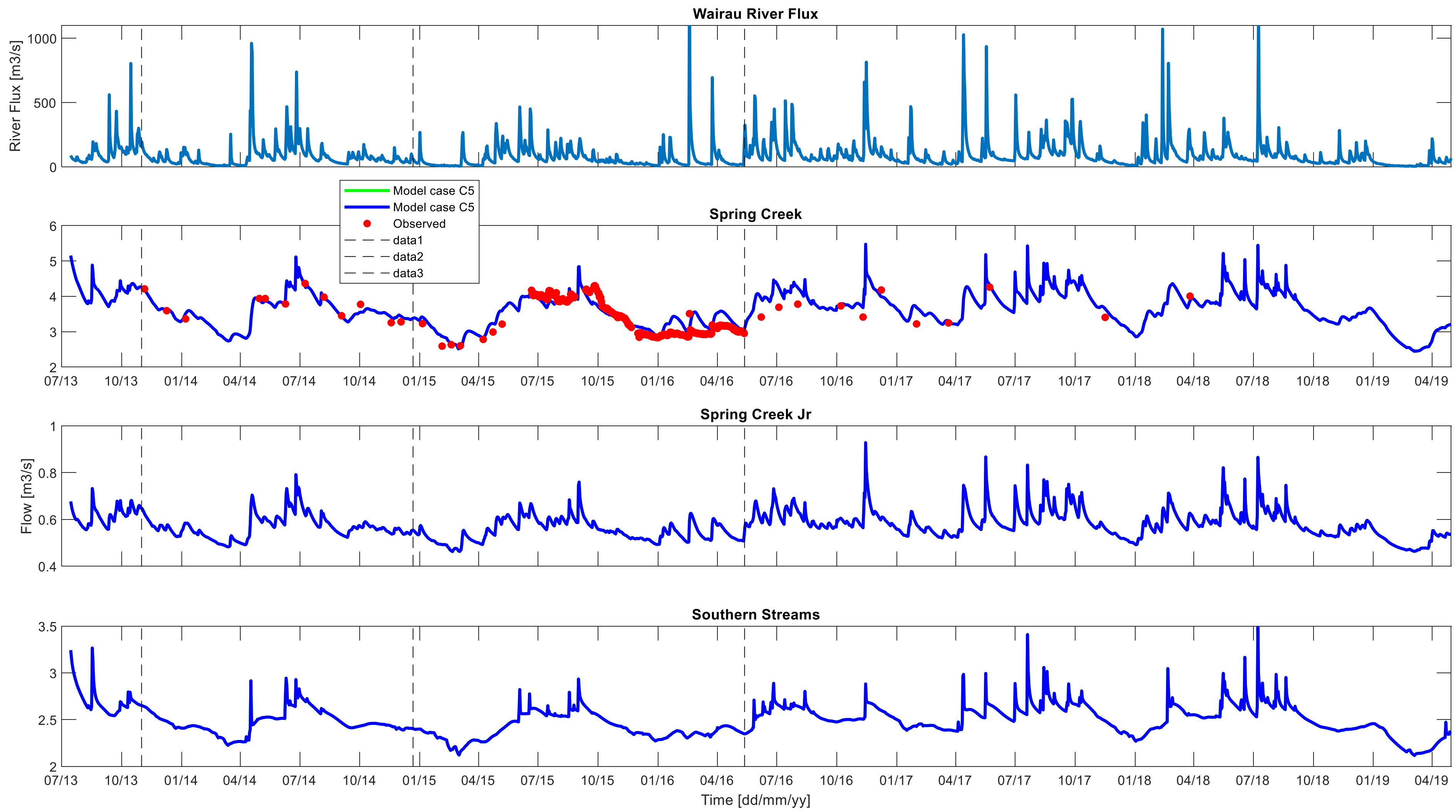




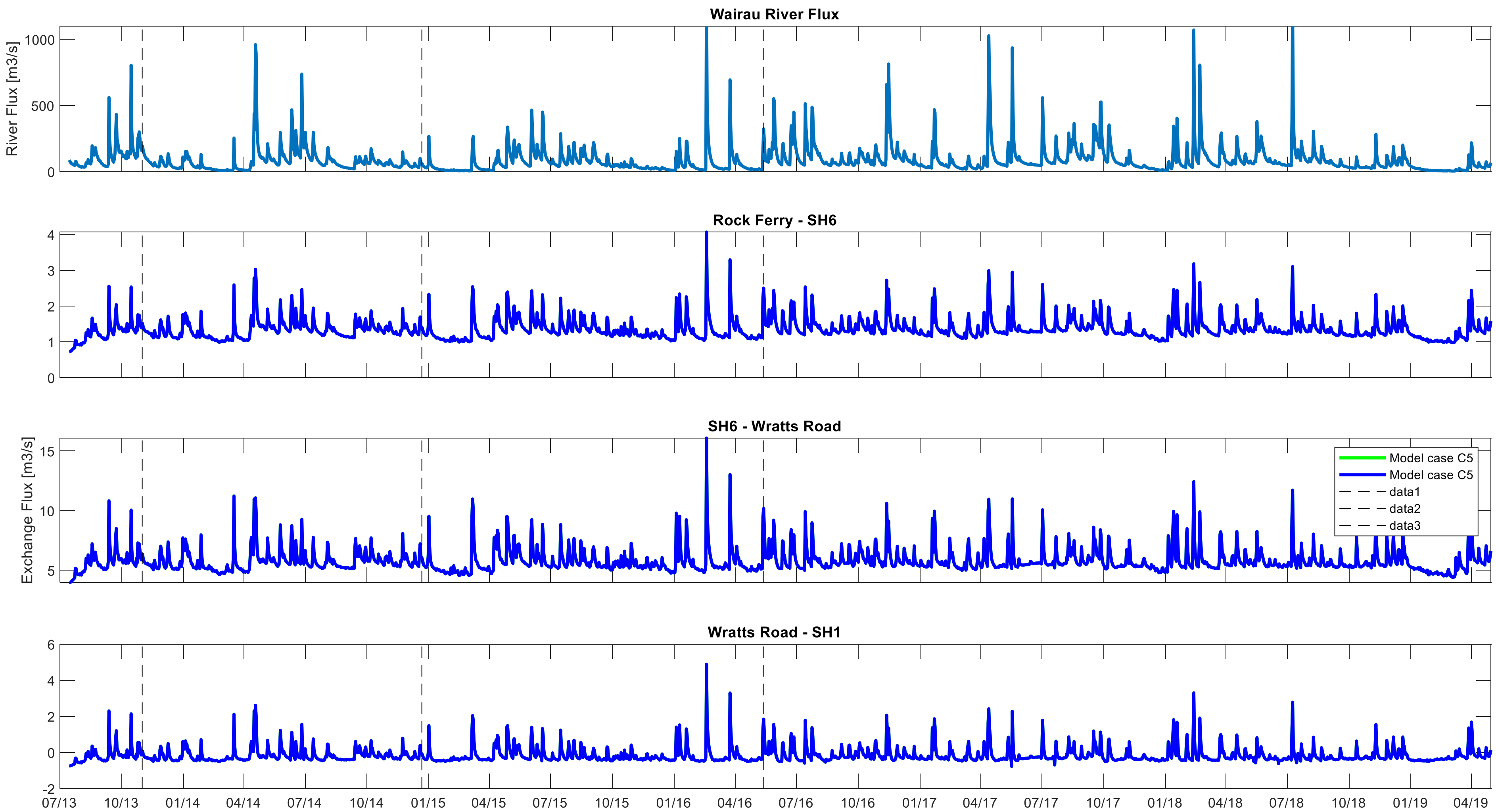
Wairau River Flux
River Flux [m3/s]
1000
500
0
Selmes Road
8
7.8
7.6
Murphys Road
Head [m]
8
7.5
7
Model case C5
Model case C5
Observed
data1
data2
data3
Pauls Road
31
30
29
28
Giffords Road
20
18
16
07/13
10/13
01/14
04/14
07/14
10/14
01/15
04/15
07/15
10/15
01/16
04/16
07/16
10/16
01/17
04/17
07/17
10/17
01/18
04/18
07/18
10/18
01/19
04/19

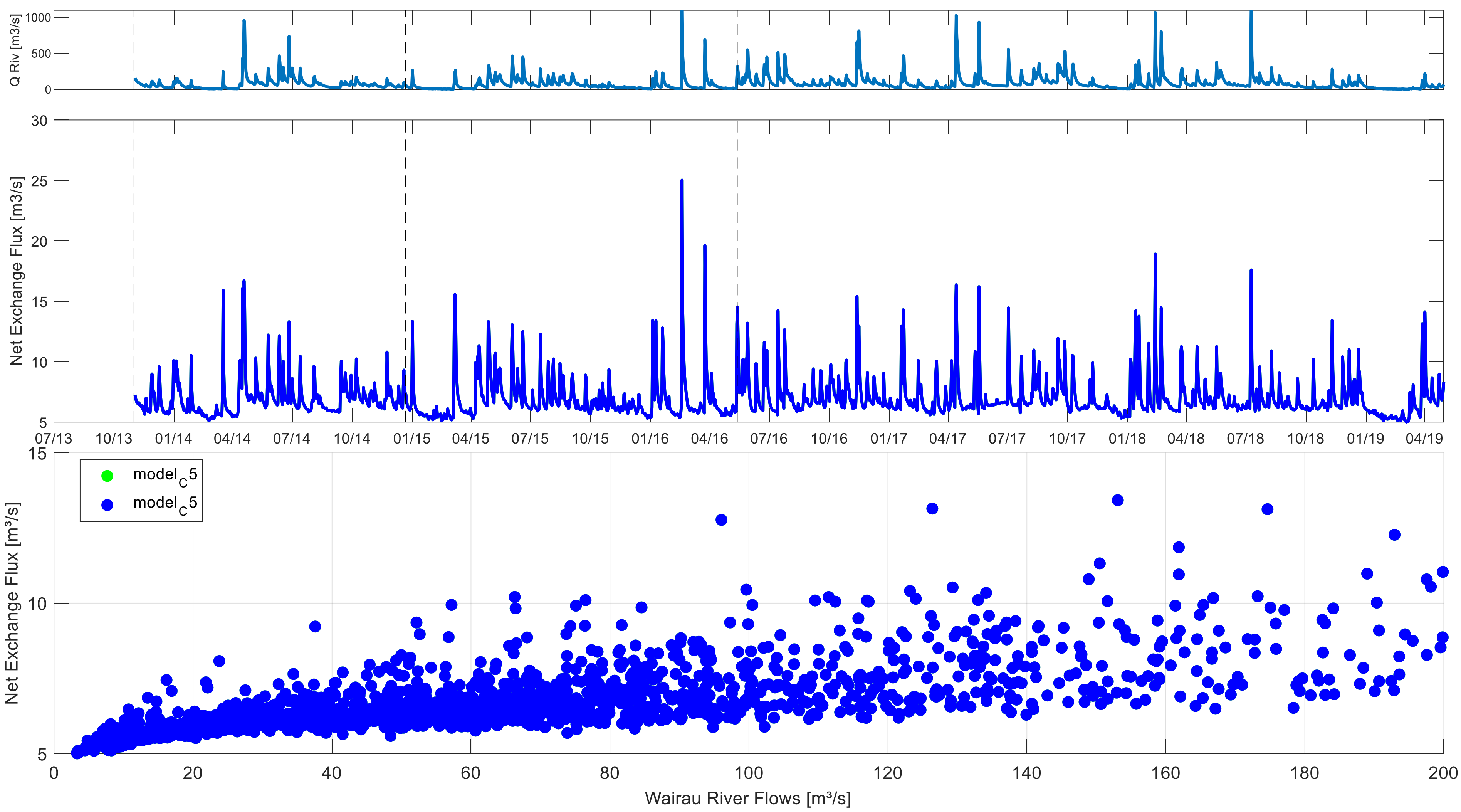


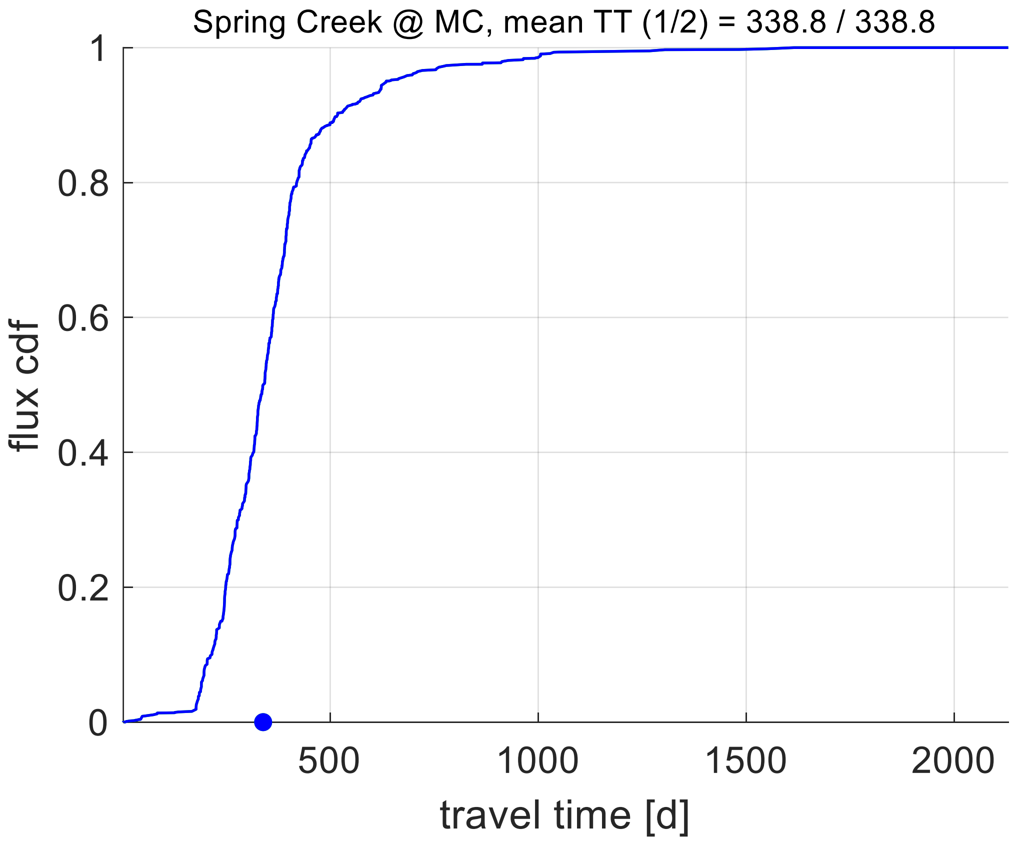
Wairau River Flux
River Flux [m3/s]
Old MCB
MCB
Head [m]
Catchment Board Shallow
P Neal
Model case C5
Model case C5
Observed
data1
data2
data3
07/13
10/13
01/14
04/14
07/14
10/14
01/15
04/15
07/15
10/15
01/16
04/16
07/16
10/16
01/17
04/17
07/17
10/17
01/18
04/18
07/18
10/18
01/19
04/19



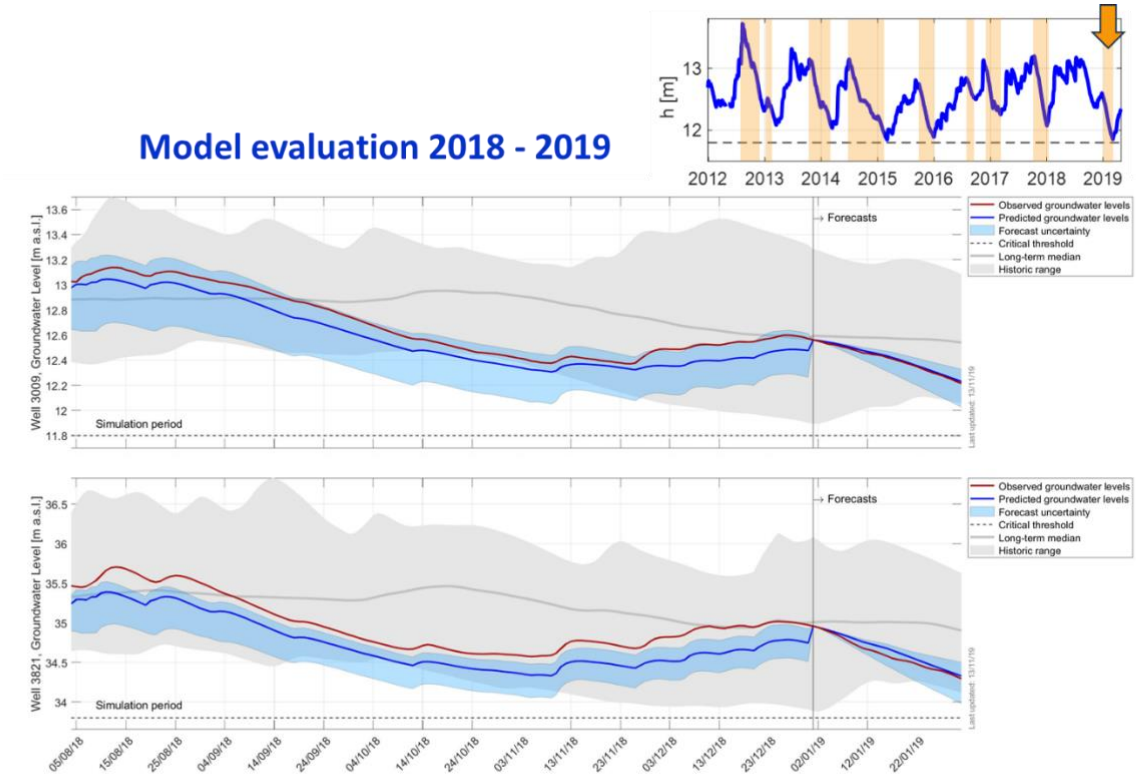
Wairau River Flux
River Flux [m3/s]
Model case C5
Model case C5
Observed
data1
data2
data3
Spring Creek
Spring Creek Jr
Flow [m3/s]
Southern Streams
Time [dd/mm/yy]

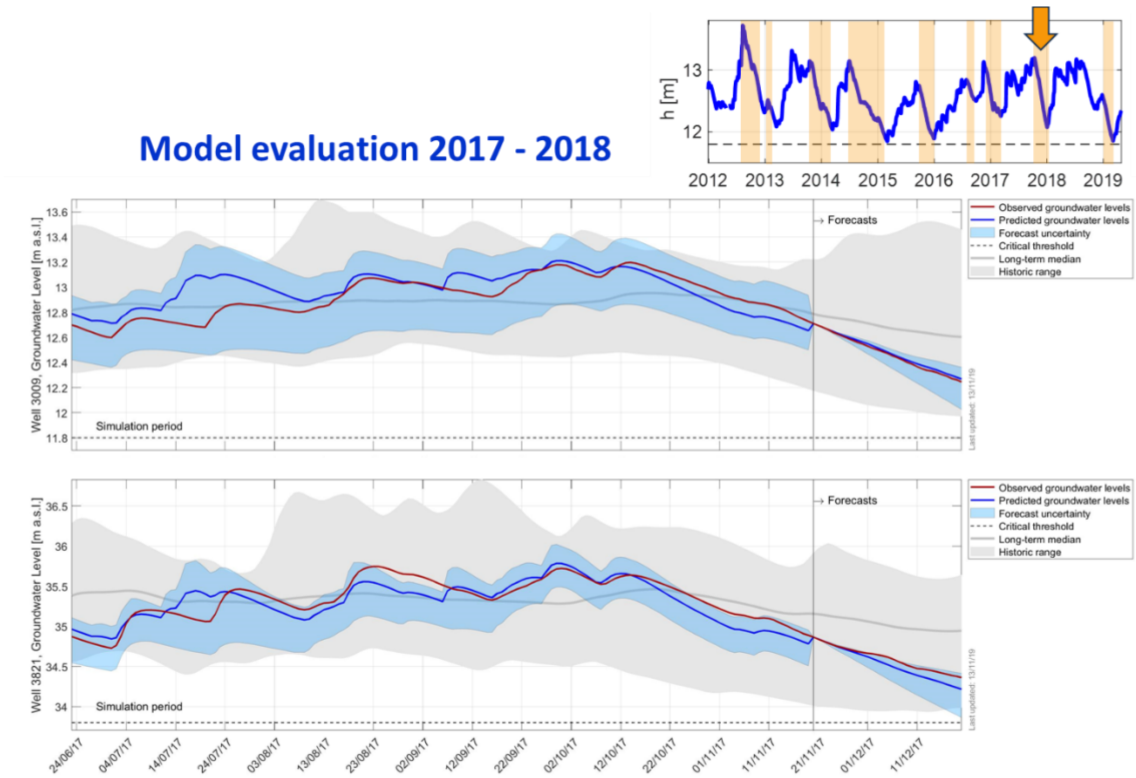

Wairau River Flux
River Flux [m3/s]
Rock Ferry - SH6
SH6 - Wratts Road
Exchange Flux [m3/s]
Model case C5
Model case C5
data1
data2
data3
Wratts Road - SH1
07/13
10/13
01/14
04/14
07/14
10/14
01/15
04/15
07/15
10/15
01/16
04/16
07/16
10/16
01/17
04/17
07/17
10/17
01/18
04/18
07/18
10/18
01/19
04/19


Q Riv [m3/s]
1000
500
0
Net Exchange Flux [m3/s]
30
25
20
15
10
5
07/13
10/13
01/14
04/14
07/14
10/14
01/15
04/15
07/15
10/15
01/16
04/16
07/16
10/16
01/17
04/17
07/17
10/17
01/18
04/18
07/18
10/18
01/19
04/19
model$_C$5
model$_C$5
Net Exchange Flux [m³/s]
15
10
5
0
20
40
60
80
100
120
140
160
180
200
Wairau River Flows [m³/s]

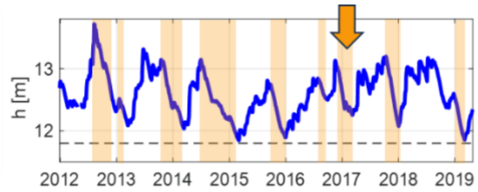

Spring Creek @ MC, mean TT (1/2) = 338.8 / 338.8
1
0.8
0.6
0.4
0.2
0
flux cdf
500
1000
1500
2000
travel time [d]

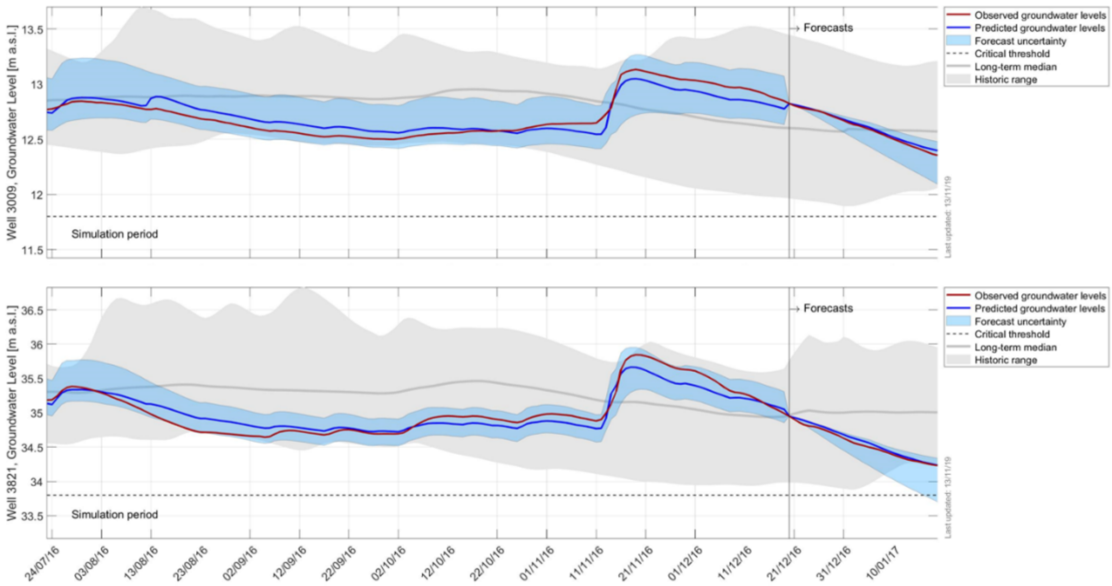
Appendix B: Eigenmodel hindcasts



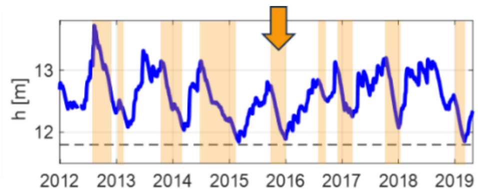


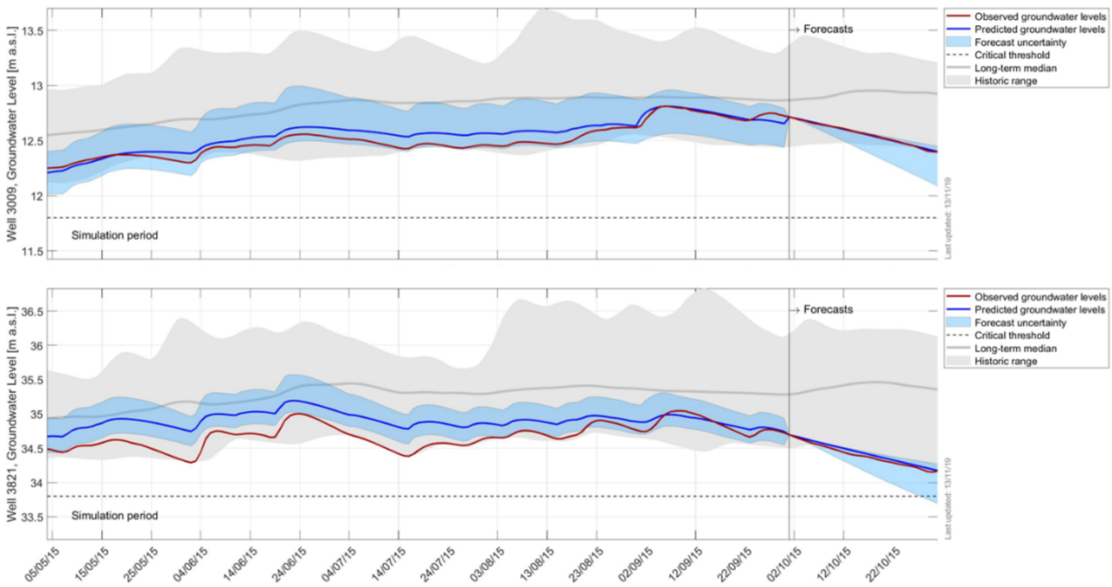
Model evaluation 2016 - 2017



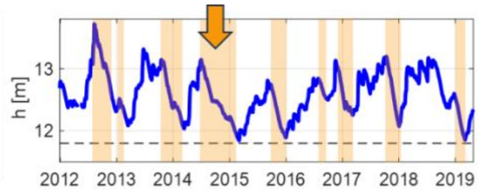


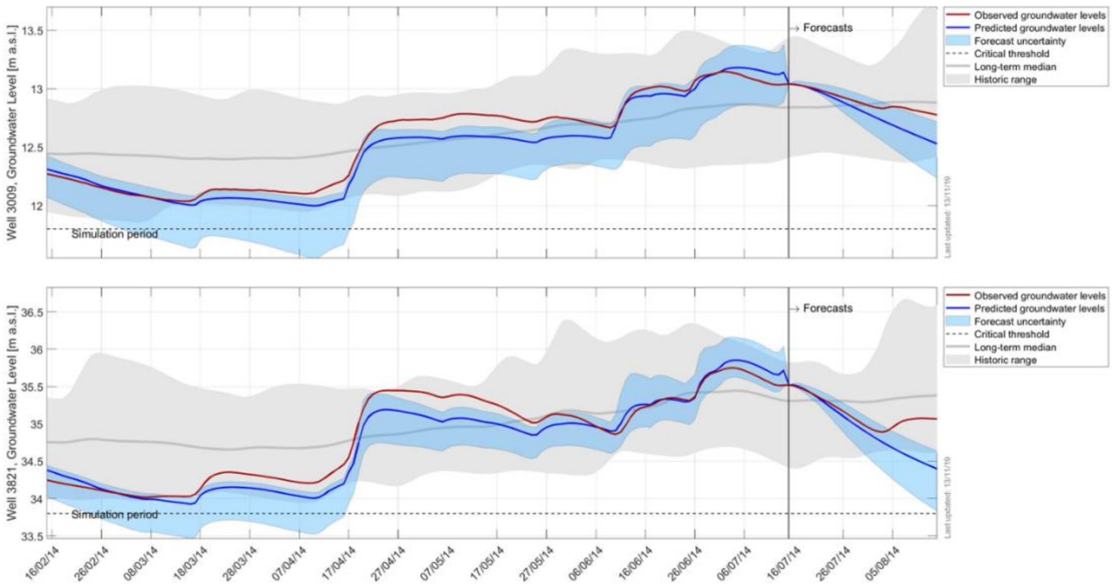
Model evaluation 2015 - 2016



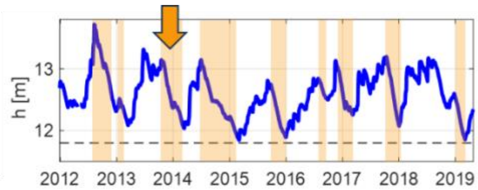


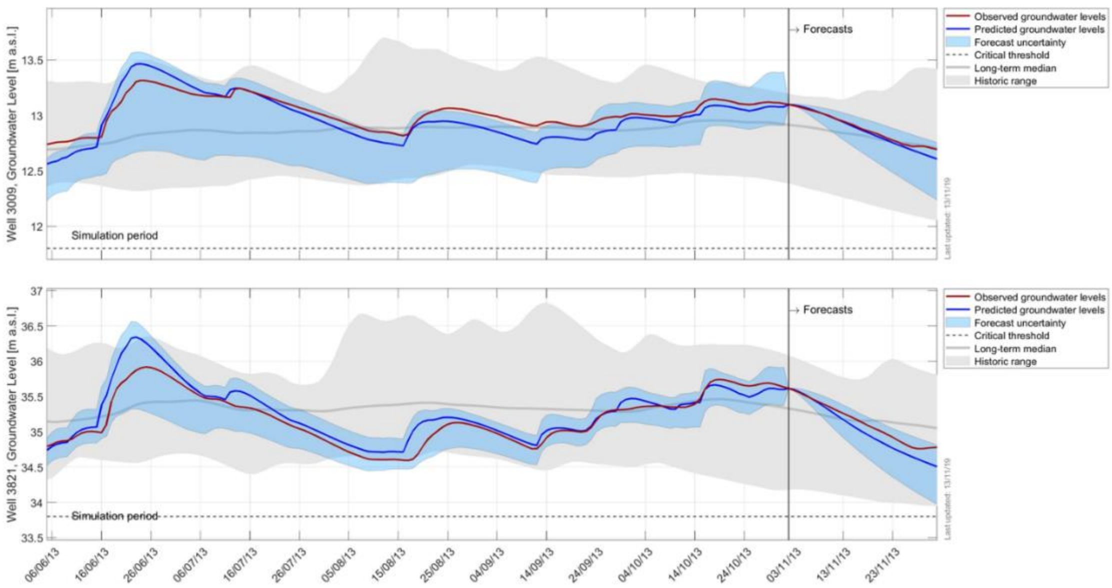
Model evaluation 2014 - 2015

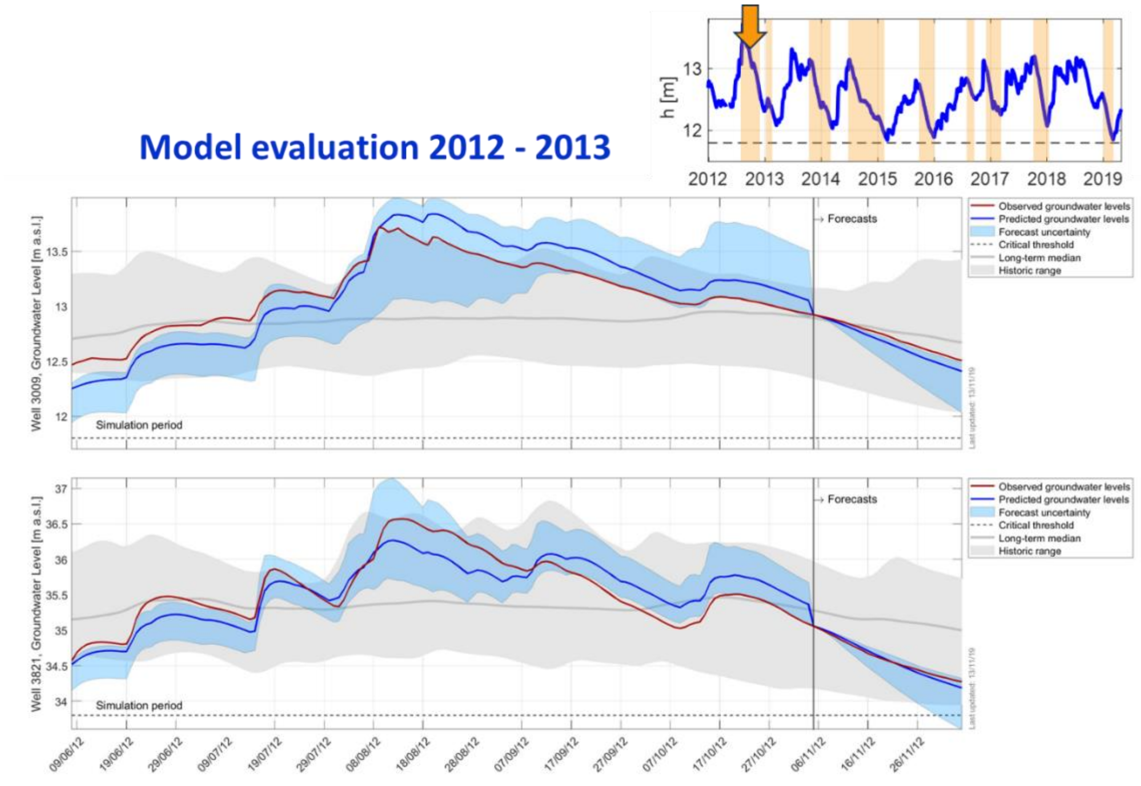




Model evaluation 2013 - 2014







Appendix C: Aquifer Storage Hindcast