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Project: MDC-1

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PROJECT MDC-1: Task 1 - Wairau Aquifer Eigen Model Project

Elemental Geoconsulting Limited (EGC) was asked by Peter Davidson to investigate the relationship between groundwater levels, flows in the Wairau River, flows in Spring Creek, and rainfall-based recharge on the Wairau Plains. The project brief requires the following deliverables:

- a letter report describing the modelling process, shortcomings of the models used, key findings and suggestions for further work;
- a list of reports on applications of eigen modelling of alluvial aquifers in New Zealand;
- a workshop to illustrate the progress of the work;
- copies of computer model files.

This letter report fulfils the first and second deliverables. EGC presented the results at a small workshop in Blenheim on July 6, 2011. Figures referred to later in this report are presented at the rear of this letter. A disc containing the report, all spreadsheets, and additional literature is the vehicle for this report.

Eigen model method

The method dates back to work undertaken by Bidwell et al. (1991). Bidwell (2003, 2010) has refined the method a number of times, producing different eigen models for different purposes. Bidwell (2010) provides the most easily accessible explanation of eigen modelling, followed by Bidwell (2003). The eigen model method uses complex mathematics to 'train' a calculation to achieve a match between predicted and actual groundwater levels (or flows), using a number of variables. The variables used in the modelling include:

- **recharge to the aquifer system** determined from variables such as rainfall, evapotranspiration, soil water holding capacity;

- **aquifer characteristics** such as length, transmissivity, storativity, time taken for groundwater to infiltrate through the vadose zone, the aquifer discharge 'half-life'.

Inputs into the model are: daily rainfall; Penman evapotranspiration; river flow; and groundwater level. The daily time series period available for analysis date from January 1997 to May 2011.

Outputs from the eigen model include: predicted groundwater levels; estimates of mean aquifer transmissivity; storativity; vadose time, aquifer response time; and soil water holding capacity.

Shortcomings of eigen modelling

Unlike Modflow and other proprietary models such as FEFLOW, eigen modelling is not able to produce a three-dimensional model, only a one-dimensional one. This is the dominant shortcoming and is perhaps the major reason why eigen modelling is only useful in certain circumstances, to answer specific questions or to guide further work.

The major shortcoming relative to 3-D numerical groundwater models is in part made up for by the ability to run the model very quickly in a spreadsheet, using very little in the way of data input. Whereas 3-D models require much data input in the form of aquifer characteristics, layer thicknesses, spatially-varying recharge and discharge, eigen modelling is much less demanding. EGC understand that Canterbury Regional Council is using eigen modelling as a calibration tool for their large-scale Modflow modelling (Lee Burbery, Scientist, Lincoln Ventures, personal communication, June 2011).

Bearing in mind that "*essentially all models are wrong but some models are useful*"[1], any model needs to be tailored to the question at hand. In this respect, eigen models are simple to use, are not input hungry, and provide reasonable indications of how systems work, without providing detailed spatial information. Simple questions such as:

- how does change in recharge and, or abstraction affect groundwater levels?
- how does change in recharge and, or abstraction affect aquifer discharge flows?
- how long does it take for an aquifer to respond to a change in conditions?
- how long does it take for an aquifer to lose half its active storage if recharge is cut off (mean residence time)?
- how long does water spend infiltrating through the vadose zone before it reaches the groundwater table?
- what can be said about the typical water holding capacity of the soil?
- what can be said about the typical transmissivity of the aquifer?
- is the rainfall series used in the model appropriate?
- are there other sources of recharge?

[1] Box, G. and N. Draper 1987: *Empirical Model-Building and Response Surfaces*. Wiley. pp. 688, (p. 424)

Some of these questions can be answered from the two types of analysis undertaken for this Task 1 project. The two types of analysis are: plotting of variables against each other; use of EWMA[2] and eigen models.

Relations between Wairau River flow and groundwater level

A smoothed Wairau River daily flow series measured at Tuamarina has been plotted against the four daily groundwater level series (**Table 1**), both as time series, and as correlation plots. A map prepared by MDC, on which the locations of the five wells and the location of the flow recorder at Spring Creek (60125) is **MAP 1**.

Time series plots of Exponential Weighted Smoothing Average (EWMA) smoothed river flow and groundwater level for four of the well data are presented in Figures 1 to 4. The smoothing coefficient, alpha, is varied to produce the best correlation (highest r^2) on plots presented as Figures 5 to 8. Recall that the nearer the smoothing coefficient to unity, the more smoothing. A smoothing coefficient of 1 is equivalent to the arithmetic mean. Smoothing coefficients in the range 0.98 down to 0.75 reflect highly smoothed data down to moderately smoothed data. Highly smoothed data has little decoration related to short-term change, and vice-versa.

In Figures 5 to 8, the Exponential Weighted Smoothing Average (EWMA) smoothing coefficient alpha has been varied in order to produce the best correlation (highest r^2). During the workshop on 6 July 2011, changes to the smoothing coefficient were made, lowering it to 0.85, that is, setting the EWMA rather than requiring a best-fit line to estimate it. This technique produces rather different plots. These plots are described in Table 1 and presented as Figures 9 to 12.

Figures 13 to 16 illustrate the relationships between Wairau River flow, Spring Creek discharge, and groundwater levels in P28w/3009, the nearest well. Again, the Wairau River flows have been smoothed so that they more nearly resemble the frequency of variation characteristic of groundwater levels or spring flows.

Preliminary conclusions based on these simple plots are:

- That there is a moderate to strong correspondence between smoothed daily flows in the Wairau River and groundwater levels, especially at Conders and Wratts, and less so at Jacksons and Wairau Bar, illustrated by the lower correlation coefficients.
- There are daily 'strings' of data reflecting relatively short periods. Analysis has indicated that these strings represent short periods of rising flow, followed by long periods of decline. Three of the wells indicate subtly different rising flow period responses.
- Reducing the EWMA smoothing coefficient to 0.85 produces similar strings of data but also produces an envelope, the base of which is similar in shape to a baseflow plot, showing the relationship between minimum flow and corresponding groundwater levels as flows decline. The base of the envelope may be significant in illustrating how flows in the river 'control' nearby groundwater levels.

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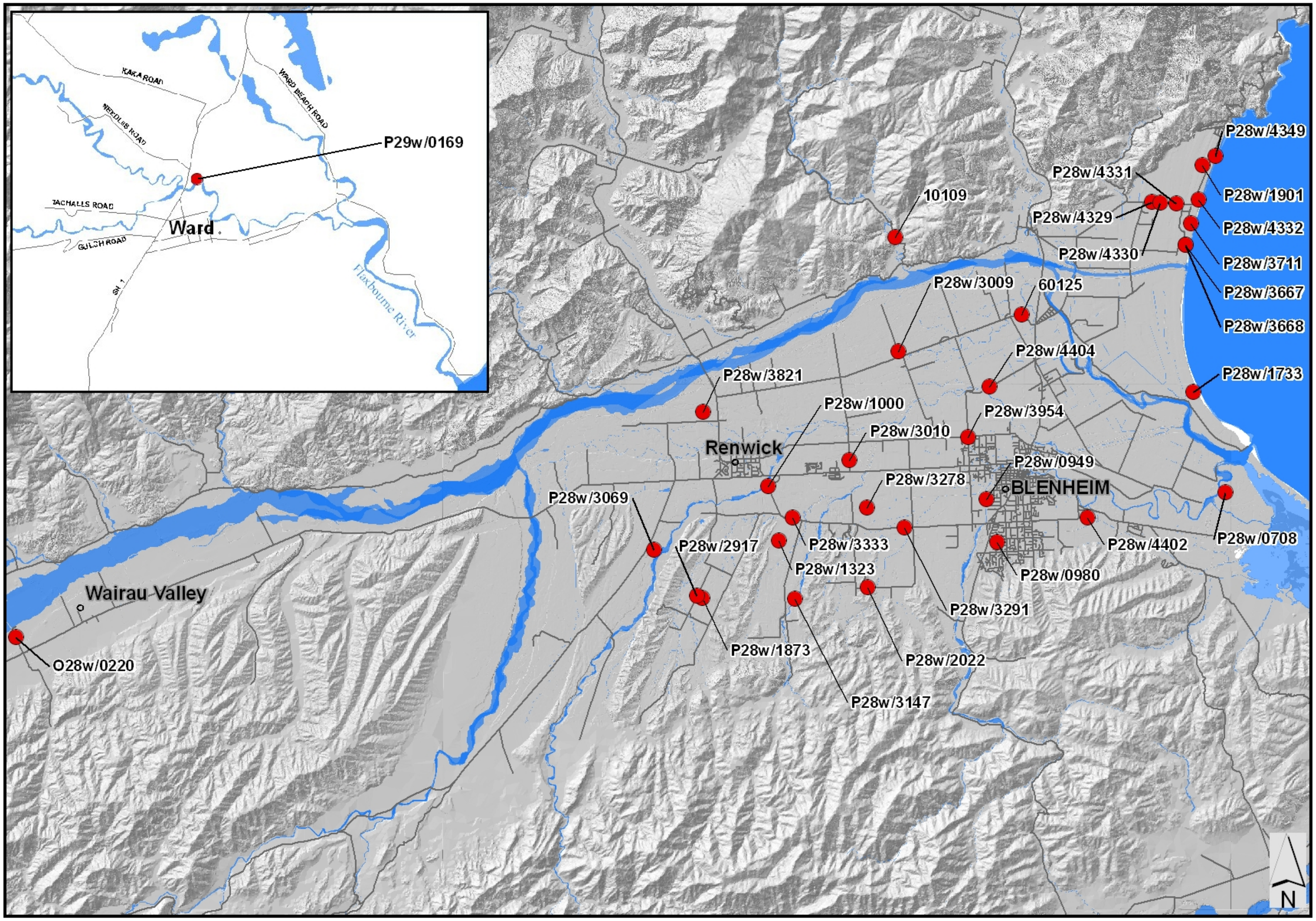
[2] Exponential weighted moving average



MAP 1: Well location map (Source MDC, June 2011)

Table 1: Details of plotted relationships between flows and groundwater levels.

Well or flow recorder	Screen depth (mbgl)	Flow	Figure number	Comments
P28w/0389 - 3821 Conders	20 to 22	Wairau	1	Strong resemblance between smoothed Wairau flow and groundwater level
P28w/3009 Wratts Road	5 to 6	Wairau	2	Strong resemblance between smoothed Wairau flow and groundwater level
P28w/3010 Jacksons Road	12 to 13	Wairau	3	Strong resemblance between smoothed Wairau flow and groundwater level
P28w/1733 Wairau Bar	45 to 50	Wairau	4	Weak resemblance between smoothed Wairau flow and groundwater level
P28w/0389 - 3821 Conders	20 to 22	Wairau	5	EWMA alpha (α) = 0.95, r^2= 0.74, slope higher at higher flows, daily strings of data parallel best-fit line
P28w/3009 Wratts Road	5 to 6	Wairau	6	EWMA alpha (α) = 0.97, r^2= 0.74, slope higher at higher flows daily strings of data parallel best-fit line
P28w/3010 Jacksons Road	12 to 13	Wairau	7	EWMA alpha (α) = 0.98, r^2= 0.63, slope higher at higher flows daily strings of data parallel best-fit line
P28w/1733 Wairau Bar	45 to 50	Wairau	8	EWMA alpha (α) = 0.75, r^2= 0.47, no evidence of daily strings of data possibly due to tidal influence.
P28w/0389 - 3821 Conders	20 to 22	Wairau	9	EWMA alpha (α) = 0.85, r^2= 0.59, slope higher at higher flows, daily strings of data produce an envelope, the base of which may define the locus of baseflow - groundwater level relationship.
P28w/3009 Wratts Road	5 to 6	Wairau	10	EWMA alpha (α) = 0.85, r^2= 0.45, slope higher at higher flows daily strings of data produce an envelope, the base of which may define the locus of baseflow - groundwater level relationship.
P28w/3010 Jacksons Road	12 to 13	Wairau	11	EWMA alpha (α) = 0.85, r^2= 0.26, slope higher at higher flows daily strings of data produce an envelope, the base of which may define the locus of baseflow - groundwater level relationship.
P28w/1733 Wairau Bar	45 to 50	Wairau	12	EWMA alpha (α) = 0.85, r^2= 0.46, no evidence of daily strings of data possibly due to tidal influence.
60125 Spring Creek		Wairau	13	Time series showing the generally poor correlation
60125 Spring Creek		Wairau	14	Poor to moderate correlation at EWMA (α) = 0.96
60125 Spring Creek		Wairau	15	Poor to moderate correlation at EWMA (α) = 0.80; at high flows, groundwater level rises to a maximum
P28w/3009 Wratts Road	5 to 6	Spring Creek	16	Moderate correlation r^2 = 0.68

- There is a poor correspondence between smoothed Wairau River flow and Spring Creek discharge. Use of a lower EWMA smoothing coefficient of 0.85 in Figure 15 indicates more clearly the relationship between spring flow and smoothed Wairau River flow at high flows. The relationship is not linear over the whole range.

- There is a moderate correspondence between flow in Spring Creek and groundwater level at Wratts Road. Note that at high groundwater levels, increases in level become less as flows continue to increase.

Physical explanations relating to these conclusions include the following:

- The moderate to strong correspondence between flows in the Wairau River and groundwater levels, especially at Conders and Wratts, less so at Jacksons and Wairau Bar is largely a function of proximity to the river but is complicated by other issues as will be described.

    - Wells relatively close to the river (Conders ~1 km; Wratts ~3 km) would be expected to show a good correspondence with smoothed flow, their water levels are only just below those in the river (this has been estimated only, not been verified with survey data).

    - The Jacksons Road well, 5 km from the river, also exhibits groundwater levels lower than those in the river. The Jacksons Road well is located in the Woodbourne sector, drilled into sedimentary strata perhaps derived from the Southern Valleys, possibly older and less permeable than the Wairau gravels, and from the poor prediction of high groundwater levels appear less directly linked with the river and may instead be recharged to a degree from the Omaka River.

    - The 50 m deep well at Wairau Bar is distant from the Wairau River, located in the coastal Wairau Plain aquifer consisting of confined strata, with strongly artesian pressures. There are no daily 'strings' of data, perhaps also due to the tidal influence.

- Preliminary analysis indicates that the strings of data are different for the three wells. Conders End and Wratts Road show initial short-term rises in groundwater level followed by gradual decline. Wratts and Jacksons are further away from the river than Conders and show less immediate groundwater level increase.

- Reducing the smoothing coefficient indicates that an envelope is evident, the base of which mimics a baseflow decay curve in shape. It is possible that the base of the envelope is an indication of the groundwater level supported by a minimum smoothed flow.

- The poor correspondence between smoothed Wairau River flow (alpha = 0.96) and Spring Creek discharge is an indicator that there are other variables, such as rainfall recharge and groundwater abstraction that control the flow in the creek. At high flows, the flow in Spring Creek seems to reach a maximum. This is more evident when the smoothing coefficient of flows in the Wairau River is reduced to 0.8.

- The moderate correspondence between flow in Spring Creek and groundwater level in the shallow well at Wratts Road is expected as a result of their proximity, and that groundwater pressures usually display a linear relationship between local groundwater pressure and the magnitude of flow in spring-dependent streams such as Spring Creek. Above a high groundwater level, increase in discharge occurs seemingly without increase in level.

Model results

The eigen model software produced by Vince Bidwell (Lincoln Ventures, now retired) contains two modelling outputs:

- an EWMA model; and
- an eigen model.

The differences between these two models are slight in terms of inputs but produce significantly different outputs (**Table 2**):

- The EWMA model does not attempt to calculate transmissivity and other aquifer physical parameters, it simply matches groundwater levels with recharge that it has calculated from rainfall and Penman evaporation. Rainfall recharge, actual evapotranspiration (AET) and soil water holding capacity are calculated by the model.

- The eigen model attempts to match groundwater levels with all forms of recharge, but in this modelling, only by using calculated dryland rainfall land surface recharge. The eigen model, can, if given sufficient input data, also account for river-sourced recharge, irrigated area, and groundwater abstraction. Calibrating the model allows estimation of aquifer properties and is undertaken using the output from the EWMA model. In Task 1, only rainfall recharge has been accounted for. In the models produced so far, any river recharge is treated as an underlying constant value that maintains groundwater levels at a higher level than they would be in the absence of river recharge. This approach is justified in Bidwell (2010).

The results of the two types of models are presented in Table 2 and as a series of time series plots the results of which are referred to and described in Table 2. The results of both types of models allow the following conclusions, regarding the relationship between groundwater levels and calculated rainfall recharge, may be drawn for each of the four wells:

- **Conders End well P28w/3821**: EWMA and eigen models illustrate a good correlation between groundwater level and rainfall recharge except when groundwater level drops below 35 m RL. Quite a few monitored groundwater level peaks have not been adequately predicted, perhaps they relate to river recharge events. This plot indicates that groundwater abstraction is evident.

Table 2: Details of EWMA model and eigen model results.

Well	EWMA model	Eigen model	Figure number	Water holding capacity (mm)	Mean residence time (days)	Alpha	Transmissivity (m^2/day)	Tv: time in vadose zone (month)	Mean AET (mm/year)	Mean rainfall recharge (mm/year)	Nash-Sutcliffe error
P28w/0389 - 3821 Conders	√		17	24	10	0.90	-	-	334	284	0.64
P28w/0389 - 3821 Conders		√	18	19	53	-	1011	1	317	289	0.67
P28w/3009 Wratts Rd	√		19	25	10	0.90	-	-	339	277	0.64
P28w/3009 Wratts Rd		√	20	58	63	-	1192	1	404	180	0.71
P28w/3010 Jacksons	√		21	16	96	0.90	-	-	300	319	0.69
P28w/3010 Jacksons		√	22	49	77	-	645	1	391	137	0.77
P28w/1733 Wairau Bar	√		23	19	10	0.90	-	-	315	267	0.51
P28w/1733 Wairau Bar		√	24	20	31	-	6	1	321	95	0.56
P28w/1901 Rarangi	√		25	20	10	0.90	-	-	355	263	0.70
P28w/1901 Rarangi		√	26	60	69	-	219	1	405	202	0.82

- **Wratts Road well P28w/3009**: EWMA and eigen models illustrate a good correlation except when groundwater level drops below 12.5 m RL. A few peaks not well predicted, perhaps they relate to river recharge events. Groundwater abstraction also evident.

- **Jacksons Road well P28w/3010**: EWMA and eigen models illustrate a good correlation except when groundwater level drops below 12.5 m RL. There are some peaks not recognised in the predicted series, perhaps these poorly-predicted peaks relate to Wairau and Omaka river recharge events. Groundwater abstraction also evident.

- **Wairau Bar well P28w/1733**: EWMA and eigen models illustrate poor correlation with both peaks and troughs, especially when groundwater level drops below 2.8 m RL. Few peaks reliably predicted, perhaps relate to tidal effects. Groundwater abstraction also evident.

- **Rarangi coastal well P28w/1901**: EWMA and eigen models; a good correlation except for peaks and troughs. Groundwater abstraction evident and perhaps higher rainfall locally in the Rarangi area, not picked up in the rainfall data used for the modelling.

The Nash-Sutcliffe error values or scores, calculated by the models are low (0 is no correlation; 1 is perfect correlation) reflecting poor to moderate models rather than good models. This may mean that the predictions cannot be ascribed to rainfall recharge alone, there may well be other sources of recharge such as derived from the Omaka River and Wairau River. In addition, groundwater abstraction, especially if it occurs progressively through the time series, would also reduce the error score. At the workshop it was learnt that some freshes in the Wairau River, that augmented groundwater levels adjacent to the river, are not apparent in the model because they were not complemented by local rainfall.

The following comments may be made:

- Calculated mean AET ranges derived from the Conders End, Wratts Road and Rarangi wells are in the range 300 to 400 mm/year, between a half and a third of the Penman data from which it is derived. The evapotranspiration AET value reflects the crop type, dominantly grapes. AET ranges derived from the two models for Jacksons, Wratts and Rarangi should be treated with caution based on the large differences between AET derived from the EWMA and eigen models.

- Similarly, where there is a significant difference between the calculated rainfall recharge derived from the two models, the recharge values should be treated with caution. Values lower than 200 mm/year are suspect and may be caused by the aquifer being partially or fully confined and, therefore, not able to respond quickly to rainfall events. In general, about a third to a half of rainfall forms recharge to the groundwater system.

- Calculated transmissivities are generally too low at all wells. This may be because the conceptual aquifer is not ideal for the model used. In the Wairau aquifer, the discharge streams such as Spring Creek, are located far from the termination of the aquifer, beyond the coastline. Potential exists for changing some of the initial dimensions of the model system that may produce more reasonable calculated aquifer characteristics.

- Calculated water holding capacities are generally low, reflecting the gravel soils. Values derived from Jacksons Road are lower than is thought reasonable. The corresponding T_v or time taken for recharge to travel down through the vadose zone is fast and has been set as one month to ease the calibration burden, after undertaking some initial experiments. This result is consistent with the geology and with experience in light gravel soils in Canterbury.

- Calculated rainfall recharge relates reasonably with groundwater level in the Conders End and Wratts Road models. Modelling of the other three wells indicates issues that may relate to recharge other than from rainfall (e.g. Omaka River flow), confined and tidal aquifer characteristics (Wairau Bar), or a different rainfall environment (Rarangi).

- Rarangi zone modelling using P28w/1901 indicates a good fit, though some rainfall peaks are not seen by the model when using the rainfall series. Furthermore, abstraction is very evident in this model.

Key findings from the modelling

1. Simple plotting of smoothed flows against groundwater levels indicates that the Wairau River and the neighbouring groundwater levels have a moderate to high correspondence, depending on the location of the wells used. It should be recognised that this apparent correlation need not be causative. Both the river and the groundwater systems through which it is flowing may be responding to similar climatic signals. This caution is evident from the occasional peaks in groundwater that are unrelated to recharge.

2. The model observation that some groundwater levels respond strongly to rainfall recharge means that at least in some areas, rainfall recharge dominates the cause of the groundwater variability. Recharge from the river is likely to bolster the groundwater levels, stopping them from declining under low recharge conditions, as is likely shown by the 0.8 EWMA smoothed plots. The observation that the rainfall recharge eigen model cannot account for low groundwater levels may be taken to be consistent with the conclusion that recharge derived from the Wairau River is unable to support groundwater levels during periods when they are lowered, possibly by abstraction. Put another way, there may be recharge derived from the river, but it is insufficient to maintain groundwater levels during high irrigation demand.

3. MDC claims that highly efficient irrigation occurs on the Wairau Plains and up to 80% of the land area is irrigated by drip systems. The inputs to the eigen modelling has not been altered to account for this reduction in groundwater storage, nor has the increased rainfall recharge resulting from the maintenance of wet ground during the irrigation season been taken into account. Details of the magnitude of water used, and when, is necessary for changing the input to the eigen model.

4. The inconsistent model-calculated transmissivities and water holding capacities indicate that further tuning of the model is needed, that variable recharge derived from the river needs to be included in the model, as does a seasonally varying abstraction. Seasonally

varying abstraction could be estimated from the AET signal; variable recharge from the river could be estimated from a highly smoothed river flow signal but I expect that only very broad climatic signals would cause significant change to the constant river recharge.

5. If the models were to be calibrated using periods when there was no abstraction, the fit of the models might be improved, the effects of abstraction would be more evident, and might be quantifiable. An initial analysis of the Rangi series of data indicate that calibration over the winter period of months May-August inclusive produces a poorer calibration of the complementary summer periods.

Recommendations for future work

The following recommendations are made as a result of this preliminary analysis:

1. A small number of changes to the model inputs in the form of the model dimensions, changing the length scale and location of the target well within that scale could improve the 'fit' of the modelled groundwater level with monitored levels.

2. If pre-irrigation period data are available, they would help calibrate the model so that a reasonable estimate of the magnitude of abstraction could be determined. Ideally, use of water use records would allow better calibration of the existing model, especially during summer low storage periods. Alternatively, the model could be calibrated for periods when abstraction is minimal, but the range of monitored levels during winter is considerably less than that developed over an entire year, so it is EGC opinion on the basis of one attempt at this winter calibration is that it is unlikely to be significantly improved.

3. Inclusion into the model of seasonally-varying groundwater abstraction and river recharge would be useful. Such changes may increase confidence in some of the calculated aquifer characteristics and improve the predictions.

4. These preliminary results appear to indicate that the existing sources of recharge, rainfall and seepage from the Wairau River are insufficient to maintain groundwater levels in face of increased irrigation. An improved eigen model could be used to inform decisions relating to additional groundwater abstraction. If an increase in abstraction were to occur, the effect that would have on groundwater levels can be predicted in the eigen model.

Locations within New Zealand where eigen modelling has been undertaken

Eigen modelling has been used predominantly in Canterbury and EGC know of only two other examples, in Southland by Karen Wilson, contained within Bidwell (2010) and Tasman, contained in Bidwell (2003). The following is an alphabetical list of reports produced from individual eigen modelling work. Copies of some of these reports are available on the web, some others can be sent to MDC.

Canterbury:

Bidwell, V.J.; Callander, P.F.; and C.R. Moore 1991: An application of time-series analysis to groundwater investigation and management in Central Canterbury, New Zealand, Journal of Hydrology (NZ) 30, 16-36. *http://www.hydrologynz.org.nz/journal.php?article_id=192*

Bidwell, V.J. 2003: Groundwater Management Tools: Analytical Procedure and Case Studies. MAF Technical Paper No: 2003/6. *http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/water-efficiency/groundwater-management-tools/tech-paper-0306-groundwater-management-tools.pdf*

Bidwell, V.J.; Stenger, R. and G.F. Barkle 2008: Dynamic analysis of groundwater discharge and partial-area contribution to Pukemanga Stream, New Zealand. Hydrology and Earth System Sciences 12: 975-987.

Bidwell, V.J. 2010: Groundwater Data Analysis - quantifying aquifer dynamics; prepared for Envirolink Project 420-NRLC50, 29 p (draft).

Burbery, L. 2011: Hydrogeological Support for the Orari Flow Plan; Prepared for Environment Canterbury; Report No 1050-7, 45 p. *http://ecan.govt.nz/publications/General/hydrogeological-support-orari-lvl-eeport.pdf*

Thorley, M.J., Bidwell, V.J., and D.M. Scott 2009: Land-surface recharge and groundwater dynamics – Rakaia-Ashburton Plains; Environment Canterbury Technical Report R09/55, 61 p. *http://researcharchive.lincoln.ac.nz/dspace/bitstream/10182/3551/1/Land_surface_recharge_groundwater_dynamics.pdf*

Williams, H.R., Scott, D.M. and V.J. Bidwell 2008: Adaptive Management of groundwater in the Rakaia-Selwyn Groundwater Allocation Zone; Environment Canterbury Technical Report R08/64, 93 p. *http://ecan.govt.nz/publications/Plans/AdaptivemanagementintheRakaiaSelwyn.pdf*

Williams, H.R. and S. Gabites 2010: Adaptive management of groundwater in the Selwyn-Waimakariri groundwater allocation zone; Environment Canterbury Technical Report R10/04, 71 p.

Williams , H.R. 2011: Modelling of stream discharge and groundwater levels in the Te Waihora / Lake Ellesmere catchment; Elemental Geoconsulting Report No: ECMP-1, 83p.

Southland:

Wilson, K : unpublished analyses included in Bidwell, V.J. 2010: Groundwater Data Analysis - quantifying aquifer dynamics; prepared for Envirolink Project 420-NRLC50, 29 p (draft).

Tasman:

Bidwell, V.J. 2003: Groundwater Management Tools: Analytical Procedure and Case Studies. MAF Technical Paper No: 2003/6. *http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/water-efficiency/groundwater-management-tools/tech-paper-0306-groundwater-management-tools.pdf*

Figures referred to in text

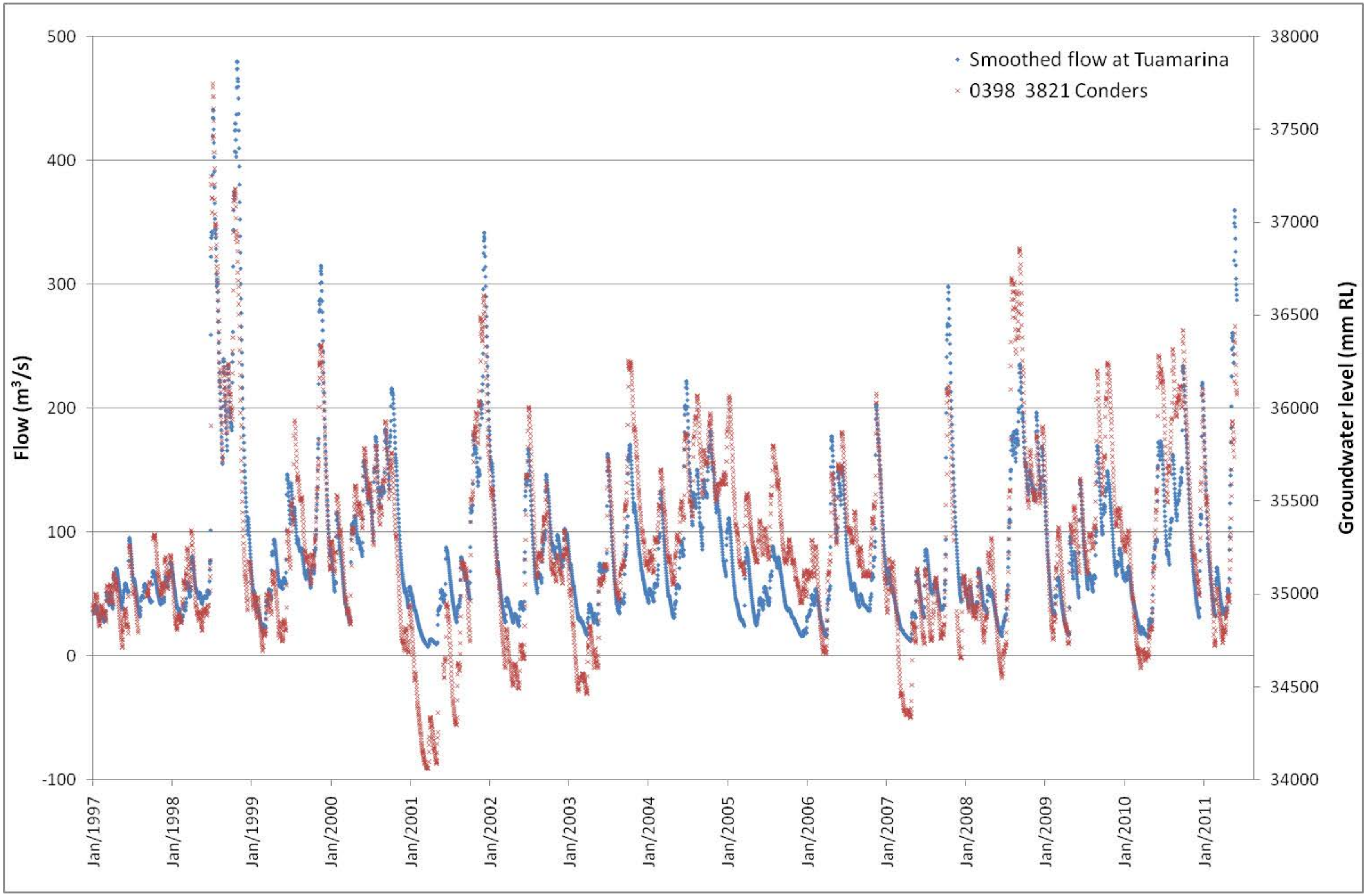


Figure 1: Smoothed flow and groundwater level (W P28w/0398 - 3821).

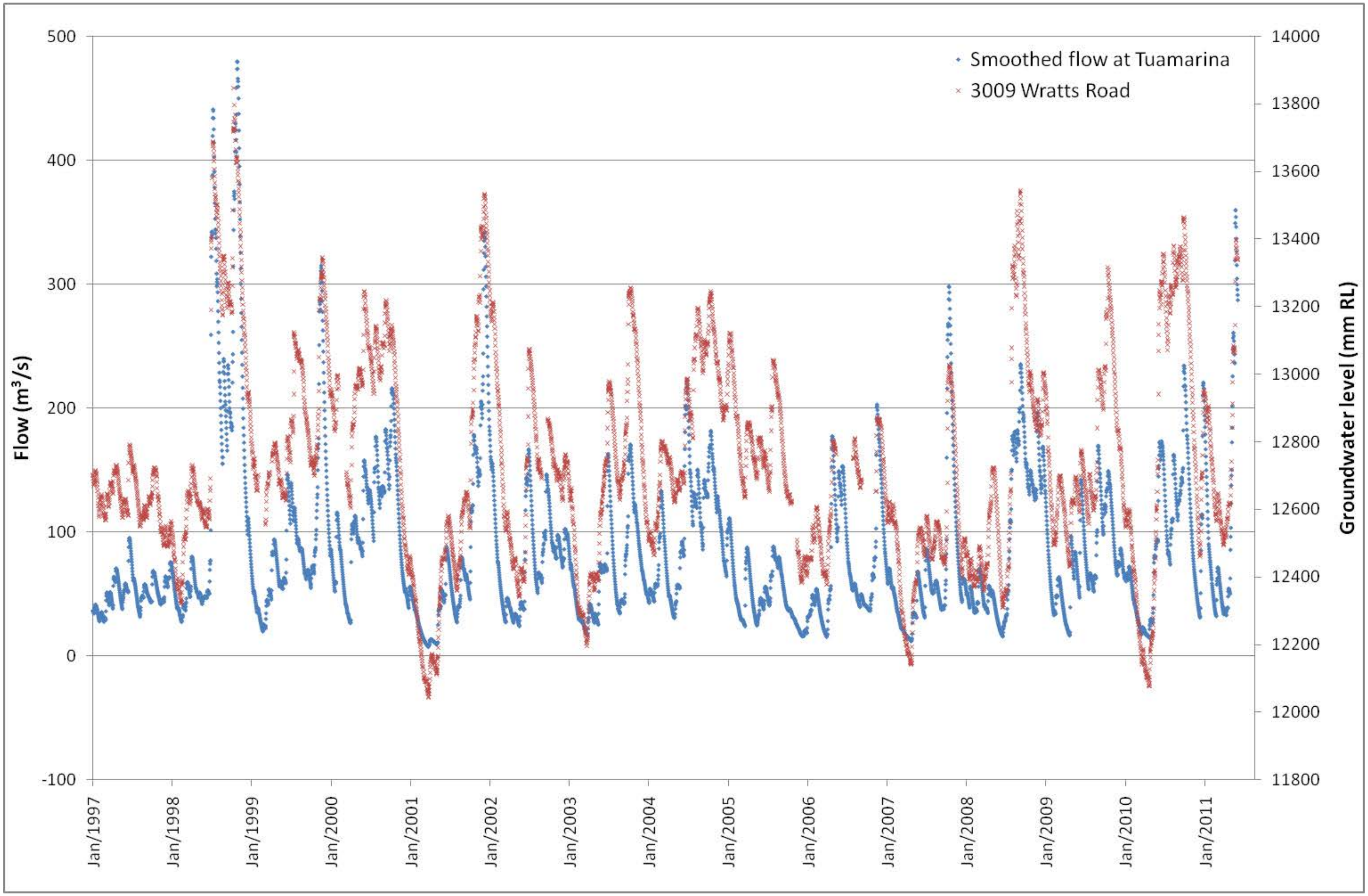


Figure 2: Smoothed flow and groundwater level (W P28w/3009).

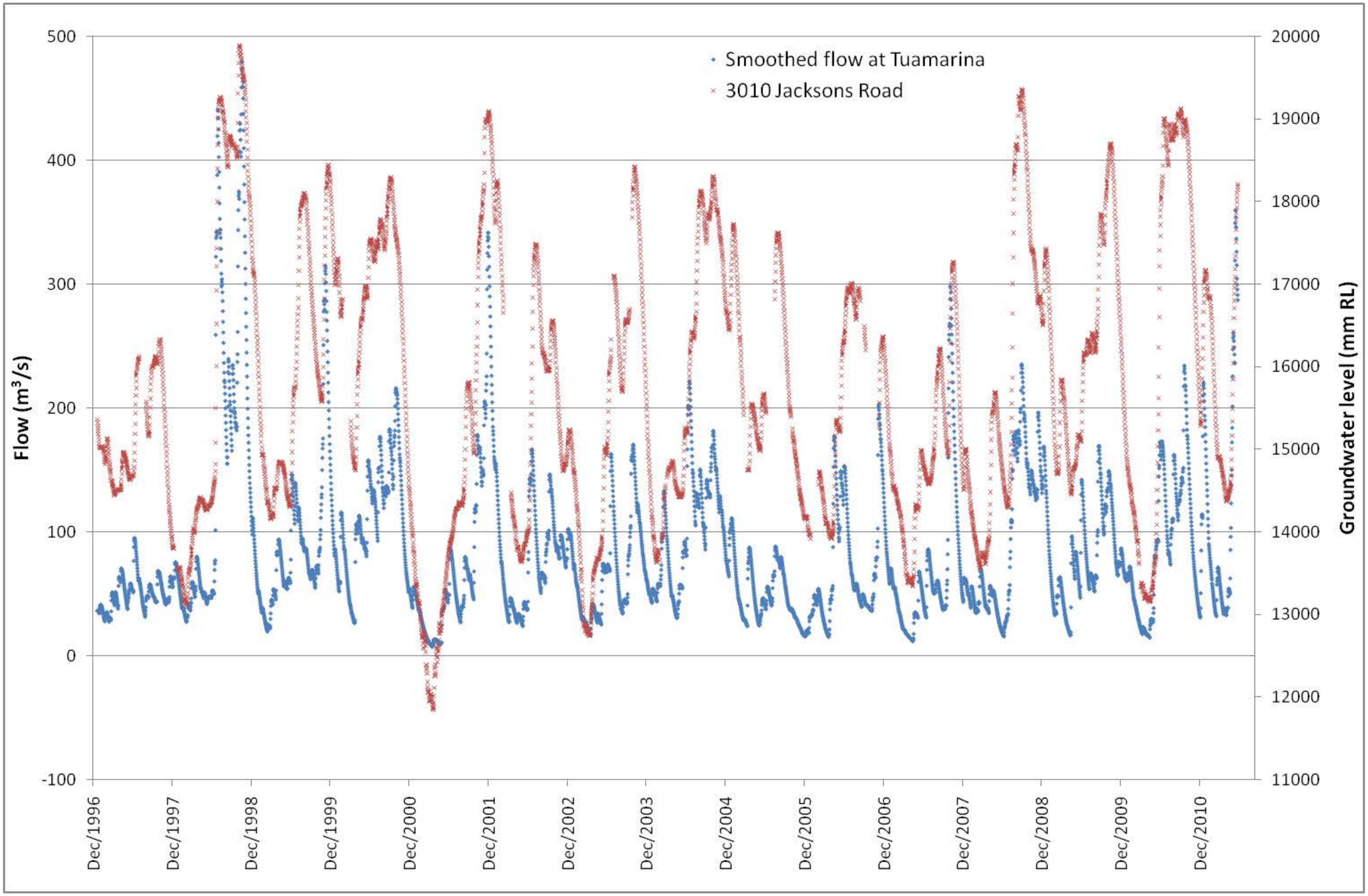


Figure 3: Smoothed flow and groundwater level (W P28w/3010).

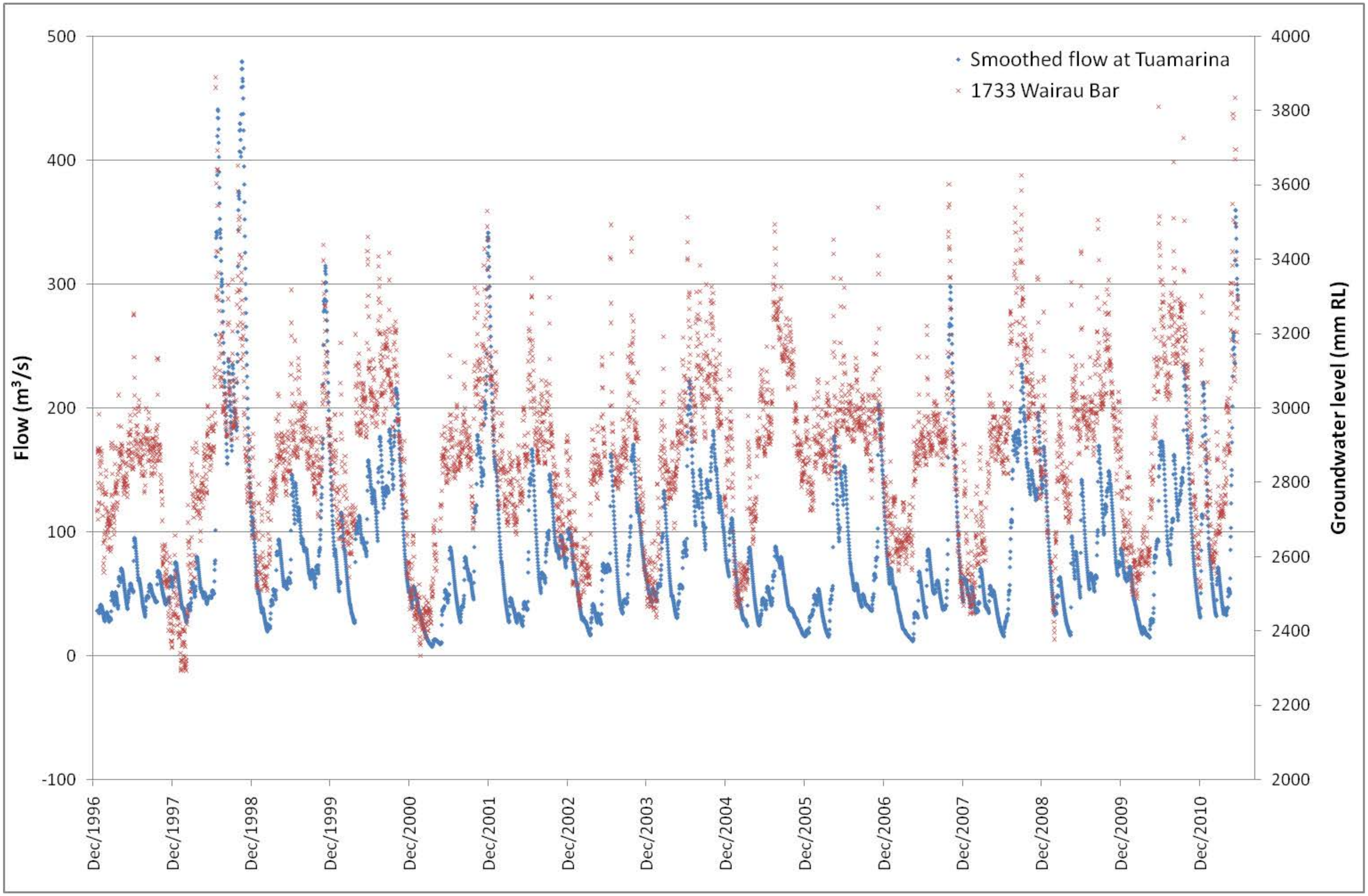


Figure 4: Smoothed flow and groundwater level (W P28w/1733).

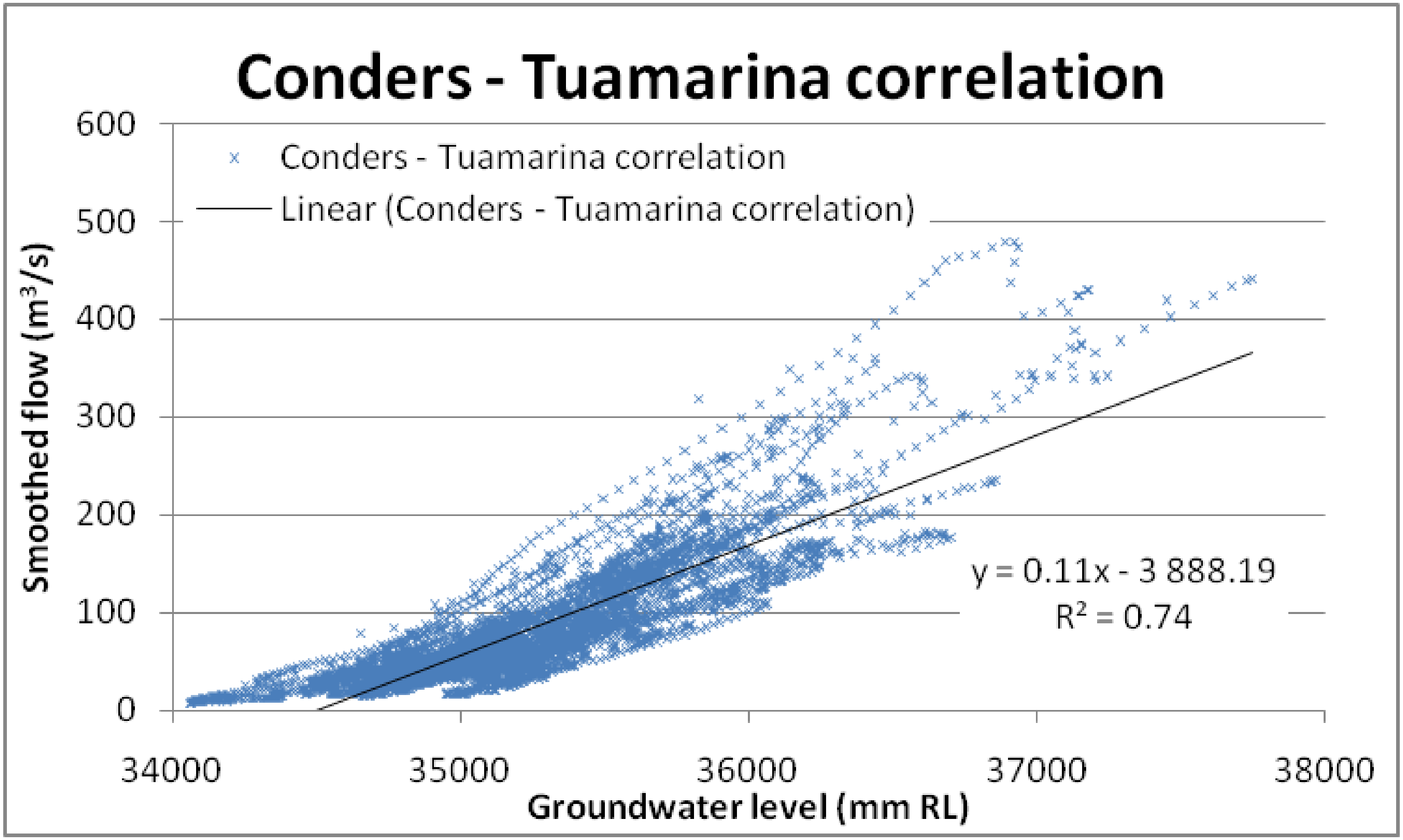


Figure 5: Smoothed flow and groundwater level (W P28w/0398 - 3821).

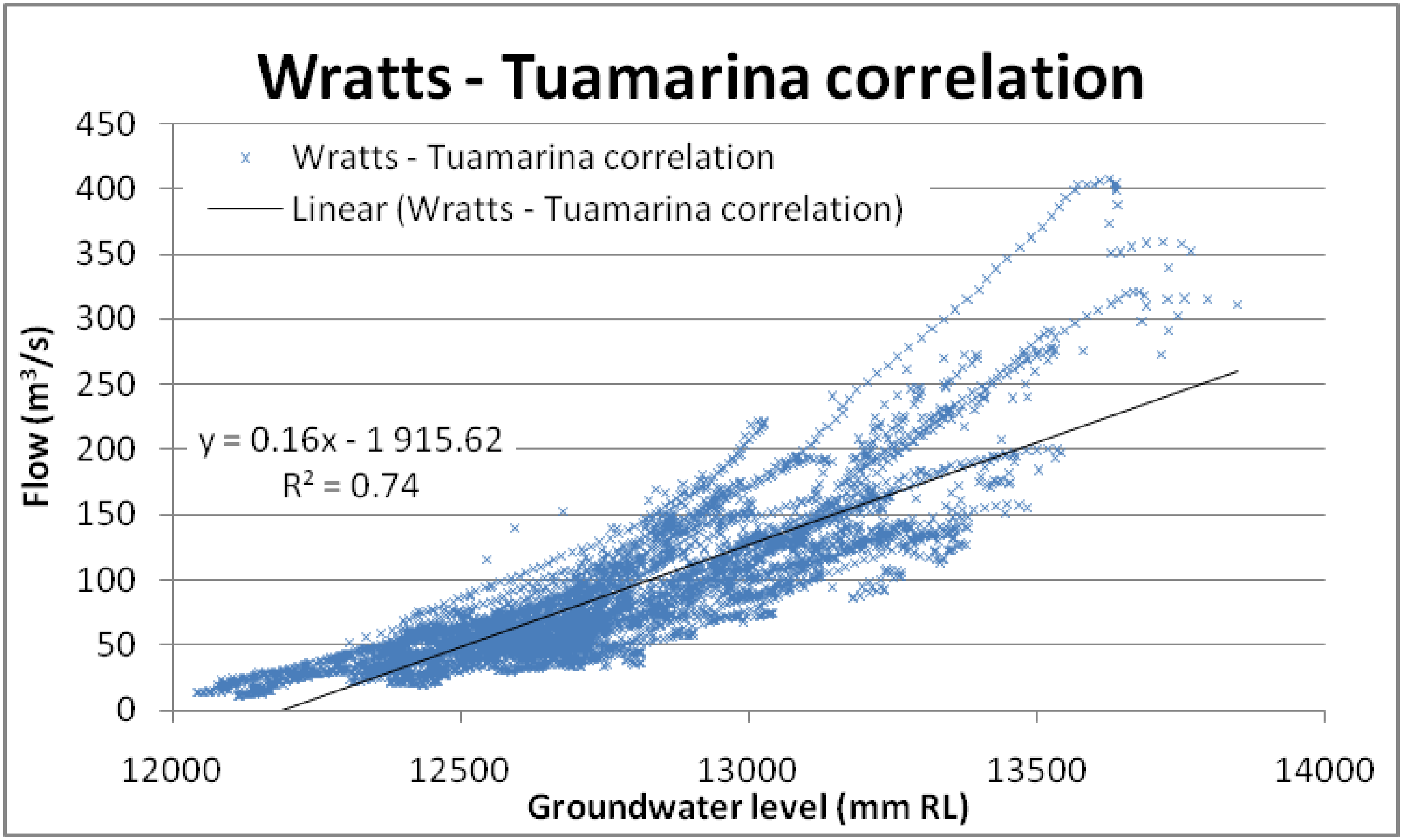


Figure 6: Smoothed flow and groundwater level (W P28w/3009).

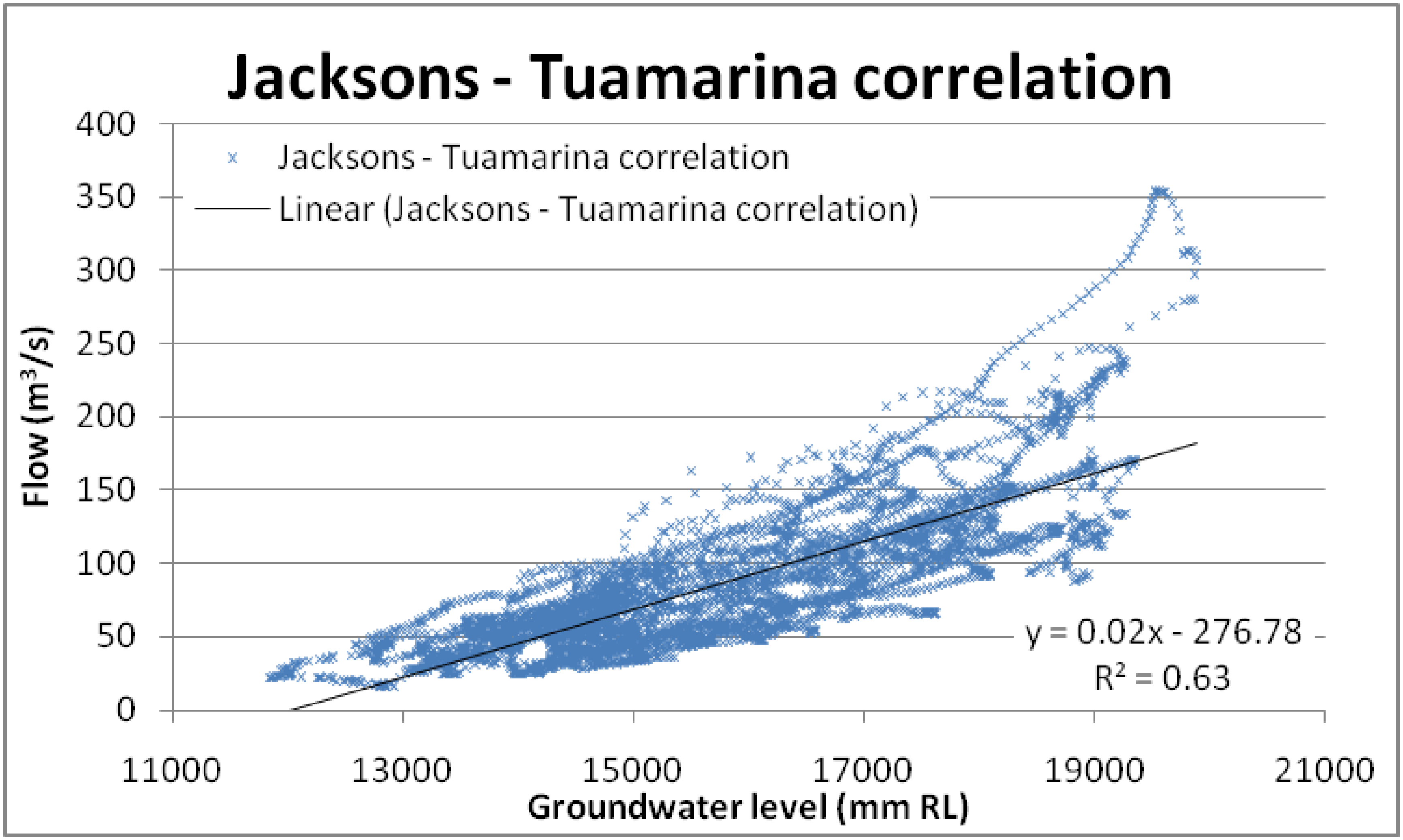


Figure 7: Smoothed flow and groundwater level (W P28w/3010).

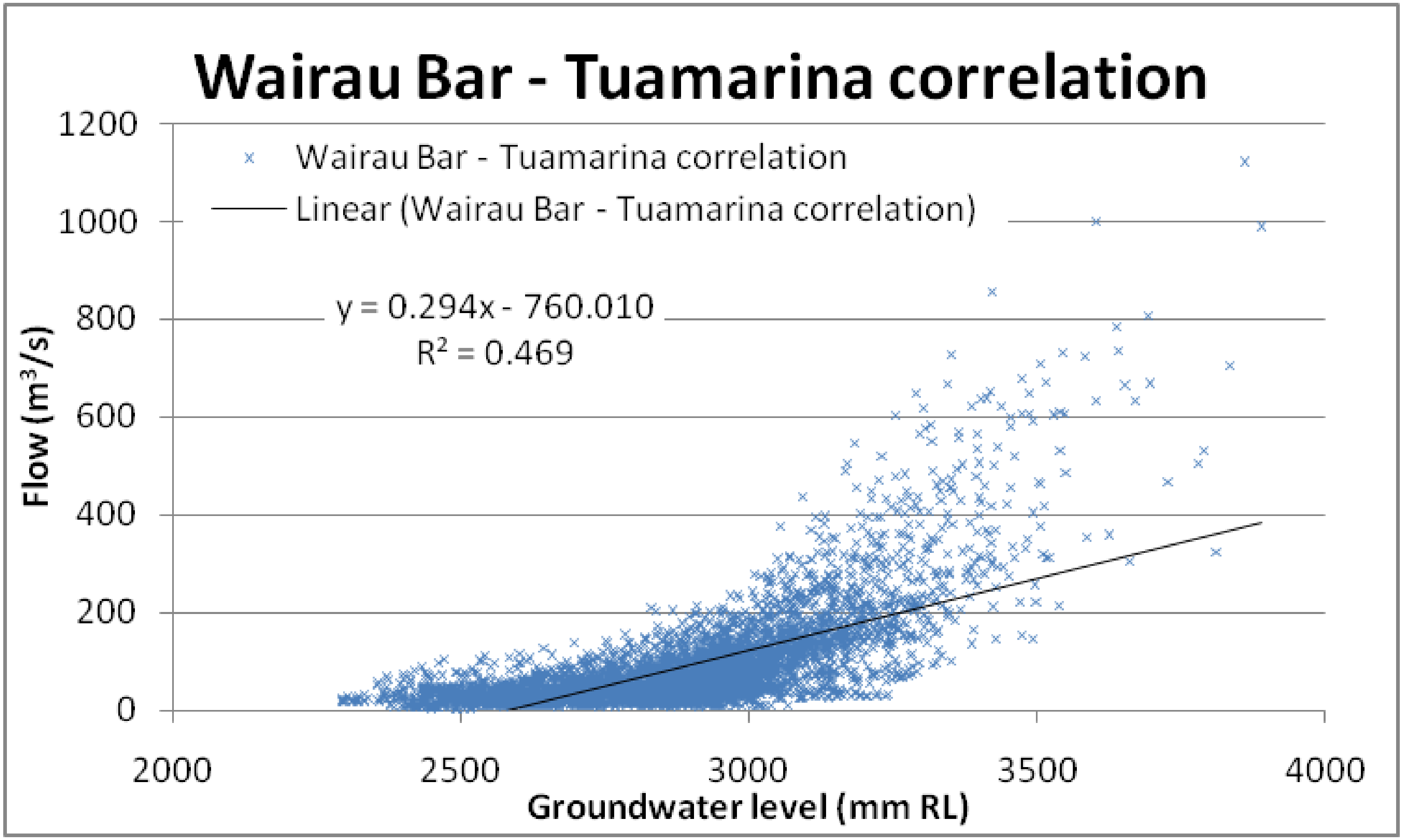


Figure 8: Smoothed flow and groundwater level (W P28w/1733).

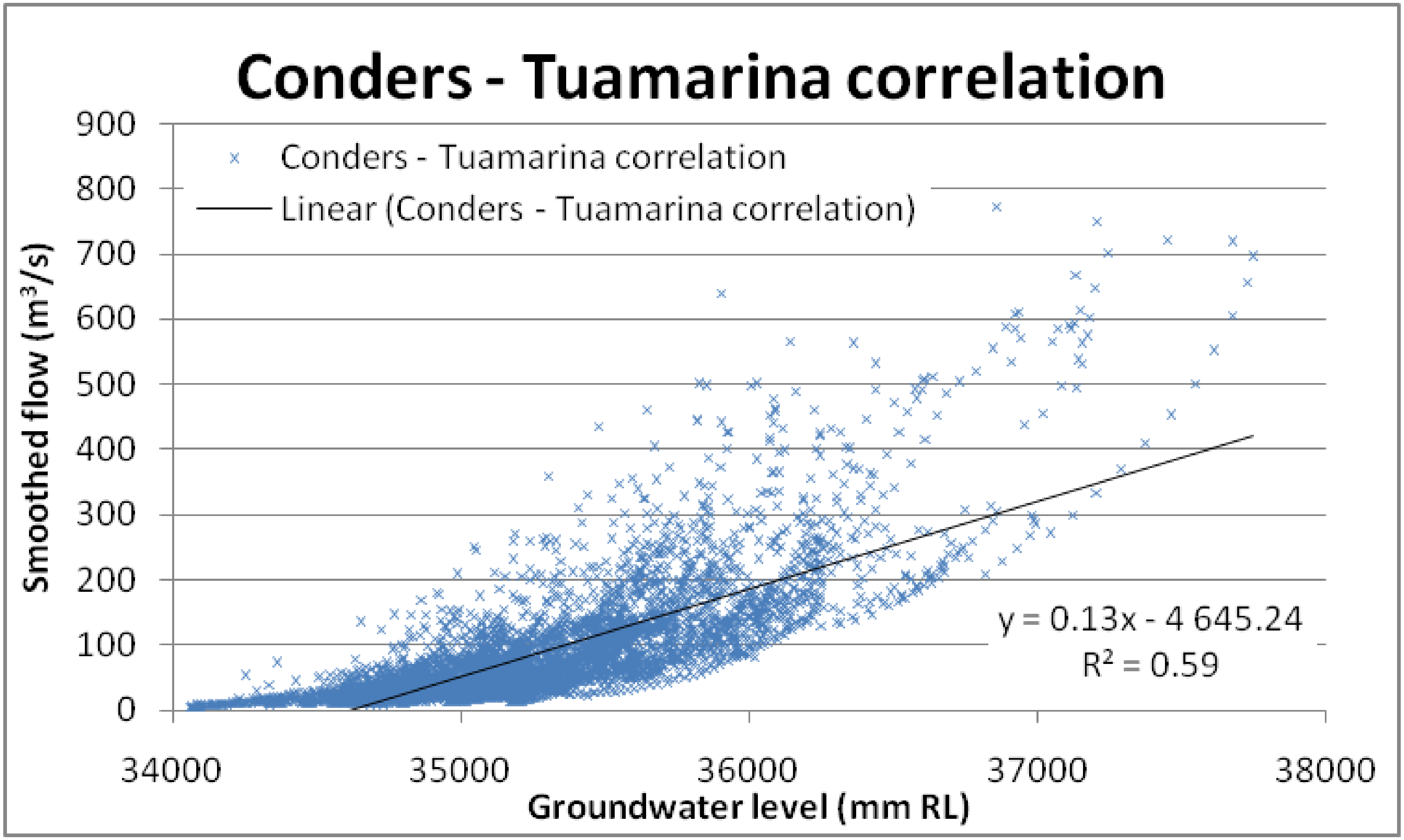


Figure 9: Smoothed flow and groundwater level (W P28w/0398 - 3821).

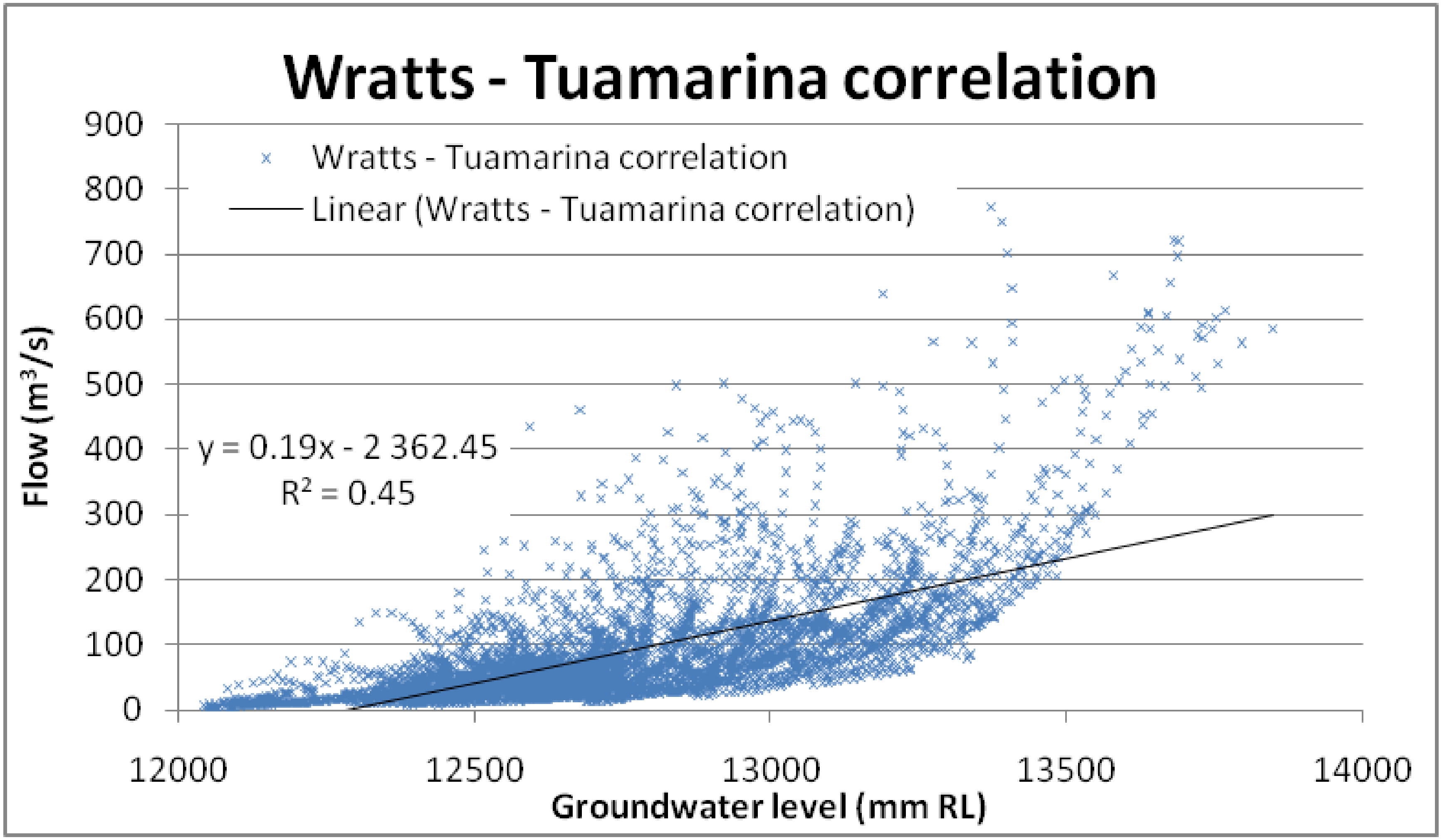


Figure 10: Smoothed flow and groundwater level (W P28w/3009).

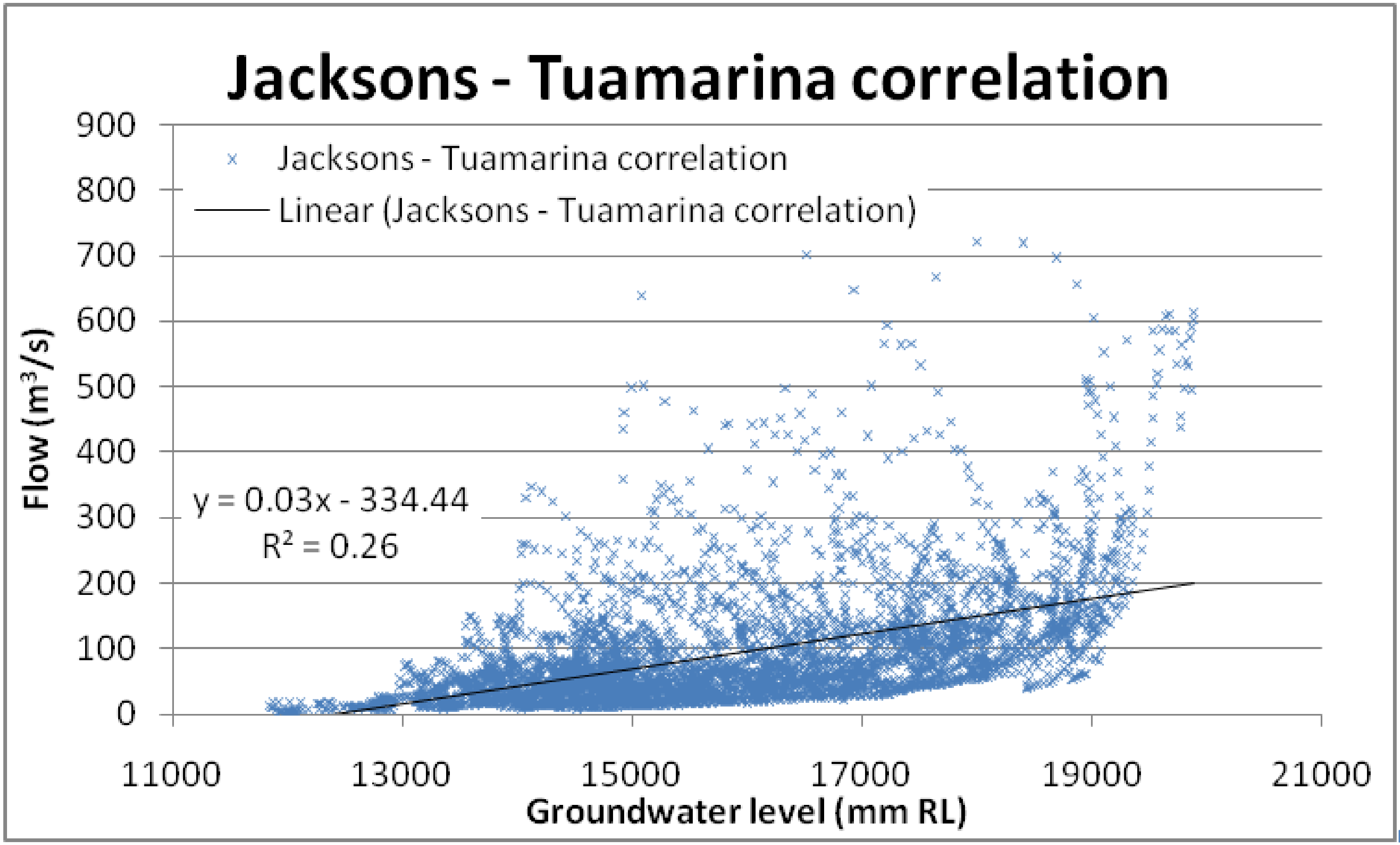


Figure 11: Smoothed flow and groundwater level (W P28w/3010).

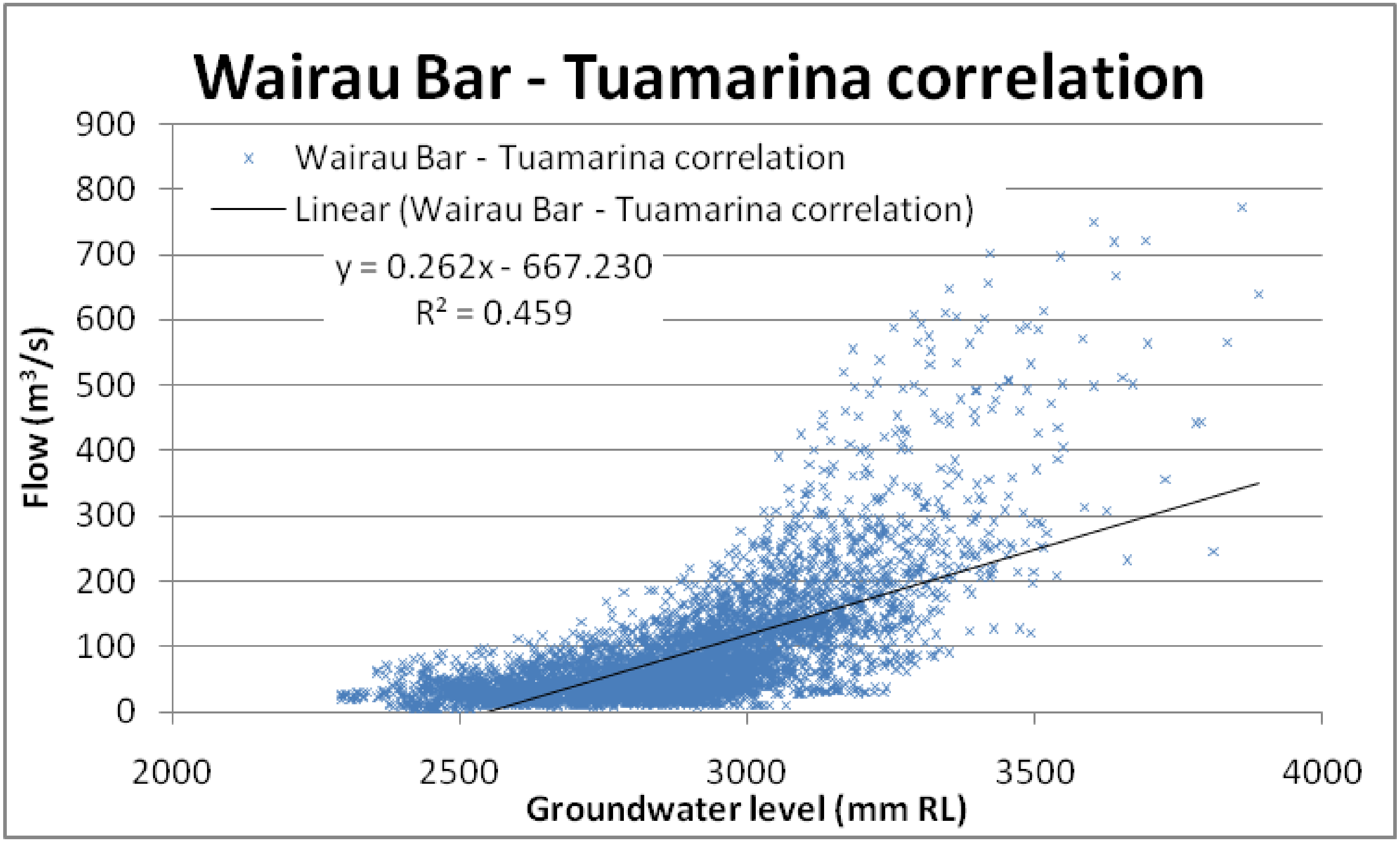


Figure 12: Smoothed flow and groundwater level (W P28w/1733).

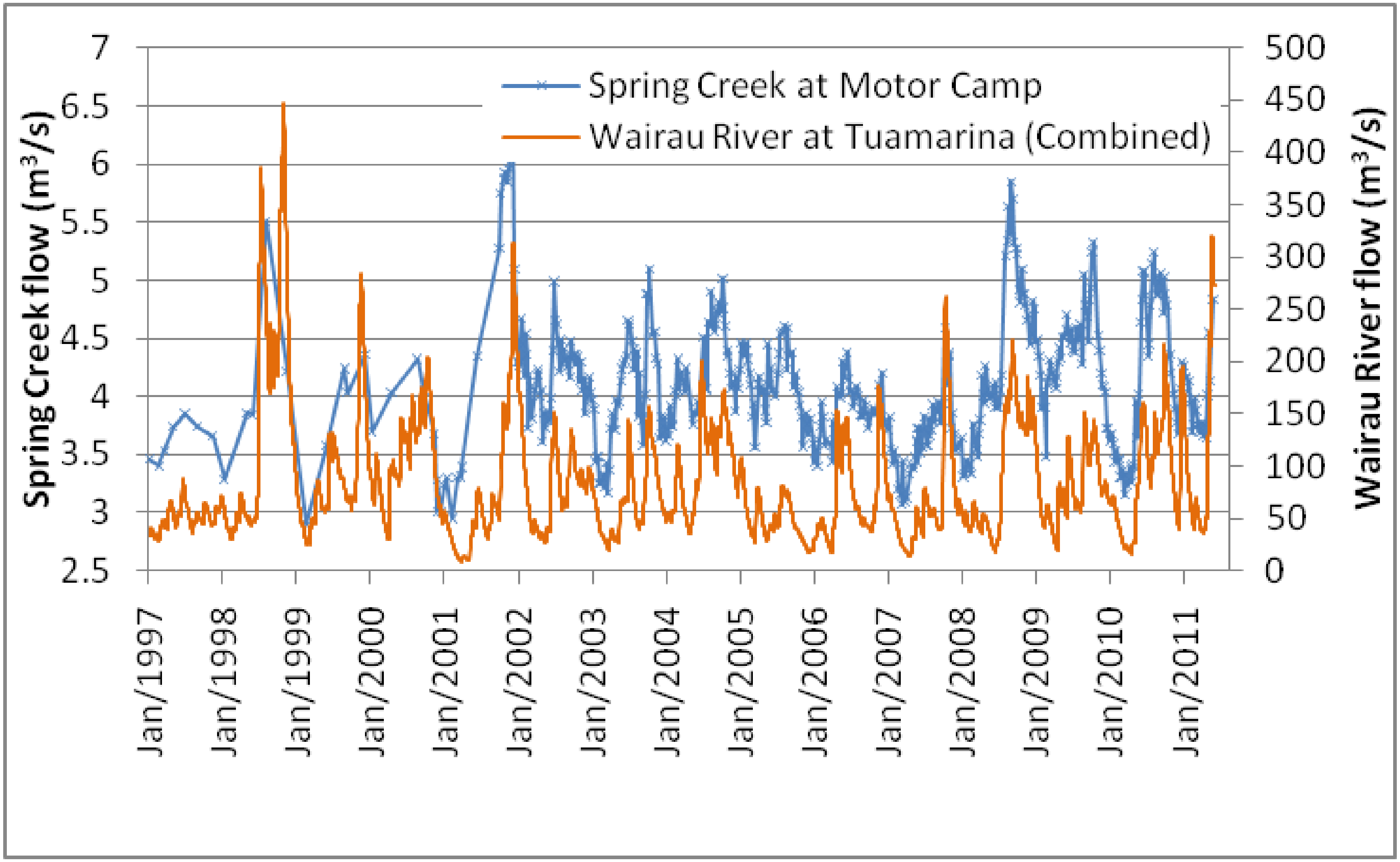


Figure 13: Smoothed Wairau River flow (alpha = 0.96) and Spring Creek flow.

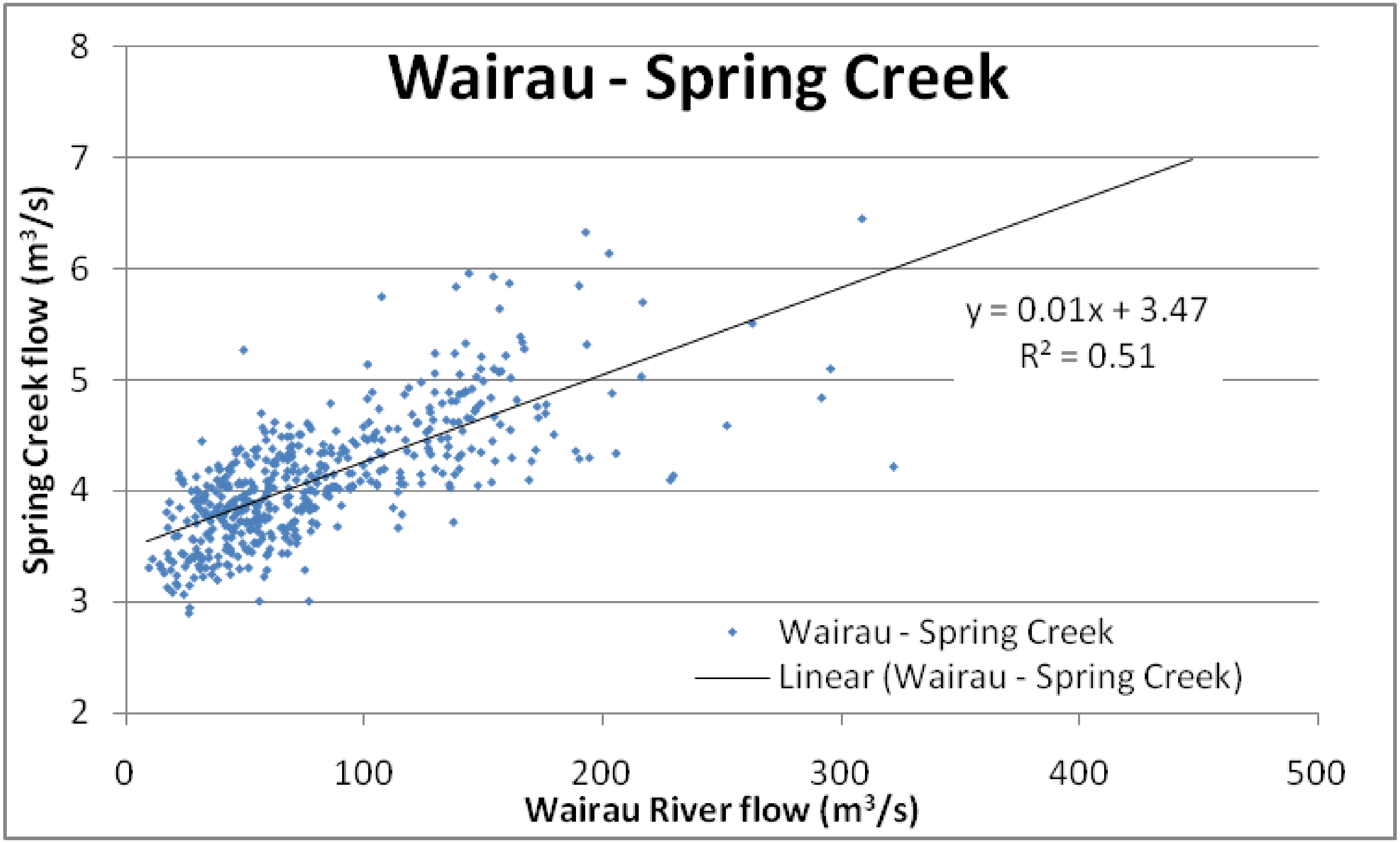


Figure 14: Spring Creek and smoothed Wairau River (alpha = 0.96) flows.

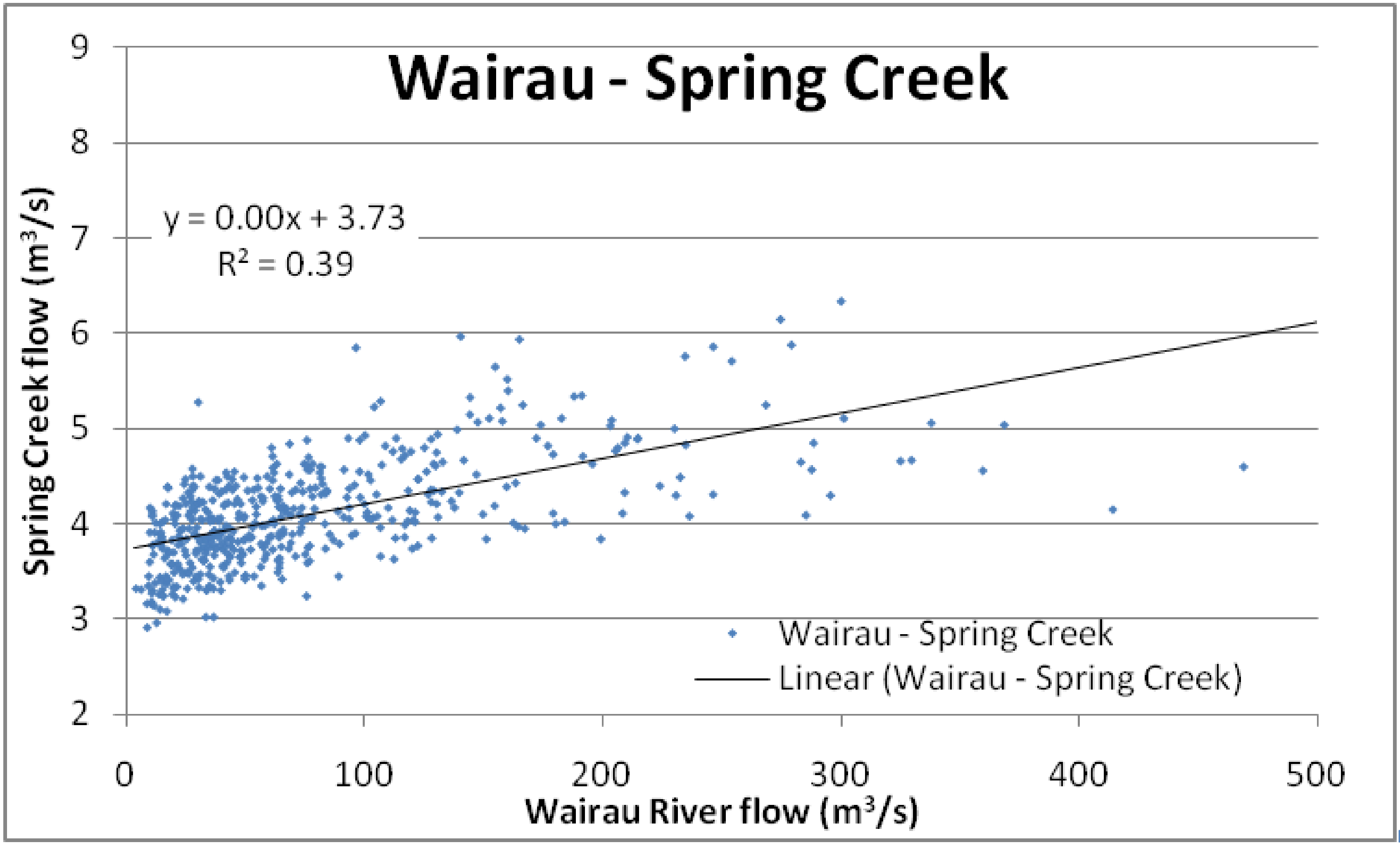


Figure 15: Spring Creek and smoothed Wairau River (alpha = 0.80) flows.

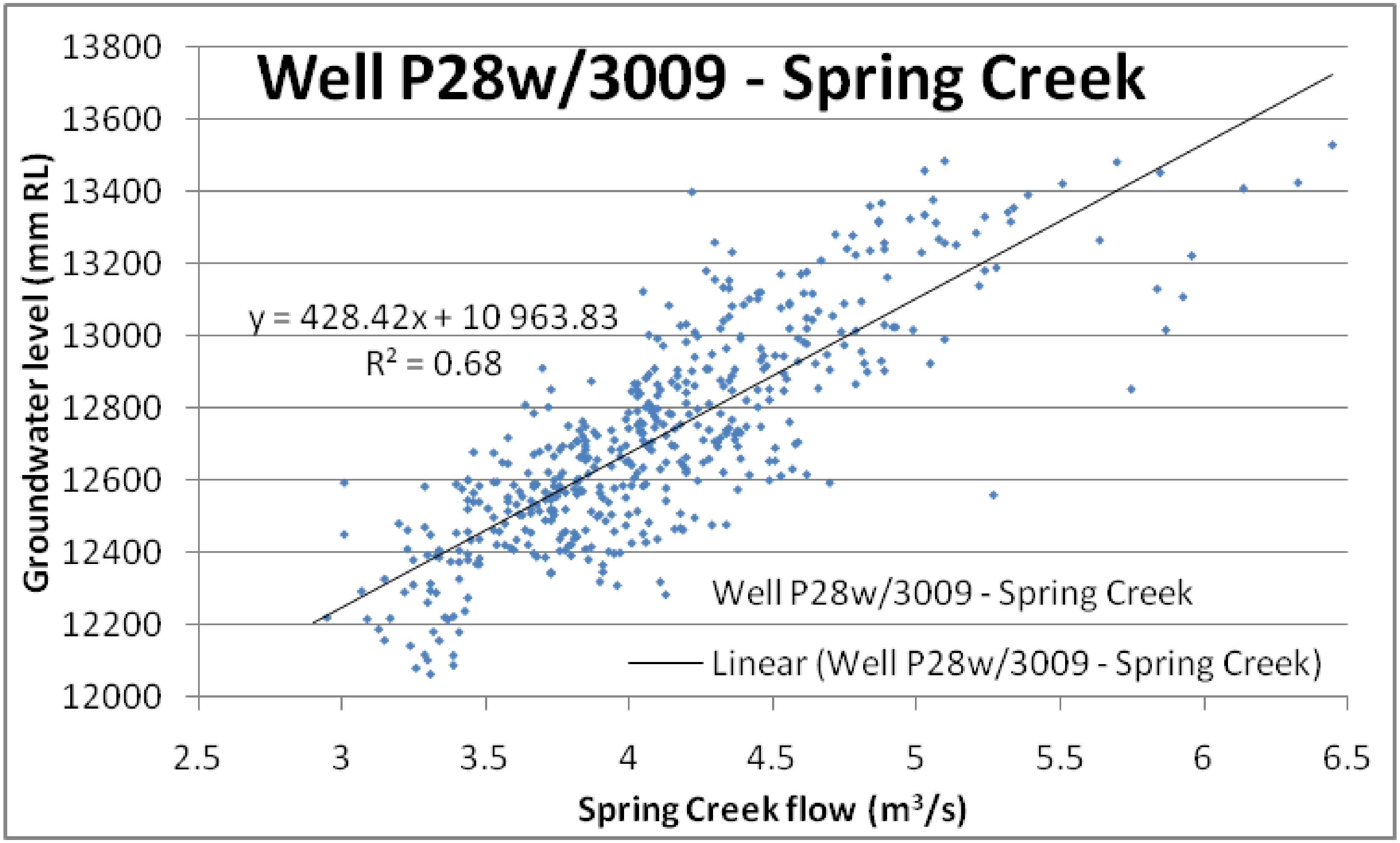


Figure 16: Spring Creek flow and groundwater level (Well P28w/3009).

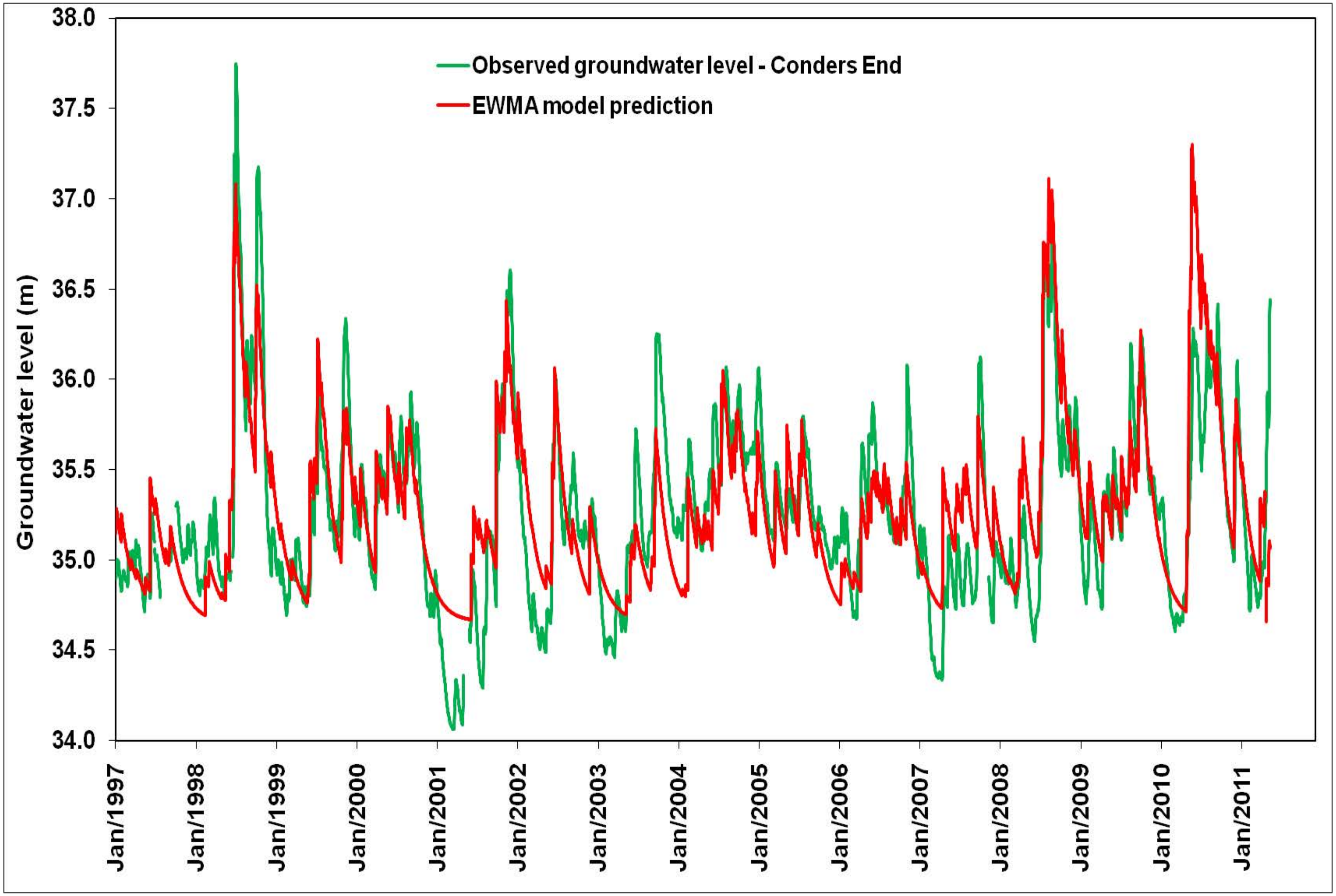


Figure 17: Conders End EWMA model.

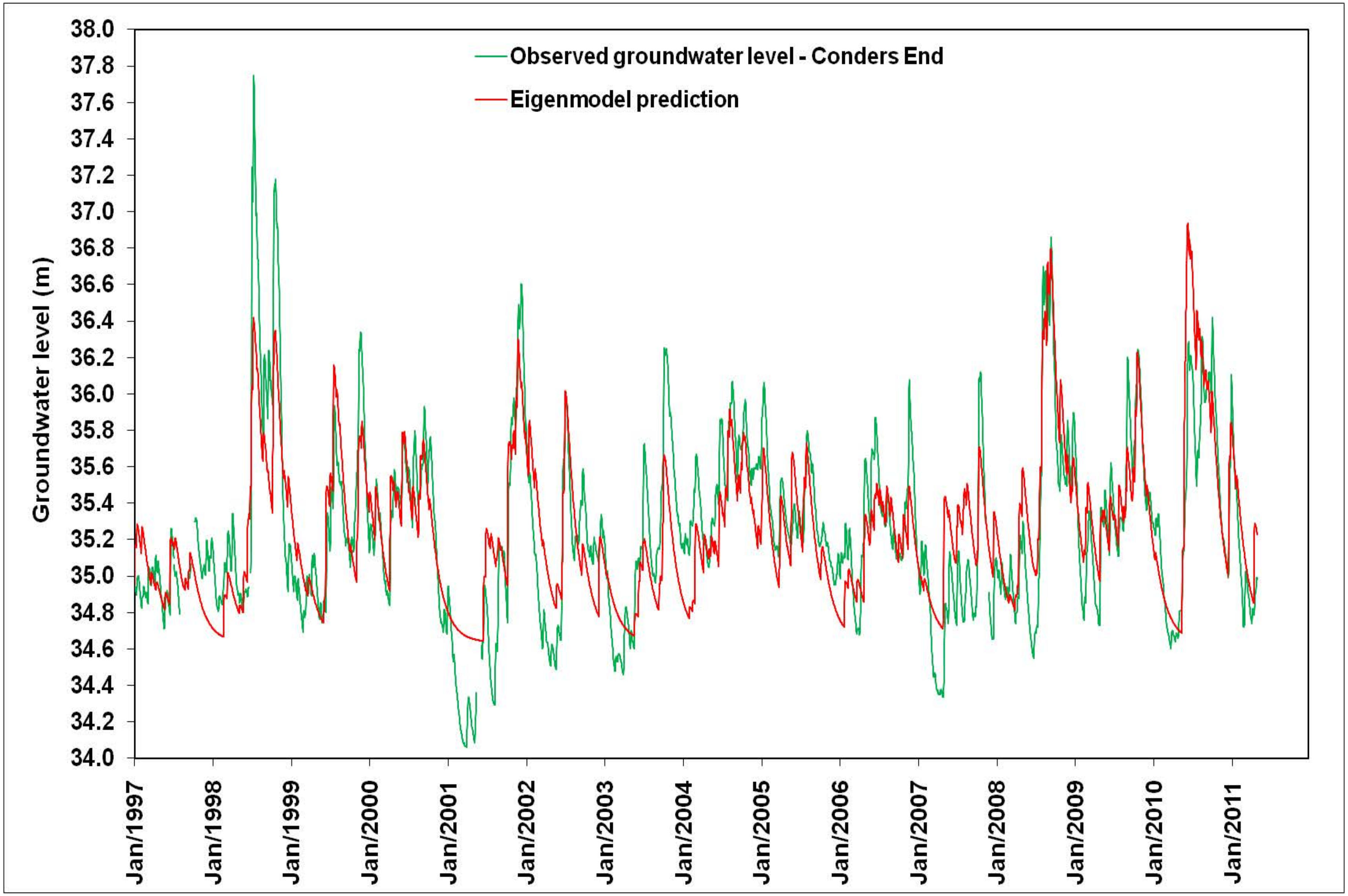


Figure 18: Conders End eigen model.

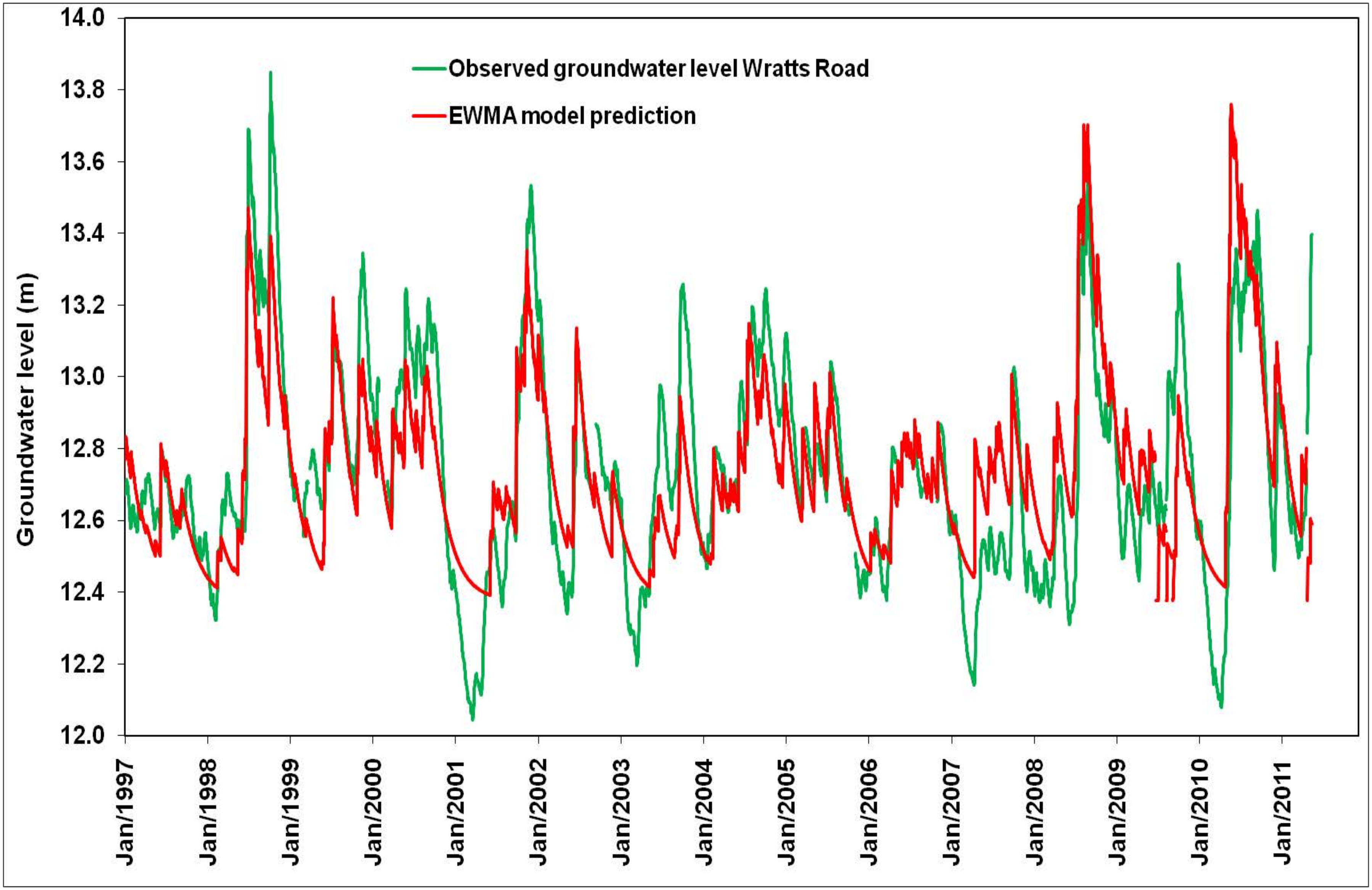


Figure 19: Wratts Road EWMA model.

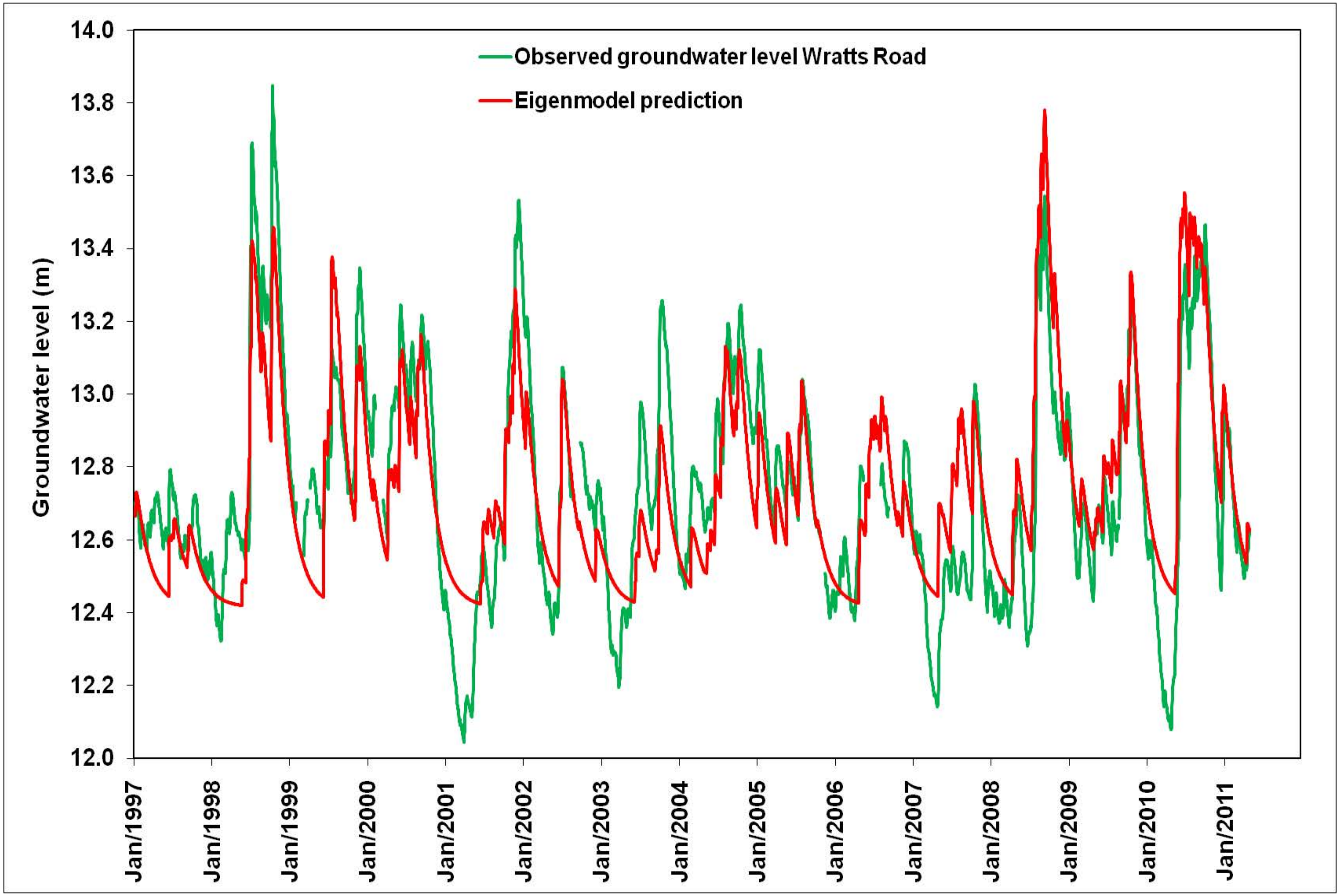


Figure 20: Wratts Road eigen model.

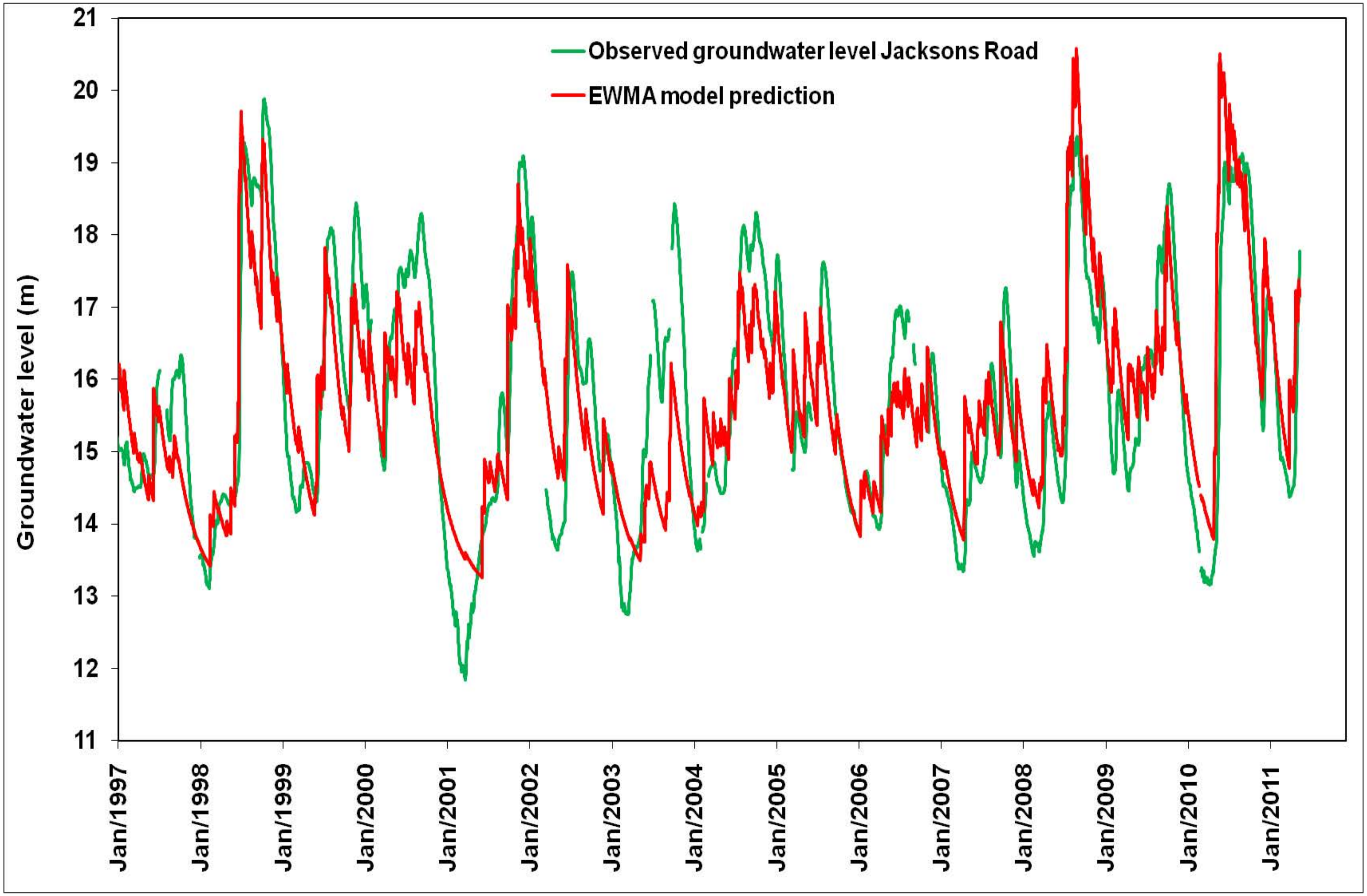


Figure 21: Jacksons Road EWMA model.

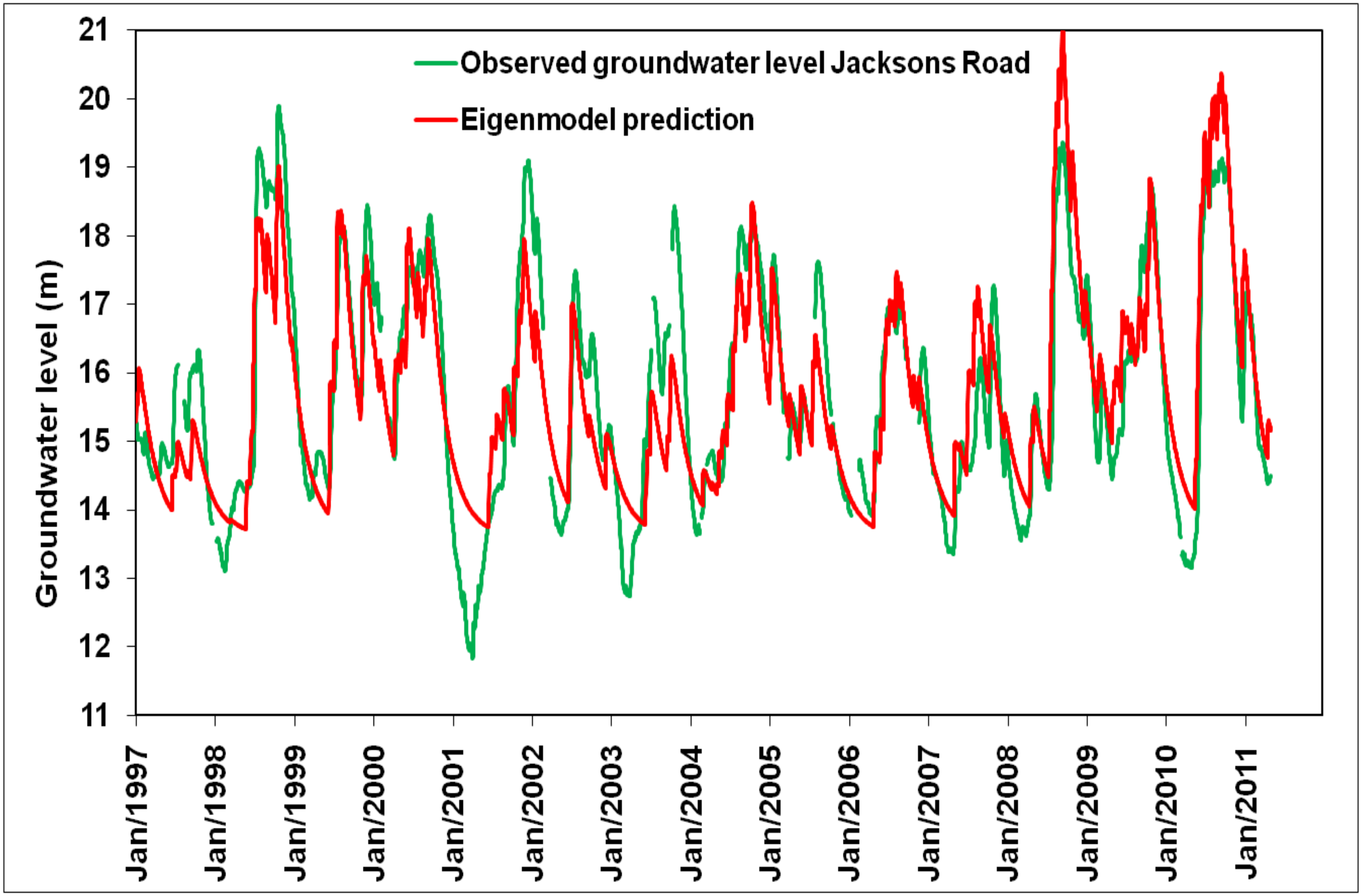


Figure 22: Jacksons Road eigen model.

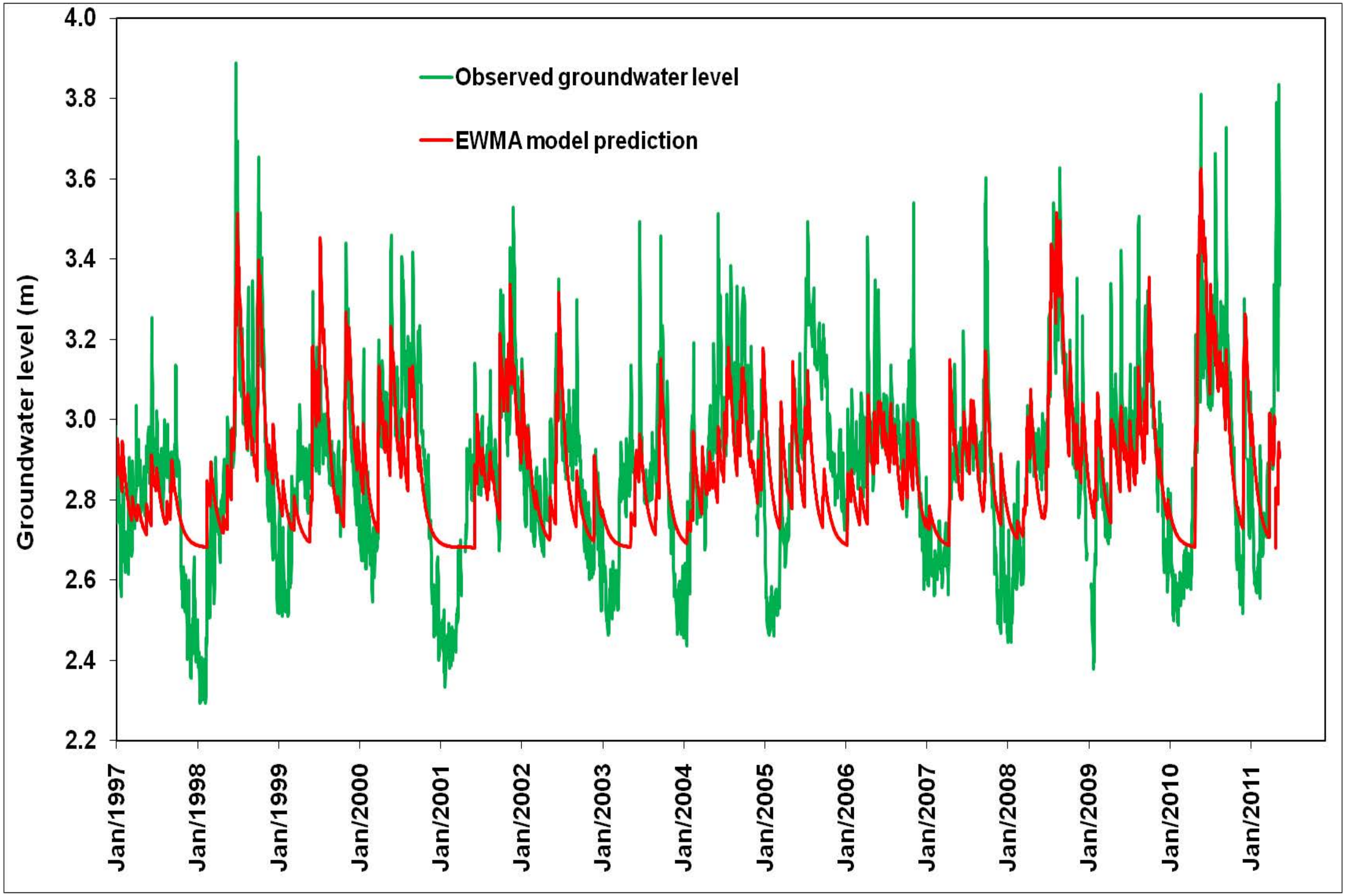


Figure 23: Wairau Bar EWMA model.

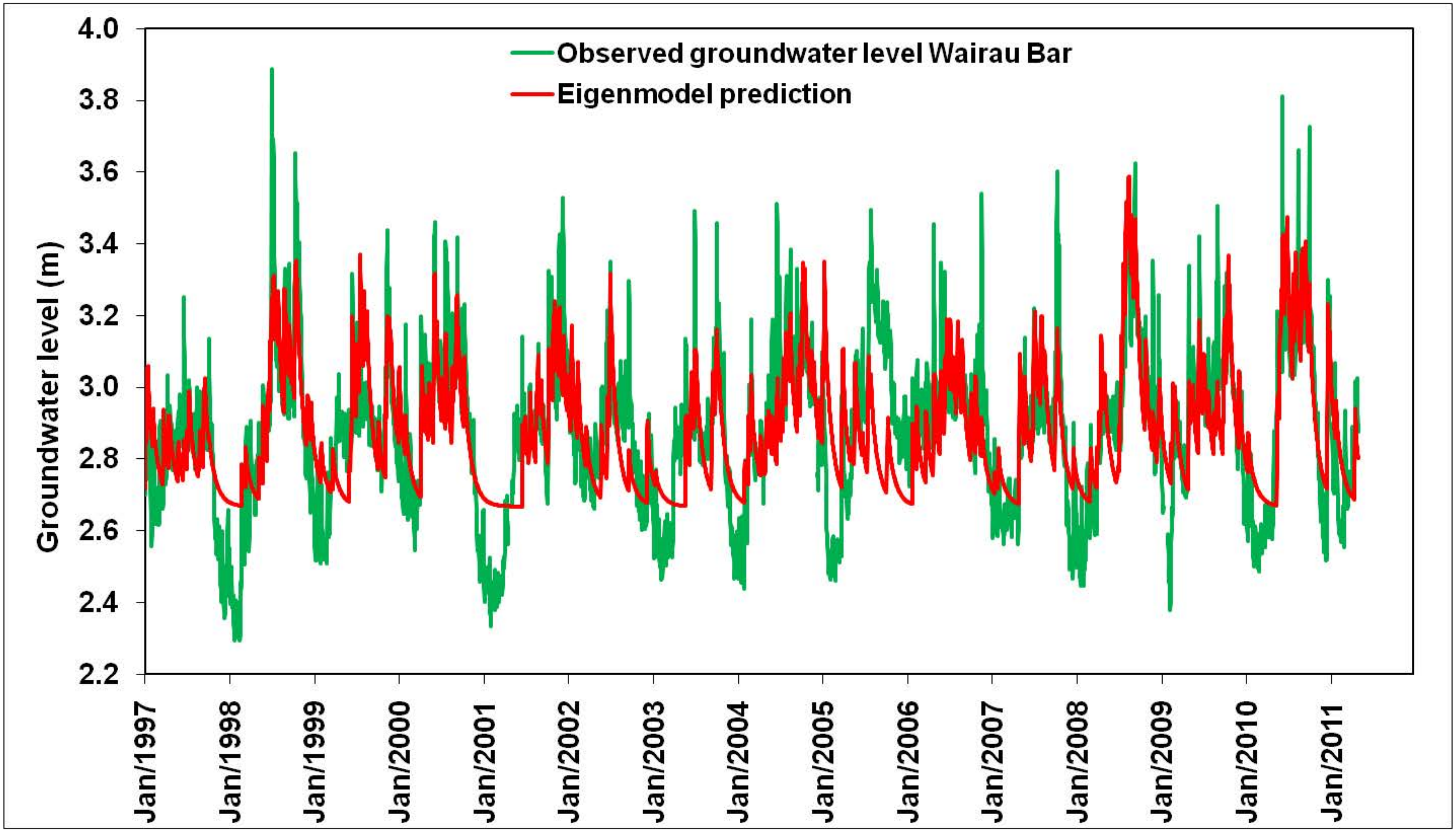


Figure 24: Wairau Bar eigen model.

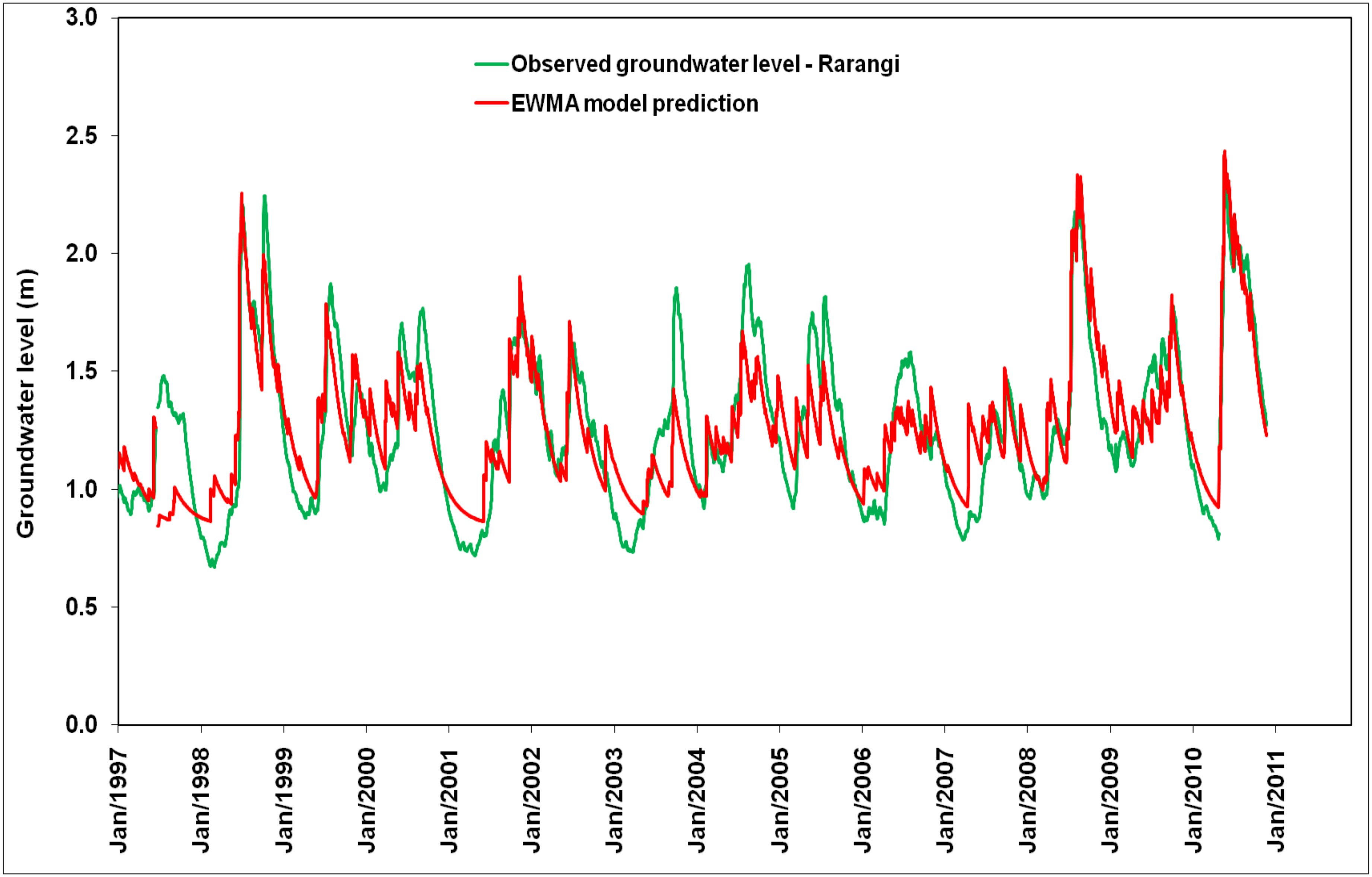


Figure 25: Rarangi EWMA model.

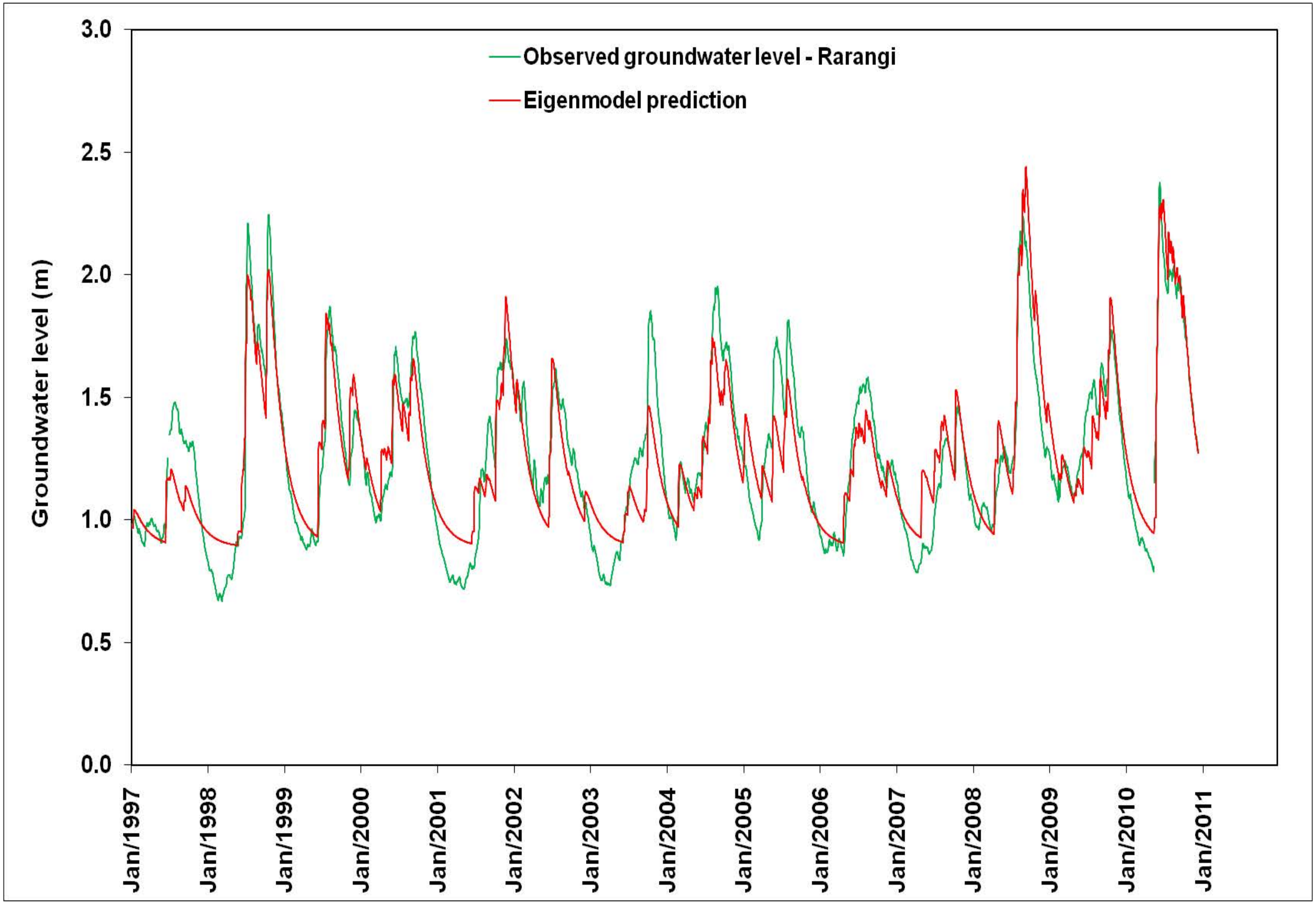


Figure 26: Rarangi eigen model.