Development of a Mathematical Model for the Forecast of Flood Flows in the Lower Rangitaiki River

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Cover Photo: View of Rangitaiki Falls, below the Aniwhenua Scheme (Ken Dodson)

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Chapter 1: Introduction

The availability of a model to forecast flood flows in the lower Rangitaiki River has been a need for a long time. Even if such a model were able to forecast into the future for between, say 24 to 36 hours, it would be valuable, as long as the responsible authority could be very certain that the model is reliable in its predictions, especially with respect to the predicted peak flow rate and the expected arrival time. Such a model will also be useful for management of flows that would otherwise necessitate spillage of water already stored. Reliable estimation will enable the responsible authorities to evacuate water in upstream storage, thereby enabling the volume let out, to the plains below, to be spread out over a longer time. This will help to minimise damage to the stopbanks or, in extreme cases, inundation of the adjacent plains and pastures.

A second, but lesser advantage that will flow from a reliable forecasting model is that electricity production could be increased. The flow at maximum generation capacity at Matahina is around 136 cumecs, but for more than 90% of the time, the available flow is less than around 90 cumecs, which means there are around 46 cumecs of generating capacity installed, with all infrastructure in place, but only rarely used.

A reliable flood flow forecasting procedure would enable more of this extra capacity to be utilised. The electricity market in New Zealand is a deregulated market. The price of electricity per kilowatt-hour (unit) varies with a seasonal, as well as a marked diurnal fluctuation occurring. At times of shortage due to drought and during peak demand, power can cost significantly more than at times of lower demand.

The diurnal fluctuation of demand, and the way the power companies respond to that demand, (in order to maximise their income), is determined by market forces and is confidential to each company. In general, the power station cannot let out stored water (stored energy) today, more than the volume expected to inflow in the immediate future, because it may miss out on the ability to gain high income during peak demand on the following day. The low flow or base flow can be reliably predicted, but if the power station operator can be sure that sufficient inflow will occur for the next days' demand, then he can generate more today.

It must nevertheless be borne in mind that extra power generation that may be achievable, can never be more than that which is being spilled and also that some spill will always have to occur.

Nevertheless, from the background given above, it should be evident that a reliable flood flow forecasting method would be quite useful, as it would have the benefit of peak flow attenuation as well as increased power production.

In summary, if the power station operator can be certain today that there is water on its way to top up the reservoir, so as to be able to also earn high income tomorrow, then he can let out more water today through his turbines, so as to exploit times (during today) when the best prices can be obtained. This will also reduce the cost to the public.

Chapter 2: Model Structure Development

2.1 Background

The development of a reliable model for flood flow forecasting in the lower Rangitaiki has been hampered over the years by a number of factors, some of which were the following:

(a) The same characteristic that makes the Rangitaiki River so suitable for power generation (i.e. flows originate from a combination of catchments with different runoff characteristics) also makes it difficult to model the whole. The downstream flow (during any event) could originate from differing combinations of sources, and cannot easily be apportioned among the sources from which it originates. Only the total flow is measured downstream. This seriously hampered model structure determination and calibration.

(b) The contributing catchments have a markedly heterogeneous nature as far as their response to similar rainfalls are concerned. For instance the flow at Murupara (at which point the Rangitaiki River has a catchment area of 1184 km^2) is little influenced by even moderately large rainfall events. A localised storm, centred over the Waihua basin, (with a catchment area of only 39 km^2) can cause a significantly higher flood flow peak than if it occurred in the upper Rangitaiki or upper Whirinaki.

Generally the Ikawhenua hills to the east of the Rangitaiki (below its confluence with the Whirinaki) are high yielding in runoff (even 150 mm of rain will cause a significant runoff response), whereas it takes a very large amount of rain (±300 mm) or more during not more than 3 of 4 days, to show a significant increase in runoff rate if it falls on the Kaingaroa plateau.

(c) Before the 1980's, there were not many autographic rainfall recorders installed in the Rangitaiki River catchment area, from which records are available. Between 1980 and 1998, a number of autographic rainfall recorders were installed, but this was a flood-poor period, ascribed to the Interdecadal Pacific Oscillation (IPO). When the July 1998 floods occurred, (due to a sea change of the IPO, to a flood rich period in which we are in now, and which is expected to continue) the important flow gauge on the Whirinaki at Galatea was washed away and much data was lost, making good calibration impossible.

(d) The flow at Te Teko is markedly influenced by the Matahina power station. In addition, it is not a gauging station operating under hydraulic control, (which would permit a unique relationship between observed stage height and flow rate to be calculated), and serious misgivings exist about its accuracy. For example, the maximum flow, calculated at the peak in July 2004, at the Te Teko station was a bit more than 500 cumec, while we know that at

Matahina it peaked at almost 750 cumecs. The flow as measured at Matahina is considered much more accurate. A map showing the Rangitaiki Catchment, its flow and rainfall gauges and principal sub catchments is attached as Figure 1. (Appendix 8).

2.2 Model Structure

The structure of any mathematical model has to be related to the quality and quantity of data available to calibrate and use it with. Model complexity will not save the day if you have no data to calibrate with. On the other hand no amount of good data can, on its own, be usable if the model is inadequate.

Much time was lost in trying to calibrate the model with Te Teko data, without achieving satisfactory results.

The Matahina power station itself can, however, be used as a flow gauging station, because the electricity generated is directly proportional to the flow through the turbines, and spillage takes place according to a known hydraulic formula, which enables reasonably accurate estimates of inflow during flood events to be made, taking into account the dam basin characteristics and data of the hourly level changes of the reservoir itself. (10 mm of level change in one hour equates to a correction of around 6.5 cumecs.) This correction is applied to the flow passing through the turbines (plus spill if any), using a positive correction for a rising level in the hour concerned and vice versa. The result gives the hourly average inflow.

Data of the flows that occurred during flood events was retrieved from the archives at Matahina, during personal visits and with commendable cooperation by the chief controller at the dam (Robert Scott). Even so, the loss of the Galatea data during July 1998, limited the usefulness of that data for adequate calibration. The July 2004 floods yielded useful data, although the Huiarau gauge malfunctioned. A temporary autographic gauge at Matawera functioned as a substitute.

The method that was followed in the analysis then focused on the development of unit hydrographs, based on data obtained during periods when heavy rain occurred mainly over a specific single flow-gauged catchment. The theoretical basis of this method is set out in a previous report (2), and is not repeated here.

With good fortune some such events were found in the data collected during earlier times, which enabled the flood runoff from the Waihua catchment to be successfully modelled. The unit graph co-efficients were then adapted and made to be applicable to the flow <u>at Matahina</u>, not only at the Waihua gauge itself.

This set a lower “boundary condition” to the speed of the flood flow reaction (due to heavy rainfall) at the most downstream gauged subcatchment of the system. (The Waihua).

Events that yielded data for the Whirinaki River, which is gauged at Galatea, and confirmation thereof by the use of data obtained from the Aniwhenua power station, during times of heavy rain, concentrated in the catchment of the <u>Whirinaki</u>, permitted the flood flow at Galatea, due to such heavy rainfall to be modelled, again with Unit Hydrograph analysis. In view thereof that the resultant hydrographs of flow at Aniwhenua and at Matahina (due to heavy rainfall over the Whirinaki catchment), can only peak some hours <u>later</u> than passing the Galatea flow gauge, which lag times can be reasonably well estimated, this effectively sets an upper “boundary condition” to the interval of time required for the flood peak to move down from the Galatea gauge to Aniwhenua and then to Matahina.

The series of co-efficients representing the unit hydrograph from the Waihua catchment (at Matahina) obviously has the shortest time from its start to its peak value. On the other hand, as mentioned above, the series of co-efficients representing the unit hydrograph from the Whirinaki Catchment at Matahina (not at Galatea) has the longest time from its start to its peak i.e. from the first co-efficient to the highest.

This then enabled the unit graph co-efficients for the Horomanga, (the biggest ungauged tributary) which is located about halfway between the Waihua confluence (with the Rangitaiki) and the Whirinaki confluence, (with the Rangitaiki), to be interpolated with reasonable certainty, thereby enabling the structure for modelling the flow from the very high yielding Horomanga River and, therefore, of the total flow at Matahina, to be determined. In other words, as long as the relative phasing between the three sets of co-efficients is preserved, the result of the total flow as calculated from the individual three "unit graph" catchments could be compared to the total flow as observed at Matahina during peak flood periods.

The July 2004 floods produced sufficient data for the approach followed above, to be confirmed and for the unit graph coefficients to be "fine-tuned", but with preservation of the relative phasing.

The prediction of flow from the upper Rangitaiki (as measured at Murupara) was not handled by the unit graph method.

The diffuse direct runoff that reaches the Rangitaiki River downstream of the Galatea gauge, but upstream of the Horomanga confluence, taken together with the diffuse direct runoff that originates downstream of the Horomanga confluence, but upstream of Aniwhenua, was "piggybacked" on to the estimated Horomanga flow and transposed to Matahina with the Horomanga unit graph.

Similarly, the diffuse runoff that reaches the Rangitaiki downstream of the Aniwhenua flow gauge, but upstream of the Waihua confluence (with the Rangitaiki), taken together with the diffuse runoff that reaches the Rangitaiki downstream of the Waihua confluence, but upstream of the Matahina dam wall, was "piggy-backed" on to the estimated Waihua flow component (and added at Matahina).

Allowance for some contribution from the potential contributing area from the western side of the main Rangitaiki River (downstream of Murupara) was also made. This does not seem to be very significant as the catchment to the west is akin to the catchment of the upper Rangitaiki River (Kaingaroa Plateau).

The problem was that the flow at a certain time at Matahina will consist of the sum of the flow at Galatea, say N hours ago, plus the flow at Waihua, M hours ago, plus the Horomanga contribution (about $\frac{N+M}{2}$ hours ago), plus the Murupara contribution, P hours ago, and finally the seepage flow, originating from diffuse sources directly from below the land surface into the river, for which a lag time is not needed.

In order to obtain values (for the initial flows) for the individual components of the total flow at Matahina, coming from each of the three "unit-graph" sources, and the two other sources as set out below, it was necessary to split up (disaggregate) the total flow at Matahina, so as to allocate this total flow between the said sources.

It will be appreciated that in order to do this, it is necessary to know the respective lag times for the four rivers. Admittedly these will also likely be a function of the magnitude of the total flow itself, but if the July 2004 flood data is used for calibration (which event is provisionally estimated to have had a return period of around 100 years) then the lag times derived from the July 2004 event will be the shortest (i.e. they will have the quickest reaction to rainfall), so that the use of these lag times will err on the conservative side during occurrence of events with lower flow. The only consequence of such error (if any) will be that the actual arrival time of the peak flood flow may be a bit later than the predicted arrival time, which will be conservative.

During the analysis of the Waihua flows, it became evident that the flow at Matahina from the Waihua (including its upstream and downstream "piggy-backing" areas), is around three times that which it would be if the areas piggy-backing on to the flow as measured at the flow gauge of the Waihua, were not included.

The data of flow at Matahina (and at the river flow gauges) shown on Figure 3, (In Appendix 8) was used to extract a composite flow, which was assumed to consist of three times the flow observed at Waihua (at 2 hours earlier) plus the flow observed at the river gauge just below Aniwhenua, 5 hours earlier.

The result of this comparison is shown in Figure 4, (also in Appendix 8) the reader may look at Figure 4 and draw his own conclusion about the above hypothesis. Based on this, as well as on other measurable river characteristics, it was taken that flood flow measured at Galatea takes around 11 hours to get to Matahina (for flows such as the July 2004 event).

The model adopted takes into account the flow contributions from five distinct sources, namely:

(i) from the Whirinaki River as measured at Galatea,:

(ii) from the Horomanga River (plus its piggybacking areas),

(iii) from the Waihua River (plus its piggy-backing areas),

(iv) from the upper Rangitaiki River (as measured at Murupara), all of them transformed to flows at Matahina, and then adding

(v) the diffuse (subterranean flow) contribution.

During the time when the gauge at Te Teko was being trialed as the point for the forecast of flow peak and arrival time, an analysis of the diffuse subterranean flow component, that accretes between the Matahina dam and Te Teko, was carried out. This was done during periods identified as dry spells. The results of this are shown in Appendix 3. Basically this seepage is estimated to be of the order of 3 cumecs. Although this is not much flow (relatively speaking), it must be included in the flow estimated to arrive at Te Teko about 3 to 4 hours after peaking at Matahina. This is mentioned for completeness sake as the model currently functions to forecast at Matahina, not Te Teko.

During future use of the method described in this report, the flood manager will have to obtain the flow actually let out at Matahina, at the time of prediction (TOP), directly from the operator on duty at Matahina at the time, or from the Trust Power offices in Tauranga. (This must include flow through turbines plus spill, if any). The staff at Matahina use a factor of 1.84 to multiply the Megawatt output in order to calculate cumecs through turbines.

As said, a lake level change of 10 mm during one hour can be taken as representing approximately 6.5 cumec of flow, which is added on to (or subtracted from) whatever flow is being let through the turbines at Matahina, plus that which is being spilled, if any, in order to estimate actual flow arriving at the dam.

Rapid input of observed hourly rainfall data was achieved by creating a data source (Hydrotel to EXCEL), which permits data to be block–transferred (copied and pasted) into the input data templates of the model spreadsheets. The details are given in the User Manual.

The model at present operates on rainfall data that has been actually measured, but the model has been constructed so as to incorporate also hourly rainfall predicted to fall during the following 48 hours (to cover the possibility that estimates that "look further into the future" can be made later) without the current model needing subsequent modification. The Technical Service Directorate is currently trialling technology to use such hourly-rainfall predictions, in a collaborative project with NIWA (see Ibbitt et al), (3). An aspect which has to be kept in mind is that the statistical properties of the predicted hourly values of rainfall as distributed in time and space must be the same as those of natural rainfall, if it is to be disaggregated from a single global value (mms per hour) over the entire catchment. If this is not done, then a significant error may result.

A copy of the abstract of Ibbitt's paper in this regard is annexed to this report (Appendix 1).

Chapter 3: Results Obtained

A Flood Flow Prediction Model for the lower Rangitaiki River has been developed and is available. It would be good to compare our model with the NIWA –owned "Top Model", using the same data set. This will provide a direct comparison of our rainfall-runoff model with the NIWA-owned model, i.e. not a comparison of a model based on rainfall prediction, with a model (geared as of now) to rainfall as measured. The unit graphs used during development of this model, were based on the Clarke-Johnston method, as set out in Johnstone and Cross (4).

It has also become evident from the present study that the original BOPCC hydrographs shown in their study of the Rangitaiki Scheme, peak quite a bit later than was now found, however this does not detract from its significance, as little data were available for calibration at that time. The valuable contribution to that study by Mr Griffiths (hydrologist with the BOPCC at the time), can be seen in the quality and number of reports that Mr Griffiths prepared.

3.1 Calibration of Model

The July 2004 flood was an ideal event for calibration of the model, being a "single-peaked" event.

Using that data, a continuing loss rate of 1.6 mm/hour and an initial loss of 28 mm over the catchment was obtained. This ties in with analyses made previously, but also highlights the need for more testing with other data, including summer data, to check if the summer loss rate could possibly be higher. Further investigation will also make possible the correlation of the initial loss with an index of antecedent wetness, which can be developed and will yield a (daily) continuing value for the degree of risk being run at any time (after good rain) but especially during winter months.

3.2 Use of Model for July 2004 Floods

After calibration of the model, it was used to make a series of predictions that could have been made, if the model had been available at the time.

Hind casting "predictions" were made at three hour intervals, starting at 21h00 on the 16 July 2004, then at midnight then at 03h00, then at 06h00, then at 09h00, then at 12h00, then at 15h00 and finally at 18h00, all on 17 July 2004.

This series of predictions are shown in Figures 5 to 12. On each of these figures, the hydrograph that actually occurred later, (i.e. as was observed during the event itself) is every time showed to start at the same time as the time of prediction. The reader must realise that comparison of the flows shown as predicted, with flows later obtained from staff at Matahina i.e. later when it was already history (especially when making such comparisons during the earlier stages of the flood) must not lead to a conclusion that the prediction was in any way wrong. This is because the higher flow, as observed later, was caused by rainfall not yet known at the time when the prediction was made, so it could not have been taken into account at the time of prediction. A valid conclusion of model and precision adequacy can only be reached when all the rainfall is taken into account. This is shown in Figure 2, (In Appendix 8) from which both the running loss rate (1.6 mm/hr) and an initial loss (28 mm average) was obtained.

Chapter 4: Conclusions

Flood flows are notoriously difficult to measure with precision, and the model accuracy achieved is of the same order of magnitude as measurement accuracy in general, especially during the vital ascending limb of the flood hydrograph.

In the following table a summary is given of the ratio of the predicted peak flow, as a percentage of the measured peak, and the time available between the time of prediction of the peak, and the time of its predicted arrival, as well as the interval of time that was available between prediction time and the actual peak arrival time. The peak flow at Matahina was taken as around 745 cumecs and occurred at about 14h00 on 18 July 2004.

Date	Time when Prediction was made T.O.P	Peak Flow Predicted at T.O.P (cumecs)	Hours Predicted to elapse between T.O.P and arrival time of peak	Actual hours that passed between T.O.P and peak	Peak Flow as Predicted at T.O.P as percentage of actual peak	Figure on which prediction is shown
16.7.2004	21h00	230	22	40	31%	5
16.7.2004	24h00	370	22	37	50%	6
17.7.2004	03h00	505	22	34	68%	7
17.7.2004	06h00	565	20	31	76%	8
17.7.2004	09h00	625	20	28	84%	9
17.7.2004	12h00	650	18	25	91%	10
17.7.2004	15h00	735	15	22	99%	11
17.7.2004	18h00	750	12	20	101%	12

Taking into account that at an inflow of 170 cumecs, spill should preferably commence, according to the Matahina consent conditions, it is evident that the gates at Matahina could already have been opened between 21h00 and 24h00 on 16 July, compared to the time that spill actually commenced, which was at 10h30 on the next day. Before 10h30 a flow of 147 cumec was passing through and at 10h30 it was increased to 183 cumecs, when the first gates were opened. (More than 12 hours lost). It would have been possible to commence major spill, almost 34 hours before peak arrival time.

From the set of prediction hydrographs, and the summary in the table above, it can be seen that the present model would have predicted the peak quite a bit earlier than that which actually occurred. However, until the model is tested on all the possible available events, I would prefer to retain this conservatism in the model. The peak predicted during the earlier stages appears low, due only to all rainfall data not yet landed at that time.

It should be noted that the flow of 505 cumecs was able to be predicted with data as at a TOP of 03h00 on 17 July 2004. The data would only have been available some time later because data transmission and calculations also takes time. But note that a prediction of 505 cumecs, based on rainfall data, as landed by 03h00, has been followed by the observed peak some 34 hours later. So if data transmission takes up 1 or 2 hours then that still leaves a good warning time.

Attached hereto is a map, showing the catchment of the Rangitaiki River system, including its tributaries, the various flow and rainfall gauges, catchment boundaries, outfalls etc. Many of these gauges belong to NIWA, from whom excellent cooperation was forthcoming during the July 2004 event.

Chapter 5: Recommendations

Following what is said in the body of this report and also due to the exposure I had in the study, to the circumstances surrounding the Rangitaiki system, the following recommendations are put forward for consideration:

(a) That the model be tested on all other flow events for which data is available or for which data may be obtained, including Matahina archived data, FCF forest rain gauge archives, Aniwhenua data and whatever can be located.

(b) That the temporary rainfall gauge at Matawera be upgraded to a permanent station.

(c) That the set of hydrographs at present used be reconsidered after the data in (a) above have been located.

(d) A study be made to quantify whether significantly more energy could be produced if better flow forecasting were to be possible.

(e) That more autographic rainfall gauges be installed, one in the gap between Matawera and Koranga and two in the Upper Rangitaiki. The proposed gauge in the gap mentioned above will also serve as a back-up for the Whakatane River Flood Forecasting Model.

Another station was installed by EDS but was repeatedly vandalised. During the July 2004 the Huitieke gauge came unserviceable. This is a common occurrence with autographic rain gauges.

With respect to the two gauges proposed for the Upper Rangitaiki, it must be noted that the catchment map in Figure 1 also shows closed stations. In the whole of the Whirinaki and Murupara catchments we have only one gauge at Kokomoka that is functioning. We need at least one near Minginui and at least one more at or around Wheao power station.

It could be considered that FCF stations be coupled with the Hydrotel System. This can best be arranged by management.

It has become evident that the fast rising flow contribution from the Waihua catchment (39 km^2) plus the upstream (40 km^2) and the downstream (25 km^2) contributing catchments that reaches Matahina (see Catchment Map on Figure 1) is much more important than previously realised.

(f) An autographic rain gauge that is well positioned should urgently be installed in the Waihua catchment, and supported by a second one at the site of the power station (Matahina) in case of malfunction of the proposed primary Waihua gauge. This must please be done as soon as possible.

(g) That the total flow at TOP at Matahina (flow through the turbines plus spill, if any) be available on a real time basis or even fully integrated into Hydrotel. (In the interim it should be made available telephonically from Matahina), upon request from the Flood Manager on duty.

(h) The possibility be considered of a joint (or linked) forecasting model or alternatively that Environment Bay of Plenty does it on contract to Trust Power.

(i) Lastly, I pose the question whether full time surveillance (by 3-hourly prediction) will work, because it will need somebody to do it round the clock in times of flood risk. The July 2004 flood started on a Friday night when at 9 o'clock in the evening it was already possible to know that 170 cumec will be exceeded and by midnight 370 cumecs could have been predicted.

It will need continuing human intervention, dedication and possibly staffing to maintain surveillance on a round the clock basis. The costs of this will have to be calculated. Intensive surveillance could be restricted to flood risk times.

References

Environment Bay of Plenty Environmental Data Services Section: Data Summaries and Unpublished Data (1)

Herbst, P H (2001): The Unit Hydrograph as used for Flood Flow Forecasting in the Bay of Plenty Region (2)

Ibbitt et al (2003): Comparison of Meso-scale Forecast rainfall with Measured Rainfall. (3)

Johnstone and Cross: Elements of Applied Hydrology (para 9-12) (4)

P L Blackwood: Review of the Flood Carrying Capacity of the Rangitaiki River below Edgecumbe (October 2000) (5)

Appendices

Appendix 1 – Abstract of paper by Dr Richard Ibbitt (NIWA) delivered at a symposium of the Meteorological Society, Wellington (2003)

Appendix 2 – Operating instructions for use of Excel files to make predictions based on final model structure.

Appendix 3 - Results of Analysis of Base Flow (seepage flow) into the lower Rangitaiki.

Appendix 4 – Site map of the Aniwhenua Power Station and Reservoir basin, supported by a sketch showing relevant technical details (with acknowledgement to Bay of Plenty Electricity)

Appendix 5 – List of flow gauges and rainfall gauges used for the analysis.

Appendix 6 – Description of Hydrotel-to-Excel application software, which is the data source for the model.

Appendix 7 – Figures comparing hydrographs as forecast with the actual hydrographs as observed and recorded during the evolution of the flood event.

Note – A map of the Rangitaiki Catchment and principal sub catchments is shown in Figure 1.

Appendix 1 – Comparison of meso-scale forecast rainfall with measured rainfalls

Comparison of meso-scale forecast rainfall with measured rainfalls

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The way forward for flood forecasting in New Zealand is through the use of quantitative rainfall forecasts. This is because our rivers are short and steep and so floods travel quickly. Using upstream river/rainfall measurements gives only a short period of warning. To extend the period of warning so that the response to a flood event is more than just flood "fleeing", requires accurate forecasts of the rainfall for the next 48-plus hours. NIWA is currently testing a flood forecasting technique that uses quantitative rainfall forecasts from a meso-scale weather model. Initially the modelling work focused on the S. Alps where it soon became apparent that the meso-scale models under-estimated the measured rainfall by about a third, Copeland et al. (2000), Henderson et al. (2002). The reasons for this under-estimation were attributed partly to an initial poor estimate of the drop size distribution parameter, and partly to the coarse representation of the orography in the model leading to an under-estimate of uplift rates. Nevertheless, the forecasts were sufficiently close to measurement to be encouraging. The initial flood work has been extended to the Rangitaiki and Waipaoa catchments in the Bay of Plenty and Gisborne regions. Each day meso-scale rainfall estimates are made available to collaborating agencies on a 20 km grid. Environment Bay of Plenty operate a number of telemetric rain gauges that are reasonably close to the centres of the grids for which rainfall is forecast. For a number of recent events the gauge totals have been extracted for a range of rainfall events and compared with the corresponding forecasts for the same events. The comparison shows considerable variation between events. However, for the larger events the model forecast rainfall tends to under-estimate the measured data by a factor of five. This is again attributed to the coarse representation of the orography leading to insufficient uplift in the meso-model forecasts. Evidence for this is seen in the fact that most of the events analysed have been of rainfall sweeping in from the south-east. Under these conditions the large events on the Gisborne side of the mountains drop their rainfall near the coast and inland areas receive less rainfall that coastal areas. However, for small events the efficiency of the rainfall process is reduced and more rainfall is carried over the mountains relative to what falls nearer the coast.

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Appendix 2 - Operating Instructions for Rangitaiki Flow Prediction

1 Introduction

If you are making a Rangitaiki prediction say on 24 March 2004, first subtract 4 days from the 24th and enter this date (20 March 2004) as the start date for the Rangitaiki Group (hourly data) from the Hydrotel to Excel data source.

Record here: Start date .... Today's date ....

Time up to which data are available (T.O.P.)..................

Export this data to new sheet.

Decide up to which hour of today sufficient usable data are available or may confidently be assumed, and record this as to T.O.P. (Time of Prediction).

Record it here. T.O.P. = ...@ .... hours on............... (date)

Record here: Matahina flow at T.O.P....... @ .... hours on............ (date)

2 Spreadsheet Preparation

Open "Murkop" and display sheet "Master Input Space" then copy zeroes into all cells of the three data templates (raw data, edited data and the "read -from" template) Paste Special, (values only).

Display sheet "Matahina Disaggregation Procedure". Enter today's date into cell F8, current month name in cell B13 and the T.O.P into cell Al106.

3 Data Entry

Display "Master Input Space" then paste data up to T.O.P. from the Hydrotel Source and also into the "edited data" template. After editing, paste edited data into the "Master Input Template", which is also located on the "Master Input Space" worksheet.

Display Matahina Disaggregation Procedure" (MDP).

The hourly data for the four flow gauges (Murupara, Galatea, Waihua and the flow obtained from Matahina) are automatically read into columns F, H, J and L.

From the row where the data stops, all flow data will have zeroes in the cells for the hours for the rest of the day on which the prediction is done (24 March in this example).

4 Horomanga Flow Calculation (Mainly Automatic)

Because the Horomanga Stream is ungauged, the Horomanga hourly flows are next calculated. First set to zero, from cell S22 to Cell S151 (from column M) (Paste Special Values only).

The Horomanga flows are calculated automatically, and from the "choices" columns O, P and Q, select the best choice of Horomanga estimate, and enter into column S (Cell S22) (Paste Special, Values only) - Column O is the best one, if available. This option is given in case of partial data loss, during flood conditions.

We now have, on the date and at the time of T.O.P., flow data from the first hour of the day, four days ago, for the flow at Murupara, Galatea, Horomanga, Waihua and Matahina, up to the T.O.P as used for this prediction, being made today.

The aim is to calculate starting values for the flows originating from Murupara, Galatea, Horomanga and Waihua as flowing at Matahina where it is all mixed, at the T.O.P (but mixed). This means that the Matahina flow must be "disaggregated". (Split up). (These include the adjacent "diffuse" runoffs for the adjacent areas, as described in the main report).

The Galatea flow is lagged by 11 hours, the Horomanga (plus adjacent areas) flow is lagged by 7 hours and the Waihua (plus adjacent area) flow is lagged by 2 hours, to give estimates of their flow magnitudes at Matahina at T.O.P.

Now go to the area of sheet MDP between cell U94 and AL164.

5 Calculation of Diffuse Flows

This part requires manual interpretation and attention. The yellow box, from cell AF94 downward, shows the estimated hourly values of "flow at Matahina from other diffuse sources". These data are also given for those hours of data already available for today (the day in which you are) from cell AF118 downwards. When you see the large negative values, then you are already past the last hour of available data. Take the average of all the values in the yellow box, plus the values for all the hours, available for today (from midnight up to T.O.P.) This is easily obtained from the "NUM Box" below right on the screen. (Right click on average).

Record here: Estimated Diffuse Flow at Matahina from "Other Sources" ....

Give greater credence to the values calculated for the most recent hours, in choosing a value for "flow at other diffuse sources". Take an average and consider if it can be rational and therefore acceptable.

6 Initialising Flows

Now choose reasonable values for the flows at T.O.P, at Matahina coming from Murupara, Galatea, Horomanga and Waihua respectively. The location where these are to be found, is to the left and slightly below the yellow panel mentioned above, and includes the estimated flows from the "piggy backing" flows added to Waihua and Horomanga. Read these values from the appropriate column in the first row with zeroes. The total Matahina flow (as calculated) will appear in cell AI161.

Record it here: Murupara flow..... Galatea .... Galatea flow....... Horomanga flow...

Waihua flow............ Matahina flow................(Calculated)....... Other Diffuse sources...................

Matahina (observed) ....

7 Murupara Flow Prediction

Now display the worksheet "Murupara predicted flow".

All available flow data at Murupara are shown in Column J, next to the time at which it was observed. This flow should exist up to the T.O.P, which will be during "today" (inside the blue block). The component of the flow at Matahina (coming from Murupara), is obtained by lagging the observed flow at the Murupara Gauge for 16 hours into the future, and is shown in Column N.

Now copy the content of column N into column S. Copy data from cell N28 to cell N151 into S28 up to S151. (Paste special, values only).

Use column S to edit the component of the flow at Matahina (coming from Murupara) from where the zeroes begin, depending on the trend expected.

After extending the above "edited" record up to cell S151, copy the contents of column "S" (Values only) into column "U" but only from T.O.P. onward, which can be seen in column J. (In the blue block).

This can best be done manually because the time of prediction will vary from case to case.

The Murupara component of the flow predicted at Matahina, is now copied from column "U" to the "Individual Results" worksheet. First set all values for Galatea, Horomanga, Waihua and Murupara to zero (values only). (This is the worksheet where the predicted flows from all the individual catchments are presented.)

The estimate of "other diffuse sources" is then brought over to the "Individual Results" worksheet from cell AF161 of the "MDP" worksheet.

All that is needed now is to make the flow predictions for the components of flow at Matahina coming from Galatea, Horomanga (+diffuse), Waihua (+diffuse) (and Murupara as estimated above) and bring them all over to the "Individual Results" worksheet. Now open the "Rainfall Themes" worksheet in "Murkop". Then open "Galkop", "Horkop" and "Waikop". These are the "Unitgraph" Catchments. Now enter, from the "Results" column (from cell S13) up to the end, in each of "Galkop", "Horkop" and "Waikop" into the "Individual Results" sheet in "Murkop", where it is summated, the diffuse flow added, and the prediction graph can be then printed from the summated values.

Appendix 3 - Results of Analysis of Base Flow (seepage flow) into the lower Rangitaiki.

[m^3/sec]

Gauging Site	Hours since recession commenced			
	1-350	351-700	580-720	Averages
	Rate of flow at site shown			
	m^3/sec	m^3/sec	m^3/sec	m^3/sec
Murupara	26.30	23.47	22.74	-
Galatea	13.23	6.31	5.01	-
Aniwhenua	58.58	47.28	45.64	-
Horomanga	4.09	2.00	1.63	-
Waihua	1.25	0.62	0.53	-
Te Teko	67.39	53.95	53.80	-
Te Teko, less Murupara, less Galatea, less Horomanga, less Waihua	22.52	21.55	23.89	22.65
Te Teko, less Aniwhenua, less Waihua	7.56	6.05	7.63	7.08
Aniwhenua, less Horomanga, less Galatea, less Murupara	14.96	15.50	16.26	15.57
Total Low Flow from Diffuse Sources	22.52	21.50	23.89	22.65
Valley Road	38.60	17.57	14.82	-

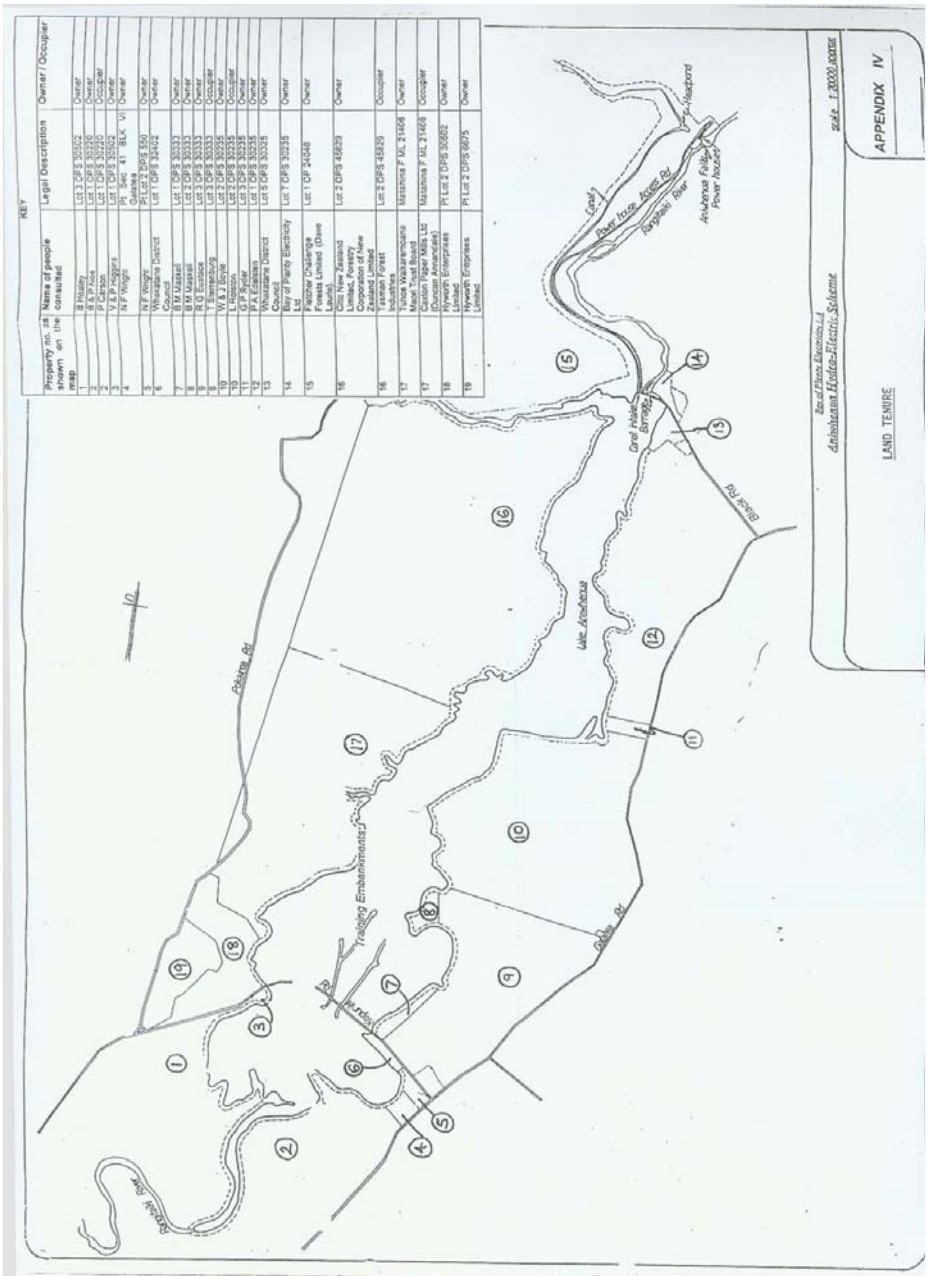
Conclusions

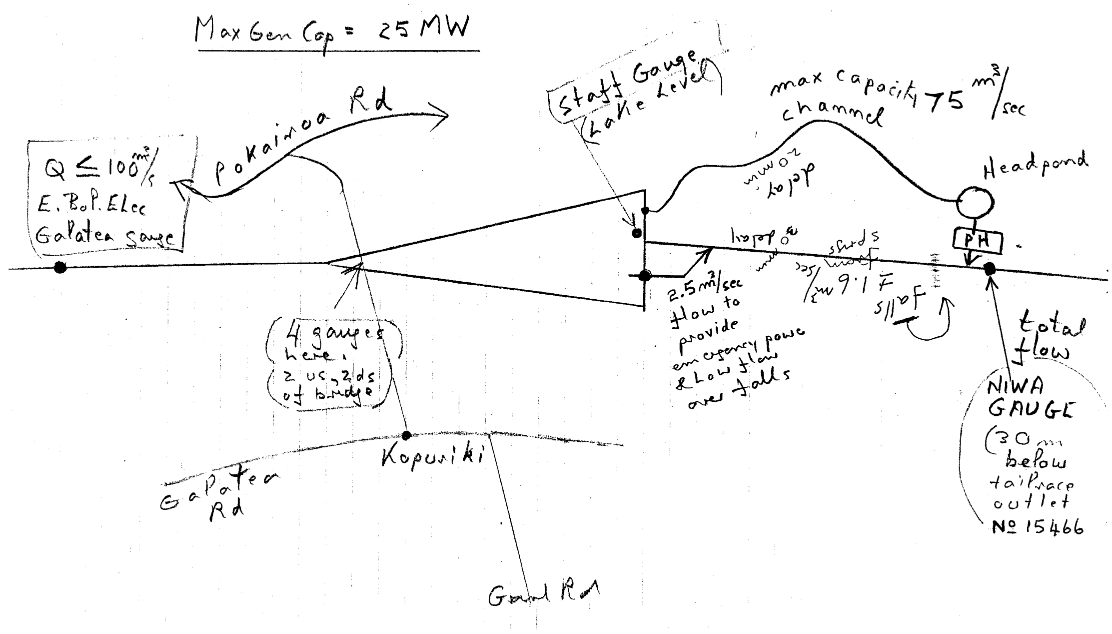
1 The low flow from diffuse sources (which are not measured at the gauging stations) seems not to be affected by the volume of flow from runoff.

2 Low flow coming from diffuse sources upstream of Aniwhenua (i.e. excluding flows measured at Murupara, Galatea and Horomanga), is approximately 15.5 cumec.

3 Low flow coming from diffuse sources downstream of Aniwhenua, down to Te Teko (i.e. excluding flows measured at Aniwhenua and Waihua), is approximately 7 cumec. This can be apportioned as about 50% above Matahina and 50% below Matahina.

Appendix 4 – Site map of the Aniwhenua Power Station and Reservoir basin, supported by a sketch showing relevant technical details (with acknowledgement to Bay of Plenty Electricity)




Max Gen Cap = 25 MW
Pokairoa Rd
Q ≤ 100 m³/s
E.BoP.Elec
Galatea gauge
Staff Gauge
(Lake Level)
max capacity 75 m³/sec
channel
Headpond
PH
2.5 m³/sec
flow to
provide
emergency power
& Low flow
over falls
total
flow
NIWA
GAUGE
(30 m
below
tailrace
outlet
Nº 15466
4 gauges
here,
2 us, 2 ds
of bridge
Kopuriki
Galatea
Rd

Appendix 5 – List of Flow Gauges and Rainfall Gauges used for the Analysis

For the above purpose, I need data to calibrate the model for Rangitaiki, which now has a structure to enable calibration.

Data needed for the June/July 1998 flood event is as follows:

FLOW	**HOURLY FLOW RATES AT:**
Site No. 15408	Rangitaiki @ Murupara
Site No. 15410	Whirinaki @ Galatea
Site No. 15466	Rangitaiki @ Aniwhenua
Site No. 15453	Waihua @ Gorge
Site No. 15544	Waimana @ Range
Site No. 3254	Rangitaiki @ Matahina Total
Site No. 15499	Lake Matahina @ Dam
Site No. 15412	Rangitaiki @ Te Teko

RAINFALL	**HOURLY RAINFALL TOTALS AT:**
Site Name	**Site No.**
Huiarau	876002
Tarapounamu	866801
Huitieke	873002
Kokomoka	868410
Galatea/Whirinaki	Shows its presence on Hydrotel
Aniwhenua	Shows its presence on Hydrotel
Pylon	?Was listed in old data summaries
Te Teko	860710
Pokairoa	Was listed in old data summaries
Range	870201
Goudies	?FCF or EBOP
Awakaponga	769701
Thornton	769810

Appendix 6 – Description of Hydrotel-to-Excel Application Software, which is the Data Source for the Model

AdeptX Ltd
Custom Software Solutions

Scope for Excel view of HydroTel Application

Prepared for Environment Bay of Plenty by AdeptX Limited

Introduction

This document outlines the requirements of a program to transfer data from the HydroTel SQL Server to an Excel spreadsheet.

Usage

The application will be used by staff in the Engineering / Technical Services section and possibly by staff in the Environmental Data Services section.

The purpose for transferring the data to Excel is to enable real-time prediction of flood events. The prediction methodology used with the transferred data, in Excel, is at the discretion of the user.

HydroTel Data

The HydroTel data is stored in an SQL Server database. It has been established three tables contain the descriptive and metered attribute data required in Excel.

Retrieving the data from the server database will not be a problem.

Excel Format

Data transposed from the server database will be placed into a blank Excel sheet in the column format given (date and time down left hand side, site names across top, and metered values as data).

Staff may modify figures in the Excel spreadsheet (to interpolate values or correct anomalies). The application must not overwrite modified figures.

The Application

The finished application will be developed as either an Excel add-in or as an MS Access application. Functionality is independent of platform.

The user will set the application to query the database and return data for a specified period (not greater that 8 weeks). Data can be returned for quarter hour intervals (the default) or for hour intervals. Data returned for hourly intervals will be summed in the case of rainfall, and the last quarter of the hour will be used in the case of water level and flow. For consistency it is proposed that the last quarter hour will be in the range > :45 and <= :00 (where the figures are minutes in the hour for consecutive hours.)

The application will re-query the server database for additions to the data currently stored on the Excel spreadsheet on user request. As stated previously, the application must not overwrite any user-modified values.

Estimate of Costs

Development:	13 hours
User documentation	2 hours

Total estimate of time to develop and deliver the database application: 15 hours

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Chargeable rate is $65.00 per hour (+GST). Estimated cost for developing this application is $975.00 [+ $121.88 GST = $1,096.88 (incl. GST)].

We stress that these figures are an estimate of costs, and actual hours will be charged. Should time be in excess of 10% of estimated hours then approval will be sort.

Contact Details

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Figures

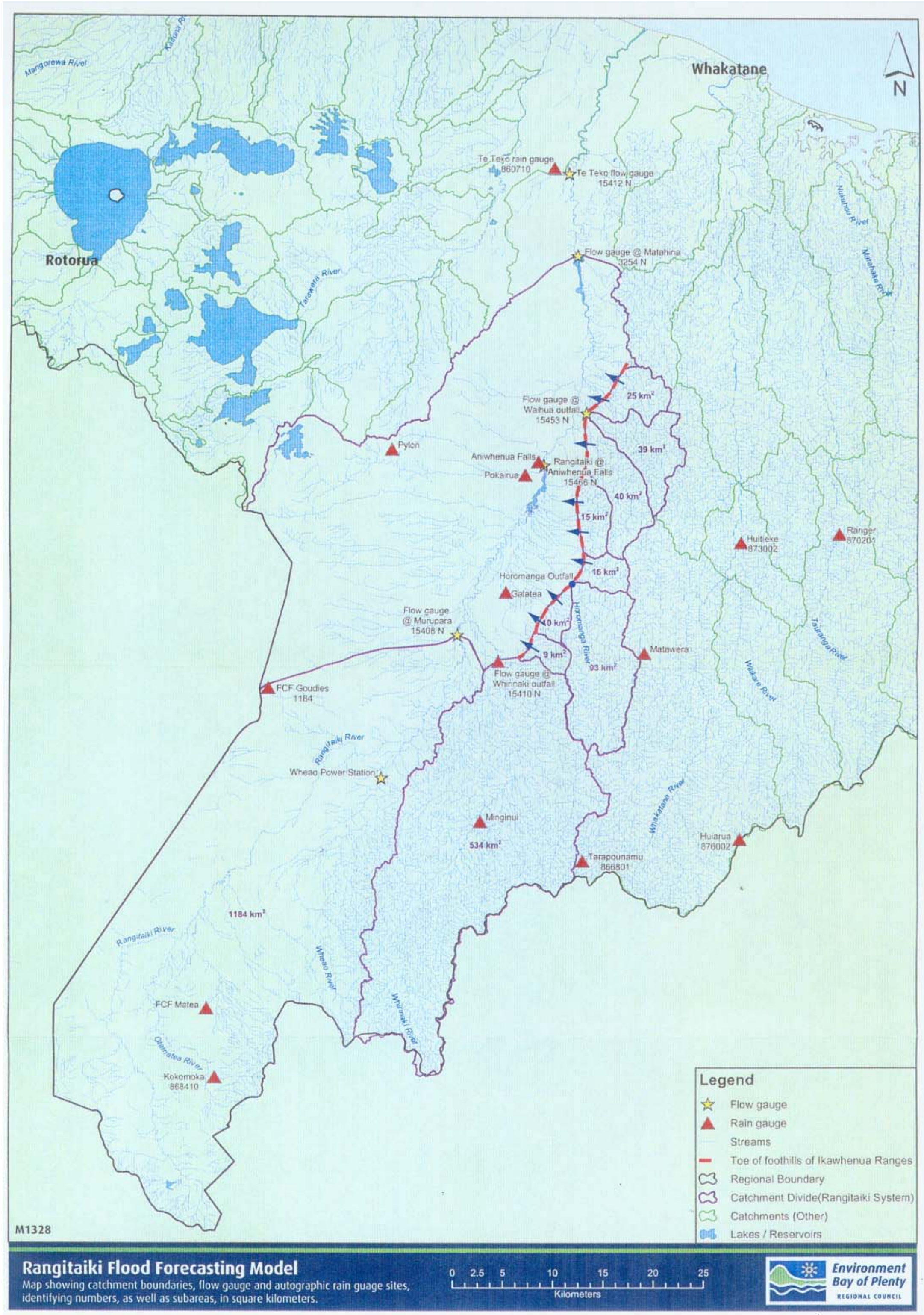

Figure 1 *Catchment map of Rangitaiki River and tributaries, showing rainfall gauges, flow gauges and other pertinent information.*

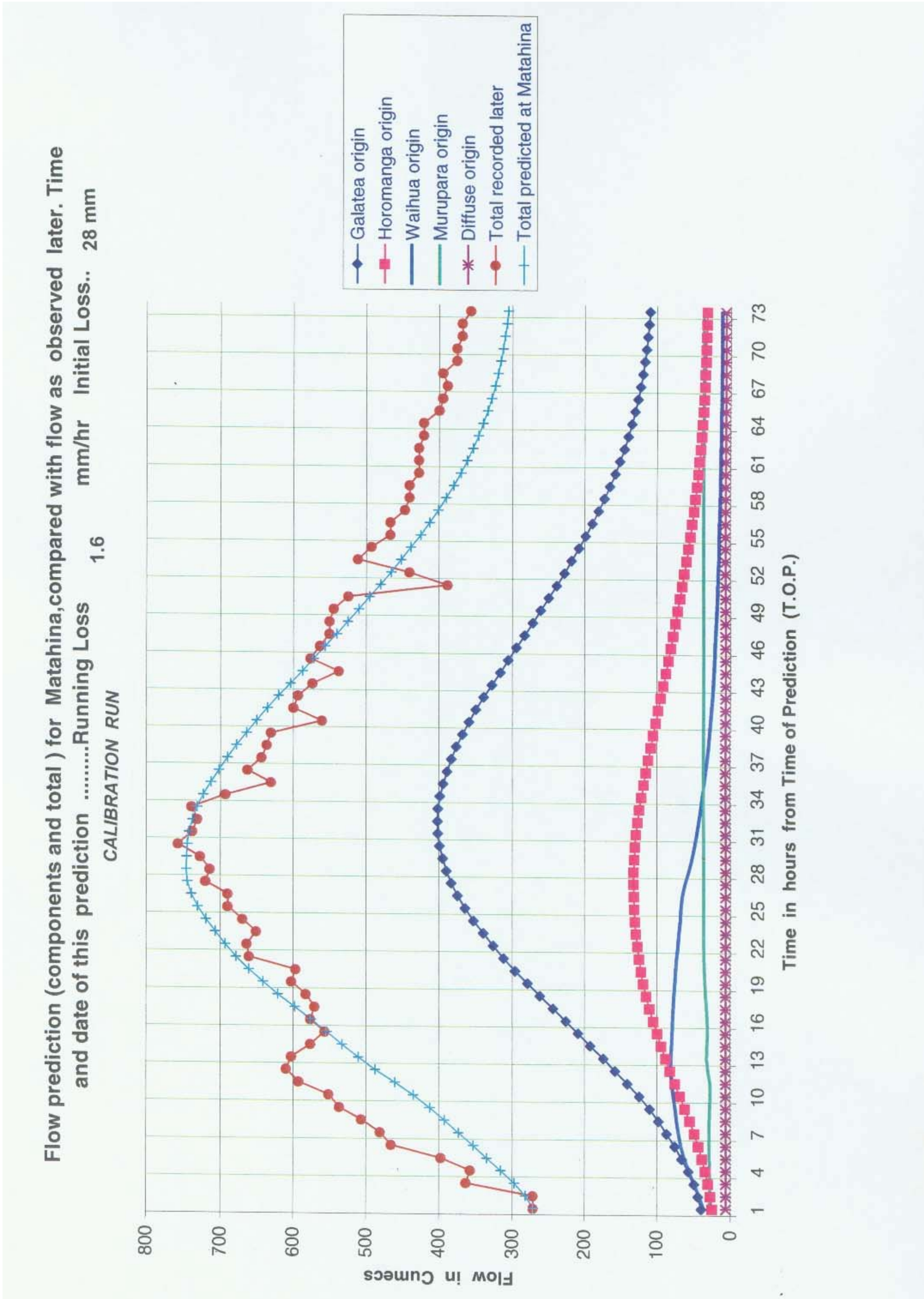

Figure 2 - *Flow as predicted (components and total) for Matahina, compared with flow as observed later. (Calibration Run)*

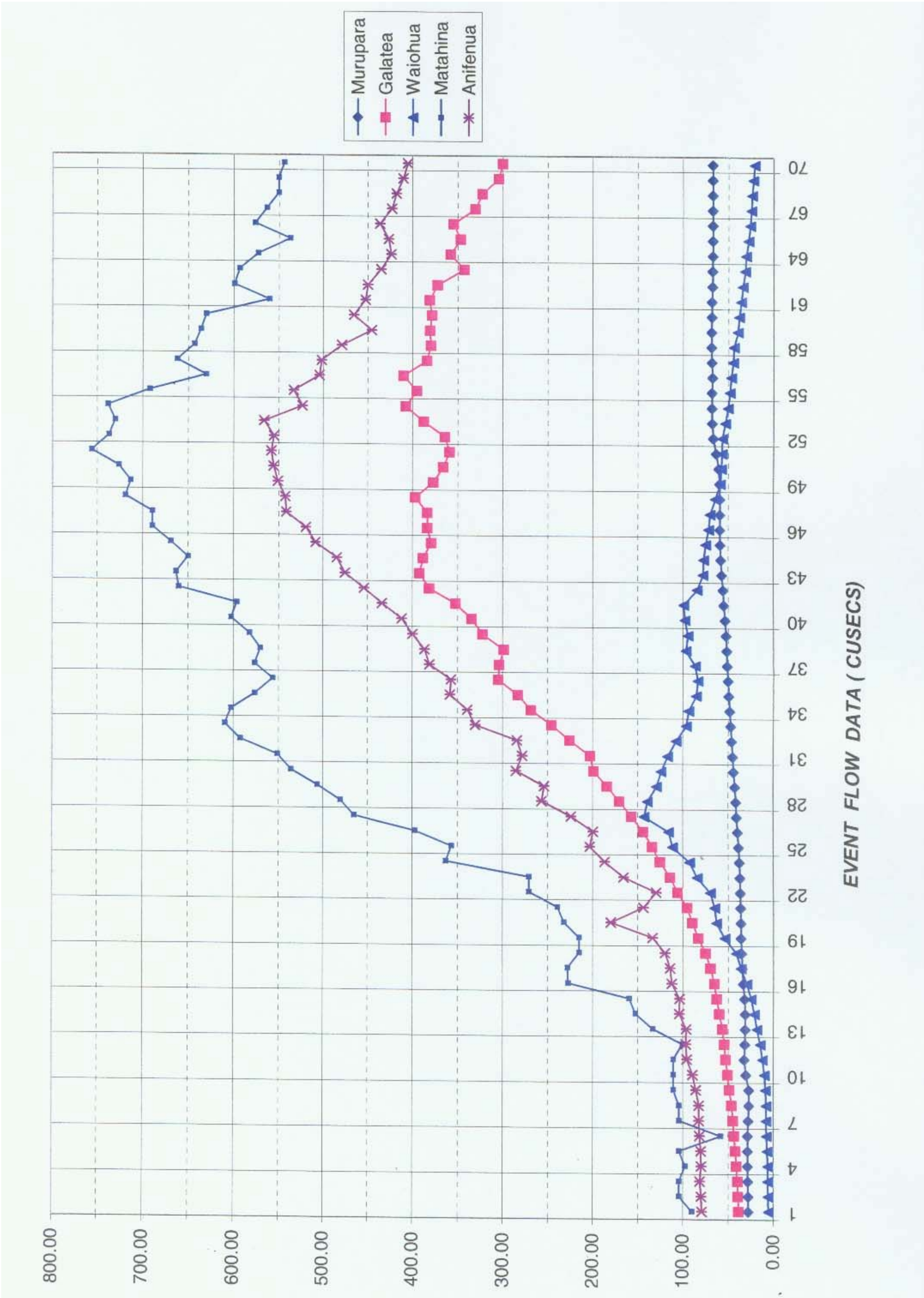

Figure 3 - Event Flow Data (cusecs) (All curves shown here are <u>observed</u> flows)

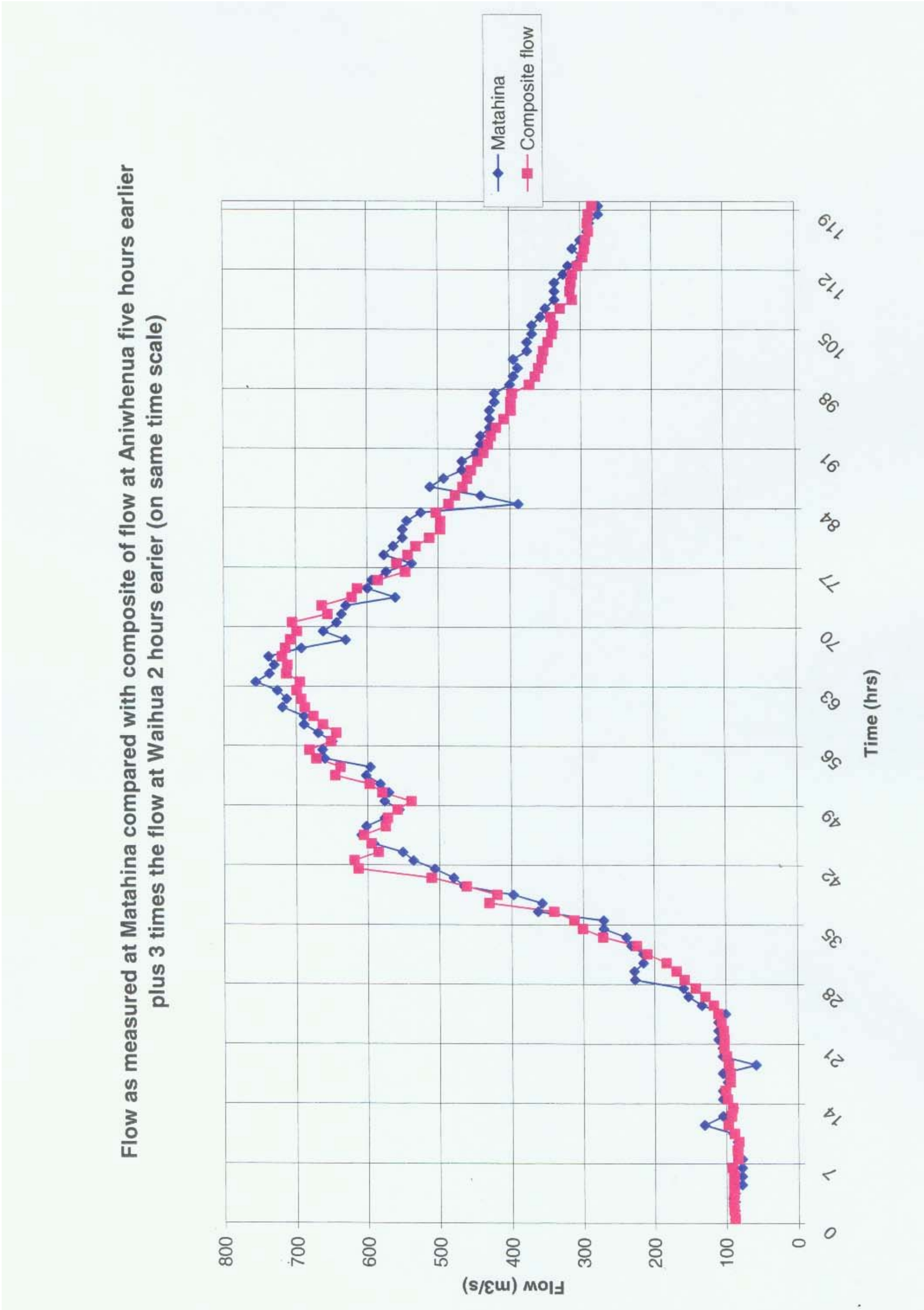

Figure 4 - Flow as measured at Matahina compared with composite of flow at Aniwhenua 5 hours earlier plus 3 times the flow at Waihua 2 hours earlier.

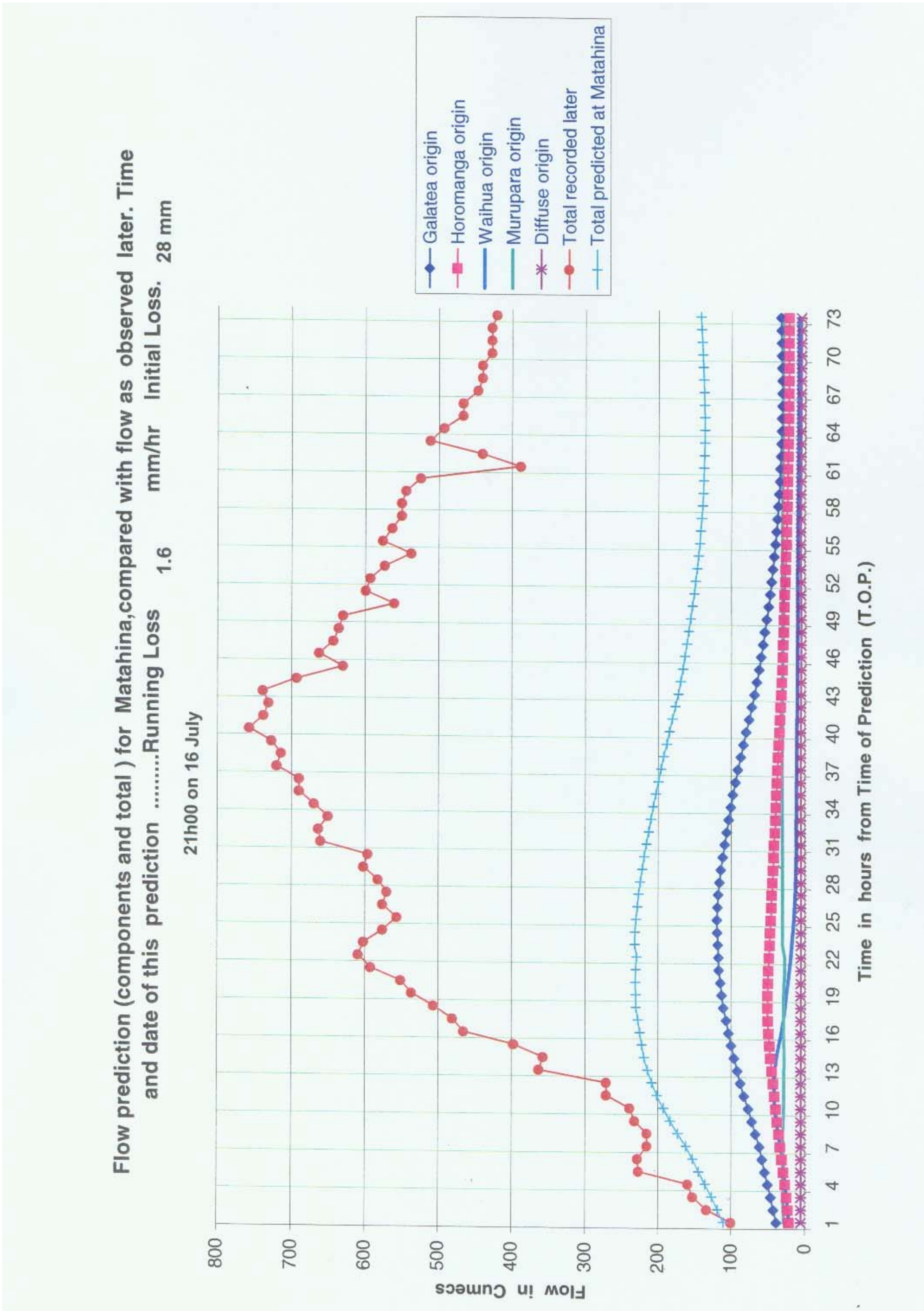

Figure 5 - Flow prediction (components and total) for Matahina, compared with flow as observed later. Prediction time 2100 on 16 July 2004.

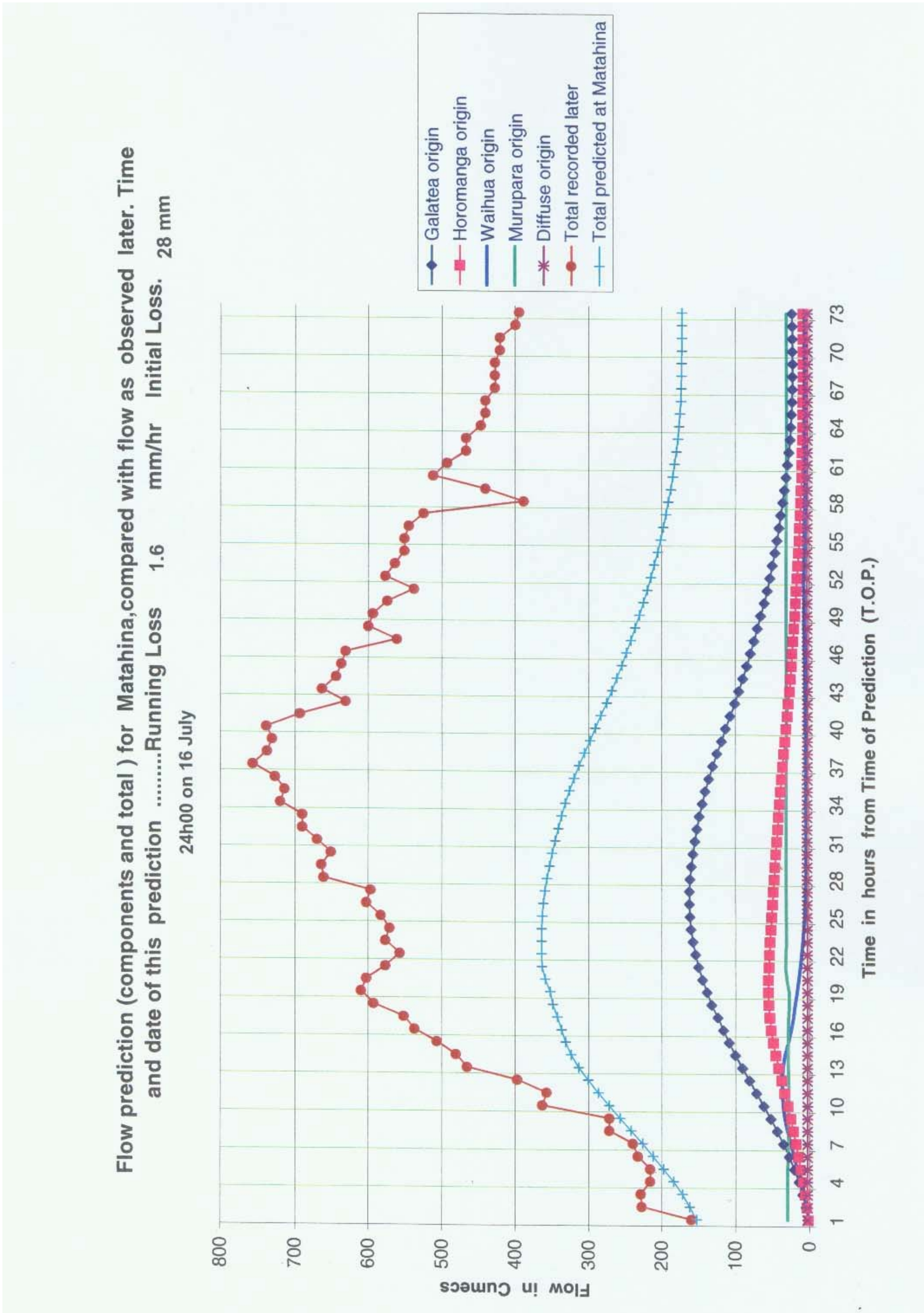

Figure 6 - Flow prediction (components and total) for Matahina, compared with flow as observed later. Prediction time 2400 on 16 July.

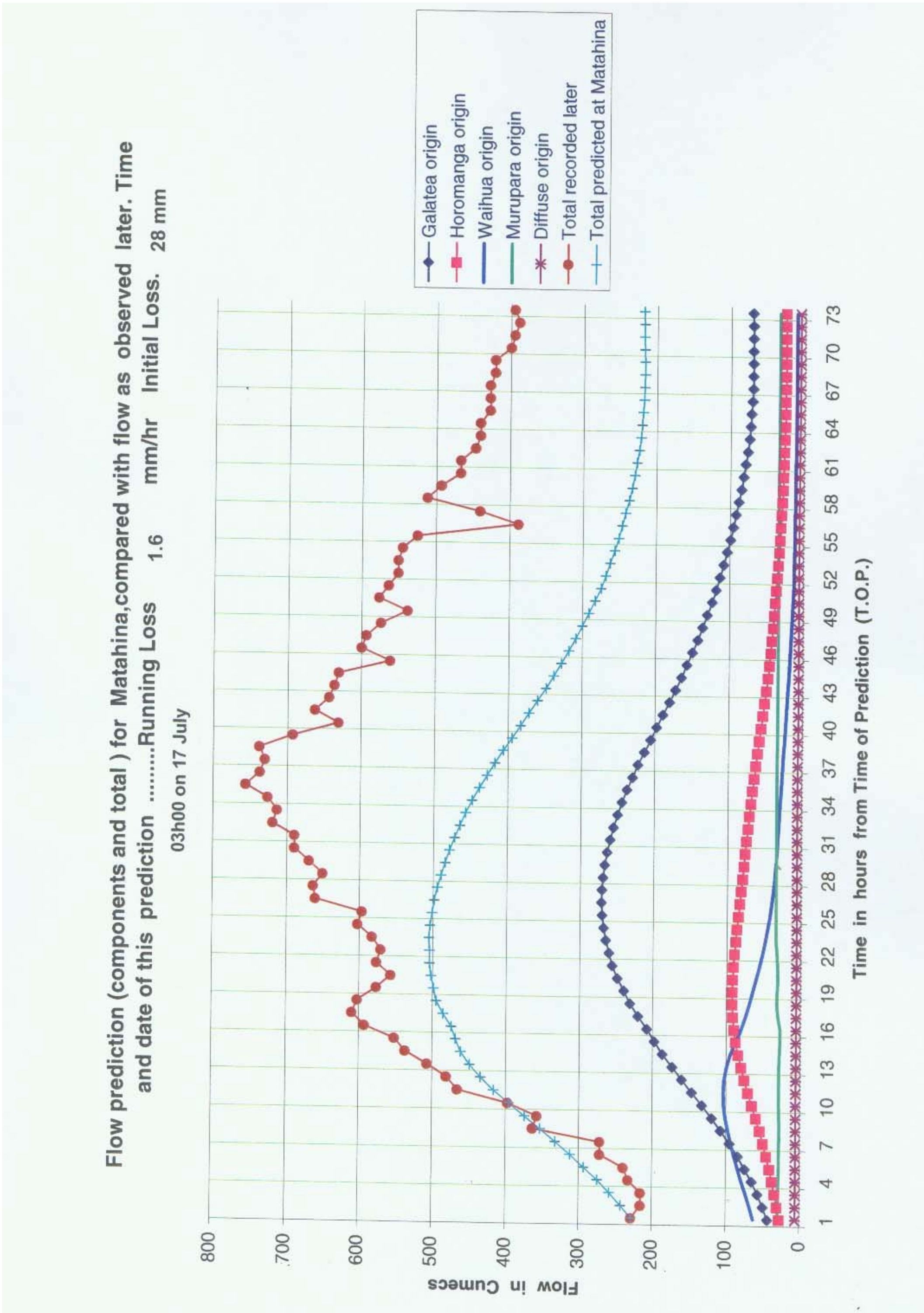

Figure 7 - Flow prediction (components and total) for Matahina, compared with flow as observed later. Time of Prediction 0300 on 17 July.

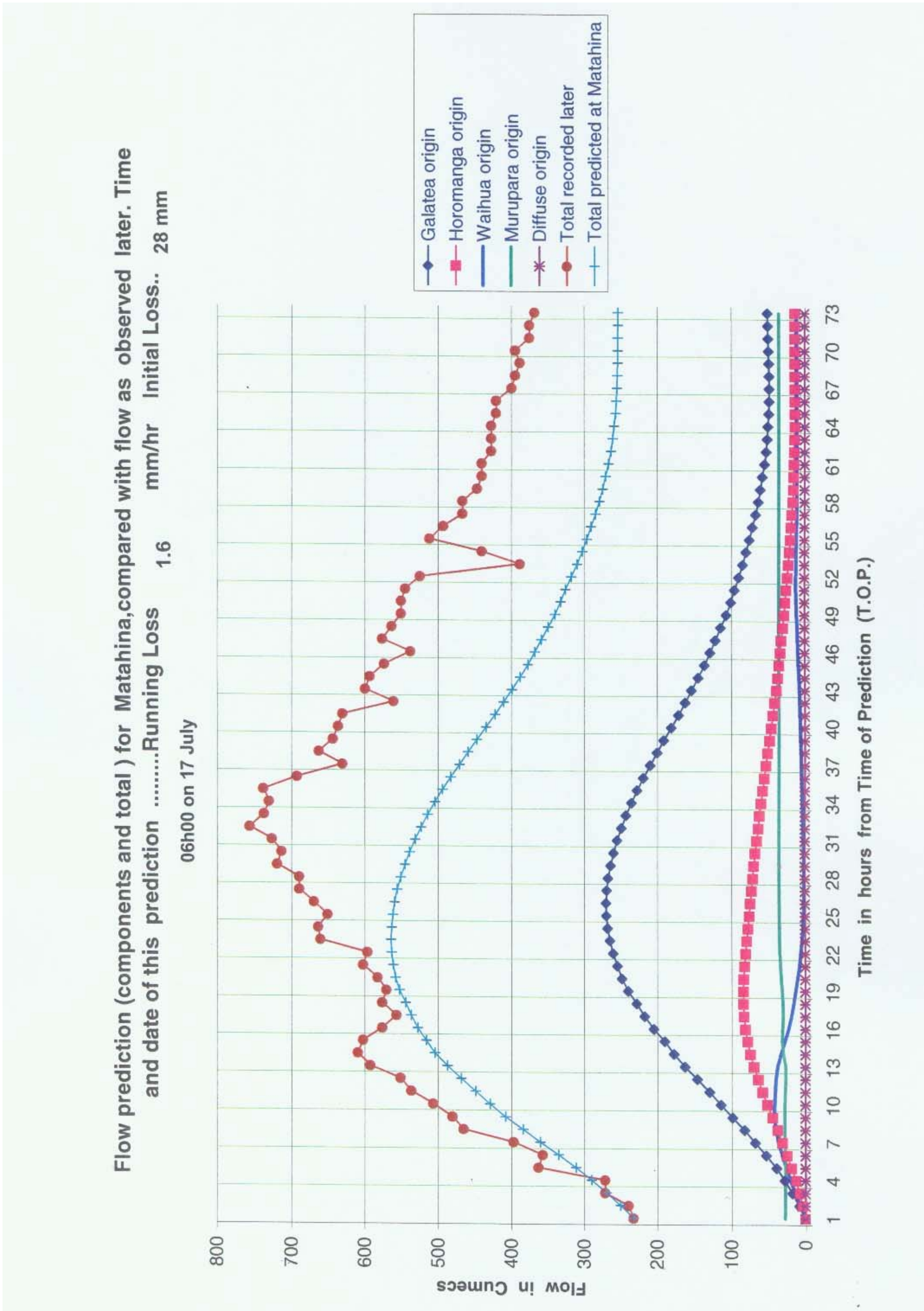

Figure 8 - Flow prediction (components and total) for Matahina, compared with flow as observed later. Time of Prediction 0600 on 17 July.

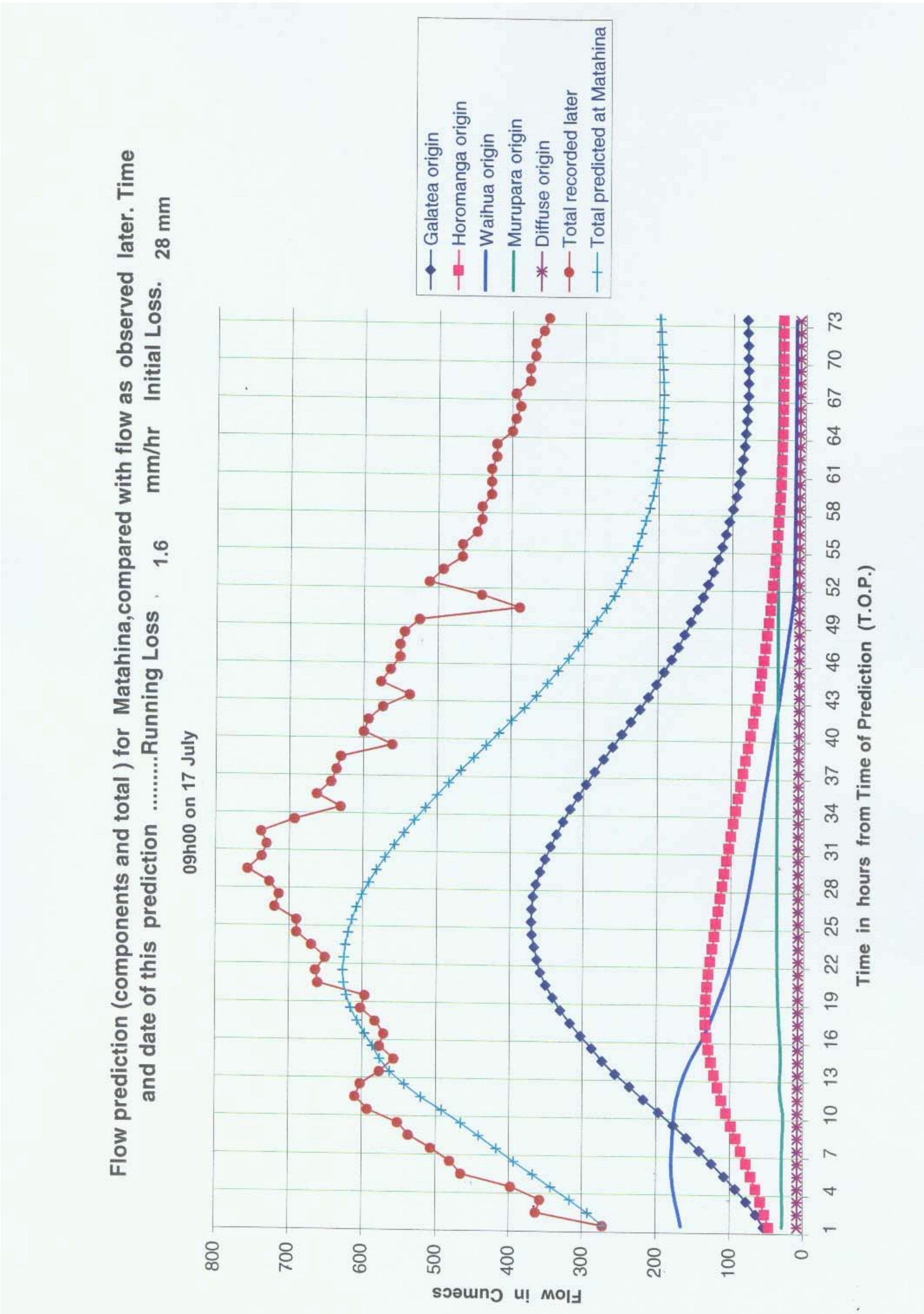

Figure 9 - Flow prediction (components and total) for Matahina, compared with flow as observed later. Time of Prediction 0900 on 17 July.

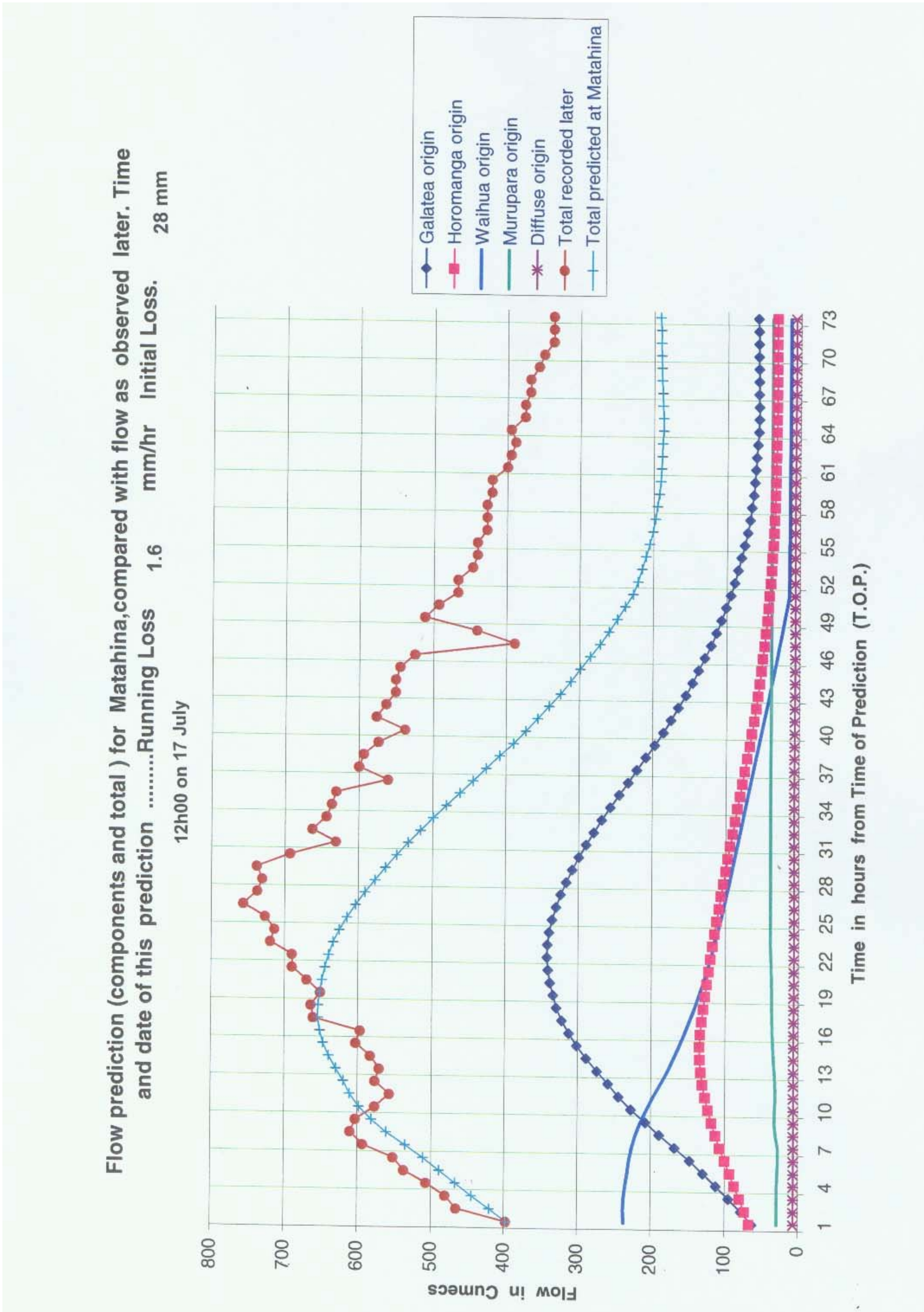

Figure 10 - Flow prediction (components and total) for Matahina, compared with flow on observed later. Time of Prediction 1200 on 17 July.

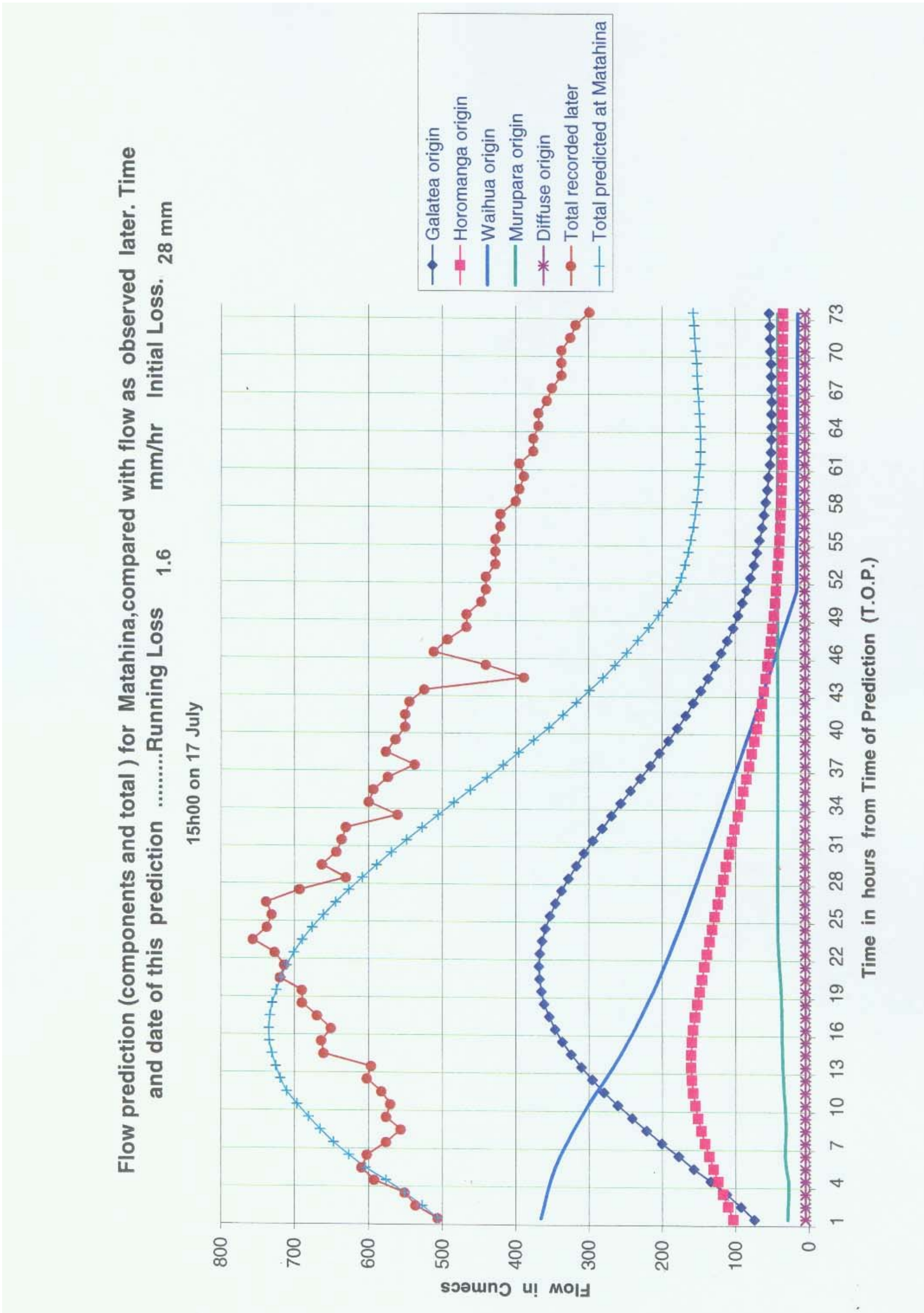

Figure 11 - *Flow prediction (components and total) for Matahina, compared with flow as observed later. Time of Prediction 1500 on 17 July 2004*

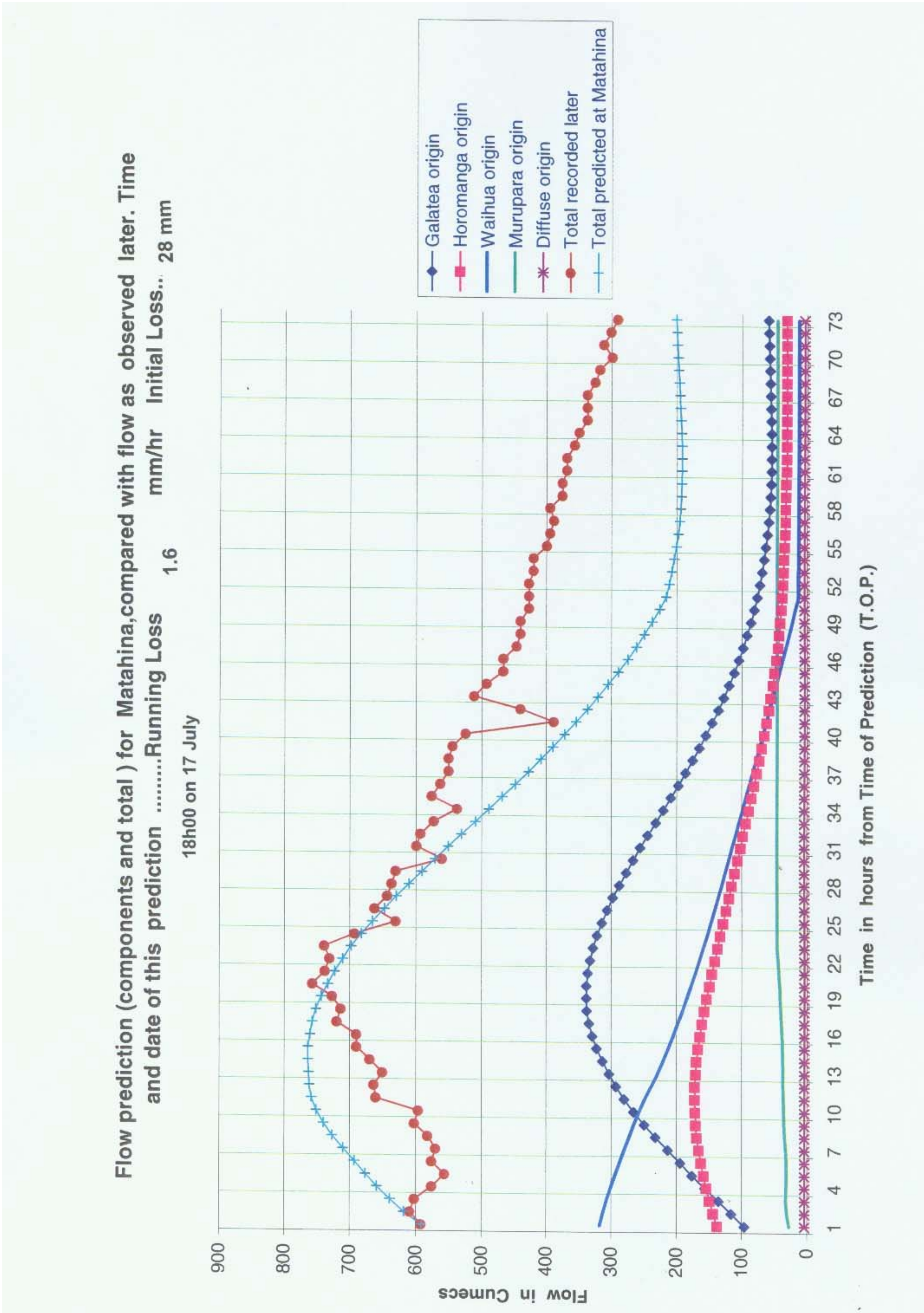

Figure 12 - Flow prediction (components and total) for Matahina, compared with flow as observed later. Time of Prediction 1800 on 17 July.