A rainfall-runoff model for the highly regulated Lake Taupo catchment, using a constrained Ensemble Kalman Filter to improve the accuracy and reliability of model output

by
Deborah H. Maxwell

Supplementary Appendices

2013
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Appendix B: Sub-catchment hydrological analyses

In this Appendix, the physical and hydrological characteristics of each sub-catchment are summarised. A brief description of catchment attributes is provided and draws on the data analysis undertaken in this study. The physical characteristics of each catchment (catchment area, altitude range, geology, soils, slopes and vegetative cover) are described. The description of land cover is based on the New Zealand Land Cover Database 2 (Ministry for the Environment, 2004). The delineation of soils and geology shown in the relevant figures are based on the New Zealand Land Resource Inventory (Landcare Research - Manaaki Whenua (NZ), 2008). More detailed information on the different lithologies is obtained from various literature including Bou (2007) and Morgenstern (2008) and the 1960 geological map by Grindley (1960).

The hydrological characteristics for the duration of the record are reported and also presented in the relevant charts for each sub-catchment. An analysis of time step lengths and distribution are included, with comments relating to the quality of the data obtained (where information is available). In this dissertation, a ‘time step’ is defined as the length of time between subsequent observations, whereas a ‘gap’ is a break in the record due to instrument or other errors.
The sub-catchments are presented in order, starting from the Waitahanui catchment, located south of Taupo township, and moving in a clockwise direction around Lake Taupo.

Figure A.1 The natural Lake Taupo catchment. The individual sub-catchments used for analysis are shown. The map does not include the foreign water catchment areas of the Tongariro Power Scheme.

**Sub-catchments analysed**

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B.1 Waitahanui River

<table>
<thead>
<tr>
<th>Site No:</th>
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</tr>
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<tbody>
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</tr>
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</tr>
<tr>
<td>Northing:</td>
<td>6262966</td>
</tr>
<tr>
<td>Record Duration:</td>
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<tr>
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<td>21 Jan 1976</td>
</tr>
<tr>
<td>Finish:</td>
<td>13 Jan 1981</td>
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</tbody>
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### Catchment physical features

- **Area:** 196.1 km²
- **Geology:** Predominantly volcanic (95%). Very top of headwaters some basement greywacke (5%).
- **Slopes:** Mainly flat or gently sloping land with some steeper slopes in headwaters. Mean slope 6.1° with 2.7% of slopes classified as steep (>26°).
- **Soils:** Mainly pumice soils (70%), organic soils near river mouth and some podzols in headwaters.
- **Vegetation:** The catchment is forested (99%) with planted forest with some indigenous forest in headwaters.
- **Relief:** 818 m
- **Elongation Ratio:** 1.63
- **Relief Ratio:** 31.7
- **Drainage density:** 1.70

### Climatic indices

- **Wetness ratio:** 2.29
- **Runoff coefficient:** 0.56

### Hydrological characteristics

- **Mean flow:** 6.9 m³/s
- **Specific Mean flow:** 0.035 m³/s per km²
- **Variability:** 0.214
- **Low flow regime:** 1.182
- **Baseflow:** 0.765
- **Flood flow regime:** 1.048
- **% of Lake Taupo outflows:** 4.7%

The Waitahanui River (196.1 km²) is located in the northeast of the Lake Taupo catchment and drains a mostly volcanic geology (mainly Taupo and Whakamaru ignimbrites) with some basement greywacke in the headwaters (Morgenstern, 2007). The relatively flat and gentle sloping catchment is covered by pumice soils with some podzols soils in the steeper headwaters. This catchment is largely covered in planted forestry, although there is some indigenous forestry at higher altitudes. These features are illustrated in Figure B.1.1.

The hydrological characteristics of the Waitahanui River are shown in Figure B.1.2. Streamflow was recorded in this catchment between January 1976 and January 1981. There is low variability in streamflow and the relatively flat nature of the flow duration curve indicates a considerable baseflow contribution.
The maximum streamflow over this period is 14.8 m$^3$/s recorded in February 1976. The minimum streamflow recorded is 5.7 m$^3$/s. Mean flow is 6.8 m$^3$/s which equates to a specific discharge of 0.04 m$^3$/s per km$^2$. The distribution of flow throughout the year is evenly dispersed with 26% of streamflow occurring during spring and 24% of streamflow during autumn. The inflow from this river is equivalent to 4.7% of the outflow from Lake Taupo over the period recorded.

The average time step for this streamflow record is 14.4 hours. Time step lengths varied between 10 minutes to 15.5 days (27 April – 13 May 1977). Over 81% of the time steps are shorter than one day, but time step length appears to increase towards the end of the record.

This time series has been quality checked by Environment Waikato. The majority of data is of good quality. There is a cluster of poorer quality data (indicated by quality code rating) occurring between the end of June 1978 and March 1979. The largest gap in the record is 14 days occurring in September 1978.
Figure B.1.1 Waitahanui River Catchment: (a) location, (b) land cover, (c) soils and (d) geology.
Figure B.1.2. Analysis of hydrological record and comparison to rainfall distribution. (a) Streamflow time series. (b) Distribution of time step length. (c) Flow duration curve. (d) Monthly distribution of rainfall and streamflow.
### Hinemaiaia River

#### B.2

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<td>Site name:</td>
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<td>153.3 km²</td>
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#### Catchment physical features

- **Geology:** The Hinemaiaia catchment (below scheme) is underlain by volcanic geology (74%) with basement greywacke in the headwaters (26%). In the catchment from above the scheme, volcanic geology accounts for 69% of the underlying geology the remainder (31%) being basement greywacke.
- **Slopes:** Steep slopes account for just over 10% for the upper and lower catchments. Mean slope is also similar at just over 10°.
- **Soils:** The Hinemaiaia catchment (below) is covered mainly by pumice soils (61%) although there are extensive areas of podzols in the upper catchment and recent soils along some river reaches. For the catchment above the scheme pumice soils account for 53.3% of soils by order.
- **Vegetation:** It is a predominantly forested catchment (98.6%) with indigenous forest in the headwaters and exotic planted forest in lower parts above the gauge. Between the two sites is predominantly planted forest with areas of indigenous scrub.

<table>
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<tr>
<th>Hinemaiaia catchment above the scheme</th>
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<td>Specific discharge (m³/s per km²):</td>
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<tr>
<td>% of Lake Taupo outflows:</td>
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#### Climatic indices

- **Wetness ratio:**
- **Runoff coefficient:**

#### Hydrological characteristics

- **Mean flow (m³/s):**
- **Specific discharge (m³/s per km²):**
- **Variability:**
- **Baseflow:**
- **Low flow regime:**
- **Flood flow regime:**
- **% of Lake Taupo outflows:**
The Hinemaiaia River enters Lake Taupo along its eastern shores, south of the Waitahanui River. This catchment has been developed for power generation since the 1950s. While it is a relatively small hydro scheme it consists of three power stations and three dams with a capacity of 6.6 MW generating around 30GWh per annum (TrustPower Ltd, 2008). The scheme is largely run-of-river with relatively little storage in the three reservoirs. The lake at Hinemaiaia A holds the largest volume of water with just 16.6 hours of storage with average inflow. Hinemaiaia C is located 2 km downstream of Hinemaiaia A and is the smallest of the lakes, covering an area of 2 ha and has negligible storage (TrustPower Ltd, 2008). Hinemaiaia B is located a further 3 km downstream. The lake at Hinemaiaia B (12.1 ha) has 7 hours of storage with average inflow. A minimum flow of 3 m$^3$/s below Hinemaiaia B station is required (where inflows into the Hinemaiaia A Lake permit) to address trout migration and erosion issues (TrustPower Ltd, 2008).

The scheme is operated by TrustPower Ltd. There are two records for locations above the scheme (Site Nos. 1543412 & 2743464). Because of the close proximity of these sites, the records are combined to provide a long-term record from April 1981 to December 2000. One record has been provided below the scheme (Site No. 3043471, June 2000 - present). The following analysis uses these sites to describe and compare the hydrological characteristics of the catchment.

There are two records for the catchment above the scheme (Site No. 1543412 and Site No. 2743464). These sites are located close together and have been combined for this analysis. There is less than 24 hours gap between these records (12/13 April 1987). The combined record starts in April 1981 and continues for 19.6 years until December 2000. The downstream record begins in April 2000 and is still operating. There is a short overlap of the data sets for a 6 month period in 2000. This upstream catchment drains an area of predominantly volcanic lithologies (Taupo and Oruanui ignimbrites) with basement greywacke in the headwaters (Morgenstern, 2007). It is covered by pumice and podzols soils, although it also has recent soils along some channels. The slopes of the catchment are gentle to moderate with steeper slopes in headwaters. This is forested catchment with a large area of indigenous forest in the headwaters.

The catchment from below the Hinemaiaia Power Scheme covers an area of 153.4 km$^2$. This extra 30 km$^2$ in catchment area (compared to the above scheme catchment) is made up of mostly planted forest, pumice soils and volcanic geology. Between Hinemaiaia A (the uppermost reservoir) and Hinemaiaia B (the most
downstream reservoir) the catchment is described as a narrow 27 m deep ignimbrite gorge (TrustPower Ltd, 2008). There are very few additional tributaries along this section so mean flow is similar (5.5 m$^3$/s below the scheme compared to 5.14 m$^3$/s above the scheme). As a result the specific discharge for the catchment is only slightly reduced from 0.041 m$^3$/s per km$^2$ to 0.036 m$^3$/s per km$^2$. In fact, for an overlapping period of record (June 2000 to January 2001) the mean flow above and below the scheme is the same (5.78 m$^3$/s).

Flow duration curves for both sites are similar and the time series shows very little impact on natural inflows (correlation coefficient of 0.96). Flow variability and baseflow contribution is similar at both sites. The discharge from this catchment is equivalent to 3.6% of outflow from Lake Taupo.

In terms of the unmodified inflow (above the scheme) the distribution of streamflow through the year follows the distribution of rainfall with the highest proportion in winter months (30.4%) and the lowest proportion in autumn months (20.7%).

The average time step for the combined record is 59.25 minutes. There were a large number of gaps in the record, the largest of which was for 96 days between November 1983 and February 1984. There were several other gaps which lasted longer than a week. There are fewer gaps from when the gauge was replaced (April 1987) with only two gaps identified. Below the scheme, the average time step length is 12 minutes although in the early part of the record between 2000 and 2005 the average length was 25 minutes. Since 2005, it has been under 10 minutes. There are four gaps in the record, the largest was for 4.6 days recorded in March 2002.
Figure B.2.1 Hinemaiaia River Catchment (above hydro scheme): (a) location, (b) land cover, (c) soils and (d) geology.
Figure B.2.2. Analysis of hydrological record and comparison to rainfall distribution. (a) Streamflow time series. (b) Distribution of time step length. (c) Flow duration curve. (d) Monthly distribution of rainfall and streamflow.
The Tauranga-Taupo River covers a largely (planted and indigenous) forested area of 197 km². The headwaters of the river drain an area of basement greywacke which can be very steep and is less permeable than the volcanic Oruanui geology of its lower reaches (Morgenstern, 2007). The catchment is covered by a mixture of pumice soils and podzols. These features are illustrated in Figure B.3.1.

The hydrological characteristics of the Tauranga-Taupo catchment are shown in Figure B.3.2. Streamflow has been recorded since February 1976. Environment Waikato has ownership of this station. The steeper nature of the flow duration curve (compared to the Waitahanui catchment) indicates that the groundwater contribution to streamflow is less and the catchment responds more quickly to rainfall events than those more permeable catchments. This is to be expected as the river originates in the less permeable greywacke highlands of the Kaimanawa Range. As a result the range of flow values is much greater than some more permeable catchments, recording between 2.3 m³/s in February 1982 up to 295 m³/s in
December 2001. The average flow over the record is 12.2 m³/s. This equates to 0.06 m³/s per km². This river has been a significant contributor to the lake accounting for 7.9% of the equivalent outflows since records began.

The largest volume of streamflow occurs in winter (30%) and spring (28%). Rainfall is highest in winter. The contribution of snow melt has not been quantified, but the spike in flow during October (Figure B.3.2) could be a result of this. Substantially less flow is recorded during summer (22%) and autumn (21%).

The average time step over the record is 27.7 minutes, although the average length of the time step decreased with time as can be seen in Figure B.3.2. From the start of the record to mid-1985, the average time step was 7.37 hours. Between July 1985 and November 2001, this dropped to about 42 minutes. Since then the average time step has been 12 minutes.

Streamflow records have been quality assessed by Environment Waikato. Approximately 94.5% of the recordings are deemed to be of good quality. The remaining 5.5% are either potentially erroneous (unconfirmed) or provisional; this data has been excluded from the analysis. There are 27 recorded gaps in the record. The longest gap in the record was over three months from 24 March 1981 through to 2 July 1981, due to recorder failure.
Figure B.3.1. Tauranga-Taupo River Catchment: (a) location, (b) landcover, (c) soils and (d) geology.
Figure B.3.2 Analysis of hydrological record and comparison to rainfall distribution. (a) Streamflow time series. (b) Distribution of time step length. (c) Flow duration curve. (d) Monthly distribution of rainfall and streamflow.
## B.4 Waimarino River

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</tbody>
</table>

### Catchment physical features
- **Area:** 63.6 km²
- **Geology:** Basement greywacke in headwaters (53.4%) with volcanic lithologies in lower part of catchment (46.6%).
- **Slopes:** Steep and very steep slopes in headwaters and in upper half of catchment. Mean slope 18.1° and with steep slopes accounting 31% (>26°).
- **Soils:** Catchment is mainly covered in pumice soils (47.4%) and podzols.
- **Vegetation:** This is a forested catchment (98.5%) with indigenous forest in headwaters and planted exotic forest in the lower part of the catchment above the gauge.
- **Relief:** 1159 m
- **Elongation Ratio:** 2.27
- **Relief Ratio:** 56.79
- **Drainage density:** 1.81

### Climatic indices
- **Wetness ratio:** 3.02
- **Runoff coefficient:** 0.67

### Hydrological characteristics
- **Mean flow:** 3.4 m³/s
- **Specific Mean flow:** 0.05 m³/s per km²
- **Variability:** 0.703
- **Low flow regime:** 2.556
- **Baseline:** 0.695
- **Flood flow regime:** 1.974
- **% of Lake Taupo outflows:** 4.4

The Waimarino River is located in between the Tauranga-Taupo and Tongariro River and drains an area of 63.6 km². Like the Tauranga-Taupo catchment, this river originates in the very steep Kaimanawa Ranges of greywacke geology. Oruanui ignimbrite is common in lowland areas (Morgenstern, 2007). The area is covered in pumice and podzols soils. The main vegetative cover is indigenous and planted forest.

There are two hydrological records for this catchment. The first period covers 6.5 years between September 1976 and March 1983. Records began again in December 1993. The station is operated by SCION. The two records have been combined for this analysis.

Average flow from this catchment is 3.41 m³/s, which is equivalent to 0.06 m³/s per km². The average flow in this river is equivalent to 4.4% of the total outflows from Lake Taupo.
Lake Taupo. The maximum recorded flow was 118.3 m³/s in December 2001. Twenty-nine percent of the annual flow is recorded during winter months and only 20% during autumn months. Like the Tauranga-Taupo catchment, a peak in spring runoff indicates a portion of the runoff could be from snowmelt. Baseflow in this catchment is the lowest of all catchments with a value of 0.695 and it has the highest variability index of 0.703.

Aside from the break in recording streamflow in this catchment between 1983 and 1993, there are no other gaps reported. The average time step for the record is 28 minutes. The earlier dataset had an average time step of over 2.6 hours. The latter record had an average time step of 20 minutes. The largest time step lasted 28 days in October and November 1982. Only 17 time steps were greater than one week long.

Comment files are not available for this record so it is difficult to ascertain the quality of these records. Of note, however, is that streamflow observations are recorded to one decimal place. As such there are some rounding errors present which are evident upon close inspection of the streamflow time series (Figure B.4.1).

Figure B.4.1 Streamflow time series for the Waimarino Catchment showing rounding/truncation issues in dataset.
Figure B.4.2. Waimarino River Catchment: (a) location, (b) land cover, (c) soils and (d) geology.
Figure B.4.3 Analysis of hydrological record and comparison to rainfall distribution. (a) Streamflow time series. (b) Distribution of time step length. (c) Flow duration curve. (d) Monthly distribution of rainfall and streamflow.
The Tongariro River has been developed for hydro-electric generation since the early 1970s. The Tongariro Power Scheme comprises two power stations. Rangipo Power Station is located south of Turangi 63m underground and has an operating capacity of 120 MW (Genesis Energy Ltd, 2010). Water is diverted from Lake Moawhango (outside of the natural Lake Taupo catchment area) and the Waihohonu River (Genesis Energy Ltd, 2011). After generation, water is released back into the Tongariro River before the Poutu Intake routes water into the Poutu Canal to the Poutu Dam. Once the water is passed through the canal it is discharged into Lake Rotoaira which is the storage lake for the Tokaanu Power Station. The Tokaanu Power Station is connected to Lake Rotoaira via a 6km tunnel through Mt Tihia and has an operating capacity of 240 MW (Genesis Energy Ltd, 2010). After generation at Tokaanu, the water is discharged directly to Lake Taupo. On average the Tongariro Power scheme generates 1350 GWh per annum, or 4% of New Zealand’s electricity generation (Genesis Energy Ltd, 2010).

In terms of inflow to Lake Taupo, it should be noted that the Tokaanu Power Station is a peaking plant, generating electricity during New Zealand’s peak demand periods (pers comm. Genesis Energy Ltd, 2009). As a result there are often zero discharges to Lake Taupo. In addition, during periods when the level of Lake Taupo enters its flood storage range, generation at (and therefore discharges from) Tokaanu ceases.

In this analysis, flow from three sites is assessed:

1. the Tongariro River at Turangi (784.2 km²);

2. the Tongariro River at the upper dam (near the confluence with the Waipakihi River, 180 km²); and

3. the Waihohonu River (which drains from the slopes of Mt Ruapehu and Mt Ngauruhoe, 96.1 km²).
B.5.1 Tongariro River at Turangi

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</table>

**Catchment physical features**

Area: 784.2 km²
Geology: Predominantly volcanic geology (71.9%) with some basement greywacke in eastern areas (28.1%).
Slopes: Mean slope 13.2° and steep slopes 18.6%.
Soils: Pumice soils make up 56.2% of the catchment, with large areas of recent and raw soils on the flanks of Mt Ruapehu, Mt Ngaruhoe and Mt Tongariro.
Vegetation: There is little vegetation in western areas. Forest cover makes up 67.3% of the catchment.
Relief: 2304 m
Relief Ratio: 80.19
Elongation Ratio: 0.91
Drainage density: 2.19

**Climatic indices**

Wetness ratio: 3.41
Runoff coefficient: 0.71

**Hydrological characteristics**

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean flow (m³/s):</td>
<td>Mean flow: 52.7</td>
</tr>
<tr>
<td>Specific discharge (m³/s per km²):</td>
<td>0.067</td>
</tr>
<tr>
<td>Variability:</td>
<td>0.591</td>
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<tr>
<td>Basellflow:</td>
<td>0.743</td>
</tr>
<tr>
<td>Low flow regime:</td>
<td>1.612</td>
</tr>
<tr>
<td>Flood flow regime:</td>
<td>1.453</td>
</tr>
<tr>
<td>% of Lake Taupo outflows:</td>
<td>40</td>
</tr>
</tbody>
</table>

The Tongariro catchment covers a large area of 784.2 km² and accounts for 29% of the Lake Taupo catchments land area. The catchment extends from the Tongariro delta near Turangi south to the northern flanks of Mt Ruapehu. Mt Ruapehu is one of three volcanoes located along the catchment’s western margin. To the east the Waipakihi River drains the Kaimanawa Mountains before converging with the Tongariro River above the upper dam.

Below the upper dam, as the river flows towards Lake Taupo, there is a clear delineation in geology, soils and slopes which coincides with the Kaimanawa Faultline (Grindley, 1960). Basement greywacke dominates to the east of the river (Bou, 2007; Morgenstern, 2007), with steep slopes and predominantly indigenous forestry. Immediately to the west of the Tongariro River are volcanic lithologies (mainly andesites) with gentle to moderate slopes and raw or recent soils, as is common in areas of volcanic activity (Rijkse, 1987). There is very little vegetation in
this part of the catchment with bare ground and tussock covering the area with small areas of indigenous forest on the lower flanks of Mt Ngauruhoe and Mt Tongariro.

The flow record for the Tongariro River at Turangi spans over 51 years. Diversions from the river to the Tongariro Power Scheme commenced in 1973. To assess the impact of this scheme on the flows of the Tongariro River this analysis has been divided into two periods. The first covers the period before 1973. The second covers the period since 1973, after the diversions commenced.

Prior to the TPS, streamflow of the Tongariro River (as measured at Turangi) was 52.7 m$^3$/s on average. Since completion of both eastern and western diversions in 1973, average streamflow have been reduced to 32.1 m$^3$/s. Maximum flow over the whole record reached 1470 m$^3$/s on 24 Feb 1958. Since the TPS diversions, flow has reached 1434 m$^3$/s (February 2004). The lowest flow recorded over the entire record was 13.975 m$^3$/s recorded in March 2005. Resource consent conditions require flow to be above 16 m$^3$/s, although in periods of low flows, natural flow conditions resume.

Between 1957 and 1983, the average time step of the record was 9.75 hours. The longest time step was 15 days recorded in 1960. Over 30 time steps are longer than one week and 10 are greater than 10 days. There are no gaps in the record. The average time step since 1985 is 20 minutes, although prior to 1990 it is over an hour and since 2000 it has been less than 10 minutes.
Figure B.5.1. Tongariro River Catchment: (a) location, (b) land cover, (c) soils and (d) geology
Figure B.5.2. Analysis of hydrological record and comparison to rainfall distribution. (a) Streamflow time series. (b) Distribution of time step length (c) Flow duration curve. (d) Monthly distribution of rainfall and streamflow.
B.5.2 Waipakihi River

<table>
<thead>
<tr>
<th>Site No:</th>
<th>1043461</th>
<th>Easting:</th>
<th>2749288</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site name:</td>
<td>Tongariro at Upper Dam</td>
<td>Northing:</td>
<td>6216582</td>
</tr>
<tr>
<td>Record Duration:</td>
<td>49 years</td>
<td>Start:</td>
<td>1 January 1960</td>
</tr>
<tr>
<td>Status:</td>
<td>Open</td>
<td>Finish:</td>
<td>24 January 2009</td>
</tr>
</tbody>
</table>

**Catchment physical features**

| Area: | 180 km² |
| Geology: | Predominantly basement greywacke geology (72.7%). Volcanic lithologies make up 27.3% of the catchment. |
| Slopes: | Mean slope 20.2° and steep slopes 37.6%. |
| Soils: | Pumice 70.3% soils are prevalent with raw and recent soils in the western-most part of the catchment. |
| Vegetation: | Forest cover accounts for 78.5% of the land cover. |

**Relief:**

| Relief: | 881 m |
| Relief Ratio: | 1.86 |

**Drainage density:**

| Drainage density: | 2.44 |

**Climatic indices**

| Wetness ratio: | 3.24 |
| Runoff coefficient: | 0.69 |

**Hydrological characteristics**

| Mean flow: | 11.9 m³/s |
| Specific Mean flow: | 0.066 m³/s per km² |
| Variability: | 0.699 |
| Baseflow: | 0.701 |
| % of Lake Taupo outflows: | 7.9 % |

The Waipakihi Rivers converges with the Tongariro River above the upper dam and drains a catchment of 180 km². The geology of the catchment is basement greywacke (Bou, 2007; Grindley, 1960; Morgenstern, 2007), covered by pumice soils. It is one of the steepest sub-catchments of Lake Taupo with a mean slope 20°, with 37% of slopes classified as steep (greater than 26°). The main vegetative cover is indigenous forestry.

Mean flow for this catchment is 11.8 m³/s, with a specific discharge of 0.066 m³/s per km². Flow ranges between a maximum of 2.1 m³/s recorded in April 1978 up to 707 m³/s recorded in February 2004. Over 31% of streamflow is recorded in winter months with less than 20% during autumn. In terms of its contribution to the inflows to Lake Taupo, the Waipakihi catchment accounts for 7.9% of the outflows for the corresponding period.

The average time step for this record is 21 minutes, although prior to 1980 this was significantly longer (1 hr 10 mins) and since 2000 it has been reduced to 8 minutes.
There are no gaps in this record. The longest time step (8 days) was recorded in March 1978. There are 13 other time steps greater than 4 days. Only 0.2% of time steps are greater than 12 hours.
Figure B.5.1. Waipakihi River Catchment: (a) location, (b) land cover, (c) soils and (d) geology.
Figure B.5.2. Analysis of hydrological record and comparison to rainfall distribution. (a) Streamflow time series. (b) Distribution of timestep length. (c) Flow duration curve. (d) Monthly distribution of rainfall and streamflow.
B.5.3 Waihohonu River

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<th>Site No:</th>
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<th>Site name: Desert Road</th>
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<th>Northing: 6217307</th>
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<td>Start: 1 August 1961</td>
<td>Finish: 24 January 2009</td>
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</tr>
<tr>
<td>Status: Open</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Catchment physical features**

- **Area**: 96.1 km²
- **Geology**: Volcanic 100%.
- **Slopes**: Mean slope 9.9° and steep slopes 8.5%.
- **Soils**: Predominantly raw and recent soils with only 0.1% of pumice soils.
- **Vegetation**: Mostly lightly vegetated or tussock grassland. Forestry covers 14% of the catchment.
- **Relief**: 1592 m
- **Elongation Ratio**: 1.28
- **Relief Ratio**: 112.83
- **Drainage density**: 3.08

**Climatic indices**

- **Wetness ratio**: 4
- **Runoff coefficient**: 0.75

**Hydrological characteristics**

- **Mean flow**: 6.28 m³/s
- **Specific Mean flow**: 0.066 m³/s per km²
- **Variability**: 0.374
- **Low flow regime**: 1.546
- **Baseflow**: 0.750
- **Flood flow regime**: 1.317
- **% of Lake Taupo outflows**: 4.2%

The Waihohonu River originates in the precipitous flanks of Mt Ruapehu and Mt Ngauruhoe. The catchment covers 96 km² and drains a largely andesitic geology (Bou, 2007) predominantly covered by raw and recent soils. Much of the catchment has little or no vegetation.

Streamflow from this river averaged 6.7 m³/s, which equates to a specific discharge of 0.066 m³/s per km². It accounted for 4.2% of total outflows over the 47.5 year record. Flow variability was second lowest of the Taupo sub-catchments (0.3743) with discharge ranging between 2.3 m³/s (May 1970) and 107.6 m³/s (February 2004). Streamflow is highest during spring months (28.8%).

The average time step for this record is 21 minutes. Again, time step length is much greater prior to 1980 (3.5 hours) and significantly reduced since 2000 (8 minutes). The longest time step was recorded in January/February 1974 (27 days). In total four time steps are greater than 10 days and 27 greater than one week. Less than 1% were greater than one day.
There are seven gaps in the record, the longest occurring between March and October 1964 (219 days). The other gaps range between 6 and 28 days and all occur before April 1987.
Figure B.5.3. Waihohonu River Catchment: (a) location, (b) land cover, (c) soils and (d) geology.
Figure B.5.4. Analysis of hydrological record and comparison to rainfall distribution. (a) Streamflow time series. (b) Distribution of time step length. (c) Flow duration curve. (d) Monthly distribution of rainfall and streamflow.
B.6  Waihi Stream

The Waihi Stream is a small catchment exiting along the Karangahape Fault scarp (Grindley, 1960), just north of Turangi on the south-western side of Lake Taupo. The catchment covers an area of 9.8 km² and drains an area of andesitic Kakaramea geology (Bou, 2007). There is a mixture of pumice, podzols, allophanic and raw soils in the catchment. Vegetative cover is predominantly scrub and tussock.

Streamflow was recorded between February 2003 and January 2006. Only two events during this period recorded more than 6 m³/s. The largest streamflow of 34 m³/s recorded in February 2004. The second largest event recorded in March 2004 measured 19 m³/s. A low flow of 0.1 m³/s was recorded multiple times during the record.

The average flow for this catchment is 0.39 m³/s which equates to 0.040 m³/s per km². In terms of the catchment’s contribution to inflows to Lake Taupo, flow from this catchment accounted for just 0.25% of outflows from the lake. Most streamflow
is recorded during winter months (28.9%) with just 17% recorded during autumn months.

There are no gaps in this streamflow record. The longest time steps in the record occur in the first month of the record. During this period the largest gap was just under 3.5 days, with only 7 gaps in the record lasting for more than 1 day. The average time step length is less than 8 minutes.
Figure B.6.1. Waihi Stream Catchment: (a) location, (b) land cover, (c) soils and (d) geology.
Appendix B

Figure B.6.2. Analysis of hydrological record and comparison to rainfall distribution. (a) Streamflow time series. (b) Distribution of timestep length. (c) Flow duration curve. (d) Monthly distribution of rainfall and streamflow.
## B.7 Kuratau River

### Catchment physical features

- **Geology:** The Kuratau catchment (above scheme) is composed of mostly volcanic geology (98.6%) with a small amount of sedimentary rocks in the catchment. There is no basement greywacke. Similarly, the catchment from below the scheme also has no basement greywacke and is predominantly volcanic.

- **Slopes:** The average slope of the catchment above the scheme is 6° with just 2% of slopes >26°. Average for the whole catchment (from below the scheme) is greater (7.2°) as is the percentage of steep slopes (3.1%).

- **Soils:** Pumice soils make up 50% of the catchment from below the scheme, although there are large areas of podzols and allophanic soils and smaller areas of gley, organic, raw and recent soils also present. The catchment above the scheme also comprises mostly pumice soils (59.6%) with areas of podzols and allophanics soils important too.

- **Vegetation:** Pasture makes up 40% of this catchment’s land cover (above and below the scheme). There are large tracts of indigenous and exotic forestry mainly in the headwaters that make up 44% and 47% of the land cover above and below the scheme, respectively.

### Hydrological characteristics

<table>
<thead>
<tr>
<th></th>
<th>Kuratau catchment above the scheme</th>
<th>Kuratau catchment below the scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean flow (m³/s):</td>
<td>4.24</td>
<td>6.56</td>
</tr>
<tr>
<td>Specific discharge (m³/s per km²):</td>
<td>0.04</td>
<td>0.034</td>
</tr>
<tr>
<td>Variability:</td>
<td>0.548</td>
<td>0.6078</td>
</tr>
<tr>
<td>Baseflow:</td>
<td>0.7466</td>
<td>0.8249</td>
</tr>
<tr>
<td>Low flow regime:</td>
<td>1.944</td>
<td>2.482</td>
</tr>
<tr>
<td>Flood flow regime:</td>
<td>2.100</td>
<td>1.679</td>
</tr>
<tr>
<td>% of Lake Taupo outflows:</td>
<td>2.8</td>
<td>4.9</td>
</tr>
</tbody>
</table>

### Area

<table>
<thead>
<tr>
<th></th>
<th>Kuratau catchment above the scheme</th>
<th>Kuratau catchment below the scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area:</td>
<td>119.3 km²</td>
<td>194.2 km²</td>
</tr>
</tbody>
</table>
King Country Energy operates a 3MW station on the Kuratau River. This power station was commissioned in 1962 and channels water down an open canal, through two penstock pipes which feeds two turbines. The station has a mean output of 30 GWh per annum. There are seven sites for which flow has been recorded along the Kuratau River. Four of these have been for surge trials below the power house. There are three other sites that have been used to gauge flow. Data has been provided for the site above the power station at SH41 (Site No. 1043468) and for a short period at a site below the power station (Site No. 1543443). These two sites are used in this study.

The Kuratau River catchment above the scheme (from SH41) covers an area of 119.3 km². It drains an area of predominantly volcanic geology, including Kakaramea and Pihanga andesites, Taupo and Whakamaru ignimbrites, and Haparangi Rhyolites (Bou, 2007; Grindley, 1960), with smaller pockets of sedimentary lithologies in the north of the catchment. Podzols, allophanic and pumice soils are widely found in the catchment with areas of organic and gley soils also present. Large areas of the catchment are classified as pastoral although there are significant areas of planted forest and some indigenous forestry in headwaters. Smaller areas of wetland and indigenous scrub are also present.

From below the power station the catchment covers 194.2 km². Sedimentary rocks make up a larger proportion of the catchment, the remainder being volcanic. There are recent soils in some of the river reaches with a large amount of podzols in the additional catchment area. The catchment comprises approximately 40% of grassland and 47% forestry (both indigenous and exotic). Both catchments are similar in terms of steepness with the mean slope.

The inflow from this catchment is equivalent to 4.9% of the outflow from Lake Taupo. Mean flow above the scheme is 4.28 m³/s (0.036 m³/s per km²). Below the scheme mean flow was greater (6.58 m³/s) but specific discharge was slightly less (0.034 m³/s per km²). The maximum flow downstream of the scheme was recorded in June 1977 (53.4 m³/s). The largest flow recorded since 1978 above the scheme was 60.1 m³/s in December 2001. Seasonally, for both sites over 33% of streamflow occurs during winter months and only 17% during autumn.

The average time step of the upstream record is around 30 minutes with time step lengths up to 3.2 days. In terms of gaps in the records, there were only two gaps in the record above the scheme. One was for half a day in October 2000 and the other
covered a period of over 10 days in June 1992. Below the scheme, the average time step was just over two hours. The longest time step was 2.3 days with only 15 time steps greater than 1 day. There were three gaps in this record, the largest of which was 18 days in May/June 1977.
Figure B.7.1. Kuratau River Catchment (above hydro scheme): (a) location, (b) land cover, (c) soils and (d) geology.
Figure B.7.2. Analysis of hydrological record and comparison to rainfall distribution. (a) Streamflow time series. (b) Distribution of timestep length. (c) Flow duration curve. (d) Monthly distribution of rainfall and streamflow.
The Whareroa River drains a 59.4 km² catchment of mainly volcanic geology. The catchment is covered mostly in pumice soils with some podzols and allophanic soils in the upper reaches. Vegetative cover is predominantly pastoral.

There are two hydrological records for the Whareroa River. The first was collected from September 1977 over a period of just under 3 years. The second record for the Whareroa River commenced in May 2002 and is still in operation. The mean flow for both periods was 1.24 m³/s (specific discharge of 0.021 m³/s per km²). In terms of the overall contribution to lake inflows, this catchment accounted for 0.8% of outflows in both recording periods.

The average time step of the earlier record is 2.5 hours. Time step interval ranged from two minutes up to 10 days. Only four time steps were greater than one week. Over 98% were less than one day. In the present record, time step intervals range
between one minute and 24 minutes with an average interval of 9.8 minutes. There are no gaps in the earlier record but numerous gaps in the present record. In addition, twenty-two time steps are identified as possibly erroneous and are included as gaps in this analysis.
Figure B.8.1. Whareroa Stream Catchment: (a) location, (b) land cover, (c) soils and (d) geology.
Figure B.8.2. Analysis of hydrological record and comparison to rainfall distribution. (a) Streamflow time series. (b) Distribution of timestep length. (c) Flow duration curve. (d) Monthly distribution of rainfall and streamflow.
The sub-catchment of the Whanganui Stream, located in the west of Lake Taupo, covers 31 km² of Whakamaru ignimbrite volcanic geology (Bou, 2007), with gentle to moderately steep slopes. Soils are predominantly podzols with some allophanic soils in channels and some areas of pumice soils (particularly below the gauge site). The catchment is largely covered in indigenous forestry with some planted forest just above the gauging site.

The hydrological record for this catchment begins in June 1976 and ends September 1980 (4.2 years). Over this period the maximum recorded flow was 13.1 m³/s in June 1977 while a minimum flow of 1.6 m³/s was recorded in April 1978. The average flow is 1.27 m³/s which equates to specific discharge of 0.049 m³/s per km². This catchment accounts for 0.9% of outflows over the recording period.
For this catchment, time step intervals range between 15 minutes up to 18 days with an average interval of over 13 hours. Nearly 14% of time steps are longer than one day with 15 intervals greater than one week. The first month of data is excluded due to inadequate data quality as identified by the quality codes. There are no other gaps in the record.
Figure B.9.1. Whanganui Stream Catchment: (a) location, (b) land cover, (c) soils and (d) geology
Figure B.9.2. Analysis of hydrological record and comparison to rainfall distribution. (a) Streamflow time series. (b) Distribution of timestep length. (c) Flow duration curve. (d) Monthly distribution of rainfall and streamflow.
The Waihaha River enters Lake Taupo in the western bays. This catchment is covered in predominantly native forestry, with some areas of scrub. The river drains an area of predominantly Whakamaru ignimbrite volcanic geology with basement greywacke in the headwaters (Bou, 2007; Grindley, 1960; Morgenstern, 2007). This catchment is relatively steep with a mean slope of 12° and over 11% of the catchment with slopes greater than 26°.

The hydrological record for the Waihaha River began in May 1976 but was discontinued 19 years later in May 1995. Flow over this period ranged between a low flow recorded in April 1978 of just 1.5 m³/s and a maximum flow of 95.5 m³/s in June 1988. The average flow for this catchment is 5.61 m³/s, which is equivalent to 0.042 m³/s per km². In terms of total inflows to the lake, this catchment accounts for 4.7% of the outflows over the recording period.
The average time step of the record is 1.2 hours, with the largest being 17 days. Between 1976 and 1985 the average time step interval was 7.8 hours. Over 7% of time steps during this period were greater than one day, with 10 time steps greater than 10 days. From 1985-1995 the average time step length decreased to just over 40 minutes, with only five time steps longer than one day. There are eleven gaps in the record, ranging between 1.4 days and up to 75 days between November 1981 and January 1982 and 84 days between April and June 1984.
Figure B.10.1. Waihaha River Catchment: (a) location, (b) land cover, (c) soils and (d) geology.
Figure B.10.2. Analysis of hydrological record and comparison to rainfall distribution. (a) Streamflow time series. (b) Distribution of time step length. (c) Flow duration curve. (d) Monthly distribution of rainfall and streamflow.
B.11 Tutaeuaua River

<table>
<thead>
<tr>
<th>Site No:</th>
<th>3043485</th>
<th>Easting:</th>
<th>2753600</th>
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<tr>
<td>Site name:</td>
<td>Longwait Bridge</td>
<td>Northing:</td>
<td>6280700</td>
</tr>
</tbody>
</table>

| Record Duration: | 5.25 years | Start: | 14 October 2004 |
| Status: | Closed | Finish: | 14 January 2010 |

### Catchment physical features

- **Area:** 3.3 km²
- **Geology:** Mostly volcanic (83.4%) with area of sedimentary geology. There is no basement greywacke in this catchment.
- **Slopes:** Mean slope 4.33° and 0.1% steep slopes.
- **Soils:** Pumice (83.4%).
- **Vegetation:** Predominantly pastoral catchment with area of wetland. Forestry accounts for only 2.1% of land cover.
- **Relief:** 102
- **Elongation Ratio:** 1.32
- **Relief Ratio:** 37.72
- **Drainage density:** 2.32

### Climatic indices

- **Wetness ratio:** 1.59
- **Runoff coefficient:** 0.37

### Hydrological characteristics

- **Mean flow:** 0.076 m³/s
- **Specific Mean flow:** 0.023 m³/s per km²
- **Variability:** 0.562
- **Baseflow:** 0.7349
- **Low flow regimes:** 1.848
- **Flood flow regimes:** 1.526
- **% of Lake Taupo outflows:** 0.05

The Tutaeuaua River drains a small pastoral area (3.3 km²) located in the northwest of the Lake Taupo catchment. It is covered in predominantly pumice soils, although organic soils associated with wetland development are found along stream reaches. It drains an area of Oruanui ignimbrite geology (Morgenstern, 2007). This catchment is gently sloping, round (elongation ratio of 1.32) and has a moderately high drainage density, compared to other catchments of Lake Taupo.

The Tutaeuaua catchment was recorded from October 2004 until January 2010. It has a mean flow of 0.076 m³/s (0.023 m³/s per km²), contributing only a small proportion to outflow from the lake.

The average time step for the record is 15 minutes, the longest time step less than six hours. There are seven gaps in the record, ranging between 1.4 days and up to 75 days during the early part of 2006.
Figure B.1.1. Tutaueua River Catchment: (a) location, (b) land cover, (c) soils and (d) geology.
Figure B.11.2. Analysis of hydrological record and comparison to rainfall distribution. (a) Streamflow time series. (b) Distribution of timestep length. (c) Flow duration curve. (d) Monthly distribution of rainfall and streamflow.
The Otaketake River (16.3 km²) drains an area of predominantly Oruanui ignimbrite geology covered by pumice soils with areas of podzols in the headwaters. The vegetation in the catchment is a mainly pasture with some scrub and planted forestry.

There are two records for the Otaketake River. The first ran between September 1973 and June 1978 and was recorded at Whangamata Road, but is stage level only. The second site was located at the weir between September 1977 and September 1980. The highest flow was recorded in August 1979 at 2.3 m³/s.

Streamflow from this catchment averaged 0.2 m³/s or just 0.01 m³/s per km². This catchment accounted for only 0.2% of outflows during the recording period. There is a wide range in flows for the catchment with variability estimated by the ratio of high flow to low flow to be 13.8. Correspondingly, the baseflow proportion in the catchment is 72%.
Figure B.12.1. Otaketake Stream Catchment: (a) location, (b) land cover, (c) soils and (d) geology.
Figure B.12. Analysis of hydrological record and comparison to rainfall distribution. (a) Streamflow time series. (b) Distribution of time step length. (c) Flow duration curve. (d) Monthly distribution of rainfall and streamflow.
Appendix C:  
Sub-catchment model calibration and sensitivity analyses

The information provided in this Appendix supports the results presented in Chapter 8 and Chapter 9. For each sub-catchment analysis of the time series is used to identify periods of reliable rainfall and streamflow data for model calibration and evaluation (for more detailed information of what this analysis shows and how to interpret the respective charts, please refer to Section 6.2). The selection of suitable data periods is based on three separate analyses. The consistency between the rainfall and streamflow records is undertaken by identifying periods of no rainfall and/or evapotranspiration and highlighting where streamflow is significantly rising during these recession periods. This assessment aims to show how representative the selected rainfall gauge is by illustrating how adequately it captures the events that are observed in the hydrograph.

Secondly, flow duration curves for the selected calibration period and the entire record are compared. Ideally, the calibration period would represent the range of hydrological phenomena experienced in the catchment including periods of floods, drought and normal flow conditions (Gupta and Sorooshian, 1985; Singh and Bárdossy, 2012). If the two curves are similar, then the calibration data is considered to be suitable for representing a wide range of hydrological responses experienced in the catchment. It is noted, however, that even with very long records not all possible hydrological responses may be represented.
Finally, residual mass curves are used to identify periods where there is inconsistency between the rainfall and streamflow records. This comparison is made using the cumulative departures from the respective means, using monthly data. The use of rainfall data which shows a significant difference to streamflow could result in poorer performance in terms of model calibration.

Once a suitable calibration period has been identified, the model is run and the five top-performing five parameter sets based on the results of the multi-criteria Kling-Gupta Efficiency index obtained (refer Section 6.3 and Appendix B). Modelled and observed streamflow are compared. The performance of each parameter set over calibration and evaluation periods is provided, as are corresponding parameter values. Parameters are then classified by degree of sensitivity and their corresponding $D$ statistic shown (refer Section 6.3.2). These results are also presented graphically in a series of scatterplots, sensitivity plots and calibration time series.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Parameter</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
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<td>Field capacity</td>
<td>mm</td>
<td>Maximum drainage</td>
<td>mm/time step</td>
</tr>
<tr>
<td>Baseflow</td>
<td>-</td>
<td>Maximum infiltration</td>
<td>mm/time step</td>
</tr>
<tr>
<td>Interflow</td>
<td>-</td>
<td>Minimum release</td>
<td>mm</td>
</tr>
<tr>
<td>Fastflow</td>
<td>-</td>
<td>Curve power/no.</td>
<td>-</td>
</tr>
<tr>
<td>Baseflow residence time ($T_b$)</td>
<td># time steps</td>
<td>Rainfall multiplier</td>
<td>-</td>
</tr>
<tr>
<td>Interflow residence time ($T_i$)</td>
<td># time steps</td>
<td>Lag time</td>
<td># time steps</td>
</tr>
<tr>
<td>Fastflow residence time ($T_f$)</td>
<td># time steps</td>
<td>Field capacity to saturation (FC to Sat)</td>
<td>mm</td>
</tr>
</tbody>
</table>

**Sub-catchment model calibration results**

- C.1 Waitahanui Catchment..........................................................63
- C.2 Hinemaiaia Catchment (below power scheme)........................69
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C.1 Waitahanui Catchment

The Waitahanui rainfall record is used for this catchment and appears to be fairly consistent with the streamflow record. There are few periods of negative recessions over the entire record and in the calibration period (Figure C.1.1). While the calibration period represents a wide range of streamflow responses (Figure C.1.2, left), the residual mass curves shows some marked differences between monthly streamflow and rainfall (Figure C.1.2, right). This is probably largely due to the considerable baseflow component of streamflow for this very permeable catchment, indicated by the parameter values shown in Table C.1.1. KGE values for this catchment are high, shown by the good fit to the observations in Figure C.1.3. Evaluation is not undertaken due to a lack of suitable data. Seven parameters are sensitive, with baseflow being the most influential parameter for this catchment, followed by the rainfall multiplier and catchment lag time (Table C.1.2). These results are supported in Figure C.1.4 and Figure C.1.5.

<table>
<thead>
<tr>
<th>Calibration and Evaluation data period for the Waitahanui catchment</th>
</tr>
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<tbody>
<tr>
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<tr>
<td>Evaluation period</td>
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<tr>
<td></td>
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</tbody>
</table>
Figure C.1.1 Plot of recession periods (light blue dots). Negative recessions (rising streamflow during periods of no rain or evapotranspiration) are highlighted (dark blue dots) (a) Entire record and (b) corresponding rainfall. (c) Calibration period and (d) corresponding rainfall.

Figure C.1.2 Calibration period data versus whole record. Left: Flow duration curves. Right: Residual mass curve.
Table C.1.1 Waitahanui Catchment Model Results

<table>
<thead>
<tr>
<th>Parameter Set</th>
<th>1</th>
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<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration time</td>
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<td>0.9207</td>
<td>0.9184</td>
<td>0.9192</td>
<td>0.9180</td>
</tr>
<tr>
<td>Calibration fdc</td>
<td>0.9752</td>
<td>0.9828</td>
<td>0.9814</td>
<td>0.9841</td>
<td>0.9757</td>
</tr>
<tr>
<td>Evaluation time</td>
<td>0.3860</td>
<td>0.4139</td>
<td>0.3733</td>
<td>0.4016</td>
<td>0.2996</td>
</tr>
<tr>
<td>Evaluation fdc</td>
<td>0.4495</td>
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<td>0.4361</td>
<td>0.4610</td>
<td>0.3712</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Parameter values</th>
</tr>
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<tbody>
<tr>
<td>Field capacity</td>
</tr>
<tr>
<td>Baseflow</td>
</tr>
<tr>
<td>Interflow</td>
</tr>
<tr>
<td>Fastflow</td>
</tr>
<tr>
<td>Tb</td>
</tr>
<tr>
<td>Ti</td>
</tr>
<tr>
<td>Tf</td>
</tr>
<tr>
<td>Field cap to sat</td>
</tr>
<tr>
<td>Max. drainage</td>
</tr>
<tr>
<td>Max. infiltration</td>
</tr>
<tr>
<td>Min. release</td>
</tr>
<tr>
<td>Curve No.</td>
</tr>
<tr>
<td>Initial storage</td>
</tr>
<tr>
<td>Rain mult.</td>
</tr>
<tr>
<td>Lag time</td>
</tr>
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</table>

Table C.1.2 Results of Sensitivity Analysis for Waitahanui Catchment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensitive D value</th>
<th>Moderately sensitive D value</th>
<th>Insensitive D value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseflow</td>
<td>0.6190</td>
<td>Ti</td>
<td>0.1773</td>
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<td>Rain mult</td>
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<td>Min. release</td>
<td>0.0568</td>
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<tr>
<td>Lag time</td>
<td>0.4209</td>
<td>Max. infiltration</td>
<td>0.0351</td>
</tr>
<tr>
<td>Interflow</td>
<td>0.4133</td>
<td>Max. drainage</td>
<td>0.0233</td>
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<tr>
<td>Tb</td>
<td>0.3675</td>
<td>Tf</td>
<td>0.0175</td>
</tr>
<tr>
<td>Fastflow</td>
<td>0.3335</td>
<td>Field cap to sat</td>
<td>0.0167</td>
</tr>
<tr>
<td>Field capacity</td>
<td>0.2639</td>
<td></td>
<td>0.0138</td>
</tr>
</tbody>
</table>
Figure C.1.3 Modelled versus observed streamflow using the top five calibrated parameter sets for the calibration period.
Figure C.1.4 Scatterplots of parameter values against their corresponding objective function value.
Figure C.1.5 HSY sensitivity analysis where $x$ is the parameter value and $F(x)$ is the cumulative distribution function. Dashed dark lines are non-behavioural parameter sets and the lighter lines are behavioural.
C.2 Hinemaiaia Catchment (below power scheme)

The Hinemaiaia catchment analysed in this section refers to the regulated catchment from below the power scheme. In this catchment, there appear to be many negative recessions (Figure C.2.1). However, close inspection of the Figure C.2.1 shows that the majority of negative recessions are related to the regulation in the catchment and not genuine events which are not represented in the rainfall record. The calibration period selected represents a wide range of hydrological conditions (Figure C.2.2, left). The Tauranga-Taupo rainfall record is used in this catchment because of difficulties in disaggregating the daily rainfall record available within the catchment. The residual mass curves show that the Tauranga-Taupo rainfall record and Hinemaiaia streamflow records follow a similar pattern (Figure C.2.2, right).

Although regulation is not incorporated into the model for this catchment, KGE values are still relatively good being above 0.83 for fit to the time series and above 0.9 for the fit to the flow duration curve for both the calibration and evaluation periods (Table C.2.1). The top five parameter sets do a reasonable job of simulating the natural rise and fall of streamflow despite the regulation (Figure C.2.3). Figure C.2.5 shows that four parameters (lag time, rainfall multiplier, fastflow proportion and baseflow residence time) are most identifiable. These parameters along with baseflow proportion, interflow proportion and fastflow residence time are also the most sensitive (Table C.2.2 and Figure C.2.6).

<table>
<thead>
<tr>
<th>Calibration and Evaluation data period for the Hinemaiaia catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration period</td>
</tr>
<tr>
<td>Evaluation period</td>
</tr>
</tbody>
</table>
Figure C.2.1 Plot of recession periods (light blue dots). Negative recessions (rising streamflow during periods of no rain or evapotranspiration) are highlighted (dark blue dots) (a) Entire record and (b) corresponding rainfall. (c) Calibration period and (d) corresponding rainfall.

Figure C.2.2 Calibration period data versus whole record. Left: Flow duration curves. Right: Residual mass curve.
### Table C.2.1 Hinemaiaia Catchment Model Results

<table>
<thead>
<tr>
<th>Parameter Set</th>
<th>1</th>
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<th>3</th>
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<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration time</td>
<td>0.8495</td>
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<td>0.8496</td>
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<tr>
<td>Calibration fdc</td>
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<td>0.9503</td>
<td>0.9522</td>
<td>0.9506</td>
<td>0.9538</td>
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<tr>
<td>Evaluation time</td>
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</table>

### Parameter values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
<th>Value 4</th>
<th>Value 5</th>
</tr>
</thead>
<tbody>
<tr>
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<td>117.4972</td>
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<tr>
<td>Baseflow</td>
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<td>0.6596</td>
<td>0.7071</td>
<td>0.6374</td>
<td>0.4424</td>
</tr>
<tr>
<td>Interflow</td>
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<td>0.082</td>
<td>0.0632</td>
<td>0.0641</td>
<td>0.3346</td>
</tr>
<tr>
<td>Fastflow</td>
<td>0.2435</td>
<td>0.2583</td>
<td>0.2298</td>
<td>0.2984</td>
<td>0.223</td>
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<tr>
<td>Tb</td>
<td>17700</td>
<td>14700</td>
<td>13400</td>
<td>18800</td>
<td>20200</td>
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<tr>
<td>Ti</td>
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<td>367</td>
<td>1350</td>
<td>2560</td>
<td>2940</td>
</tr>
<tr>
<td>Tf</td>
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<td>236</td>
<td>189</td>
<td>191</td>
<td>147</td>
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<tr>
<td>Field cap to sat</td>
<td>5.68</td>
<td>13.2717</td>
<td>18.7876</td>
<td>5.5202</td>
<td>3.5979</td>
</tr>
<tr>
<td>Max. drainage</td>
<td>63.832</td>
<td>19.4787</td>
<td>56.4854</td>
<td>74.6112</td>
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</tr>
<tr>
<td>Max. infiltration</td>
<td>143.9496</td>
<td>143.5639</td>
<td>91.4894</td>
<td>110.1144</td>
<td>58.1567</td>
</tr>
<tr>
<td>Min. release</td>
<td>0.3088</td>
<td>0.6225</td>
<td>0.2894</td>
<td>0.2326</td>
<td>0.2359</td>
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<tr>
<td>Curve No.</td>
<td>5.0543</td>
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<tr>
<td>Initial storage</td>
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<td>64.568</td>
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<td>36</td>
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### Table C.2.2 Results of Sensitivity Analysis for the Hinemaiaia Catchment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensitive D value</th>
<th>Moderately sensitive D value</th>
<th>Insensitive D value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain mult</td>
<td>0.6318</td>
<td>Ti 0.1429</td>
<td>Max. drainage 0.0928</td>
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<tr>
<td>Lag time</td>
<td>0.4898</td>
<td>Field capacity 0.1182</td>
<td>Max. infiltration 0.0842</td>
</tr>
<tr>
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<td>Field cap to sat 0.1054</td>
<td>Curve No. 0.062</td>
</tr>
<tr>
<td>Fastflow</td>
<td>0.4085</td>
<td></td>
<td>Min. release 0.0615</td>
</tr>
<tr>
<td>Interflow</td>
<td>0.2402</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tf</td>
<td>0.2191</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TB</td>
<td>0.2002</td>
<td></td>
<td></td>
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</tbody>
</table>
Figure C.2.3 Modelled versus observed streamflow using the top five calibrated parameter sets for the calibration period.
Figure C.2.4 Modelled versus observed streamflow using the top five calibrated parameter sets for the evaluation period.
Figure C.2.5 Scatterplots of parameter values against their corresponding objective function value.
Figure C.2.6 HSY sensitivity analysis where \( x \) is the parameter value and \( F(x) \) is the cumulative distribution function. Dashed dark lines are non-behavioural parameter sets and the lighter lines are behavioural.
C.3  Tauranga-Taupo Catchment

The consistency between rainfall and streamflow records in this catchment are good, with very few negative recessions identified over the 35 year record (Figure C.2.1). The calibration period selected represents a wide range of hydrological conditions (Figure C.3.2, left) and the residual mass curves follow relatively closely (Figure C.3.2, right) indicating that the rainfall record is suitable for model calibration.

KGE values are strong for both calibration and evaluation periods (Table C.3.1). Figure C.3.3 shows that the top five parameter sets are able to simulate streamflow well, but tend to over-estimate flood peaks. Figure C.3.5 shows that the rainfall multiplier and fastflow proportion are the most identifiable parameters. They are also the most sensitive followed by lag time and baseflow proportion (Table C.3.2 and Figure C.3.6).

<table>
<thead>
<tr>
<th>Calibration and Evaluation data period for the Tauranga-Taupo catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration period</td>
</tr>
<tr>
<td>Evaluation period</td>
</tr>
</tbody>
</table>
Figure C.3.1. Plot of recession periods (light blue dots). Negative recessions (rising streamflow during periods of no rain or evapotranspiration) are highlighted (dark blue dots) (a) Entire record and (b) corresponding rainfall. (c) Calibration period and (d) corresponding rainfall.

Figure C.3.2. Calibration period data versus whole record. Left: Flow duration curves. Right: Residual mass curve.
Table C.3.1. Tauranga-Taupo Catchment Model Results

<table>
<thead>
<tr>
<th>Parameter Set</th>
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<tbody>
<tr>
<td>Calibration time</td>
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<td>0.9070</td>
<td>0.9052</td>
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<tr>
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<tr>
<td>Evaluation time</td>
<td>0.8038</td>
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<td>Evaluation fdc</td>
<td>0.8367</td>
<td>0.8372</td>
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<table>
<thead>
<tr>
<th>Parameter values</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Field capacity</td>
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<td>47.141</td>
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<tr>
<td>Baseflow</td>
<td>0.4243</td>
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<td>0.3318</td>
<td>0.3094</td>
<td>0.4343</td>
</tr>
<tr>
<td>Interflow</td>
<td>0.4348</td>
<td>0.4081</td>
<td>0.4617</td>
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<td>0.3318</td>
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<tr>
<td>Fastflow</td>
<td>0.1409</td>
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<tr>
<td>Tb</td>
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<td>11419</td>
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<tr>
<td>Ti</td>
<td>303</td>
<td>490</td>
<td>490</td>
<td>627</td>
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</tr>
<tr>
<td>Tf</td>
<td>20</td>
<td>45</td>
<td>45</td>
<td>59</td>
<td>53</td>
</tr>
<tr>
<td>Field cap to sat</td>
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<td>Max. drainage</td>
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<td>24.379</td>
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<td>Max. infiltration</td>
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<td>130.07</td>
<td>54.724</td>
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<tr>
<td>Min. release</td>
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<td>0.85623</td>
</tr>
<tr>
<td>Curve No.</td>
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</tr>
<tr>
<td>Initial storage</td>
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<td>17.642</td>
<td>65.703</td>
</tr>
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<td>Rain mult.</td>
<td>1.2828</td>
<td>1.2691</td>
<td>1.267</td>
<td>1.2671</td>
<td>1.296</td>
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<td>Lag time</td>
<td>19</td>
<td>16</td>
<td>16</td>
<td>15</td>
<td>15</td>
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</tbody>
</table>

Table C.3.2. Results of Sensitivity Analysis for Tauranga-Taupo Catchment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensitive D value</th>
<th>Moderately sensitive D value</th>
<th>Insensitive D value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain mult</td>
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<td>Baseflow 0.1832</td>
<td>Tf 0.0981</td>
</tr>
<tr>
<td>Fastflow</td>
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<td>Lag time 0.1145</td>
<td>Field capacity 0.0444</td>
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<tr>
<td></td>
<td></td>
<td>Interflow 0.0301</td>
<td>Ti 0.0227</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Curvane No. 0.0154</td>
<td>Field cap to sat 0.0099</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max. infiltration 0.0075</td>
<td>Min. release 0.0065</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max. drainage 0.0059</td>
<td>Tb 0.0053</td>
</tr>
</tbody>
</table>
Figure C.3.3 Modelled versus observed streamflow using the top five calibrated parameter sets for the calibration period.
Figure C.3.4 Modelled versus observed streamflow using the top five calibrated parameter sets for the evaluation period.
Figure C.3.5 Scatterplots of parameter values against their corresponding objective function value.
Figure C.3.6 HSY sensitivity analysis where $x$ is the parameter value and $F(x)$ is the cumulative distribution function. Dashed dark lines are non-behavioural parameter sets and the lighter lines are behavioural.
C.4 Waimarino Catchment

The rainfall record used for the Waimarino catchment is located within the catchment. It is considered to be representative, as there are few times when there is a hydrograph response but no rainfall (Figure C.4.1). A wide range of hydrological responses fall within the calibration period selected (Figure C.4.2) and the residual mass curves follow relatively closely (Figure C.4.2, right) indicating that the rainfall record is suitable for model calibration.

While KGE values are good for both calibration and evaluation periods (Table C.4.1), they are not as strong as the Tauranga-Taupo catchment, possibly due to rounding errors in the observation record (refer Appendix B.4). Similar to the Tauranga-Taupo catchment, the top five parameter sets are able to simulate streamflow well, but peak flows are missed (Figure C.4.3). Figure C.4.5 shows that while the interflow residence time is identifiable, it is not one of the most sensitive parameters for this catchment (Table C.4.2 and Figure C.4.6).

<table>
<thead>
<tr>
<th>Calibration and Evaluation data period for the Waimarino catchment</th>
</tr>
</thead>
<tbody>
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<td>Calibration period</td>
</tr>
<tr>
<td>Evaluation period</td>
</tr>
</tbody>
</table>
Figure C.4.1. Plot of recession periods (light blue dots). Negative recessions (rising streamflow during periods of no rain or evapotranspiration) are highlighted (dark blue dots) (a) Entire record and (b) corresponding rainfall. (c) Calibration period and (d) corresponding rainfall.

Figure C.4.2 Calibration period data versus whole record. Left: Flow duration curves. Right: Residual mass curve.
### Table C.4.1. Waimarino Catchment Model Results

<table>
<thead>
<tr>
<th>Parameter Set</th>
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</tr>
<tr>
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<td>0.3396</td>
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</tr>
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<td>0.3174</td>
<td>0.3446</td>
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<td>8595</td>
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<td>14873</td>
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<td>500</td>
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<td>678</td>
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<tr>
<td>Field capacity</td>
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<td>12.53</td>
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<td>83.955</td>
<td>43.274</td>
<td>90.669</td>
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<td>Max. infiltration</td>
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<td>60.622</td>
<td>49.352</td>
<td>122.22</td>
<td>147.01</td>
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<td>Min. release</td>
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### Table C.4.2 Results of Sensitivity Analysis for Waimarino Catchment

<table>
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<tr>
<th>Parameter</th>
<th>Sensitive D value</th>
<th>Moderately sensitive D value</th>
<th>Insensitive D value</th>
</tr>
</thead>
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<tr>
<td>Rain mult</td>
<td>0.4150</td>
<td>Interflow 0.1923</td>
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<td>Fastflow</td>
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<td>Baseflow 0.1037</td>
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<td></td>
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<td>Curve No. 0.0131</td>
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</tr>
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<td></td>
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<td>Min. release 0.0122</td>
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<tr>
<td></td>
<td></td>
<td>T_b 0.0100</td>
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<td>Max. infiltration 0.0074</td>
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<td>Field cap to sat 0.0066</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Field capacity 0.0062</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Max. drainage 0.0041</td>
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</tr>
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</table>
Figure C.4.3 Modelled versus observed streamflow using the top five calibrated parameter sets for the calibration period.
Figure C.4.4 Modelled versus observed streamflow using the top five calibrated parameter sets for the evaluation period.
Figure C.4.5 Scatterplots of parameter values against their corresponding objective function value
Figure C.4.6 HSY sensitivity analysis where x is the parameter value and $F(x)$ is the cumulative distribution function. Dashed dark lines are non-behavioural parameter sets and the lighter lines are behavioural.
C.5 Tongariro Catchment

C.5.1 Lower Tongariro Catchment

While there are many periods of rising streamflow and no associated rainfall, many of these tend to be associated with the problems deriving this time series (see Section 7.2.2) rather than necessarily missed events (Figure C.5.1). The flow duration curves show that the period of data selected for model calibration represents the majority of streamflow responses in this catchment (Figure C.5.2, left) and that the Waipakihi rainfall record, although located some distance upstream from this catchment, is reasonably suitable for model calibration (Figure C.5.2, right).

Model calibration is reasonable given the issues with the time series with KGE values above 0.77 for the fit to the time series and over 0.95 for the fit to the flow duration curve for the calibration period (Table C.5.1). Over the evaluation period, KGE values are lower. Optimal parameter sets simulate recession periods reasonably well but tend to under-estimate larger flood peaks (Figure C.5.3). None of the parameters for this sub-catchment seem to be highly identifiable (Figure C.5.5), although four parameters are sensitive (baseflow and fastflow proportions, rainfall multiplier and catchment lag time) and residence times associated with the two sensitive stores showing moderate sensitivity (Table C.5.2 and Figure C.5.6).

<table>
<thead>
<tr>
<th>Calibration and Evaluation data period for the Lower Tongariro catchment</th>
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<tbody>
<tr>
<td>Calibration period</td>
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<td>Evaluation period</td>
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</table>
Figure C.5.1 Plot of recession periods (light blue dots). Negative recessions (rising streamflow during periods of no rain or evapotranspiration) are highlighted (dark blue dots) (a) Entire record and (b) corresponding rainfall. (c) Calibration period and (d) corresponding rainfall.

Figure C.5.2 Calibration period data versus whole record. Left: Flow duration curves. Right: Residual mass curve.
### Table C.5.1. Lower Tongariro Catchment Model Results

<table>
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<tr>
<th>Parameter Set</th>
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<tbody>
<tr>
<td>Calibration time</td>
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<table>
<thead>
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<tbody>
<tr>
<td>Field capacity</td>
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<td>549.52</td>
<td>376.44</td>
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<td>Baseflow</td>
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<td>1469</td>
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### Table C.5.2. Results of Sensitivity Analysis for lower Tongariro Catchment

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<th>Insensitive</th>
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<tbody>
<tr>
<td>Parameter</td>
<td>D value</td>
<td>Parameter D value</td>
<td>Parameter D value</td>
</tr>
<tr>
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<td>0.1872</td>
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<tr>
<td>Lag time</td>
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<td>Max. infiltration</td>
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<tr>
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<td>Ti</td>
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</table>
Figure C.5.3 Modelled versus observed streamflow using the top five calibrated parameter sets for the calibration period.
Figure C.5.4 Modelled versus observed streamflow using the top five calibrated parameter sets for the evaluation period.
Figure C.5 Scatterplots of parameter values against their corresponding objective function value.
Figure C.5.6 HSY sensitivity analysis where $x$ is the parameter value and $F(x)$ is the cumulative distribution function. Dashed dark lines are non-behavioural parameter sets and the lighter lines are behavioural.
C.5.2 Poutu Catchment

The Waipakihi rainfall record used for model calibration in this catchment has no identified gaps since 1997, providing a good continuous record from which a calibration period can be selected (Figure C.5.7). Although there are many periods where streamflow is increasing with no corresponding rainfall, some of these are associated with the regulation in the catchment rather than natural events which are not represented in the rainfall record. The calibration period selected covers a wide range of streamflow responses of the catchment, although the lower flows associated with a lower minimum flow level below the Poutu Intake prior to 1994 (Smart, 2005) are not represented (Figure C.5.8, left). Residual mass curves show that while the monthly streamflow and rainfall observations follow a fairly similar pattern, there is a much larger deviation from the mean for rainfall than for streamflow in the first half of the time series, which could reduce the performance of the model overall (Figure C.5.8, right).

Given the extensive regulation in this catchment and limited data and information available, the model simulates streamflow reasonably well. Some of the regulation is not captured and peak flows tend to be over-estimated (Figure C.5.9). Despite this, KGE values over the calibration period are over 0.75 and 0.90 for fits to the time series and flow duration curve, respectively (Table C.5.3). Outside of the calibration period the KGE values are much lower and do not reach the threshold above which parameter sets are considered behavioural (see Section 6.3.2). Baseflow proportion values for this catchment are some of the lowest in Lake Taupo, although residence times for this store are reasonably long (up to 230 days, Table C.5.3).

Although the scatterplots in Figure C.5.11 indicate that the lag time and field capacity are the most identifiable parameters, neither of these are strongly sensitive. Store proportions are all sensitive in this catchment, along with the rainfall multiplier and fastflow residence time (Table C.5.4 and Figure C.5.12). Lag time and interflow residence time are moderately sensitive.

<table>
<thead>
<tr>
<th>Calibration and Evaluation data period for the Poutu catchment</th>
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<tbody>
<tr>
<td>Calibration period</td>
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<td>Evaluation period</td>
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</table>
Figure C.5.7 Plot of recession periods (light blue dots). Negative recessions (rising streamflow during periods of no rain or evapotranspiration) are highlighted (dark blue dots). (a) Entire record and (b) corresponding rainfall. (c) Calibration period and (d) corresponding rainfall.

Figure C.5.8 Calibration period data versus whole record. Left: Flow duration curves. Right: Residual mass curve.
Table C.5.3. Poutu Catchment Model Results

<table>
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<tr>
<th>Parameter Set</th>
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<tbody>
<tr>
<td>Calibration time</td>
<td>0.7572</td>
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<td>Calibration fdc</td>
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<table>
<thead>
<tr>
<th>Parameter values</th>
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<tbody>
<tr>
<td>Field capacity</td>
</tr>
<tr>
<td>Baseflow</td>
</tr>
<tr>
<td>Interflow</td>
</tr>
<tr>
<td>Fastflow</td>
</tr>
<tr>
<td>Tb</td>
</tr>
<tr>
<td>Ti</td>
</tr>
<tr>
<td>Tf</td>
</tr>
<tr>
<td>Field cap to sat</td>
</tr>
<tr>
<td>Max. drainage</td>
</tr>
<tr>
<td>Max. infiltration</td>
</tr>
<tr>
<td>Min. release</td>
</tr>
<tr>
<td>Curve No.</td>
</tr>
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<td>Initial storage</td>
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<td>Rain mult.</td>
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<tr>
<td>Lag time</td>
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Table C.5.4 Results of Sensitivity Analysis for Poutu Catchment

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>Moderately sensitive D value</th>
<th>Insensitive D value</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
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<td>Baseflow</td>
<td>0.4372</td>
<td>Min. release 0.0244</td>
<td>Max. infiltration 0.0226</td>
</tr>
<tr>
<td>Interflow</td>
<td>0.3222</td>
<td>Max. infiltration TB 0.0212</td>
<td>Field cap to sat 0.0154</td>
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<tr>
<td>Tf</td>
<td>0.2709</td>
<td></td>
<td>Max. drainage 0.013</td>
</tr>
</tbody>
</table>

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Figure C.5.9 Modelled versus observed streamflow using the top five calibrated parameter sets for the calibration period.
Figure C.5.10 Modelled versus observed streamflow using the top five calibrated parameter sets for the evaluation period.
Figure C.5.11 Scatterplots of parameter values against their corresponding objective function value
Figure C.5.12 HSY sensitivity analysis where $x$ is the parameter value and $F(x)$ is the cumulative distribution function. Dashed dark lines are non-behavioural parameter sets and the lighter lines are behavioural.
C.5.3 Waipakihi Catchment

The section of the Tongariro River above the upper dam near the confluence of the Waipakihi River is unmodified by regulation. The Waipakihi rainfall station is located near this streamflow gauge and tends to capture the overall rainfall dynamics of the catchment, with relatively few negative recessions over the 24 year record (Figure C.5.13). To support this, the residual mass curves show the monthly streamflow and rainfall follow a similar pattern for most of the period selected for calibration (Figure C.5.14, right). This period also represents almost all of the hydrological responses that have been observed in the catchment (Figure C.5.14, left).

Model calibration is reasonably good in this sub-catchment. Recession periods and low flows are simulated relatively closely, but flood peaks are typically underestimated (Figure C.5.15). This is the only sub-catchment in which KGE values are higher over the evaluation period (Table C.5.5). The residence times associated with the fastflow and interflow stores are very identifiable along with the rainfall multiplier (Figure C.5.17). In terms of parameter sensitivity, the fastflow residence time and rainfall multiplier are some of the most sensitive along with lag time and the store proportions (Table C.5.6 and Figure C.5.18).

<table>
<thead>
<tr>
<th>Calibration and Evaluation data period for the Waipakihi catchment</th>
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<tbody>
<tr>
<td>Calibration period</td>
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<tr>
<td>Evaluation period</td>
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</tbody>
</table>
Figure C.5.13 Plot of recession periods (light blue dots). Negative recessions (rising streamflow during periods of no rain or evapotranspiration) are highlighted (dark blue dots) (a) Entire record and (b) corresponding rainfall. (c) Calibration period and (d) corresponding rainfall.

Figure C.5.14 Calibration period data versus whole record. Left: Flow duration curves. Right: Residual mass curve
Table C.5.5. Waipakihi Catchment Model Results

<table>
<thead>
<tr>
<th>Parameter Set</th>
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<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration time</td>
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<td>0.8448</td>
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<tr>
<td>Calibration fdc</td>
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<td>Evaluation time</td>
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<td>0.8647</td>
<td>0.8796</td>
<td>0.8660</td>
<td>0.8674</td>
</tr>
<tr>
<td>Evaluation fdc</td>
<td>0.9375</td>
<td>0.9341</td>
<td>0.9765</td>
<td>0.9385</td>
<td>0.9358</td>
</tr>
</tbody>
</table>

**Parameter values**

| Field capacity         | 111.83| 116  | 127  | 97.01 | 148.33 |
| Baseflow               | 0.3634| 0.2117| 0.3672| 0.3420| 0.2328 |
| Interflow              | 0.2498| 0.4298| 0.2436| 0.2913| 0.4467 |
| Fastflow               | 0.3868| 0.3585| 0.3892| 0.3667| 0.3205 |
| Tb                     | 151.57| 151.14| 7124 | 16193 | 15382  |
| Ti                     | 445   | 866   | 343  | 492   | 604    |
| Tf                     | 33    | 29    | 31   | 30    | 24     |
| Field cap to sat       | 11.341| 19.403| 9.7492| 3.9767| 8.0681 |
| Max. drainage          | 91.986| 40.901| 32.492| 97.165| 21.43  |
| Max. infiltration      | 132.4 | 36.0  | 34.842| 46.408| 113.26 |
| Min. release           | 0.25996| 0.27637| 0.14688| 0.40663| 0.62348|
| Curve No.              | 2.5285| 4.9462| 2.3777| 3.4158| 2.8881 |
| Initial storage        | 71.819| 78.693| 50.195| 50.741| 4.6044 |
| Rain mult.             | 1.2172| 1.2281| 1.2191| 1.2254| 1.2424 |
| Lag time               | 6     | 7     | 7    | 7     | 8      |

Table C.5.6 Results of Sensitivity Analysis for Waipakihi Catchment

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>D value</th>
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<th>D value</th>
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<tr>
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<td>Interflow</td>
<td>0.1549</td>
<td>Field capacity</td>
<td>0.0645</td>
<td>Field cap to sat</td>
<td>0.0542</td>
<td>Curve No.</td>
</tr>
<tr>
<td>Ti</td>
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<td></td>
<td></td>
<td>Field capacity</td>
<td>0.0645</td>
<td>Field cap to sat</td>
<td>0.0542</td>
<td>Curve No.</td>
</tr>
<tr>
<td>Rain mult</td>
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<td>Interflow</td>
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<td>Max. drainage</td>
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<td>Max. drainage</td>
<td>0.0408</td>
<td>TB</td>
<td>0.0378</td>
<td>Ti</td>
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</table>
Figure C.5.15 Modelled versus observed streamflow using the top five calibrated parameter sets for the calibration period.
Figure C.5.16 Modelled versus observed streamflow using the top five calibrated parameter sets for the evaluation period.
Figure C.5.17 Scatterplots of parameter values against their corresponding objective function value
Figure C.5.18 HSY sensitivity analysis where $x$ is the parameter value and $F(x)$ is the cumulative distribution function. Dashed dark lines are non-behavioural parameter sets and the lighter lines are behavioural.
C.5.4 Waihohonu Catchment

The Waihohonu catchment drains the slopes of Mt Ruapehu, naturally entering the Tongariro River below Rangipo Dam. There is an obvious baseflow pattern in the streamflow record which, given its location, may be associated with seasonal snow storage and melt. The Waipakihi rainfall gauge is used for model calibration in this sub-catchment. From Figure C.5.19, this rainfall gauge appears to capture most of the events seen in the hydrograph, but the residual mass plots (Figure C.5.20, right) show that there are some considerable differences in monthly deviations from respective means.

The Tukino rainfall gauge (located on the flanks of Mt Ruapehu) was initially considered for use in this catchment but residual mass curves showed similar discrepancies and initial calibrations were poor (KGE (time) <0.3, based on 500,000 calibration runs). The Waipakihi rainfall gauge, however, has generated reasonable KGE values over the calibration period, although performance was much poorer outside of this period (Table C.5.7). This sub-catchment has a considerable baseflow proportion, which is reflected in the baseflow parameter values of the calibrated parameter sets.

Figure C.5.23 show the correspondence between the modelled streamflow from the top five parameter sets and the observed streamflow. Overall, the model does not appear to simulate the hydrological response of this catchment very well despite relatively good KGE values. Again, this could be due to the seasonal snow storage and melt component which is not explicitly modelled (Figure C.5.21).

The most identifiable parameters include the rainfall multiplier, the three store proportions and residence time of the baseflow store (Figure C.5.23). These parameter are also the most sensitive (Table C.5.8 and Figure C.5.24).

<table>
<thead>
<tr>
<th>Calibration and Evaluation data period for the Waihohonu catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration period</td>
</tr>
<tr>
<td>Evaluation period</td>
</tr>
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</table>
Figure C.5.19 Plot of recession periods (light blue dots). Negative recessions (rising streamflow during periods of no rain or evapotranspiration) are highlighted (dark blue dots) (a) Entire record and (b) corresponding rainfall. (c) Calibration period and (d) corresponding rainfall.

Figure C.5.20 Calibration period data versus whole record. Left: Flow duration curves. Right: Residual mass curve.
### Table C.5.7. Waihohonu Catchment Model Results

<table>
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<tr>
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<tbody>
<tr>
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<td>0.8180</td>
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<td>0.8168</td>
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<td>0.9679</td>
<td>0.9694</td>
<td>0.9532</td>
</tr>
<tr>
<td>Evaluation time</td>
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<td>0.6880</td>
<td>0.6770</td>
<td>0.7085</td>
</tr>
<tr>
<td>Evaluation fdc</td>
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<td>0.7777</td>
<td>0.7847</td>
<td>0.7882</td>
<td>0.8259</td>
</tr>
</tbody>
</table>

#### Parameter values

| Field capacity | 273.2128 | 239.9289 | 247.072 | 296.6465 | 291.2319 |
| Baseflow      | 0.8536   | 0.9336   | 0.8877  | 0.9387   | 0.9286   |
| Interflow     | 0.0774   | 0.0073   | 0.0442  | 0.0027   | 0.0023   |
| Fastflow      | 0.0690   | 0.0591   | 0.0681  | 0.0586   | 0.0691   |
| Tb            | 14516    | 13328    | 12234   | 11840    | 11646    |
| Ti            | 2489     | 2203     | 1860    | 1745     | 1882     |
| Tf            | 25       | 32       | 22      | 34       | 33       |
| Field cap to sat | 5.6341  | 9.6618   | 4.0125  | 8.0594   | 14.7785  |
| Max. drainage | 76.3813  | 99.8171  | 74.1615 | 18.2288  | 71.4295  |
| Max. infiltration | 32.7251 | 75.4412  | 120.1964| 90.8171  | 142.5888 |
| Min. release  | 0.428    | 0.3374   | 0.1672  | 0.6837   | 0.2207   |
| Curve No.     | 0.7506   | 5.8945   | 0.7259  | 1.9054   | 3.3899   |
| Initial storage | 76.8797 | 207.2124 | 40.3415 | 172.6357 | 106.473  |
| Rain mult.    | 1.3224   | 1.336    | 1.3068  | 1.3285   | 1.2992   |
| Lag time      | 3        | 1        | 4       | 1        | 2        |

### Table C.5.8 Results of Sensitivity Analysis for Waihohonu Catchment

<table>
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<tr>
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<td>Parameter</td>
<td>D value</td>
</tr>
<tr>
<td>Tb</td>
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<td>Log time</td>
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<td>Tf</td>
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<td>Baseflow</td>
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<tr>
<td>Fastflow</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Interflow</td>
<td>0.2019</td>
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<td></td>
</tr>
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</table>
Figure C.5.21 Modelled versus observed streamflow using the top five calibrated parameter sets for the calibration period
Figure C.5.22 Modelled versus observed streamflow using the top five calibrated parameter sets for the evaluation period.
Figure C.5.23 Scatterplots of parameter values against their corresponding objective function value
Figure C.5.24 HSY sensitivity analysis where $x$ is the parameter value and $F(x)$ is the cumulative distribution function. Dashed dark lines are non-behavioural parameter sets and the lighter lines are behavioural.
C.6 Waihi Catchment

The Waihi catchment is located north west of Turangi. As there is no rainfall gauge within or near the catchment, the gauge at Turangi is used for this analysis. While most events appear to the represented (Figure C.6.1) the residual mass curves show some differences which will impact on model performance (Figure C.6.2, right). KGE performance values are around 0.75 for the fit to the time series and 0.83 to 0.86 for the fit to the flow duration curve (Table C.6.1). Given the short duration of the streamflow record, the full time series is used for calibration (no evaluation is undertaken). In general, the recession and baseflow response is captured reasonably well but flood peaks are generally over-estimated except during very large events where it is under-estimated (Figure C.6.3). The parameters which are the most well-defined and identifiable (Figure C.6.4) are also the most sensitive (Table C.6.2 and Figure C.6.5) and include the baseflow and fastflow proportions, fastflow residence time and rainfall multiplier.
Figure C.6.1 Plot of recession periods (light blue dots). Negative recessions (rising streamflow during periods of no rain or evapotranspiration) are highlighted (dark blue dots) (a) Entire record and (b) corresponding rainfall. (c) Calibration period and (d) corresponding rainfall.

Figure C.6.2 Calibration period data versus whole record. Left: Flow duration curves. Right: Residual mass curve.
### Table C.6.1. Waihi Catchment Model Results

<table>
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<td>Field capacity</td>
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<tr>
<td>Interflow</td>
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<td>Ti</td>
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<td>Tf</td>
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<td>24</td>
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<tr>
<td>Field cap to sat</td>
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<td>Max. drainage</td>
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<td>Max. infiltration</td>
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<td>110.6</td>
<td>105.14</td>
<td>16.66</td>
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<tr>
<td>Min. release</td>
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<td>0.14001</td>
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<tr>
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<tr>
<td>Initial storage</td>
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<td>16.846</td>
<td>29.915</td>
<td>120.11</td>
<td>169.17</td>
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### Table C.6.2 Results of Sensitivity Analysis for Waihi Catchment

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Figure C.6.3 Modelled versus observed streamflow using the top five calibrated parameter sets for the calibration period.
Figure C.6.4 Scatterplots of parameter values against their corresponding objective function value.
Figure C.6.5 HSY sensitivity analysis where $x$ is the parameter value and $F(x)$ is the cumulative distribution function. Dashed dark lines are non-behavioural parameter sets and the lighter lines are behavioural.
C.7 Kuratau Catchment (above power scheme)

This analysis relates to the Kuratau catchment from above the Kuratau Power Scheme. Located close to the streamflow gauge is a rainfall station which has collected rainfall data since 1994. There are many gaps in this rainfall record (Figure C.7.1) and as such to obtain a suitable period of time for calibration gaps, were infilled. Overall, this rainfall record is suitable for model calibration for the period 1998-2004, although there is some differences in the residual mass curves in the middle of the time series which may impact on model performance (Figure C.7.2). The flow duration curve of the calibration period captured a wide range of hydrological responses at the higher and lower end of the curve, although mid-high range flows were less adequately characterised (Figure C.7.2, left).

While model performance is reasonable over the calibration period, it is considerably weaker over the evaluation period (Table C.7.1). Similar results were found for other periods in the record over which the parameter sets were evaluated. While the model seems to over-estimate peak flows, recessions and baseflow characteristics appear to be fairly consistent with the observations (Figure C.7.4), suggesting that the KGE in this case is under-estimating the model’s performance. Many parameters are identified as sensitive in this sub-catchment (Table C.7.2 and Figure C.7.6).

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<tr>
<td>Calibration period</td>
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<td>Evaluation period</td>
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</table>
Figure C.7.1 Plot of recession periods (light blue dots). Negative recessions (rising streamflow during periods of no rain or evapotranspiration) are highlighted (dark blue dots) (a) Entire record and (b) corresponding rainfall. (c) Calibration period and (d) corresponding rainfall.

Figure C.7.2 Calibration period data versus whole record. Left: Flow duration curves. Right: Residual mass curve.
Table C.7.1. Kuratau Catchment Model Results

<table>
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<tr>
<th>Parameter Set</th>
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### Parameter values

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<tr>
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Table C.7.2. Results of Sensitivity Analysis for Kuratau Catchment

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</tr>
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<td>Fastflow</td>
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</tr>
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<td>TB</td>
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<td>Max. infiltration</td>
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<td>Interflow</td>
<td>0.2373</td>
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<td>Field cap to sat</td>
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</table>
Figure C.7.3: Modelled versus observed streamflow using the top five calibrated parameter sets for the calibration period.
Figure C.7.4 Modelled versus observed streamflow using the top five calibrated parameter sets for the evaluation period.
Figure C.7.5 Scatterplots of parameter values against their corresponding objective function value
Figure C.7.6 HSY sensitivity analysis where $x$ is the parameter value and $F(x)$ is the cumulative distribution function. Dashed dark lines are non-behavioural parameter sets and the lighter lines are behavioural.
C.8 Whareroa Catchment

The Whareroa catchment is a largely pastoral area located north of Kuratau. The Kuratau rainfall record is used as input for model calibration. There are many gaps in the hydrological record and some large gaps in the rainfall record which has limited the amount of data suitable for model calibration and evaluation (Figure C.8.1). As such, a two year period of data is selected for calibration (2002-2004). Fortunately, this period represents a large amount of the hydrologic response observed in the catchment (Figure C.8.2, left), and the residual mass curves follow a similar pattern (Figure C.8.2, right).

Model calibration reveals a relatively high baseflow component in this catchment. KGE performance values are good, with the fit to the time series being greater than 0.85 and fit to the flow duration curve greater than 0.95 (Table C.8.1). Figure C.8.3 shows that the modelled streamflow is doing a reasonable job of simulated the observed response, with relatively small errors over the calibration period. Three parameters (rainfall multiplier, lag time and baseflow) are the most well-defined parameters in this sub-catchment (Figure C.8.4). These parameters are also the most sensitive (Table C.8.2 and Figure C.8.5).

<table>
<thead>
<tr>
<th>Calibration and Evaluation data period for the Whareroa catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration period</td>
</tr>
<tr>
<td>Evaluation period</td>
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</tbody>
</table>
Figure C.8.1 Plot of recession periods (light blue dots). Negative recessions (rising streamflow during periods of no rain or evapotranspiration) are highlighted (dark blue dots) (a) Entire record and (b) corresponding rainfall. (c) Calibration period and (d) corresponding rainfall.

Figure C.8.2 Calibration period data versus whole record. Left: Flow duration curves. Right: Residual mass curve.
### Table C.8.1. Whareroa Catchment Model Results

<table>
<thead>
<tr>
<th>Parameter Set</th>
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### Table C.8.2 Results of Sensitivity Analysis for Whareroa Catchment

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<th>Insensitive D value</th>
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<td>Field cap to sat 0.0082</td>
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</table>
Figure C.8.3 Modelled versus observed streamflow using the top five calibrated parameter sets for the calibration period.
Figure C.8.4 Scatterplots of parameter values against their corresponding objective function value.
Figure C.8.5 HSY sensitivity analysis where $x$ is the parameter value and $F(x)$ is the cumulative distribution function. Dashed dark lines are non-behavioural parameter sets and the lighter lines are behavioural.
The Whanganui catchment is located on the western side of Lake Taupo. There is no rainfall gauge located within this catchment. The Waihaha rainfall gauge, which is the gauge closest to the catchment, is used as input for model calibration as it is relatively consistent with the streamflow record (Figure C.9.1). Two years of data are used for model calibration. This period represents most of the streamflow responses observed in the catchment (Figure C.9.2, left) and the residual mass curves are reasonably consistent (Figure C.9.2, right).

The performance of optimal parameter sets is strong. Figure C.9.3 shows good correspondence between the modelled and observed streamflow. KGE values are above 0.91 and 0.97 for the fits to the time series and flow duration curve, respectively (Table C.9.1). Aside from catchment lag time and fastflow proportion, most parameters are not strongly identifiable (Figure C.9.5). Along with these two identifiable parameters, the rainfall multiplier and baseflow proportion are most sensitive (Table C.8.2 and Figure C.8.5). The residence time associated with the baseflow store is moderately sensitive.

<table>
<thead>
<tr>
<th>Calibration and Evaluation data period for the Whanganui catchment</th>
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<td>Calibration period</td>
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<tr>
<td>Evaluation period</td>
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</table>
Figure C.9.1 Plot of recession periods (light blue dots). Negative recessions (rising streamflow during periods of no rain or evapotranspiration) are highlighted (dark blue dots) (a) Entire record and (b) corresponding rainfall. (c) Calibration period and (d) corresponding rainfall.

Figure C.9.2 Calibration period data versus whole record. Left: Flow duration curves. Right: Residual mass curve.
Table C.9.1. Whanganui Catchment Model Results

<table>
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<tr>
<th>Parameter Set</th>
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<tbody>
<tr>
<td>Field capacity</td>
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<tr>
<td>Baseflow</td>
</tr>
<tr>
<td>Interflow</td>
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<tr>
<td>Fastflow</td>
</tr>
<tr>
<td>Tb</td>
</tr>
<tr>
<td>Ti</td>
</tr>
<tr>
<td>Tf</td>
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<tr>
<td>Field cap to sat</td>
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<td>Max. drainage</td>
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<tr>
<td>Max. infiltration</td>
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<tr>
<td>Min. release</td>
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<td>Curve No.</td>
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<td>Initial storage</td>
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<td>Rain mult.</td>
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<td>Lag time</td>
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Table C.9.2. Results of Sensitivity Analysis for Whanganui Catchment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensitive D value</th>
<th>Moderately sensitive D value</th>
<th>Insensitive D value</th>
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<td>Max. drainage</td>
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</table>
Figure C.9.3 Modelled versus observed streamflow using the top five calibrated parameter sets for the calibration period.
Figure C.9.4 Modelled versus observed streamflow using the top five calibrated parameter sets for the evaluation period.
Figure C.9.5 Scatterplots of parameter values against their corresponding objective function value
Figure C.9.6 HSY sensitivity analysis where $x$ is the parameter value and $F(x)$ is the cumulative distribution function. Dashed dark lines are non-behavioural parameter sets and the lighter lines are behavioural.
Streamflow and rainfall were recorded in the Waihaha catchment for almost 20 years between 1976 and 1995. Although there are many gaps in the rainfall record, there is a period during the early 1990s which shows good consistency between streamflow and rainfall and for which there are no gaps (Figure C.10.1). The majority of hydrologic responses are represented (Figure C.10.2, left) and the residual mass curves are very similar (Figure C.10.2, right). This period is selected for model calibration.

Similar to the Whanganui catchment, the model does a good job of simulating streamflow in this catchment. Most flood flows are over-estimated, except for the largest flows in the period which are under-estimated (Figure C.10.3). Recession and low flow periods are closely matched. Table C.10.1 lists the KGE performance index values for each of the parameters sets and associated parameter values. Performance is strong with KGE values above 0.91 for the fit to the time series and over 0.96 for the fit to the flow duration curve. The rainfall multiplier and baseflow proportion parameters are the most identifiable (Figure C.10.5) and are also the most sensitive along with catchment lag time and fastflow proportion (Table C.10.2 and Figure C.10.6).

<table>
<thead>
<tr>
<th>Calibration and Evaluation data period for the Waihaha catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration period</td>
</tr>
<tr>
<td>Evaluation period</td>
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</tbody>
</table>
Figure C.10.1 Plot of recession periods (light blue dots). Negative recessions (rising streamflow during periods of no rain or evapotranspiration) are highlighted (dark blue dots) (a) Entire record and (b) corresponding rainfall. (c) Calibration period and (d) corresponding rainfall.

Figure C.10.2 Calibration period data versus whole record. Left: Flow duration curves. Right: Residual mass curve.
## Table C.10.1. Waihaha Catchment Model Results

<table>
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<tr>
<th>Parameter Set</th>
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Table C.10.2. Results of Sensitivity Analysis for Waihaha Catchment

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<tr>
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<tr>
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<td>Max infiltration</td>
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</table>
Figure C.10.3 Modelled versus observed streamflow using the top five calibrated parameter sets for the calibration period.
Figure C.10.4 Modelled versus observed streamflow using the top five calibrated parameter sets for the evaluation period
Figure C.10.5 Scatterplots of parameter values against their corresponding objective function value
Figure C.10.6 HSY sensitivity analysis where $x$ is the parameter value and $F(x)$ is the cumulative distribution function. Dashed dark lines are non-behavioural parameter sets and the lighter lines are behavioural.
C.11  Tutaeuaua Catchment

The Tutaeuaua catchment is the smallest catchment included in this study, covering an area of only 3.3 km². The rainfall record used as input to the model is located several kilometres outside of the catchment (and outside the Lake Taupo catchment) at Mangakino. Despite its location, it is reasonably consistent with the streamflow response in the catchment (Figure C.11.1), although there is some differences evident in the residual mass curves (Figure C.11.2, right). Evaluation is not undertaken due to there being many gaps in the hydrological record, limiting the amount of data to calibrate to.

There are, however, numerous gaps in the hydrological record which limits the number of points on which performance can be measured (Figure C.11.3). KGE values are relatively good (Table C.11.1) ranging between 0.83 and 0.85 for the fit to the time series and 0.90 to 0.97 for the fit to the flow duration curve over the evaluation period. In this catchment, the rainfall multiplier, fastflow proportion and associated residence time are the most identifiable (Figure C.11.4). Along with catchment lag time and baseflow proportion these five parameters are the most influential (sensitive) in this catchment (Table C.11.2 and Figure C.11.5).

<table>
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</thead>
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<td>Calibration period</td>
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<td>Evaluation period</td>
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</table>
Figure C.11.1 Plot of recession periods (light blue dots). Negative recessions (rising streamflow during periods of no rain or evapotranspiration) are highlighted (dark blue dots). (a) Entire record and (b) corresponding rainfall. (c) Calibration period and (d) corresponding rainfall.

Figure C.11.2 Calibration period data versus whole record. Left: Flow duration curves. Right: Residual mass curve.
Table C.11.1. Tutaeuaua Catchment Model Results

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<th>Fastflow</th>
<th>Tb</th>
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<th>Tf</th>
<th>Field cap to sat</th>
<th>Max. drainage</th>
<th>Max. infiltration</th>
<th>Min. release</th>
<th>Curve No.</th>
<th>Initial storage</th>
<th>Rain mult.</th>
<th>Lag time</th>
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Table C.11.2. Results of Sensitivity Analysis for Tutaeuaua Catchment

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<th>Insensitive</th>
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Figure C.11.3 Modelled versus observed streamflow using the top five calibrated parameter sets for the calibration period.
Figure C.11.4 Scatterplots of parameter values against their corresponding objective function value
Figure C.11.5 HSY sensitivity analysis where $x$ is the parameter value and $F(x)$ is the cumulative distribution function. Dashed dark lines are non-behavioural parameter sets and the lighter lines are behavioural.
Appendix D:  
Bivariate Sensitivity Analysis

This Appendix presents Scatterplots showing two-way parameter response surfaces with respect to the performance measure used. The values of two selected parameters are plotted against each other. Again, the top 1000 (unless fewer are obtained) behavioural parameter sets are plotted with the five highest highlighted. If these behavioural parameter sets are observed across the entire parameter space then there is little, if any, interaction between the two parameters. If the plots show some (positive or negative) relationship between the corresponding parameter sets, some form of parameter interaction can be assumed.

This bivariate sensitivity analysis is undertaken for each sub-catchment.

<table>
<thead>
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<th>Parameter</th>
<th>Unit</th>
<th>Parameter</th>
<th>Unit</th>
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<td>Maximum drainage</td>
<td>mm/time step</td>
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<tr>
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<td>-</td>
<td>Minimum release</td>
<td>mm</td>
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<td>Fastflow</td>
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<td>Curve power/no.</td>
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<td>Rainfall multiplier</td>
<td># time steps</td>
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<td>Interflow residence time (Ti)</td>
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<td>Field capacity to saturation (FC to Sat)</td>
<td>mm</td>
<td></td>
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Sub-catchment bivariate sensitivity analyses

D.1 Waitahanui Catchment ................................................................. 159
D.2 Hinemaiaia Catchment .............................................................. 174
D.3 TaurangaTaupo Catchment ....................................................... 189
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D.1  Waitahanui Catchment
D.1.1 Field Capacity
D.1.2 Baseflow

![Graphs showing various parameters related to baseflow, including field capacity, interflow, fastflow, lag time, rainfall multiplier, maximum infiltration, minimum release, curve number, and rain multiplier.](image)
D.1.3 Interflow

Field capacity

Baseflow

Fastflow

Interflow

Tb

Maximum drainage

Maximum infiltration

Minimum release

Curve no.

Rain multiplier

Log time

Interflow

Interflow

Interflow

Interflow

Interflow

Interflow
D.1.4 Fastflow
D.1.5 Baseflow Residence Time

![Baseflow Residence Time Diagrams]

- Field capacity
- Baseflow
- Interflow
- Fastflow
- Maximum drainage
- Maximum infiltration
- Minimum release
- Curve no.
- Rain multiplier
- Lag time
D.1.6 Interflow Residence Time
D.1.7 Fastflow Residence Time
D.1.8 Field Capacity to Saturation
D.1.9 Maximum Drainage
Minimum Release

Field capacity

Baseflow

Interflow

Fastflow

TC to sat

Max drainage

Max infiltration

Lag time

Minimum release

Minimum release mult

Rain multiplier

Curve no.

Minimum release
D.1.12 Curve Power
Appendix D

D.1.13 Rainfall Multiplier

- Field capacity
- Baseflow
- Interflow
- Fastflow
- Tb
- Ti
- Tf
- FC to sat
- Max drainage
- Max infiltration
- Minimum release
- Curve No.
- Log time

Rainfall Multiplier

Rainfall Multiplier

Rainfall Multiplier

Rainfall Multiplier
D.2 Hinemaiaia Catchment
D.2.1 Field Capacity
D.2.2 Baseflow
D.2.3 Interflow
D.2.5 Baseflow Residence Time
D.2.6 Interflow Residence Time

Field capacity

Baseflow

Interflow

Fastflow

Maximum drainage

Maximum infiltration

Rain multiplier

Log time

Ti

Tb

FC to sat

Tf

Ti

Rain multiplier

Curve no.
D.2.7 Fastflow Residence Time

- Field capacity
- Baseflow
- Interflow
- Fastflow
- Field capacity to saturation
- Maximum drainage
- Maximum infiltration
- Minimum release
- Curve number
- Rain multiplier
- Lag time
D.2.8 Field Capacity to Saturation
Appendix D

D.2.9  Maximum Drainage
D.2.11 Minimum Release

Field capacity

Baseflow

Interflow

Fastflow

FC to sat

Max drainage

Max infiltration

Log time

Minimum release

Tb

Ti

Tf

Curve no.

Rain multiplier

Minimum release

Maximum infiltration

Lag time
D.2.12 Curve Power

[Graphs showing different data sets such as Field capacity, Baseflow, Interflow, Fastflow, FC to sat, Max drainage, Max infiltration, Minimum release, Rain multiplier, and Log time vs. Curve no.]

186 | Appendix D
D.2.13 Rainfall Multiplier

187 | Appendix D
D.2.14 Lag time

[Graphs showing various hydrological parameters plotted against lag time]
D.3 Tauranga-Taupo Catchment
D.3.1 Field Capacity

- Baseflow
- Interflow
- Fastflow
- Tb
- Ti
- Tf
- FC to sat
- Max drainage
- Max infiltration
- Minimum release
- Lag time
- Curve no.
- Rain multiplier
D.3.3 Interflow
D.3.4 Fastflow
D.3.5 Baseflow Residence Time

Field capacity

Baseflow

Interflow

Fastflow

Max drainage

Max infiltration

Minimum release

Log time

Rain multiplier

Curves no.

Rain multiplier

Baseflow Residence Time

Field capacity

Baseflow

Interflow

Fastflow

Max drainage

Max infiltration

Minimum release

Log time

Rain multiplier

Curves no.

Rain multiplier

Baseflow Residence Time
D.3.6 Interflow Residence Time
D.3.7 Fastflow Residence Time
D.3.9 Maximum Drainage
D.3.10 Maximum Infiltration

[Graphs and data plots showing relationships between various hydrological parameters such as field capacity, baseflow, interflow, fastflow, FC to sat, maximum drainage, minimum release, curve no., rain multiplier, and lag time, with data points scattered across graphs to illustrate distribution and trends.]
D.3.11 Minimum Release

Field capacity
- $x \times 10^4$
- $T_0$
- Max. drainage
- Log. time
- Rain multiplier
- Curve no.
- Minimum release
- Max. infiltration
D.3.12 Curve Power
D.3.13 Rainfall Multiplier
D.4  Waimarino Catchment
D.4.1 Field Capacity

- Baseflow
- Interflow
- Fastflow
- Field capacity
- Maximum drainage
- Maximum infiltration
- Minimum release
- Curve no.
- Rain multiplier
- Lag time
D.4.2 Baseflow

Field capacity

Interflow

Fastflow

Tb

Ti

FC to sat

Maximum drainage

Rain multiplier

Minimum release

Curve no.

Rain multiplier

Log time

Baseflow
D.4.3 Interflow

Field capacity

Baseflow

Fastflow

Maximum drainage

Field capacity to saturated

Tb

Ti

FC to sat

Tf

Maximum infiltration

Minimum release

Rain multiplier

Lag time

Log time

Interflow

Interflow
D.4.4 Fastflow

- Field capacity
- Baseflow
- Interflow
- T
- Maximum drainage
- Maximum infiltration
- Minimum release
- Curve no.
- Rain multiplier
- Lag time

Graphs showing various hydrological parameters and their distributions.
D.4.5 Baseflow Residence Time
D.4.6 Interflow Residence Time

Field capacity

Baseflow

Interflow

Fastflow

Tb

Tf

FC to sat

Maximum drainage

Maximum infiltration

Minimum release

Curve no.

Rain multiplier

Lag time

Log time
D.4.7 Fastflow Residence Time

Field capacity

Baseflow

Interflow

Fastflow

Tb

Tb

Ti

Ti

FC to sat

Maximum drainage

Maximum infiltration

Minimum release

Curve no.

Rain multiplier

Lag time

Log time
D.4.8  Field Capacity to Saturation

Field capacity

Baseflow

Interflow

Fastflow

Maximum drainage

Maximum infiltration

Minimum release

Log time

Rain multiplier

Curve no.
D.4.9 Maximum Drainage
D.4.10  Maximum Infiltration
D.4.12 Curve Power
D.4.13 Rainfall Multiplier

Field capacity

Baseflow

Interflow

Fastflow

Tb

Ti

Fc to sat

Max drainage

Max infiltration

Minimum release

Curve No.

Log time

Rain multiplier

Rain multiplier

Rain multiplier

Rain multiplier
### D.4.14 Lag time

- Field capacity
- Baseflow
- Interflow
- Fastflow
- Lag time
- Min release
- Curve No.
- Rain multiplier

![Graphs of various hydrological parameters](image-url)
D.5 Lower Tongariro Catchment
D.5.1 Field Capacity
Appendix D

D.5.2 Baseflow

Field capacity
Interflow
Fastflow
Tb
FC to sat
Maximum drainage
Minimum release
Curve no.
Rain multiplier
Lag time
Baseflow
D.5.3 Interflow
D.5.4 Fastflow
Appendix D

D.5.5  Baseflow Residence Time

[Graphs and data plots related to baseflow residence time and other hydrological parameters are shown.]
D.5.6 Interflow Residence Time
D.5.7 Fastflow Residence Time
D.5.8  Field Capacity to Saturation
D.5.9 Maximum Drainage

![Graphs showing various hydrological parameters including field capacity, baseflow, interflow, and fastflow over a range of values.](image)
D.5.10  Maximum Infiltration

Field capacity

Baseflow

Interflow

Fastflow

$T_b$

$T_i$

$T_f$

FC to sat

Max drainage

Minimum release

Curve no.

Rain multiplier

Log time

Max infiltration

0 50 100 150

0

200

400

600

Field capacity

0 50 100 150

0

0.5

1

Baseflow

0 50 100 150

0

0.2

0.4

0.6

0.8

Interflow

0 50 100 150

0

0.2

0.4

0.6

0.8

Fastflow

0 50 100 150

0

0.2

0.4

0.6

0.8

Ti

0 50 100 150

0

10

20

30

40

50

60

70

Ti

0 50 100 150

0

10

20

30

40

50

60

70

$T_f$

0 50 100 150

0

10

20

30

40

50

60

70

FC to sat

0 50 100 150

0

2

4

6

8

10

Curve no.

0 50 100 150

0

2

4

6

8

10

Rain multiplier

0 50 100 150

0.4

0.6

0.8

1

Max infiltration

0 50 100 150

0

5

10

15

$L_{in}$

0 50 100 150

0

5

10

15

Max infiltration

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D.5.11 Minimum Release

Field capacity

Baseflow

Interflow

Fastflow

Tb

Ti

Tf

FC to sat

Max drainage

Max infiltration

Curve no.

Rain multiplier

Lag time

Log time

Minimum release
D.5.12 Curve Power

Field capacity

Baseflow

Interflow

Fastflow

To

Ti

Max drainage

Max infiltration

FC to sat

Minimum release

Rain multiplier

Lag time
D.5.13 Rainfall Multiplier
D.6 Poutu Catchment
D.6.1 Field Capacity

Baseflow

Interflow

Fastflow

Routing factors

Maximum drainage

Maximum infiltration

Minimum release

Rain multiplier

Lag time
D.6.2 Baseflow
D.6.3 Interflow
D.6.5 Baseflow Residence Time

[Graphs and data plots showing relationships between various parameters such as field capacity, baseflow, interflow, fastflow, water table, maximum drainage, maximum infiltration, minimum release, curve number, and rain multiplier.]
D.6.6 Interflow Residence Time
D.6.7 Fastflow Residence Time

Field capacity

Baseflow

Interflow

Fastflow

FC to sat

Maximum drainage

Maximum infiltration

Minimum release

Curve no.

Rain multiplier

Lag time

Log time
Appendix D

D.6.8 Field Capacity to Saturation

[Graphs and plots related to field capacity, baseflow, interflow, fastflow, maximum drainage, maximum infiltration, minimum release, curve number, and rain multiplier versus field capacity to saturation.]
D.6.9 Maximum Drainage
D.6.10 Maximum Infiltration
D.6.11 Minimum Release

- Field capacity
- Baseflow
- Interflow
- Fastflow
- FC to sat
- Max drainage
- Max infiltration
- Curve no.
- Rain multiplier
- Minimum release mult
- Lag time
D.6.12 Curve Power

Field capacity

Baseflow

Interflow

Tb

Ti

Max drainage

Max infiltration

FC to sat

Minimum release

Rain multiplier

Lag time
D.6.13 Rainfall Multiplier

Field capacity
- Values range from 0 to 0.8 with increments of 0.2
- Graph shows a quadratic relationship with rainfall multiplier

Baseflow
- Values range from 0 to 100 with increments of 50
- Graph shows a linear relationship with rainfall multiplier

Interflow
- Values range from 0 to 4000 with increments of 2000
- Graph shows an exponential relationship with rainfall multiplier

Fastflow
- Values range from 0 to 200 with increments of 100
- Graph shows a linear relationship with rainfall multiplier

FC to sat
- Values range from 50 to 100 with increments of 50
- Graph shows a linear relationship with rainfall multiplier

Max drainage
- Values range from 0 to 150 with increments of 50
- Graph shows a linear relationship with rainfall multiplier

Max infiltration
- Values range from 0 to 6 with increments of 2
- Graph shows a linear relationship with rainfall multiplier

Log time
- Values range from 4 to 8 with increments of 2
- Graph shows a linear relationship with rainfall multiplier
D.6.14 Lag time

Field capacity

Baseflow

Interflow

Fastflow

$T_b$

$T_i$

$T_f$

FC to sat

Max drainage

Max infiltration

Minimum release

Curve No.

Rain multiplier

Lag time

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D.7 Waipakihi Catchment
### D.7.1 Field Capacity

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D.7.2 Baseflow

Field capacity

Interflow

Fastflow

Tb

Ti

FC to sat

Maximum drainage

Minimum release

Curve no.

Rain multiplier

Lag time

Log time
D.7.3 Interflow
D.7.4 Fastflow

Field capacity

Baseflow

Interflow

Tb

Ti

Tf

FC to sat

Maximum drainage

Minimum release

Curve no.

Rain multiplier

Lag time

Log time
D.7.5 Baseflow Residence Time

- Field capacity
- Baseflow
- Interflow
- Fastflow
- Maximum drainage
- FC to sat
- Maximum infiltration
- Minimum release
- Curve no.
- Lag time
- Rain multiplier

![Graphs showing the relationship between various hydrological parameters and time.](image-url)
D.7.6 Interflow Residence Time
D.7.7 Fastflow Residence Time
D.7.8 Field Capacity to Saturation

- Field capacity vs. FC to Sat
- Base flow vs. FC to Sat
- Interflow vs. FC to Sat
- Fast flow vs. FC to Sat
- Maximum drainage vs. FC to Sat
- Maximum infiltration vs. FC to Sat
- Minimum release vs. FC to Sat
- Curve no. vs. FC to Sat
- Rain multiplier vs. FC to Sat
- Log time vs. FC to Sat
D.7.9 Maximum Drainage
D.7.10  Maximum Infiltration
D.7.11 Minimum Release
D.7.12 Curve Power
D.7.13 Rainfall Multiplier

![Graphs showing various hydrological processes and their multipliers]
D.7.14  Lag time

- Field capacity
- Baseflow
- Interflow
- Fastflow
- Infilt
- FC to sat
- Min drainage
- Max infiltration
- Curve No.
- Rain multiplier
D.8.1 Field Capacity
D.8.2 Baseflow

Field capacity

Interflow

Fastflow

Tb

Ti

FC to sat

Maximum drainage

Maximum infiltration

Minimum release

Curve no.

Rain multiplier

Lag time

Log time

Baseflow
D.8.3 Interflow
D.8.4 Fastflow

Field capacity

Baseflow

Interflow

Tb

FC to sat

Maximum drainage

Minimum release

Curve no.

Rain multiplier

Lag time

Fastflow

Fastflow

Fastflow

Fastflow

Fastflow

Fastflow

Fastflow

Fastflow
D.8.5 Baseflow Residence Time
Appendix D

D.8.6 Interflow Residence Time

The plots illustrate the relationships between various hydrological parameters, including:

- **Field capacity**
- **Baseflow**
- **Interflow**
- **Rainflow**
- **Fastflow**
- **Tb**
- **ToF sat**
- **Maximum drainage**
- **Maximum infiltration**
- **Minimum release**
- **Curve no.**
- **Rain multiplier**
- **Lag time**

Each plot shows a scatter of data points varying across the specified range, indicating the distribution and correlation of these parameters within the study area.
D.8.7 Fastflow Residence Time

Field capacity

Baseflow

Interflow

Fastflow

To

Tb

FC to sat

Maximum drainage

Maximum infiltration

Minimum release

Curve no.

Rain multiplier

Lag time

Log time
D.8.8 Field Capacity to Saturation
D.8.9 Maximum Drainage
D.8.10 Maximum Infiltration
Appendix D  Curve Power

Field capacity

Basflow

Interflow

Fastflow

Tb

Ti

Tf

FC to sat

Max drainage

Max infiltration

Minimum release

Rain multiplier

Lag time
D.8.13 Rainfall Multiplier

- Field capacity
  - 0 to 300
  - 1.2 to 1.8
- Baseflow
  - 0.7 to 1
  - 1.2 to 1.8
- Interflow
  - 0 to 0.4
  - 1.2 to 1.8
- Fastflow
  - 0 to 0.5
  - 1.2 to 1.8
- Tb
  - 0 to 1000
  - 1.2 to 1.8
- Ti
  - 0 to 20
  - 1.2 to 1.8
- Tf
  - 0 to 10
  - 1.2 to 1.8
- FC to sat
  - 0 to 50
  - 1.2 to 1.8
- Max drainage
  - 0 to 150
  - 1.2 to 1.8
- Max infiltration
  - 0 to 50
  - 1.2 to 1.8
- Minimum release
  - 0 to 0.5
  - 1.2 to 1.8
- Curve No.
  - 0 to 6
  - 1.2 to 1.8
- Lag time
  - 0 to 15
  - 1.2 to 1.8
D.8.14 Lag time

Field capacity

Baseflow

Interflow

Fastflow

Tb

To

Tf

Max drainage

Max infiltration

Minimum release

Curve No.

Rain multiplier

Lag time
D.9 Waihi Catchment
D.9.1 Field Capacity
D.9.2 Baseflow
### D.9.3 Interflow

<table>
<thead>
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<th>Field capacity</th>
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<th>Fastflow</th>
<th>Interflow</th>
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<td>0</td>
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<td>2000</td>
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</tr>
<tr>
<td>4000</td>
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</tr>
<tr>
<td>6000</td>
<td>2</td>
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**Rain multiplier**

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**Minimum release**

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</tr>
<tr>
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</tr>
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<table>
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</tr>
<tr>
<td>0.4</td>
</tr>
<tr>
<td>0.6</td>
</tr>
<tr>
<td>0.8</td>
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D.9.4 Fastflow


D.9.5  Baseflow Residence Time
D.9.6 Interflow Residence Time
D.9.7 Fastflow Residence Time
D.9.8 Field Capacity to Saturation
D.9.9 Maximum Drainage
D.9.10 Maximum Infiltration
D.9.11 Minimum Release
D.9.13 Rainfall Multiplier

- Field capacity
- Baseflow
- Interflow
- Fastflow
- Max drainage
- Max infiltration
- Minimum release
- Curve No.
- Lag time
- Log Tire

Rainfall Multiplier

Field capacity
Baseflow
Interflow
Fastflow
Max drainage
Max infiltration
Minimum release
Curve No.
Lag time
Log Tire
Rain multiplier

292 | Appendix D
D.9.14 Lag time

Field capacity

Baseflow

Interflow

Fastflow

Tb

To

Ti

Tf

Max drainage

Max infiltration

FC to sat

Minimum release

Curve No.

Rain multiplier
D.10 Kuratau Catchment
D.10.1 Field Capacity

Baseflow

Interflow

Fastflow

$T_b$

$T_i$

$T_f$

$FC_{to\ sat}$

Maximum drainage

Maximum infiltration

Minimum release

Curve no.

Rain multiplier

Lag time

Field capacity
Appendix D

D.10.2 Baseflow

- Field capacity
- Interflow
- Fastflow
- Maximum drainage
- Maximum infiltration
- Minimum release
- Curve no.
- Rain multiplier
- Lag time

Graphs showing various relationships between variables such as Field capacity vs. Baseflow, Interflow vs. Baseflow, and so on.
D.10.3  Interflow

Field capacity

Base flow

Fast flow

FC to sat

Maximum drainage

Minimum release

Log time

Curve no.

Rain multiplier

Lag time

Rain multiplier

Field capacity

Base flow

Fast flow

FC to sat

Maximum drainage

Minimum release

Log time

Curve no.

Rain multiplier

Lag time
D.10.4 Fastflow
D.10.6  Interflow Residence Time
D.10.7  Fastflow Residence Time
D.10.8 Field Capacity to Saturation
D.10.9  Maximum Drainage
D.10.10  Maximum Infiltration
Minimum Release

- Field capacity
- Base flow
- Interflow
- Fastflow
- TC
- Ti
- TF
- FC to sat
- Max drainage
- Max infiltration
- Lag time
- Minimum release

Rain multiplier

Curve no.

Maximum release mult
D.10.12 Curve Power

Field capacity

Base flow

Interflow

Fast flow

Tb

Tb

Ti

Ti

FC to sat

Max drainage

Max infiltration

Min release

Rain multiplier

Lag time
D.11.1 Field Capacity
D.11.2 Baseflow
D.11.3 Interflow
D.11.4 Fastflow

Field capacity

Baseflow

Interflow

Tb

Ti

FC to sat

Maximum drainage

Maximum infiltration

Minimum release

Curve no.

Rain multiplier

Lag time

Log time
D.11.5  Baseflow Residence Time

Field capacity

Baseflow

Interflow

Fastflow

Maximum drainage

Maximum infiltration

Lag time

Tb

FC to sat

Rain multiplier

Curve no.
D.11.6 Interflow Residence Time
D.11.7 Fastflow Residence Time

Field capacity, Baseflow, Interflow, Fastflow, FC to sat, Maximum drainage, Maximum infiltration, Minimum release, Curve no., Rain multiplier, Lag time.
Field Capacity to Saturation

Field capacity

Baseflow

Interflow

Fastflow

Tb

Ti

Tf

Maximum drainage

Maximum infiltration

Minimum release

Curve no.

Rain multiplier

Log time

FC to Sat
D.11.9  Maximum Drainage

Field capacity

Baseflow

Interflow

Fastflow

Tb

Ti

Tf

FC to sat

Maximum infiltration

Minimum release

Curve no.

Rain multiplier

Lag time

Log time

Maximum drainage
D.11.12 Curve Power

Field capacity

Baseflow

Interflow

Fastflow

Tb

Ti

Max drainage

Max infiltration

Minimum release

Rain multiplier

Lag time

Log time

Curve no.

Curve no.

Curve no.

Curve no.
### D.11.13 Rainfall Multiplier

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<th>Interflow</th>
<th>Fastflow</th>
<th>FC to sat</th>
<th>Max drainage</th>
<th>Max infiltration</th>
<th>Curve No.</th>
<th>Lag Time</th>
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<td>50</td>
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<td>1.0</td>
<td>1.0</td>
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<td>100</td>
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<td>1.2</td>
<td>1.2</td>
<td>0.6</td>
<td>0.5</td>
<td>150</td>
<td>150</td>
<td>4</td>
<td>15</td>
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<tr>
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<td>1.4</td>
<td>1.4</td>
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<td>0.5</td>
<td>200</td>
<td>200</td>
<td>6</td>
<td>20</td>
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Whanganui Catchment
D.12.1 Field Capacity

- Baseflow
- Interflow
- Fastflow
- Maximum drainage
- Maximum infiltration
- Minimum release
- Curve no.
- Lag time
- Rain multiplier
- Field capacity

- $T_b$
- $T_i$
- $T_f$
- $T_i$
- $T_f$
- $F_{\text{c to sat}}$
D.12.2 Baseflow
D.12.3  Interflow
D.12.4 Fastflow
D.12.5 Baseflow Residence Time
D.12.6  Interflow Residence Time
D.12.7 Fastflow Residence Time

- Field capacity
- Baseflow
- Interflow
- Fastflow
- Maximum drainage
- Maximum infiltration
- Minimum release
- Curve no.
- Rain multiplier
- Lag time
D.12.8 Field Capacity to Saturation
## D.12.9 Maximum Drainage

<table>
<thead>
<tr>
<th>Field capacity</th>
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<th>Interflow</th>
<th>Fastflow</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
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<td>50</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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</table>

<table>
<thead>
<tr>
<th>Tb</th>
<th>Ti</th>
<th>Tf</th>
<th>FC to sat</th>
</tr>
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<tr>
<td>2 x 10^4</td>
<td>2000</td>
<td>300</td>
<td>10</td>
</tr>
<tr>
<td>4 x 10^4</td>
<td>4000</td>
<td>200</td>
<td>20</td>
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</table>

<table>
<thead>
<tr>
<th>Maximum infiltration</th>
<th>Minimum release</th>
<th>Curve no.</th>
<th>Rain multiplier</th>
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<tr>
<td>150</td>
<td>100</td>
<td>6</td>
<td>1.5</td>
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<tr>
<td>100</td>
<td>50</td>
<td>4</td>
<td>2.0</td>
</tr>
<tr>
<td>50</td>
<td>0</td>
<td>2</td>
<td>1.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lag time</th>
<th>Maximum drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>
Maximum Infiltration
D.12.11 Minimum Release
D.12.12 Curve Power

Field capacity
Baseflow
Interflow
Fastflow
FC to sat
Max drainage
Max infiltration
Minimum release
Rain multiplier
Lag time
D.12.13  Rainfall Multiplier

![Graphs of various hydrological parameters against rainfall multipliers]

- **Field capacity**
- **Baseflow**
- **Interflow**
- **Fastflow**
- **Max drainage**
- **Max infiltration**
- **Minimum release**
- **Lag time**
- **Curve No.**

The graphs show the relationship between rainfall multipliers and various hydrological parameters, indicating how changes in rainfall can impact these parameters.
D.12.14 Lag time

Field capacity

Baseflow

Interflow

Fastflow

Tb

Ti

Tf

FC to sat

Max drainage

Max infiltration

Minimum release

Curve No.

Rain multiplier

Lag time
D.13  Waihaha Catchment
D.13.1 Field Capacity
D.13.2 Baseflow

Field capacity

Interflow

Fastflow

Tb

Ti

FC to sat

Maximum drainage

Maximum infiltration

Minimum release

Rain multiplier

Lag time
D.13.3 Interflow
<table>
<thead>
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<th>Parameter</th>
<th>Values</th>
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<td>Baseflow</td>
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</tr>
<tr>
<td>Interflow</td>
<td>0-1</td>
</tr>
<tr>
<td>Interflow</td>
<td>0-3x10^4</td>
</tr>
<tr>
<td>Ti</td>
<td>0-2000</td>
</tr>
<tr>
<td>Td</td>
<td>0-300</td>
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<tr>
<td>Maximum drainage</td>
<td>0-50</td>
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<td>Maximum infiltration</td>
<td>0-150</td>
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<tr>
<td>Minimum release</td>
<td>0-1</td>
</tr>
<tr>
<td>Curve no.</td>
<td>1-1.4</td>
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<tr>
<td>Rain multiplier</td>
<td>0-20</td>
</tr>
<tr>
<td>Lag time</td>
<td>0-10</td>
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</table>
D.13.5 Baseflow Residence Time

Field capacity

Baseflow

Interflow

Fastflow

Ti

FC to sat

Maximum drainage

Log tmy

Minimum release

Curve no.

Rain multiplier

Tb

Maximum infiltration

Lag time
D.13.6 Interflow Residence Time
D.13.7  Fastflow Residence Time

![Graphs showing various flow dynamics and parameters related to Fastflow Residence Time.](image-url)
D.13.8  Field Capacity to Saturation

Field capacity

Baseflow

Interflow

Fastflow

Maximum drainage

Lag time

Minimum release

Curve no.

Rain multiplier

Maximum infiltration

Log time
D.13.10  Maximum Infiltration
D.13.11 Minimum Release
D.13.13 Rainfall Multiplier

Field capacity

Baseflow

Interflow

Fastflow

To

Ti

FC to sat

Max drainage

Max infiltration

Minimum release

Curve No.

Rain multiplier

Lag time

Rain multiplier
D.13.14  Lag time
D.14 Tutaeuaua Catchment
D.14.1  
Field Capacity
D.14.2 Baseflow
D.14.3  Interflow

- Field capacity
- Baseflow
- Fastflow
- Interflow
- Ti
- Ti
- Maximum infiltration
- Minimum release
- Curve no.
- Rain multiplier
- Log flow
D.14.4 Fastflow
D.14.5 Baseflow Residence Time
D.14.6 Interflow Residence Time
D.14.7 Fastflow Residence Time

- Field capacity
- Baseflow
- Interflow
- Fastflow
- Field capacity
- Baseflow
- Interflow
- Fastflow
- Minimum release
- Curve no.
- Rain multiplier
- Lag time

Graphs showing the relationship between various parameters and Fastflow residence time.
D.14.8 Field Capacity to Saturation

```
Field capacity

Baseflow

Interflow

Fastflow

Maximum drainage

Maximum infiltration

Minimum release

Curve no.

Rain multiplier

Lag time

Log time
```
D.14.9 Maximum Drainage

Field capacity

Baseflow

Interflow

Fastflow

Tb

Ti

Tf

FC to sat

Maximum infiltration

Minimum release

Curve no.

Rain multiplier

Lag time
D.14.10  Maximum Infiltration
D.14.11 Minimum Release

Field capacity

Baseflow

Interflow

Fastflow

Tb

Ti

Tf

FC to sat

Max drainage

Max infiltration

Curve no.

Rain multiplier

Log time

Minimum release
D.14.13 Rainfall Multiplier

Field capacity

Baseflow

Interflow

Fastflow

FC to sat

Max drainage

Max infiltration

Minimum release

Curve No.

Log time

Rain multiplier
D.14.14 Lag time

Field capacity

Baseflow

Interflow

Fastflow

Tb

Ti

Max drainage

Max infiltration

Minimum release

Curve No.

Rain multiplier
Appendix E: Correlation Analysis – physiographic attributes and parameter values

E.1 Correlation analysis

Relationships between sub-catchment physical features and modelled parameter values provide additional information about the hydrological response and behaviour in the Lake Taupo catchment. Similar to the methodology outlined in Chapter 5, correlation coefficients are used to describe the strength of these relationships. Correlation coefficients provide an easy and convenient way to describe the strength of the relationship between two variables but do not imply a causal relationship (Gordon et al., 2004). The results of the analysis are presented in Table E.1.1.

One of the short-comings of correlation analysis is that in large samples significance can be easily achieved, but the strength of the correlation may be weak (Field, 2005). In this analysis, all five parameter sets are used for each of the 11 catchments. This gives a total of 55 parameter values which are cross-correlated against each other and against the catchment attributes described in Chapter 5. As a result, a number of significant relationships have been obtained, with $|r|$ values as low as 0.215. It should also be noted that the strength of a relationship may be obscured where parameters are less well-defined, especially where only a few catchments
show some parameter identifiability. The most reliable results, therefore, will be for those most identifiable parameter sets (baseflow and fastflow proportions and associated residence times, rainfall multiplier and lag time) as well as those parameters which present strong and consistent parameter interactions (for example, interflow versus baseflow proportion). Following Devore (1982), a correlation is considered strong if $0.8 \leq |r| \leq 1$ and moderate if $0.5 < |r| < 0.8$. Between -0.5 and 0.5 the correlation is considered weak.

Some of the strongest correlations are between the parameters associated with store proportions (Figure E.1.1). These parameters are interdependent; together they must equal one. Interflow and fastflow proportions are constrained by the baseflow proportion, so that as baseflow increases, interflow and fastflow proportions show a corresponding decrease. Correlations with other attributes often show a similar pattern. For example, an increase in baseflow reduces flow variability. Conversely, variability increases with increasing interflow and fastflow proportions (implying decreased baseflow).

The correlation between the baseflow index and values for the baseflow model parameter show a moderate positive correlation ($r = 0.6495$). The calculation of the baseflow index as outlined in Chapter 5 has some inherent challenges and so the estimation of baseflow in this way is more uncertain. Since the baseflow model parameter is well-defined (identifiable) and the model generally does a good job of simulating the baseflow response characteristics in most catchments, correlations with this parameter are more reliable.

Figure E.1.1 Correlation plots between the three modelled stores.
Table E.1.1 Correlation coefficients between catchment physical attributes and hydrologic characteristics and parameter values

<table>
<thead>
<tr>
<th></th>
<th>Field capacity</th>
<th>Baseflow</th>
<th>Interflow</th>
<th>Fastflow</th>
<th>TB</th>
<th>TI</th>
<th>TF</th>
<th>Rain mult.</th>
<th>Lag time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>0.2072</td>
<td>0.1328</td>
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<td>-0.2168</td>
<td>0.3636</td>
<td>-0.3551</td>
<td>0.1162</td>
<td>0.0505</td>
<td>-0.3141</td>
</tr>
<tr>
<td>Mean</td>
<td>0.0629</td>
<td>-0.0197</td>
<td>0.0527</td>
<td>-0.0310</td>
<td>0.1289</td>
<td>-0.3161</td>
<td>-0.1803</td>
<td>0.0233</td>
<td>-0.2611</td>
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<td>Spec. discharge</td>
<td>0.0223</td>
<td>-0.2217</td>
<td>0.1980</td>
<td>0.1844</td>
<td>-0.1843</td>
<td>-0.1678</td>
<td>-0.4992</td>
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<td>-0.0343</td>
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<td>Low flows</td>
<td>-0.3696</td>
<td>-0.8886</td>
<td>0.7916</td>
<td>0.7416</td>
<td>-0.5730</td>
<td>-0.1766</td>
<td>-0.2335</td>
<td>0.0695</td>
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<tr>
<td>High flows</td>
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<td>-0.7570</td>
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<td>-0.6809</td>
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<td>-0.1686</td>
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<td>Basflow</td>
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<td>0.4542</td>
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<td>0.1940</td>
<td>-0.0010</td>
<td>-0.0541</td>
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Of the physical attributes, the shape of the catchment had the strongest relationship to baseflow proportion (Figure E.1.2a). There are two factors to consider here. The elongation ratio is an index of shape which measures the length of the longest drainage channel against the diameter of a circle with the same area as the catchment in question. In some of the sub-catchments of Lake Taupo, this definition of shape may not be sufficient. For example, the Kuratau catchment has three main branches which could affect how quickly water reaches the channel. Secondly, catchments which are more elongated tend to be in the steeper, higher elevation areas of the catchment, often draining areas of less permeable geology. However, the relationship between geology and baseflow contribution (as well as all other model parameters) is weak. In this study, the classification of catchment geology does not take into account the range of permeabilities volcanic lithologies. Stronger or more reliable relationships may be found if the volcanic geology is divided according to the permeability of the material.

Baseflow proportion is, however, inversely related to the steepness of the catchment (mean slope: $r = -0.5409$; steep slopes: $r = -0.4561$, Figure E.1.2b and Figure E.1.2c). Fastflow and interflow proportions are positively correlated but to a lesser degree. Catchments of the western bays (excluding Whareroa), however, show relatively low baseflow proportions despite relatively low mean slope and steep slope values. These catchments are underlain by less permeable volcanic lithologies which reduce baseflow contributions.
The shape and slope of the catchment is moderately correlated to the interflow proportion. In more elongated catchments, the interflow proportion tends to have greater significance than in rounder catchments ($r = -0.5395$). Interflow proportion also increases with increasing steepness ($r = 0.4895$), although it is noted that this is likely to be due to the fact that baseflow contribution in these catchments is less.

Steeper slopes, however, tend to reduce the residence times of the stores (Figure E.1.3). Although significant, only weaker correlations between these factors were found. The correlations for baseflow residence time are plotted on log-scale due to the exceptionally long residence time for the spring-fed Waitahanui. The three steepest catchments (Waipakihi, Waimarino and Tauranga-Taupo) clearly have very short residence times for all three stores. The gently sloping Tutaeuaua catchment also has relatively short residence times for both baseflow and fastflow stores. This catchment is the smallest of the sub-catchments studied and has a relatively high drainage density. Water does not stay in the stores for very long before exiting the catchment.

The interflow residence time presents weak correlations with hydrologic attributes but shows stronger correlations to other physical attributes (Figure E.1.4). Interflow residence time is longer in rounder catchments which have higher drainage densities. One notable exception is the Whanganui catchment which is one of the most elongated catchments and has the highest drainage density. Interflow

![Figure E.1.3 Store residence times versus mean slope and proportion of slopes greater than 26 degrees for all catchments.](image-url)
residence times in this catchment are much longer than might be expected. This catchment is relatively impermeable, draining an area of older Whakamaru ignimbrites, but it is generally less steep than its nearest neighbour (Waihaha catchment) which also drains an area of basement greywacke.

The residence time for the fastflow store presented significant but generally weak correlations to a number of catchment attributes (Figure E.1.5). A shorter fastflow residence time is generally associated with catchments that have higher specific discharges ($r = -0.4992$) and greater flow variability ($r = -0.3715$). Climatic indices were also negatively correlated to fastflow residence time so that residence times were shorter in catchments where the wetness ratio ($r = -0.5520$) and runoff coefficients ($r = -0.4835$) were higher. Catchments of generally steeper terrain also had shorter residence times (mean slope: $r = -0.4401$; steep slopes: $r = -0.4448$).

The fastflow residence time, in conjunction with the fastflow proportion, are important aspects in determining the flood peak response of a catchment which is generally influenced by catchment physical attributes. Conversely, the baseflow proportion and residence times are generally influenced most by the permeability of surficial and sub-surface materials.

As catchments become steeper, the rainfall multiplier also increases (Figure E.1.6a and Figure E.1.6b). In the Lake Taupo catchment, some sub-catchments rise steeply and the elevation range between the observation point and the headwaters of the

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Figure E.1.4 Interflow residence time versus catchment attributes (a) elongation ratio, (b) drainage density, (c) percentage of pumice soils and (d) percentage of forest cover.
Figure E.1.5 Fastflow residence time versus (a) specific discharge, (b) wetness ratio, (c) runoff coefficient, (d) steep slopes, (e) basement geology, and (f) volcanic geology.
catchment can be considerable. In these higher elevation areas, more rainfall would be expected to fall. Rainfall gauges, however, are generally located at much lower elevations where rainfall is often less. A higher rainfall multiplier suggests that much more rainfall is falling in other areas of the catchment compared to the gauge location. Wetness ratios ($r = 0.6021$) and runoff coefficients ($r = 0.6208$) also tend to be high in steeper catchments. This results in higher specific discharge values. The Waihohonu and Waipakihi catchment, however, do not quite fit this characterisation. These two catchments are located in the higher elevation areas of Mt Ruapehu and Kaimanawa Ranges. The relief of the Waihohonu is also one of the highest and the Waipakihi catchment is the steepest (mean slope). These catchments are likely to experience higher precipitation and less evapotranspiration due to cooler air temperatures which would produce higher wetness ratios. However, the rainfall multiplier is relatively low given their respective locations. The rainfall gauge used for these two catchments records relatively higher rainfall depths and is one of the highest elevated rain gauges used in this study. It is therefore more likely to be representative of rainfall at a higher elevation. Runoff coefficients are also relatively high compared to the rainfall multipliers required to achieve mass balance.

In the Tauranga-Taupo catchment, the relatively high wetness ratio and runoff coefficient reflects the higher altitude and steeper nature of this drainage basin. The rainfall multiplier, however, is relatively low. The rain gauge in this catchment is
located at 720 m a.s.l (upstream in the catchment), generally higher than many other gauges in the catchment. It is more likely to provide a more balanced estimate of catchment rainfall between the higher and lower elevation areas.

Catchment lag times were moderately correlated to area, so that in larger catchments it takes longer for water to find its way out. Other factors may also contribute to this parameter. For example, the steepness of the catchment and permeability (in terms of the type of soil) and drainage density will all contribute to how quickly water is able to exit the catchment (Figure E.1.7). All of these attributes also present significant correlations to catchment lag times.

Of note, is the relationship between the minimum release threshold and hydrological parameters. This parameter represents the saturation level of the catchment required before water can drain to the subsurface. In catchments with a larger amount of baseflow and longer residence times, this parameter is generally higher with correlation coefficients of $r = 0.4471$ and $r = 0.4594$, respectively. Correspondingly, flow variability and fastflow proportion is lower in these areas.

### E.2 Conclusions

Baseflow proportion is controlled largely by the underlying geology and permeability of catchment. This has not been strongly evident in this analysis of the Lake Taupo catchment. More significant results may be found if the type of geology is further divided according to the various permeabilities (hydraulic conductivities).
of volcanic lithologies. The fastflow residence time is important in terms of flood flow response, with residence times increasing in more permeable catchments with greater baseflow volumes.

One of the drawbacks of correlation analysis is that even weak correlations can be significant. In this analysis, some potentially significant relationships with catchment physiographic attributes were diluted because of a lack of identifiability (in a univariate sense) for some model parameters of some catchments. Multivariate analyses, such as Sobol’s global sensitivity analysis, would provide a more robust analysis of individual parameter influence and parameter interactions, but can be computationally expensive (Yang, 2011).