REPORT

WAIMEA WATER AUGMENTATION COMMITTEE/TASMAN DISTRICT COUNCIL

Waimea Water Augmentation - Component 1 Water Demand and Availability

Report prepared for:

WAIMEA WATER AUGMENTATION COMMITTEE/TASMAN DISTRICT COUNCIL

Report prepared by:

TONKIN & TAYLOR LTD

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1 Introduction

In November 2004, Tonkin and Taylor Ltd (T&T) was commissioned by the Waimea Water Augmentation Committee (WWAC) and Tasman District Council (TDC) to undertake Phase 1 of a feasibility study of water storage in the upper parts of the Wairoa/Lee catchments in Tasman District. The specific brief was to address the recurrent water shortages experienced on the Waimea Plains and to investigate enhancing water availability for consumptive and environmental/community/aesthetic benefits downstream on the Waimea Plains and surrounds.

The basic principle behind the project has been to develop an augmentation scheme that would capture river flows (leaving an appropriate residual flow in the river), store the water in a reservoir, and then allow release of that stored water into the river system during periods of high water demand and/or low natural river flows to augment those supplies, either directly or via a recharging of the groundwater system.

The project is multi-disciplinary and Phase 1 (preliminary) feasibility extended over a three year period. It has four main components:

1. water availability analysis
2. identification of storage options, and water delivery methods and costs
3. environmental assessment, and economic analysis of scenarios with and without augmentation
4. water allocation for optimisation of water use, environmental/community benefits/funding.

This report addresses Component 1 – identification and assessment of water demand for various consumptive and non-consumptive uses, and water availability. It has covered:

- identification of potential water demand for irrigation use, as well as community and industrial demands
- identification of instream water requirements
- development of a hydrological model of the Wairoa and Lee Catchments including the relationship between surface and groundwater resources in the Waimea Basin
- from the above, determination of the volume of storage required to service the identified needs
- identification of key hydrological characteristics that affect engineering design of the scheme and its construction

Component 1 incorporates input from the following parties:

- Tonkin and Taylor (overall management and integration; hydrological model and storage demand assessment)
- Agfirst Consultants (consumptive water demand)
- GNS Science (groundwater modelling)
- Cawthron (instream requirements)
- Landcare Research (review role)

The timing of the various aspects of Component 1 work was related to the progress of the storages assessment (see Component 2 Report). The water demand identification was commenced early in the overall study, as it was an essential starting point to determine storage needs. In addition, the results were applicable regardless of the eventual preferred dam site selection. Determination of the residual flow for instream requirements at Appleby Bridge, and the inter-relationship of groundwater and surface water resources in the Waimea Basin were also largely independent of site selection, although later stages were specifically related to Site 11 Lee. The analysis of catchment hydrology became more specific as site selection progressed. Overall, the Component 1 work has progressively focussed on Site 11 Lee.

2 Water Demand

2.1 Introduction

A required reservoir storage capacity of between 15 to 20 million m^3 had originally been estimated (see Component 2 Report - Appendix 2) based on a simple and approximate analysis and mainly for site comparative purposes. The demand associated with this estimate was equivalent to full irrigation of 4055 hectares of pasture at the rate of 35 mm/ha/week at 100% plant ground cover over a continuous 15 week period. Included in this figure was an urban and industrial demand allowance (within the Waimea Basin) equivalent to 380 ha of pasture. As an initial and conservative estimate, and based on the information available at that stage of the project, this storage estimate did not allow for the existing recharge and storage available in the Waimea groundwater aquifers or any incident rainfall during the irrigation season which may offset some of the demand.

A technical workshop on water demand was held on 8 February 2006 attended by Joseph Thomas (TDC), John Bealing (Agfirst), Timothy Hong (GNS), and Sally Marx and David Leong (T&T). The purpose of this workshop was to refine and agree the demand assumptions on which to base the live storage requirement for the proposed dam and, critically, the detailed input requirements for the complex groundwater model.

Among other things, the workshop covered the following:

- Overview of the overall process to determine live storage, and thus dam height
- Overview of the groundwater model, its geographical coverage, including its upstream and downstream boundaries, its layering system and the format of input required in terms of demand data
- Clarification of the area served by the Waimea East Irrigation Scheme (WEIS) (river intake) and that by groundwater takes, both as conceptualised in the groundwater model and in reality
- Limitations of the historical groundwater pumping and WEIS take data in the groundwater model
- Agreement of the assumptions and approach for estimating future irrigation and urban and industrial water demand
- Discussion of the effect of incident rainfall during irrigation season in moderating irrigation demand, and selection of an appropriate design drought year for groundwater modelling
- Agreement of timeframes and responsibilities for preparation of modelling datasets

A summary of the outcomes from the workshop was advised to WWAC representatives on the evening of 8 February 2006.

Details of the demand assumptions, including the assumed geographical distribution and seasonal pattern of take for different soil and crop types, are provided in Agfirst Consultants' report (see **Appendix 1 to this report**).

A summary covering both consumptive and in-stream water demand and the dam storage modelling is provided in the following sub-sections.

2.2 Consumptive Water Demand

The equivalent net irrigable area in the Waimea Basin has been assessed as follows:

- Existing irrigated area: 3800 hectares
- Additional potentially irrigable area: 1500 hectares
- Total: 5300 hectares

Note that the original area was assessed at 6,582 ha, and reduced to 5,306 ha when urban areas, road reserves, river reserves and other such areas were excluded.

WWAC has taken the decision to potentially provide water for part of the lower Wai-iti Valley that is not serviced by the (now constructed) Wai-iti Community Dam (Kainui). An allowance has therefore been made for a further 300 hectares in the lower Wai-iti from Wakefield to Aldourie Rd. This brings the total to about 5600 hectares.

In addition to irrigation water, there is also a need for the Waimea augmentation project to provide for urban and industrial water demand – both existing and future expected demand. These demands (as provided by TDC) are as follows:

- Existing urban allocation (TDC): 540 hectare-equivalents (note that actual current *demand* (as distinct from *allocation*) is approximately 420 hectare-equivalents)
- Future TDC demand: 280 hectare-equivalents
- Total urban/industrial demand for Tasman District for projected timeframe (50 years): 820 hectare-equivalents

Table 2.1 presents the approximate areas and corresponding demand. Note that these figures update those used in interim reports.

Table 2.1: Expected Water Demand (by Water Zones) from Proposed Waimea Augmentation Scheme (50 year projection)

Zone	Net Irrigable Area (Ha)	Urban Allocation (Area Equivalents - ha)	Total Hectare Equivalents	Approx. Demand (Peak Daily Flow) l/s
Upper Catchments	Minimal		Minimal	5
Reservoir	580	56 (Brightwater & Wakefield)	636	316
Waimea West	385	23 (Redwood*)	408	202
Hope & Eastern Hills (includes Upper and Lower Confined)	2,170	154 (Richmond)	2324	1345
Golden Hills	300		300	149
Delta	1,246	307 (Waimea)	1553	693
Redwood*	625		625	258
Wai-iti: Aldourie Rd to Wakefield	300		300	174
Future urban demand		280	280	162
TOTALS	**5,606 ha**	**820 ha**	**6426**	**3304 l/s**

Note: In this table, the demand figures are based on the zone in which the land needing to be irrigated actually lies. The demand has been based on the predominant soil type making up that zone.

* For the purposes of this exercise it has been assumed that all Redwood supply is provided from the Waimea West Zone

The actual irrigation usage depends heavily on the actual rainfall pattern over the season, and to a lesser extent on other climatic variables (wind, solar radiation, etc.) Clearly, the total volume of water required will be greater when in a drought situation. It is reasonable to assume that high irrigation usage will often coincide with lower than average river flows over an irrigation season. This is because both variables are driven by rainfall patterns to a large extent – low rainfall generally equates to low flows and high usage. In terms of reservoir storage utilisation, low inflows to the reservoir and high irrigation usage are compounding factors, and so must be captured appropriately in the reservoir simulation. Otherwise the result would be unconservative. Thus, an irrigation usage pattern which corresponds with a drought year must be used.

Complete datasets of soil moisture and aquifer recharge for groundwater modelling are only available for the following years: 1982/83, 1991/92 and 2000/01. Of these, the 1982/83 year plots at about the 90th percentile mark in terms of theoretical irrigation usage, and as such may be interpreted as being the 1 in 10 highest usage year. Thus, the 1982/83 year has been selected as the design drought year. The 2000/01 year is more severe and likely to be too conservative (see Section 3.6) while the 1990/91 year appears to be an average year (i.e. not a high usage year).

Figure 2.1 shows the theoretical demand pattern adopted for subsequent groundwater modelling and reservoir storage simulations. The WEIS intake (red), which is abstracted directly from the Wairoa River downstream of the Irvines flow recorder, is shown separately from the combined groundwater take from the Waimea Basin (dark blue). The actual takes for the 1982/83 season (pink for groundwater take and light blue for WEIS abstraction) are also shown for comparison.

In summary, over the full season from 1 July 1982 to 30 June 1983:

- total theoretical water usage for the future assumed allocations is about 32 million m^3
- the total actual water usage was about 22 million m^3
- the theoretical peak daily demand is about 3300 l/s or 280,000 m^3/day, inclusive of WEIS abstraction.

Note that these demand figures exclude additional allowance for any "future regional need". The additional demand for this future regional need (based on regional figures and provided to us by TDC) is approximately 22,000m^3/day. This equates to a constant year round take of 254 l/s, and an annual take volume of about 8 million m^3. In our modelling, for simplicity (and to be on the conservative side) the supply for such a need is assumed to be a surface water take above the Waimea aquifers rather than a groundwater take from the Waimea Basin.

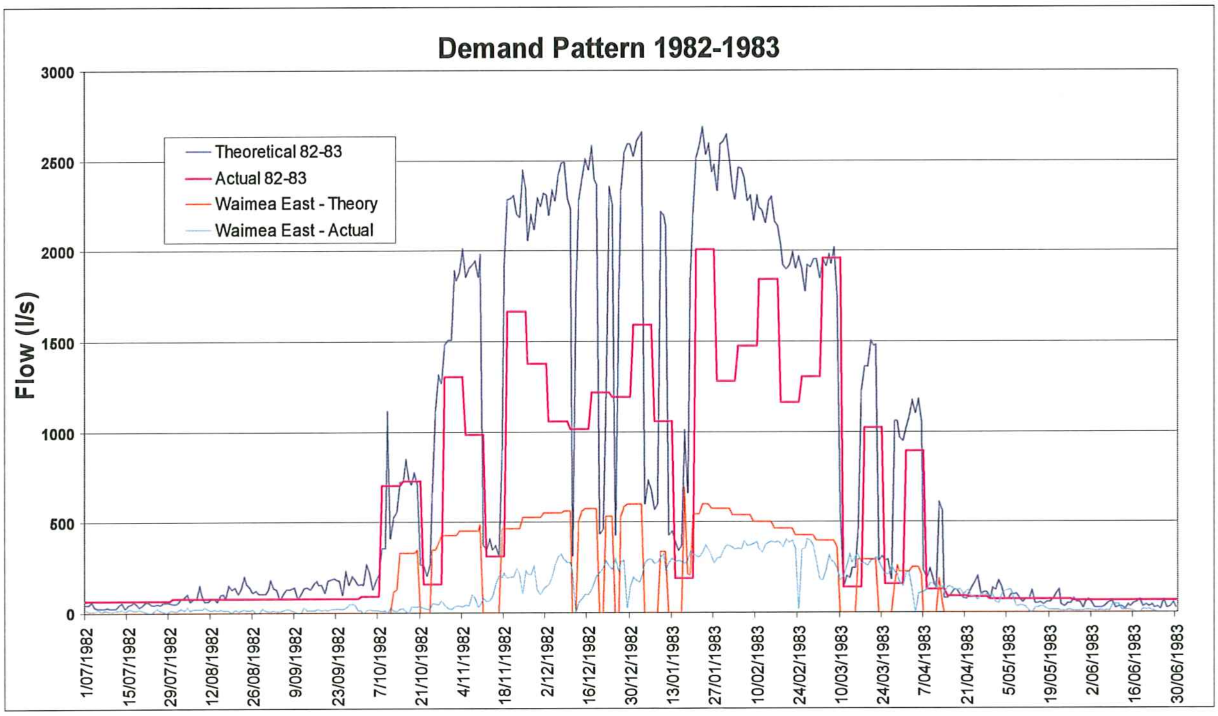


Figure 2.1 Assumed demand pattern for consumptive use

2.3 In-Stream Requirements

For this project Cawthron undertook an assessment of the minimum flows required to provide instream habitat in the Waimea River and immediately below those potential dam sites being considered at that stage of the project (refer to Component 3 Report – Environmental and Economic Assessment). Different minimum flows were identified to span a range from an "environmental benchmark" minimum flow that would be conservative in terms of environmental protection, to a minimum flow that would be weighted towards out-of-stream values.

The results were:

1. instream residual flow requirements at Appleby
   - 1300 l/s (environmental benchmark)
   - 800 l/s (minimum flow retaining 80% of the adult brown trout habitat)
   - 500 l/s (minimum flow retaining 70% of the adult brown trout habitat).
2. instream residual flow requirements immediately below the two potential dam sites:
   - existing MALF (environmental benchmark)
   - 1 in 5 year low flow
   - 1 in 10 year low flow

WWAC subsequently took a decision to assess the live storage requirements necessary to maintain flows covering much of this range, specifically requesting T&T to assess two scenarios for flows at Appleby:

- 600 l/sec
- 1100 l/sec

At each of the dam sites being considered at that stage, a residual flow immediately below the dam equal to the mean annual low flow (MALF) was conservatively assumed.

2.4 Groundwater Modelling

Groundwater modelling was undertaken by GNS. The full report is included in **Appendix 2** to this report. The modelling was undertaken to determine the augmented flows required at Wairoa Gorge (Irvines) to sustain a pre-determined residual flow at Appleby Bridge while meeting unrestricted abstractive demands from the Waimea aquifers. This entailed multiple runs of the existing Waimea Plains groundwater model, which has been developed and calibrated by GNS in collaboration with TDC over the past few years. The modelling adopted the future allocation regime based on the 1982/83 theoretical demand profile and soil moisture (drainage) data.

The groundwater model was developed to simulate recharge to and abstractions from the confined and unconfined aquifer systems which underlie the Lower Wairoa/Waimea River plains. Particular care was exercised in the representation of the groundwater-river interaction. Using this model, the sequence of required augmented flows at Wairoa Gorge was determined for a number of scenarios from repeated (trial-and-error) runs of the model. Modelling was undertaken in three stages.

The first stage modelling determined the flow sequence needed to sustain a 500 l/s minimum flow at Appleby Bridge based on actual irrigation takes over the 1991/92 season. Augmentation flows, averaged over a week, of up to 364 l/s were indicated, with a daily maximum of 459 l/s required in early winter (6 June 1992).

Stage 2 modelling determined the required flow augmentation for two scenarios as determined by WWAC: preserve minimum flows of 600 l/s and 1100 l/s respectively at Appleby Bridge, based on the unrestricted take regime corresponding with a nominal 20 year return period design drought (as represented by the 1982/83 dry year outlined in Section 2.2). The modelling predicted:

- Without augmentation flows at Appleby Bridge would be less than 100 l/s for 17 days (inclusive of zero flow periods), less than 250 l/s for 37 days and less than 500 l/s for 48 days.
- For the 600 l/s minimum flow scenario, the maximum weekly-averaged flow augmentation required at Wairoa Gorge was 1394 l/s, and this was predicted to be required for the week starting 2 March 1983.
- For the 1100 l/s minimum flow scenario, the maximum weekly averaged flow augmentation predicted was 1766 l/s, occurring in the week beginning 2 March 1983 also.

Results from the groundwater modelling stages 1 and 2 were then analysed to develop a relationship (transfer function) between the level of irrigation demand and the minimum flow required at Irvines to maintain a particular residual flow at Appleby Bridge. This is discussed further in Section 2.5 below. A long-term flow simulation utilising flow records for the Wairoa River from 1957 to 2006 relied on this transfer function to determine the daily flow release required from a storage reservoir in the Upper Lee River to meet downstream demands while preserving the minimum flow at Appleby Bridge – see Section 4.

Stage 3 groundwater modelling was undertaken after the storage simulation had been undertaken to assess/confirm the ability the augmented flow (as determined by the transfer function) to maintain the 1100 l/s minimum flow specified for Appleby Bridge in the nominal design drought conditions (1982/83 dry year). The simulation indicated that the minimum river flow at Appleby Bridge would be slightly below 1100 l/s for 12 days (lowest flow was 973 l/s on 7 March 1983). Subsequently, an adjustment was applied to the transfer function to compensate for this shortfall and the storage simulations redone.

An important part of the groundwater model is the representation of the river – aquifer interaction and recharge process. While the groundwater model has been calibrated to a satisfactory level based on observed groundwater level and river level data, there remains a level of uncertainty in the results. In particular, the sensitivity of the aquifer recharge to riverbed level changes and potential for seawater intrusion in certain areas would need further assessment in subsequent study phases.

2.5 Coupling of Groundwater Modelling With Dam Storage Simulation

Results from groundwater modelling Stages 1 and 2 included predicted daily time-series flows for Appleby Bridge and the augmented flow required at Wairoa Gorge. The pattern (timing and quantity) of surface flow loss in the river reach between Wairoa Gorge and Appleby Bridge predicted by the groundwater model was analysed to determine its dependency on a range of variables, including:

- natural river flow at Wairoa Gorge

- rate of groundwater abstraction
- combinations of the above with various lags or lead times and aggregations
- targeted minimum flow at Appleby Bridge (500, 600 or 1100 l/s)
- time-of-year (within the irrigation season)

From this assessment relationships were developed between the flow augmentation required and the natural flow at Wairoa Gorge (Irvines) for each Appleby Bridge minimum flow scenario, with a dependency on the level of demand. Figures 2.2 and 2.3 show the model data and the approximating relationships for Appleby Bridge minimum flows of 600 and 1100 l/s respectively. These relationships allow the groundwater system behaviour to be coupled (although imprecisely – see below) with the catchment surface water system and simulated storage operation in the Upper Lee River. In effect, these relationships determine the required flow release on a day-to-day basis from a storage dam in the upper catchment to supplement tributary inflows between the dam site and Wairoa Gorge.

Clearly, the "black box" approach adopted here by necessity has its limitations as it simplifies the physical processes involved in the groundwater-surface water interaction and aquifer storage dynamics. The relationships had also been based specifically on the 1982/83 hydrological/hydro-geological/water demand conditions (and to a lesser extent the 1991/92 conditions), and thus would be less representative for other years in the long-term storage simulation. Overall, the use of a reasonably dry year (1982/83) for representing water demand over the full simulation period (1957 to 2006) would likely result in slightly to moderately conservative (over-predicted) dam storage requirements.

Limitations inherent in the adopted "black box" approach were addressed by the Stage 3 groundwater modelling to confirm and (as it turned out) fine-tune the trial flow augmentation regime. In addition, to provide increased confidence, all of the Component 1 assessments (Water Demand and Availability), covering water demand profiling, groundwater modelling, catchment and storage modelling, and the coupling of groundwater and surface water components, were subjected to independent peer review by Landcare Research (Andrew Fenemor).

A more sophisticated coupling of the groundwater and surface water models, ideally with varying demand profiles based on historical climatic data, plus a sensitivity analysis, should be undertaken in subsequent study phases. The emphasis on reliably integrating the groundwater and surface water models is warranted as this nexus is key to the flow augmentation regime.

Figure 2.4 below shows the finally adopted flow augmentation regime for the 1100 l/s Appleby residual flow. This regime allows for an average increase of about 25 l/s in the augmented flow to eliminate the minor shortfalls predicted from Stage 3 groundwater modelling in the driest period in 1982/83 year (see Section 2.4).

Figure 2.2 Trial flow relationship for 600 l/s Appleby Bridge minimum flow

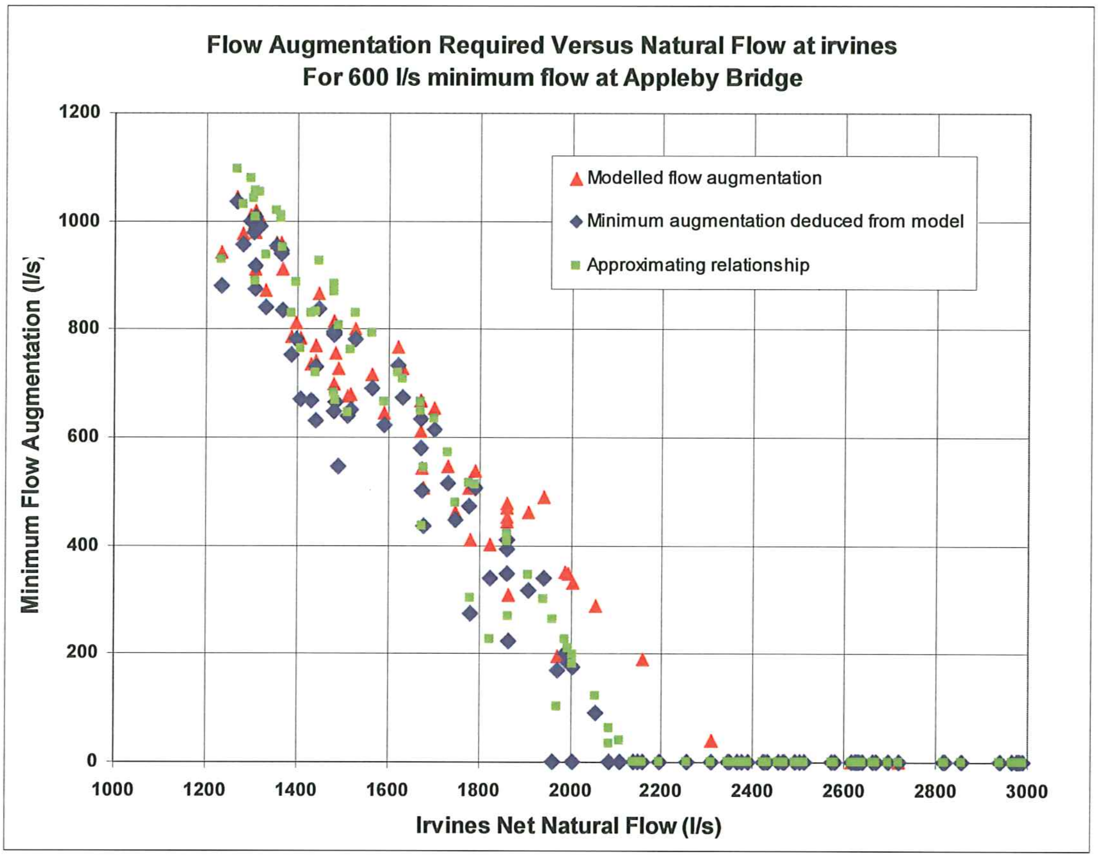


Figure 2.3 Trial flow relationship for 1100 l/s Appleby Bridge minimum flow

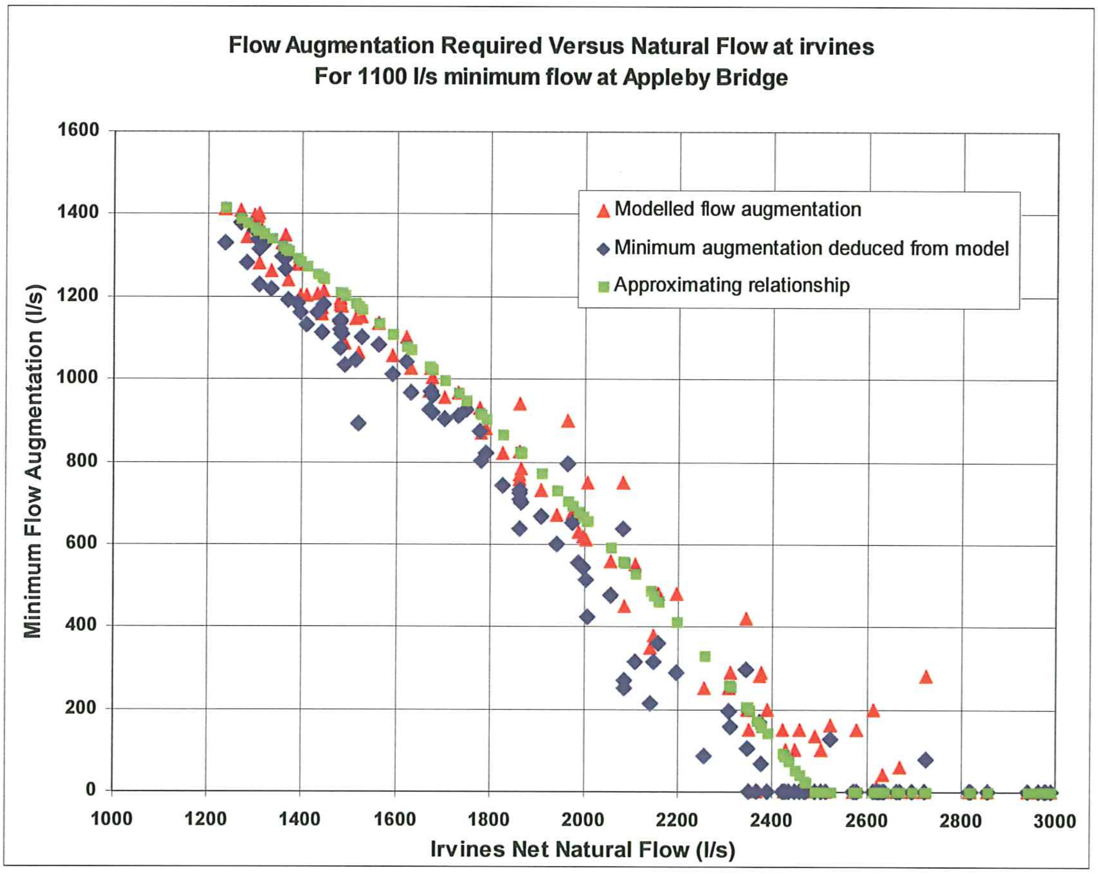
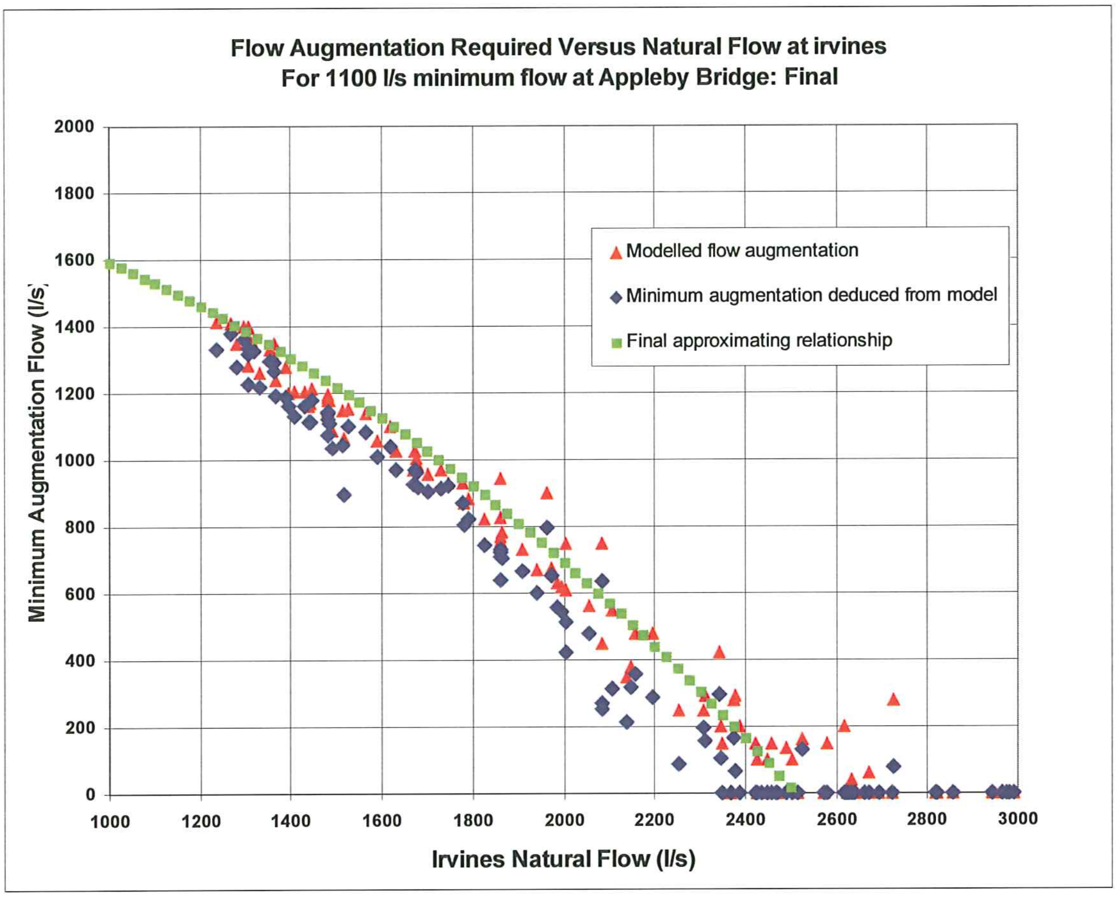


Figure 2.4 Final flow augmentation relationship for 1100 l/s Appleby Bridge minimum flow case



3 Catchment Hydrology

3.1 Introduction

Early stages of the study (see Component 2 Report – Storages Assessment) assessed the potential for dams at identified locations to capture the required volume of water to meet initial demand. It was noted that the winter flows in both the Lee and Wairoa rivers should amply assure capture of the volume required (then assessed at being 15 million m^3) without contravening flow allocation rules, and capture of high flows in the irrigation season may also be achievable. Hydrological assessment at those early stages of the project (up until the stage that the decision was taken to focus on Site 11 Lee) was limited mainly to calculation of flood peaks for preliminary sizing of diversions and spillways, water balance analyses for estimation of mean flows at a number of storage sites, and derivation of flow duration characteristics on the Lee and Wairoa rivers for appreciation of hydro-electric potential.

3.2 Catchment Water Balance and Mean Flows

Figure 3.1 shows the location of the potential dam site on the Lee River and the area of catchment above the dam site (84 km^2). There are no continuous flow records available for the Lee River, and the nearest long-term flow recorder with reliable data is at Wairoa Gorge (Irvines). The catchment boundary corresponding with the Wairoa Gorge gauging station is also shown in Figure 3.1. Contours of mean annual rainfall (based on rainfall normals from 1941 to 1970 published by the NZ Meteorological Service) in Figure 3.1 indicate the rainfall variation across both catchments.

Table 3.1 summarises the long-term catchment water balance for the Wairoa at Gorge/Irvines site. The catchment-averaged rainfall loss, defined as:

rainfall loss = mean annual rainfall – mean flow

for the ungauged Upper Lee dam site is assumed to be the same as for the larger Wairoa Gorge catchment. On this basis, the mean flow at the ungauged dam site is estimated to be 3.58 m^3/s or 21.6% of the mean flow recorded at Wairoa Gorge.

Table 3.1 Wairoa River at Gorge and Lee dam site: water balance analysis

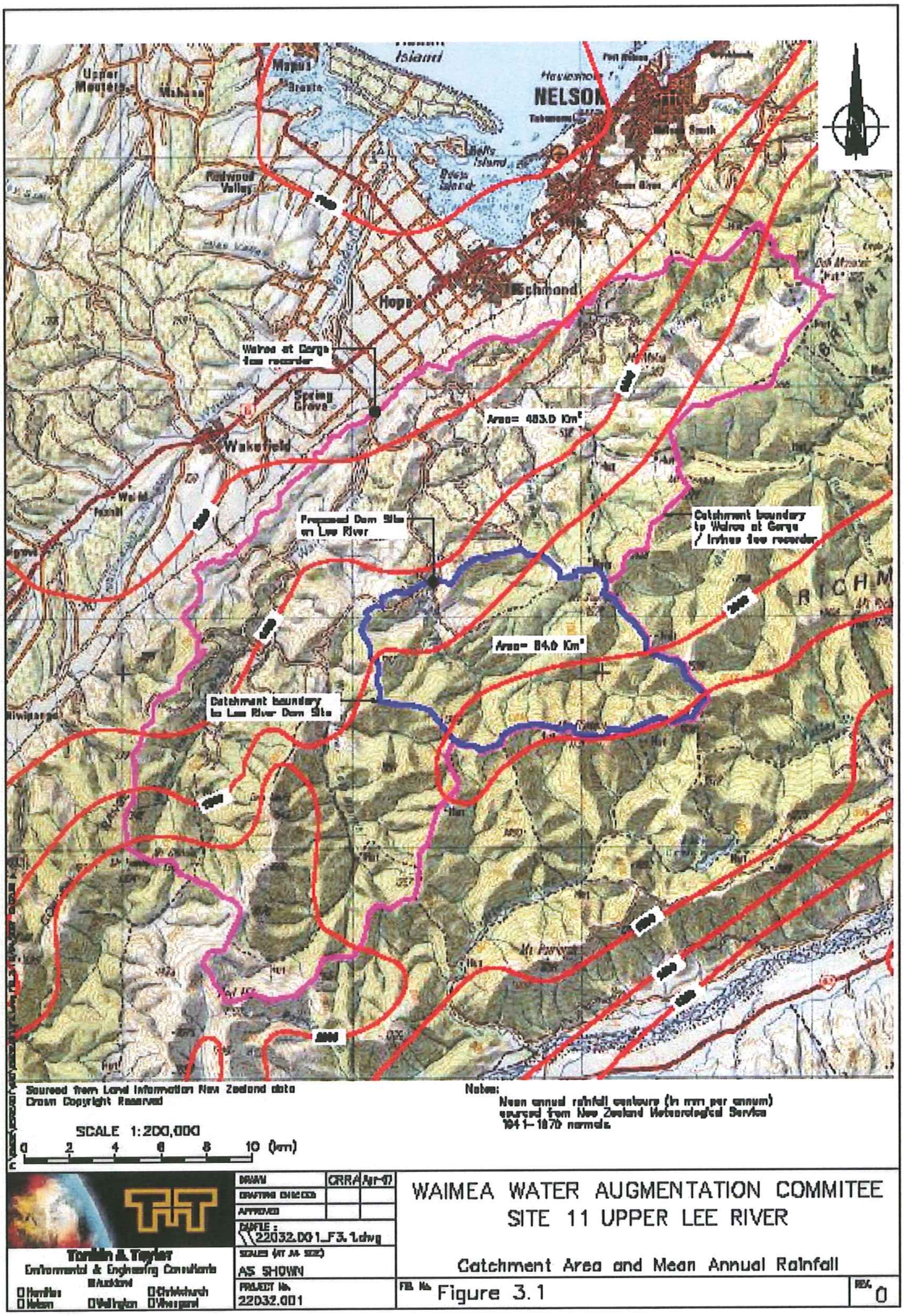
Site	Catchment Area (km²)	[1] Mean Annual Rainfall (mm p.a.)	Mean Flow (m³/s)	Mean Runoff (mm p.a.)	Rainfall Loss (mm p.a.)
Wairoa River at Gorge (Period of Flow Data : 1958 to 2005)	463	1609	16.57	1130	479 (see note 2)
Upper Lee River dam site	84	1827	3.58 (see note 3)	1348	479

Notes:

1 Mean annual rainfall estimated from the 1:500,000 scale map of 1941- 1970 rainfall normals. Values have not been adjusted to match the period of flow data.

2 Typical values of rainfall loss for other gauged catchments in the greater area lie in the range 600 mm p.a. to 900 mm p.a., so this value computed for the Wairoa Gorge appear abnormally low. It is likely to be the result of underestimation in the mean rainfall contours, particularly in the higher elevations, since the long-term flow record at Wairoa Gorge/Irvines is considered to be fairly reliable.

3 The mean flow for this site has been calculated from the estimated rainfall loss value.


NELSON
Richmond
Hope
Wakefield
Spring Grove
Waimea at Gorge flow recorder
Area= 483.0 Km²
Catchment boundary to Waimea at Gorge / Irvines flow recorder
Proposed Dam Site on Lee River
Area= 84.0 Km²
Catchment boundary to Lee River Dam Site
Sourced from Land Information New Zealand data
Crown Copyright Reserved
Notes:
Mean annual rainfall contours (in mm per annum) sourced from New Zealand Meteorological Service 1941-1970 normals.
SCALE 1:200,000
0 2 4 6 8 10 (km)
Tonkin & Taylor
Environmental & Engineering Consultants
DRAWN CRRA Apr-07
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SCALES (AT A4 SIZE) AS SHOWN
PROJECT No. 22032.001
WAIMEA WATER AUGMENTATION COMMITEE
SITE 11 UPPER LEE RIVER
Catchment Area and Mean Annual Rainfall
FIG No. Figure 3.1
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3.3 Low Flow Analysis

In the absence of site-flow data specifically for the Lee dam site, flow records for Wairoa Gorge provide the most appropriate basis for estimating low flow parameters at the dam site. Other long-term and proximate flow records which were used as supplementary reference sites included the Motueka at Gorge to the south-west and Wai-Iti at Belgrove to the west. On a unit area basis, low flows are likely to be related to land use, average rainfall and geology, and the supplementary sites provide an indication of the influence of these factors on various low flow parameters.

Figure 3.2 below shows the low flow frequency distribution fitted to the annual minimum flows (7-day averaged flows) recorded at Wairoa Gorge between 1958 and 2005. Of the three trial distributions (General Extreme Value (GEV), Normal and Lognormal), the GEV distribution was selected as the best-fit curve. Table 3.2 summarises the low flow frequency analysis results for the Wairoa Gorge and the supplementary sites.

Figure 3.2 Wairoa at Gorge/Irvines Low Flow Frequency Analysis

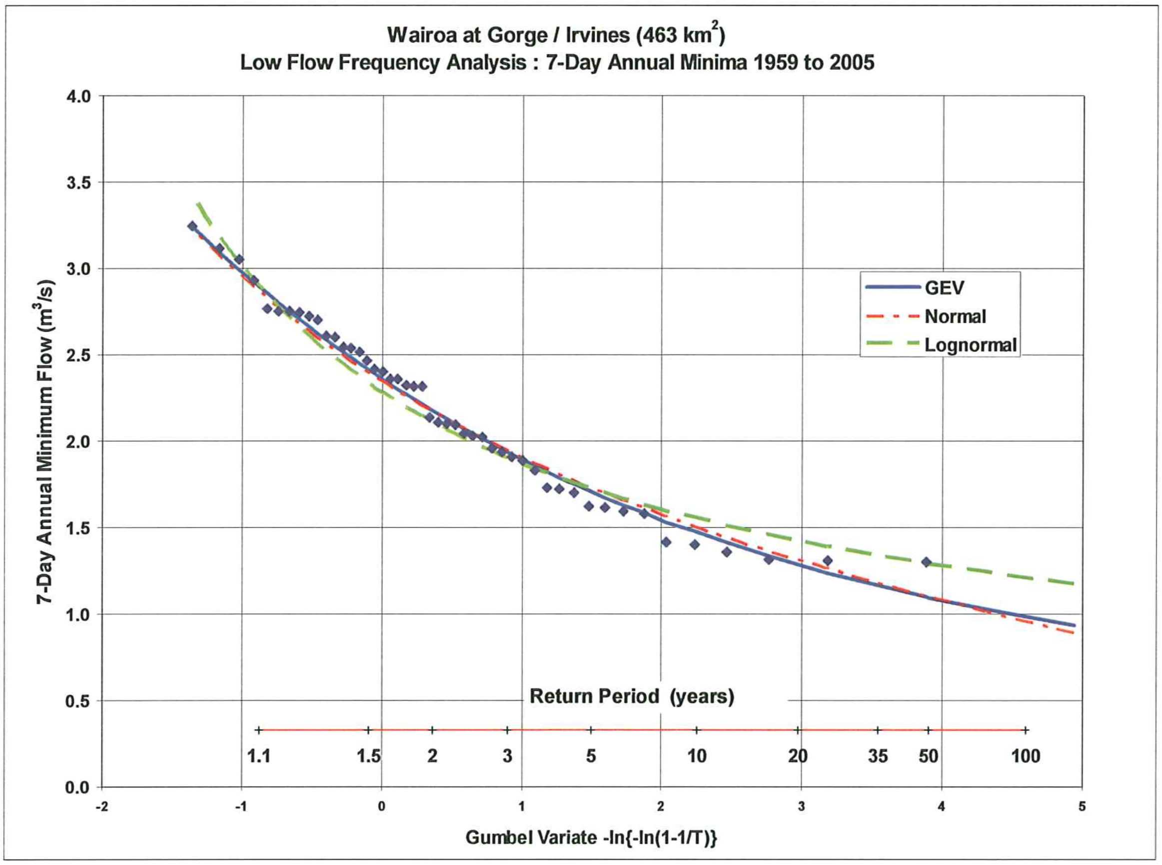


Table 3.2 Wairoa River and environs- low flow frequency analysis results (all based on 7-day averaged flows)

Flow Gauging Site	Data Period	Catchment (km^2)	[1] Mean Annual Rainfall (mm p.a.)	Mean Annual Low Flow		5-Year Low Flow		10-Year Low Flow	
				(l/s)	(l/s/km²)	(l/s)	(l/s/km²)	(l/s)	(l/s/km²)
Wairoa River at Gorge	1957 - 2005	463	[3] 1609	2176	4.70	1709	3.59	1466	3.11
Wai Iti River at Belgrove	1963 – 2005	61	~ 1400	135	2.21	84	1.38	60	0.98
[2] Motueka River at Gorge	1965 - 2001	163	~ 2000	1536	9.42	1254	7.69	1126	6.91

Notes:

1 Mean annual rainfall estimated from the 1:500,000 scale map of 1941- 1970 rainfall normals. Values have not been adjusted to match the period of flow data.

2 Low flow parameters for Motueka at Gorge are elevated not only because its catchment receives significantly higher rainfall but also because of its unique geological composition (greater proportion of ultramafics and limestone).

3 The mean annual rainfall for Wairoa at Gorge is likely to be an underestimate as noted in Table 3.1.

In transposing low flow parameters from Wairoa Gorge to the dam site, low flows were assumed to be primarily proportional with catchment area (i.e. constant specific low flow). An adjustment was made to account for the higher catchment-averaged rainfall in the Upper Lee compared with that at Wairoa Gorge. Otherwise, land use, geology and catchment cover were generally not significantly different (between Upper Lee and Wairoa Gorge). Table 3.3 presents estimated low flow parameters for the Lee dam site and includes both a best-estimate and the possible range.

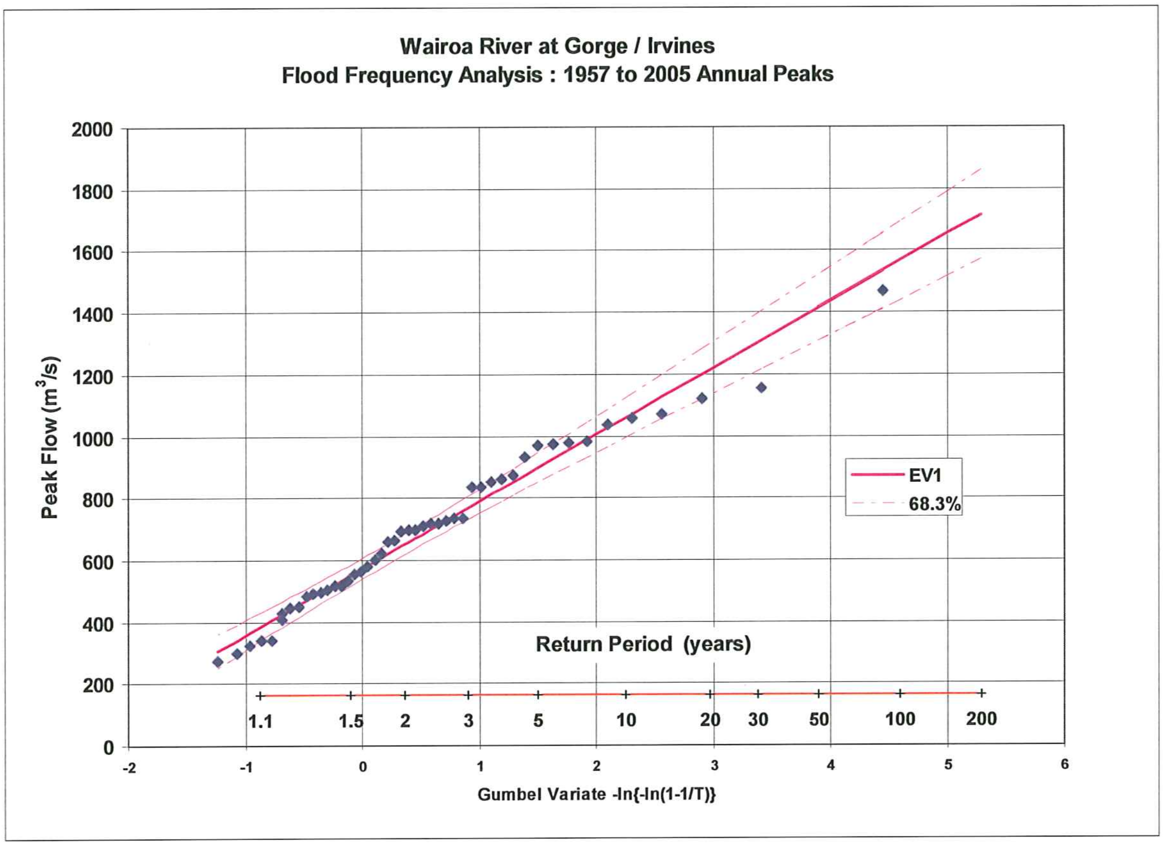
Table 3.3 Estimated low flow parameters for the Lee dam site (based on 7-day averaged flows)

Upper Lee Dam Site	Best Estimate	Possible Range
Catchment Area (km^2)	84	-
Estimated Mean Flow (m^3/s)	3.58	± 10%
Mean Annual Low Flow (l/s)	470	400 to 600
5 Year Low Flow	360	300 to 500
10 Year Low Flow	310	250 to 400

3.4 Flood Frequency Analysis

Figure 3.3 below shows the flood frequency distribution fitted to the annual maximum flows recorded at Wairoa Gorge/Irvines. The one standard error envelope is also shown (68.3% confidence interval). The estimated 100 year return flood peak is 1570 m^3/s (± 125 m^3/s).

Figure 3.3 Wairoa at Gorge/Irvines Flood Frequency Analysis



Preliminary flood estimates for the Upper Lee dam site have been computed from flood parameters for the Wairoa Gorge/Irvines site using the transposition equation recommended by McKerchar and Pearson (Flood Frequency in New Zealand, Publication No. 20 Hydrology Centre, DSIR, 1989), which assumes flood peaks are related by catchment area ratio raised to the power of 0.8, viz.:

$$Q_{\text{Lee dam site}} = Q_{\text{Wairoa Gorge}} \times (\text{Catchment Area}_{\text{Lee dam site}} / \text{Catchment Area}_{\text{Wairoa Gorge}})^{0.8}$$

Table 3.4 summarises estimated flood peaks for a range of return periods for both the Wairoa Gorge/Irvines and Upper Lee dam sites.

Table 3.4 Flood estimates for the Wairoa Gorge/Irvines and Lee dam site (based on instantaneous peak flows)

Parameter	Wairoa at Gorge/Irvines	Upper Lee dam site
Catchment Area (km^2)	463	84
Mean Flow (m^3/s)	16.57	~ 3.58
Mean Annual Flood (l/s)	698 ± 33	~ 180
10 Year Return Period Flood	1060 ± 65	~ 270
50 Year Return Period Flood	1420 ± 110	~ 360
100 Year Return Period Flood	1570 ±125	~ 400
200 Year Return Period Flood	1720 ±145	~ 440
1000 Year Return Period Flood	~ 2060 ±190	~ 530

4 Dam Storage Modelling

4.1 General

The live storage required at a dam is dependent on the following factors:

- consumptive water demand – this has been discussed in Section 2.2 earlier
- environmental or residual flows for protection of in-stream values – this has been discussed in Section 2.3 earlier
- flow variability and the level of drought security desired - in the current system, year to year flow variability has been represented by the long-term record of Wairoa River flows at Irvines from 1958 to 2005; drought security is discussed in Section 4.2 below
- system characteristics and response – these revolve around drainage pattern of the catchment, its rainfall-runoff response, the groundwater-aquifer interaction and other processes

A simulation method which takes into the account the parameters and characteristics above has been used to model the dam storage behaviour at the Lee dam site over the period of the Wairoa River flow record (1958 to 2005). The key to this spreadsheet based model, which operates on a daily timestep, is the maintenance of a threshold minimum flow (see Section 2.5) at Irvines whereby predicted shortfalls in the remaining natural river flow must be met by controlled dam releases. The same water demand pattern, based on the theoretical usage for the 1982/83 drought year (Section 4.3), has been assumed for each year of record.

4.2 Drought Definition and Security of Supply

For a given amount of live storage, the level of full service provided by the reservoir is expressed as the level of security against a drought with a particular return period, viz. the "design drought return period". This drought return period has been assessed from the simulated storage inflow-outflow behaviour described in Section 5.1.

By using a standard approach similar to that applied to estimating floods or low flows, an analysis of the magnitude of the storage fluctuations over time (specifically the minimum level attained in each year of record) produces a relationship between the minimum storage and the expected recurrence frequency or return period. The required live storage, or "storage drawdown" is equal to the full storage less this minimum storage.

Figure 5.3 in Section 5.1 provides an example of the simulated storage behaviour from 1958 to 2005. This shows what the magnitude of the drawdown (shown as inverted "spikes") would have been in each year of record. Figure 5.3 shows that the greatest "need" would have been in the 2000/01 season where a storage capacity in the order of 13 million m^3 would have been required. Figure 5.1 is an example of a frequency plot of the storage drawdown from which the live storage required versus drought return period is determined. Using the 2000/01 season again as an example, this shows that the 2000/01 drought had a return period in the order of 80 years.

Note that there is an important and fundamental difference in the drought definition for a river system with regulated storage and one without (i.e. a run-of-river system).

To elaborate:

> When required, storage is released from the reservoir to supplement natural river flows according to downstream requirements, typically under low flow

conditions. In general, the highest flow releases occur when periods of high demand coincide with very low natural flows.

While the maximum rate of release is related to the magnitude of this shortfall on an instantaneous (or daily) basis, the level to which storage in the reservoir is drawn down depends on the sum of all the preceding releases made. That is, the storage drawdown is a reflection of the accumulated shortfall over time. Thus, for a storage reservoir, the critical situation is one in which the total volume of shortfall over an entire season (or longer if the dam were not full at the start of the season) is a maximum. The magnitude of any one short-lived shortfall episode rarely governs the storage requirement.

For a run-of-river system, such as the Wairoa River currently, the return period of a drought event is typically determined from an analysis of short-term low flow events, such as the instantaneous low flow, the mean daily low flow, or the mean 7-day low flow. So, what may be a significant drought event in a run-of-river system may not necessarily have the same level of significance in terms of the security of supply from a reservoir due to the different timeframes being considered.

4.3 Total Water Demand/Storage Requirement

The modelling for the determination of storage volume requirements, based on Agfirst's water demand and GNS's groundwater modelling was completed and peer reviewed by Andrew Fenemor of Landcare Research. The outcome was that the required storage volume to meet the identified target drought security (1 in 10 years) was found to be substantially lower than the initial assessment of 15 million m^3 (which had been based purely on water demand). Accordingly, Tonkin and Taylor sought instructions from WWAC on whether to:

- retain the original drought security (1 in 10 years) with consequential savings in cost and (potentially) effects OR
- provide additional storage to increase the drought security (but potentially still within the original cost estimate range)

The decision also needed to include:

- which downstream residual flow scenario to adopt (for in-stream habitat purposes)
- whether the reservoir is to perform any function additional to irrigation water supply; e.g. recreational resource, habitat provision, cultural purposes etc
- provision for dead storage

WWAC considered these issues at a meeting on 8 June 2006 (based on memos from Tonkin and Taylor setting out the storage volumes associated with various scenarios - see **Appendix 3**). WWAC's decision was to determine a total storage volume that was large enough to provide flexibility to respond to certain events, take into account the uncertainties in modelling and climate change, and to manage the storage in response to those events.

The volume chosen by WWAC for further study was:

- 12 million m^3 live storage
- plus provision for an additional 1 million m^3 dead storage (allowing for 0.6 million m^3 for 100 years of sediment infill)

- giving a total of 13 million m³ storage capacity

This volume was considered sufficient to provide storage to allow for the equivalent of approximately a drought security of 1 in 50 years plus provision for a minimum in-stream flow at Appleby of 1100 l/s, as well as supply a potential future regional need of in the order of 22,000m³/day. Alternatively, the volume could be managed to provide a higher security of supply under drought conditions with a lower residual in-stream flow at Appleby, but still within environmental guidelines.

Key points from the dam storage modelling are as follows:

- based on storage utilisation and in descending order, the three worst droughts on record are the 2000/01, 1972/73 and 1982/83 seasons, with estimated drought return periods of about 80 years, 40 years and 30 years
- to maintain the higher residual flow at Appleby Bridge (i.e. 1100 l/s rather than 600 l/s), the additional storage required is between about 2 and 3 million m³ depending on the drought standard adopted
- to provide for a future regional supply of 22,000 m³/day, the additional storage capacity required is between about 1 and 2 million m³ depending on the drought standard adopted
- the rate of increase in the required storage for higher drought standards is steep – for example, the storage requirement for a 50 year drought standard is double that for a 10 year drought standard. One implication of this characteristic is that it would be very challenging to manage the resulting shortfall if a drought event significantly greater than the adopted design drought were to occur
- natural river flows and groundwater storage appears to meet the bulk of the demand, which stands at about 32 million m³ per annum (or 40 million m³ per annum with future regional supply), with only occasional flow boosts from the reservoir to maintain the minimum flow at Appleby Bridge

The above results and findings (including the hydrographs and plots shown in Section 5) were obtained prior to GNS' Stage 3 confirmatory modelling. As noted earlier in Section 2.5, a minor adjustment to the prescribed flow augmentation regime was necessary to eliminate the predicted small shortfall in meeting the 1100 l/s Appleby Bridge minimum flow during the driest periods e.g. the shortfall totalled 73,000 m³ over the 1982/83 irrigation season. The effect of this adjustment, which was purposely conservative, resulted in an increase of between 1.3% and 2.4% (140,000 to 190,000 m³) in the required live storage, depending on the drought return period considered. In terms of security of supply, the drought return period reduces slightly from 63 years to 60 years for a live storage of 12 million m³ (for the 1100 l/s Appleby Bridge minimum flow scenario with allowance for future regional supply).

(Note that the resulting minor changes to the various simulated storage volume, reservoir level and comparative flow hydrograph plots in Section 5 would not be discernible at the scale of the plots.)

5 Upper Lee River Storage Site - Flow and Storage Simulation

5.1 Preliminary Operating Regime

Figure 5.3 is a time-series plot of the simulated storage behaviour (volume) from 1958 to 2005 for a dam at Site 11 Lee with a gross storage capacity of 13 million m³ and releases for maintaining a residual flow of 1100 l/s at Appleby Bridge and for meeting future allocations corresponding with the 1982/83 theoretical demand profile. The demand includes provision for a future regional need of 22,000 m³/day.

Figure 5.4 shows the same data but plots simulated reservoir levels instead of reservoir volume.

Figure 5.1 below shows the frequency distribution fitted to time-series of storage drawdowns from which the quantity of live storage versus drought return period has been ascertained.

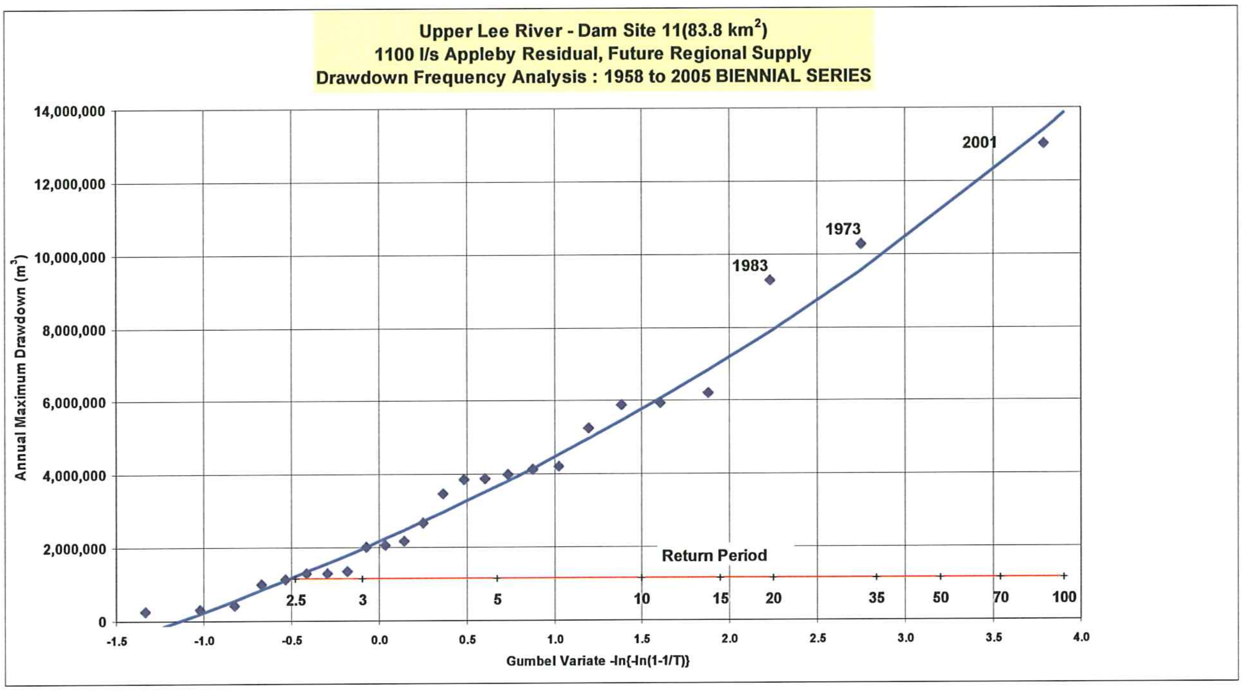


Figure 5.1 Lee River Dam Site: Storage Drawdown Versus Return Period

Figure 5.2, which is a drawdown duration curve, provides an indication of the proportion of time the Lee reservoir would be full and the proportion of time for which the reservoir is at a particular level range. In effect, this plot is a condensed form of the time-series data contained in Figure 5.4. Figure 5.2 shows that the Lee reservoir would be virtually full about 85% of the time, within 1 m of full about 91% of the time and within 5 m of full for about 97% of the time on long-term average assuming fully allocated supply.

Figure 5.5 compares the flows immediately below the Lee dam before and after dam construction for a sample period (1 July 1981 to 30 June 1983). The 1982/83 season is a drought year with a return period of about 30 years, whereas the 1981/82 season is a more typical year in terms of flows. Note that the pre-construction flows are represented by (and are the same as) the reservoir inflows. Figure 5.6 compares the flows in the Wairoa River at Irvines before and after construction of a dam at Site 11 Lee.

As can be seen from Figure 5.6, the reservoir inflows or natural flows (blue) match the reservoir outflows (pink) for the majority of the time (i.e. the pink line plots on the blue line). Periods of flow augmentation provided by the reservoir are indicated by the reservoir outflow plotting higher than the reservoir inflow. In 1982, this occurs between late January and early April, while in the 1983 drought year, flow augmentation was provided from early November (1982) to mid April (1983). Reservoir refilling is indicated by periods where the reservoir inflow plots higher than the reservoir outflow. A clear example of this is seen in mid January 1983 where a fresh, peaking at about 10,000 l/s, is captured entirely to reservoir storage.

A similar interpretation can be drawn from Figure 5.7 in terms of flow augmentation. That is, Wairoa River flows at Irvines before and after Lee dam construction are almost identical most of the time, except over summer low flow periods during which the flow augmentation can be clearly seen (pink line plotting higher than the blue line between late January and early April 1982, and from November 1982 to April 1983). However, there is a notable difference between Irvines and the dam site in terms of flow regime changes. That is, the impact of the reservoir refilling is far less obvious at Irvines. For example, the fresh that occurred in mid January 1983 and the series of smaller freshes that preceded it are mostly preserved at Irvines albeit with a slight reduction in the peak flows (15% or so less). This is not unexpected and is attributed to the natural inflows from the tributaries below the dam continuing to contribute to the overall river flow. At the dam site, these freshes were absorbed entirely into the reservoir.

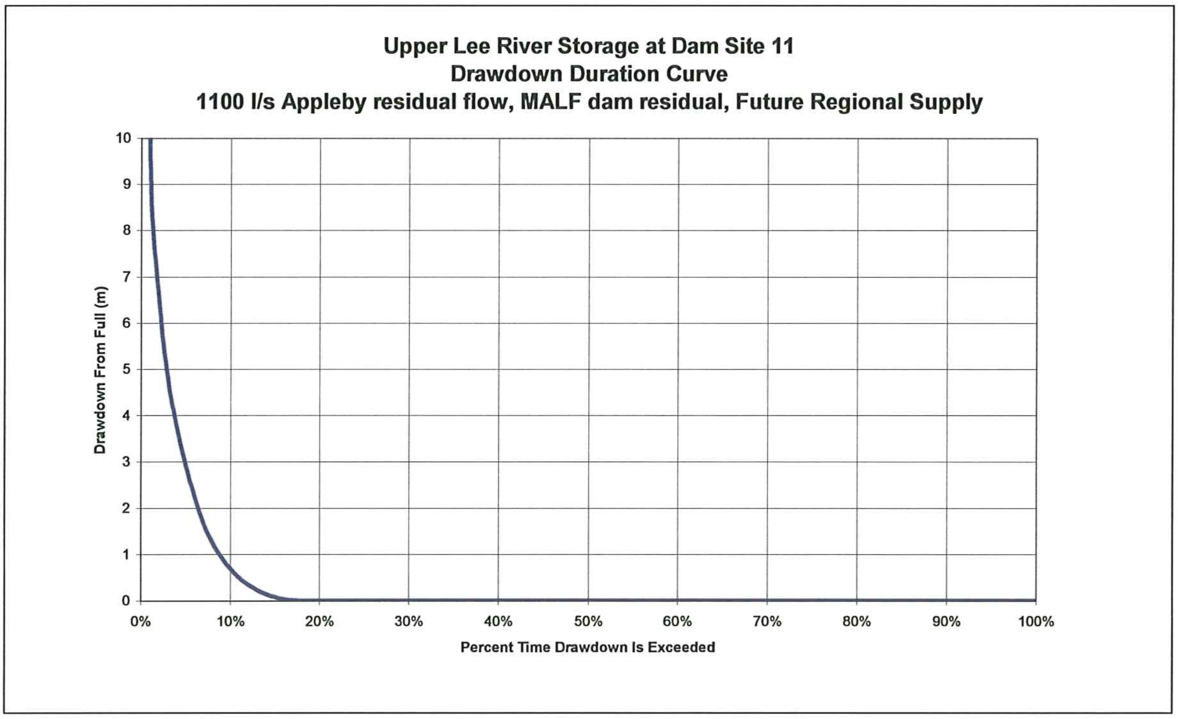


Figure 5.2 Lee River Dam Site: Storage Drawdown VersusDuration

Figure 5.3 Lee dam site – simulated storage behaviour: volume time-series plot 1958 to 2006

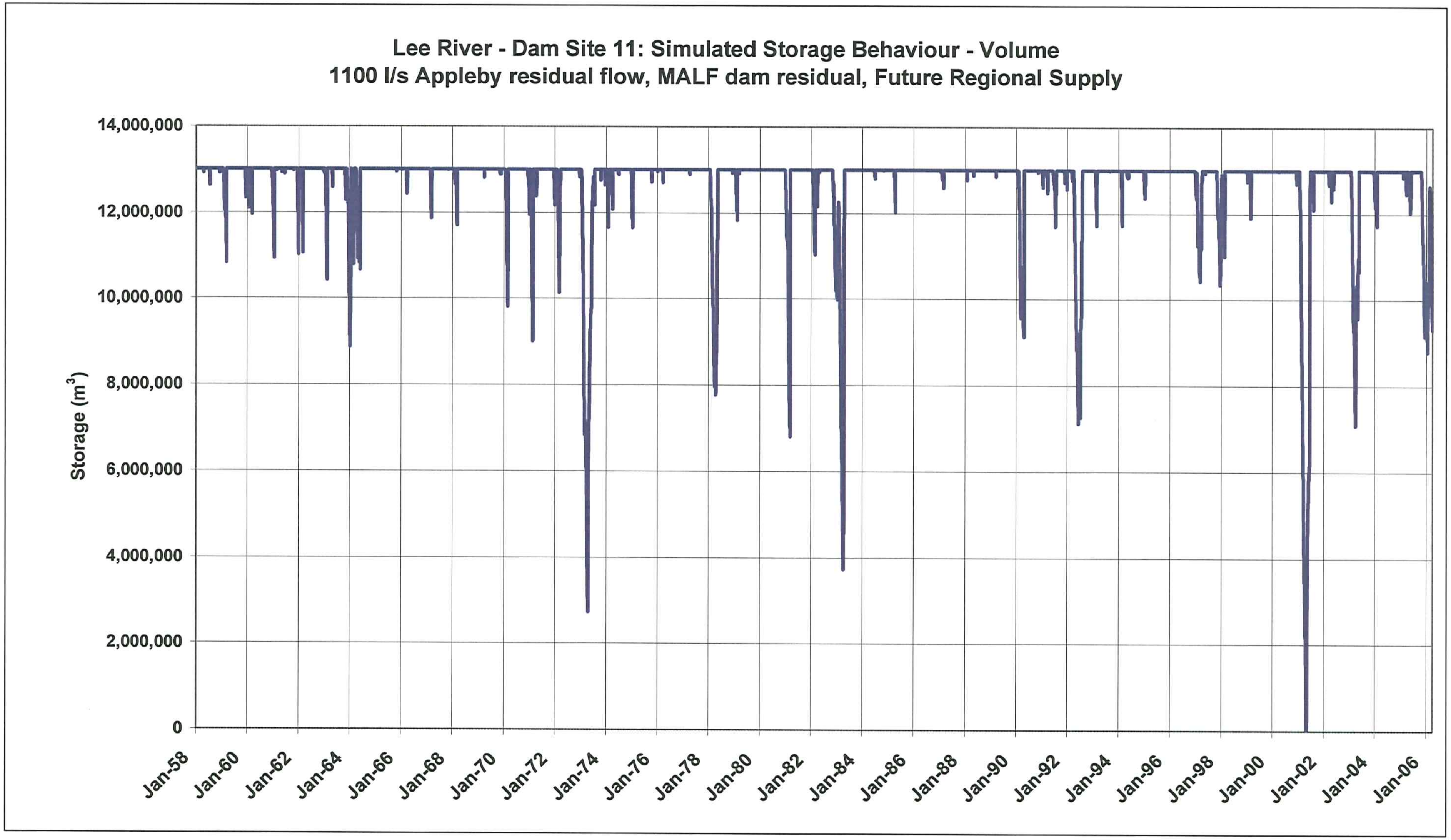


Figure 5.4 Lee dam site – simulated storage behaviour: level time-series plot 1958 to 2006

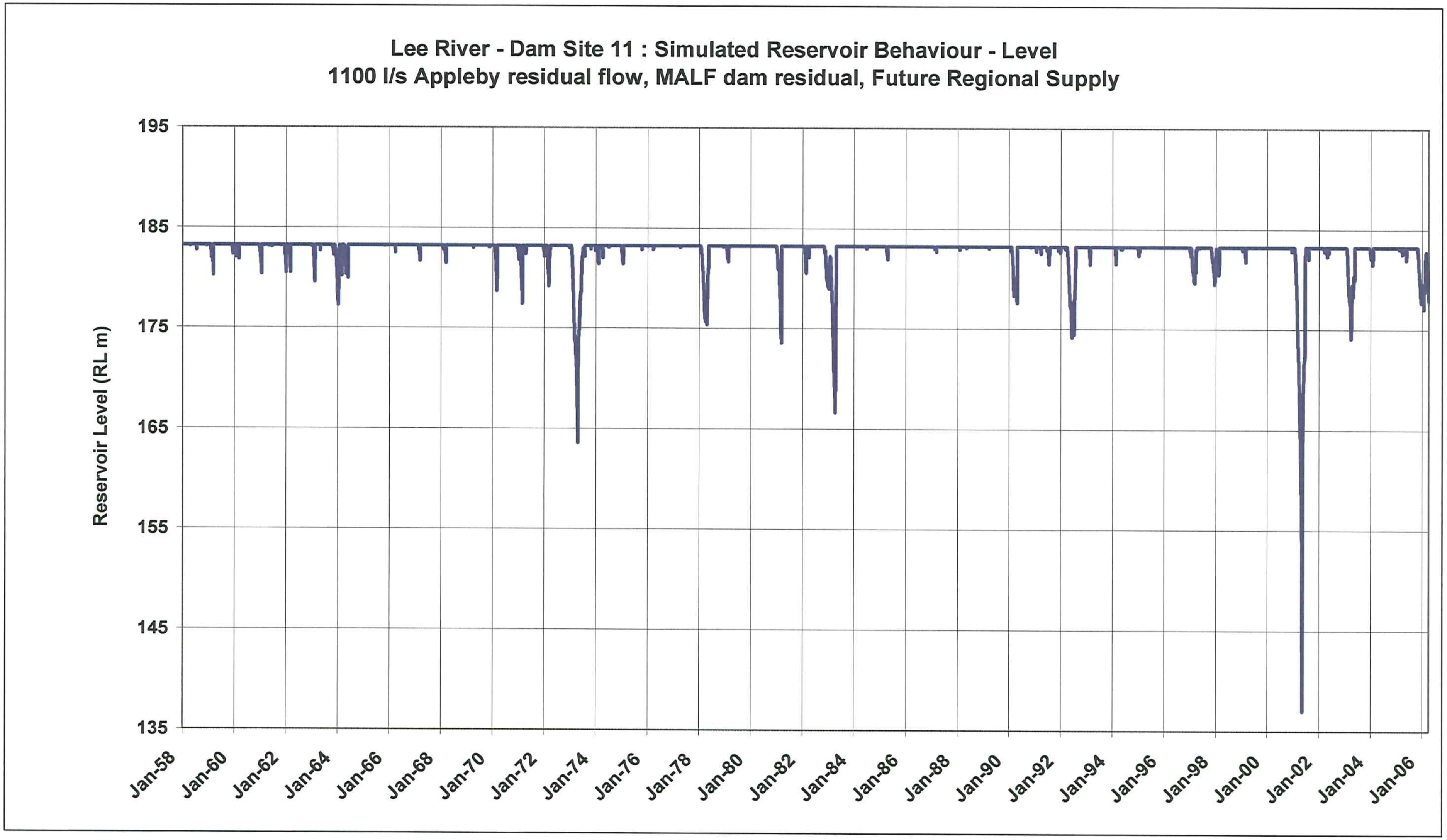


Figure 5.5 Comparison of flow hydrographs at the Lee dam site before and after (simulated) dam construction 1981 to 1983

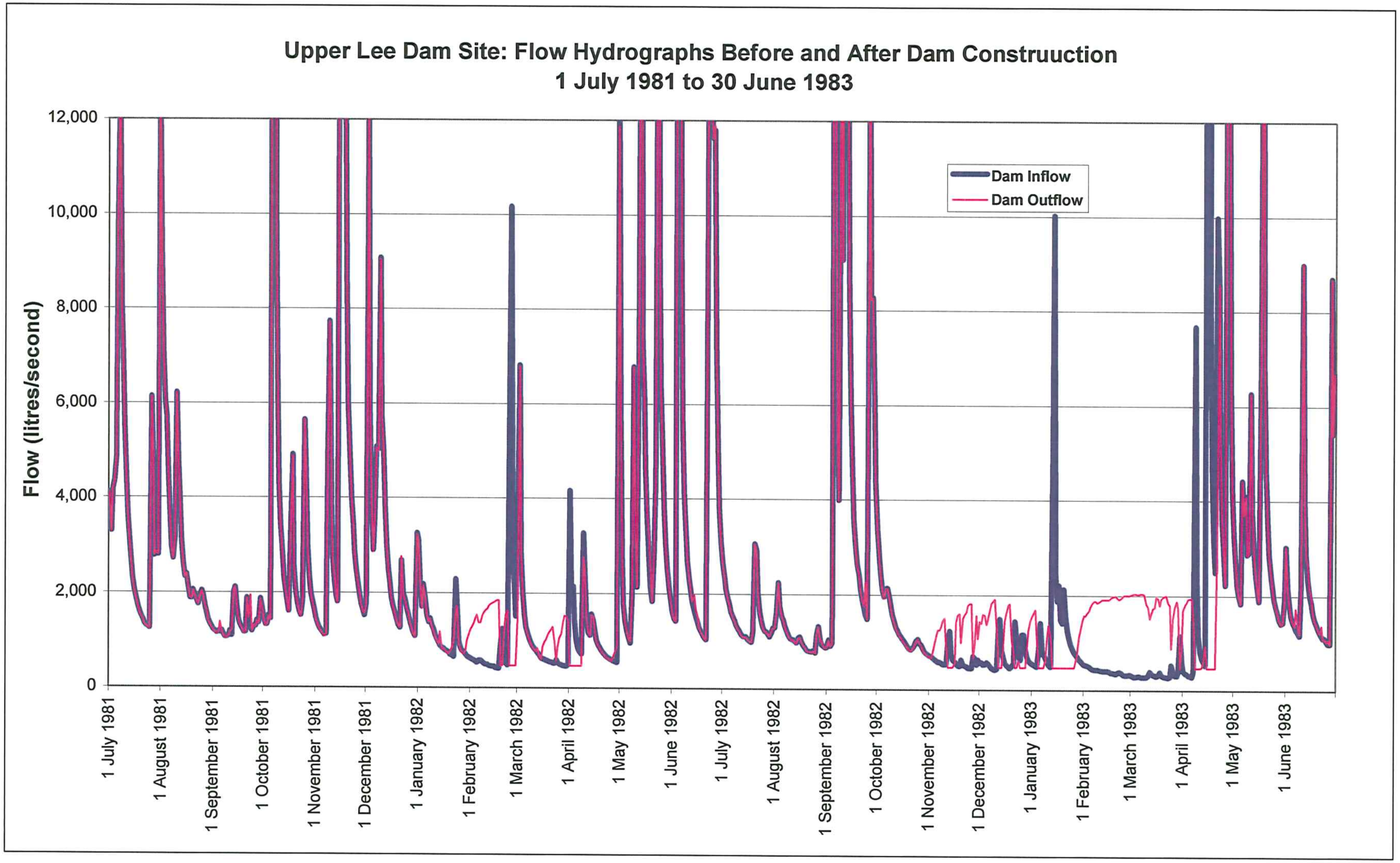
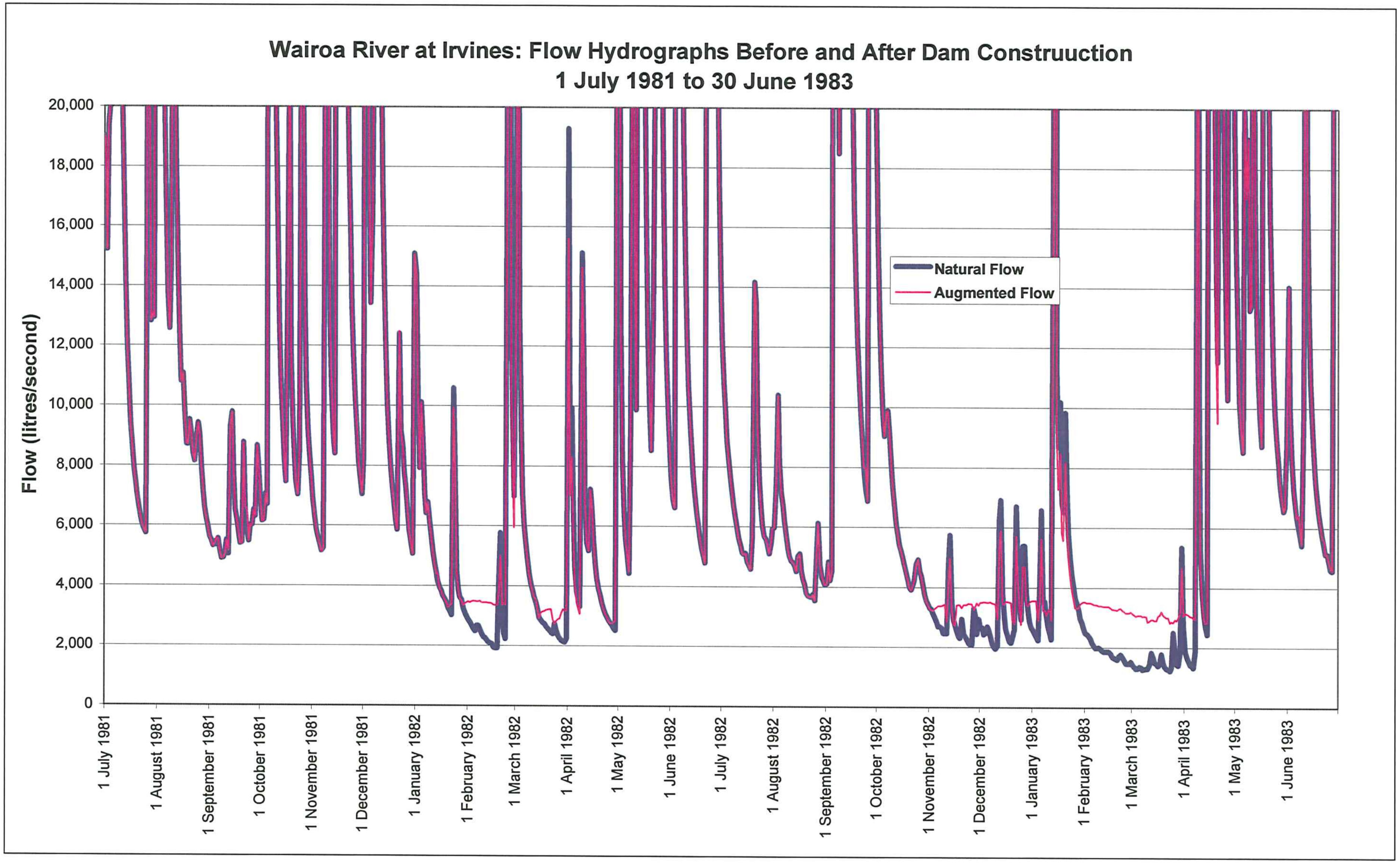


Figure 5.6 Comparison of flow hydrographs at Wairoa Gorge/Irvines before and after (simulated) dam construction 1981 to 1983



5.2 Sedimentation Potential

The Wairoa River overall (as measured at Irvines) has a relatively low to moderate sediment load in comparison with other comparable rivers in New Zealand. The river transports the great majority of its sediment load during flood events. Flows below mean flow are virtually free of suspended sediment.

Over a 100 year period, the amount of sediment that would be trapped within a Lee River reservoir (based on Site 11) is estimated to be about 600,000 m^3. This estimate uses a relationship between river flow and suspended sediment concentration which was developed from a series of suspended sediment gaugings carried out at the Wairoa River at Irvines between 1976 and 1992.

Implicitly, the estimate assumes that the factors which control sediment generation, notably land-use, currently or in the future, are not significantly different from those in the gauging period. In this regard, it is noted that (uncontrolled) forestry operations have the potential to generate a substantially increased sediment load, from the time of harvest until a closed canopy with the new crop has established. The very steep hillslopes of the catchment afford limited opportunity for mitigation, i.e. it would be very difficult to implement effective erosion and sediment controls. (It is noted that conversion to exotic forestry from bush or pasture also has the potential to reduce water yield of the catchment.)

6 Applicability

This report has been prepared for the benefit of the Waimea Water Augmentation Committee/Tasman District Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

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Appendix 1: Future Water Demand by Water Zone. Agfirst Consultants, July 2006

Appendix 2: Groundwater-river interaction modelling for a water augmentation feasibility study, Waimea Plains, Nelson. GNS Science Consultancy Report 2006/200

Appendix 3: Storage Volumes and Drought Security – Future Regional Demands. Memo Tonkin and Taylor Ltd, 6 June 2006