Groundwater-river interaction modelling for a water augmentation feasibility study, Waimea Plains, Nelson

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EXECUTIVE SUMMARY

The effects of water abstraction from groundwater and from surface water (i.e. principally the Waimea East Irrigation Scheme pumping) on groundwater levels and Waimea/Wairoa River flow are an important issue for water management in the Waimea Plains for Tasman District Council (TDC).

A feasibility study into 'water augmentation for the Waimea Plains' by Tasman District Council aims to study the feasibility of water storage in the upper parts of the Wairoa/Lee catchments, which would release water into the river systems during summer for downstream irrigation use. The aim of this project is to determine the flow release required from storages in the upper Wairoa/Lee catchments by re-running the existing Waimea Plains groundwater-river interaction model developed by GNS Science in collaboration with TDC.

This project has been structured into the following three modelling stages: (1) modelling stage 1: establish the river flow at Irvine-Wairoa Gorge to maintain a minimum flow of 500 l/s at Nursery-Appleby Bridge in the Waimea River based on actual water usage in a 1 in 10 dry year (1991/1992), (2) modelling stage 2: after achieving modelling stage 1, deduce river flow rate at Irvine-Wairoa Gorge needed to maintain the target minimum flow for two scenarios: 600 l/s and 1100 l/s at Nursery-Appleby Bridge with future water demand in a nominal 1 in 20 dry year (1982/1983), and (3) modelling stage 3: forward scenario simulation to confirm that the proposed augmented water release regime by Tonkin and Taylor Ltd will meet downstream requirements.

In modelling stage 1, the Waimea Plains groundwater-river interaction model calculates that the minimum flow at Irvine-Wairoa Gorge would need to be 1650 l/sec and 1825 l/s to maintain minimum flows of 250 l/s and 500 l/s at Nursery-Appleby Bridge respectively, in the Waimea River for a 1 in 10 dry year (1991/1992) with pumpage at actual water usage.

Future water demand in each cell in the Waimea Plains groundwater-river interaction model has been calculated based on daily irrigation demand calculation for a range of crops with a range of soil types using a daily climate data for the 1982/1983 (July to June) year .

The model calculates that the Waimea River flow at Nursery-Appleby Bridge will be less than 100 l/s on 17 days, less than 250 l/s on 37 days and less than 500 l/s on 48 days for the 1982/1983 year if pumpage is equal to future water demand. A significant increase in the occurrence of zero flow, or very low flow of less than 250 l/s, at Nursery-Appleby Bridge for the 1982/21983 year is calculated if pumpage is equal to future water demand compared to actual water usage.

For modeling stage 2, the Waimea Plains groundwater-river interaction model has been used to establish the minimum river flow rate at Irvine-Wairoa Gorge needed to maintain minimum flows of 600 l/s and 1100 l/s at Nursery-Appleby Bridge in the Waimea River based on future water demand and the 1982/1983 dry year (a nominal 1 in 20 dry year). The model calculates that a minimum flow at Irvine-Wairoa Gorge of 2260 l/s (excluding Waimea East Irrigation Scheme) would be required to maintain a minimum flow of 600 l/s at Nursery-Appleby Bridge in the Waimea River with future water demand over the period 01-03-1983 to

23-03-1983 (the driest period over 1982/1983). If Waimea East Irrigation Scheme (WEIS) take is included, a minimum flow at Irvine-Wairoa Gorge of 2513 l/s would be required to maintain a minimum flow of 600 l/s at Nursery-Appleby Bridge. The model predicts that a minimum flow of 2663 l/s (excluding Waimea East Irrigation Scheme) at Irvine-Wairoa Gorge would be needed to maintain a minimum flow of 1100 l/s at Nursery-Appleby Bridge in the Waimea River with future water demand. The calculated minimum flow at Irvine-Wairoa Gorge needed to maintain the target minimum flow of 1100 l/s at Nursery-Appleby Bridge in the Waimea River is calculated to be 2981 l/s if Waimea East Irrigation Scheme (WEIS) take is included.

In modeling stage 3, forward simulation was undertaken to assess the ability of a proposed augmented river flow at Irvine-Wairoa Gorge to maintain a minimum flow of 1100 l/s at Nursery-Appleby Bridge in the Waimea River in a nominal 1:20 dry year (1982/1983). River flow at Nursery-Appleby Bridge in the Waimea River would be an average of 1148 l/s with future water demand and proposed augmented river flow at Irvine-Wairoa Gorge between 01-03-1983 and 23-03-1983 (the driest period over 1982/1983 year). However, the model calculates that the minimum river flow at Nursery-Appleby Bridge would be slightly below 1100 l/s in the period late February 1983 to early March 1983. Some minor recalculation of the proposed augmented river flow would be necessary to achieve above 1100 l/s at Nursery-Appleby Bridge at all times.

1.0 INTRODUCTION

The effects of water abstraction from surface water (i.e. principally the Waimea East Irrigation Scheme pumping) and from groundwater are an important issue for water management in the Waimea Plains for Tasman District Council. The Waimea Plains are clearly water-short with the most recent studies conducted by GNS Science showing the water resources to be over-allocated by 22% (597 l/s) for a 1:10 year drought security (Hong, 2003).

A feasibility study into water augmentation for the Waimea Plains is established to complete a holistic study into the feasibility of water storage in the upper parts of the Wairoa/Lee catchments to enhance water availability for both regional use and environmental/community/aesthetic benefits downstream on the Waimea Plains. The project is led by the Waimea Water Augmentation Committee (WWAC) which represents irrigation interests in the Waimea Plains but also has representation from Tasman District Council, Fish & Game Council, Department of Conservation and local iwi. One of the main goals of this feasibility study is to investigate the potential storage options in the upper Wairoa and/or Lee catchments, which would release water into the Lee/Wairoa/Waimea River system during summer for downstream irrigation use. The aim of this groundwater modelling study is to gain a better understanding of the relationships and interactions between groundwater and Waimea River system and quantify the residual surface water flow after groundwater abstraction from the aquifers.

2.0 PURPOSE OF THIS PROJECT

The aim of this project is to determine the flow release required from storages in the upper Wairoa or Lee catchments to maintain specified flows in the Waimea River. The Waimea Plains groundwater-river interaction model (Hong, 2003; Hong 2005) developed by GNS Science in collaboration with TDC is used in this study.
The assessment is structured into the following three stages:

1. establish river flow rate at Irvine, Wairoa Gorge to maintain a minimum flow of 500 l/s in the Waimea River at Nursery-Appleby Bridge based on actual water usage in a 1 in10 dry year (1991/1992);

2. deduce a river flow at Irvine-Wairoa Gorge needed to maintain the target minimum flow at Nursery-Appleby Bridge with future water demand;

3. forward scenario simulation to confirm that the augmented water release regime proposed by Tonkin and Taylor Ltd will meet downstream requirements.

3.0 GROUNDWATER RESOURCES IN THE WAIMEA PLAINS

The Waimea Plains cover an area of 75 km^2 and are located at the coastal margin of the Waimea Catchment, adjacent to the town of Richmond. The Waimea Plains are formed of late Quaternary terrestrial terrace and floodplain gravels deposited by the Waimea River and its major tributaries, the Wairoa River to the east and the smaller Wai-iti River to the south. The soils of the Waimea Plains are highly productive, with the principal source of water for irrigation, domestic, industrial and urban supply being groundwater from the various aquifers that underlie the area.

Three major aquifers (Figure 1) have been delineated under the Waimea Plains and are named the Lower Confined Aquifer (LCA), Upper Confined Aquifer (UCA) and the Appleby Gravel Unconfined Aquifer (AGUA). There are also minor aquifers called Hope Minor Confined and Unconfined Aquifers (HU). Figure 2 represents the three dimensional hydrogeology of the Waimea Plains.

3.1 Appleby Gravel Unconfined Aquifer (AGUA)

The Appleby Gravel Unconfined Aquifer underlies the floodplains of the Wai-iti, Wairoa and Waimea Rivers and the delta of the Waimea River. The AGUA is up to 15 m thick, with the water table averaging 2 to 3 m below ground level. The AGUA is underlain by the Hope Gravel, with the Hope Gravel being a clay-bound gravel. The contact with the Hope Gravel is less distinct in the Wai-iti Valley, where the AGUA is less permeable than in other areas of the Waimea Plains. Transmissivity values in the Wai-iti area range from 2,000-3,500 m^2/day. The AGUA is most permeable in the youngest gravel, adjacent to the Wairoa and Waimea Rivers. Transmissivity values of 20,000 m^2/day have been measured adjacent to the Waimea River and in the delta part of the plains. The AGUA is in contact with the Upper Confined Aquifer, and in lateral contact with marine gravel and sand in the Waimea delta region. Recharge to the AGUA occurs from the rivers, from rainfall and irrigation drainage. The main river recharge zones are between the Wairoa Gorge and Brightwater township, upstream of the State Highway 60 Bridge near Appleby and downstream of Spring Grove on the Wai-iti River.

3.2 Hope Minor Confined and Unconfined Aquifer (HU)

East of the Appleby Gravel deposits, minor water-bearing lenses occur in gravel fans in the Hope Gravel, derived from the eastern hills. These unconfined and confined aquifers are seldom more than 0.5 m thick and exist to a depth of about 15 m. Laterally they are discontinuous, so drawdowns due to pumping are high.

Recharge is only from rainfall, and associated runoff, because the aquifers are above the level of any river influence. Pumpage from this aquifer is primarily for domestic use and small-scale irrigation. Water levels and yields decline markedly in this aquifer in summer.

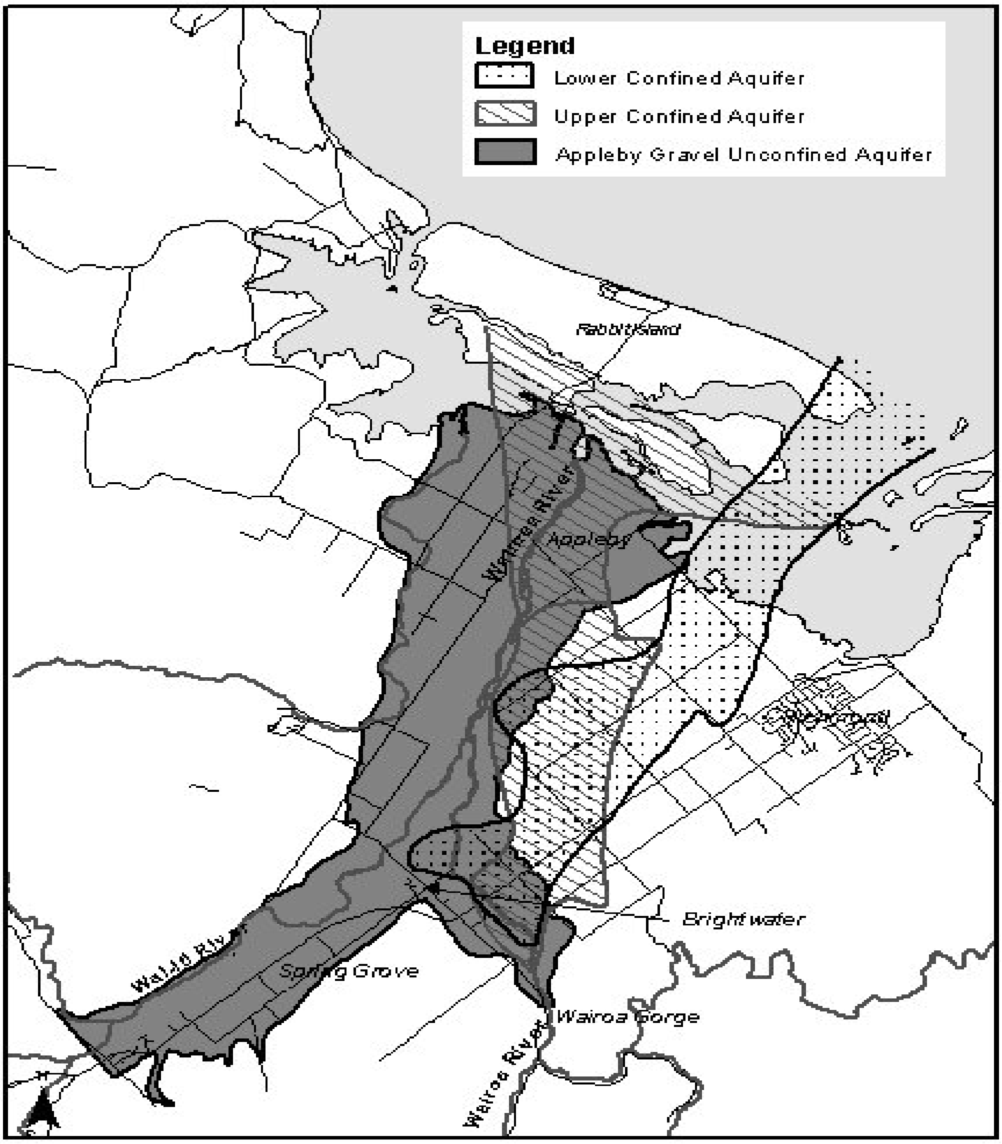

Figure 1. Major aquifers of the Waimea Plains.

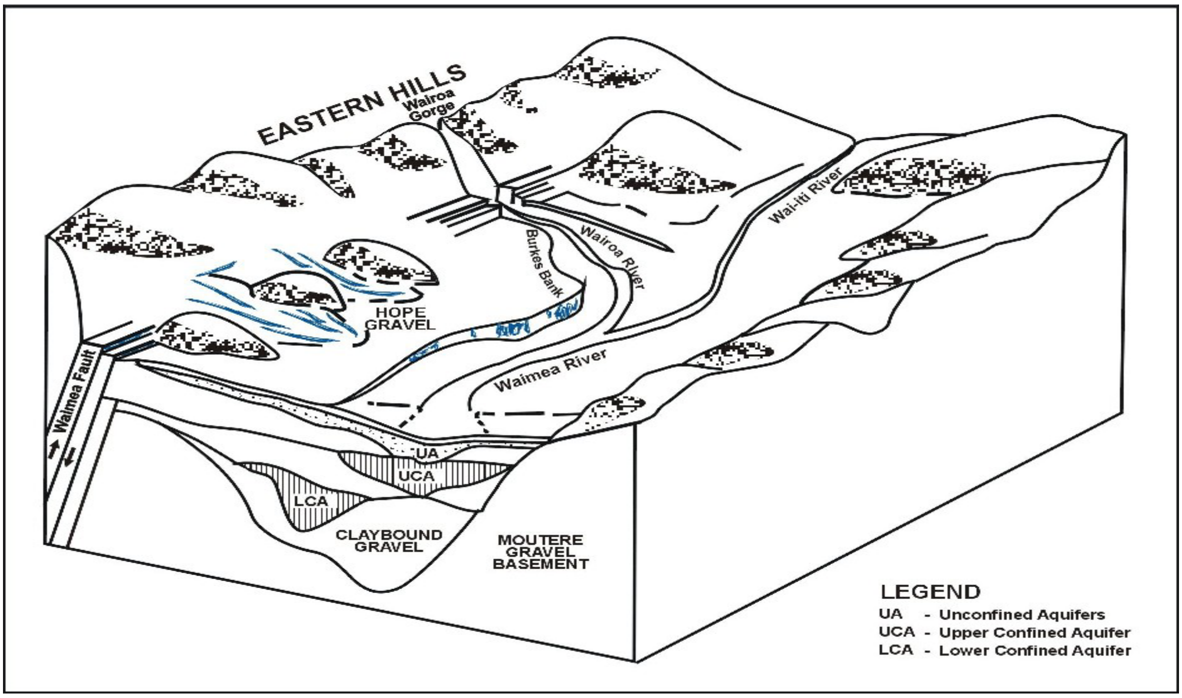

Figure 2. Three-dimensional hydrogeology of the Waimea Plains.

3.3 Upper Confined Aquifer (UCA)

The Upper Confined Aquifer (UCA) consists of clean river gravel deposited within the clay-bound Hope Gravel and accumulated on a degradation surface in the valleys of the Wairoa and Waimea Rivers.

The UCA extends from its recharge zone near the Wairoa Gorge towards the coast at Rabbit Island in the depth range from 18-32 m. The upper confining layer is ruptured within the recharge zone and also from Appleby northwards, providing a hydraulic connection with the overlying Appleby Gravel Aquifer. Transmissivity values for the UCA range from 600 to 1300 m^2/day. Highest yields in the UCA are obtained along the western edges of Burkes Bank. Recharge occurs from the Wairoa River via the Appleby Gravel and in winter from the Hope Aquifers via the gravel fans. The latter source is confirmed by the high nitrate levels measured in the UCA and by the flow directions derived from a winter piezometric survey.

3.4 Lower Confined Aquifer (LCA)

The Lower Confined Aquifer (LCA) is lithologically similar to the Upper Confined Aquifer. It extends from the Wairoa Gorge to beyond the entrance of the Waimea Inlet east of Rabbit Island. The LCA is from 30-50 m deep and is recharged near the Wairoa Gorge. Recharge occurs in winter from the gravel fans, which recharge the UCA from the eastern hills. Seawater intrusion is a potential concern in this aquifer because large pumping wells are near the coast, the aquifer extends under the Waimea inlet, and the nature of the seaward contact of the aquifer is unclear. Pump testing shows a transmissivity range of between 200–1,600 m^2/day.

4.0 GROUNDWATER-RIVER INTERACTION MODEL OF THE WAIMEA PLAINS

The groundwater-river interaction model of the Waimea Plains includes the following assumptions (Hong, 2000):

1. A three-layered aquifer system consisting of the Unconfined Aquifer (Appleby Gravel Unconfined Aquifer), Upper Confined Aquifer (UCA), and the Lower Confined Aquifer (LCA);
2. The Waimea groundwater flow model with a uniform grid of 210 m x 225 m cells in the horizontal plane (65 rows by 60 columns), see Figure 3, Figure 4, and Figure 5;
3. The boundary of Waimea Plains aquifer system consisting of constant head cells and general head cells;
4. Major water sources in the model being rainfall recharge and river (Lee/Wairoa River, Waimea River, and Wai-iti River) inflow.

The U.S. Geological Survey's numerical model for simulating groundwater flow, MODFLOW-96 (with Groundwater Modeling System (GMS), interface of MODFLOW), is used to represent the conceptual model of the Waimea Plains. The following MODFLOW packages are used to represent the Waimea Plains groundwater-river interaction model:

- Basic package;
- Block-Centered Flow package;
- Well package;
- General Head Boundary package;
- Drain package;
- Recharge package;
- Stream package;
- Slice Successive Overrelaxation package;
- Output package.

The groundwater-river interaction model of the Waimea Plains simulates flow in the Unconfined Aquifer (1st layer), the Upper Confined Aquifer (2nd layer), and the Lower Confined Aquifer (3rd layer). The model grid for the Unconfined Aquifer (1st layer) is shown in Figure 3 with a topographic map. Figures 4 and 5 show the model structure of the Upper Confined Aquifer (2nd layer) and the Lower Confined Aquifer (3rd layer), respectively. Figure 6 shows water management zones and hydrological monitoring sites (Table 1) for surface water and groundwater on the Waimea Plains.

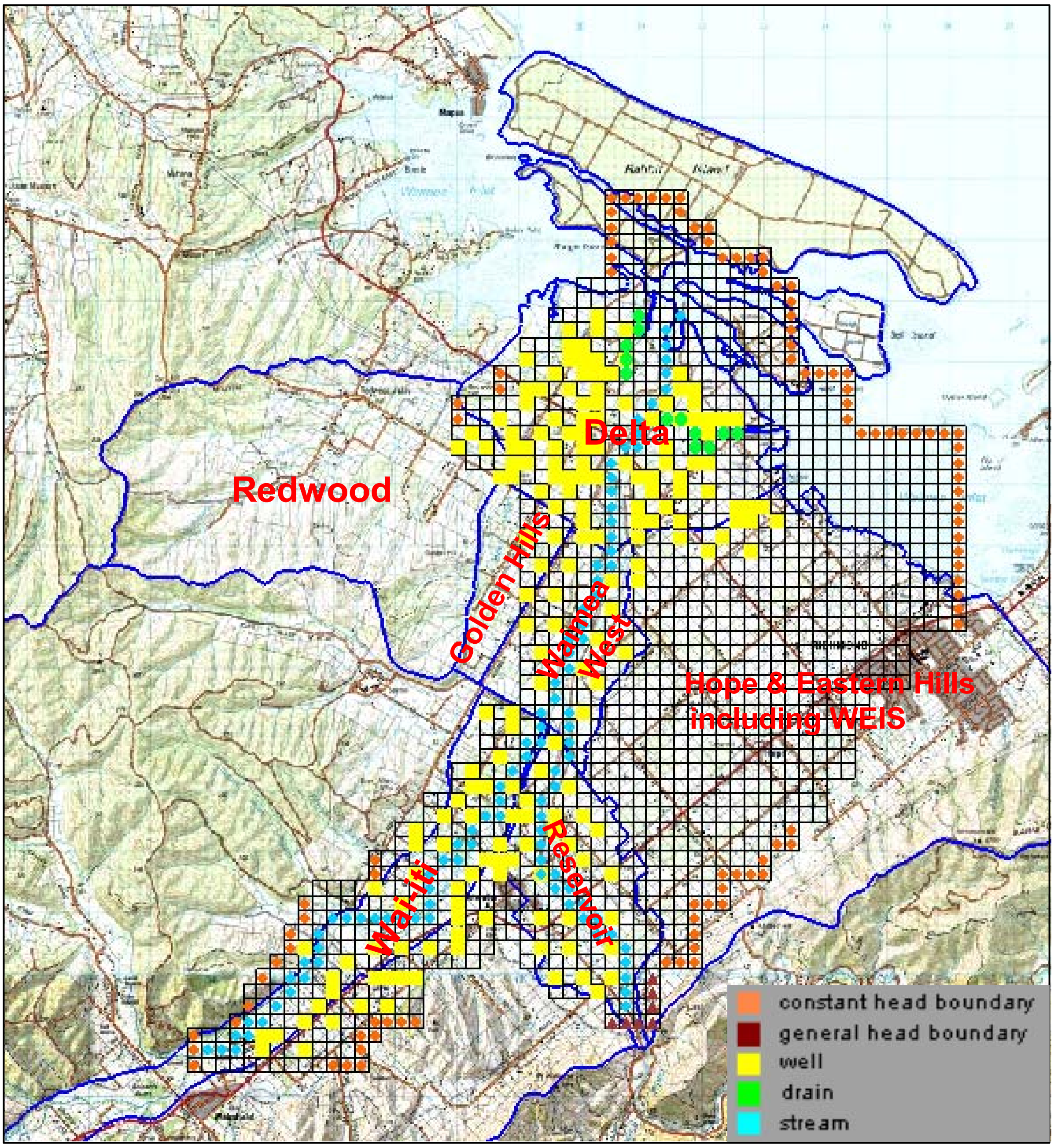

Figure 3. Water management zones for the Appleby Gravel Unconfined Aquifer (AGUA) and Hope Minor Confined and Unconfined Aquifer (HU) and top layer of groundwater flow model.

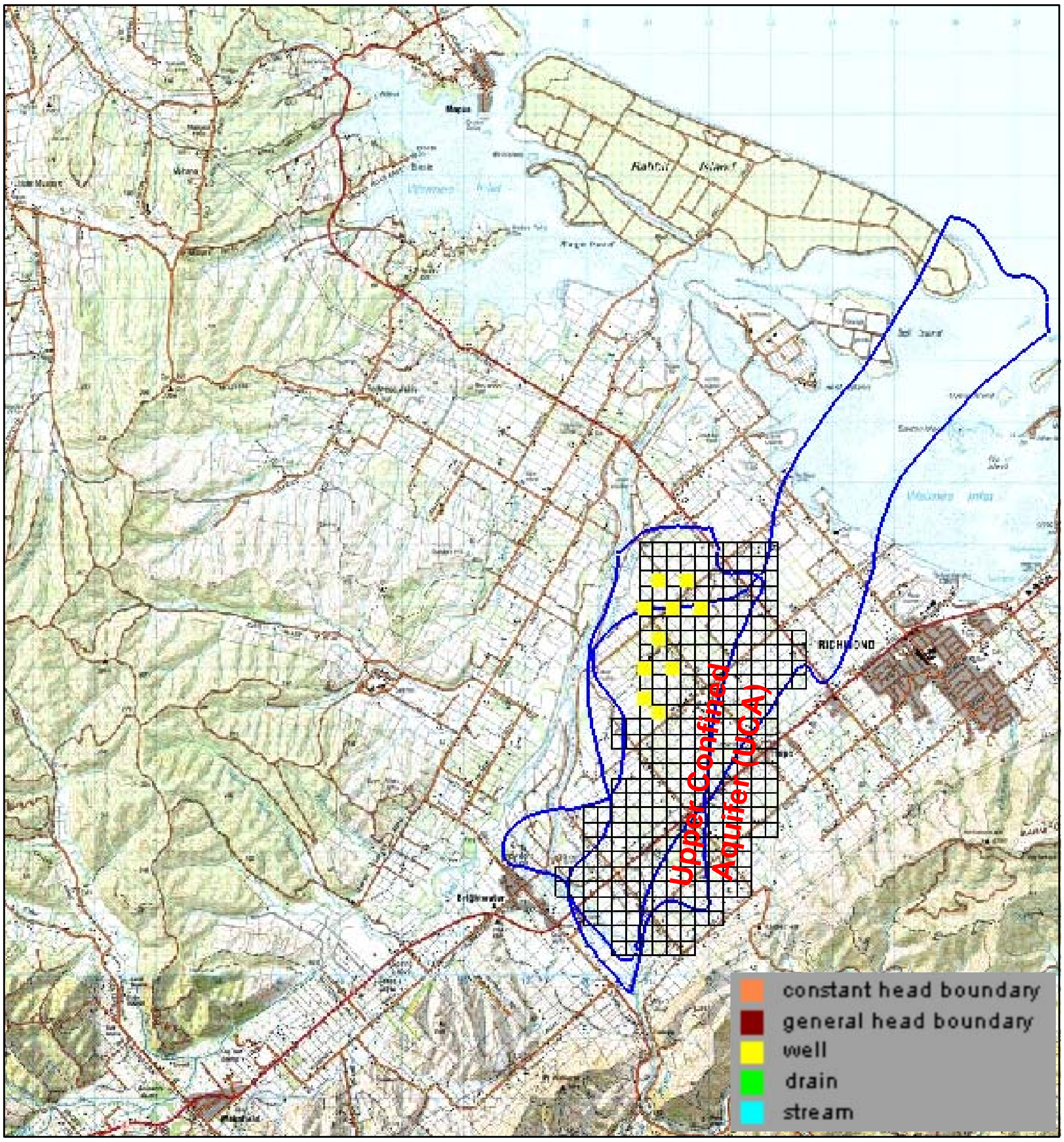

Figure 4. Upper Confined Aquifer water management zone and second layer of groundwater flow model.

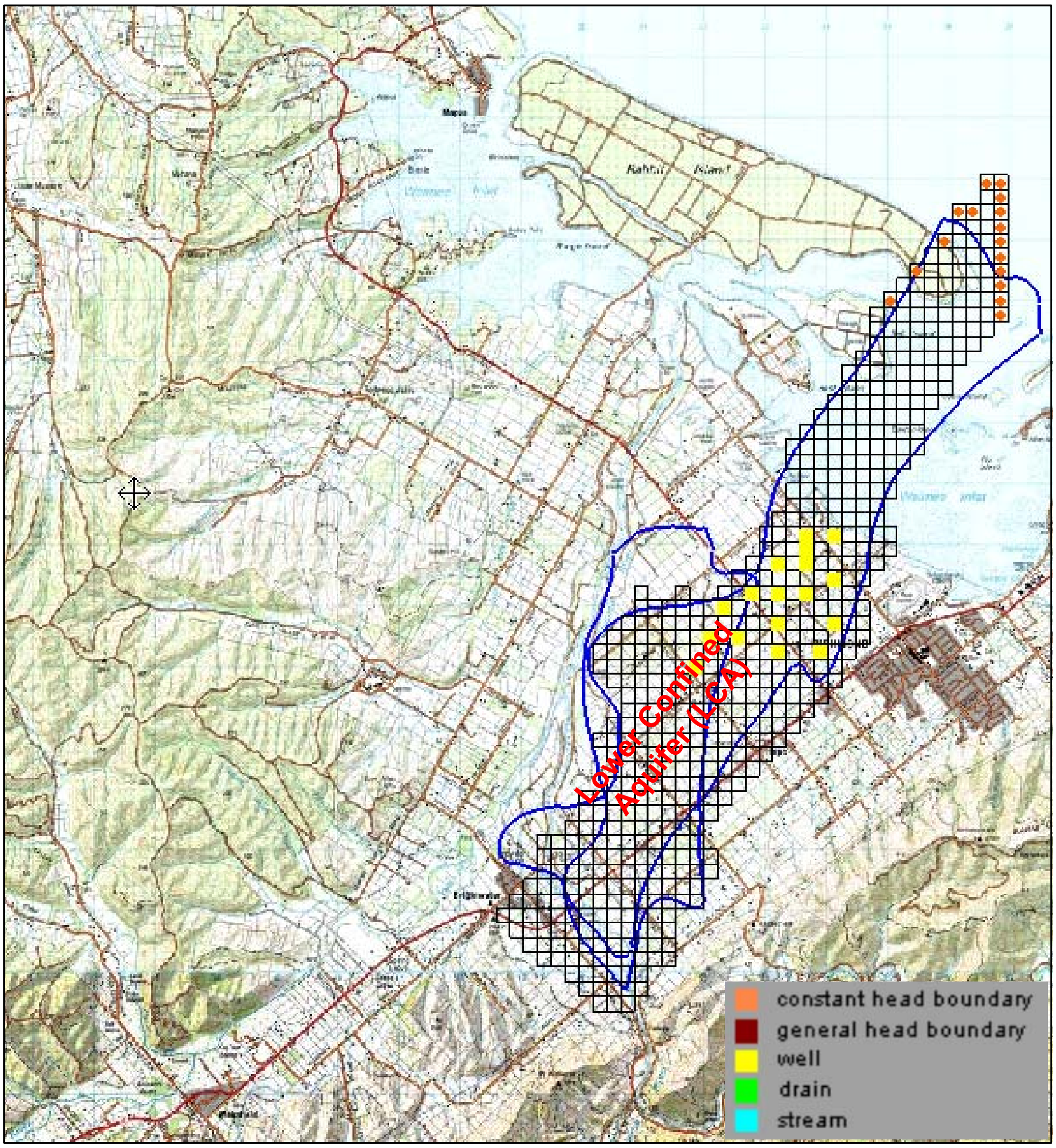

Figure 5. Lower Confined Aquifer water management zone and third layer of groundwater flow model.

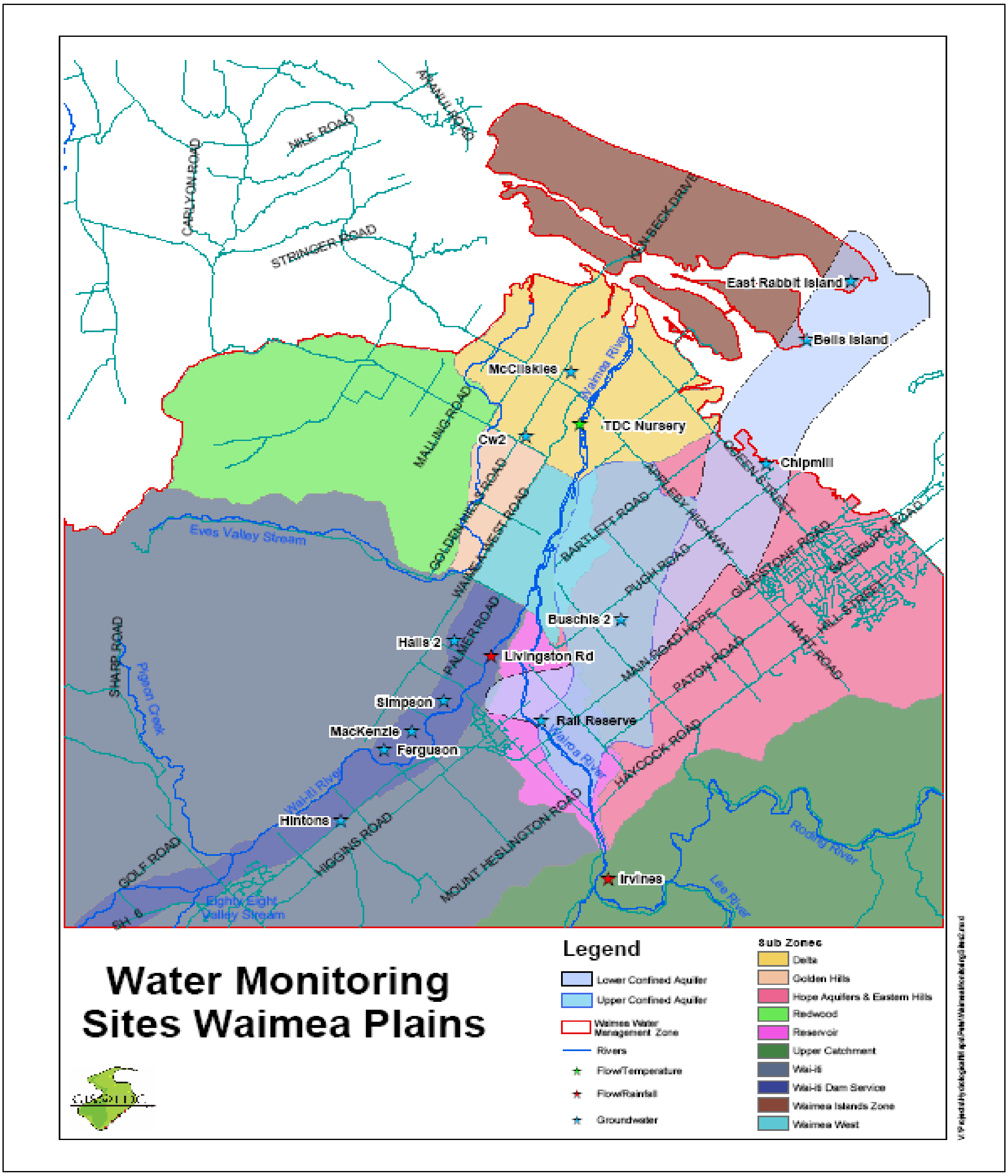

Figure 6. Water management zones and hydrological monitoring sites in the Waimea Plains (Hong, 2005).

Table 1. Hydrological monitoring sites in the Waimea Plains.

Site number	Area	Site Name	Grid reference	NZMG Easting	NZMG Northing
Groundwater Level					
1330108	Redwood	Redwood Lane	N27:1654-8942	2516541	5989419
1330127	Wai-iti	Simpson	N27:1786-8202	2517861	5982024
1330128	Wai-iti	MacKenzie	N27:1721-8138	2517213	5981376
1330129	Wai-iti	Ferguson	N27:1667-8096	2516666	5980960
1330247	Waimea	Hintons	N28:1580-7940	2515800	5979400
1330375	Waimea	Halls 2	N27:1807-8334	2518071	5983344
1331014	Waimea	Bells Island	N27:2510-8990	2525100	5989900
1331069	Waimea	McCliskies	N27:2040-8923	2520400	5989230
1331098	Waimea	CW2	N27:1950-8780	2519500	5987800
1331105	Waimea	Rail Reserve	N27:1980-8160	2519800	5981600
1331119	Waimea	Chipmill	N27:2430-8720	2524300	5987200
1331238	Waimea	Buschls 2	N27:2140-8380	2521400	5983800
1331255	Waimea	East Rabbit Island	N27:2600-9120	2526000	5991200
River Flow					
57517	Wai-iti	Belgrove	N28:0650-7260	2506500	5972600
57520	Wai-iti	Livingston Rd	N27:1880-8300	2518800	5983000
57521	Wairoa	Irvines	N28:2160-7820	2521600	5978200
57523	Waimea	TDC Nursery	N27:2057-8808	2520573	5988085
57524	Roding	Caretakers	O27:3182-8329	2331819	5983289

4.1 Model of interaction between rivers and groundwater

The MODFLOW Stream package (or the stream-routing package) is used to model the interaction between aquifers and rivers in the Waimea Plains. The Stream package is a combination of a known flux and head-dependent flux boundary. It is similar to the MODFLOW River package since it allows flow into and from a stream. However, it is more sophisticated than the River package because it considers the flow rate in the stream and limits the leakage between the aquifer and the stream accordingly. This package increases stream flow in areas of gaining stream segments (reaches) and reduces the flow by taking water out through riverbed seepage in losing reaches (Hong, 2000). The package also calculates the stream stage needed by other MODFLOW modules by using a set of required data whereas the River package uses a pre-assigned stage value. Because of its versatility, the Stream package requires intensive preparation and more input parameters than the River package (Hong, 2000).

GNS studies (Hong, 2000; Hong 2003) in collaboration with Tasman District Council have used the Stream package to simulate observed groundwater levels and river flows more accurately than the River package. The Waimea Plains groundwater-river interaction model has been upgraded with the Stream package. This model has been run in the 2000/2001 year for the period from 1-07-2000 to 30-06-2001. The model has been calibrated with observed Waimea River flow at Nursery-Appleby Bridge (site 57523) using a daily time step. Model parameters were adjusted until calculated hydrologic conditions (Waimea River flow at Nursery-Appleby Bridge) were similar to observed river flow data.

Observed and calculated flows at Nursery-Appleby Bridge in the Waimea River in the period from 01-01-2001 to 30-04-2001 are displayed in Figure 7 (Hong, 2003). Model calculations match well with observed data set of river flows at Nursery-Appleby Bridge in the period of 01-01-2001 to 30-04-2001.

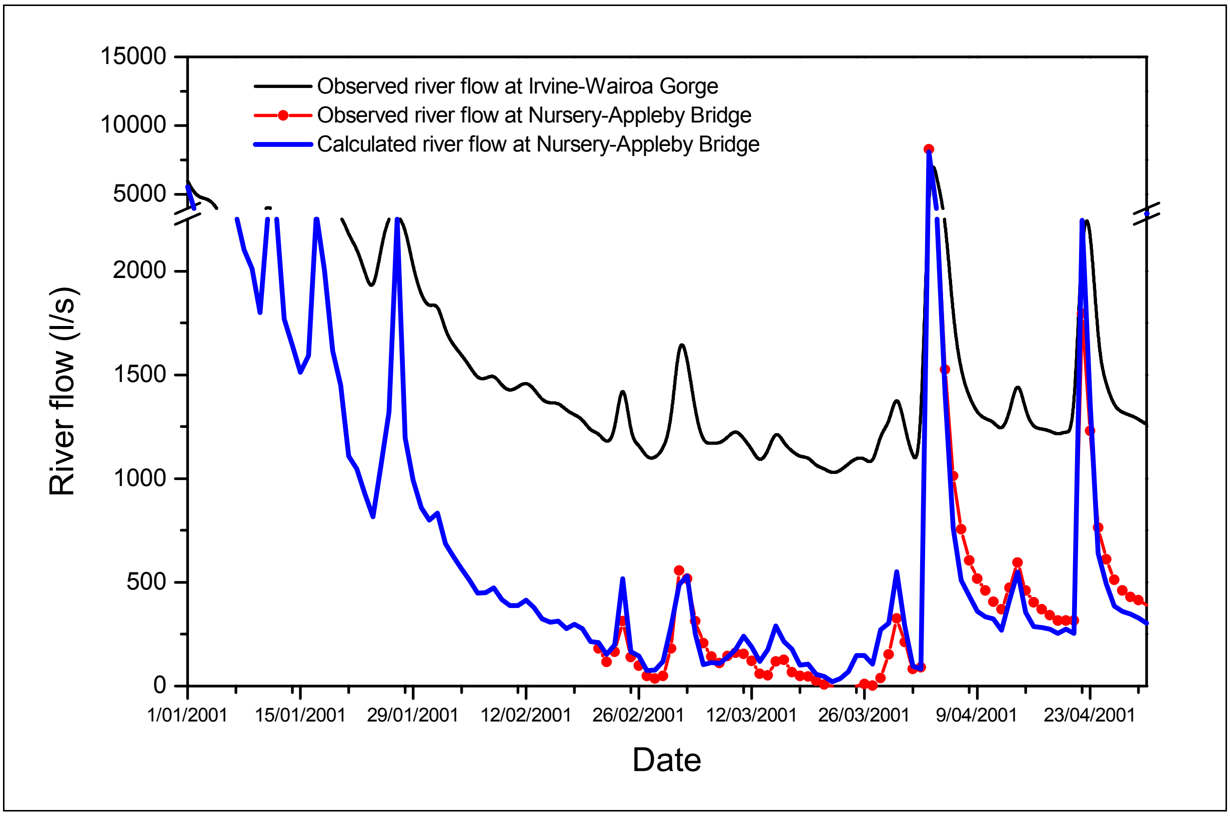

Figure 7. Observed river flow and calculated river flow after model calibration for the Waimea River at Nursery-Appleby Bridge in the period from 01-01-2001 to 30-04-2001.

4.2 Water management zones in the Waimea Plains

Groundwater resources occur in the Appleby Gravel Unconfined Aquifers (Figure 3), Upper Confined Aquifer (UCA) (Figure 4) and Lower Confined Aquifer (LCA) (Figure 5) under the Waimea Plains and aquifers within the river terraces associated with Wai-iti River. Groundwater recharge is predominantly by surface water (Waimea/Wairoa/Wai-iti Rivers) losses to groundwater and direct rainfall recharge from infiltration of precipitation. The area in the Waimea Plains is predominantly irrigated by groundwater taken from the AGUA, UCA, and LCA. The water management zones of the AGUA are shown in Figure 3.

Water allocation limits (Table 2) in the Waimea Plains are quoted in the proposed Tasman Resource Management Plan (TRMP 2001). These allocations exclude dams and include the water take for the Waimea East Irrigation Scheme (WEIS). The water take for the WEIS is a surface water take from the Wairoa River and is included in the Reservoir Zone. Water allocation limits for each management zone are based on the principle that up to a 35% reduction in the water availability can be expected during a 1 in 10 year drought (pers. comm., Joseph Thomas, Tasman District Council).

Under the Tasman Resource Management Plan (TRMP), an allocation limit of 2699 l/s has been set for summer (November to April inclusive) abstraction from either surface or groundwater on the Waimea Plains. A minimum flow in the Waimea River of 500 l/s is proposed for the summer months (November to April inclusive) and 1000 l/s for the winter months (May to October inclusive). Most allocation (85%) is from AGUA with a further 6 % (147 l/s) from the UCA and 9% (230 l/s) from the LCA.

Table 2. Water allocation limits set by Tasman District Council for water management zones in the Waimea Plains (Hong, 2005).

Water Management Zones	Current allocation limits (l/s)
Waimea Zones	
Wai-iti	105
Reservoir	826
Upper Catchments (Wairoa, Lee and Roding Rivers)	3
Waimea West	178
Hope and Eastern Hills	97
Golden Hills	113
Delta	1000 (subject to condition)
Upper Confined Aquifer	147
Lower Confined Aquifer	230
Total	2699

5.0 MODELLING STAGE 1 RESULT

Modelling stage 1 aims to establish the river flow rate at Irvine-Wairoa Gorge needed to maintain a minimum 500 l/s flow rate at Nursery-Appleby Bridge in the Waimea River based on actual pumping rate for the 1 in 10 dry year (1991/1992).

The minimum river flow at Irvine- Wairoa Gorge needed to maintain the target minimum flows at Nursery-Appleby Bridge in the Waimea River is calculated for average flows in 2-week periods. The simulation results are shown in Table 3. The model calculates that minimum flows at Irvine-Wairoa Gorge would need to be 1650 l/sec and 1825 l/s to maintain minimum flows of 250 l/s and 500 l/s in the Waimea River at Nursery-Appleby Bridge, respectively, for a 1 in 10 dry year with pumpage at actual water usage. The model calculates that a minimum flow of 1930 l/s at Irvine-Wairoa Gorge would be needed to maintain a minimum flow of 500 l/s at Nursery-Appleby Bridge in the Waimea River for a 1 in 10 dry year with pumpage at the current allocation limits of the TRMP.

Figure 8 shows river flow calculations at Irvine-Wairoa Gorge needed to maintain a minimum river flow of 500 l/s at Nursery-Appleby Bridge in the summer period from 01-07-1991 to 30-06-1992. An expanded view of calculated river flows for the period from 01-02-1992 to 30-04-1992 to maintain a minimum river flow of 500 l/s at Nursery-Appleby Bridge is shown in Figure 9.

Table 3. Calculated minimum river flow at Irvine-Wairoa Gorge to maintain target minimum flow at Nursery-Appleby Bridge for the 1 in 10 dry year (1991/1992).

Year	Target minimum flows at Nursery-Appleby Bridge (l/s)	Actual water usage	Current water allocation limits
		Calculated minimum river flow at Irvine-Wairoa Gorge, to maintain target minimum flow at Nursery-Appleby Bridge (l/s)	Calculated minimum river flow at Irvine-Wairoa Gorge to maintain target minimum flow at Nursery-Appleby Bridge (l/s)
1: 10 dry year (1991/1992)	250 500	1650 1825	1763 1930

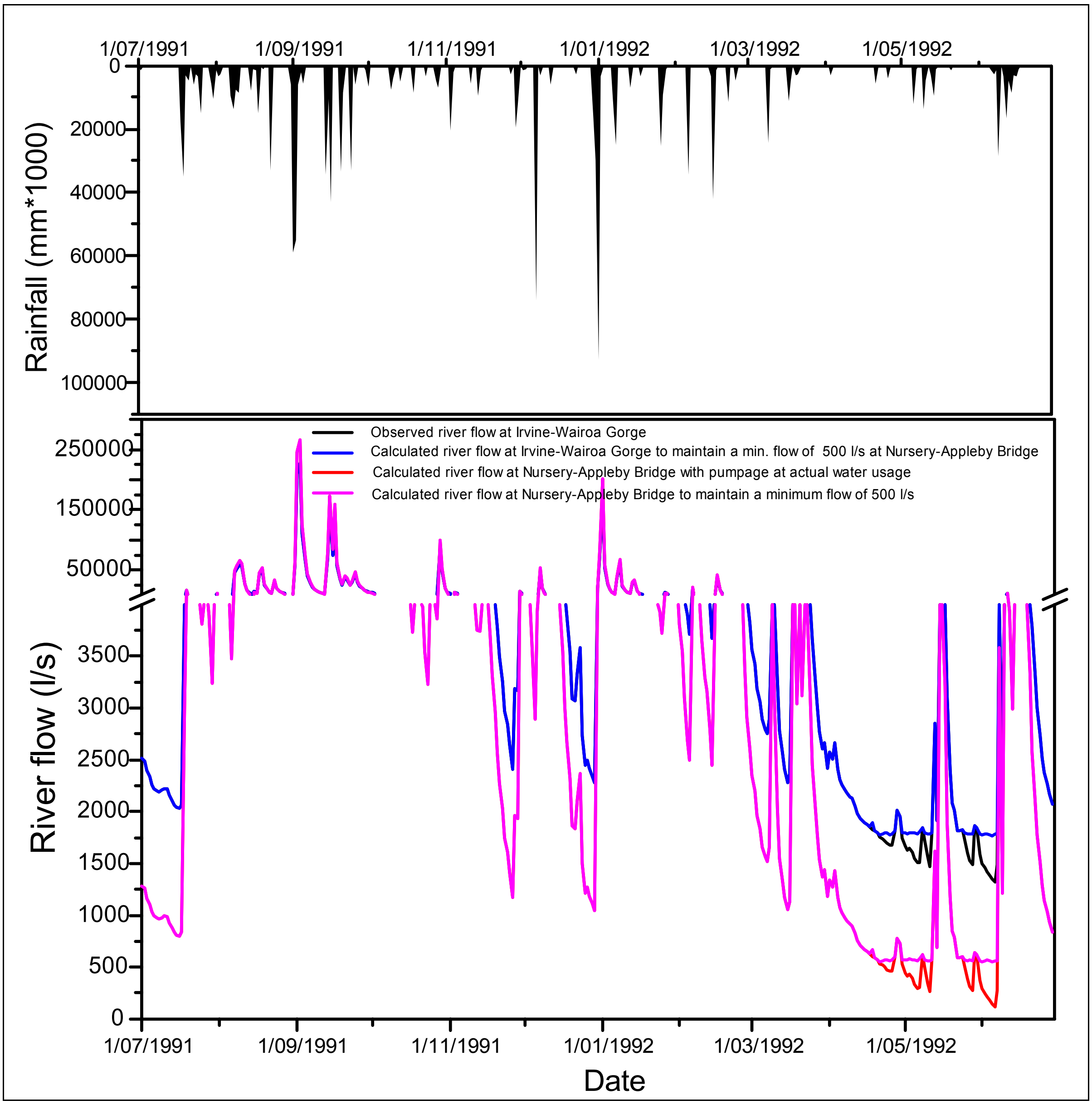

Figure 8. Observed river flow and calculated river flow for the Waimea River at Nursery-Appleby Bridge in the period from 01-07-1991 to 30-06-1992.

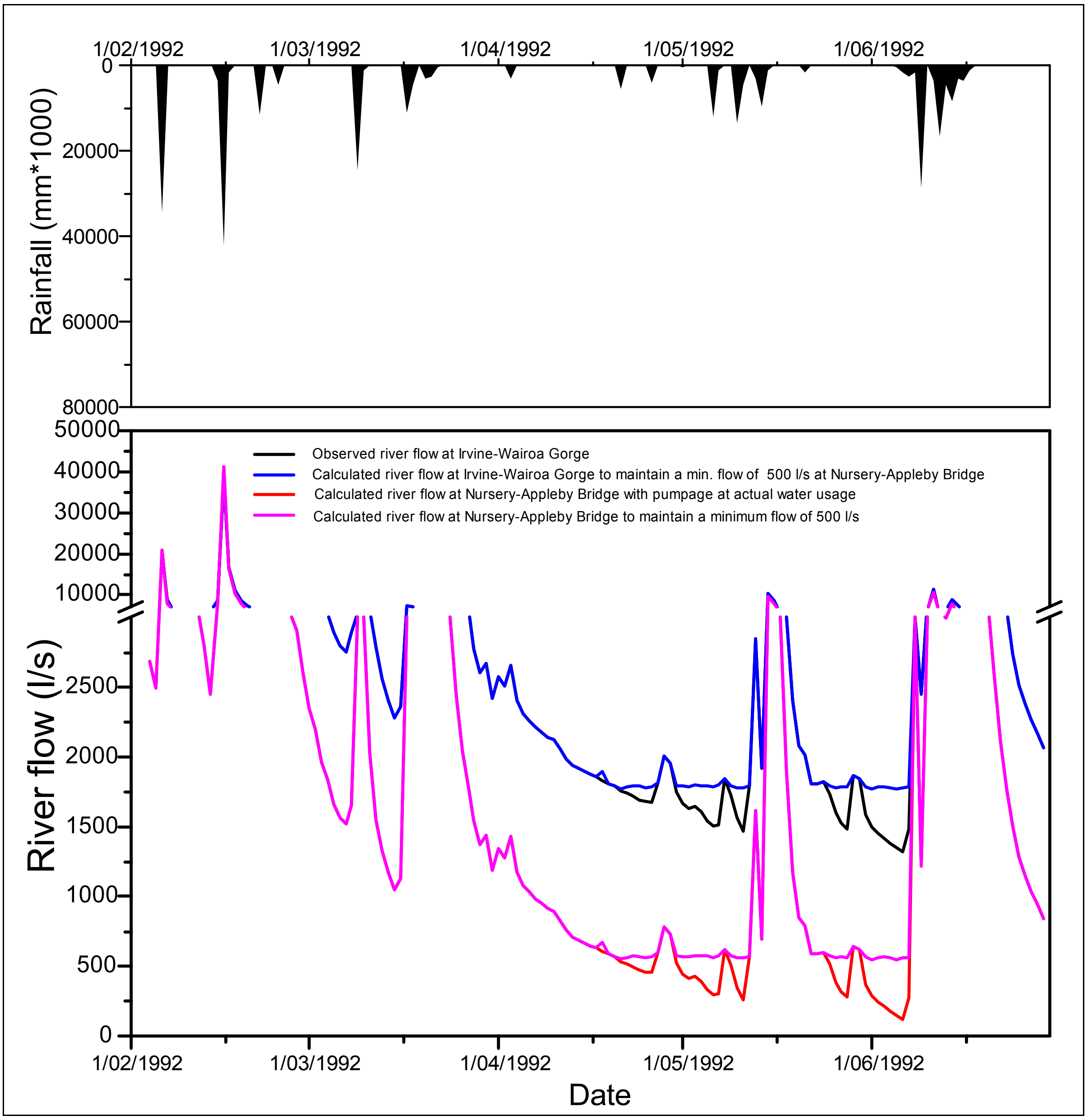

Figure 9. Observed river flow and calculated river flow for the Waimea River at Nursery-Appleby Bridge in the period from 01-02-1992 to 30-06-1992.

6.0 MODELLING STAGE 2 RESULT

The Waimea Plains groundwater-river interaction model is used to deduce river flow rate at Irvine-Wairoa Gorge required to maintain minimum flows of 600 l/s and 1100 l/s at Nursery-Appleby Bridge in the Waimea River based on a future water demand scenario estimated by John Bealing (Agfirst) in a 1:20 dry year. The summer of 1982/1983 is used to represent a nominal 1:20 dry year.

6.1 Future water demand in the Waimea Plains

Future water demand in the Waimea Plains has been computed based on the climate data for the 1982/1983 (July to June), and an irrigation water balance budget (John Bealing, Agfirst) for a range of crops:

- pasture;
- apples and kiwi fruit (KF);
- grapes and olives;

over a range of soil types:

- 38 mm soil moisture holding capacity;
- 78 mm soil moisture holding capacity;
- 130 mm soil moisture holding capacity.

Table 4 summarises the annual water requirement (mm/year) calculated by John Bealing for various crops and soil types. For example, the annual irrigation requirement for pasture with 130 mm soil moisture holding capacity for the 1982/1983 year is estimated at 475 mm/year. The irrigation demand profile for a range of crops and soil types based on the daily climate data for the 1982/1983 (July to June) year in the Waimea Plains is shown in Figure 10.

Table 4. Annual irrigation requirement (mm/year) calculated by John Bealing for a range of crops and a range of soil types based on 1982/1983 climate data.

Crop types	Soil moisture holding capacity related to soil type		
	130 mm	**78 mm**	**38 mm**
pasture	475 mm/yr	499 mm/yr	515 mm/yr
apples & kiwi fruit	496 mm/yr	525 mm/yr	535 mm/yr
grapes/olives	137 mm/yr	159 mm/yr	186 mm/yr

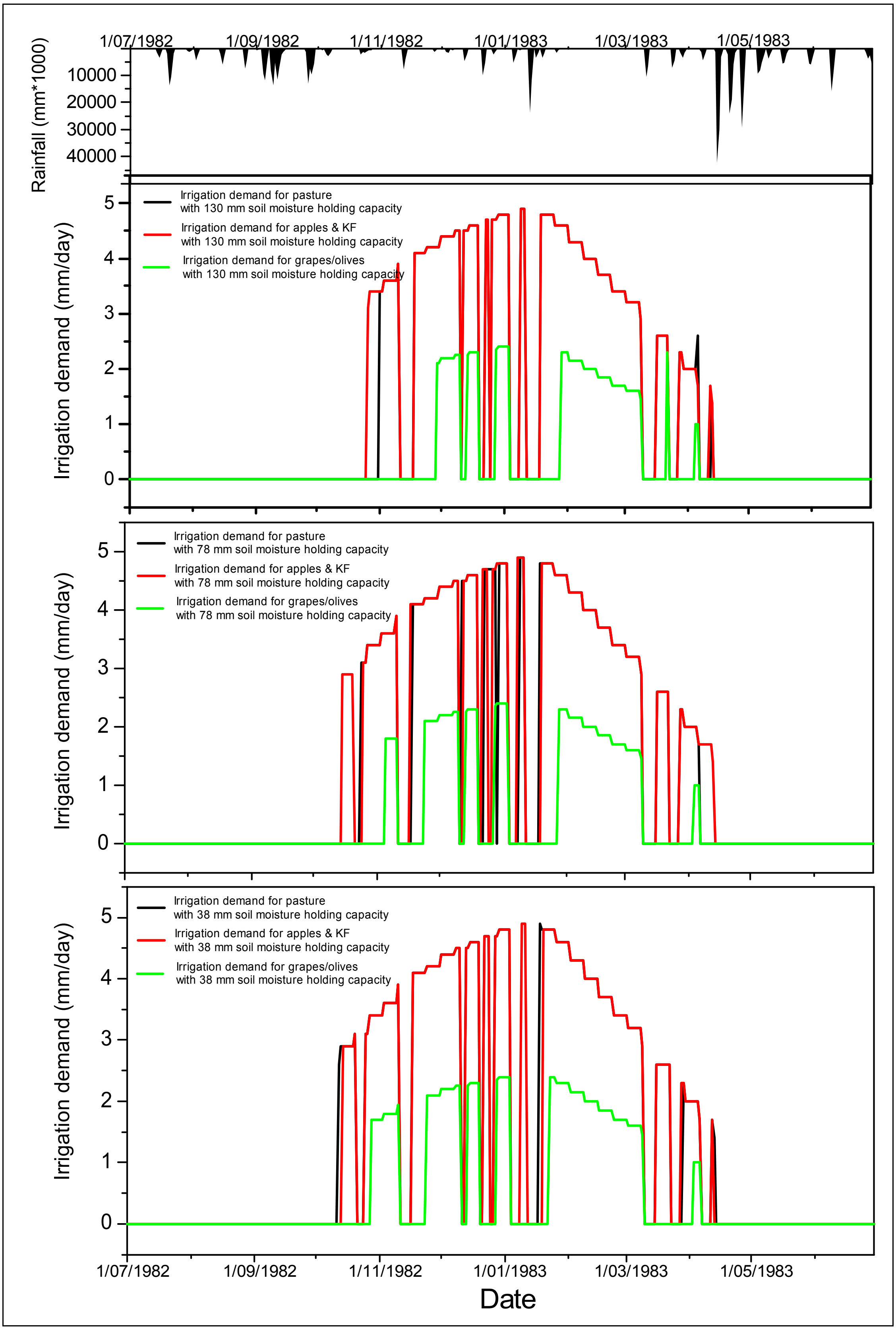

Figure 10. Daily irrigation demand for a range of crops and a range of soil types based on the climate data for the 1982/1983 (July to June) year in the Waimea Plains.

Based on the irrigation demand displayed in Figure 10, the irrigation demand for each cell in the Waimea Plains groundwater-river interaction model is calculated by the following formula:

*Irrigation demand per day in each cell = 5.47 ha * daily irrigation demand (mm/day) for each crop type and soil type * crop mix (%) * 0.8 (irrigated portion of the land)* (1)

In Eq. (1), the factor 0.8 represents the "irrigated" part of the land. The non-irrigated portion of land of 20% is estimated by Tasman District Council from: total land area less townships, road and river reserves. John Bealing (Agfirst) recommends that the irrigated portion could drop by a further 5% if individual rural property including houses, gardens and farm sheds is considered. If we wish to adopt the 25% non-irrigated portion of land in Eq. (1), then the water requirements would be correspondingly lower. The crop mix (%) is given in Table 5.

Table 5. Crop mix (%) provided by John Bealing for a range of crops and a range of soil types.

Crop types	Soil types (soil moisture holding capacity)		
	130 mm	78 mm	38 mm
pasture	30 %	40 %	15 %
apples & kiwi fruit	55 %	50 %	63 %
grapes/olives	15 %	10 %	22 %

Table 6 shows the areas of each soil type within the Waimea Plains and the allocation per hectare. This will allow the calculation of the water deficit, given rainfalls at different times of the year. Figure 11 shows the soil types in the Waimea Plains overlaid on the Waimea Plains groundwater-river interaction model. In Figure 11, the red lines are the water management zones defined by Tasman District Council.

Table 6. Irrigable areas by soil type in the Waimea Plains.

Soil Type	Area Ha		Allocation Limits[1] m^3/ha/week	Comments
	Total	Irrigable		
Mapua sandy loam	258	200	190	Foothills around the Redwood Valley
Dovedale gravelly loam	525	520	250	Mostly found in the Redwood Valley area.
Richmond clay loam, silt loam & Wakatu silt loam	643	610	270	Towards the estuary and the foothills along Patons Road.
Waimea silt loam & sandy loam	2,137	2,130	300	Alongside the Waimea River
Ranzau Soils	1,649	1,640	350	Waimea Plains
Totals	**5,212**	**5,100**		
Motupiko loams (Wai-iti)	1180	480	350	Wai-iti Valley (Brightwater to Wakefield)
Totals	**6,392**	**5,580**		

[1] These limits are taken from the TRMP, Chapter 31, Fig 31.1D

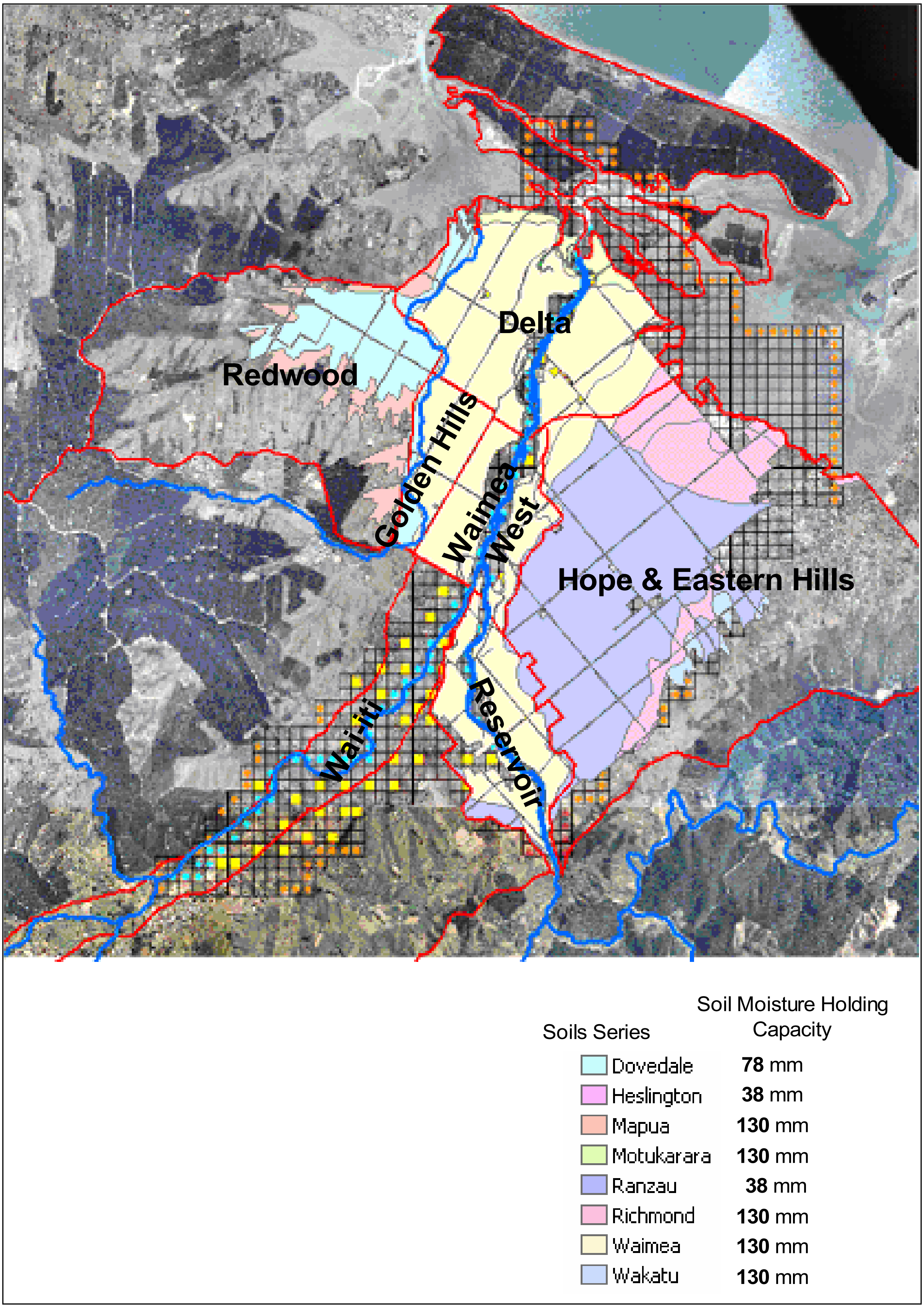

Figure 11. Soil types in the Waimea Plains.

Eq. (1) provides an estimate of the daily irrigation water required for each cell in the Waimea Plains groundwater-river interaction model in the period July 1982 to June 1883. The irrigation water requirement for a model cell with 130 mm soil moisture water holding capacity on 1/02/1983 would be:

Daily irrigation water requirement = [5.47 (ha)*4.6 (mm/day) for pasture* 0.3 (crop mix for pasture with 130mm)*0.8] + [5.47 (ha)*4.6 (mm/day) for apples & kiwi fruit]* 0.55 (crop mix for apples & kiwi fruit with 130mm)*0.8] + [5.47 (ha)*2.3 (mm/day) for grapes/olives]* 0.15 (crop mix for grapes/olives with 130mm)*0.8]
= **186.2 m^3/day** (2)

The irrigation water requirement for a model cell with 78 mm soil moisture water holding capacity on 1/02/1983 would be 191.3 m^3/day. The irrigation water requirement for the model cell with 38 mm soil moisture water holding capacity on 1/02/1983 would be 229.5 m^3/day.

Future water demand in the Waimea Plains for the 1982/1983 year is calculated using an equation like Equation (2). Table 7 compares actual water usage and calculated future water demand for the 1982/1983 year. Table 7 also shows the approximate areas associated with each of the water management zones in the Waimea Plains groundwater-river interaction model.

In Table 7, outside irrigation in the Brightwater/ Wakefield of 300ha represents an additional 300 ha worth of water to service some of the lower Wai-iti zone, in addition to the current allocation already allowed for this zone. Outside irrigation in the Redwood Valley of 476ha also represents an additional 476 ha worth of water to service Redwood Valley Zone. This includes the existing 63 ha irrigation in the Redwood Valley zone. Urban water demand is also included in Table 7.

About half of the Hope aquifers and Eastern Hills water management zone (Figure 3 and 11) are covered by the Waimea East Irrigation Scheme (WEIS), and much of the remainder by either the unconfined gravels alongside the Waimea River, or from the Upper Confined Aquifer (UCA) and Lower Confined Aquifer (LCA).

Future daily maximum water demand for a dry year is estimated to be 3277 l/s, compared to 1741 l/s of actual water usage in the dry year 1982 /1983 for the total 5864 ha of the Waimea Plains model area.

A new water abstraction model in the Waimea Plains groundwater-river interaction has been created. The Waimea Plains groundwater-river interaction model now includes future water demand model excluding the water demand in the Waimea East zone. Waimea East Irrigation Scheme (WEIS) take is taken directly from the Wairoa River, just below Irvine-Wairoa Gorge. So this water take is excluded from the model. Figure 12 shows time series of actual water usage and calculated daily future water demand in the Waimea Plains for the 1982/1983 year.

Table 7. Actual water usage and future water demand based on the climate data for 1982/1983 (July to June).

Water Management Zone	Area in the Waimea Plains GW model (ha)	Actual water usage in the 1982/1983 year		Future water demand in a nominal 1:20 dry year	
		Peak daily water usage (l/s)	Total annual water usage (liters)	Peak daily water demand (l/s)	Total annual water demand (liters)
Urban demand		-	-	510	6.18E+09
Reservoir	635 (713)	156	1.28E+09	266	2.28E+09
Waimea West	542 (544)	133	1.08E+09	223	1.89E+09
Waimea East Irrigation Scheme (WEIS)	1182	-	-	692	5.55E+09
Golden Hills	77 (300)	100	7.90E+08	31	2.67E+08
Delta	1530 (1479)	1007	9.23E+09	689	5.92E+09
UCA	361	127	1.07E+09	211	1.69E+09
LCA	574	190	2.12E+09	335	2.68E+09
Redwood	87	28	2.5E+08	-	-
Outside irrigation in the Redwood Valley, 476ha	476	-	-	196	1.66E+09
Outside irrigation in the Brightwater/ Wakefield, 300ha	300	-	-	124	1.05E+09
TOTALS	**5864**	**1741**	1.58E+10	**3277**	2.92E+10
Hope & Eastern Hill*	2117	-	-	1238	9.92E+09

* Hope & Eastern Hill is covered by UCA, LCA, and Waimea East Irrigation Scheme.

Red coloured number represents area based on water management zones (Figures 3 and 11).

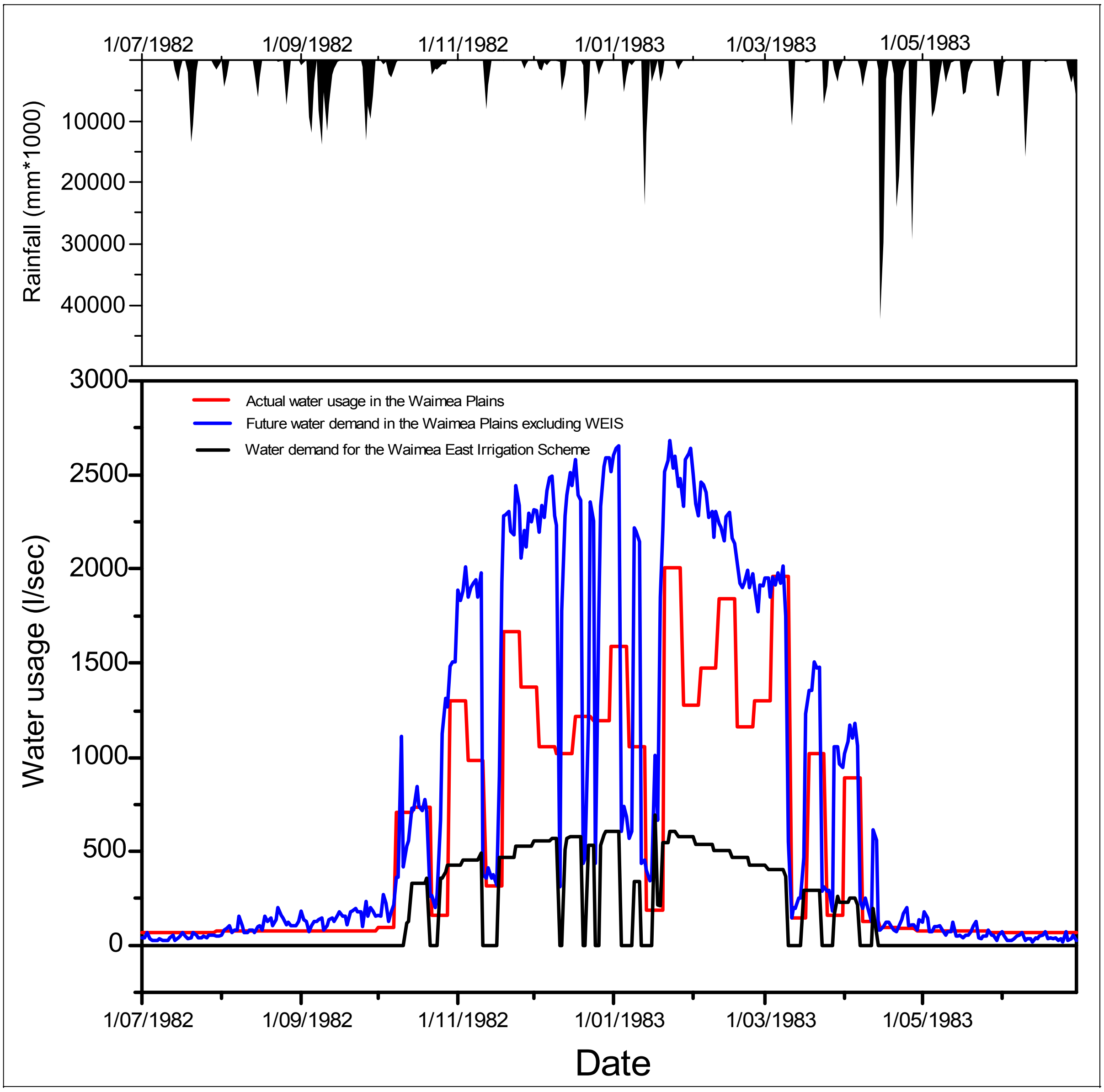

Figure 12. Actual water usage and calculated future water demand in the Waimea Plains for the 1982/1983 year.

6.2 Future water demand and river flow in the Waimea Plains

This section evaluates the effect of future water demand on Waimea River flow. The Waimea Plains groundwater-river interaction model is used to establish the frequency of 100 l/s, 250 l/s and 500 l/s flows in the Waimea River at Nursery-Appleby Bridge for the 1982/1983 year drought (a nominal 1 in 20 dry year) with pumpage at future water demand.

Figure 13 displays river flow calculations at Irvine-Wairoa Gorge and flows at Nursery-Appleby Bridge for the full year from 01-07-1982 to 30-06-1983. Calculated river flows at Irvine-Wairoa Gorge and flows at Nursery-Appleby Bridge in the summer – autumn period from 01-01-1983 to 30-04-1983 are shown in Figure 14.

Table 8 summarises the number of days when the calculated river flow is less than 100 l/s, less than 250 l/s, or less than 500 l/s at Nursery-Appleby Bridge for the 1982/1983 year. The model predicts that the river flow at Nursery-Appleby Bridge will be less than 100 l/s on 17 days, less than 250 l/s on 37 days and less than 500 l/s on 48 days for the 1982/1983 year if pumpage is equal to future water demand. A significant increase in the occurrence of zero flow, or very low flow of less than 250 l/s at Nursery-Appleby Bridge for the 1982/21983 year, is calculated if pumpage is equal to future water demand compared to actual water usage.

Table 8. Number of days where calculated river flow at Nursery-Appleby Bridge is less than 100 l/s, less than 250 l/s, and less than 500 l/s in 1982/1983 with actual water usage and future water demand.

Year	Water usage	Number of days where river flow is less than 100 l/s	Number of days where river flow is less than 250 l/s	Number of days where river flow is less than 500 l/s
1982/1983 year	Actual water usage	6	17	37
	Calculated future water demand	17	37	48

Table 9 summarises observed rainfall at Irvine-Wairoa Gorge, observed daily average river flows at Irvine-Wairoa Gorge, and calculated daily average river flows at Nursery-Appleby Bridge. The observed daily average flow at Irvine-Wairoa Gorge is 1756 l/s in the period of February 1983 to March 1983. The Waimea Plains groundwater-river interaction model calculates an average river flow of 426 l/s at Nursery-Appleby Bridge with pumpage at future water demand. The average flow loss between Irvine-Wairoa Gorge (observed) and Nursery-Appleby Bridge (calculated) in the period of February 1983 and March 1983 is calculated at 971 l/s with pumpage at actual usage and 1359 l/s with pumpage at future water demand. The model shows that if pumpage is equal to future water demand during the driest period then the average river flow loss between Irvine-Wairoa Gorge and Nursery-Appleby Bridge would increase by 359 l/s at Nursery-Appleby Bridge, compared to actual water usage.

Table 9. Average river flows at Irvine-Wairoa Gorge and Nursery-Appleby Bridge for the 1982/1983 year.

Period		Average water usage		Average river flow			
	Total rainfall, Irvine (mm)	Actual water usage (l/s)	Future water demand (l/s)	Observed flow at Irvine (l/s)	Observed flow at Appleby Bridge (l/s)	Calculated flow at Appleby Bridge with actual water usage (l/s)	Calculated flow at Appleby Bridge with future water demand (l/s)
July 82 – June 83	664	572	835	10682	not observed	9828	9759
Feb. 83 – Mar. 83	45	1138	1573	1756	not observed	785	426
Feb. 83 – April 83	223*	853	1169	10966	not observed	10088	9775

* The rainfall events on 14/04/83, 21/04/83, and 26/04/83 were 77.4 mm, 21.1 mm, and 40.2 mm respectively.

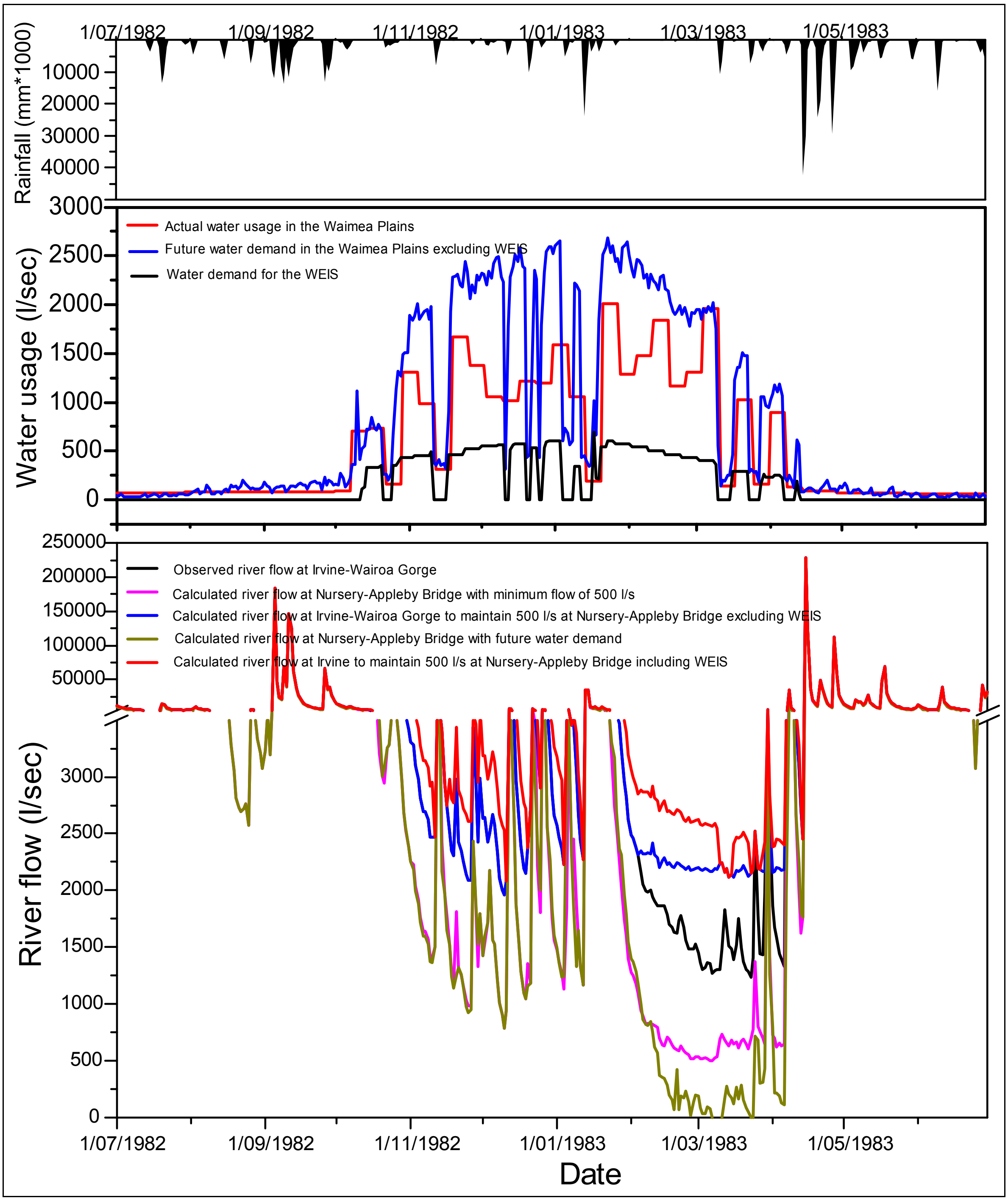

Figure 13. Rainfall, water use and river flow at Nursery-Appleby Bridge and Irivine-Wairoa Gorge in the period from 01-07-1982 to 30-06-1983.

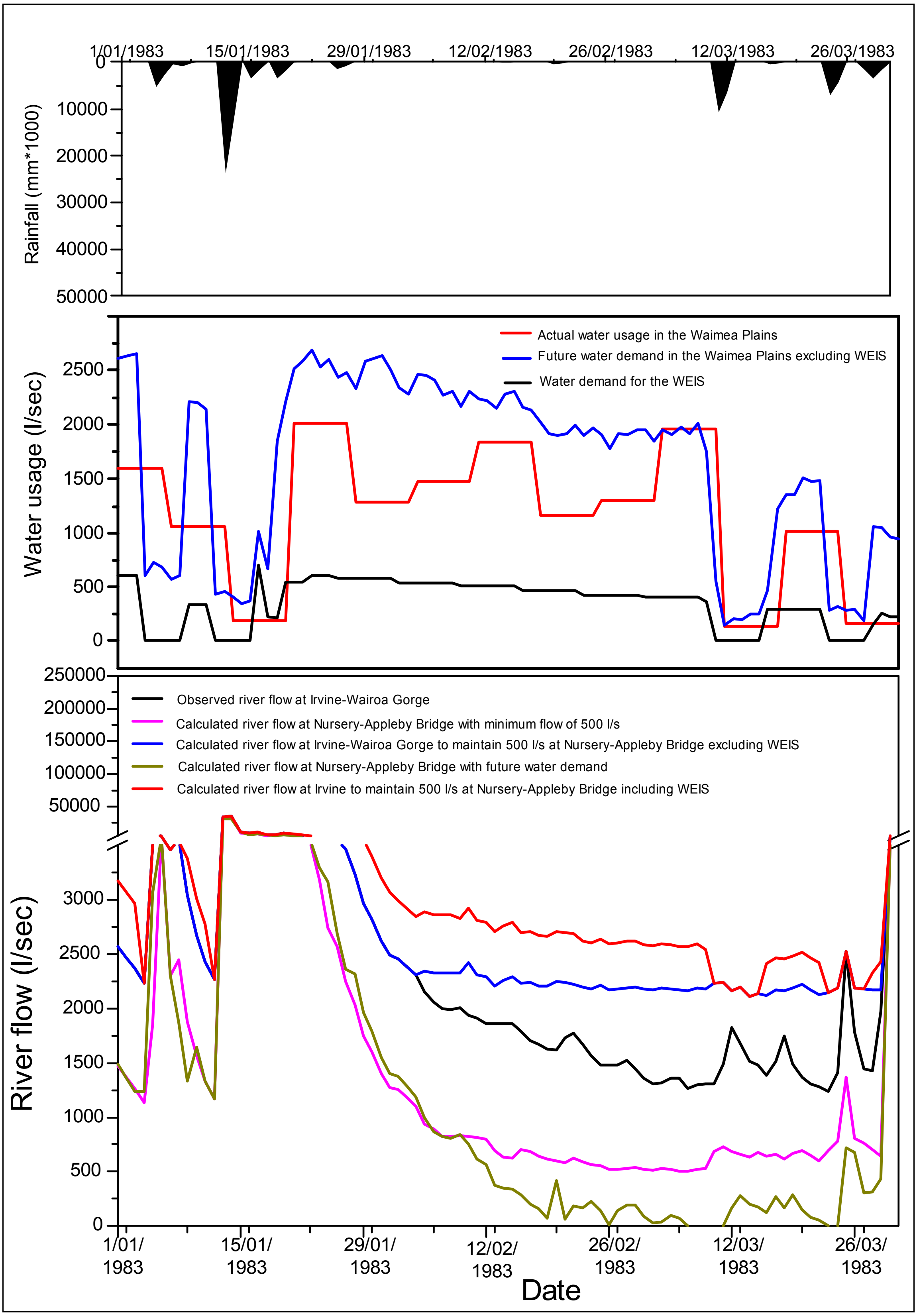

Figure 14. Rainfall, water use and river flow at Nursery-Appleby Bridge and Irvine-Wairoa Gorge in the period from 01-01-1983 to 31-03-1983.

6.3 Minimum river flows at Irvine-Wairoa Gorge needed to maintain a minimum flow of 600 l/s and 1100 l/s at Nursery-Appleby Bridge with future water demand

The Waimea Plains groundwater-river interaction model is used to establish minimum river flow rates at Irvine-Wairoa Gorge needed to maintain minimum 600 l/s and 1100 l/s flows at Nursery-Appleby Bridge in the Waimea River based on future water demand calculation for the 1982/1983 dry year (a nominal 1 in 20 dry year).

The minimum river flow at Irvine-Wairoa Gorge needed to maintain the target minimum flow at Nursery-Appleby Bridge in the Waimea River is calculated for average flows in 2-week periods between 01-03-1983 and 23-03-1983 (the driest period in the 1982/1983 year).

The Waimea Plains groundwater-river interaction model calculates that the minimum flow at Irvine-Wairoa Gorge would need to be 2260 l/s (excluding Waimea East Irrigation Scheme) to maintain a minimum flow of at least 600 l/s at Nursery-Appleby Bridge in the Waimea River with future water demand. If Waimea East Irrigation Scheme (WEIS) take is included, the minimum flow at Irvine-Wairoa Gorge would be 2513 l/s to maintain a minimum flow of at least 600 l/s at Nursery-Appleby Bridge (Figure 15).

The model predicts that a minimum flow of 2663 l/s (excluding Waimea East Irrigation Scheme) at Irvine-Wairoa Gorge would be needed to maintain a minimum flow of at least 1100 l/s at Nursery-Appleby Bridge in the Waimea River with future water demand between 01-03-1983 and 23-03-1983 (the driest period of 1982/1983 year). The calculated minimum flow at Irvine-Wairoa Gorge needed to maintain the target minimum flow of at least 1100 l/s at Nursery-Appleby Bridge in the Waimea River is calculated to be 2981 l/s if Waimea East Irrigation Scheme (WEIS) take is included (Figure 16).

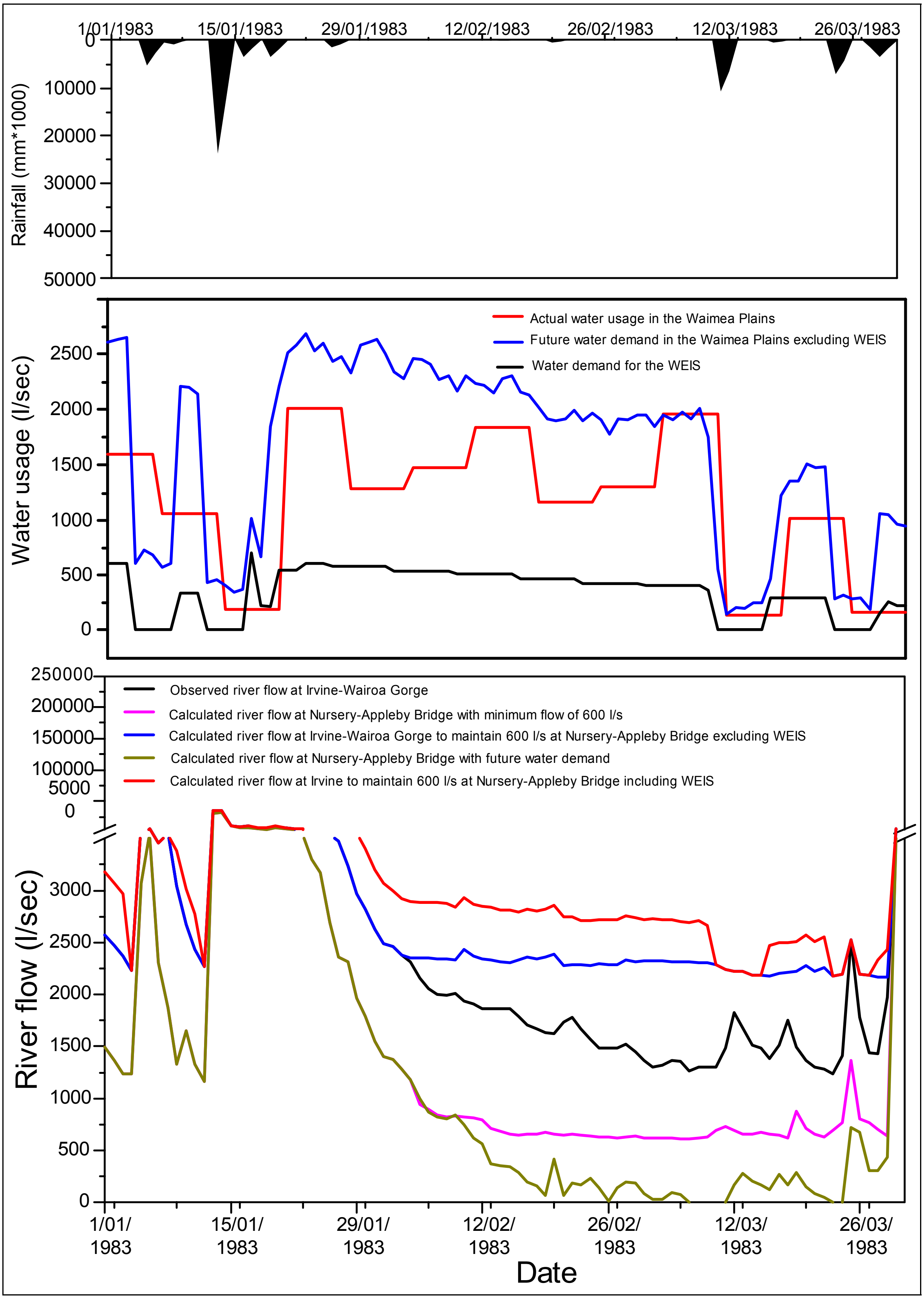

Figure 15. Observed river flow and calculated river flow to maintain a minimum river flow of 600 l/s at Nursery-Appleby Bridge in the period from 01-01-1983 to 31-03-1983.

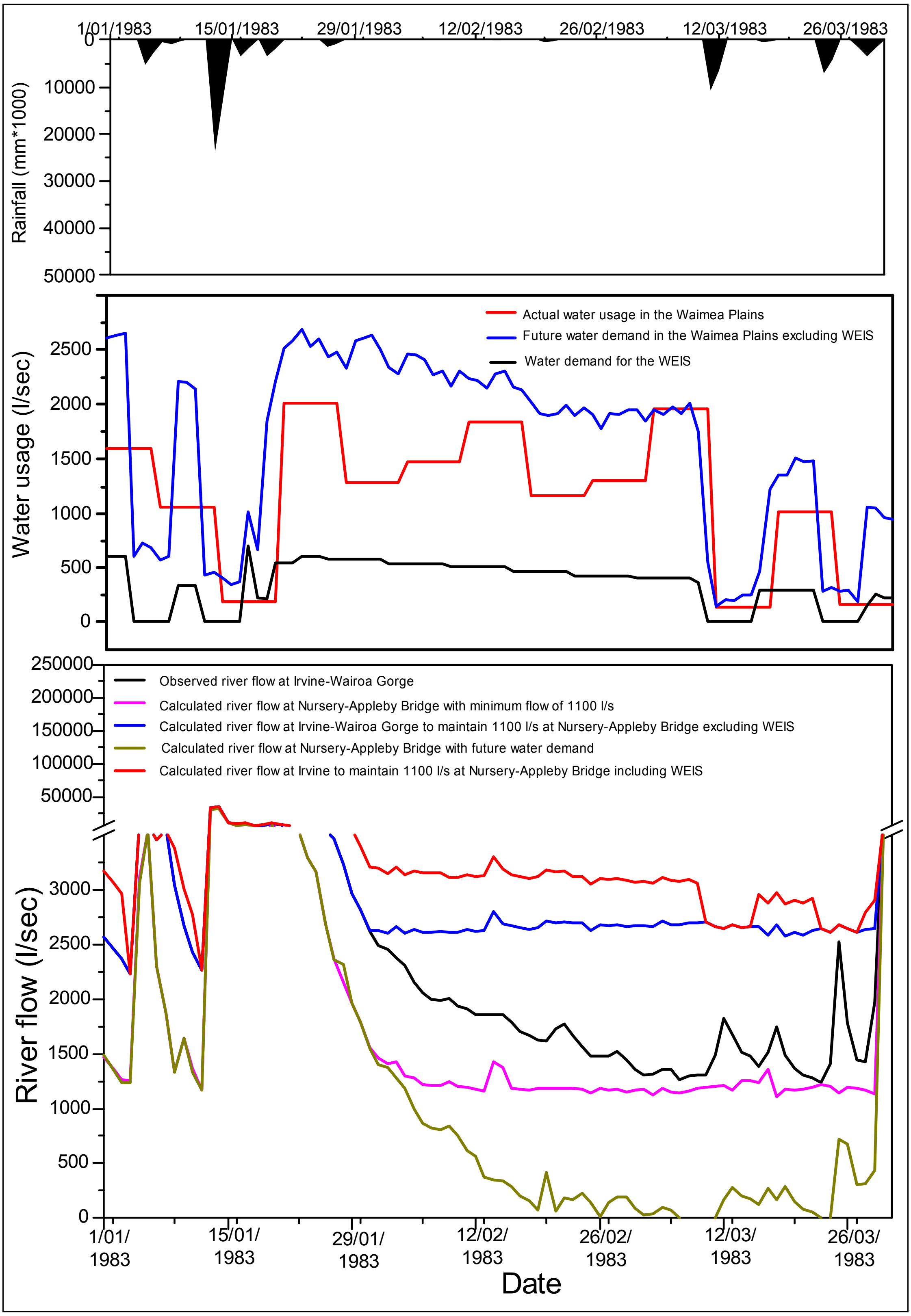

Figure 16. Observed river flow and calculated river flow to maintain a minimum river flow of 1100 l/s at Nursery-Appleby Bridge in the period from 01-01-1983 to 31-03-1983.

7.0 MODELLING STAGE 3 RESULT

Based on modelling stage 2 results, Tonkin & Taylor Ltd calculated the augmented river flow required at Irvine-Wairoa Gorge. GNS then used this river flow information and undertook a forward simulation of the Waimea Plains groundwater-river interaction model to assess the ability of the augmented river flow at Irvine-Wairoa Gorge proposed by Tonkin and Taylor Ltd to maintain a minimum flow of 1100 l/s at Nursery-Appleby Bridge in the Waimea River in a nominal 1:20 dry year (1982/1983).

Figure 17 shows rainfall, future water demand, and water demand by the Waimea East Irrigation Scheme (WEIS) in the period from 01-01-1983 to 31-03-1983. The forward simulation result of calculated river flow at Nursery-Appleby Bridge is also shown with observed river flow at Irvine-Wairoa Gorge and augmented river flow at Irvine-Wairoa Gorge which aims to maintain at least 1100 l/s flow at Nursery-Appleby Bridge in the Waimea River.

The Waimea Plains groundwater-river interaction model calculates that river flow at Nursery-Appleby Bridge in the Waimea River would be an average flow of 1148 l/s (excluding Waimea East Irrigation Scheme) with future water demand and augmented river flow at Irvine-Wairoa Gorge between 01-03-1983 and 23-03-1983 (the driest period of 1982/1983 year). The calculated river flow at Nursery-Appleby Bridge in the Waimea River would be an average flow of 1225 l/s between 01-02-1983 and 31-03-1983. However, the model calculates that river flow at Nursery-Appleby Bridge would be below 1100 l/s on the following days:

- 25 February, 1983: 1080 l/s;
- 26 February, 1983: 1087 l/s;
- 27 February, 1983: 1078 l/s;
- 1 March, 1983: 1061 l/s;
- 2 March, 1983: 1032 l/s;
- 3 March, 1983: 999 l/s;
- 4 March, 1983: 996 l/s;
- 5 March, 1983: 1028 l/s;
- 6 March, 1983: 1022 l/s;
- 7 March, 1983: 973 l/s;
- 8 March, 1983: 981 l/s;
- 9 March, 1983: 1025 l/s.

Forward simulation results show that the proposed augmented river flow at Irvine-Wairoa Gorge will maintain river flow above 1100 l/s at Nursery-Appleby Bridge at most times, but not in the period late February and early March 1983. Some minor recalculation of the proposed augmented river flow would be necessary to achieve above 1100 l/s at Nursery-Appleby Bridge at all times.

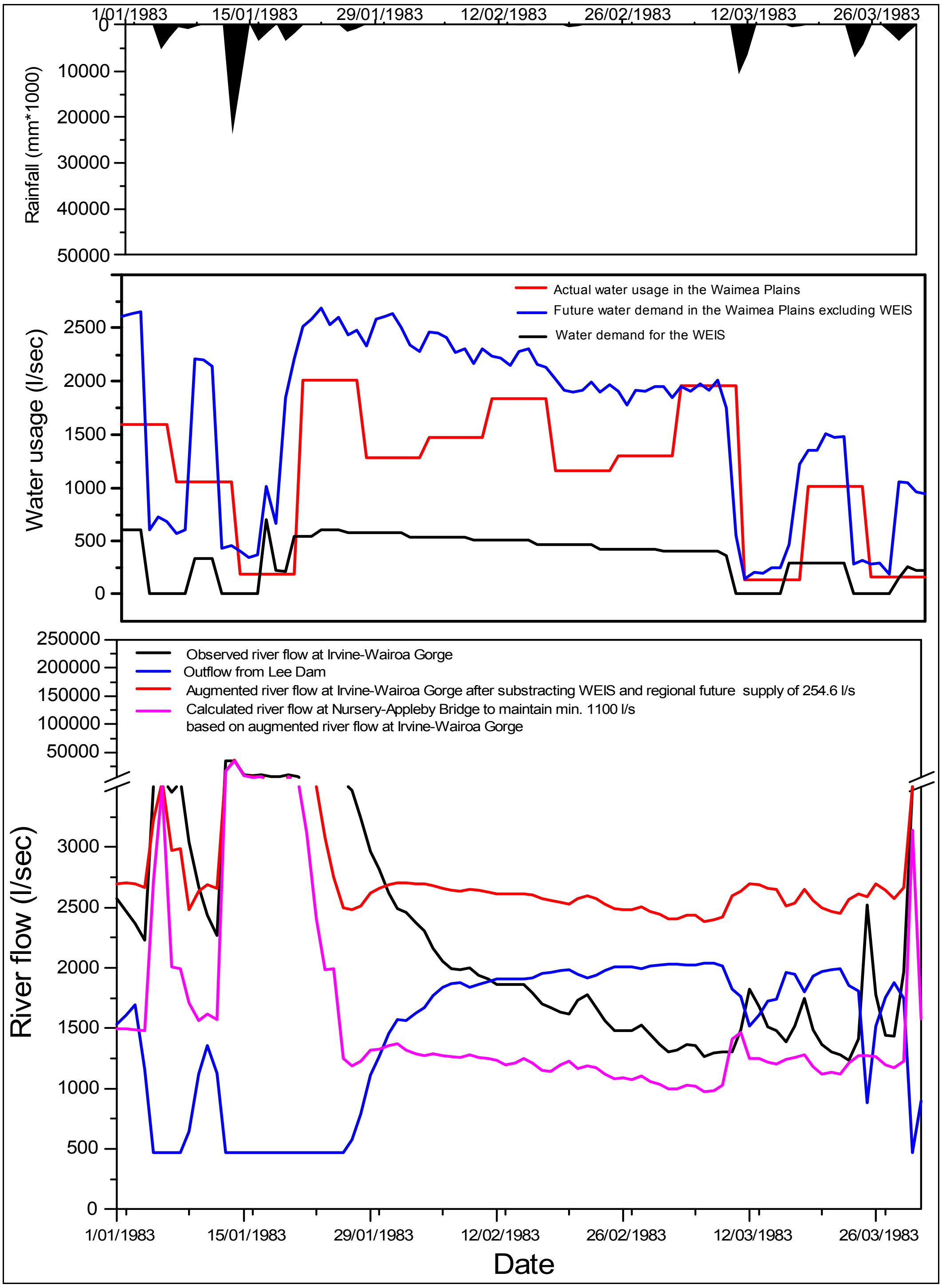

Figure 17. Forward simulation result to maintain a minimum river flow of 1100 l/s at Nursery-Appleby Bridge based on augmented river flow at Irvine-Wairoa Gorge in the period from 01-01-1983 to 31-03-1983.

8.0 SUMMARY

A feasibility study of water augmentation for the Waimea Plains by Tasman District Council aims to study into the feasibility of water storage in the upper parts of the Wairoa/Lee catchments. The aim of this project is to assess augmentation of Wairoa River flow to enhance water availability for regional use and for environmental community benefits. The Waimea Plains groundwater-river interaction has been modelled by GNS Science to assess the effects of proposed augmentation on river flow.

In modelling stage 1, the Waimea Plains groundwater-river interaction model calculates that the minimum flow at Irvine-Wairoa Gorge would need to be 1650 l/sec and 1825 l/s to maintain minimum flows of 250 l/s and 500 l/s at Nursery-Appleby Bridge respectively, in the Waimea River for a 1 in 10 dry year (1991/1992) with pumpage at actual water usage.

In modeling stage 2, the Waimea Plains groundwater-river interaction model is used to assess the river flow rate at Irvine-Wairoa Gorge needed to maintain minimum flows of at least 600 l/s and 1100 l/s at Nursery-Appleby Bridge in the Waimea River based on future water demand in a nominal 1:20 dry year (1982/1983). To calculate the future water demand in the Waimea Plains based on the climate data for the 1982/83 (July to June) year, an irrigation water balance budget has been computed by John Bealing (Agfirst) for a range of crops: (1) pasture; (2) apples and kiwi fruit; and (3) grapes and olives over a range of soil types: (1) 38 mm soil moisture holding capacity; (2) 78 mm soil moisture holding capacity; and (3) 130 mm soil moisture holding capacity. Future water demand for each cell in the Waimea Plains groundwater-river interaction model has been calculated based on daily irrigation demand for the range of crops and the range of soil types.

The Waimea Plains groundwater-river interaction model has been used to evaluate the effect of calculated future water demand on river flows in the Waimea Plains, especially at Nursery-Appleby Bridge in the Waimea River. The model predicts that the Waimea River flow at Nursery-Appleby Bridge will be less than 100 l/s on 17 days, less than 250 l/s on 37 days and less than 500 l/s on 48 days for the 1982/1983 year if pumpage is equal to future water demand. A significant increase in the occurrence of zero flow, or very low flow of less than 250 l/s, at Nursery-Appleby Bridge for the 1982/1983 year is calculated if pumpage is equal to future water demand, compared to actual water usage.

The Waimea Plains groundwater-river interaction model has been used to establish minimum river flows at Irvine-Wairoa Gorge needed to maintain minimum 600 l/s flow and 1100 l/s flow at Nursery-Appleby Bridge in the Waimea River based on future water demand for the 1982/1983 dry year (a nominal 1 in 20 dry year). The model calculates that a minimum river flow at Irvine-Wairoa Gorge would need to be 2260 l/s (excluding Waimea East Irrigation Scheme) to maintain a minimum flow of 600 l/s at Nursery-Appleby Bridge in the Waimea River with future water demand between 01-03-1983 and 23-03-1983 (the driest period of 1982/1983 year). If Waimea East Irrigation Scheme (WEIS) take is included, the minimum flow at Irvine-Wairoa Gorge would need to be 2513 l/s to maintain a minimum flow of 600 l/s at Nursery-Appleby Bridge (Figure 15). The model predicts that a minimum flow of 2663 l/s (excluding Waimea East Irrigation Scheme) at Irvine-Wairoa Gorge would be needed to maintain a minimum flow of 1100 l/s at Nursery-Appleby Bridge in the Waimea River with

future water demand The calculated minimum river flow at Irvine-Wairoa Gorge needed to maintain the target minimum flow of 1100 l/s at Nursery-Appleby Bridge in the Waimea River is calculated to be 2981 l/s if Waimea East Irrigation Scheme (WEIS) take is included.

GNS Science has undertaken a forward simulation to assess whether the augmented river flow at Irvine-Wairoa Gorge proposed by Tonkin and Taylor Ltd could maintain a minimum 1100 l/s flow at Nursery-Appleby Bridge in the Waimea River in a nominal 1:20 dry year (1982/1983). The river flow at Nursery-Appleby Bridge in the Waimea River would be an average of 1148 l/s with future water demand and augmented river flow at Irvine-Wairoa Gorge between 01-03-1983 and 23-03-1983 (the driest period of 1982/1983 year). However, the model calculates that the minimum river flow at Nursery-Appleby Bridge would be slightly below 1100 l/s in the period from late February to early March 1983. Some minor recalculation of the proposed augmented river flow would be necessary to achieve above 1100 l/s at Nursery-Appleby Bridge at all times.

9.0 ACKNOWLEDGEMENTS

I thank David Leong (Tonkin & Taylor Ltd), John Bealing (Agfirst), and Joseph Thomas (Tasman District Council). They provided advice and helpful comments and assisted with various aspects of the study for which I am particularly grateful. I also thank Paul White (GNS Science) for his valuable comments and suggestions.

10.0 REFERENCES

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