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River-aquifer interaction modelling in the Upper Motueka River catchment: three-dimensional finite-element groundwater flow model

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River-aquifer interaction modelling in the Upper Motueka River catchment: three-dimensional finite-element groundwater flow model

Motueka Integrated Catchment Management (Motueka ICM) Programme Report Series

by

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Cover Photo: Confluence of the Motupiko and Motueka Rivers with the groundwater model grid shown in red.

PREFACE

An ongoing report series, covering components of the Motueka Integrated Catchment Management (ICM) Programme, has been initiated in order to present preliminary research findings directly to key stakeholders. The intention is that the data, with brief interpretation, can be used by managers, environmental groups and users of resources to address specific questions that may require urgent attention or may fall outside the scope of ICM research objectives.

We anticipate that providing access to environmental data will foster a collaborative problem-solving approach through the sharing of both ICM and privately collected information. Where appropriate, the information will also be presented to stakeholders through follow-up meetings designed to encourage feedback, discussion and coordination of research objectives.

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1.0 INTRODUCTION

The area upstream of the Wangapeka confluence of the Motueka River catchment has a sizeable area of fertile alluvial river terrace land that is suitable for irrigated agriculture. Since the mid 1990's there has been an increasing demand for irrigation water especially from groundwater in these terraces. There is concern that extraction of more groundwater for irrigation may lower groundwater levels and consequently the baseflow of rivers/streams during the summer season due to strong shallow aquifer-surface water interactions in this area. This would reduce the availability of surface water to existing users and add pressure in terms of water allocation to keep minimum baseflow requirements for the Motueka River in compliance with the requirements of the Motueka River Conservation Order. In order to manage the water resources in a holistic manner in this region the development of a three-dimensional groundwater flow model is required to analyse the effects of groundwater abstraction on rivers/streams flow and groundwater levels.

The purpose of this study is to gain a better understanding of the relations and interactions between the shallow aquifer and the surface water systems by developing a state-of-art 3-dimensional adaptive finite-element groundwater flow model. It is hoped that this joint study, conducted with Landcare Research and Tasman District Council (TDC) as a component of the FRST funded Integrated Catchment Management (ICM) programme (C09X0305), will identify some of the important factors controlling the response of the systems to groundwater abstraction, and enable more holistic and integrated management of water resources in the area. This report is stage one of the 3-dimensional groundwater modelling work for the Upper Motueka.

2.0 Purpose and Scope of Report

The aim of this report is to describe the initial results from a study using 3-dimensional, adaptive finite-element, steady-state, groundwater flow model to simulate the interaction between shallow aquifer and surface water systems in the Upper Motueka River catchment.

The specific objective of this study is:

- to develop a generalised three-dimensional adaptive finite-element steady-state groundwater flow model in the Upper Motueka River catchment.

3.0 Study area

Groundwater in the Upper Motueka catchment is abstracted from shallow unconfined alluvial aquifers that occur in the Quaternary river terrace formations and modern river deposits. Five gravel formations have been identified within the study area upstream of the Wangapeka River confluence (Figure 1). These are (from oldest to youngest) the Moutere Gravel, Manuka, Tophouse, Speargrass, and modern river gravel formations. The Quaternary Gravels are underlain by the Moutere Gravel Formation throughout the whole study area (Stewart, et al, GNS Science Report 2003/32, 2003).

The Moutere Gravel Formation consists of rounded greywacke clasts up to 0.6m diameter (most less than 0.2m diameter) in a yellowish-brown, silty, clay matrix. The formation contains minor clasts of very weathered ultramafics in the Motueka River upstream of the Motupiko River confluence. Moutere gravel is widespread throughout the upper Motueka River catchment and forms the hill country between the valleys of the Motueka, Motupiko, and Tadmor rivers (Stewart, et al, GNS Science Report 2003/32, 2003).

The Speargrass Formation is widespread in upper reaches of the valleys but absent in the lower reaches. The formation forms the lowest terrace at approximately 8 m above the river level (Figure 1, Suggate, 1988). An aggradation surface occurs on the Speargrass Formation terrace that is approximately one to two meters higher than the degradation surface. Groundwater is abstracted from the formation within the study area. The average saturated thickness of the Speargrass Formation is estimated be between 5 and 8.5 m.

The Tophouse Formation is widespread throughout all of the river valleys in the upper Motueka River catchment (Figure 1). Tophouse Formation surfaces lie between approximately 17 m to 35 m above river level. The potential saturated thickness of the Tophouse Formation is estimated to be between 0 and 12 m. Bores drilled into the formation just south of Stanley Brook Hill and just north of Kohatu were abandoned due to insufficient groundwater. This suggests that either the permeability of the formation is very low or the base of the Tophouse Formation is above the groundwater level in these areas. The top surface of the Tophouse Formation is typically between 10 to 20 m above the top surface of the Speargrass Formation (Stewart, et al, GNS Science Report 2003/32

In this study, the hydrological monitoring network consists of eight groundwater level, eleven river flow recorder sites, and one rainfall sites in the model domain (Figure 2, Table1). Rainfall distribution does not vary hugely within the study area (Figure 2). There is a gradient both north and southwards away from the Tapawera gauge. At the furthest point of the model grid the annual precipitation is approximately 14% higher than at Tapawera.

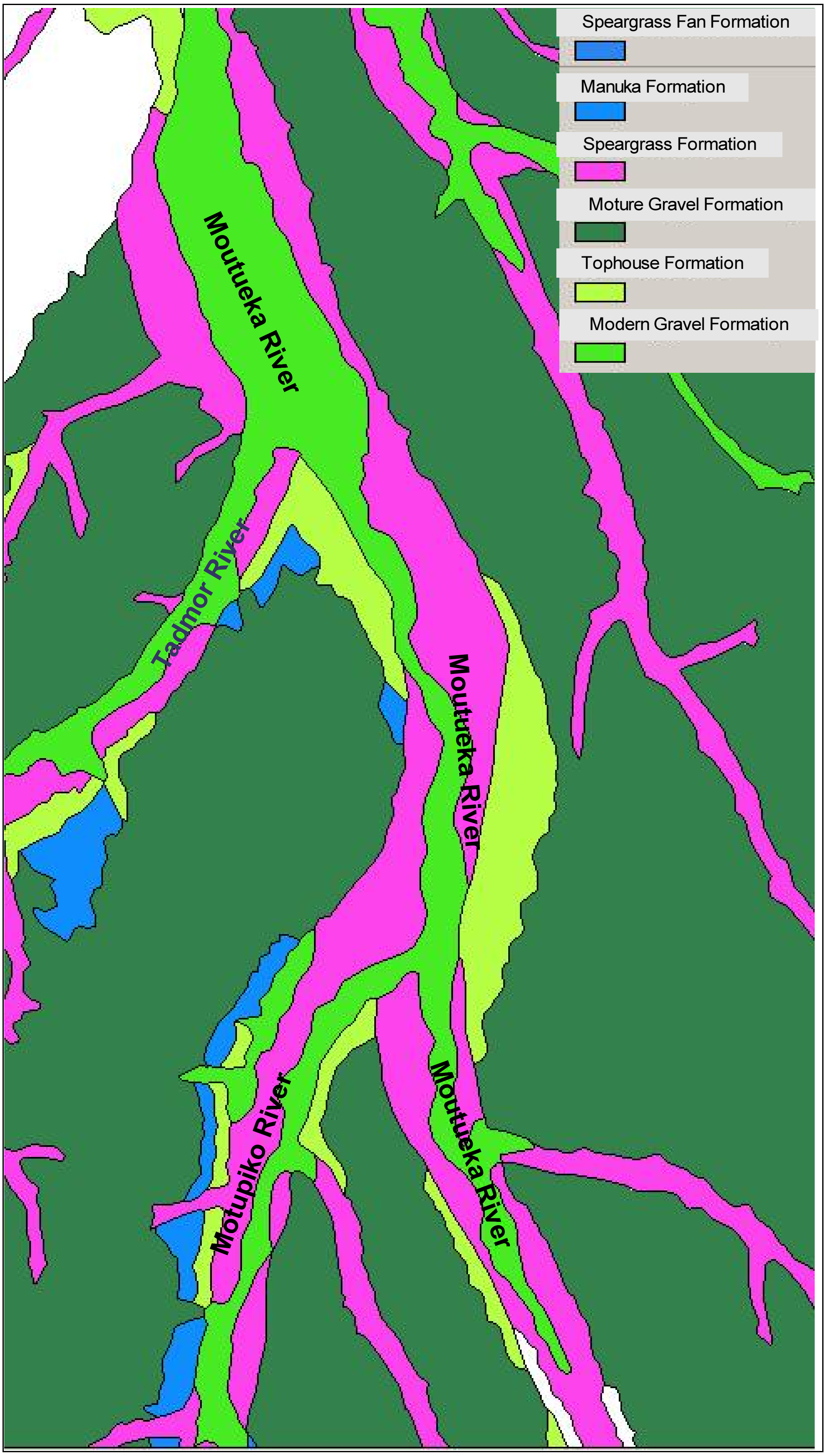

Figure 1 Simplified geology map in the Upper Motueka River Catchment.

Table 1 Summary of hydrological monitoring sites. The value is based on annual average.

Type	Site Name	X	Y	GWL (m)
GW	Higgins (North Bridge)	2496379	5969958	201.51
GW	Quinney's Bush	2494645	5972174	191.30
GW	Crimp	2495743	5973426	179.11
GW	Hyatt	2495927	5977500	154.97
GW	Campbell	2496432	5977765	155.58
GW	Biggs	2494085	5980869	136.62
GW	Oldham	2493500	5978950	150.35
				Discharge (l/sec)
River	Above Wangapeka confluence	2492737	5985290	1855
River	Glenrae	2492777	5984045	1427
River	Smiths	2493328	5982558	2419
River	Below Tapawera	2494040	5981439	1692
River	Tapawera bridge	2494499	5980096	1880
River	Rogers	2495102	5978701	1778
River	Hyatts	2495515	5977426	1584
River	Reynolds	2496422	5976055	1607
River	Downstream Kohatu	2496152	5973305	1781
River	Kohatu bridge	2496187	5972915	1539
				Rainfall (mm/year)
Rain	Woodstock	2495100	5994300	1250
Rain	Tapawera Bridge	2494500	5979900	1300
Rain	Motueka Gorge	2502800	5952600	1550

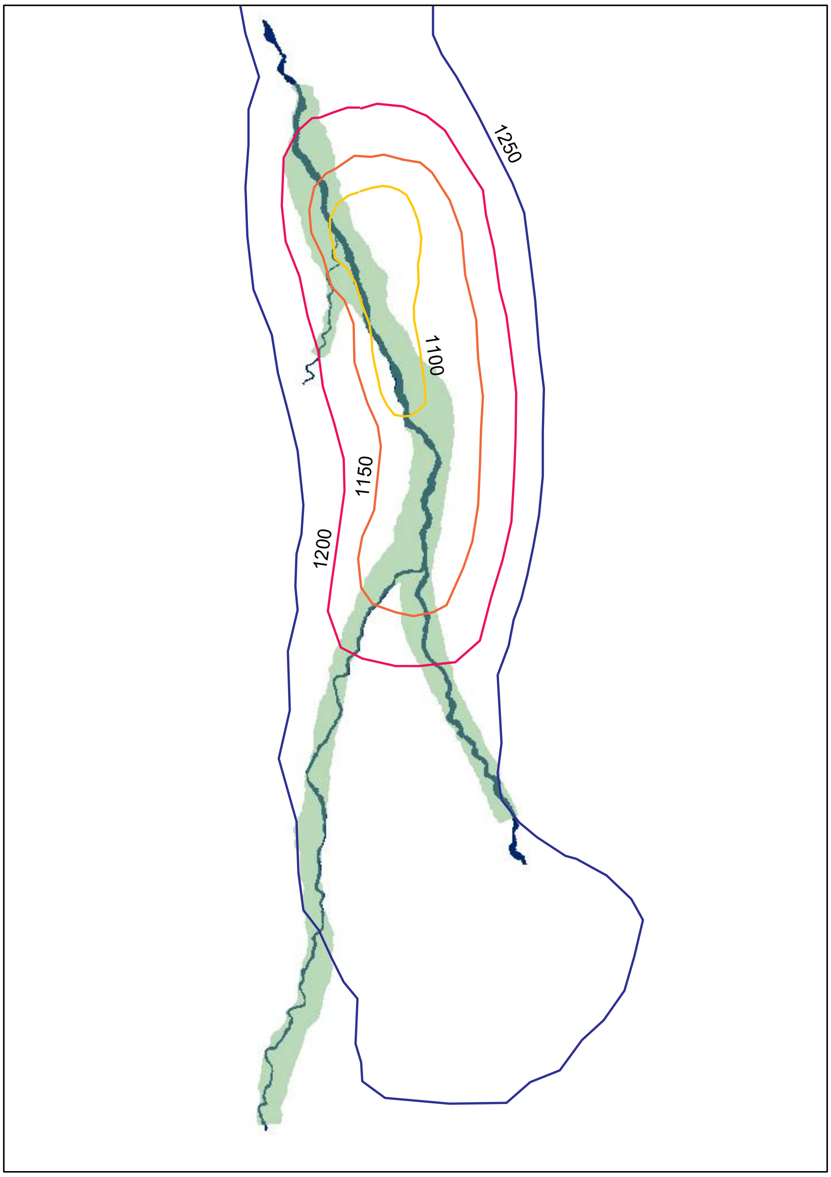

Figure 2 Annual rainfall isohyets for the Upper Motueka valley. Model grid is shown in green (with river channel embedded in blue). Isohyet data from Tasman District Council.

4.0 Finite-element groundwater flow model for the Upper Motueka

4.1 General feature of the 3-D finite-element groundwater flow modelling system

Many methods have been devised to simulate the interactions between a shallow aquifer and stream, ranging from relatively simple analytical methods to site-specific 3-dimensional numerical models. Models that describe water flux interchange between shallow aquifer and stream systems at large spatial and temporal scales are comparatively new and still at the stage of development and improvement. In this study, a state-of-art adaptive finite element groundwater modelling system is implemented to simulate the relations and interactions between shallow aquifer and stream systems in the Upper Motueka River catchment.

There are several advantages of using an adaptive finite-element groundwater modelling system.

- The mesh generation allows refinement of the model structure in areas where intensive interactions between shallow aquifer and stream are likely;
- The fully adaptive mesh generation approach can be implemented for a 3-D model for mesh refinement or derefinement to enhance the reliability of the numerical solution.

4.2 Model grid and boundary

At this stage of the study the groundwater flow model is a steady-state; in future it will be progressed into a dynamic simulation model. The aquifer domain is discretised using 6 modal transigular prism elements with 12365 mesh elements and 13080 mesh nodes. After the finite-element mesh is generated automatically, the mesh structure in the model domain has been partially refined to simulate the interaction between aquifer and river. The finite-element grid design used is denser in the parts of the aquifer where the flow flux interchange due to head-dependent condition were assessed to be important, for example, at the area of the confluence at the Motueka River and the Motupiko River catchment. Figure 3 shows the full map extent of the Upper Motueka groundwater flow model domain with aquifer discretisation using a finite element mesh.

The model boundary of the Motueka groundwater flow model focuses from the 3 km downstream area of the Motueka River at the confluence of the Tadmor River and Motueka River, to 3 km upstream of the Tadmor River from the confluence of the Tadmor River and Motueka River, to approximately 8 km upstream of Kohatu on the Motueka River, and to approximately 15 km upstream of the Motupiko River from the confluence of the Motueka River and Motupiko River (Figure 3). The model boundary includes the majority of groundwater extraction in the Upper Motueka River catchment.

Finite-element mesh size in Figure 3 has been chosen as appropriate to describe features, particularly the rivers and is small enough to simulate the groundwater-river interaction in the Upper Motueka River catchment. Figures 3 to 7 show the extent view of aquifer discretization using 6 modal transigular finite element mesh structure on the area of the confluence of Tadmor River and Motueka River, the confluence of the Motupiko River and Motueka River, and the upstream areas of the Motupiko River and Motueka River, respectively. In Figures 3 to 7 the blue colour shows the active river channel in the model domain and the size of a finite-element mesh that represents rivers as taken from measured cross section of rivers.

The cross section of the Tadmor River in the model domain is approximately 23 m, showing that a width of the Tadmor River is a quite narrow compared to other rivers, particularly the Motueka River. The finite element mesh structure that represents the Tadmor River has been refined until the mesh is small enough to show the measured width of the Tadmor River (Figure 4).

The finite element mesh structure that represents the Motueka River and Motupiko River is also refined to match with the real cross section of the Motueka River and Motupiko River. The finite element mesh structure for the Motueka and Motupiko valleys is coarser than for the Tadmor valley. However, the mesh structure for the major rivers in the model domain is generally dense and fine, compared to the areas where aquifer-river interaction is not applied.

In this model, the one layer aquifer system is defined as free movable surface type due to the shallow unconfined aquifer characteristics. The free movable surface type can simulate the free movable water table and therefore change its vertical position for the top slice of the model. The adjustment of moving surface in the following order:

1. compute groundwater head;
2. determine the new free surface location according to computed groundwater head; and
3. correct inner slice between movable slice and bottom slice (fixed slice).

During the simulations, the model has been set so that the aquifer is always unconfined.

The 3-dimensional ground elevation model for the Upper Motueka groundwater model is developed and visualised in Figure 8. In Figure 8, the bottom slice of the 3-dimensional ground elevation model is represented with the bottom of aquifer in the model domain. The 3-dimensional projection view of the ground elevation in the model domain is also visualised in Figure 9. The 3-dimensional view of the ground elevation model shows that the valley structure is basinal, trending down valley. (Figures 8 and 9). This indicates that the hillside valley recharge is one of the major factors to estimate the volume of water resources in the area.

The ground elevation at the area below at the Tapawera bridge ranges between approximately 113m to 155m. The ground elevation at the confluence of the Motupiko River and the Motueka River ranges from approximately 185m to 200m. The average ground elevation at the top upstream area of the Motupiko River and Motueka River in the model boundary is approximately 310 m and 245 m, respectively.

Estimates of aquifer thickness used in the model setup are based on the previous hydrogeological work conducted by GNS (Stewart, et al, GNS Science Report 2003/32, 2003) for the Upper Motueka River catchment. The thickness of the aquifer is ranges from 6.5 m to 8 m at the area of low reaches of the Motueka River valleys from the Tapawera bridge. The average thickness of aquifer is defined at 11.5m in the area from the Tapawera bridge to the confluence of the Motupiko river and Motueka River. Due to lack of precise information, the aquifer thickness is modelled at an average13.5 m in the Motupiko River and Upper Motueka River valleys above the confluence of two rivers.

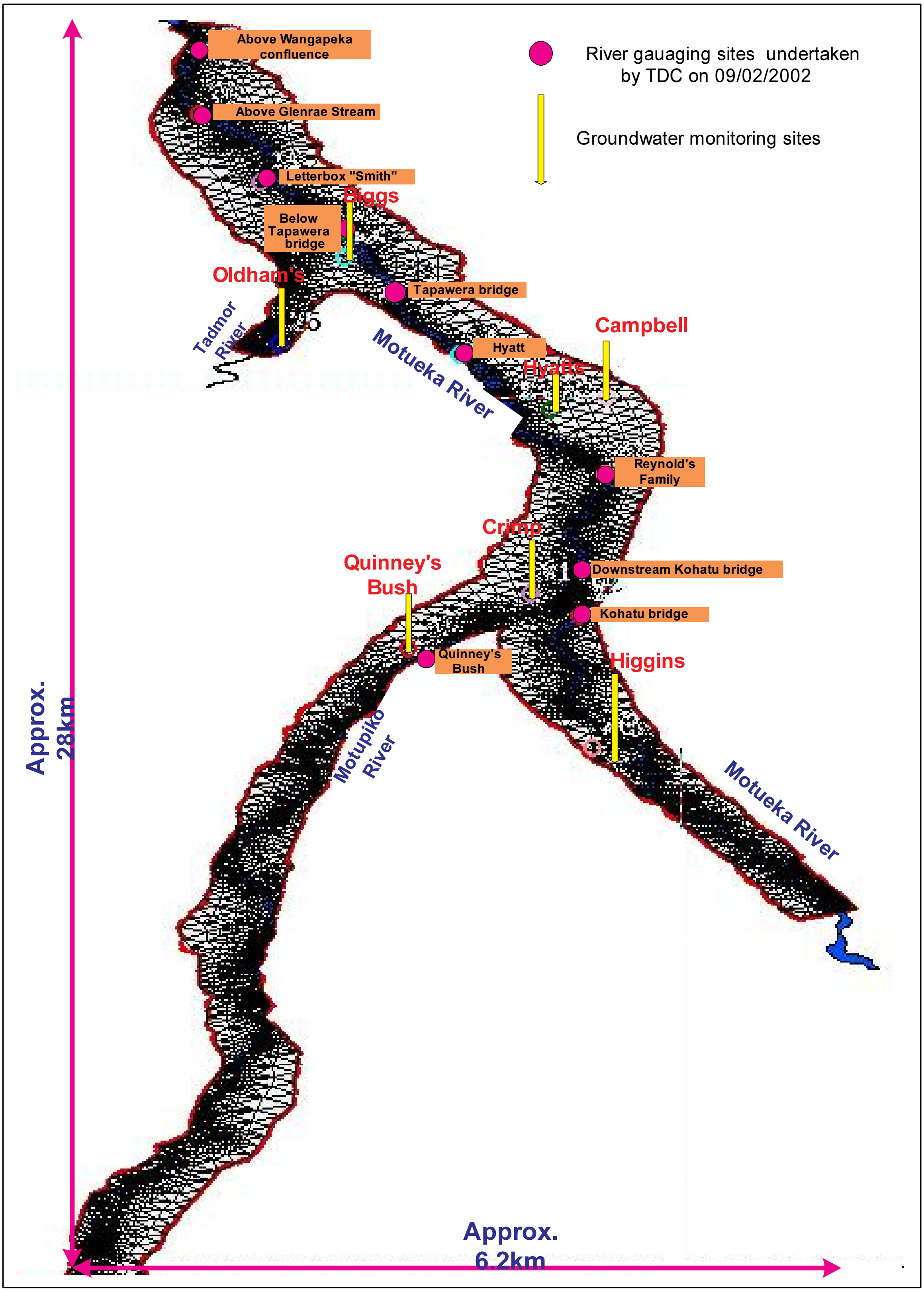

Figure 3 Two-dimensional view of the Upper Motueka groundwater model domain with aquifer discretization and a finite element mesh.

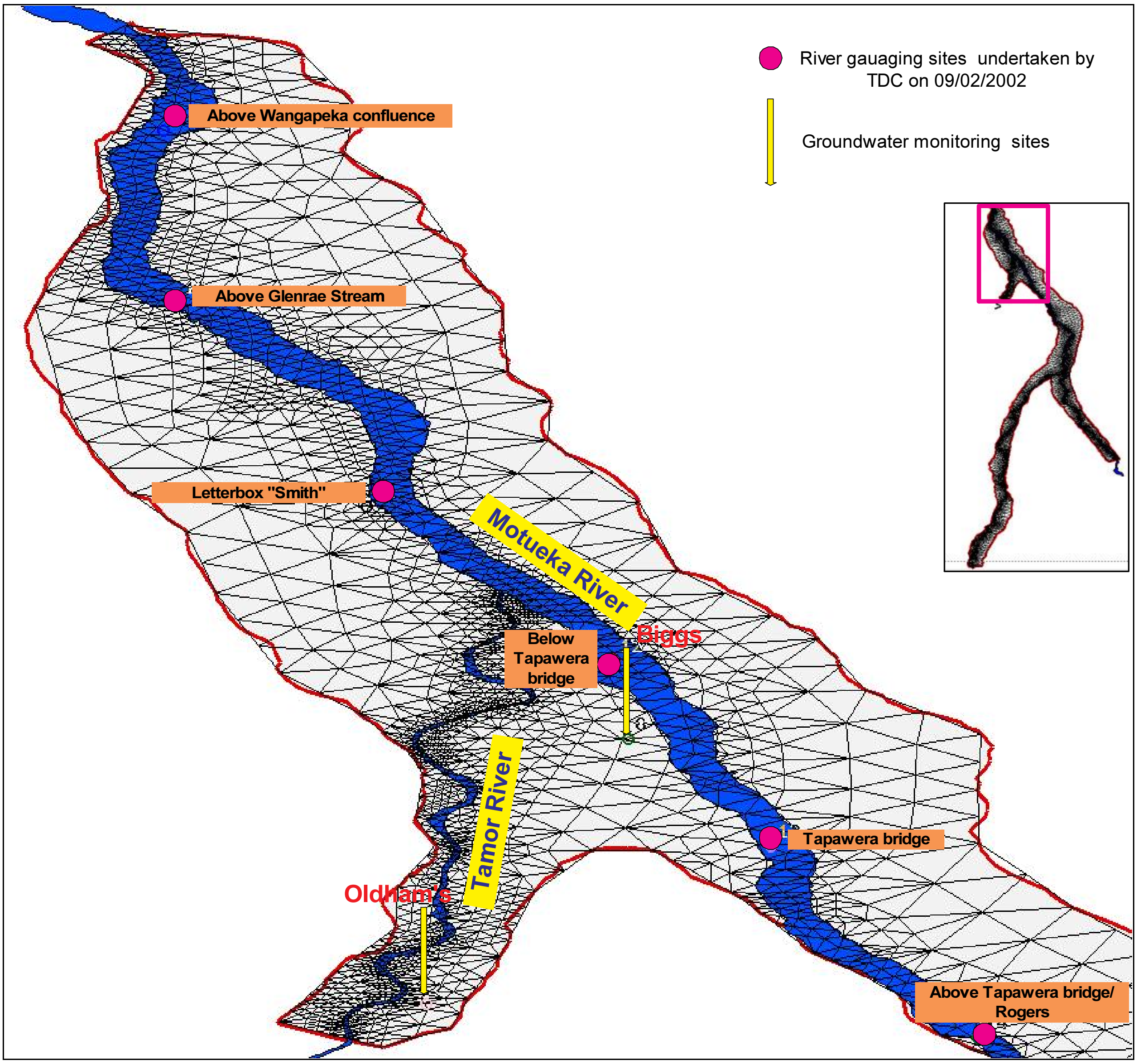

Figure 4 Aquifer discretization and a finite element mesh at the area of the confluence of the Tadmor River and Motueka River.

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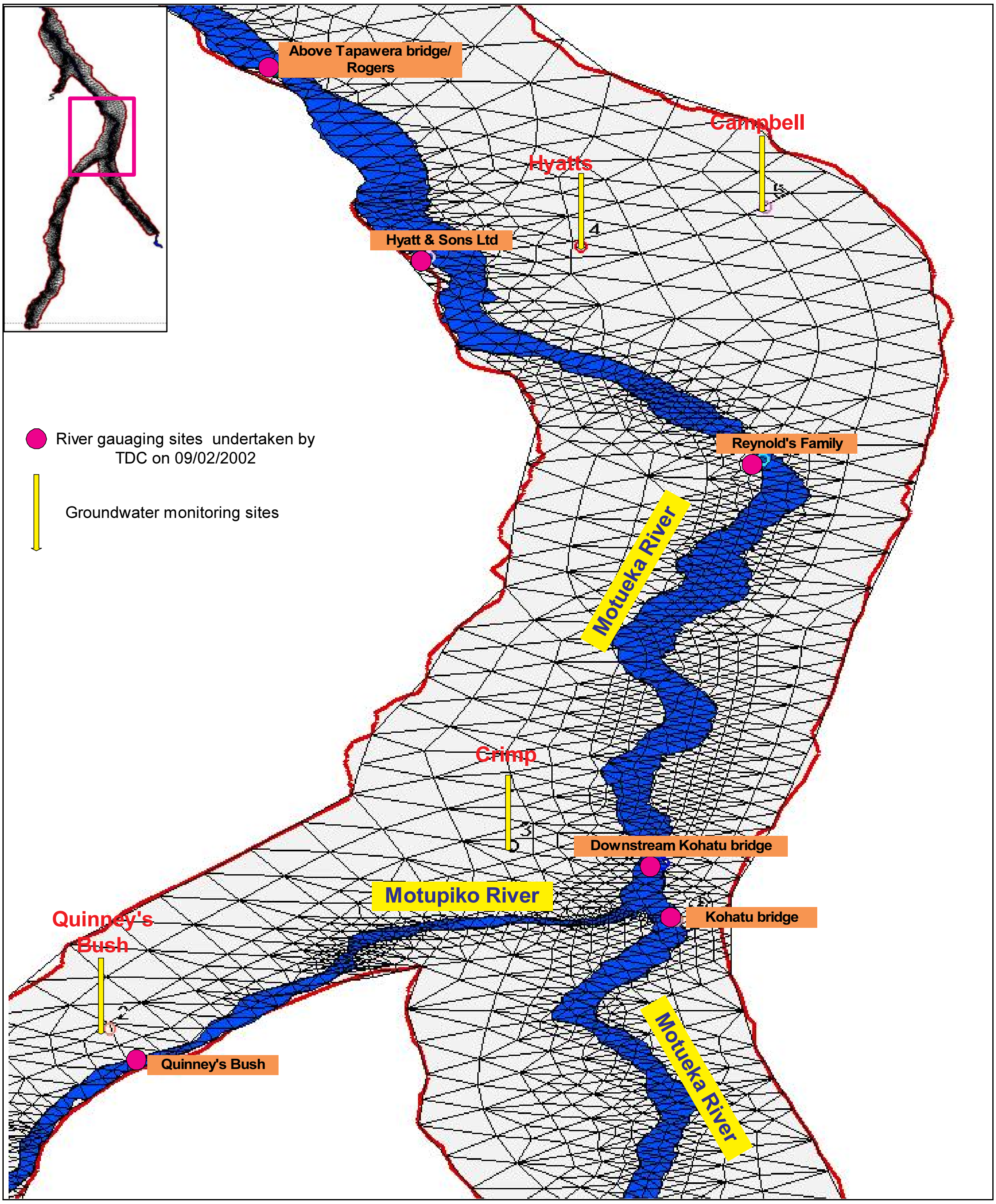


Figure 5 Aquifer discretization and a finite element mesh in the upper valley of the Motueka River and Motupiko River.

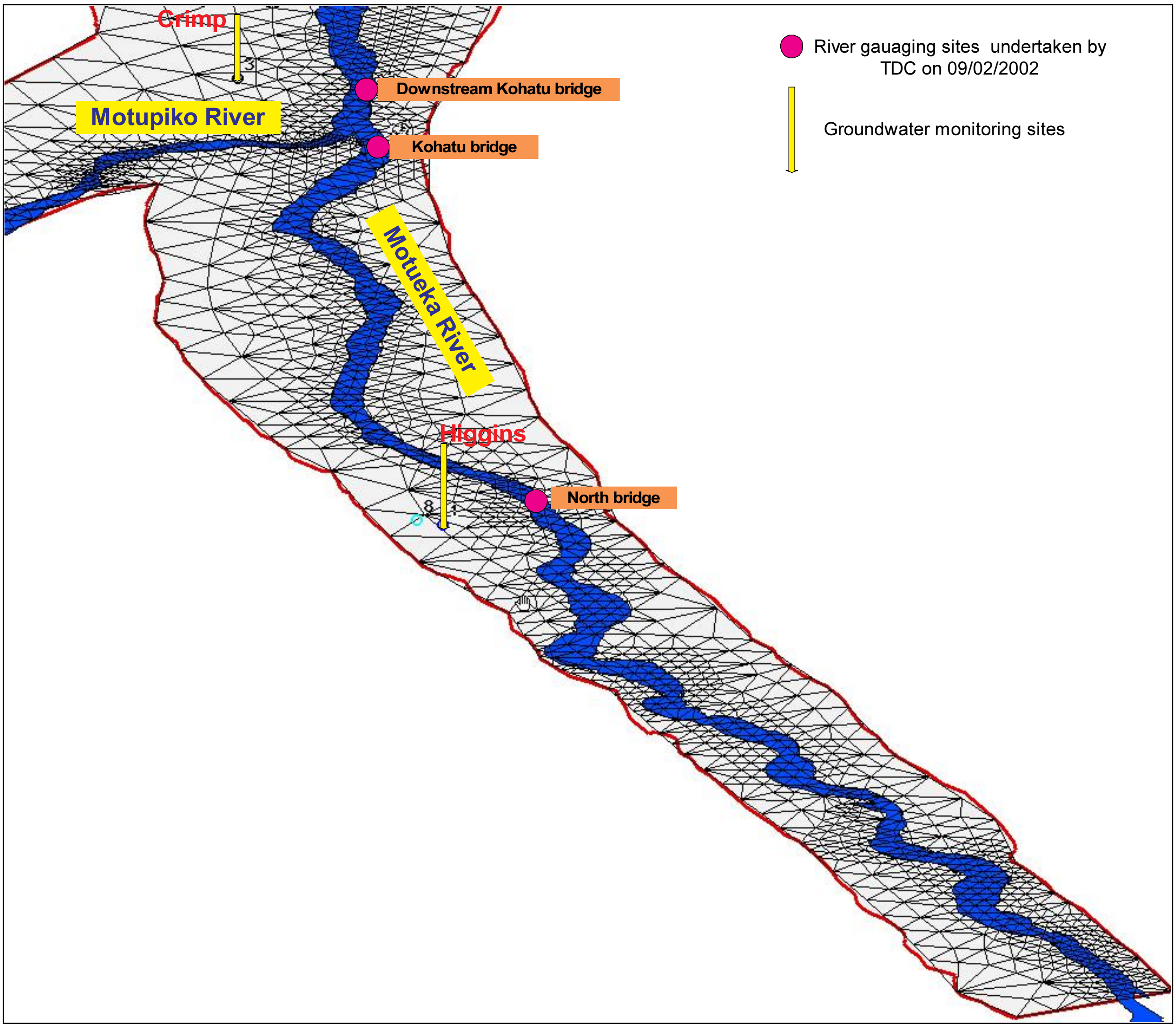


Figure 6 Aquifer discretization and a finite element mesh in the upper valley of the Motueka River.

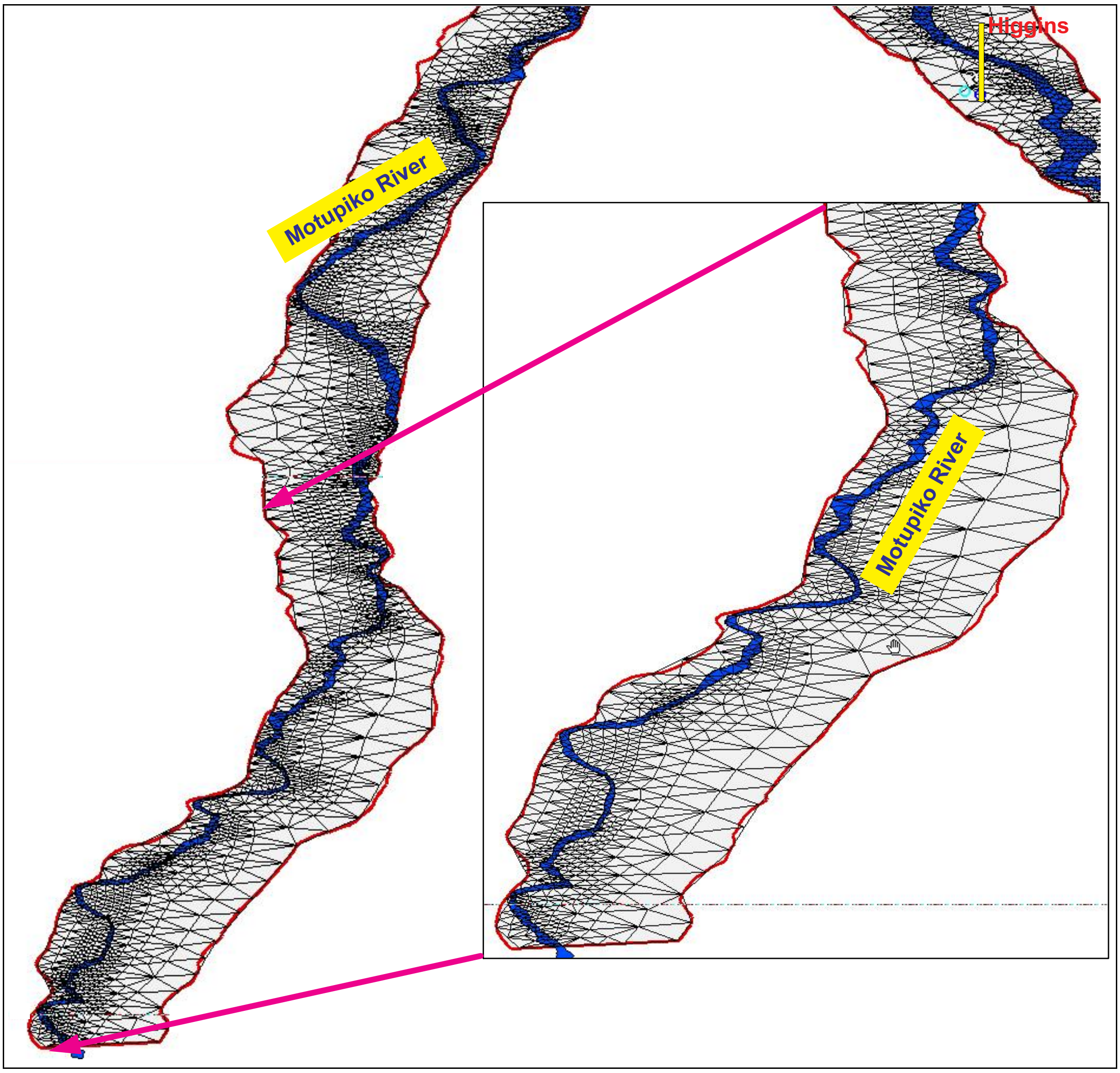


Figure 7 Aquifer discretization and a finite element mesh at the Motupiko River valley.

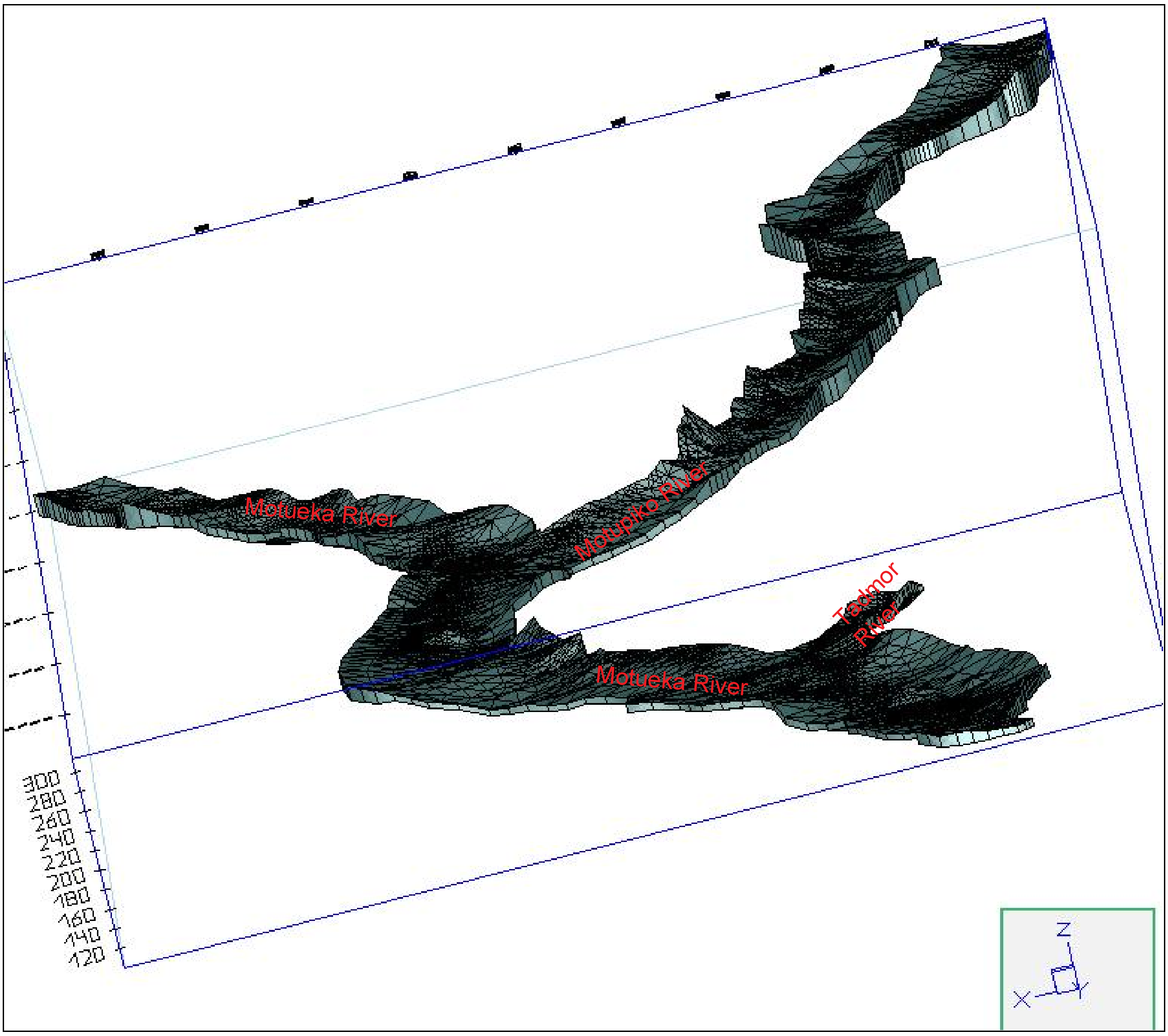


Figure 8 Three-dimensional view of the ground elevation structure from the bottom of the aquifer with aquifer discretization by transigular finite-element mesh.

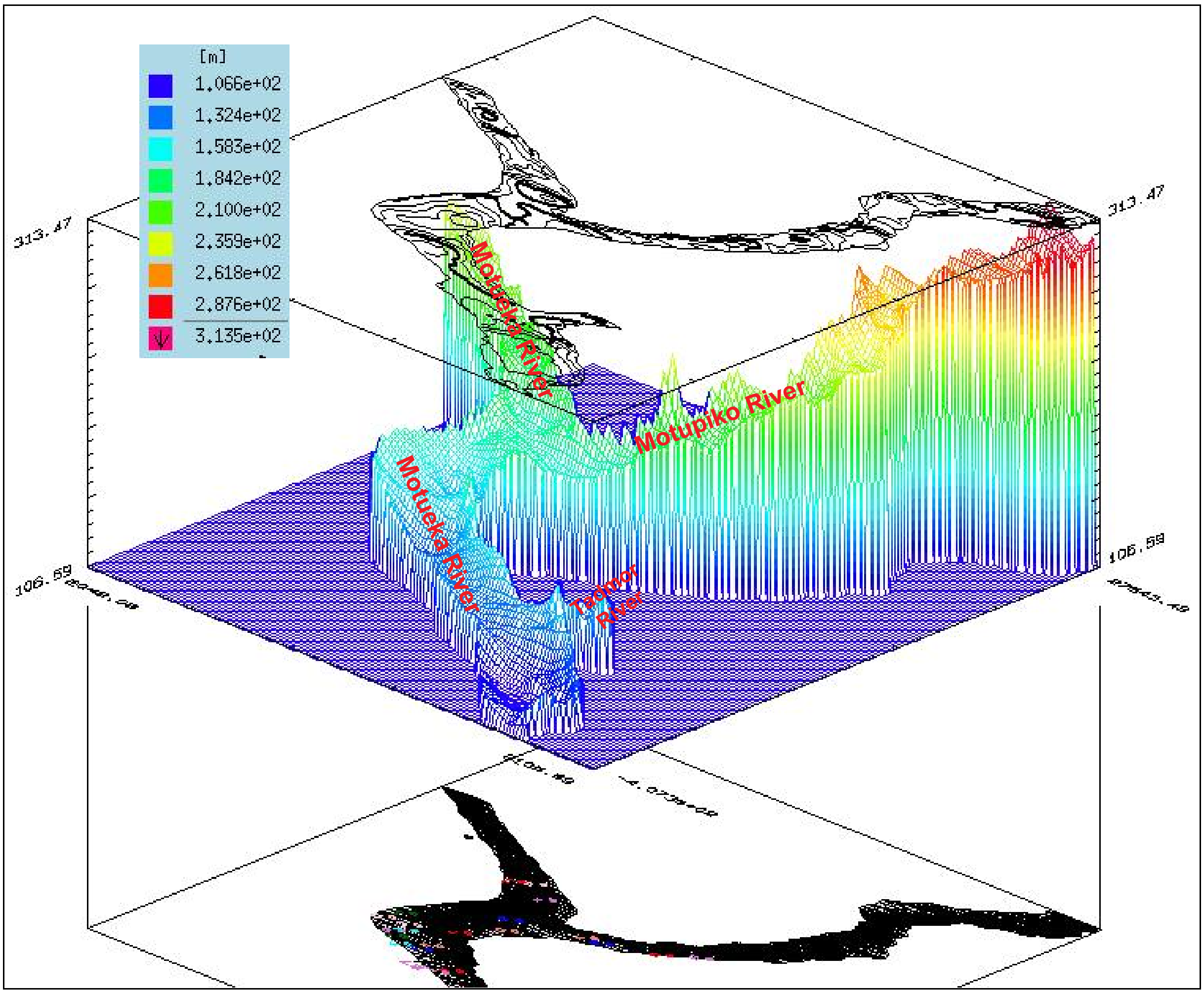


Figure 9 Three-dimensional projection view of the ground elevation on the basis of 106.6m.

4.3 Hydraulic Characteristics - aquifer properties

In order to simulate a groundwater flow system with a numerical finite element model, the hydraulic characteristics of the aquifer and confining beds must be specified for each nodal point of 6 modal transigular finite elements. The hydraulic characteristics normally required to simulate a groundwater flow system are aquifer thickness, hydraulic conductivity, and specific storage. Specific storage is not specified for this study because all simulations are for the steady-state conditions. The aquifer thickness in the model domain is described in Section 4.2.

Hydraulic conductivity values estimated from slug test and constant rate pump test analysis provided by Tasman District Council are summarised in Table 2. At some localities where no pump tests were undertaken the hydraulic conductivity was assumed to be the same as at the closest pump test sites, or an average. The calculated hydraulic conductivity values from pump test data vary by an order of magnitude, from 54 m/day to 940 m/day. The calculated hydraulic conductivity values at the area of Speargrass formation (Figure 1) varies from 460 m/day to 706 m/day. Modern gravels are widespread in lower reaches of the valleys, particularly downstream from the Tapawera Bridge, and riverside along with the Motupiko River and Motueka River in upper reaches of the valleys in the model domain. The hydraulic conductivity value in the Modern Gravels is estimated to be 620 m/day. The hydraulic conductivity value in the Tadmor River valley is approximately 54 m/day. It is possible that the hydraulic conductivity values may be higher in the region near Hinetai Hops; results are pending from recent step testing.

The Upper Motueka groundwater flow model is divided into regions each representing a different hydraulic conductivity (K) based on the geological map (Figure 1) and slug and pump test results (Table 2). It is assumed that the hydraulic conductivity is constant in both horizontal directions (X and Y directions). The regionalization of horizontal hydraulic conductivity is executed in each region using the Akima inter/extrapolation technique based on the cubic transfer function with the observed hydraulic conductivity data and geological formations. The hydraulic conductivity assigned to each zone is a major variable adjusted during the calibration. Figures 10 and 11 show the resulting regionalization of hydraulic conductivity (X and Y direction) from two different view points.

The heterogeneity of the geological formation shown in Figure 1, particularly of Modern Gravels and Speargrass formation imparts considerable anisotropy to their hydraulic conductivity. Anisotropy is the condition of having different properties in different directions. Expressed as the ratio of horizontal to vertical hydraulic conductivities, the anisotropy ratio is usually greater than one. Based on the horizontal hydraulic conductivity value of 620m/day and the anisotropy ratio, the effective vertical hydraulic conductivity will be 62 m/day. In this study, the anisotropy ratio value is assumed to be 10. (Spitz and Moreno, 1996; Morgan and Jones, 1999) The resulting distributions of hydraulic conductivity in the vertical direction have a range from 4.9 m/day to 80 m/day in the model domain.

Table 2 Hydraulic characteristics of the aquifer in the Upper Motueka River catchment.

ID	Well Number	Bore ID	X	Y	GWL RL (m)	Surveyed Ground Level (m)	Well Depth (m)	Hydraulic Conductivity (m/d)	RL top of Moutere (m)
1	4614	Higgins	2496379	5969958	202.51	205.21	7.2	940	197.113
2	4615	Quinney's Bush	2494645	5972174	191.30	193.68	7.5	620	185.682
3	4616	Crimp	2495743	5973426	179.11	182.18	11	465	170.68
4	4617	Hyatt	2495927	5977500	154.97	158.29	12.6	213	145.285
5	4618	Campbell	2496432	5977765	155.58	160.01	11.3	753	148.213
6	4619	Biggs	2494085	5980869	136.62	139.03	6.5	620	130.03
7	4620	Oldham	2493500	5978950	150.35	153.32	4.5	54	148.824

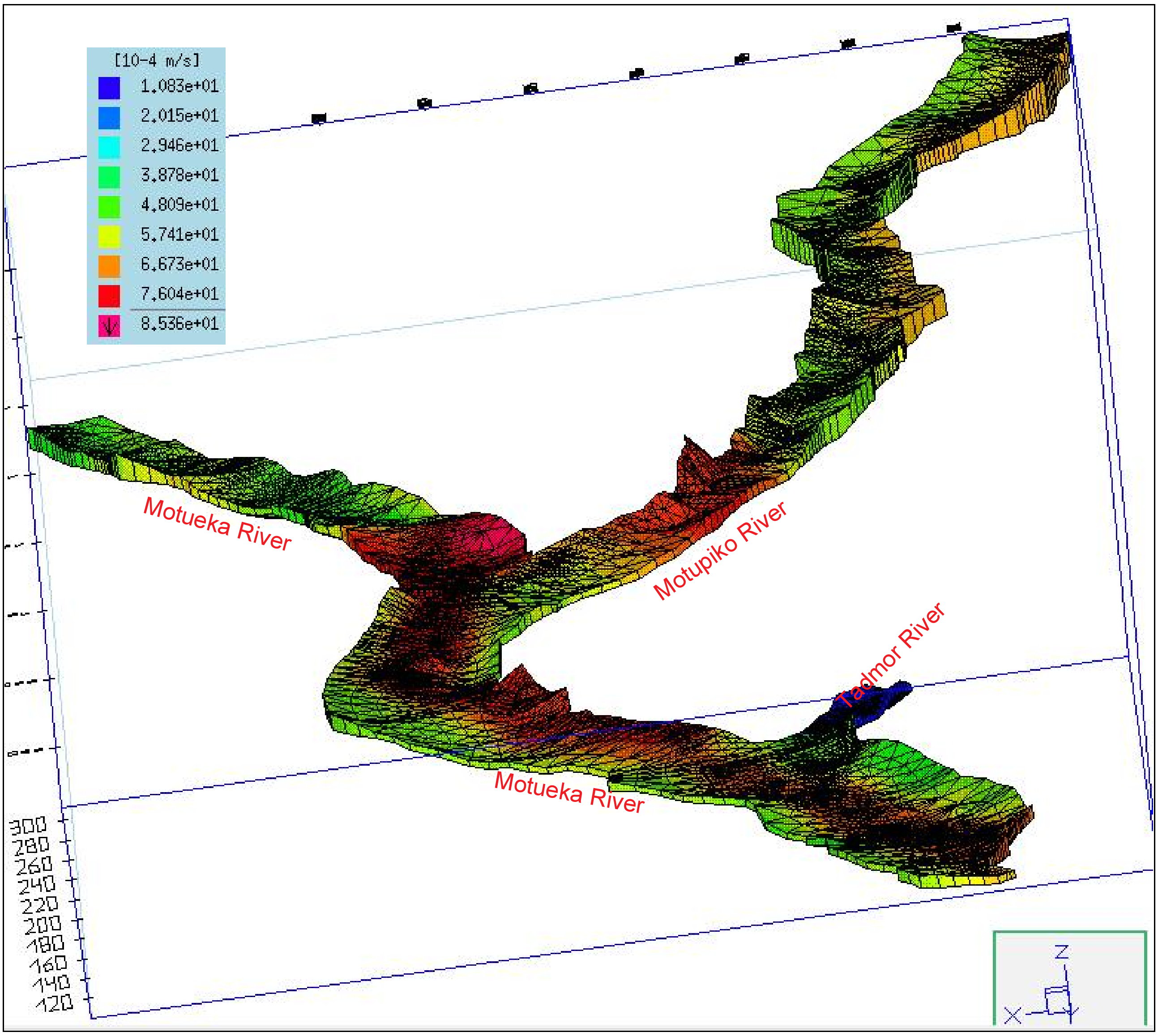


Figure 10 Plot of regional hydraulic conductivity distribution in the model.

4.4 Recharge

Groundwater recharge is commonly derived from infiltration of precipitation and percolation through the soil zone and variably saturated sediments to the water table. Another major source of recharge can be from rivers flowing over an unconfined aquifer. Recharge from infiltration of precipitation has been investigated in previous GNS work (Stewart et al, 2003). Three potential sources of groundwater recharge were identified:

1. Groundwater discharge from the Moutere Gravel
2. Rainfall infiltration
3. River flow loss to groundwater
4. Hillslope recharge

The annual average rainfall at Tapawera site for the period 1993 to 2001 years is 1100mm (Stewart et al, 2003). To generate the regional recharge model in the model domain, the recharge coefficient is estimated to be 0.3 on the basis of the rainfall recharge data in the Canterbury Plains (Hong, et al, 2005). The mean annual rainfall recharge to aquifers is estimated at 0.121×10^{-4}m/day (350 l/sec) on recharge coefficient of 0.3. The spatial distribution of annual average rainfall is strongly correlated to the topographic elevation. Therefore it is assumed that the recharge in the high elevation area is a little higher than the recharge in the lower valleys in the model domains (Figure 3). The recharge is assigned to each finite element mesh of the model. The regional rainfall recharge distribution is shown in Figure 11.

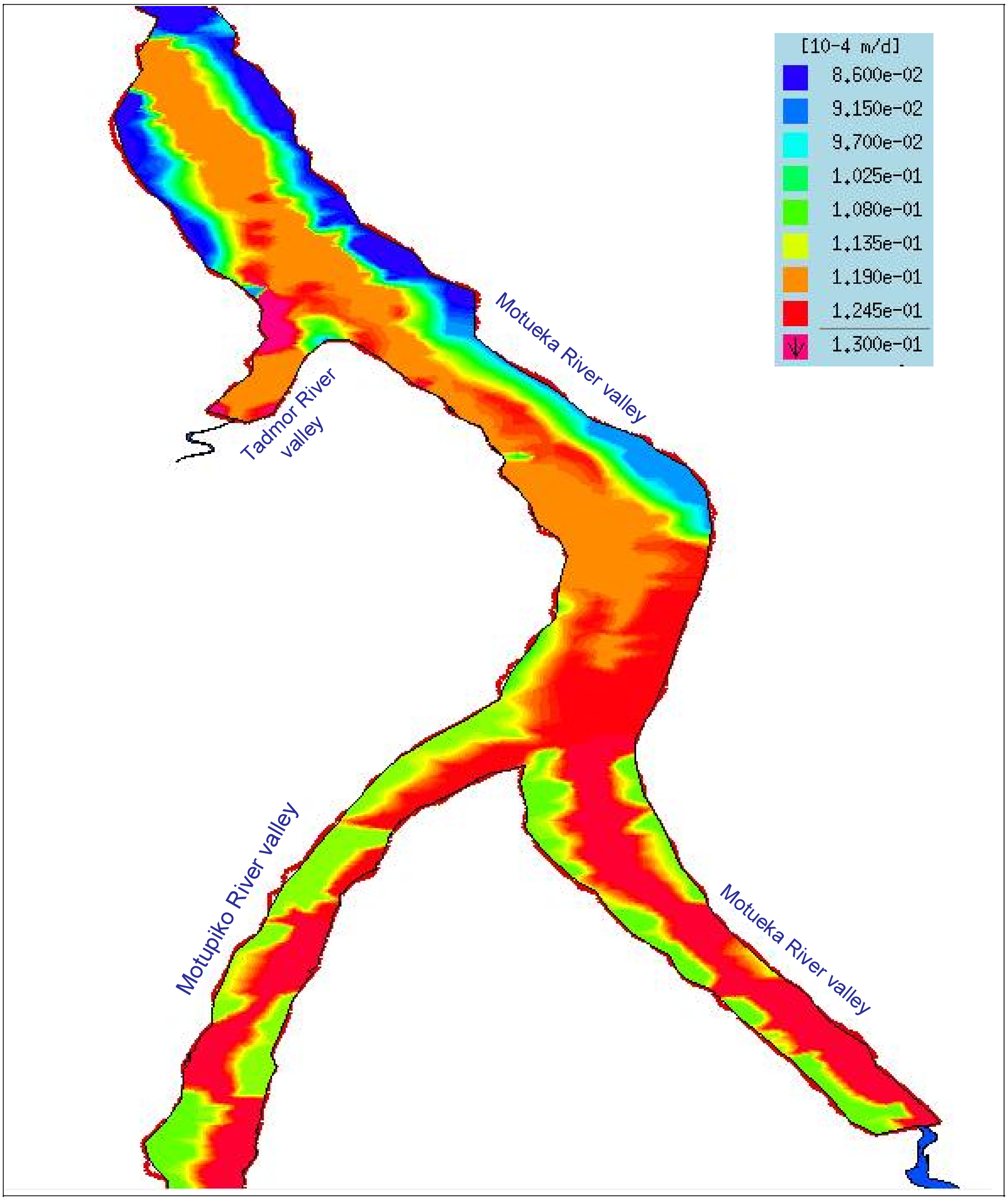


Figure 11 Contour plot of regional rainfall recharge distribution in the model.

4.5 Groundwater abstraction model

To simulate the effect of groundwater abstraction on river flows and groundwater levels, the abstraction model was developed. Figures 12 to 14 show the groundwater abstraction wells that have consent approval from the Tasman Distract Council. Their locations and consented abstraction rate for each of wells are shown in Table 5. There are total 41 groundwater abstraction wells in the model domains. 5 wells are located at the Motupiko River valley (Figure 14) and there are 8 wells below from the confluence of the Tadmor River and Motueka River (Figure 12). Groundwater is mainly abstracted from shallow valley gravels in the area between Tapawera bridge and the confluence of the Motupiko River and the Motueka River. In this region, groundwater abstraction wells are located near the Motueka River, the hydraulic gradient is reversed such that the groundwater recharge to the Motueka River (see Figure 15B) stops entirely and the surface water will be induced from the Motueka River into the aquifer as additional recharge. This causes a significant flow loss of the Motueka River between Tapawera bridge and downstream Kohatu bridge.

Total allowable maximum abstraction rate from 5 wells (W1, W2, W3, W4, W5 in Figure 14) that are located at the lower reaches of the Motupiko River are 3974 m^3/day. Total maximum allowable abstraction rate of 8 wells (Figure 12, Table 3) that are located in the lower reaches below the confluence of the Tadmor River and the Motueka River is 10736 m^3/day. 18985 m^3/day of the maximum allowable abstraction rate is allocated in the wells that are located between Tapawera bridge and North bridge near the Motueka River. In the model domains, total maximum allowable abstraction rate over the 41 wells is 36395 m^3/day. To simulate the effect of the groundwater abstraction on the river flows and groundwater levels, 60% of maximum allowable abstraction rate is assigned to each well in the steady-state model. The 60% figure is based on Tasman District Council monitoring of average water take in the region. Therefore, the Upper Motueka groundwater flow model is simulated on total 21827 m^3/day groundwater abstraction from 41 wells.

The surface water is taken directly from rivers in this area. This surface water take is not implemented in the steady-state model due to strong seasonal variation. The surface water take is will be implemented in the transient model.

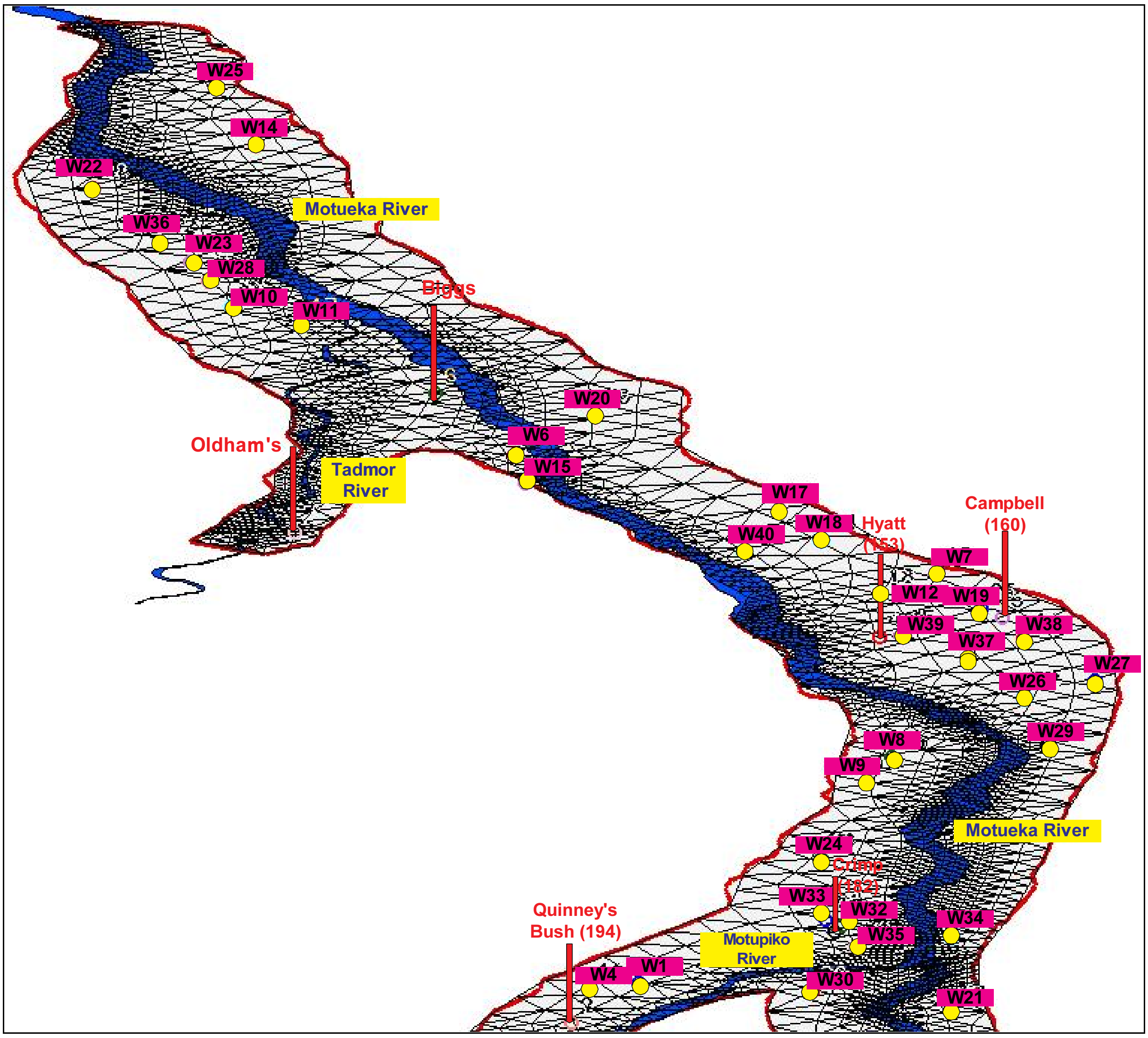


Figure 12 Locations of the groundwater abstraction wells in the lower reaches of the Motueka River.

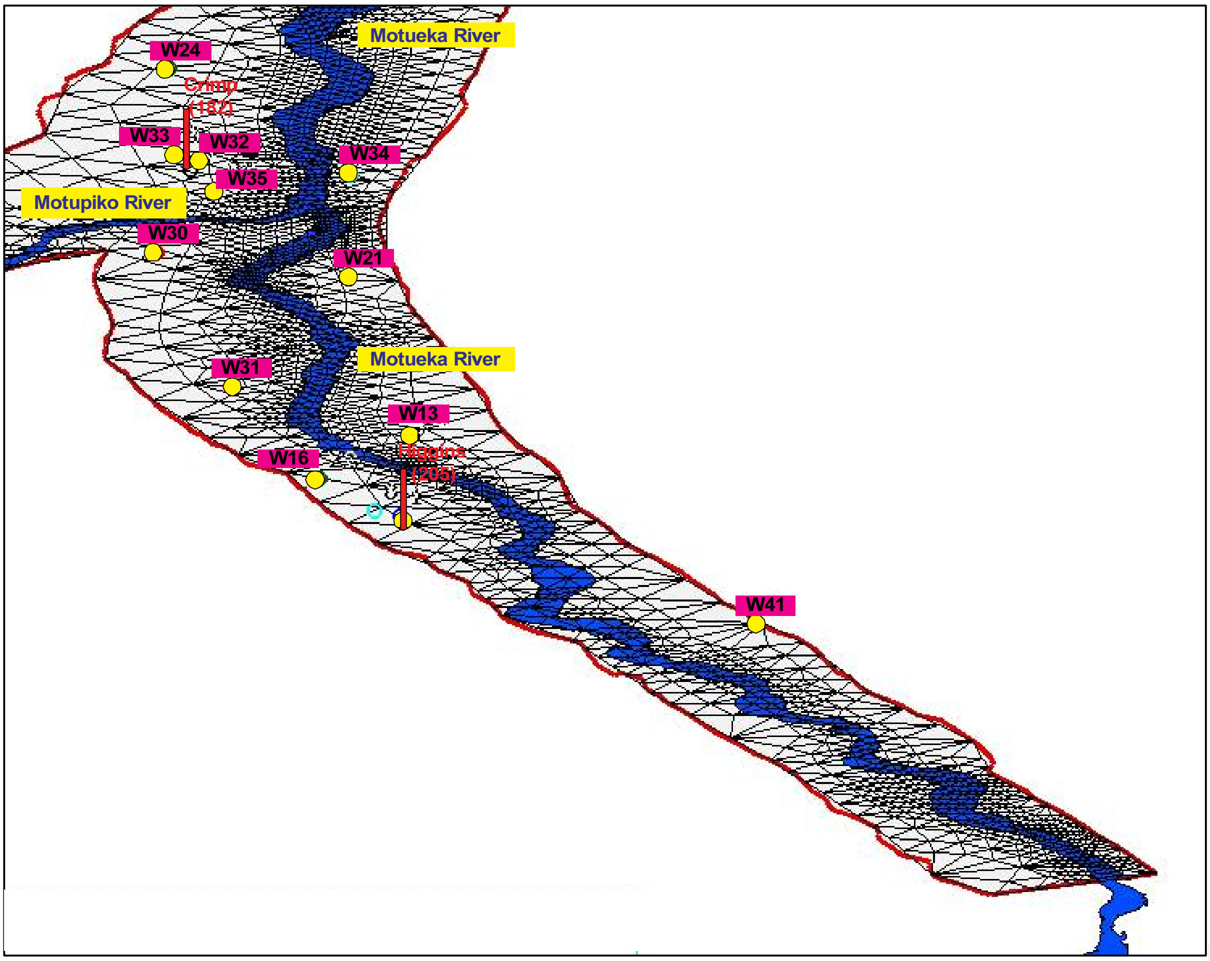


Figure 13 Locations of the groundwater abstraction wells in the upper reaches of the Motueka River.

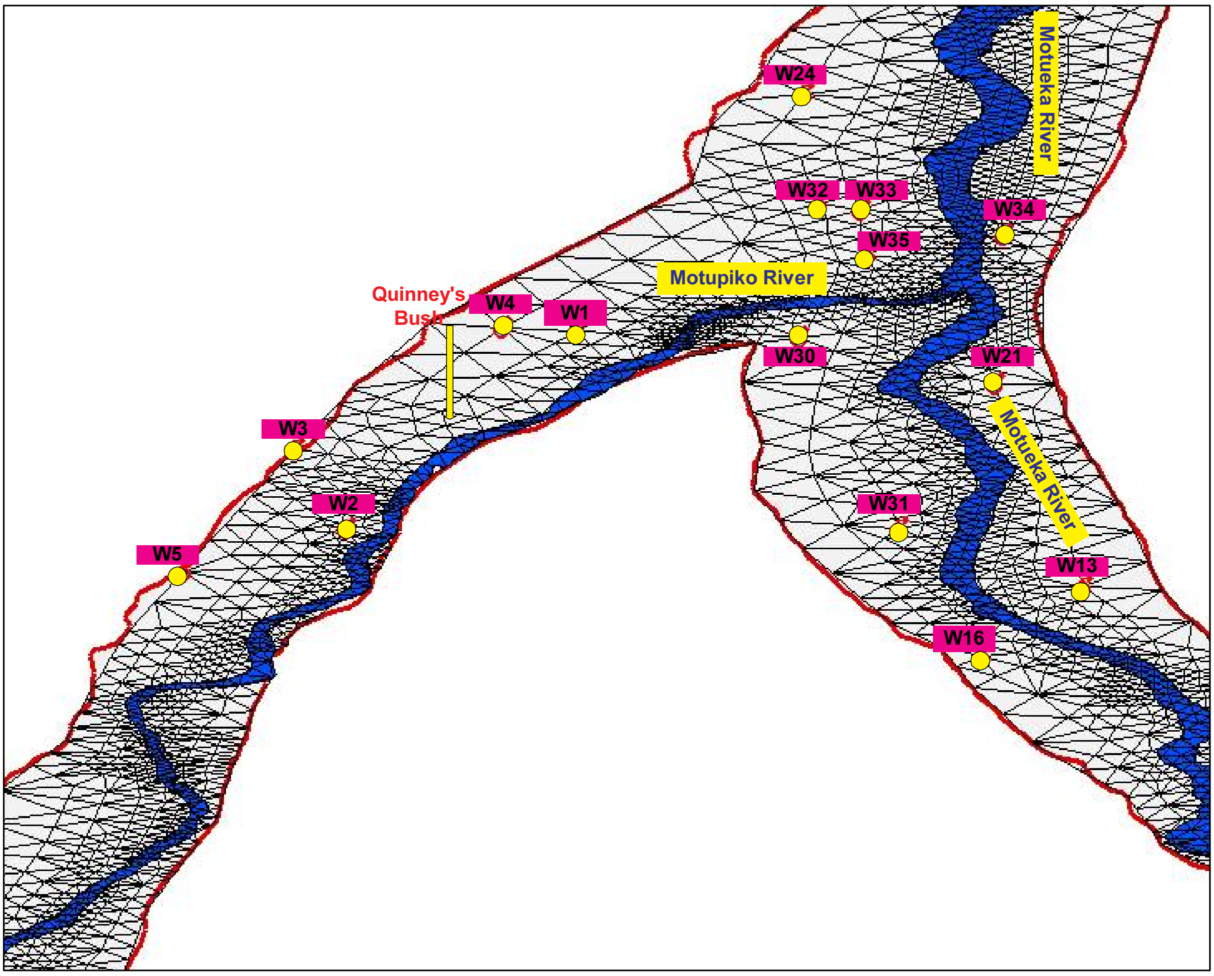


Figure 14 Locations of the groundwater abstraction wells in the lower reaches of the Motupiko River.

5.0 aquifer-river interaction model for the Upper Motueka River catchment

5.1 Technical basis of the aquifer-river interaction model

A head-dependent flux boundary is generally used to represent leakage from surface bodies where the exchanges of water between aquifer and surface water depends on the head differences between surface water and groundwater (flux or groundwater head cannot be described in advance). Such flow conditions can occur if the river bed acts as a semipermeable membrane between the river and aquifer. Several synonyms are common for the semipermeable boundary, e.g. *third-kind boundary, Cauchy's boundary* or *head-dependent boundary*.

Figure 15 shows the interaction between the river and the aquifer in the head-dependent, third-kind Cauchy's boundary condition. The formulation of the third-kind boundary conditions is based on a general transfer relation between the reference value h_2^R on the boundary portion and the hydraulic head h to be computed at the same place. The reference hydraulic head h_2^R can also be time-dependent $h_2^R = h_2^R(t)$. The dual transfer coefficient Φ_h possesses the property of a resistance coefficient which constrains the discharge through the boundary and, additionally, differs between inflowing and outflowing conditions by means of Φ_h^{in} and Φ_h^{out}, respectively. If $\Phi_h = 0$ the boundary becomes impervious. On the other hand, using a very large value $\Phi_h \to 0$ the boundary condition of third-kind is reduced to a Dirichlet-type (1st kind) boundary condition approaching $h = h_2^R$.

For flow problems the transfer coefficient φ_h can be identified as a specific *colmation* (or *leakage*) coefficient as outlined in Figure 15(A) for inflowing (infiltration) conditions i.e. $\Phi_h \to \Phi_h^{in}(h_2^R > h)$. An adjacent river bed is sealed ('colmated') by a layer of thickness d and a conductivity of K_0^{in}. Normally, the layer conductivity K_0^{in} is much smaller than the conductivity K_1 of the aquifer to be modelled. Thereby the model boundary Γ represents the inner boundary of the 'colmation' layer Γ_3, where the model domain Ω ends.

The flux through such a 'colmation' layer can be estimated from the Darcy equation (see Figure 15(A), viz.:

$$q_{n_h} \approx -K_0^{in} \frac{\Delta h}{\Delta h} = -K_0^{in} \frac{h_2^R - h}{d} \qquad (4.1)$$

a simple relationship results for the transfer coefficient φ_h^{in} in 3D and 2D (vertical, horizontal unconfined) cases:

$$\Phi_h^{in} \approx \frac{K_0^{in}}{d} \text{ in } [d^{-1}] \qquad (4.2)$$

For horizontal confined flow problems an inherent vertical averaging becomes necessary (in the aquifer all fluxes are integrated over the depth) resulting in a depth-integrated transfer coefficient $\overline{\Phi}_h^{in}$ as:

$$\overline{\Phi}_h^{in} = B\Phi_h^{in} \approx B\frac{K_0^{in}}{d} \text{ in } [md^{-1}] \qquad (4.3)$$

For outward directed (exfiltrating) boundary fluxes according to Figure 15(B) following relationships for Φ_h^{out} and $\overline{\Phi}_h^{out}$ can be derived, analogously to the above, viz.,

$$\Phi_h^{out} \approx \frac{K_0^{out}}{d} \text{ in } [d^{-1}] \qquad (4.4)$$

$$\overline{\Phi}_h^{out} = B\Phi_h^{out} \approx B\frac{K_0^{out}}{d} \text{ in } [md^{-1}] \qquad (4.5)$$

The coefficients Φ_h^{in} and φ_h^{out} (also $\overline{\Phi}_h^{in}$ and $\overline{\Phi}_h^{out}$) differ if in case of infiltration the conductivities of the 'colmation' layer become depart from that of the exfiltration $K_0^{in} \neq K_0^{out}$.

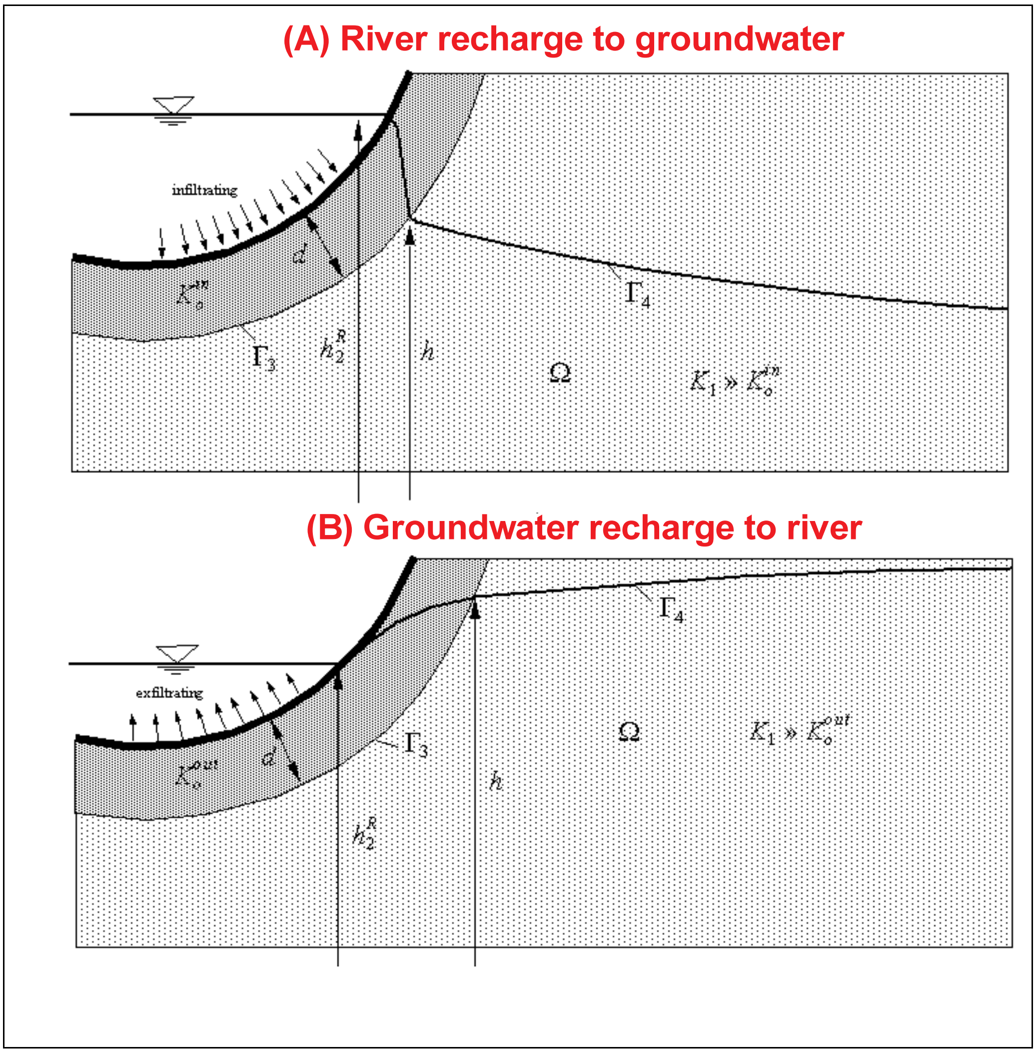


Figure 15 Description of the interaction between river and aquifer in the head-dependent, third-kind Cauchy's boundary condition.

5.2 Aquifer-river interaction model structure in the Upper Motueka River catchment

In the model domain the following rivers are considered as head-dependent, third-kind Cauchy's boundary:

- Tadmor
- Motueka
- Motupiko

Figures 16 to 20 show the discretization using 6 modal transigular finite element mesh and the river model structure generated by head-dependent, third-kind Cauchy's boundary condition in the Upper Motueka groundwater flow model. This river channel within the model is used to simulate the interaction between the surface water body and the aquifer. The amount and direction of flow depends on the simulated head differences between the rivers and groundwater. The blue colour in Figures 16–20 represents the river channel in the model domain and the size of finite-element mesh that from measured river cross sections.

The finite-element mesh size for the rivers used is appropriate to describe features of rivers, particularly the width of the rivers and is small enough to simulate the groundwater-river interaction in the Upper Motueka River catchment. The finite element mesh structure that represents the Tadmor, Motueka, and Motupiko Rivers has been refined until the finite element mesh is small enough to match the measured cross sections of the rivers. A very fine mesh structure is used to represent the Tadmor River due to relatively narrow river cross section characteristics compared with the Motueka River and the Motupiko River.

The cross section surveys data (1999/2000 year) provided by Tasman District Council is used at the corresponding nodal points of the finite element mesh to generate the head-dependent, third-kind Cauchy's boundary condition in the model. The Akima inter/extrapolation technique based on the cubic transfer function has been applied for the river channel where cross section surveys data are not available.

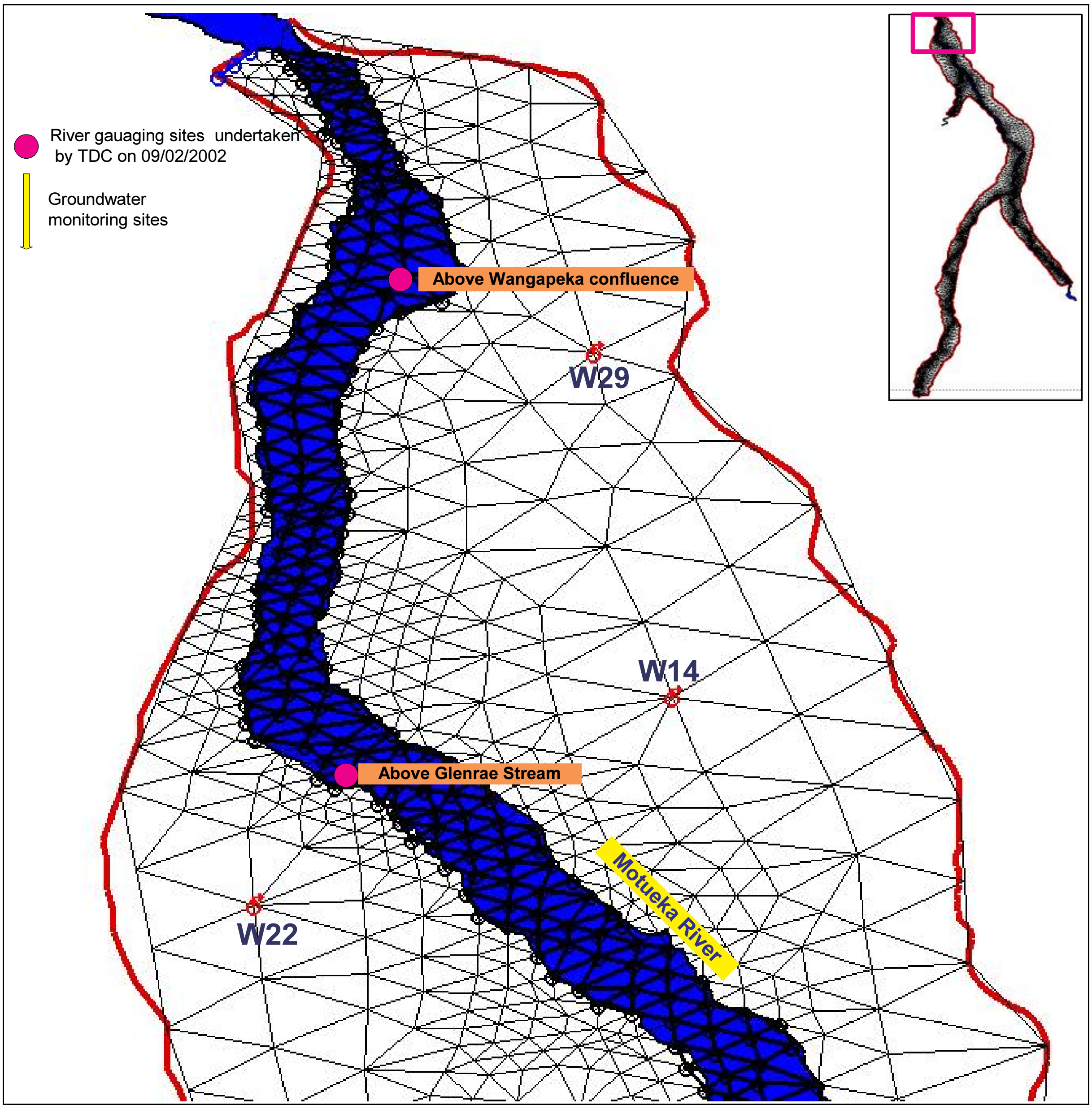


Figure 16 River model structure generated by *head-dependent, third-kind Cauchy's boundary condition* below the confluence of the Tadmor River and the Motueka River. The black marked circles and lines represent the river structure in the model domain. The blue colour represents the river channel.

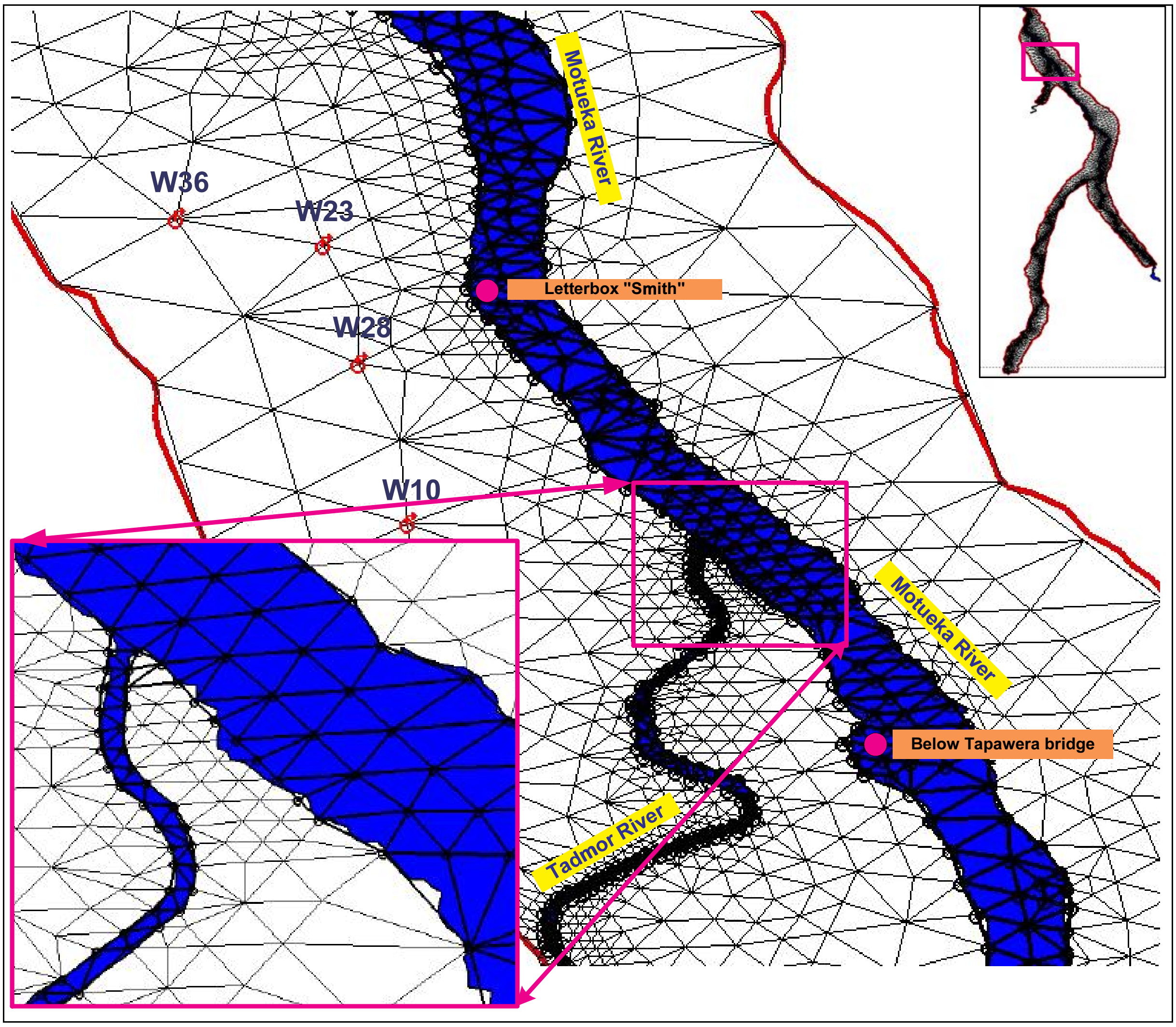


Figure 17 River model structure generated by *head-dependent, third-kind Cauchy's boundary condition* at the confluence of the Tadmor River and the Motueka River. The black marked circles and lines represent the river structure in the model domain. The blue colour represents the river channel.

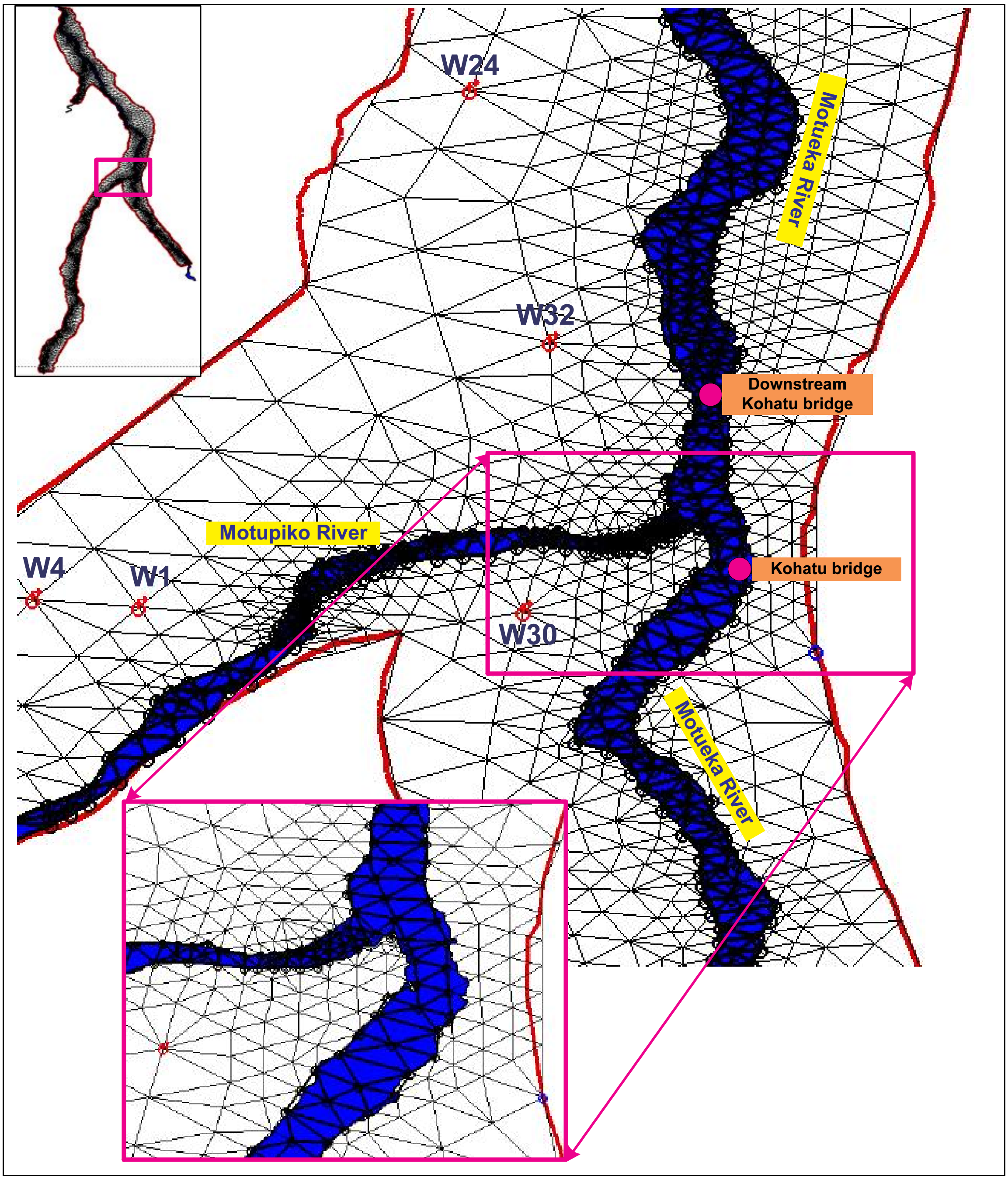


Figure 18 River model structure generated by *head-dependent, third-kind Cauchy's boundary condition* at the confluence of the Motupiko River and the Motueka River. The black marked circles and lines represent the river structure in the model domain. The blue colour represents the river channel.

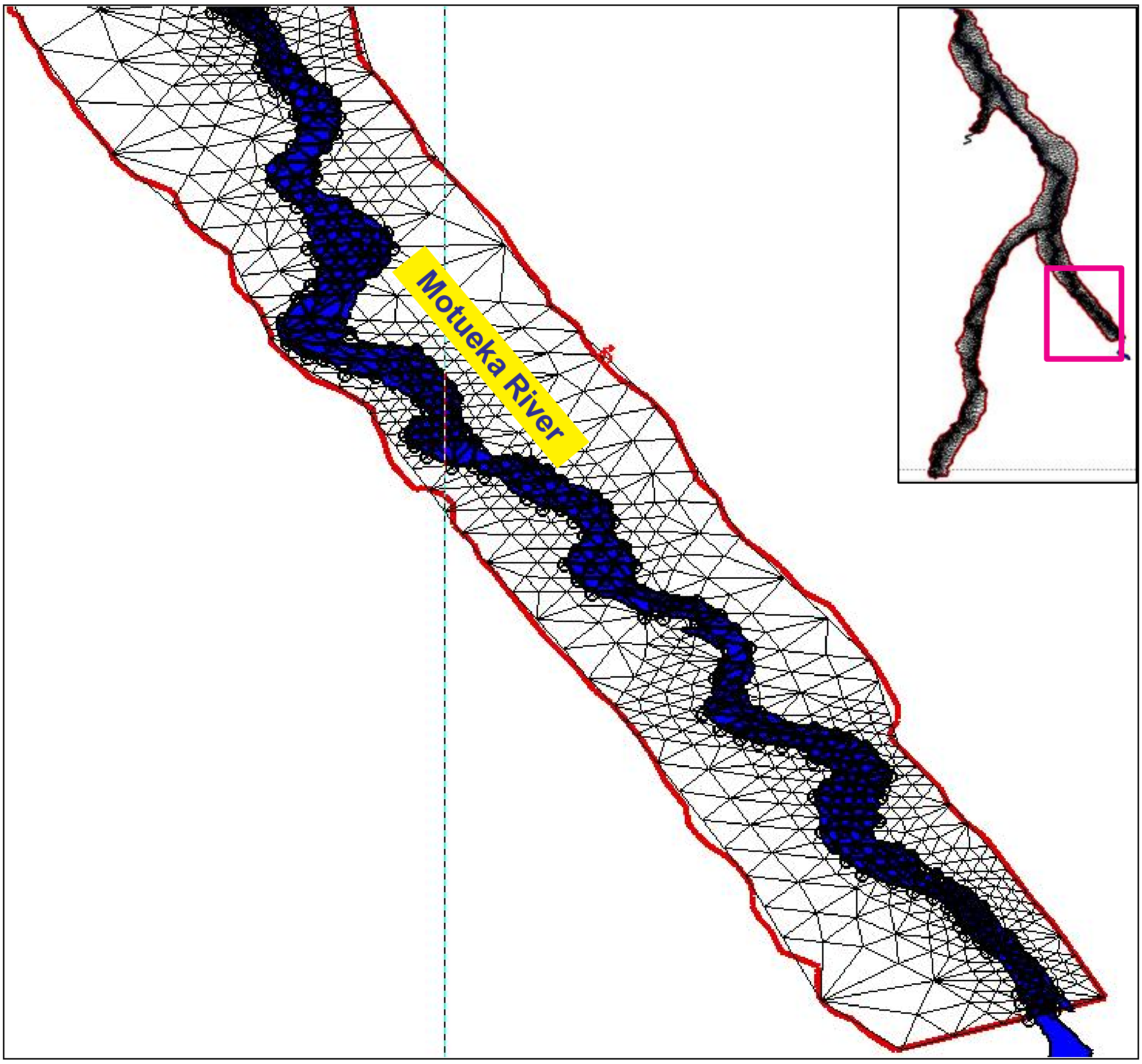


Figure 19 River model structure generated by *head-dependent, third-kind Cauchy's boundary condition* in the upper Motueka River valley. The black marked circles and lines represent the river structure in the model domain. The blue colour represents the river channel.

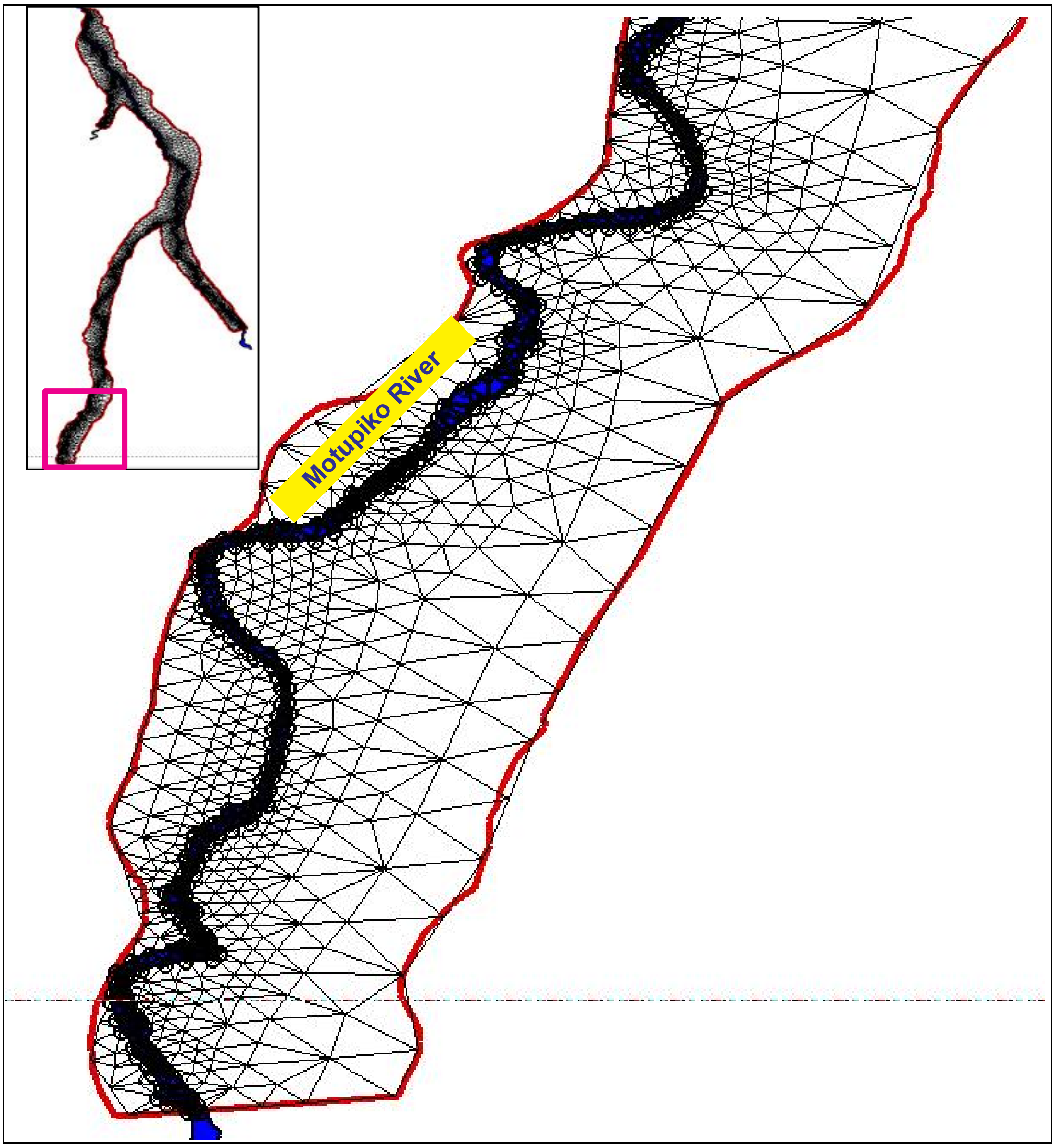


Figure 20 River model structure generated by *head-dependent, third-kind Cauchy's boundary condition* in the Motupiko River valley. The black marked circles and lines represent the river structure in the model domain. The blue colour represents the river channel.

5.3 Hydrological information of the aquifer-river interaction in the Upper Motueka River catchment

The three main river systems that contribute to flow in the Motueka River upstream of the Wangapeka River confluence are the Motueka, Tadmor, and Motupiko rivers. The reaches of these rivers where flow loss or gain occurs have been identified from eleven river gauging sites and two piezometric survey. undertaken by TDC. However the steady state groundwater flow model is calibrated using data from the survey on the 09/02/02 (Figures 22 and 23).

From Figures 21 and 22, it appears that river flow is generally lost to groundwater in reaches (river recharge to groundwater shown in Figure 15A) where the river valley widens and the cross sectional area of the aquifer increases. Conversely, groundwater generally discharges into the river (groundwater recharge to river shown in Figure 15B) along reaches where the river valley becomes narrower.

The flow rate values of approximately 134352 m^3/day (1555 l/sec) at Higgins reflect the amount of water that enters the study area via the upper Motueka River valley. Similarly, the flow rates of approximately 18144 m^3/day (210 /sec) at Quinney's Bush reflect the amount of water that enters the system via the Motupiko River valley. Total flow rates of approximately 153000 m^3/day (1770 l/sec) at Higgins and Quinney's Bush correspond closely with flow rates at Downstream Kohatu bridge, suggesting the flow rate values at Higgin's, and Quinney's Bush are reasonably accurate.

The 09/02/2002 gauging data shows that the Motueka River reaches between Tapawera bridge and Hyatt gains from approximately 25574m^3/day (295l/sec). Between Above Wangapeka confluence and Above Glenrae Stream gains approximately 36800m^3/day (426l/sec) because groundwater discharges back into the river downstream of Glenrae due to a narrowing of the valley as the Motueka River enters the gorge above the Wangapeka River confluence. This is the point where the Moutere Gravel and the valley quaternary gravels comes against the less permeable Separation Point Granite.

It is interesting to observe that from Figure 22, the Motueka River reaches between Downstream Kohatu bridge and Hyatt & Sons Ltd show that there is a loss in the Motueka River flow of approximately 17000m^3/day (198 l/sec). In this reach, fifteen groundwater abstraction wells (Figure 12) are located near the Motueka River and their total maximum allowable groundwater abstraction rate is approximately 18000 m^3/day (208 l/sec). Total maximum allowable groundwater abstraction rate (18000 m^3/day) of fifteen wells corresponds closely with the Motueka River flow loss rate (17000 m^3/day) between Downstream Kohatu bridge and Hyatt & Sons Ltd. The possibilities for this apparent Motueka River flow loss is that the hydraulic gradient is reversed such that the groundwater recharge to the Motueka River (see Figure 15B) stops entirely and the surface water will be induced from the Motueka River into the aquifer as additional recharge. This would cause a significant flow loss of the Motueka River between Downstream Kohatu bridge and Hyatt & Sons Ltd.

Similarly, the Motueka River reaches between Letterbox "Smith" and Above Glenrae Stream show that there is a loss in river flow of approximately 86000m^3/day (992 l/sec). In this region, six groundwater abstraction wells (W10, W11, W22, W23, W28, and W36 in Figure 12) are located near the Motueka River and their total maximum allowable groundwater abstraction rate is approximately 9858m^3/day (114 l/sec). The wide cross section of the Motueka River valley and the groundwater abstraction would cause the reverse hydraulic gradient to aquifer such that the surface water recharge into the aquifer begins.

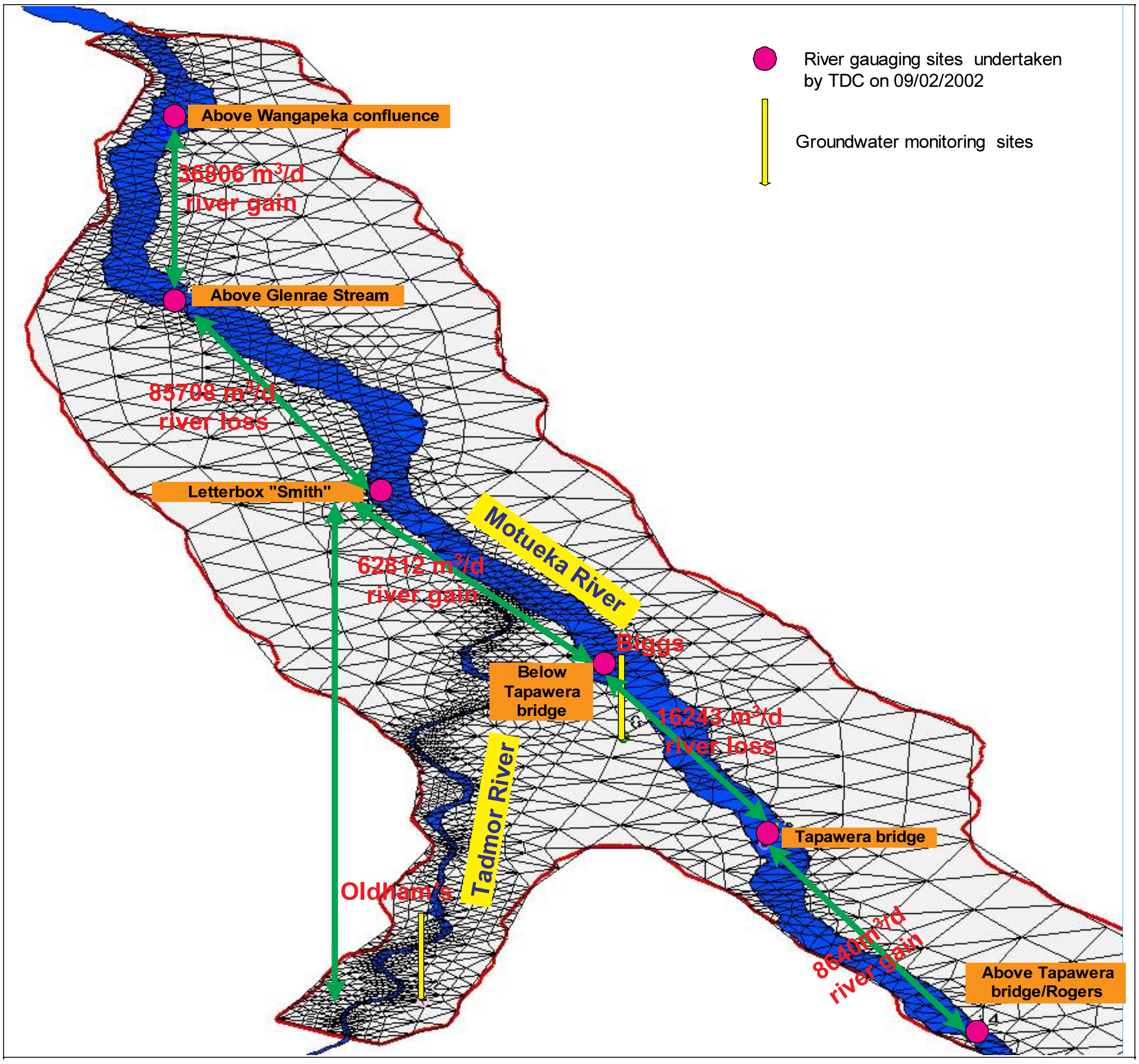


Figure 21 River flow loss and gain information at the confluence of the Tadmor River and Motueka River from concurrent gauging undertaken on 9 February 2002.

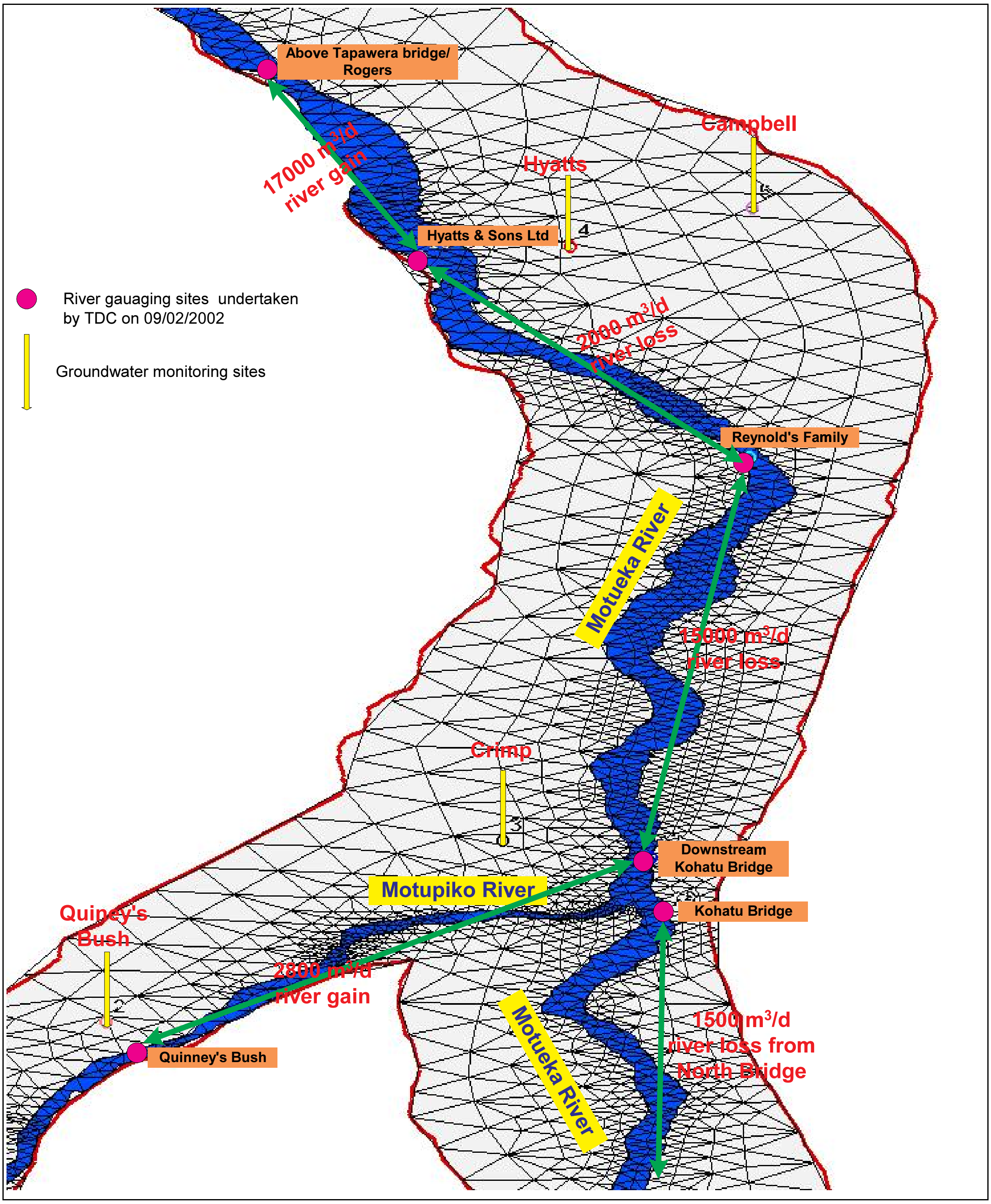


Figure 22 River flow loss and gain information at the confluence of the Motupiko River and Motueka River from concurrent gauging undertaken on 9 February 2002.

6.0 Calibration of the Upper Motueka groundwater flow model

Groundwater flow modelling needs to establish a best fit between observed and predicted head distribution through a phase of model calibration process. The model used here has been calibrated using water level recording from the eight groundwater monitoring wells shown in Figure 3 and Table 1. The model has been calibrated using visual comparison of the match between predicted and observed values at each of monitoring wells. The river model displayed in Figures 16–20 is also calibrated on the basis of measurement of the river gauging data shown in Figures 21 and 22, to match river flows loss and gain through the flow budget analysis. The following parameters in the groundwater model were optimised:

1. spatial hydraulic conductivity
2. spatial in-transfer coefficient and out-transfer coefficient between river and aquifer

For the river loss and gain calibration, the spatial Φ_h^{in} in-transfer coefficient and Φ_h^{out} out-transfer coefficient between river and aquifer defined in Eqs. (4.1) and (4.4), respectively need to be defined in the model. In Eqs. (4.1) and (4.4), a thickness of the colmation (leakage) layer (Figure 15), *d* must be assumed at each river finite-element mesh to describe the materials that restrict the flow of the water between the river and aquifer system. This thickness is typically unknown so has been specified as 0.3 m throughout the river model domain. The conductivity of the river bed is adjusted during the calibration. Values of K_h^{in} and K_h^{out} which represent a colmation (leakage) layer conductivity (conductivity of the river bed) in Eqs. (4.1) and (4.4) are normally much smaller than the hydraulic conductivity of the aquifer and are known to be equal to 1~8 percent of the horizontal hydraulic conductivity of the aquifer (Spitz and Moreno, 1996; Morgan and Jones, 1999). The Φ_h^{in}, in-transfer coefficient and Φ_h^{out}, out-transfer coefficient in the river model are varied in the range of the 1~8 percent of the hydraulic conductivity of the aquifer with the fixed 0.3m of a colmation (leakage) layer thickness, *d*. The Φ_h^{in}, in-transfer coefficient varied from 4200x10^{-4} 1/day to 150000x10^{-4} 1/day. The value of Φ_h^{out}, out-transfer coefficient is in the range of 5000x10^{-4} 1/day to 510000x10^{-4} 1/day. These values are derived from calibration.

Figure 23 displays the model simulation of flow gain and loss between rivers and groundwater in the area of the confluence of the Tadmor River and the Motueka River after calibration. The model simulation of the flow gain and loss between rivers and groundwater at the area of the confluence of the Motupiko River and the Motueka River is shown in Figure 24. In Figures 23 and 24, the blue colour represents the groundwater recharge to rivers (river flow gain) and groundwater loss due to abstraction from the wells. The groundwater loss due to abstraction from the wells is displayed with well ID number and their modelled pumping rate (Table 3). The magnitude of groundwater recharge to rivers (river flow gain) and groundwater loss due to abstraction from the wells is displayed by the size of blue circle; a large groundwater recharge to rivers and groundwater abstraction from the wells occurs at the region of big blue circle. For example, the relatively large size of the blue colour circle for the well W14 in Figure 23 indicates a high abstraction rate of 2083m^3/day. The red colour represents the river and rainfall recharge to groundwater (river flow loss). Similarly, the magnitude of the river recharge to groundwater (river flow loss) and rainfall recharge to groundwater is displayed by the size of red circle. The number in the yellow box in Figure 23 and Figure 24 indicates the observed river flow loss or gain from eleven river gauging sites undertaken by TDC on the 09/02/02.

The river-groundwater interaction simulation demonstrates that the model result is well matched with observation data of river flow loss and gain undertaken on 09/02/2002 (Figures 21 and 22). For example, the February 2002 gauging data shows that the Motueka River reaches between Tapawera bridge and Hyatt and between Above Wangapeka confluence and Above Glenrae Stream gain flows of approximately 25573 m^3/day (295 l/sec) and 36979 m^3/day (428 l/sec) from groundwater, respectively. The Upper Motueka groundwater flow model predicts that there is a flow gain of 25932 m^3/day (300 l/sec) between Tapawera bridge and Hyatt (Figures 23 and 24) and of 36102 m^3/day (418 l/sec) between Above Wangapeka confluence and Above Glenrae Stream (Figure 24, Table 4).

The river flow loss between Above Glenrae Stream and Letterbox "Smith" to groundwater is predicted to be 83452m^3/day (966 l/sec), compared to the observed river flow loss of approximately 85708m^3/day (992 l/sec). The river-aquifer interaction model structure in the model simulates very well a significant river flow loss between Above Glenrae stream and Letterbox "Smith" to the Moutere gravel due to the possibility of the wide cross section of the Motueka River valley and the groundwater abstraction. There is an observed river flow loss of approximately 16243m^3/day (188 l/sec) to groundwater between Below Tapawera bridge and Tapawera bridge (Figure 23, Table 4) and the predicted river flow loss between these reaches of the Motueka Rive would be 16436m^3/day (190 l/sec). The river flow loss between Hyatt and Downstream Kohatu bridge to groundwater is predicted to be 16217m^3/day (197 l/sec), compared to an observed river flow loss of approximately 17000m^3/day (197 l/sec). The river flow loss rate, 17000m^3/day (197 l/sec) between two reaches corresponds with total maximum allowable abstraction in the fifteen well, 18000m^3/day (208 l/sec). The modelled groundwater abstraction rate from the fifteen wells between those two reaches is 10200m^3/day (118 l/sec) that is 60% of total maximum allocable abstraction in the fifteen wells. The size of blue colour at the abstraction wells that represents the magnitude of groundwater flow loss is relatively big, indicating that the river flow loss in this area is due to the groundwater abstraction wells that are located near the Motueka River. The model developed simulates very well the river flow loss due to the groundwater abstraction. It demonstrates that the Upper Motueka groundwater flow model developed can be used as a tool to investigate the effect of the abstraction on the river flow and groundwater levels.

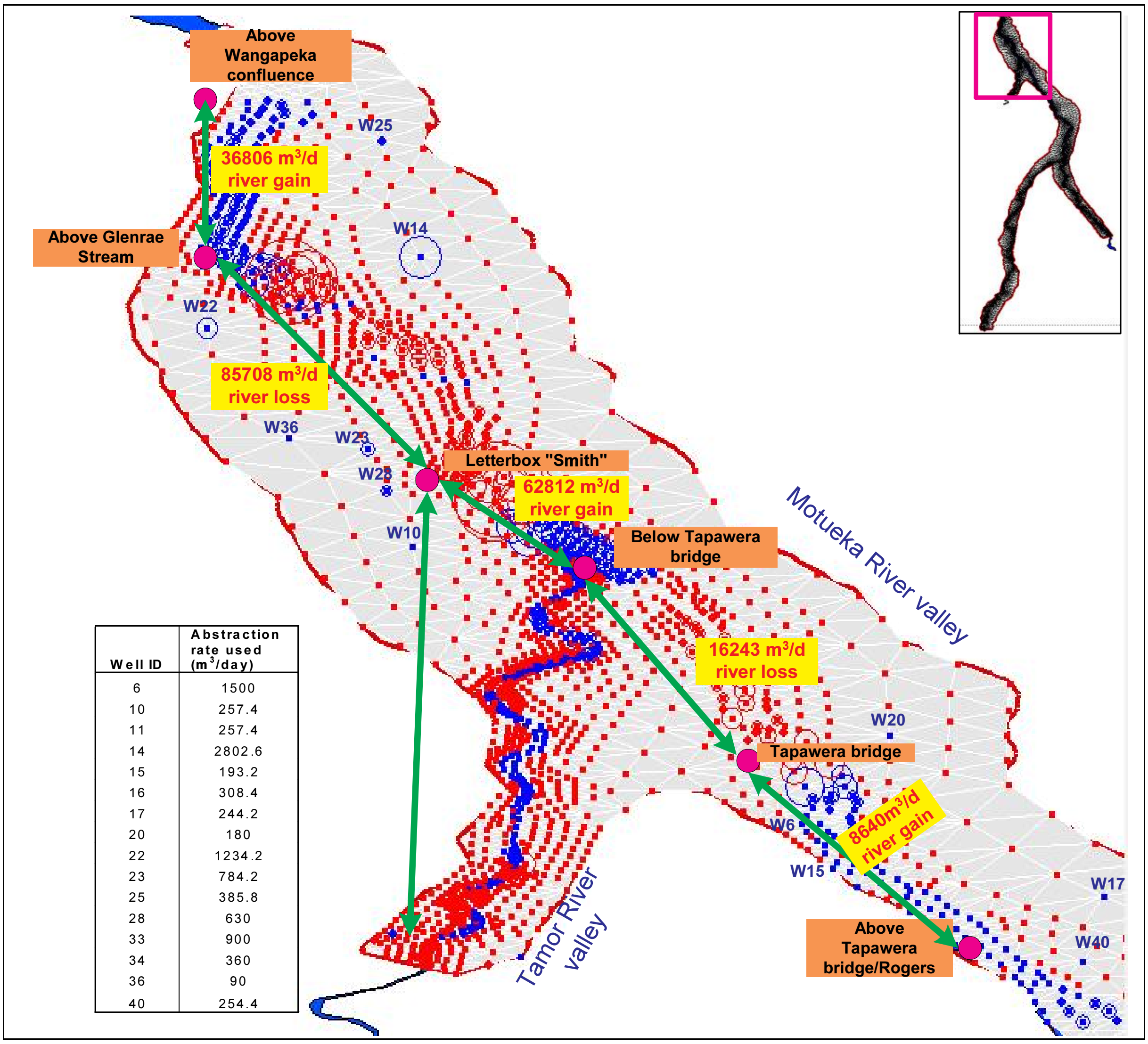
Table 5 shows the observed and predicted groundwater levels in the eight calibration wells used in the steady-state calibration. The predicted groundwater levels are well matched with the observed groundwater levels. The model calibration is well achieved in terms of both groundwater levels and river flow loss and gain. Figures 25 and 26 show the contour map of predicted groundwater head distribution with vectors indicating groundwater flow direction at the area of the confluence of the Tadmor River and the Motueka River and at the confluence of the Motupiko River and the Motueka River, respectively. The three-dimensional projection view of the predicted groundwater head distribution is also visualised in Figures 27 and 28.

Table 3 Observed River flow loss and gain and predicted after calibration. + and – represent river flow gain and loss, respectively.

Reach	X	Y	Discharge (m^3/day)	Observed river loss or gain (m^3/day)	Predicted river loss or gain (m^3/day)
Kohatu bridge	2496187	5972915	132969	No gauging	??
Downstream Kohatu	2496152	5973305	153878	No gauging	??
Reynolds	2496422	5976055	138844	-15034	-16217 between Hyatt and Downstream Kohatu
Hyatts	2495515	5977426	136857	-1987	
Rogers	2495102	5978701	153619	16761	17031
Tapawera bridge	2494499	5980096	162432	8812	8901
Below Tapawera	2494040	5981439	146188	-16243	-16436
Smiths	2493328	5982558	209002	62813	60498
Glenrae	2492777	5984045	123292	-85708	-83452
Above Wangapeka confluence	2492737	5985290	160272	36979	36102

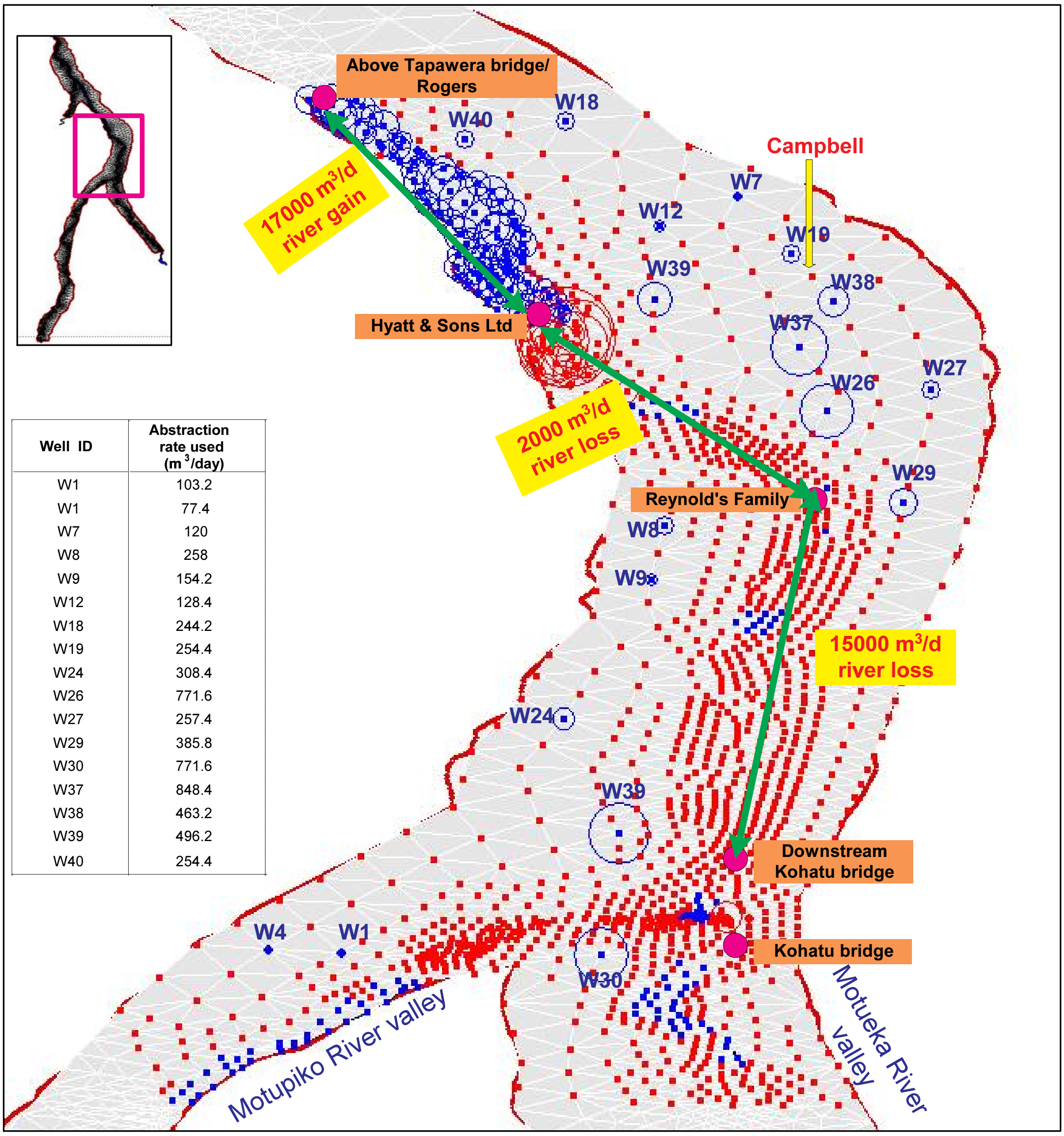
Table 4 Observed groundwater levels and predicted groundwater levels after calibration for the eight monitoring sites.

Site Name	Grid Ref	X	Y	Observed GWL (m)	Predicted GWL (m)
Oldham	N28:9350-7895	2493500	5978950	150.35	149.1
Biggs	N27:9409-8087	2494085	5980869	136.62	137.1
Campbell	N28:9643-7777	2496432	5977765	155.58	156.2
Hyatt	N28:9593-7750	2495927	5977500	154.97	155.3
Crimp	N28:9574-7343	2495743	5973426	179.11	181.6
Quinney's Bush	N28:9465-7217	2494645	5972174	191.30	191.7
Higgins	N28:9638-6996	2496379	5969958	201.51	199.23



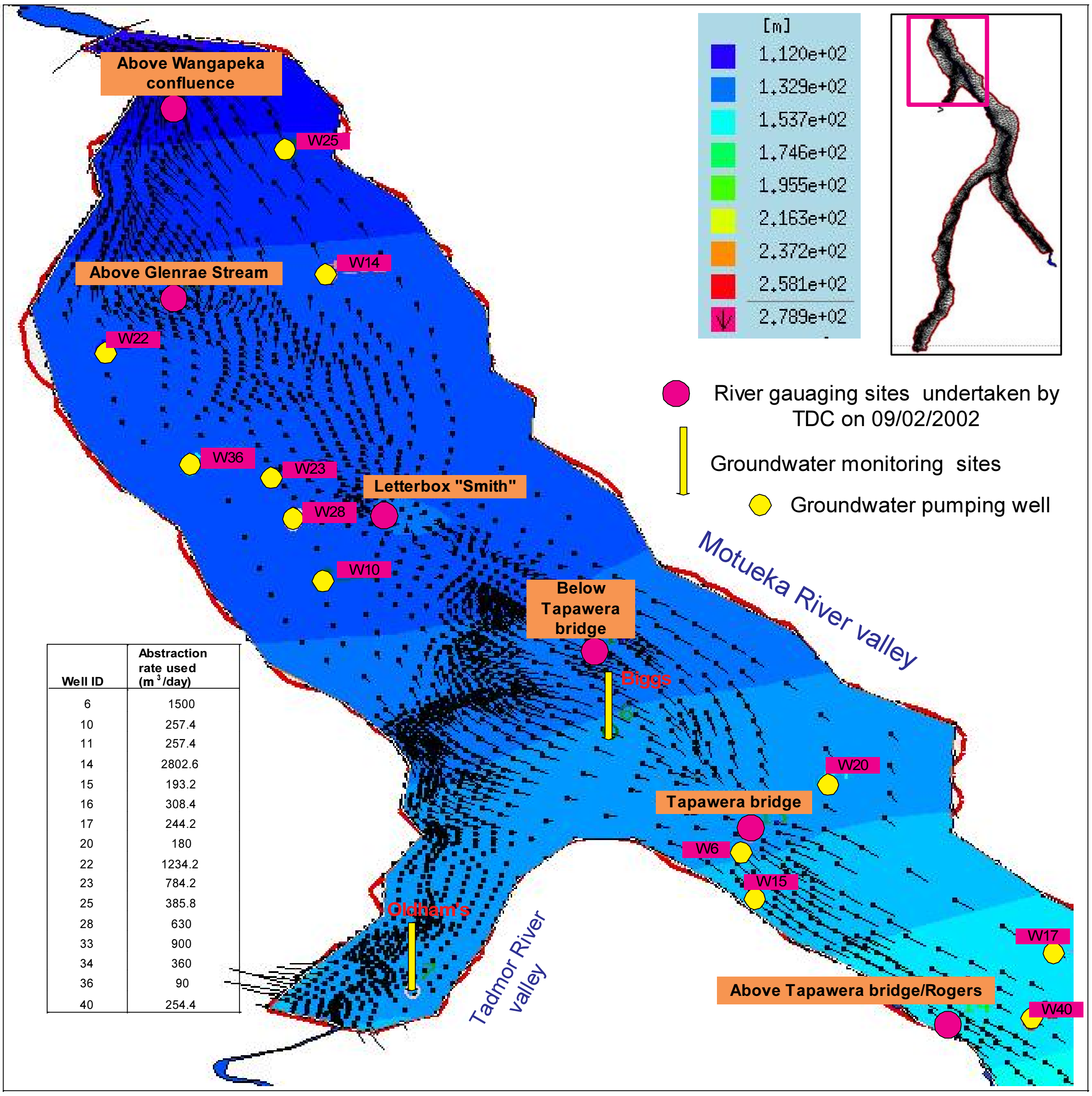
Well ID	Abstraction rate used (m^3/day)
6	1500
10	257.4
11	257.4
14	2802.6
15	193.2
16	308.4
17	244.2
20	180
22	1234.2
23	784.2
25	385.8
28	630
33	900
34	360
36	90
40	254.4

Figure 23 Simulation result of flow gain and loss between rivers and groundwater at the area of the confluence of the Tadmor River and the Motueka River after calibration. See text (section 6.0) for explanation of symbols.



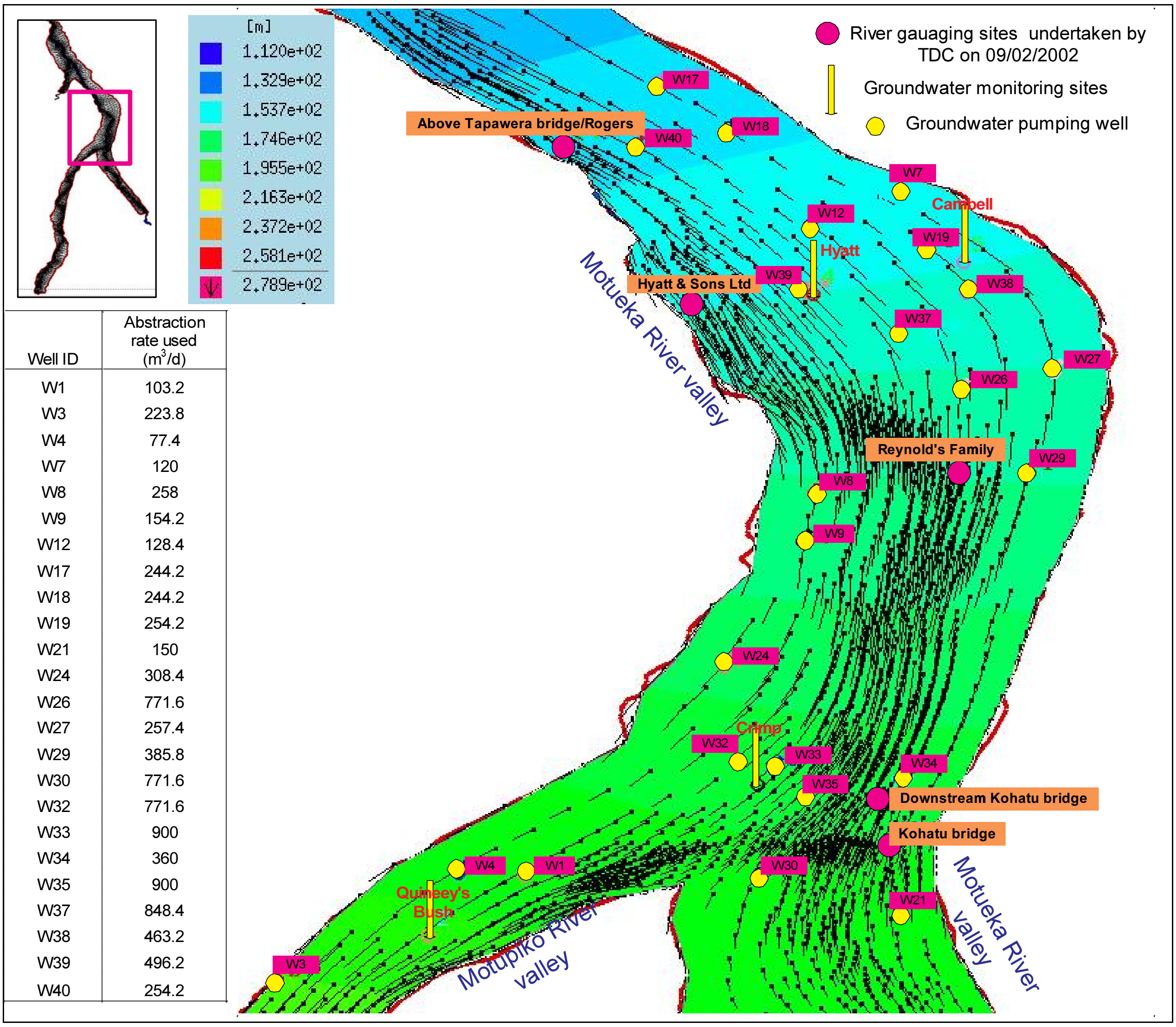
Well ID	Abstraction rate used (m^3/day)
W1	103.2
W1	77.4
W7	120
W8	258
W9	154.2
W12	128.4
W18	244.2
W19	254.4
W24	308.4
W26	771.6
W27	257.4
W29	385.8
W30	771.6
W37	848.4
W38	463.2
W39	496.2
W40	254.4

Figure 24 Simulation result of flow gain and loss between rivers and groundwater at the area of the confluence of the Motupiko River and the Motueka River after calibration. See text (section 6.0) for explanation of symbols.



Well ID	Abstraction rate used (m^3/day)
6	1500
10	257.4
11	257.4
14	2802.6
15	193.2
16	308.4
17	244.2
20	180
22	1234.2
23	784.2
25	385.8
28	630
33	900
34	360
36	90
40	254.4

Figure 25 Predicted groundwater levels and groundwater flow pattern after calibration at the confluence of the Tadmor River and the Motueka River.



Well ID	Abstraction rate used (m^3/d)
W1	103.2
W3	223.8
W4	77.4
W7	120
W8	258
W9	154.2
W12	128.4
W17	244.2
W18	244.2
W19	254.2
W21	150
W24	308.4
W26	771.6
W27	257.4
W29	385.8
W30	771.6
W32	771.6
W33	900
W34	360
W35	900
W37	848.4
W38	463.2
W39	496.2
W40	254.2

Figure 26 Predicted groundwater levels and groundwater flow pattern after calibration at the confluence of the Motupiko River and the Motueka River.

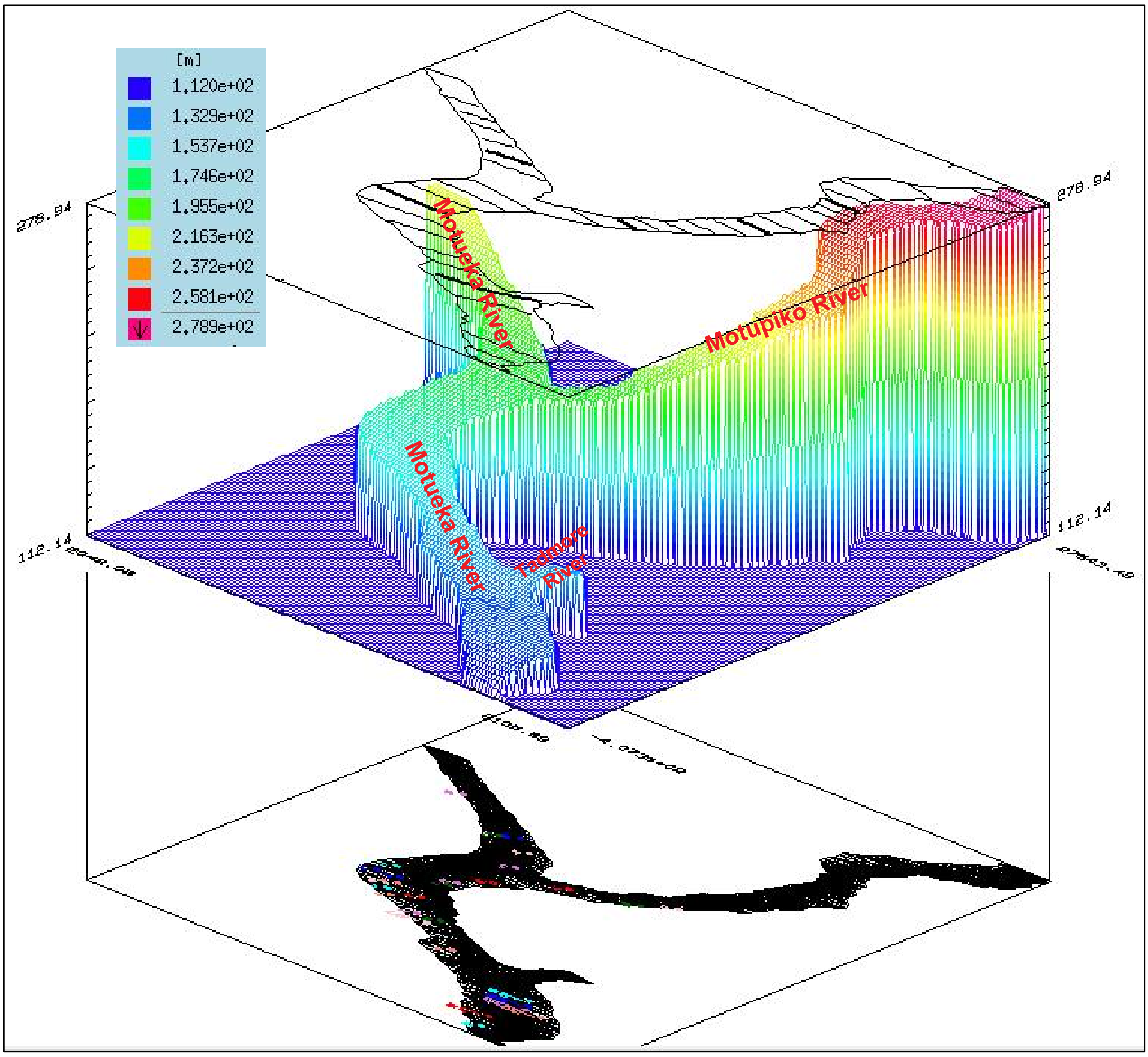


Figure 27 Three-dimensional projection view of the predicted groundwater levels in the model domain.

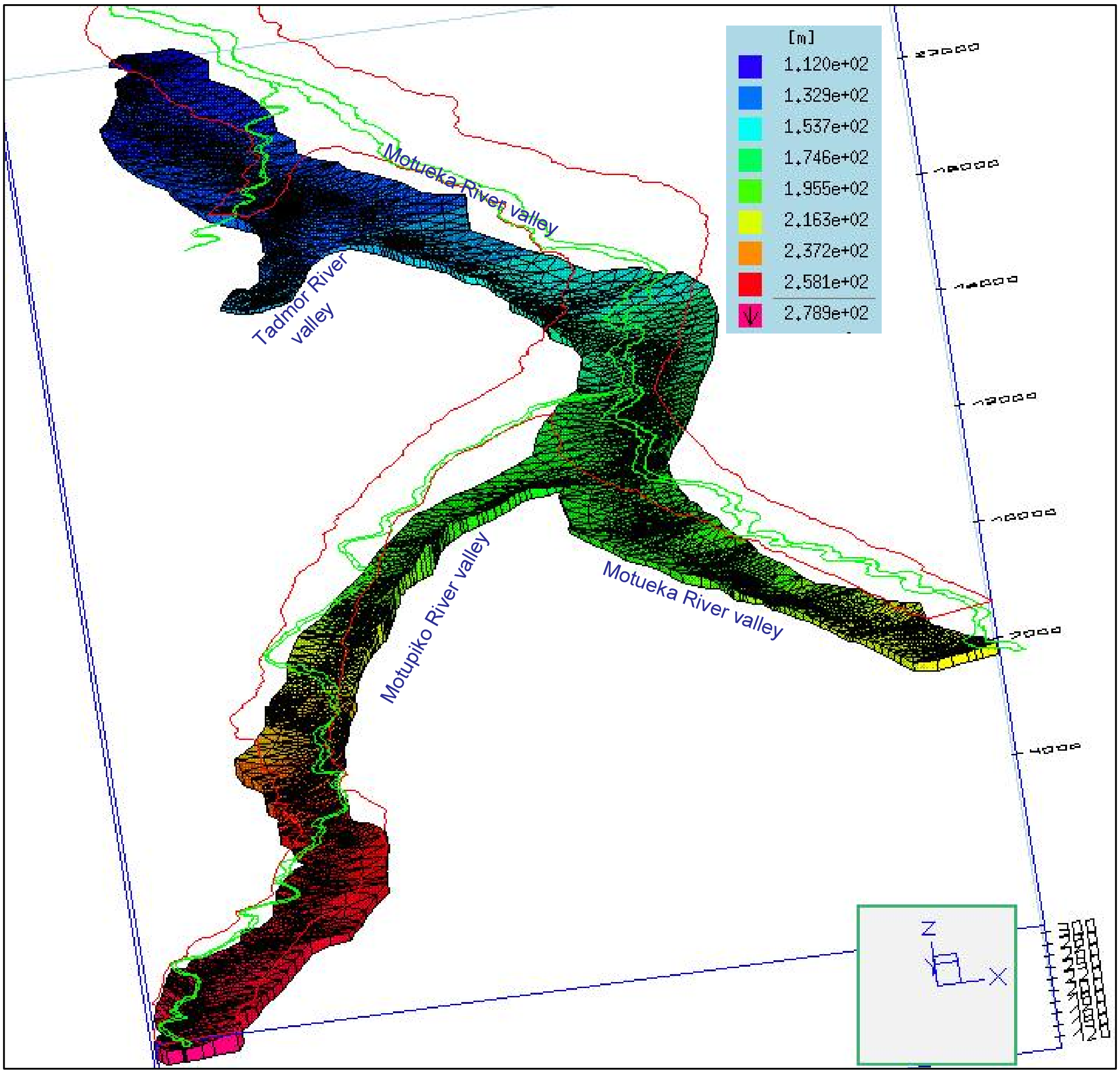


Figure 28 Three-dimensional view of the predicted groundwater levels with the aquifer thickness in the model domain.

7.0 SUMMARY

- The effects of water abstraction from groundwater and surface water is a growing issue for water management in the Upper Motueka River catchment. The purpose of this study is to develop a three-dimensional groundwater flow model that is capable of analysing the effects of groundwater abstraction on stream flow and groundwater levels in order to manage the water resources in the Upper Motueka area sustainably.

- In this study, an adaptive finite-element groundwater modelling system is implemented to simulate the relations and interactions between shallow aquifer and river systems in the Upper Motueka River catchment. The model boundary of the Motueka groundwater flow model focuses from the 3km downstream area of the Motueka River at the confluence of the Tadmor River and Motueka River, to 3km upstream of the Tadmor River from the confluence of the Tadmor River and Motueka River, to approximately 8 km upstream of Kohatu on the Motueka River, and to approximately 15 km upstream of the Motupiko River from the confluence of the Motueka River and Motupiko River.

- This report provides results from the development of the model in a steady state condition. The study will continue with the development of the model into a dynamic state for transient and water management simulations.

- The aquifer domain is discretised using 6 modal transigular prism elements. The 3-D finite-element groundwater flow model in the Upper Motueka River catchment has been upgraded continually by changing the structure of triangular finite-element mesh to simulate the interaction between aquifer and river. The finite element mesh structure that represents the Tadmor, Motueka, and Motupiko Rivers is refined to match with the measured cross sections of the Motueka and Motupiko Rivers. The Upper Motueka groundwater flow model has 12365 mesh elements and 13080 mesh nodes.

- The thickness of the aquifer is estimated raging from 6.5m to 8m at the area of low reaches of the Motueka River valleys from the Tapawera Bridge. The average thickness of aquifer is defined at 11.5m in the area from the Tapawera Bridge to the confluence of the Motupiko and Motueka Rivers. Due to lack of field data the aquifer thickness has been simulated at approximately average 13.5m in the Motupiko River and Upper Motueka River valleys above the confluence of two rivers

- The groundwater abstraction model has been developed using a first-kind *Dirichlet*-type boundary conditions in the model. There are 41 groundwater abstraction wells in the model domain. Total maximum allowable abstraction rate over the 41 wells is 36395m^3/day. To simulate the effect of the groundwater abstraction on the river flows and groundwater levels, 60% of maximum allowable abstraction rate is assigned to each well in the steady-state model. Therefore, the groundwater abstraction model in the Upper Motueka groundwater flow model is simulated on total 21827m^3/day groundwater abstraction from 41 wells.

- The river model structure is developed using *head-dependent, third-kind Cauchy's boundary condition* in the model domain. Three rivers (Tadmor, Motueka and Motupiko) are represented in the model domain. This river model is used to simulate the leakage and/or gain from surface bodies where the exchanges of water between aquifer and rivers depend on the head differences between rivers and groundwater. Finite-element mesh size for the rivers is chosen as appropriate to describe features of rivers and is small enough to simulate the groundwater-river interaction in the Upper Motueka River catchment. The finite element mesh structure that represents the Tadmor, Motueka, and the Motupiko Rivers has been refined until the finite element mesh was small enough to match the observed cross section data. A fine mesh structure has used to represent the Tadmor River due to relatively narrow river cross section characteristics compared with the Motueka and Motupiko Rivers.

- The steady-state Upper Motueka groundwater flow model has calibrated using water level recording from the eight groundwater monitoring wells (Figure 3 and Table 1) and on the basis of measurement on the basis of river gauging data (Figures 22 and 23). The model has been calibrated using visual comparison of the match between predicted and observed values. During calibration the hydraulic conductivity and the in and out transfer coefficients (between river and aquifer) were optimised. The model calibration shows good results in terms of both groundwater levels and river flow loss and gain (Section 6).

- In this work, it is demonstrated that the Upper Motueka groundwater flow model developed in 3-D adaptive finite-element structure is feasible and can be used as a tool to investigate the effect of the abstraction on the river flow and groundwater levels. The next step, a dynamic Upper Motueka groundwater flow model currently being developed. This dynamic model will provide a better understanding of groundwater flow and its interaction with surface water in the Upper Motueka River catchment, and provide a tool to assess different water allocation management regimes in the Upper Motueka River catchment.

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Table 5 Information on the groundwater abstraction wells in the model domain.

Well ID	Eastings	Northings	Pumping rate modelled (m^3/day)	Max Daily Take (m^3/day)	Irrigation Area (ha)	Landuse	Well No.	Consent	Applicant	Address
W1	2494930	5972736	**103.2**	172	4	Pasture	4550	40504	B J & E M Duncan	Motupiko
W2	2494288	5971216	**951.6**	1586	37			40548	K J Fry	Motupiko
W3	2494103	5971805	**223.8**	373	8.7		4810	40596	A F Morton	Motupiko
W4	2494723	5972643	**77.4**	129	3		4611	40631	Motupiko Dairy Farm Ltd	C/- J R Raine
W5	2493819	5970981	**1028.4**	1714	40	Pasture	4551	40632	Motupiko Dairy Farm Ltd	C/- J R Raine
W6	2494410	5980020	**1500**	2500	50		4638 & 4612	40519	N C Warnes	Tadmor Valley Road
W7	2496167	5978388	**120**	200	4	Barley, Red clover	4553	40550	R S Wilkinson	R D 2
W8	2495977	5975847	**258**	430	15	Pasture	4777	40205	D M Hajdu	7 Arrow Street
W9	2495870	5975530	**154.2**	257	6	Pasture	4772	40277	Hubbard Partnership	4 Glover Place
W10	2493241	5982076	**257.4**	429	10	Potato and Pasture	4584	40392	S P & D K Phillips	Glenrae Road
W11	2493528	5981846	**257.4**	429	10	- See map for diff. areas	4583	40393	S P & D K Phillips	Glenrae Road
W12	2495927	5978111	**128.4**	214	5	Blackberries	4559	40416	C R Fry	C/- Ross Fry
W13	2496412	5970755	**216**	360	10	Pasture	4648	40430	M J & H A Gillard	Kohatu
W14	2493338	5984308	**2802.6**	4671	109	Hops & Blackcurrants	4564	40446	Hinetai Hops Ltd	P O Box 2244

W15	2494458	5979645	**193.2**	322	9	Raspberries	4641	40518	P B Higgins & Sons Ltd	P O Box 1
W16	2496133	5970328	**308.4**	514	12		5641	40530	Boscobel (Golden Downs) Ltd	C/- Harry Mortimer
W17	2495509	5979291	**244.2**	407	9.5		4555	40561	D A & J K Cooper	4741 Motueka Valley Highway
W18	2495683	5978858	**244.2**	407	9.5	Red clover, Barley, Lamb feed	4554	40562	D A & J K Cooper	4741 Motueka Valley Highway
W19	2496351	5977890	**254.4**	424	9.9	Red clover (is grown in different paddocks each year) and Pasture	4558	40566	J W Rodgers	Tapawera
W20	2494750	5980580	**180**	300	7		4769	40570	K R Haakma	C/- Tapawera Postal Agency
W21	2496219	5972330	**150**	250	5		4598	40576	JN McGaveston	State Highway 6
W22	2492665	5983721	**1234.2**	2057	48	Pasture	4563	40583	F J & E A O`Connor	C/- Martin O`Connor
W23	2493063	5982691	**784.2**	1307	30.5	Pasure	4476	40584	Fj & Ea & Mp O`Connor & F & T Leov	C/- Martin O`Connor
W24	2495682	5974438	**308.4**	514	12	Pasture	4581	40610	I D Diack	Old School Road
W25	2493179	5985135	**385.8**	643	15	Pasture and Clover for seed production and foda crops	4568	40613	David E & Daphne J McGaveston & Hamish Kennedy	Main Road Tapawera
W26	2496525	5976679	**771.6**	1286	30	Blackcurrants	4548	40616	Toka Farms Ltd	C/- Robbie Reynolds

W27	2496821	5976898	**257.4**	429	10	Pasture	4547	40618	Toka Farms Ltd	C/- Robbie Reynolds
W28	2493142	5982438	**630**	1050	24.5	Pasture	4630	40619	M & J Bonny	47 Leicester Street
W29	2496619	5976027	**385.8**	643	15	Pasture	4592	40622	Toka Farms Ltd	C/- Robbie Reynolds
W30	2495644	5972602	**771.6**	1286	30	Pasture (Dairy)	4570	40623	Paul Dewhirst	Boscobel
W31	2495866	5971244	**1543.2**	2572	60	Pasture (Dairy)	4569	40624	Paul Dewhirst	Boscobel
W32	2495768	5973517	**771.6**	1286	30	Pasture	4792	40650	Wairua Farm (2001) Ltd	C/- E N & M A Baigent
W33	2495827	5973233	**900**	1500	35	Pasture	4578	40651	Wairua Farm (2001) Ltd	C/- E N & M A Baigent
W34	2496226	5973367	**360**	600	14	Pasture	4599	40652	Wairua Farm (2001) Ltd	C/- E N & M A Baigent
W35	2495700	5973590	**900**	1500	35	Pasture	4579	40655	Wairua Farm (2001) Ltd	C/- E N & M A Baigent
W36	2492940	5982936	**90**	150	3.5	Pasture	4567	40715	O B & J E Oxnam and M N Oxnam	345 Tapawera-Baton Road
W37	2496291	5977170	**848.4**	1414	33	Blackcurrants	4556	40730	Hyatt & Sons Ltd	Sunrise Valley
W38	2496519	5977477	**463.2**	772	18	Pasture and lamb fattening crops	4774	40732	Hyatt & Sons Ltd	Sunrise Valley
W39	2496016	5977533	**496.2**	827	19.3	Blackcurrants	4802	40733	Hyatt & Sons Ltd	Sunrise Valley
W40	2495362	5978677	**254.4**	424		Red clover, Lucern - This is grown in different paddocks each year.	4541	40751	R J & S A Rodgers	Tapawera
W41	2497448	5968847	**28.2**	47	1.1	Golf green	4650	40849	Golden Downs Golf Club Inc	C/- Grant R Faulknor