2. Literature review and synthesis

2.1 PHYSICAL SETTING

The Motueka Catchment is situated at the western margin of the Moutere Depression and drains an area of 2180 km^2 – the largest catchment in the Nelson region (Fig. 1). It flows into Tasman Bay, a shallow but productive coastal water body of high economic, ecological and cultural significance. The Riwaka River drains a 105 km^2 catchment that flows into Tasman Bay 3 km north of the Motueka River mouth (Fig. 1 and Photo 1a).

The main stem[4] of the Motueka River rises in the Red Hills and flows north for about 110 km to the sea (Fig. 1). The river is joined from the east by a series of small and medium-sized tributaries (Stanley Brook, Dove, Orinoco, and Waiwhero) draining hilly terrain underlain by Moutere gravels, and from the west by a series of generally much larger tributaries, which drain both hilly terrain on Moutere gravels (Motupiko, Tadmor) and mountainous terrain underlain by a complex assemblage of sedimentary and igneous rocks (Wangapeka, Baton, Pearse, Graham, Pokororo, Rocky River and Brooklyn Stream). Similarly, the Riwaka River drains dominantly mountainous terrain underlain by sedimentary and igneous rocks. The major subcatchments and their areas are listed in Table 1. Elevation ranges from sea level up to 1600–1850 metres on the catchment divide in the upper reaches of the Motueka, Baton and Wangapeka rivers. Most of the catchment lies at relatively low elevation, with more than 50% being between sea level and 500 m.

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[4] This is the main stem of the Motueka only in a geographical sense; hydrologically the Wangapeka is more important as it drains a larger area and contributes more water.

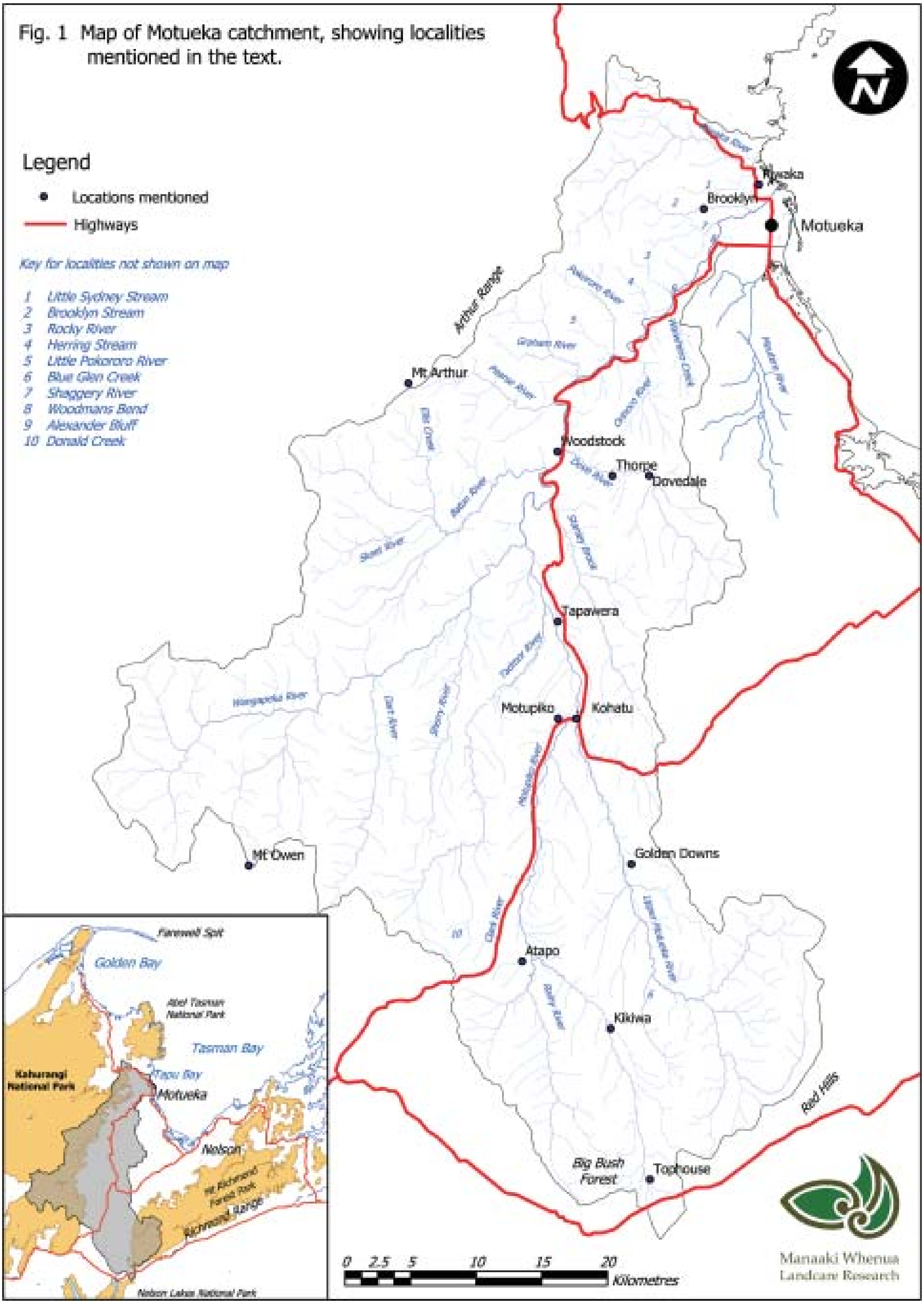

Fig. 1 Map of Motueka catchment, showing localities mentioned in the text.

Photo 1a Broad, low-angle fan of the Motueka–Riwaka plains. Riwaka River enters Tasman Bay in the foreground and the Motueka in the middle distance. Note the prominent wetlands, delta and sandspit formed by the Motueka River.

Photo 1b Meandering channel of the lower Motueka River across the Motueka–Riwaka plains. Channel is confined between stopbanks. Note the old cutoff meander bends and intensive horticulture on the plains. Motueka township in the background.

TRIBUTARY	AREA (km²)	AREA (%)
Upper Motueka	419	19
Motupiko	344	16
Tadmor	124	6
Stanley Brook	93	4
Dove	102	5
Orinoco, Waiwhero	92	4
Wangapeka	483	22
Baton	212	10
Pearse	49	2
Graham	40	2
Pokororo, Herring, Rocky	93	4
Brooklyn	17	1
Riwaka	105	5

Table 1: Subcatchment areas

2.1.1 Physiography

The catchment is dominated by mountains and hill country (Fig. 2). About 67% of the catchment has slopes greater than 15º (Fig. 3). The mountains are characterised by strong lithologic and structural control of landforms (Photos 2 and 3), with dip-and-scarp[5] topography common and notable areas of karst[6] on Mt Owen and Mt Arthur. The hilly terrain can be grouped into three types:

- intensely fluvially dissected hill country on Moutere gravels, with linear, regularly spaced valleys and ridges (Photo 4);
- smaller areas of dip-and-scarp topography on young sedimentary rocks; and
- smoothly rounded hill country on granite (Photo 5).

There are limited areas of gently sloping floodplain, terraces, and fans. The two most extensive flat areas are the 40-km² Motueka-Riwaka Plain near the coast (Photo 1) and the 33-km² upper Motueka Plains around Tapawera and Motupiko (Photo 4). Other significant areas of flat land flank the Dove, Tadmor, Stanley Brook, Motupiko, lower Wangapeka, and Sherry rivers. At the coast there is a small area of dunes and gravel ridges.

The New Zealand Land Resource Inventory (NZLRI) maps most of the catchment as Land Use Capability classes 6–8, with only 13.3% being classed as suitable for arable cropping (classes 1–4) and 1.8% as highly versatile classes 1 and 2 (Table 2).

The main features of the river system include:

- steep, narrow headwater channels (Photos 2 and 3);
- broad floodplain and terrace systems within hilly Moutere gravel terrain, from below the upper Motueka Gorge to the Wangapeka confluence (Photo 4);
- a confined granite section below the Wangapeka confluence to Woodstock (Photo 5);

[5] Landscapes (usually in sedimentary rocks) characterised by a pattern of gentle dip slopes parallel to rock bedding and steep scarp slopes cutting across bedding.

[6] Landscapes formed from marble and limestone where solution of the rock is the major weathering process, characterised by sinkholes, caves, pitted relief, extensive bare rock and highly irregular drainage patterns.

Fig. 2 Map of Landforms in the Motueka catchment (legend shows percentage of the catchment in each landform).

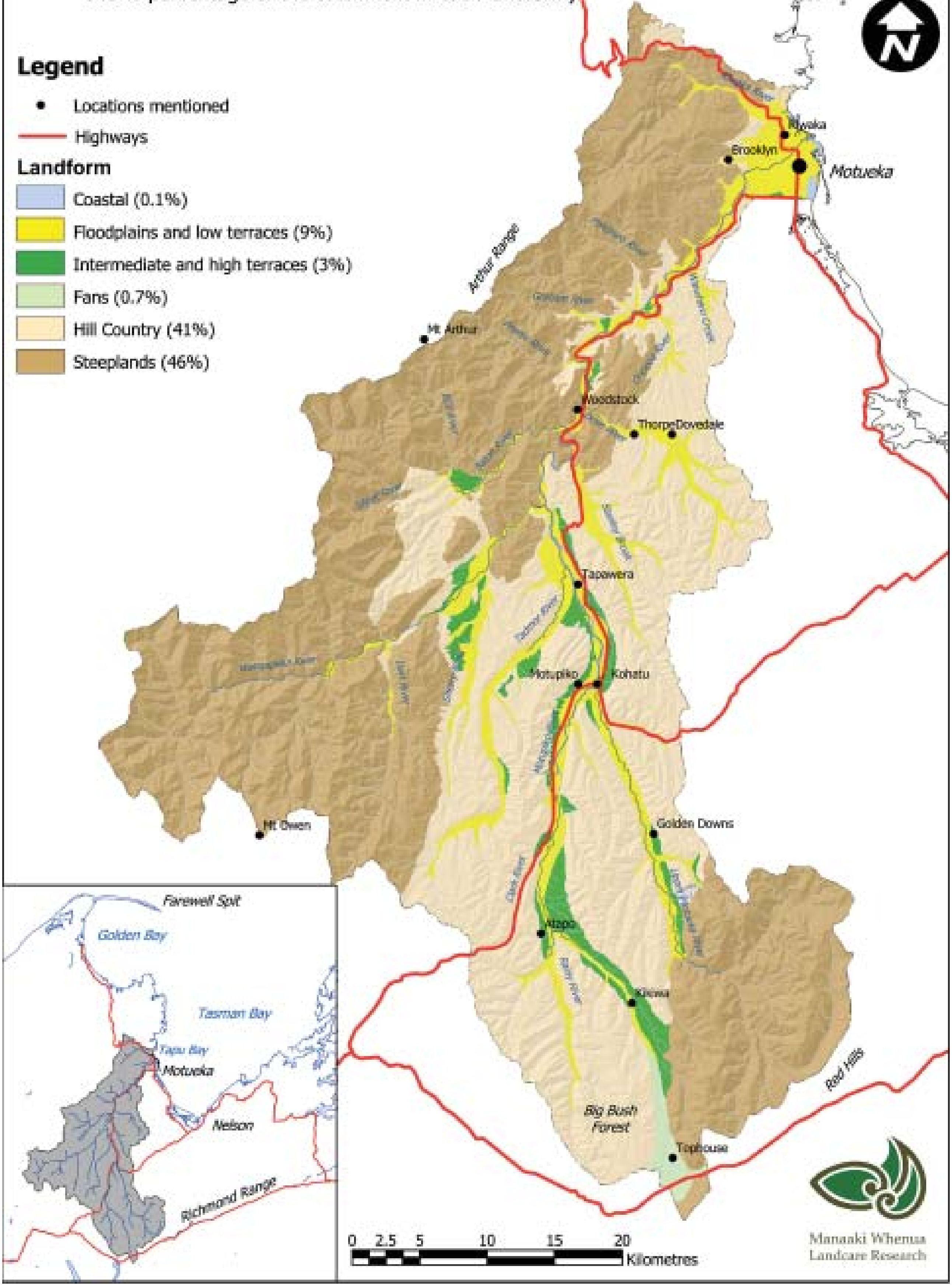

Fig. 3 Map of slope classes in the Motueka Catchment based on digital elevation model analysis (legend shows percentage of the catchment in each slope class).

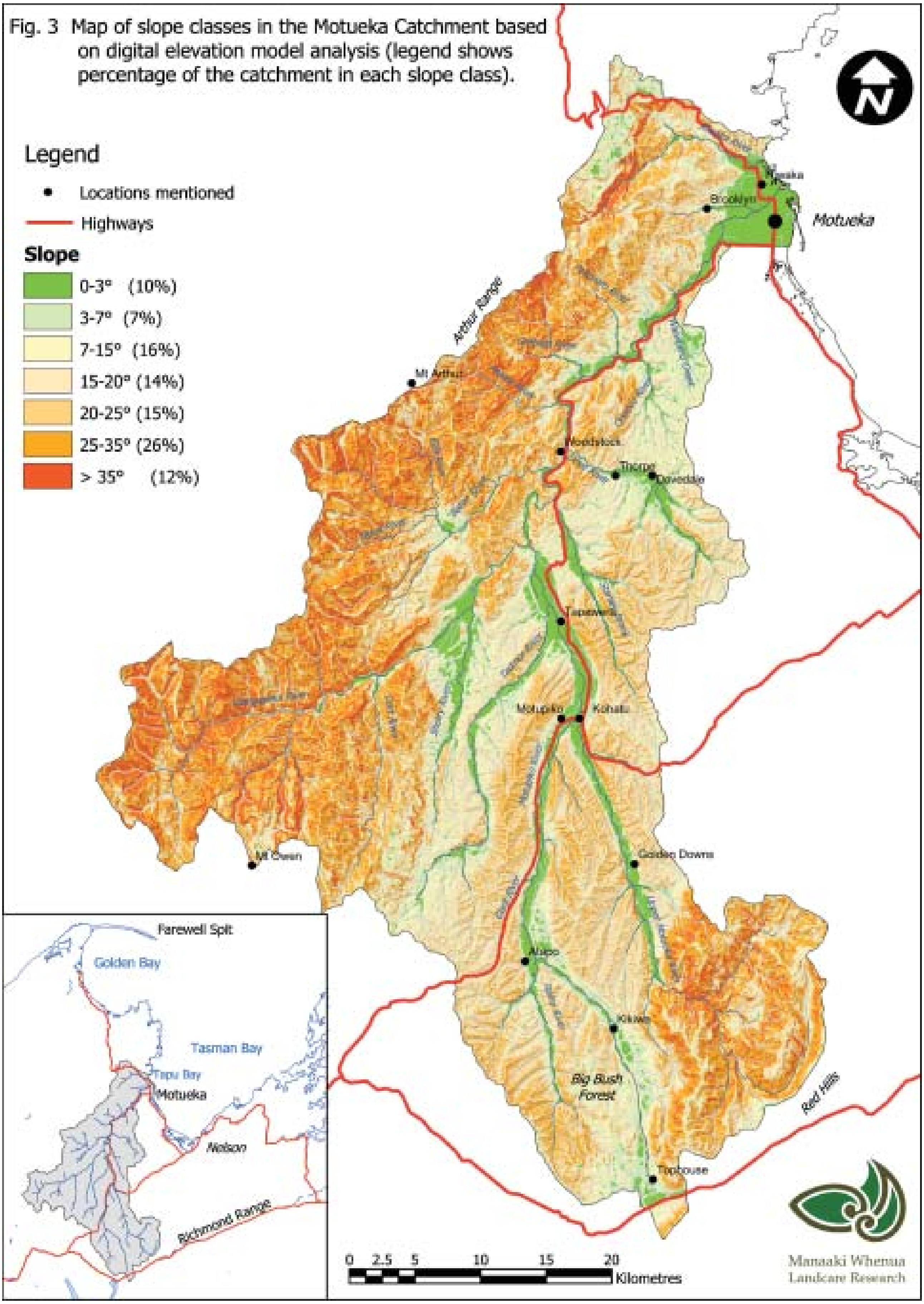

Photo 2 Steep narrow headwater channels and mountainous terrain in the upper reaches of the Wangapeka River. A few landslides are visible on the left of the photo.

Photo 3 Steep headwater channels in the right branch, upper Motueka River. Note the sharp vegetation contrast between the scrub on Dun Mountain ultramafic rocks (to the right) and forest on the Maitai Group sediments (to the left), and the active sedimentation of the stream channel caused by a localised storm in 1998.

Photo 4 Motueka–Motupiko confluence with broad floodplain and terrace systems flanked by fluvially dissected Moutere gravel hill country with extensive plantation forestry.

Photo 5 Motueka River below the Wangapeka confluence with meandering channel cut into granite ranges.

LUC CLASS	AREA (km^2)	AREA (%)
1	22.6	1.0
2	17.9	0.8
3	146.4	6.7
4	104.1	4.8
5	4.5	0.2
6	344.1	15.8
7	872.1	40.0
8	661.0	30.3

Table 2: Percentage of land in different Land Use Capability classes (derived from the New Zealand Land Resource Inventory)

Photo 6 Motueka River near Woodstock with narrow valley flanked by terraces confined between granite ranges.

2.1.2 River forms

Landforms, along with geology and rainfall, tend to be the key determinants of the type of rivers and streams found in the Motueka Catchment. The general form of rivers and streams can be grouped within three regional types: (1) those of the western and headwater ranges, (2) those of the lower-relief Moutere gravel hill country, and (3) those of the alluvial terraces and plains. Together these regions contain a diversity of river forms (or morphologies), providing a wide range of habitats for native fish and trout and locations for river-based recreation.

Streams in the western and headwater mountain ranges are characteristically bouldery, with steep gradients. Smaller stream channels at higher elevations tend to have cascade-step pool or riffle-pool morphologies, and bed materials range from boulder to cobble and gravel reflecting the wide variety of source lithologies. In many places bedrock controls the frequency of pools and the lateral form of the river. These streams show increasing entrenchment and the development of river terraces at lower elevations and lower river gradients. The banks of most of these rivers are clad in native forest and scrub, and the characteristically steep catchments remain in tussock, native forest, or scrub vegetation. The headwaters of the Wangapeka, Baton, Pearse and upper Motueka rivers are typical of these types of streams.

The lower-relief Moutere gravel hill country is characterised by high drainage density – with many small ephemeral streams – and generally lower gradients than for the mountain streams. River form tends to be riffle-pool or riffle-run with characteristically narrow, moderately entrenched channels, and generally well-developed alluvial terraces. Bed materials are typically cobble-gravel-sand-silt reflecting the dominance of Moutere gravel source lithologies. Surrounding land uses are varied and include grassland, exotic forestry, reverting scrub, and native forest remnants. Riparian areas are typically modified, particularly in areas of pastoral farming, with little or no tall vegetation.

Rivers and streams of the alluvial plains typically have low gradients and well-developed terrace sequences. River morphology tends to be riffle-pool with wide channels, and grain size tends to be cobble-gravel-sand. River channels are typically meandering though constrained by bedrock in some areas, particularly in the middle to lower reaches of the Motueka where the river cuts through Separation Point granite. These alluvial plains are predominantly in pastoral farming and horticulture. In many areas stopbanks control the lateral extent of the river course and some streams have been modified for drainage purposes in the area around Motueka (e.g., Little Sydney Stream).

2.1.3 Man-made modifications

Management of the river for flood control purposes has resulted in significant modification of the channel of the main stem of the Motueka River and some of its tributaries. An early map (1842) of the lower Motueka River shows a completely different configuration of the lower reaches of the river and the coastline (Fig. 4). Works have been undertaken as part of the Motueka Catchment Control Scheme (Green 1982) and earlier schemes. The Lower Motueka Flood Control Scheme provided flood control in the lower 12 km of the Motueka and the lower 3 km of the Riwaka River in 1954. River control works (fairway clearance and bank protection) were implemented in 18 km of the upper Motueka and 14 km of the Motupiko in 1958. Complementing these river control measures were soil conservation farm plans and erosion control schemes, primarily for gully and streambank stabilisation on Moutere gravel terrain with some on granite. The major works initiated in 1982 as part of the Motueka Catchment Control Scheme, (see Green 1982; Fenemor 1989), include:

- stopbanks – these are located along the lower Motueka from about 2 km below the Alexander Bluff bridge to the sea, the east bank of the middle Motueka between Tapawera and Kohatu, the lower reaches of the Brooklyn Stream, and the lower Motupiko;

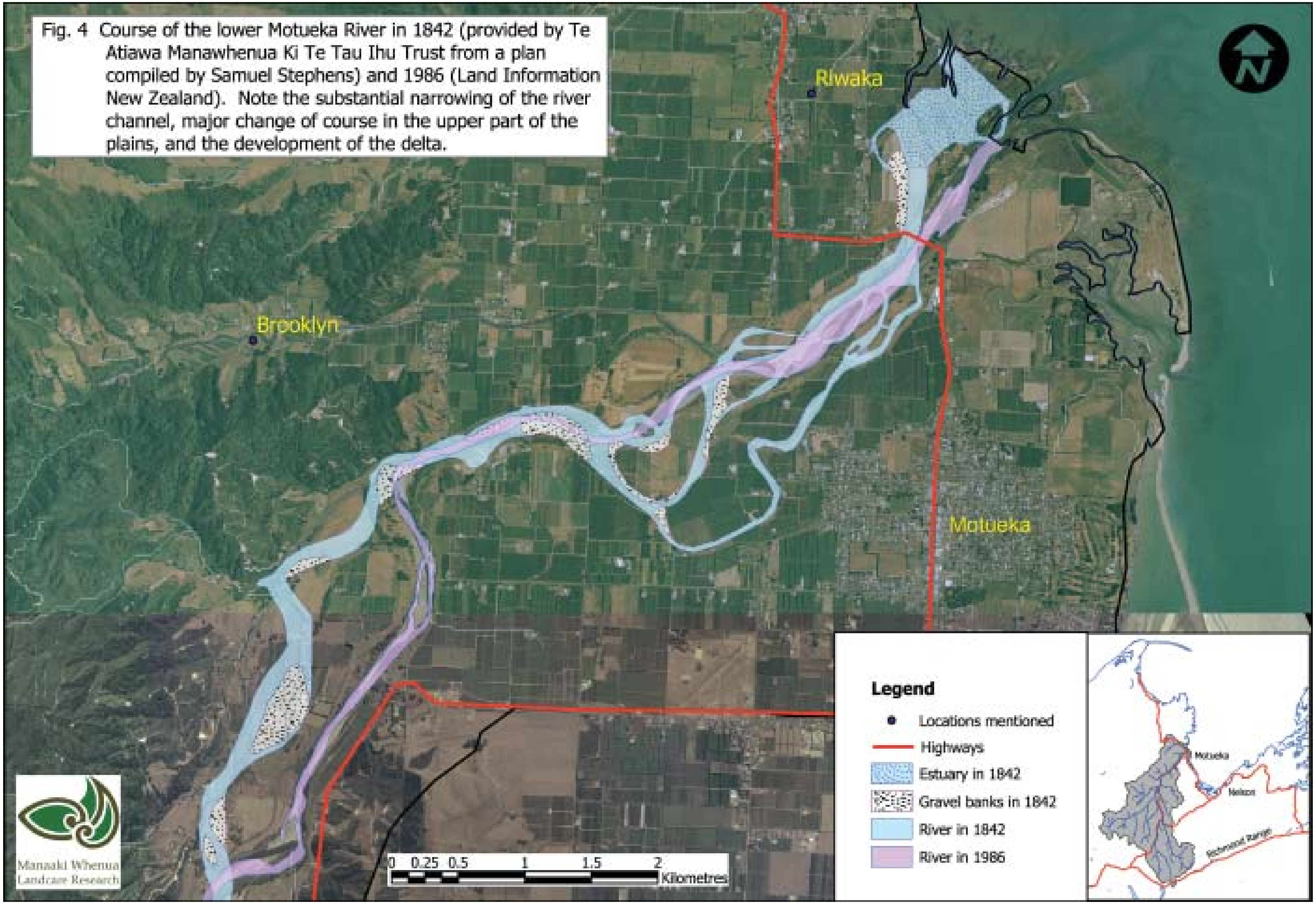

Fig. 4 Course of the lower Motueka River in 1842 (provided by Te Atiawa Manawhenua Ki Te Tau Ihu Trust from a plan compiled by Samuel Stephens) and 1986 (Land Information New Zealand). Note the substantial narrowing of the river channel, major change of course in the upper part of the plains, and the development of the delta.

- a series of cuts to straighten the channel of the lower Motueka;
- establishment of clear channels of uniform width, using a combination of river training, fairway clearance, bank protection (using rock, plant materials, or a combination of both), and groynes;
- provision of vegetation screens along riverbanks to contain the spread of water and sediment from rivers during floods.

The river control works have been complemented by streambank and gully stabilisation works.

The major impact of river control has been to narrow and straighten the main channel of the river, particularly in the lower reaches (see Fig. 4). The within-channel works have been complemented by soil conservation works and land management practices aimed at stabilising small and ephemeral watercourses, reducing gully and streambank erosion, and controlling vegetation disturbance, particularly on Separation Point granite (Green 1982).

2.2 GEOLOGY

The Motueka Catchment is geologically very complex compared to many other South Island catchments. The geology is described by Grindley (1961, 1980), Beck (1964), and Johnston (1982a,b, 1983, 1990), and has recently been remapped by Rattenbury et al. (1998). A wide variety of rock types are present, including:

- old ultramafic and sedimentary rocks in the upper Motueka headwaters;
- a complex array of sedimentary and igneous rocks underlying the western tributaries;
- Moutere gravels and younger alluvium underlying the middle and lower reaches and eastern tributaries of the Motueka.

Each of these groups of rock types comprises several different lithologies whose distribution is shown in Fig. 5.

Ultramafic and old sedimentary rocks form the mountains at the south-western end of the Richmond Range in the headwaters of the Motueka. This group includes strongly indurated[7], ultramafic[8] rocks of the Dun Mountain Group (early Permian age, 260–290 Ma), and old sediments of the Maitai Group. The latter comprise well-bedded, strongly indurated, and weakly metamorphosed sandstone, siltstone, and argillite of late Permian age (c. 250 Ma).

Similarly, the headwaters of the western tributaries of the Motueka, and part of the middle reaches of the Motueka, are underlain by a complex array of sedimentary and igneous rock types including:

- old basement rocks of Devonian to Cambrian age (350–500 Ma). These include indurated and faulted marble, limestone, greywacke, argillite, and schist of the Mt Arthur, Mt Patriarch and Greenland groups, and diorite and gabbro of the Riwaka igneous complex;
- granitic rocks (granite and granodiorite) of the Separation Point Suite (dated to the Cretaceous period, 109–121 Ma). These rocks are often deeply weathered and highly erodible;
- younger and less-indurated sediments (marine mudstone, sandstone, limestone) of the Rapahoe, Nile and Blue Bottom groups. These are Eocene to Miocene in age (5–50 Ma). These rocks extend from the Tadmor Valley across the Sherry, to the lower Wangapeka and Baton catchments.

The hilly terrain of the Moutere Depression, making up most of the eastern side of the catchment and the Motupiko and Tadmor valleys, is underlain by much younger alluvial sediments of the Moutere gravel formation. This is a thick (0.7 km near Tapawera), weakly indurated, and deeply weathered gravel of late Pliocene to early Pleistocene age (1–3 Ma). It is dominated by

7 Hardened by heat, pressure or cementation.

8 Igneous rocks rich in iron, magnesium and nickel.

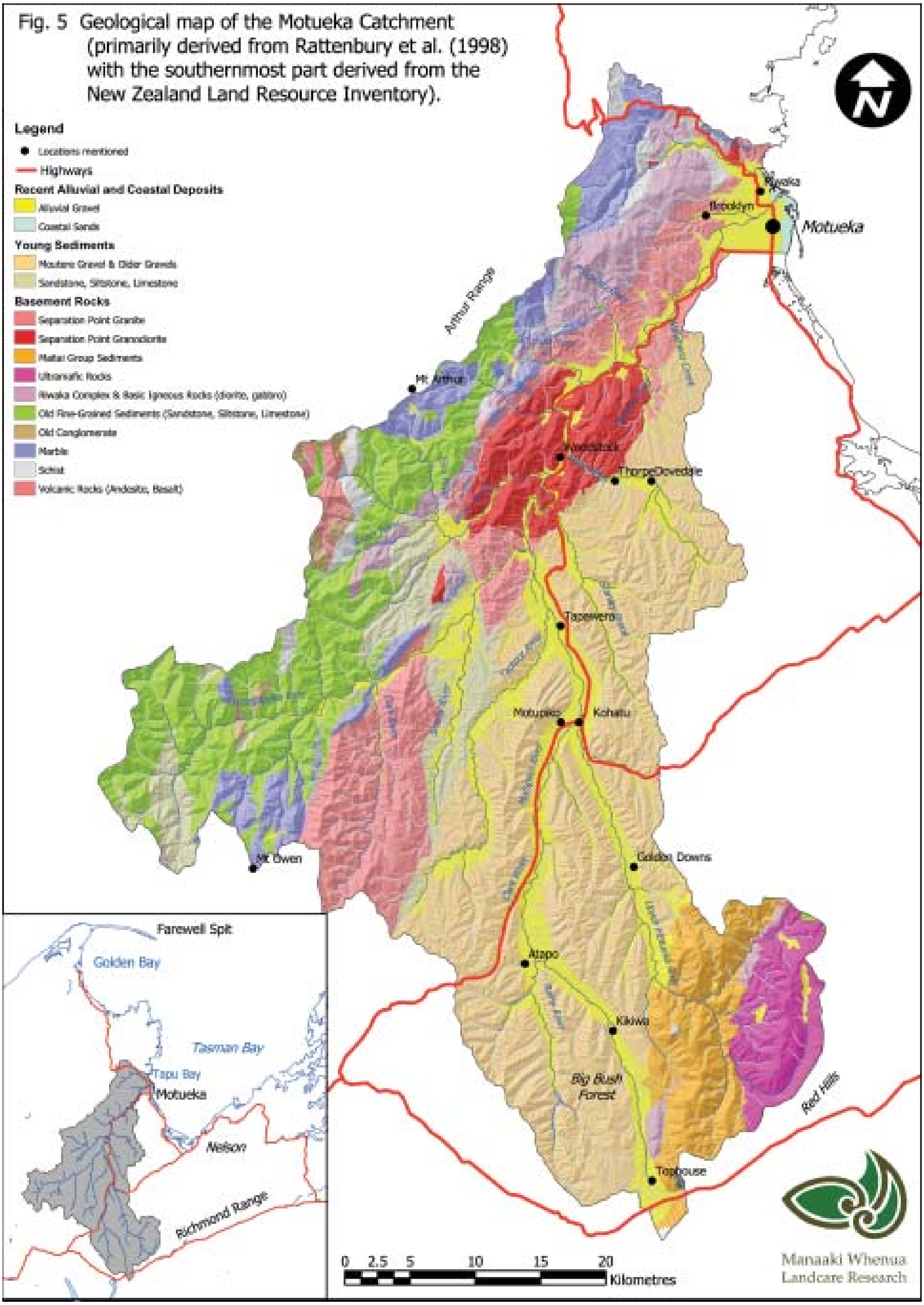

Fig. 5 Geological map of the Motueka Catchment (primarily derived from Rattenbury et al. (1998) with the southernmost part derived from the New Zealand Land Resource Inventory).

greywacke sandstone clasts[9], mainly <200 mm diameter, in a silt and clay matrix that cements the clasts together. Alluvial gravels of late Quaternary age underlie the terraces and floodplains of all the major valleys, and form the Motueka Plains. A series of aggradation surfaces, up to 100 metres above current river levels, dating back several hundred thousand years are recognised by Rattenbury et al. (1998). Young beach deposits are found along the coast at the mouth of the Motueka River.

Johnston (1980) groups the rocks of the catchment into three classes based on their influence on water yield.

- Indurated basement rocks of pre-Upper Cretaceous age. These include the Dun Mountain ultramafic rocks, the Maitai, Mt Arthur, Mt Patriarch and Greenland group sedimentary rocks, the Riwaka Igneous Complex, and the Separation Point Suite. This group has an important influence on water yield because although the rocks are strongly indurated and have low permeability, they are fractured to great depth allowing infiltration and storage of water that is released slowly to sustain streamflow. In addition this group of rocks is widespread, particularly in the higher rainfall areas of the catchment in the major western tributaries and the upper Motueka.
- Less-indurated rocks including the young sediments (mudstone, sandstone, limestone of the Rapahoe, Nile and Blue Bottom groups) and the Moutere gravels. These rocks have slow permeability and store limited amounts of water. They also occur mainly in the lower rainfall areas of the catchment.
- The unconsolidated late Quaternary gravels and sands underlying the terraces and floodplains. Although of limited extent in the Motueka, these young sediments are critically important to water yield as they are highly permeable, store large quantities of water, form the main aquifers from which groundwater is obtained, and play an important role in sustaining streamflow.

2.3 SOILS

The complexity of landforms, climate, and rock types in the Motueka Catchment results in a wide variety of soils. The catchment was mapped at 1:126,720 scale by Chittenden et al. (1966) and at 1:250,000 scale by New Zealand Soil Bureau (1968). This soil information was reinterpreted at 1:63,360 scale for the NZLRI maps (Hunter, 1974, 1975a,b; Lynn, 1975a,b, 1977a,b,c; Williams 1975). Fifty-six mapping units are depicted on the best available maps[10] of the catchment. Fig. 6 shows the distribution of soils and Appendix 1 lists key characteristics of each mapping unit.

Soil characteristics are closely related to geology, landform, elevation, rainfall and vegetation cover, and can be grouped into six broad classes:

- **Soils of the floodplains and low terraces** are formed from recent river alluvium of varying parent material composition. These are mainly Recent[11] (Riwaka, Sherry, Wangapeka, Tapawera, Motupiko, and Dovedale) and Gley soils (Riwaka wet phase, Braeburn),with Saline Gley Recent soils (Motukarara) near the coast. Fertility ranges from very low to high depending on the parent material from which the alluvium is formed. These soils are well drained except for the Gley, and Saline Gley Recent soils, which have high groundwater tables and are poorly drained.

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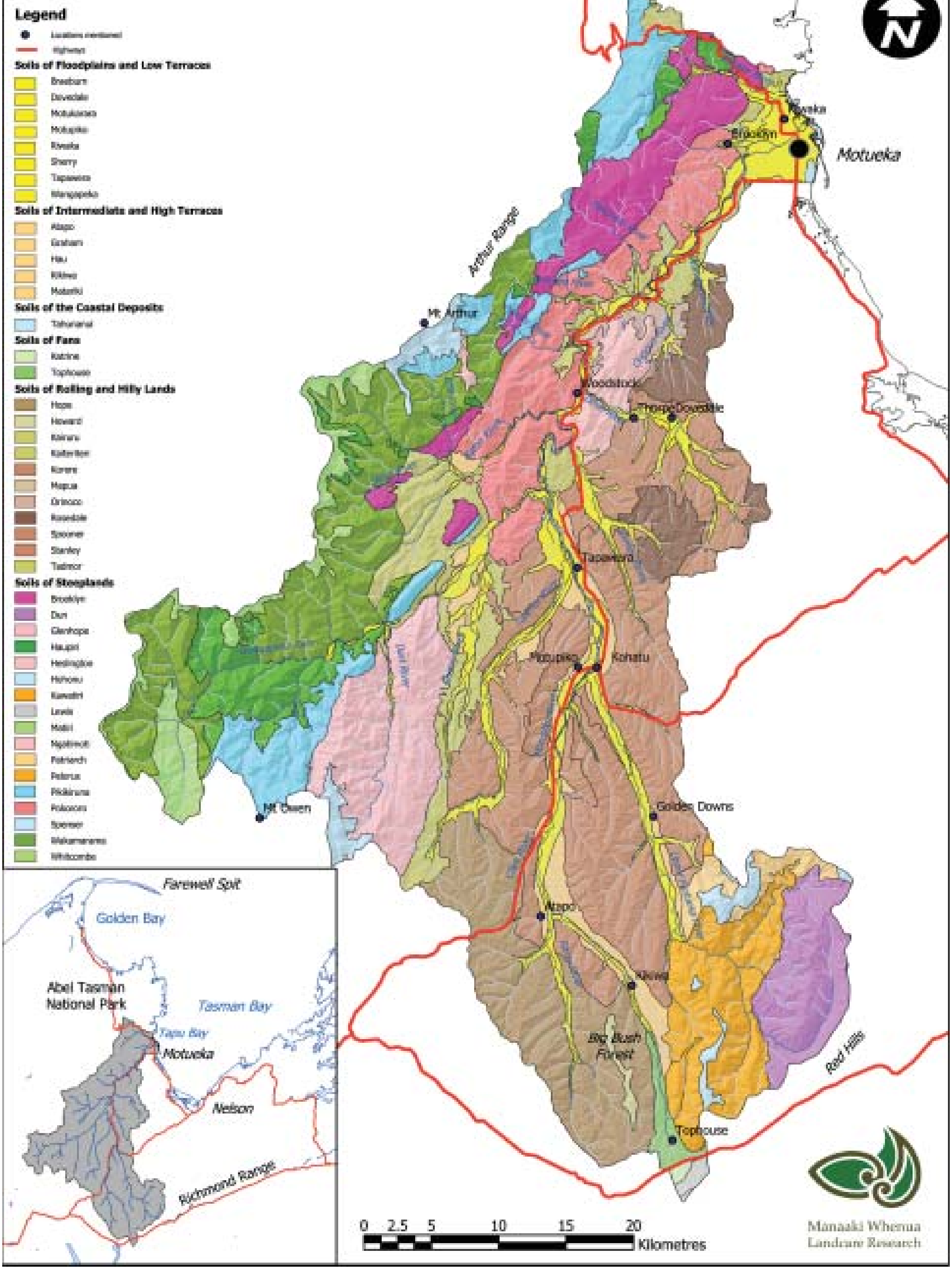
[9] Rock fragments.

[10] Cawthron Institute produced detailed soil maps of the plains and major valley floors at 1:15,840 scale in the 1940s, but these were never published. Map unit boundaries are currently being digitised by Tasman District Council to provide improved soil-map-unit information for these areas.

[11] Soils are classified according to the New Zealand Soil Classification (Hewitt 1992). Appendix 1 also lists the New Zealand Genetic soil classification (after New Zealand Soil Bureau 1968).

Fig. 6 Soil map of the Motueka Catchment (derived from the New Zealand Land Resource Inventory).



- **Soils of the intermediate and high terraces** are formed from older alluvium of varying parent material composition (Matariki, Hau, Graham, Kikiwa, Atapo). They are mainly Brown soils with low to very low fertility, and are mostly well drained.
- **Soils of the coastal sands** are formed in a small area of beach sands and gravels near the coast. Tahunanui soils are Recent soils with low fertility and are very free draining.
- **Soils of the fans** are formed from older alluvium (Tophouse soils) or till[12] (Katrine soils) and have a restricted extent in the upper reaches of the Motupiko River. They are Brown soils with low fertility, and are well drained.
- **Soils of the rolling and hilly lands**. This group comprises a wide variety of soils distinguished according to climate and parent material, including Moutere gravels (Mapua, Rosedale, Stanley, Spooner, Korere, and Hope soils form a climosequence), alluvium (Howard), basic igneous rocks (Brooklyn hill), young sedimentary rocks (Tadmor), granite (Orinoco, Kaiteriteri), greywacke (Pelorus hill) and marble (Kairuru). Most are classified as Brown soils (Rosedale, Stanley, Spooner, Korere, Howard, Orinoco, Tadmor, Brooklyn hill, and Pelorus hill), with some Podzols (Hope), Ultic (Mapua and Kaiteriteri) and Melanic (Kairuru) soils. Fertility depends on parent material, and is generally low on the Moutere gravels and granite, and higher on sedimentary and basic igneous rocks. Soils of this group are well drained, except on the Moutere gravels where there are many soils with slow subsoil drainage. The soils formed on Moutere gravel are prone to sheet and gully erosion when cleared, and runoff from these soils has in the past been considered a significant contributor to erosion rates and flood flows (Chittenden et al. 1966). The soils formed on weathered granite are prone to erosion when disturbed, and can release large quantities of sand into streams. Exotic forestry, once established and well managed, has stabilised some of this country.
- **Soils of the steeplands**. This group also comprises a wide variety of soils distinguished according to climate, parent material (basic igneous and volcanic rocks, Maitai Group and other old sediments, greywacke, schist, marble, young sediments, granite) and elevation. Most are classified as Brown soils (Kawatiri, Brooklyn, Heslington, Wakamarama, Whitcombe, Patriarch, Haupiri, Pelorus, Dun, Pokororo and Glenhope), with significant areas of Podzols (Lewis, Spenser, Matiri and Hohonu) and Melanic soils (Ngatimoti and Pikikiruna). Fertility depends on parent material, and is generally low on greywacke, schist, argillite, quartzite, and acidic igneous rocks (granite, diorite, granodiorite) and higher on calcareous sedimentary rocks and basic igneous rocks. These soils are dominantly well drained. They are mostly in the Motueka headwaters and western ranges, and are best suited for water and soil protection uses because of the steep slopes, high rainfall and potential for erosion. The soils from ultramafic rocks (Dun soils) contain some trace elements toxic to plant health (e.g., nickel, chromium) and rock exposures and screes are common (Photo 3).

Few of the soil mapping units have been characterised in detail, particularly for their physical and hydraulic characteristics. Basic chemistry of many of the soil types is included in Chittenden et al. (1966). The National Soils Database held by Landcare Research contains data for 14 of the mapping units (Table 3), but few were sampled in the Motueka Catchment.

Estimates for key physical and chemical attributes for all mapping units are contained in a Fundamental Data Layer extension of the NZLRI (Wilde et al. 1999). These attributes include soil temperature regime, soil drainage class, potential rooting depth, depth to a slowly

[12] Sediments deposited by glaciers as moraine.

SOIL MAPPING UNIT	DATA TYPE	LOCATION OF SAMPLED SOIL
Motupiko	C*	88 Valley
Mapua	C, P, M, PSA	DSIR Research Orchard, Mapua
Korere	C, PSA	Korere
Hope	C, M, PSA	Big Bush
Kaiteriteri	C, M	Nelson (location unkown)
Pelorus	C, M, PSA	Whangamoa Saddle
Wakamarama	C, PSA	Grey Valley, north Westland
Lewis	C, P, M, PSA	Mt Misery, Lake Rotoiti
Spenser	C, P, M, PSA	Mt Misery, Lake Rotoiti
Whitcombe	C, P, M	Mt Misery plateau, north Westland
Haupiri	C, PSA	Head of Fyffe River near Mt Owen
Pikikiruna	C, M	Near Mt Patriarch
Matiri	C, M	Kiwi Saddle, Arthur Range
Dun	C, M	Bryant Range

* Data types are listed as chemistry (C), physics (P), mineralogy (M), particle size analysis (PSA).

Table 3: Soil data in the National Soils Database for mapping units in the Motueka Catchment.

permeable layer, topsoil gravel content, rock outcrops and surface boulders, minimum pH (0.2–0.6 m), maximum salinity (0–0.6 m), cation exchange capacity (0–0.6 m), total carbon (0–0.2 m), phosphorus retention (0–0.2 m), profile available (PAW) and readily available water (PRAW), and macroporosity (at depths of 0–0.6 and 0.6–0.9 m). Maps of key soil attributes (derived from the fundamental data layers) affecting water storage and movement are shown in Figs 7–10.

Detailed studies of some of the soils within the Motueka Catchment include:

- an investigation of the reasons for poor growth of *Pinus radiata* on Kaiteriteri, Pokororo and Mapua soils (Adams 1970);
- a nutritional survey of Pokororo and Kaiteriteri soils at Pokororo Forest (Thorns 1997);
- soil distribution and fertility in Brooklyn, Brooklyn–Pikikiruna, and Kaiteriteri soils (Betitis 2000);
- soil distribution and soil–vegetation relationships on schist (Whitcombe) and marble (Pikikiruna) in the mountains of west Nelson (Bell 1970, 1973a,b; Heine et al. 1987);
- soil distribution, chemical and mineralogical properties of soils mapped as Hope soils on Moutere gravel at Big Bush (Campbell and Mew 1986). In this same area Davis (1999) describes a study of soil chemical differences between undisturbed beech forest and radiata pine soils 19 years after conversion from beech forest to pine;
- description of soil distribution in 10 small catchments mapped as Rosedale Hill soils on Moutere gravels (Duncan 1990), and analysis of soil moisture deficits under pasture and pine (Duncan 1992).

Fig. 7 Map of soil permeability class in the Motueka Catchment (derived from the New Zealand Land Resource Inventory).

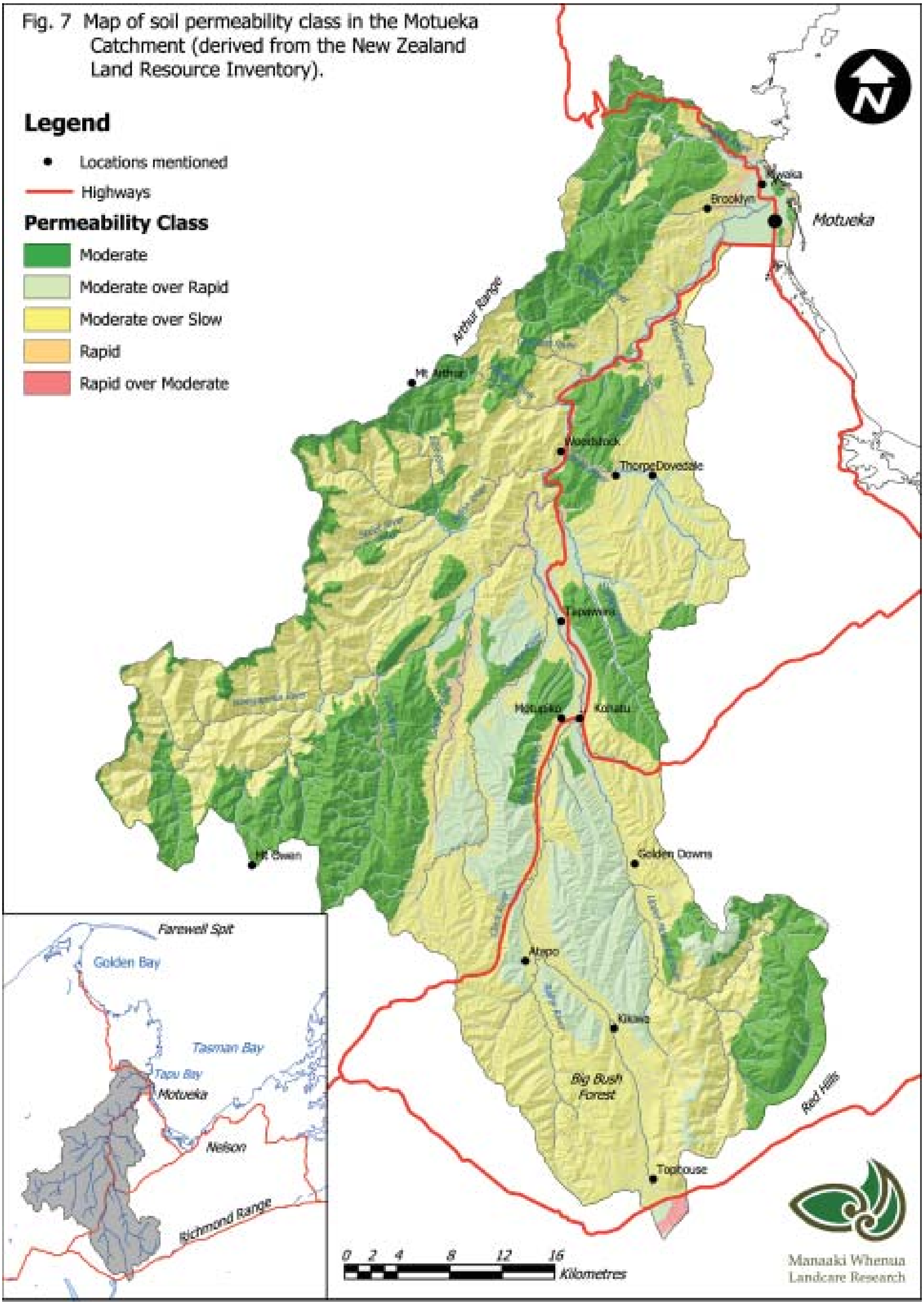


Fig. 8 Map of potential rooting depth of soils in the Motueka Catchment (derived from the New Zealand Land Resource Inventory).

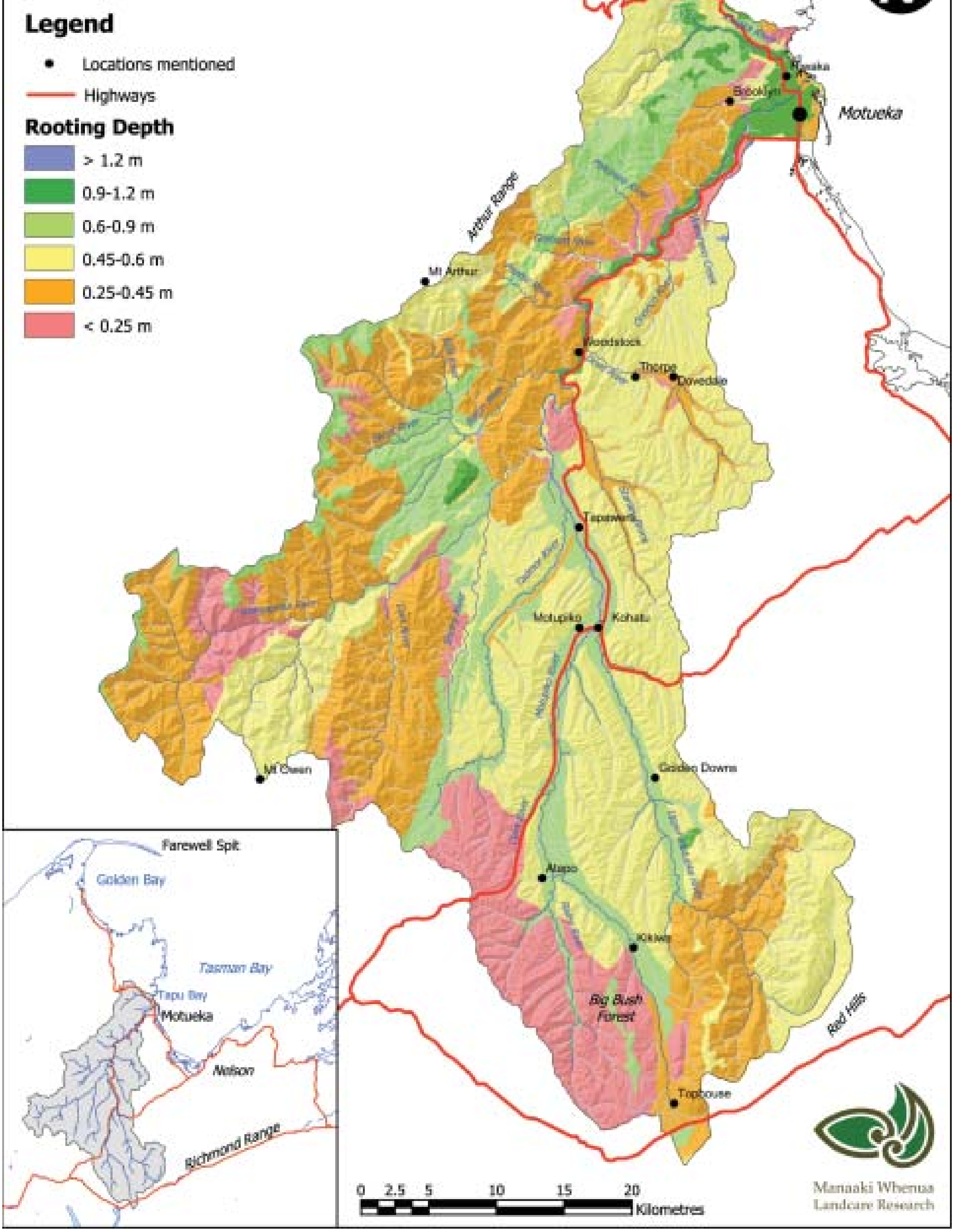


Fig. 9 Map of profile available water for soils in the Motueka Catchment (derived from the New Zealand Land Resource Inventory).

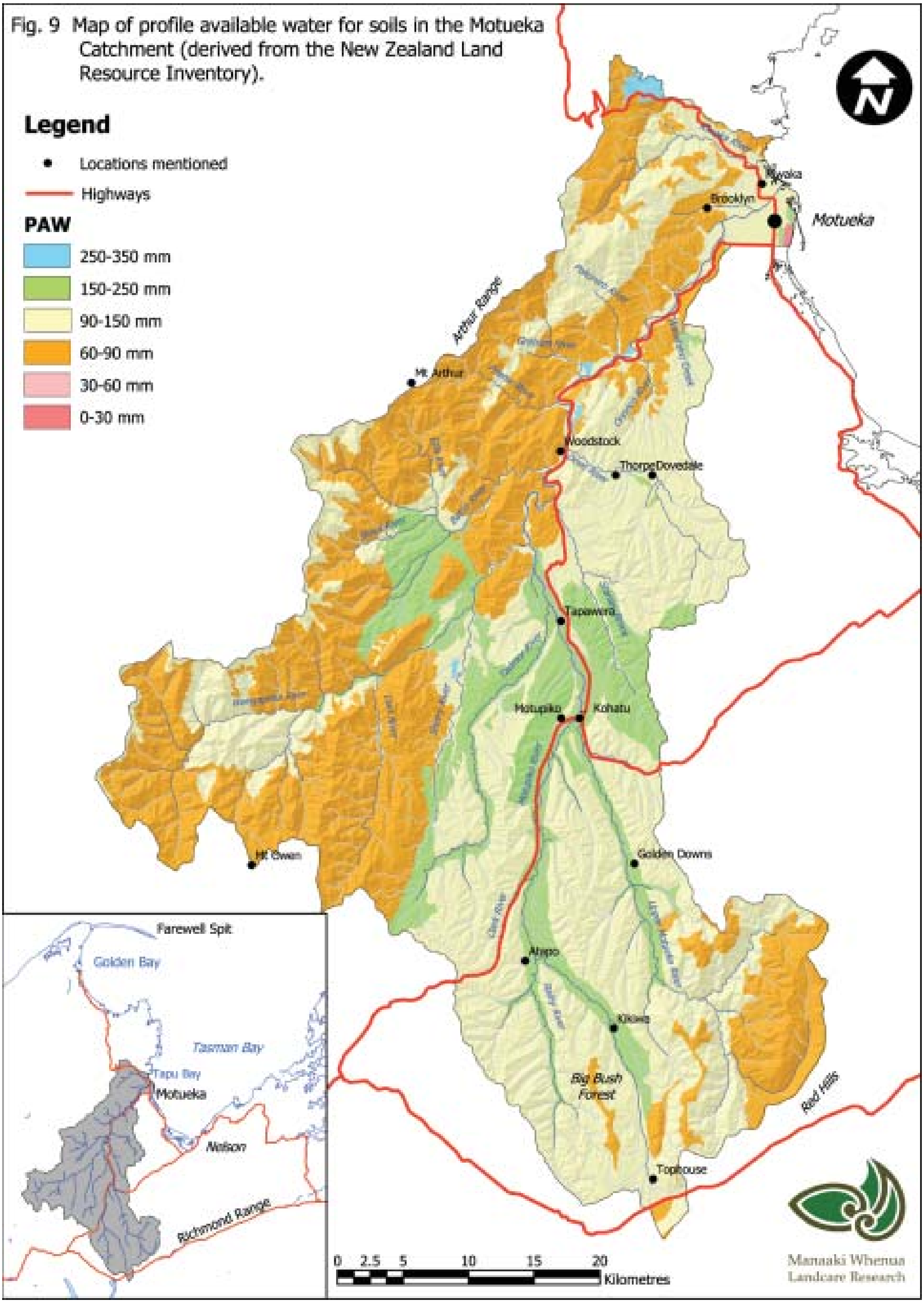
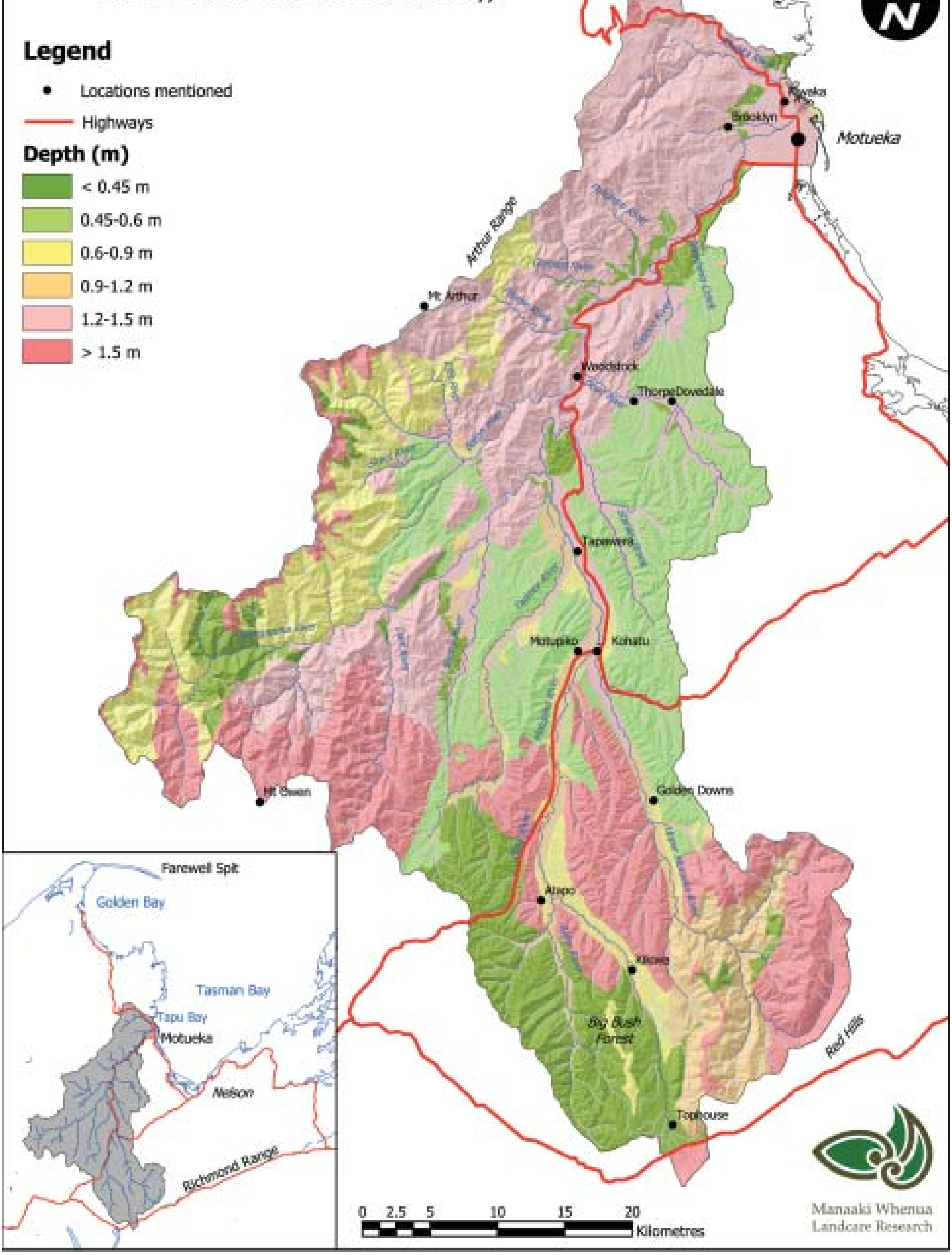


Fig. 10 Map of depth to a slowly permeable layer for soils in the Motueka Catchment (derived from the New Zealand Land Resource Inventory).



2.4 EROSION, SEDIMENTATION AND RIVER GRAVEL

2.4.1 Sources of erosion

Historically there have been concerns about erosion where land on the Moutere gravels has been cleared for pastoral or orchard development (e.g., McCaskill, 1973). Soil conservation reserves and experimental stations were operated at Appleby – to investigate erosion management in orchards (at the time, soils were cultivated and kept bare between the trees) –and at Moutere – to investigate erosion associated with clearing for pastoral development. McCaskill (1973) reports erosion rates from small plots at Moutere of 360 t/km^2/yr from bare soil, compared with 160 t/km^2/yr from pasture.

More recently attention has focused on land disturbance and forestry activities (e.g., roading, landing construction) on the Separation Point granite (e.g., Coker and Fahey 1993, 1994; Fahey and Coker 1989). Concern about fine sediment (silt and sand) in runoff has been heightened by its potential to affect the internationally renowned trout fishery in the Motueka River. The presence in the river of sand-sized sediment derived from Separation Point granite is thought to have affected trout spawning and growth, and trout habitat and cover. It may have been responsible for a recent decline in trout numbers by reducing water quality and primary production in the river, and smothering macroinvertebrate communities. There are also concerns about the offshore impacts of sediment on the developing aquaculture industry in Tasman Bay.

A wide variety of erosion types have been mapped throughout the catchment as part of the NZLRI (Hunter 1974, 1975a,b; Lynn 1975a,b, 1977a,b,c; Williams 1975).These maps show generally low severity erosion (Grades 1–2), with the most severe[13] erosion (wind and gully) mapped on the soils of the ultramafic rocks and on high-elevation soils on greywacke, schist and granite.

2.4.2 Sediment yields

The amount of sediment from the catchment carried to the coast by the Motueka River has been estimated at 277 tonne(t)/km^2/yr (Griffiths and Glasby 1985). However, this estimate was based on a relationship between suspended sediment yield and rainfall derived from catchments throughout the South Island (Griffiths 1981) and probably overestimates the yield. D. M. Hicks (pers. comm. 2002), using limited data on the relationship between sediment concentration and river flow for the Motueka at Woodstock, has calculated a lower yield of 180 t/km^2/yr. The distribution of sediment yield across the catchment is not well known. Mosley (1980), using the Griffiths (1981) method, suggests much of the yield is derived from the high-rainfall, steep terrain of the west-bank tributaries and estimates rates of 119 t/km^2/yr from the Dart River and 583 t/km^2/yr from the entire Wangapeka River. However, Hicks' (pers. comm. 2002) analysis of available suspended-sediment data suggests the east-bank Stanley Brook on Moutere gravel has a much higher sediment yield (169 t/km^2/yr) than the Wangapeka (46 t/km^2/yr). The relative contribution of erosion under native vegetation compared with erosion from areas converted to pasture or production forest is not known.

Sediment yield measured from small catchments at two sites underlain by Moutere gravels was relatively low. Under an annual rainfall of 1000 mm/yr, suspended sediment yields were 79 t/km^2/yr from pasture and 4 t/km^2/yr from pine forest (Hicks 1990). Similarly, Smith (1992) measured

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[13] Severity mapped in the NZLRI was largely a function of the extent of bare ground and has an undefined, but probably poor, relationship with rate of erosion. For example, most concern about sediment generation from erosion is on Separation Point granite under forestry land use yet this is ranked as low severity in the NZLRI.

21 t/km^2/yr under pasture, and 32 and 67 t/km^2/yr from two catchments under pasture with riparian pine. She suggested increased erosion was associated with poor ground cover in riparian forest causing overland flow and streambank erosion. At Big Bush under a higher rainfall (1700 mm/yr), sediment yield was 6–11 t/km^2/yr under undisturbed native forest. Most sediment was derived from streambank erosion. Following harvesting of the trees, sediment yields increased up to 100 times, depending on the harvesting method, with most of the sediment delivered in a few high-intensity storms (O'Loughlin et al. 1978; Fahey et al. 1993; Fahey and Jackson 1993).

Several studies have been carried out on erosion under production forestry on Separation Point granite, which is well known for its erosion problems particularly associated with development of roads and landings. Mosley (1980) suggested the area of the Dart Valley that was roaded had a sediment yield of 710 t/km^2/yr (derived from surface erosion, gullying, mass movement), compared with a background rate for the Dart of 119 t/km^2/yr. However, he indicated that the high sediment yield from the relatively small roaded area had a minor impact on the Wangapeka River because this river has a naturally high sediment yield (583 t/km^2/yr), and much of the sediment associated with roading was stored on slopes and in headwater channels. Rates of sediment production from surface erosion on existing roads in maturing forests were estimated by Fahey and Coker (1989) at 37 t/km^2/yr. At the time of peak harvesting this was predicted to rise to 160–320 t/km^2/yr, compared with a background erosion rate for the Wangapeka of about 580 t/km^2/yr.

Infrequent high-magnitude storms are the major contributors to erosion rates. Four major storms in July and August 1990 caused erosion at rates up to 2800 t/km^2 (of which 50% entered streams), mostly from failures in the cutbanks and sidecasts of forest roads (van de Graaf and Wagtendok 1991; Coker and Fahey 1993, 1994).

Coker and Fahey (1994) provided a comprehensive evaluation of the erosion and sedimentation risk associated with forestry activities on Separation Point granite terrain. While natural erosion rates at the whole-catchment scale on Separation Point granite were higher (estimated at about 500 t/km^2/yr) than those induced by disturbance associated with forestry at the local scale (37 t/km^2/yr for surface erosion and 280 t/km^2/yr for mass movement), they made a number of recommendations to limit sediment production. These included regulation of landing size, regulation of roading and cutbank formation, safe storage of excess sidecast material, avoidance of stream crossings by use of appropriate culverts, and promotion of revegetation following disturbance. These methods, including end hauling of roading spoil, are now used routinely in forestry activities on Separation Point granite (C. Michie, pers. comm.) and are included in the Tasman Resource Management Plan (Tasman District Council 1998).

2.4.3 Gravel supply

Supply of river gravel within the Motueka Catchment is low and extraction is limited by the Tasman District Council (Tasman District Council 1993a), based on an understanding of rates of gravel supply and riverbed stability. Peterson (1997) describes the geomorphic evolution of the Motueka spit and delta and calculates the long-term supply of gravel to the coast at about 9000 cubic metres per year (m^3/yr) (of which 7000–7600 m^3/yr accumulates in the delta and 1000–1500 m^3/yr is transported along the coast). He suggests, from the volume of material trapped in the Motueka delta, that there has never been a large volume of gravel supplied to the coast or transported down the coast by long-shore drift. He suggests any gravel is being deposited in the lower Motueka River channel, with only sand and silt reaching the coast (Petersen 1997). The calculated rate of gravel

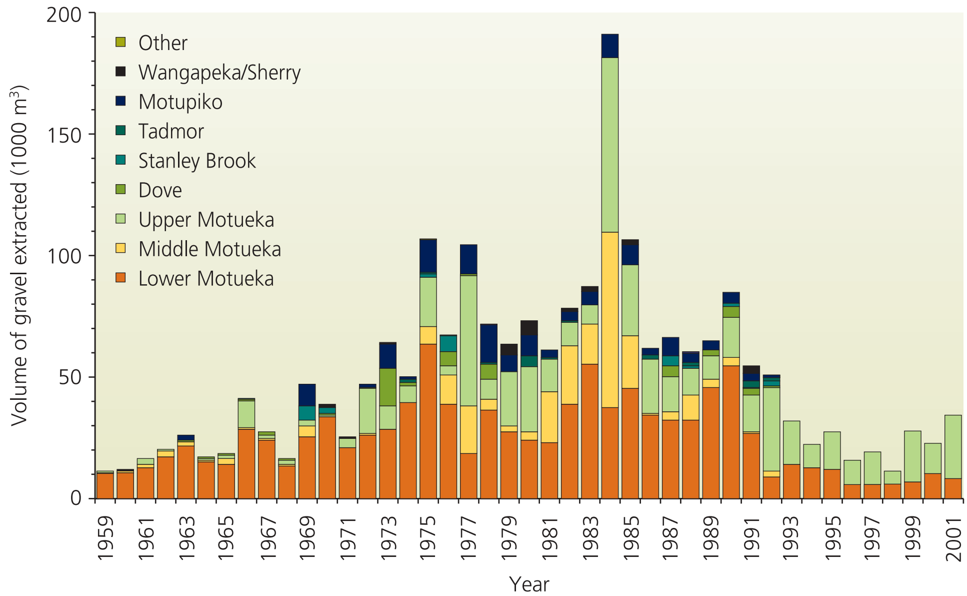


Fig. 11 Volumes of gravel extracted from the Motueka River 1959–2001 (source Tasman District Council).

supply is far less than historical gravel extraction rates, which exceeded 40,000 m^3/yr for most of the period between 1969 and 1991 (E. Verstappen, pers. comm. 2002). As a consequence gravel extraction has been limited by Tasman District Council (reduced from 34,000 m^3 in 1991/92 to 11,000 m^3 in 1995/96), although these restrictions have now been eased with 35,000 m^3 permitted in 1999/2000 (Tasman District Council 1993a, 2000e). Limits are set for the upper Motueka (above the Wangapeka confluence), middle Motueka (Wangapeka confluence to Alexander Bluff bridge), lower Motueka (below Alexander Bluff bridge), and Motupiko rivers (Tasman District Council 2000e). Historical changes in gravel extraction rates are shown in Fig. 11.

Current understanding (Tasman District Council 1993a) suggests riverbed levels in the lower Motueka are lower than natural levels, with bed degradation continuing upstream. In the lower Motueka River, gravel extraction has in recent years been limited to around 5000–6000 m^3/yr. There has also been a policy of limited to no extraction from the middle reaches of the Motueka River from 1991 to 2000. Comparison of river surveys in 1993, 1997 and 2001 indicates that by allowing material in the middle Motueka to flow through to the lower Motueka, a 5000-m^3/yr extraction rate from the lower Motueka River appears to be sustainable, as there is no significant net loss of material from the reach as a whole (E. Verstappen pers. comm. 2002). However, recent observations indicate a lack of replenishment of beaches in the deposition reach of the lower Motueka in the last 2 years. This may be indicative of the higher than desirable extraction rates in the upper Motueka, along with some extraction beginning to occur in the middle Motueka, limiting potential downstream aggradation. Any trends of this nature will become more evident after the upper and lower Motueka reaches are resurveyed in 2004 and 2005, respectively

The upper Motueka riverbed is in a degradation phase, due partly to natural post-glacial effects that influence most of the upper reaches of the river and partly to gravel extraction. The degradation rate, based on three river-surveys between 1960 and 1995 between North's

Bridge and the Wangapeka River confluence, is assessed as about 4000 m^3/year. Annual gravel extraction rates in the upper Motueka have significantly exceeded what is considered to be the long-term average supply rate, estimated at roughly 1000–2000 m^3/yr, from sources other than riverbed and bank erosion. Gravel extraction has resulted in accelerated bed degradation, particularly in the vicinity of bridge sites, where access is generally easiest.

The sources of gravel deposited within the Motueka Catchment have been analysed by Waterhouse (1996). Gravel composition varies systematically down the river as a function of the input of gravel from major tributaries. In the upper reaches of the river, clasts from the headwaters (ultramafics and Maitai Group) and Moutere gravels dominate, but below the Wangapeka confluence clasts from the western tributary lithologies and granite are most common. The bulk of the clasts in the lower Motueka are from the western tributaries, with negligible amounts from the headwaters of the Motueka or the Moutere gravel. In the lower Motueka more than half of the clasts are from the Baton and Wangapeka catchments, with the Rocky River also a substantial contributor to gravel at the river mouth.

2.5 VEGETATION AND LAND USE

2.5.1 Prehuman vegetation

The Motueka Catchment was originally almost entirely forested, with podocarp species in the fertile lowland areas and varying beech species elsewhere (Walls 1985). Alpine tussock grasslands would have covered the catchment above an elevation of about 1200–1400 metres (c. 5% of the catchment). In parts of the catchment vegetation had been burned by Māori by the time the early European settlers arrived, when further extensive clearing of forest occurred causing erosion and increased flooding (Fenemor 1989).

2.5.2 Present land use

The Motueka Catchment today is largely rural. Current vegetation (Fig. 12) is dominated by native (35%) and exotic (25%) forest with smaller areas of pastoral grassland (19%), scrub (12%) and tussock grasslands (7%). The only significant urban centre is the township of Motueka. Small but ecologically significant areas of wetland are found at the coast and scattered throughout the catchment (Preece 2000).

The largest areas of native forest are found in the headwaters of the western tributaries (Kahurangi National Park) and in the upper catchment (Mt Richmond Forest Park). These areas are managed by the Department of Conservation for recreation and protection purposes. Smaller areas of native forest occur in Big Bush Forest and scattered throughout the catchment (Park and Walls 1978; Walls 1985). Commercial production forests (mainly radiata pine, with smaller areas of Douglas fir) occupy large areas of the steeper and less fertile soils on both Moutere gravel and Separation Point granite. The largest single forest is at Golden Downs, where the first plantings began in 1927, largely as a result of failed attempts at pastoral farming on infertile hill country. Scrubland, dominated by fern, gorse and mānuka, occurs throughout the catchment, mainly on the poorer soils on steep hill country. Scrub reversion is a major challenge for pastoral farming in many parts of the catchment. Pasture grassland generally occupies the lower and easier slopes of the Moutere Depression, the west-bank tributaries, and the river flats and terraces. Pastoral land is mainly used for sheep grazing (52% of the grassland) and beef production (26%), with limited, but increasing, dairying (particularly in the Sherry and Rainy rivers). Horticulture is limited to the river flats and terraces, and makes up only 0.6% of the catchment area. Of this 46% is in pipfruit (mainly apples and kiwifruit), 18% in berryfruit, 16% in hops, 16% in vegetables, and 4% in other crops

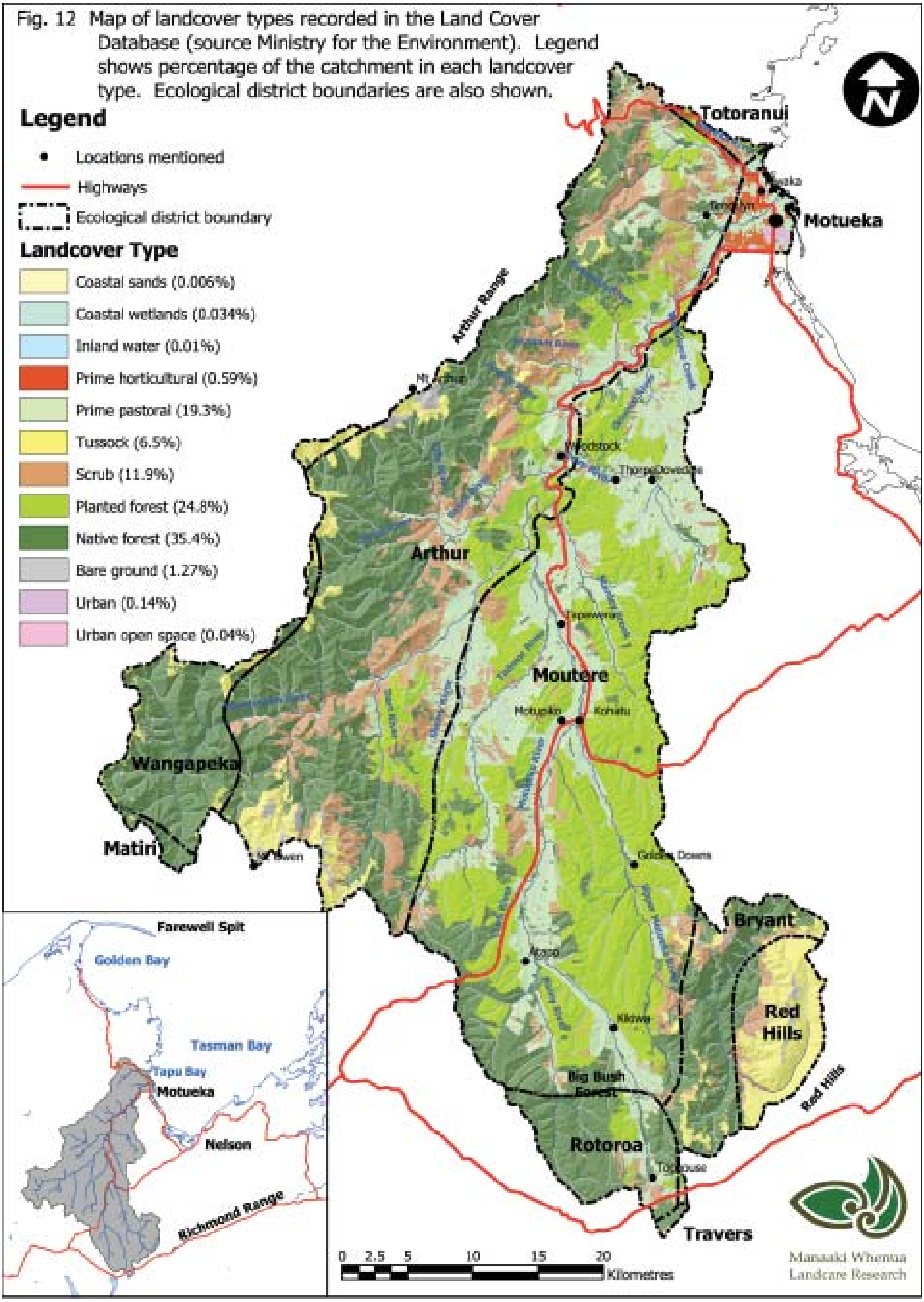


Fig. 12 Map of landcover types recorded in the Land Cover Database (source Ministry for the Environment). Legend shows percentage of the catchment in each landcover type. Ecological district boundaries are also shown.

(e.g., flowers, grapes). Fruit trees and hops are the main crops grown on the coastal plains, while berryfruit and hops are more commonly grown on the inland river flats and terraces. Horticulture is currently expanding on river flats and terraces in the Tapawera area. Most crops are irrigated from surface or groundwater during the dry summer months.

2.5.3 Ecological Districts

The ecological character of the catchment is described in ten ecological districts by McEwen (1987): Red Hills, Bryant, Rotoroa, Travers, Arthur, Wangapeka, Matiri, Moutere, Motueka, and Totaranui, (see Fig. 12). These are defined primarily on geology, topography, climate and natural vegetation. None of the ecological districts (EDs) has been covered by a Protected Natural Areas Programme survey to describe in detail their ecological character, and to identify those areas with high ecological value.

The Red Hills ED covers the ultramafic rocks in the Motueka headwaters and has a distinctive flora adapted to the soils of low fertility with high levels of magnesium, chromium, and nickel. The vegetation comprises red tussock, mountain beech forest and shrubland (mānuka), and includes a number of endemic species. The vegetation types and patterns have been strongly influenced by frequent burning since Polynesian times. Adjacent to the Red Hills ED is a segment of the Bryant ED on Maitai Group sediments, dominated by mixed beech forest. A small area of Travers ED, on greywacke parent materials under high rainfall, is characterised by beech forest (red, silver and mountain beech) and alpine tussock grasslands.

Most of the west-bank tributaries of the Motueka lie in the Arthur ED. This area is characterised by complex geology (old sedimentary rocks, volcanic rocks, and schist), moderate to high rainfall, and mountainous topography. It retains more of its original vegetation, bird, and animal life than most other EDs. The forests comprise podocarp and podocarp/beech forest on lower slopes and valleys, red beech and silver beech with black beech on lower alluvial terraces, silver beech and mountain beech at higher elevation, and above this, subalpine scrub, red tussock grassland, and alpine herbfield. Davis and Orwin (1985) describe the forests and scrublands of the upper Wangapeka River and the factors controlling their distribution (parent material/soil fertility, elevation, rainfall, drainage, topography). The main communities were grouped by Davis and Orwin (1985) as:

- low-altitude forests (red/silver beech, beech/rātā), high-altitude forests (mountain beech, mountain beech/silver beech, silver beech/mountain beech/red beech, silver beech);
- seral shrubland communities in the forest zone;
- subalpine shrublands;
- grasslands including tall-tussock (*Chionochloa*) grassland dominated by *C. rubra*, *C. flavescens* or *C. pallens*, and *Chionochloa*/carpet grass communities.

The Wangapeka ED has similar landforms and geology but occurs in the higher-rainfall headwaters of the Wangapeka River. A small area in the headwaters of the south branch of the Wangapeka on young sedimentary rocks under high rainfall is mapped in Matiri ED and is dominated by silver beech, mountain beech and tall-tussock grasslands. Similarly a small area of hilly terrain on granite in the northern headwaters of the Riwaka is mapped as Totaranui ED.

The Moutere ED covers the extensively modified hilly terrain of the Moutere Depression on Moutere gravel. This was originally forested throughout, with a progression from black beech in the north, hard beech and red/silver beech further inland, and mountain/silver beech forests in the south. Tall podocarps (tōtara, mataī, miro, rimu, and kahikatea) originally dominated the river valleys, and tall hardwood forests with podocarps (tawa, pukatea, tītoki, karaka, māhoe, tōtara, mataī, nīkau) occurred near the coast. Today there are only small remnants of the podocarp, hardwood and beech forests in the north of the ED. The large areas of continuous beech forest in the south of the Motueka Catchment at Big Bush (on Moutere gravel and alluvium, under higher rainfall) are mapped in the Rotoroa ED.

The Motueka Plains and estuary form part of the Motueka ED, originally covered in tall podocarp-hardwood-beech forest. Formerly extensive wetland and estuarine areas are now mainly drained.

More-detailed studies of native vegetation have been made at a few sites in the catchment including:

- the grassland and shrub communities, and soils, on marble and schist at high elevation near Mt Owen (Bell 1970, 1973a,b);
- subalpine and alpine plant communities on old sedimentary and volcanic rocks in the western ranges (Williams 1993);
- the remaining native forest and scrub stands on the Moutere gravels (Park and Walls 1978; Walls 1985).

2.6 TERRESTRIAL WILDLIFE

The distribution and abundance of native fauna have been severely affected by the removal of much of the forest from lowland areas of the Motueka Catchment. There are still large upland areas of native forest with a wide variety of birds and other animals, but few examples of large tracts of lowland forest or unmodified freshwater and coastal wetlands. Walker (1987) surveyed "sites of special wildlife interest" throughout the catchment and ranked their relative value. Large forested areas tended to have a greater variety of native birds than did small stands, and some species were restricted to large tracts (e.g., kākā, falcon, parakeet). Walker (1987) identifies a large number of key sites within the Motueka Catchment (Appendix 2). These include forest sites (e.g., Kahurangi National Park, Mt Richmond Forest Park and Big Bush Forest), freshwater wetland sites (e.g., the middle braided reaches of the Motueka riverbed around Tapawera) and coastal wetland sites at the Motueka River delta (the rivermouth, sandspit and Kumeras tidal flats). The ecological district descriptions of McEwen (1987) also include a brief description of important fauna in each district, including reptiles (geckos and skinks), birds, snails, and insects. The threatened blue duck has been reported from the Pearse, Baton, Wangapeka and upper Motueka rivers.

Forest sites contain a wide variety of birds (including kākā, yellow-crowned parakeet, falcon, kiwi, blue duck, fernbird, robin, rock wren, kea, long-tailed cuckoo) and are also notable for large land snails (*Powelliphanta*). Freshwater wetland sites are important for survival of a number of birds (e.g., fernbird, waterfowl, pūkeko), and are used seasonally for breeding by coastal species (including the banded dotterel, pied stilt, Paradise shelduck, South Island pied oystercatcher and black-fronted tern). The coastal wetlands, tidal flats and saltmarsh (see Photo 1a) provide feeding and breeding areas for a very large variety and number of birds including estuarine edge species (banded rail, and South Island fernbird until recently), waders (South Island pied oystercatcher, Eastern bar-tailed godwit, turnstones, banded dotterel, wrybill, New Zealand dotterel, royal spoonbill, white heron), coastal species (shags, gannets, gulls, white-fronted tern, black-fronted and caspian terns). These coastal areas include some of the most threatened (from stock grazing, drainage and land development) wildlife areas in the catchment. The Department of Conservation regards the Motueka delta as being of national importance (Davidson et al. 1993).

Introduced plants and animals are a threat to wildlife (Walker 1987). These include browsing animals (e.g., deer, goats, pigs, possums, hares), predators (e.g., stoats, ferrets, weasels, rats, mice, cats, dogs), competitors, and exotic plants (e.g., old man's beard in forests, shrubland and river beds; *Spartina* grass on tidal flats – which has now largely been eradicated).

2.7 CLIMATE

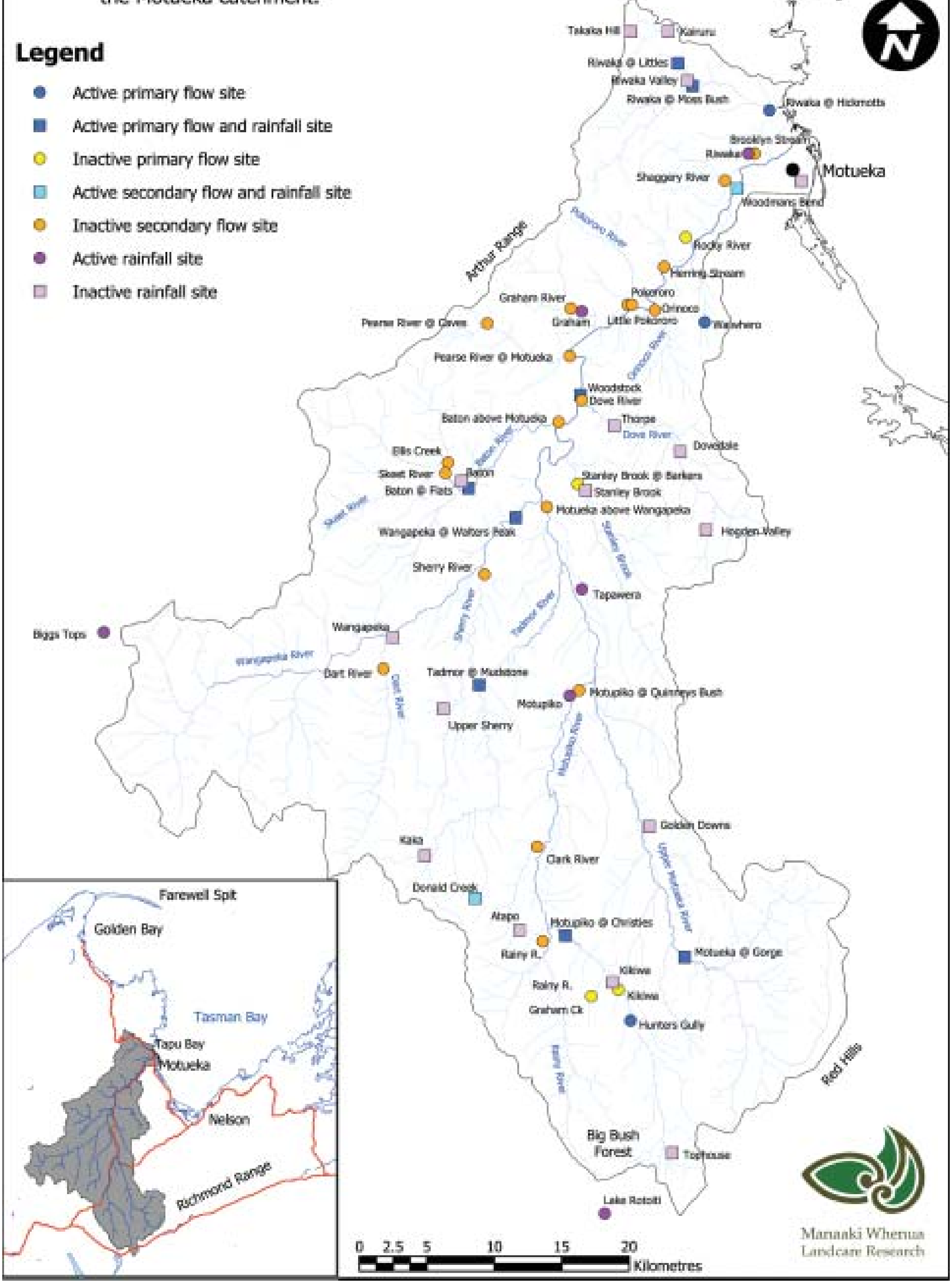
Aspects of the climate of the Motueka Catchment are described by De Lisle and Kerr (1965), Coulter and Hessell (1980), and New Zealand Meteorological Service (1983, 1985). The data presented in this section are derived from these sources, from the New Zealand Meteorological Service database (CLIDB) and Tasman District Council climate stations. Currently climatic data are recorded by NIWA (the National Institute for Water and Atmospheric Research) at Riwaka (rainfall, air, grass and earth temperature, wind run, vapour pressure and radiation), Graham (rainfall), Motupiko (rainfall), Tapawera (rainfall), and Lake Rotoiti (rainfall, air, grass and earth temperature, vapour pressure). Tasman District Council record rainfall at Woodstock, the upper Motueka Gorge, Baton Flats, Wangapeka (at Walters Peak), Tadmor (at Mudstone), Motupiko (at Christies), and Biggs Tops (immediately adjacent to the Wangapeka headwaters). Landcare Research record rainfall at Donald Creek in Big Bush Forest. NIWA also holds historical rainfall data for Motueka (1899–1985), Riwaka Valley (1947–1998), Kairuru (1961–1979), Takaka Hill (1947–1959), Dovedale (1947–1985), Thorpe (1959–1981), Stanley Brook (1911–1983), Hogden Valley (1947–1955), Baton (1952–1998), Wangapeka (1924–1928 and 1963–1996), upper Sherry River (1913–1923), Golden Downs (1929–1980), Atapo (1947–1955), Kaka (1947–1998), Kikiwa (1947–1965), and Tophouse (1913–1931 and 1961–1971). The location of these sites is shown in Fig. 13.

The climate of the Motueka Catchment is characterised as "cool humid". In general terms it tends to be sunny and mild, less windy than other areas of New Zealand, and prone to frost in sheltered areas. Elevation has a major influence on both rainfall and temperature patterns. The catchment tends to be sheltered from both southerly and easterly weather systems, and from westerly storms except in the headwaters of the western catchments. It is most exposed to weather from the north and north-east. Intense localised storms are also a feature of the climate. Summer droughts may occur, usually between December and March, and are occasionally prolonged.

Mean annual rainfall for the catchment is estimated at 1600 mm. However, there is a strong spatial pattern of rainfall variation, primarily related to topography (Fig. 14). Rainfall ranges from <1000 mm/yr on the eastern side of the catchment to about 3500 mm/yr in the headwaters of the Wangapeka. Annual rainfalls in the mountainous, western tributaries are far higher (1500–3500 mm/yr) than in the eastern tributaries (1000–1400 mm/yr), and within the main valley rainfall increases slightly from the coast (c. 1300 mm/yr) to the headwaters (c. 1500 mm/yr). The lowest rainfall occurs in the headwaters of the Dove River and the middle reaches of the Stanley Brook. Annual rainfall totals are relatively well characterised in the mountainous areas of the western tributaries, but are poorly known in the upper Motueka. Rain falls on average between 100 and 150 days per year, increasing at higher elevation to 200 rain days per year. The northerly aspect and western ranges shelter the catchment from severe westerly storms, except in the headwaters of the Baton and Wangapeka catchments. High-intensity rainfalls can occur from north and north-easterly weather systems. Characteristics of rainfall depth, duration, and frequency for the Motueka Catchment are shown in Fig. 15 (Coulter and Hessell 1980; M. Doyle pers. comm. 2002). Rainfall of short- to-medium duration is often of high intensity and can cause severe flooding and erosion. However, as high-intensity short-duration rainfalls come from thunderstorms, such flooding and erosion tends to be localised. The most severe and extensive flooding and erosion tend to come from long-duration, moderate-intensity north-easterly storms.

In the lower-elevation, drier areas of the catchment (e.g., Motueka) rainfall is markedly seasonal, with a winter maximum in rainfall distribution (Fig. 16). In the wetter areas (e.g., Biggs Tops), and probably at

Fig. 13 Map of climatic and hydrological monitoring sites in the Motueka catchment.



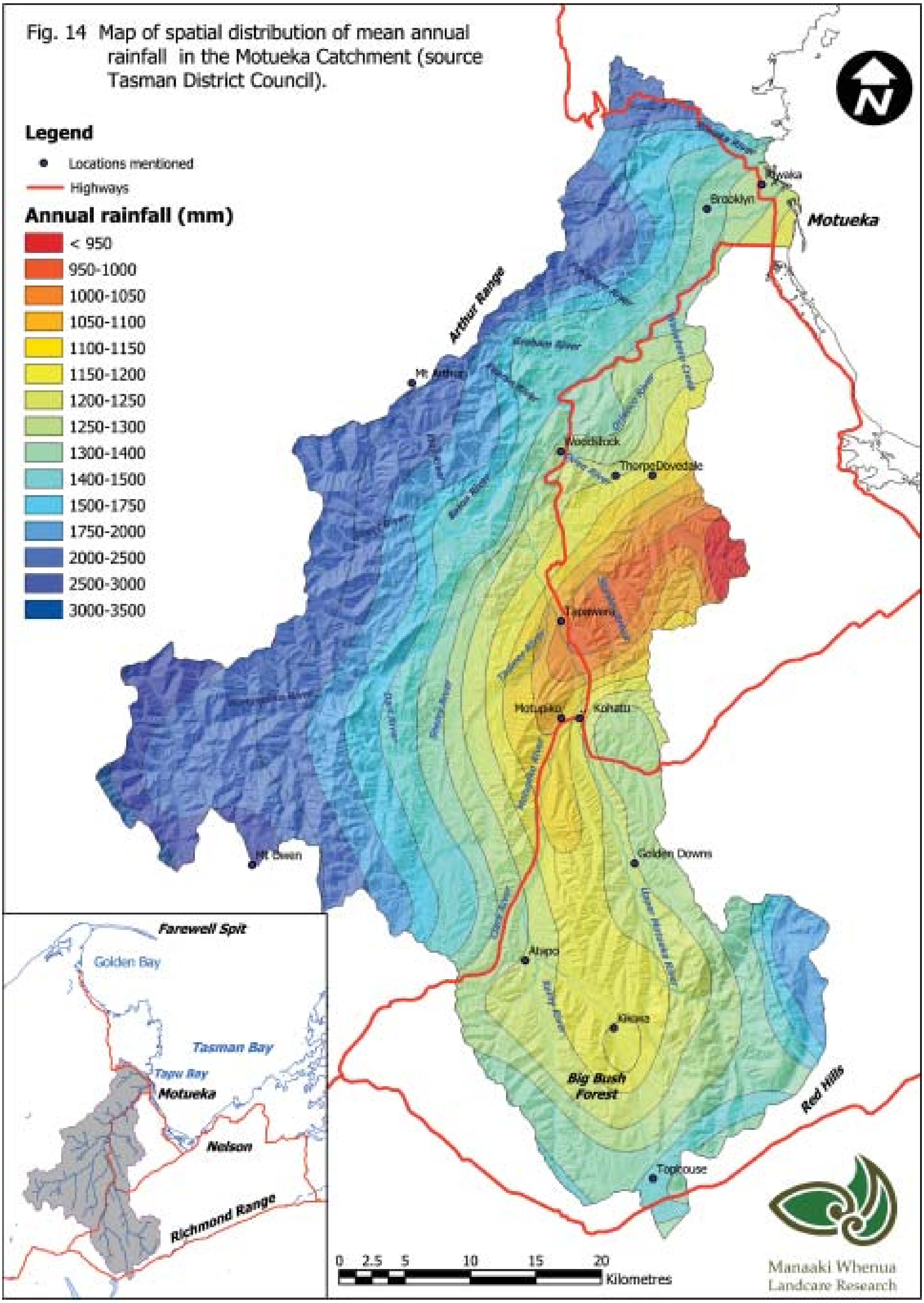


Fig. 14 Map of spatial distribution of mean annual rainfall in the Motueka Catchment (source Tasman District Council).

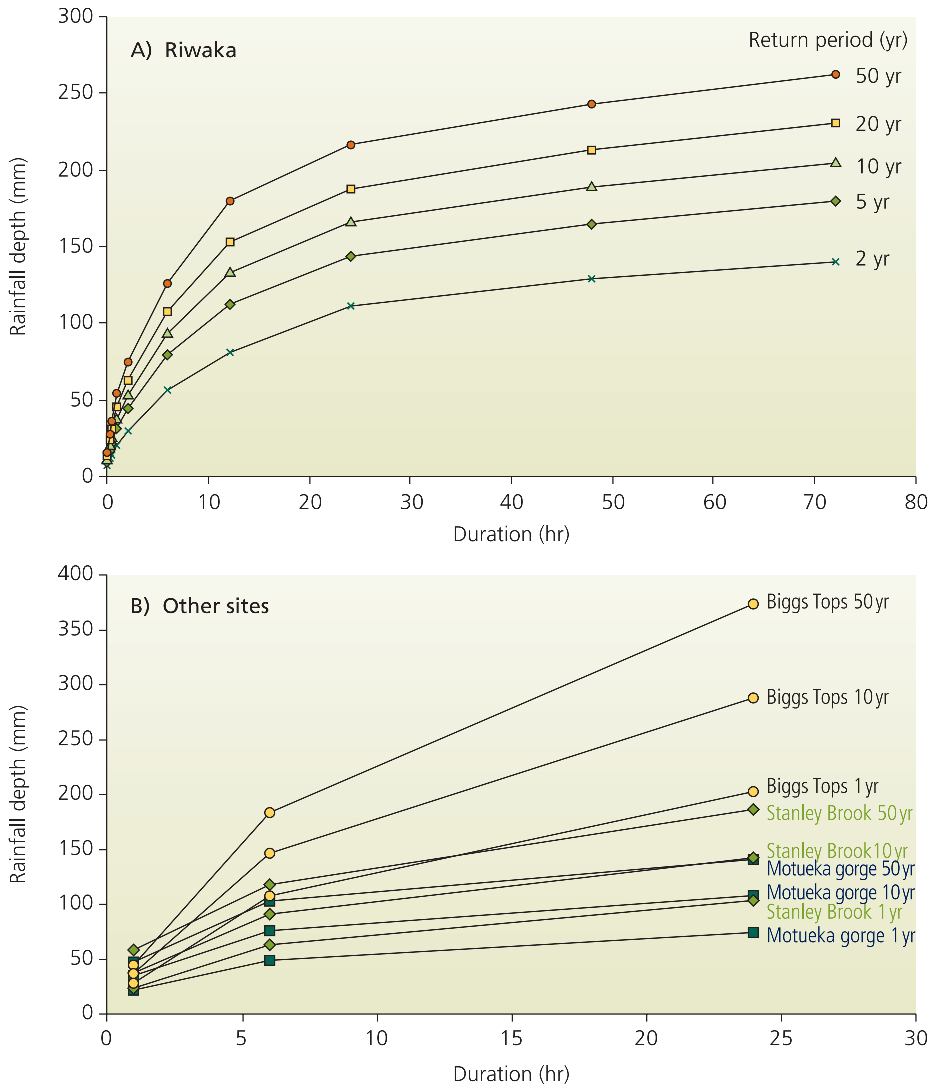


Fig. 15 Rainfall depth-duration-frequency statistics at (a) Riwaka (from Coulter and Hessell 1980), and (b) other sites in the Motueka Catchment (source Tasman District Council).

higher elevation, rainfall appears to be less seasonal, although the summer months tend to have lower rainfall than other months. Another characteristic feature of the rainfall pattern is marked variability of annual rainfall totals. For example, at Motueka between 1900 and 1985 annual rainfall ranged from 687 to 1747 mm and at Biggs Tops between 1990 and 1999 it ranged from 3043 to 5116 mm (Fig. 17). At the monthly level, rainfall is even more variable (Fig. 16).

Temperatures are milder in the north and east of the catchment and nearer the coast, and decrease inland and with elevation. At lower elevations summers are very warm and winters mild. Mean monthly temperature at Riwaka (8 metres elevation) ranges from 7.0ºC in July to 17.4ºC in January (Fig. 18). By comparison, at Golden Downs (274 metres elevation) mean monthly temperature ranges from 4.6ºC in July to 15.7ºC in January. The daily range of temperature is often large, with an average daily range of 11–12ºC. Annual days of air and ground frost also increase away from the coast and with

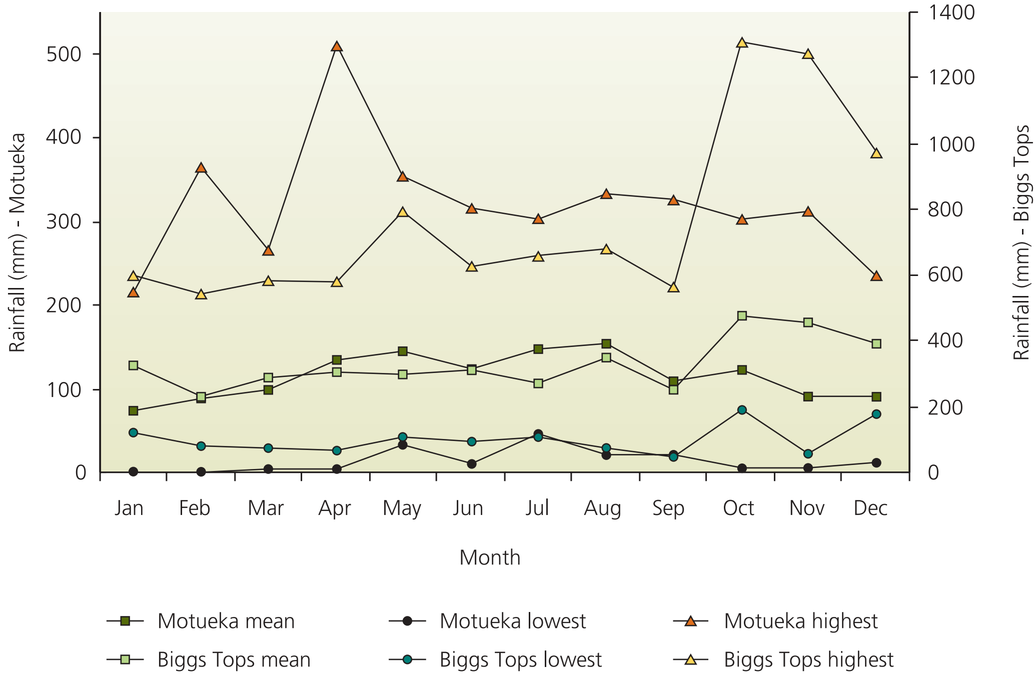


Fig. 16 Variation in mean monthly rainfall at Motueka and Biggs Tops (source NIWA and Tasman District Council).

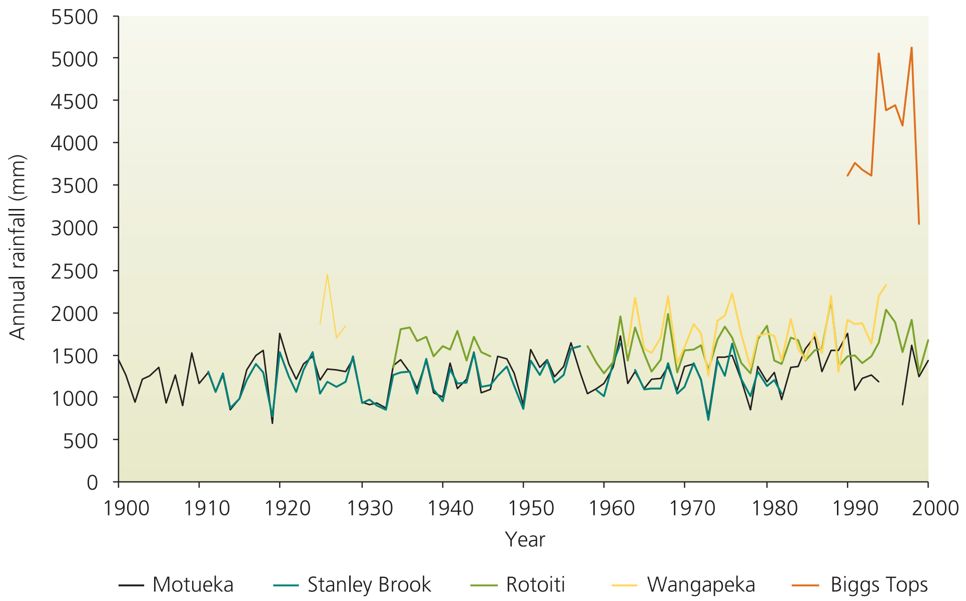


Fig. 17 Temporal variation in annual rainfall at Motueka, Stanley Brook, Lake Rotoiti, Wangapeka and Biggs Tops (source NIWA and Tasman District Council).

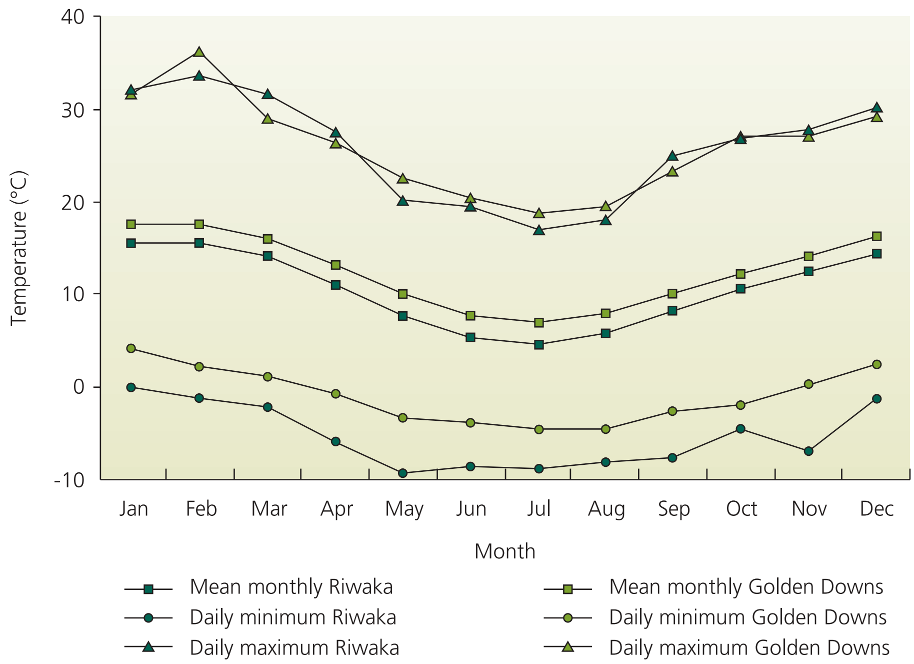


Fig. 18 Monthly mean temperature, highest and lowest daily temperatures at Riwaka (8 metres elevation) and Golden Downs (274 metres elevation) (data from New Zealand Meteorological Service 1983).

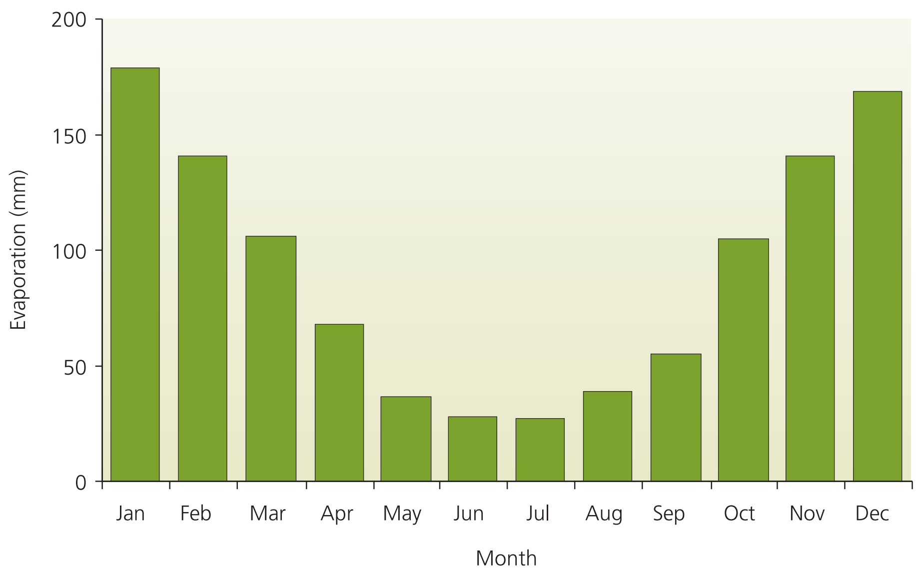


Fig. 19 Monthly mean open pan evaporation at Motueka (data from New Zealand Meteorological Service 1983).

elevation (31 and 82 days, respectively, at Riwaka, compared to 74 and 118 days at Golden Downs). Sunshine hours are among the highest in New Zealand averaging over 2400 hours at Riwaka, with mean monthly values ranging from 264 hours in January to 157 hours in July.

Annual open pan evaporation[14] at Motueka is 1106 mm and is strongly seasonal, with mean monthly values ranging from 27 mm in July to 179 mm in January (Fig. 19). While annual evaporation is less than annual rainfall, soil moisture deficits are common in summer when evaporation exceeds rainfall and irrigation is required on many crops. Scarf (1972) estimates annual potential evapotranspiration[15] to vary across the catchment from 540 to 700 mm.

2.8 FRESHWATER HYDROLOGY AND WATER QUALITY

2.8.1 Surface water

Surface water hydrology statistics are summarised in Green (1982), Fenemor (1989, 2002b) and Tasman District Council (2000a, b, c). Data presented in this section are derived from these sources. Tasman District Council and its predecessors have operated a network of 16 primary sites with flow recorders in the Motueka Catchment (Fig. 13, Table 4). At 19 secondary sites flow statistics have been derived by correlation of streamflow gaugings with a similar nearby primary site. Currently flow is monitored on the main stem at Woodmans Bend, Woodstock and the upper Motueka Gorge, and on the Baton at Baton Flats, the Wangapeka at Walters Peak, the Tadmor at Mudstone, the Motupiko at Christies Bridge, the Waiwhero, Hunters Gully at Weir, and at three sites on the Riwaka River (north and south branches, and main stem below the confluence of the north and south branches). Long-term flow records are available for the main stem sites at Gorge (since 1965) and Woodstock (since 1969), the Baton (since 1971), the Wangapeka (since 1986), the north branch of the Riwaka (since 1981) and the south branch of the Riwaka (since 1961). Flow is also measured by Landcare Research from four small catchments in Donald Creek at Big Bush Forest – one of these catchments is a control catchment in beech forest and in the other three the beech was harvested by different techniques and then the catchments were replanted in pines.

Annual flow[16] of the Motueka River at Woodstock is 844 mm, compared to a mean annual rainfall for the contributing catchment of 1600 mm. It is a reasonably large river with a mean flow of 58,560 L/s (7-day running mean for Motueka at Woodstock), and a measured flow range from about 5600 L/s to >2,100,000 L/s. River flow is lower than the mean flow about 70% of the time with a median flow[17] of 33,950 L/s (Fig. 20). The mean annual low flow ranges from 9,552 L/s (1-day mean flow) to 10,216 L/s (7-day mean flow). River flow lies between the mean annual 1-day low flow and the median flow 46% of the time. Like rainfall, mean monthly flow shows a distinctly seasonal fluctuation, with higher values in winter and spring, and lower values in the summer months (Fig. 21). This seasonality is more marked for low flows. River flow statistics for primary and secondary sites in the Motueka are listed in Table 4 and a comprehensive analysis of the low-flow characteristics of the river is included in Fenemor (2002b) and Waugh (2002).

Periodic large floods are a characteristic feature of the hydrology of the Motueka River and were a

[14] Measured using raised, open pans of water – a measure of maximum potential evaporation from the land surface.

[15] Evaporation from the ground and plant surfaces, plus transpiration by plants (expressed in *L,* or for comparison with rainfall in *mm*).

[16] Total volume of water carried on an annual basis, converted to *mm* by dividing by catchment area.

[17] Discharge which is exceeded 50% of the time.

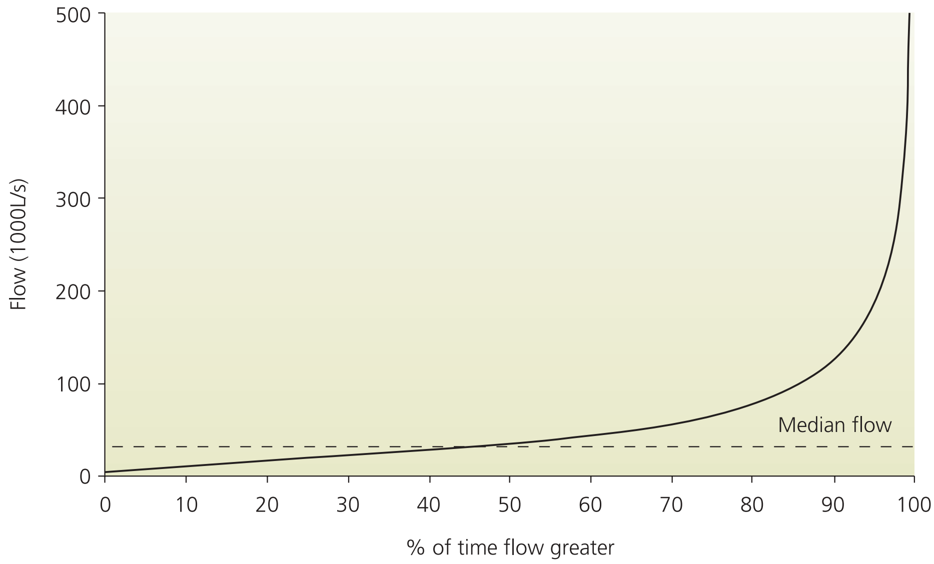


Fig. 20 Flow duration curve for the Motueka River at Woodstock (source Tasman District Council). Shows the percentage of time that flow is lower than a given value.

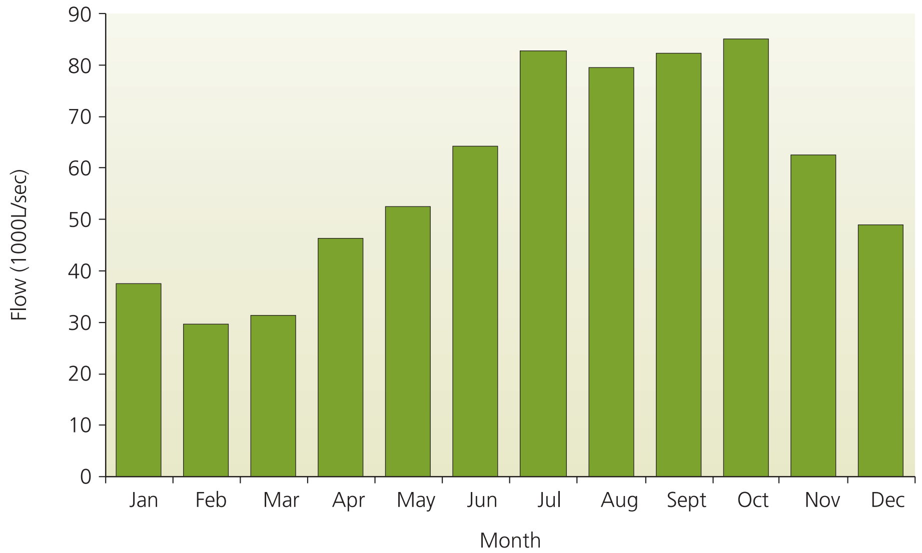


Fig. 21 Mean monthly flow for the Motueka River at Woodstock (source Tasman District Council).

severe hazard to transport and land use prior to the implementation of the Motueka Catchment Control Scheme (Green 1982). The largest flood is thought to be the "Big Flood" of February 1877[18] with a maximum flow at Woodstock estimated to lie between 2,500,000 L/s (M. Doyle, Tasman District Council, pers. comm. 2002) and 3,500,000 L/s (Green 1982). Other large floods occurred in January 1895, July 1929, June 1954, April 1957, August 1972, April 1974, July 1983, October 1988, and August 1990 (Green 1982; Fenemor 1989). Rainfalls in excess of about 150 mm over the

[18] Brereton (1947) and Beatson and Whelan (1993) provide good historical accounts of the character and impact of this "earth" flood, which caused many landslides, widespread erosion and sedimentation, and changed the character of the river in many areas.

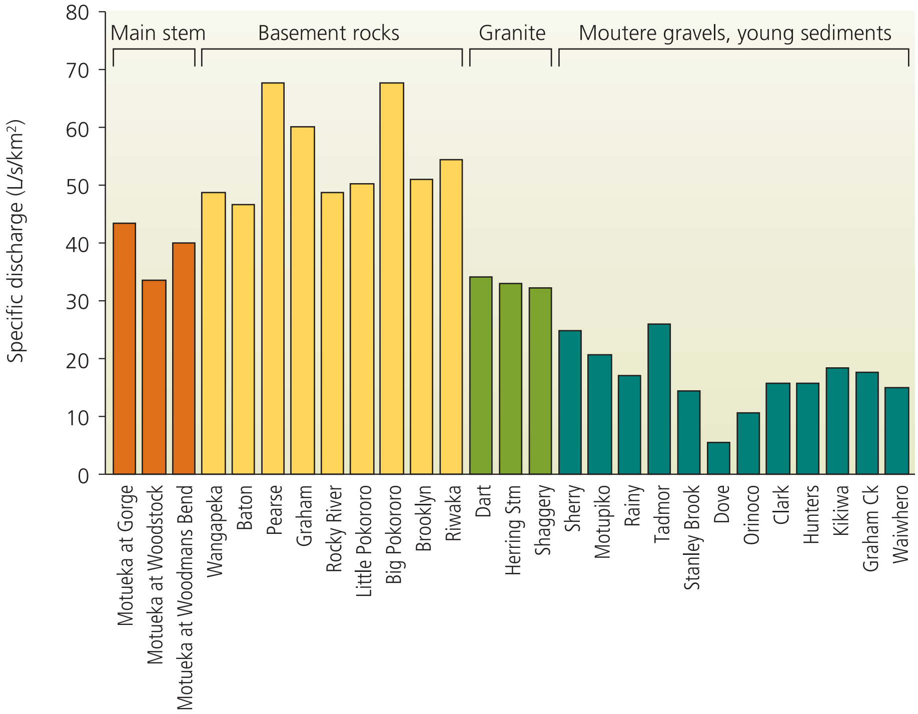


Fig. 22 Variation in specific discharge in the Motueka Catchment (source Tasman District Council).

catchment produce large floods on the main stem, while more-localised flooding can occur in any of the smaller tributaries in response to localised high-rainfall events. This is particularly true of the Wangapeka and Baton catchments, which can produce large floods at Woodstock from heavy westerly rainfall in their headwaters alone.

River flow generation is controlled by rainfall distribution (section 2.7) and geology (section 2.2), with striking contrasts between subcatchments in specific discharge (Table 4, Fig. 22). The largest contributors to flow in the lower Motueka are the mountainous catchments of the west and south-east (Wangapeka, Baton, upper Motueka) as they cover the largest area, have the highest rainfall, and are underlain by basement rocks that provide the highest sustained water yields (specific discharges >40 L/s/km^2). These areas provide a large proportion of the mean annual flow for the Motueka at Woodstock. The Wangapeka (27% of the catchment area above Woodstock) and Baton (9% of area) supply 40% and 13%, respectively, of the mean flow[19] of the Motueka at Woodstock. The proportion of flow contributed by these catchments increases as flow declines. The Wangapeka and Baton contribute 49% and 17%, respectively, of the mean annual low flow at Woodstock. Similarly, the upper Motueka is 9% of the catchment area above Woodstock, but provides 12% of the mean flow and 15% of the mean annual low flow.

The Moutere gravels are relatively impervious and make a significant contribution to flood events, but they have very low specific discharges (<20 L/s/km^2) and provide a small low-flow contribution. Flow in many tributaries underlain by Moutere gravel ceases completely during longer droughts. Strong seasonality of rainfall and evapotranspiration in areas underlain by Moutere gravel causes river flow to have high seasonal variability, with the

[19] All mean and median flows are quoted as 7-day averages.

Table 4 Motueka Catchment flow statistics (from Fenemor 1989, 2002b; Tasman District Council 2000a,b,c)

SITE	Area (km^2)	Mean (L/s)	Median (L/s)	Specific discharge (L/s/km^2)[A]	MALF	7-day low flow (L/s) 5 yr	10 yr	20 yr	50 yr	Period of record
Primary sites										
Motueka at Gorge	163	7067	3966	43.4	1550	1243	1109	1005	894	1965– 2001
Hunters at Weir	5.02	79.5	30.5	15.8	3.5	1.1	0.3	0	0	1977– 2001
Kikiwa at Weir	2.85	52.5	23.4	18.4	1.6	0.21	0	0	0	1977–1986
Graham Creek at Weir	4.74	84.4	37.3	17.8	1.3	0	0	0	0	1977–1986
Motupiko at Christies	105.4	2173	1136	20.6	347	239	182	-	-	1990– 2001
Tadmor at Mudstone (prior to Hope River diversion)	88	2289	1060	26.0	195	121	96	77	-	1983– 2002
Tadmor at Mudstone (after Hope River diversion)	88	2347	1098		256	172	143	122	-	1988– 2002
Wangapeka at Walters Peak	479	23400	13590	48.9	4975	4005	3586	3261	2917	1986– 2001
Stanley Brook at Barkers	81.6	1185	428	14.5	30	18.5	0	0	0	1969–1994
Baton at Baton flats	168	7854	4748	46.8	1764	1387	1259	1165	1070	1971– 2001
Motueka at Woodstock	1750	58560	33950	33.5	10216	7422	6472	5774	5067	1969– 2001
Waiwhero Creek at Rosedale	3.79	57	21	15.0	8.9	-	-	-	-	1994–1998
Rocky River at Old Kiln	10.9	532	330	48.8	142	-	-	-	-	1981–1985
Riwaka River at Littles (north branch)	41[B]	1500		36.6	304	232	209	190	173	1981– 2001
Riwaka River at Moss Bush (south branch)	46[B]	2510	1412	52.2	619	469	418	380	342	1962– 2001
Secondary sites										
Rainy River below Big Gully	105	1794	882	17.1	187					
Clark River at SHB	21.5	339	179	15.8	25					
Dart River at Devils Thumb	80.6	2750	1600	34.1	820					
Sherry River at Blue Rock	78.4	1953	1070	24.9	218					
Ellis River at Baton confluence	35.8	930	580	26.0	260					
Skeet River at Baton confluence	38.2	1550	1100	40.6	610					
Dove River at Motueka confluence	102.3	582	331	5.7	89	61	51			
Pearse River at Caves	N/A	2200	1300		400					
Pearse River at Motueka confluence	51.2[B]	3464	2293	67.7	1163					
Graham River below forks	34.9[B]	2100	1450	60.2	800					
Little Pokororo at Motueka confluence	8.5	426	236	50.1	99					
Pokororo at Motueka confluence	25.2	1706	913	67.7	340					
Orinoco at Ngatimoti	33.4	360	240	10.8	140					
Herring Stream at Motueka confluence	9.8	323	179	33.0	76					
Shaggery River at Tom Evans	9.2	295	172	32.1	83					
Brooklyn Stream at West Bank Bridge	17.52	891	509	50.9	233					
Motupiko at Quinneys Bush	344	5152	2504	15.0	488	212	67			
Baton above Motueka confluence	212	9032	5460	42.6	2029	1595	1448			
Motueka above Wangapeka confluence	845	12030	6990	14.2	2132	1560	1421			
Motueka at Woodmans Bend[C]	2047	82148	47275	40.1	13318	9778	8656			

Primary sites – flow is recorded *Secondary sites* – flow is estimated by correlation with primary sites
MALF = mean annual low flow calculated as the average of each year's minimum flow for the period of record, or synthesised for secondary sites by correlation with adjacent primary sites; [A] discharge per unit area, calculated from mean flow; [B] Actual area is larger because of cave contribution to flow; [C] This site is recently established (2000) so flow statistics have been derived by correlation with primary sites

lowest flows in summer and highest flows in the winter months.

Areas underlain by Separation Point granite tend to be intermediate in hydrological character between the Moutere gravel and the complex geology of the western catchments, with specific discharges of 20–35 L/s/km^2.

Some general features of subcatchment hydrology are listed below.

- The upper Motueka drains a large area of steep, relatively high rainfall terrain on ultramafic and Maitai Group rocks and makes a significant contribution to both low flows and flood flows. Median flow at the Motueka Gorge flow recorder is 3966 L/s and specific discharge is 43.4 L/s/km^2.
- The Motupiko is a large catchment on Moutere gravels, and with a large area of exotic forest it has low base flows[20]. Although rainfall is generally not too intense in this catchment, during the longer-duration storms the large catchment area means it provides a significant contribution to flood flows in the Motueka. Median flow at Christies Bridge in the upper catchment is 1136 L/s and specific discharge is 20.6 L/s/km^2.
- The Tadmor is partly underlain by Moutere gravel and partly by granite and young sedimentary rocks. It has a higher annual rainfall than the Motupiko. Summer river flows are heavily used for irrigation (mainly of berry crops). Flows have been augmented by diverting water from the Hope River (a tributary of the Buller River) into the Tadmor – this contributes up to 500 L/s from 1 October to 30 April. In drought conditions, the diverted flow can be as little as 62 L/s. Median natural flow at the Mudstone recorder (halfway down the catchment) is 1060 L/s and specific discharge is 26.0 L/s/km^2; with the diversion operating, the median flow increases to 1098 L/s.
- The Stanley Brook is one of the largest eastern, low rainfall tributaries draining Moutere gravels and it has a high proportion of its catchment in exotic forestry . At the Barkers recorder in the lower catchment it has a low median flow (428 L/s) and specific discharge (14.5 L/s/km^2), and makes a small contribution to low flows in the Motueka.
- The Dove, Orinoco and Waiwhero have similar runoff characteristics to the Stanley Brook. They have estimated median flows of 331, 240, and 21 L/s, and specific discharges of 5.7, 10.8, and 15.0 l/s/km^2, respectively.
- The Wangapeka is the largest tributary and drains steep, high-rainfall terrain on fractured basement rocks, providing sustained base flow and a major contribution to flood flows. Median flow at the Walters Peak recorder in the lower catchment is 13,590 L/s and specific discharge is 48.9 L/s/km^2.
- The Baton is hydrologically similar to the Wangapeka but covers a smaller area. At the Baton Flats recorder it has a median flow of 4748 L/s and specific discharge of 46.8 L/s/km^2.
- The smaller west-bank tributaries (Pearse, Graham, Pokororo, Brooklyn, Rocky, and Shaggery) are short, steep rivers draining basement rocks and granite and have relatively high estimated median flows (2293, 1450, 913, 509, 330, 172 L/s, respectively) and specific discharges (67.7, 60.2, 67.7, 50.9, 48.8, 32.1 L/s/km^2, respectively). The Pearse has a major karst spring in its headwaters, while the Graham and Pokororo have smaller areas of karst that influence their hydrology.
- At Woodstock (until recently the most downstream recorder site on the main stem) the median flow is 33,950 L/s and specific discharge is 33.5 L/s/km^2.
- Below Woodmans Bend the river flows across the Motueka Plains, constrained within stopbanks to a meandering single-thread channel. In this reach the river loses a small percentage of its flow to groundwater, with the pattern of flow

[20] Proportion of stream flow carried between flood flows.

loss being highly variable (Fenemor 1989). River flow has been monitored at Woodmans Bend only since 2001. Median flow is estimated at 47,275 L/s and specific discharge is 40.1 L/s/km^2.

- The Riwaka comprises two main tributaries, which are hydrologically similar. Both drain steep catchments underlain by marble, granite and schist, and have high median flows and specific discharges (36.6 L/s/km^2 for the north branch and 52.2 L/s/km^2 for the south branch). Both tributaries have a significant karst influence on their hydrology. The two tributaries join at Moss Bush and below this junction the Riwaka flows across a small alluvial plain to the sea.

Water is taken from the Motueka River mainly for irrigation, but also for public and private water supply. As at March 2002, Tasman District Council has allocated surface water abstractions of 172 L/s above Woodstock, with 28 existing permits irrigating 305 hectares of land, and 215 L/s between Woodstock and Woodmans Bend, with 43 permits irrigating 395 ha. An assessment of water use in 1997/98 indicated that up to 62% of the allocations below Woodstock, and 43% of those above Woodstock, were actually being used (Shaw 1998). On the Motueka Plains a further 78 L/s from surface water (from the Motueka River and Brooklyn Stream) are allocated. The Riwaka River has an allocation limit of 200 L/s, with an agreed rostering regime by water users to maintain a minimum flow of 400 L/s in the river.

2.8.2 Effect of land use on water yields

The effects of changing land use and vegetation cover on streamflow from the Moutere gravels have been the subject of several small experimental catchment studies because of concerns about the impact of land-use change on water yield[21] and streamflow. These studies have been undertaken at Moutere, Big Bush, and Kikiwa. While the Moutere study catchments lie outside the Motueka Catchment, with an annual rainfall of 1020 mm they are representative of the drier part of the Moutere gravel hill country. The Big Bush and Kikiwa catchments are representative of the wetter part of the Moutere gravel hill-country, with 1200–1550 mm annual rainfall. Results of these studies are reported in Scarf (1970), Duncan (1980, 1995), McKerchar (1980), O'Loughlin (1980), Pearce (1980), Pearce et al. (1982), Rowe (1983), Jackson (1985), Fahey and Rowe (1992), Fahey et al. (1993), Jackson and Fahey (1993), Fahey (1994), Jackson and Payne (1995), Fahey and Jackson (1993, 1995a,b, 1997a,b), Jackson and Rowe (1996) and summarised in Rowe et al. (1997).

At Moutere, converting small (<10 ha) hill-country catchments in pasture and gorse to *Pinus radiata* forest, and subsequent felling of the mature forest, resulted in major changes in water yield and flow patterns due to changes in interception and evapotranspiration (Duncan 1980, 1995). Afforestation of pasture led to reduced flow and water yield, an increase in the number of days with no flow, and a reduction of peak flows in small storms. Scrub clearance led to short-term increases in peak flows, a decrease in the number of days with no flow, and an increase in the magnitude and persistence of low flows. Mean annual flood peaks from pines averaged 35% of those from pasture, while 50-yr-flood peaks averaged about 50% of those from pasture. Flood peaks following harvesting of pines were 20% (yr 1) and 62% (yr 2) of those from a pasture catchment (due to very low soil moisture levels under the pines at harvest). Harvesting of pines increased base flow (compared to pasture).

The effects on the hydrological regime at Moutere of the development of small gorse catchments by cultivation and cropping are discussed by Scarf (1970). This change in land use resulted in an increase in annual total

[21] Total quantity of water discharged from a catchment on a storm, seasonal or annual basis.

runoff and peak flows, but a decrease in the number of days on which runoff occurred. Peak flows increased in small to moderate-sized floods but showed little change for large floods.

At Big Bush the changes in water yield, flood hydrology, and low flows caused by replacing beech forest with radiata pine forest were studied in catchments ranging in size from 5 to 20 ha. For the first 4 years after harvesting native forest, the average water yield increased 60–70%. Mean flood peaks increased on a skidder-logged catchment after harvesting, especially for small and medium storms (75–100%). The response of storm quickflow[22] to harvesting was similar but much more subdued. Low flows also increased after harvesting. Planting the harvested areas caused the water yield from both catchments to return to preharvesting levels within 8 years. Tree growth brought storm peak flows, quickflows, and low flows back to the levels of those in the original beech forest within 10 years.

At Kikiwa, rainfall and flow from four catchments (ranging in size from 2.8 to 4.8 km^2) – in native forest, cutover and replanted exotic forest (50% replanted in 1969), reverting pasture (recently (1975) planted in exotic forest), and pasture – are described by McKerchar (1980). In contrast to the Moutere and Big Bush studies, preliminary analysis suggested the pasture catchment had similar runoff to the adjacent native forest catchment, while water yield from the two catchments in young pines was slightly higher. A later analysis (1978–1983) by Hewitt and Robinson (1983) suggested no major changes in total water yield, but significant reductions in summer water yield in the afforested catchment. However, the changes in water yield are very small and may largely reflect understorey regrowth (Jackson 1995).

2.8.3 Water quality

Bruce et al. (1987) summarised existing water quality data (from Nelson Catchment Board, MAF, Ministry of Works and Development, Wildlife Service, Nelson Acclimatisation Society) and the results of a one-off sampling exercise (spread over 1986 and 1987) that sampled the Motueka main stem (7 reaches), Wangapeka, Motupiko, and Tadmor rivers for water chemistry and nutrients. This showed that water quality in the Motueka River was high, but there was evidence of enrichment in the lower reaches. The enrichment was greater in 1987 than in 1980-81, suggesting that changes within the catchment were affecting water quality. Water quality was strongly influenced by variation in catchment geology as well as land use. During winter, nitrate concentrations were high and phosphorus low, while in summer the reverse was true (due to uptake by algae and in-stream flora). Ratios of nitrogen to phosphorus were high enough in both the 1986-87 and 1980-81 surveys to suggest that biological productivity was limited by the availability of soluble reactive phosphorus. No mass-flow data[23] were available for the catchment, severely restricting the interpretation of water quality data and identification of enrichment sources.

Bruce et al. (1987) recommended a systematic survey of the catchment to describe the present water quality, nutrient status, and biological communities during low flow, winter base flow, and spring – prior to peak aquatic production; collection of mass-flow data to identify the contribution of each tributary and identify enrichment sources; and routine water quality monitoring at the mouth, Woodstock, and the Gorge, as well as some tributaries, to improve understanding of variation in concentrations of suspended solids and nutrients downstream and seasonally.

Fenemor (1989, 2002b) summarised variation in water quality characteristics throughout the catchment. He suggests water quality is generally

[22] Proportion of flow which occurs during floods.

[23] Estimates of the total quantity of nutrients, derived from combining estimates of nutrient concentrations with river flow.

high although it depends on adjacent land use:

- faecal coliform bacteria and increased nitrate and phosphate are often associated with agricultural land use;
- elevated concentrations of suspended sediment are associated with forestry activities (particularly at harvesting).

He suggests water quality and clarity are particularly high in rivers and streams draining the western ranges and in the headwaters of the upper Motueka.

The "100 Rivers" survey (Close and Davies-Colley 1990a,b) characterised the water quality of a wide range of New Zealand rivers, including one site on the Motueka River at Woodstock. The Motueka River was grouped into a cluster of 35 rivers characterised by very low concentrations of major ions, phosphorus, organic matter, and nitrogen.

Biggs and Gerbeaux (1993) sampled water quality and periphyton[24] monthly for a year at five sites down the Motueka River and at one site in the Riwaka River. They found no systematic variation in water quality down the length of the Motueka River, although nitrate concentrations tended to be highest in the middle reaches, and were similar to the Riwaka River. Measurements of cellular nitrogen concentrations in periphyton indicated that their growth appeared to be limited by nitrogen concentrations for much of the year, but by phosphorus concentrations during low flow. Average periphyton biomass (mass per volume of water sampled) was strongly correlated with the proportion of marble geology in the catchment upstream. Nitrogen turnover and export is expected to be higher from soils overlying marble geology because of reduced acidity and enhanced microbial populations in the soil. Seasonal changes in periphyton biomass were influenced by flow variability, and during low flows biomass was negatively correlated with water velocity.

Two sites in the Motueka River catchment (at Woodstock and Gorge) have also been monitored since 1989 as part of the New Zealand National River Water Quality Network. The main water quality parameters (except suspended sediment and indicator bacteria) are measured monthly at 77 sites around the country. Maasdam and Smith (1994) used the first two years of data to classify the sites, and trends in water quality parameters for the first five years of the network's operation have been reported by Smith et al. (1996). The two Motueka River sites were classified in groups described as pristine waters, although water quality downstream at Woodstock was not as good as that in the upper reaches at the Gorge (Maasdam and Smith 1994). Over the first five years there were significant reductions in water temperature and nitrate at both sites and an increase in water clarity. At the Woodstock site there was also an indication of increasing dissolved oxygen and pH, and decreasing phosphorus concentrations, over time (Smith et al. 1996). Trends in mean annual water clarity, nitrate-nitrogen, and dissolved reactive phosphorus from the two Motueka sites up until June 2001 are shown in Fig. 23. Water in the upper reaches of the Motueka River at the Gorge site has a consistently higher clarity and lower concentrations of dissolved nutrients than in the middle to lower reaches at the Woodstock site (Fig. 23). Changes in these parameters from year to year are largely the result of differences in flow on the sampling days, rather than consistent trends.

As part of the ICM Programme an environmental sampling network has been initiated to provide an improved understanding of the variation in water quality through the catchment, and of the influence of land use and geology on water quality. This network provided monthly values over a 13-month period for a range of chemical and biological parameters (dissolved oxygen, temperature, water clarity, turbidity, total

[24] Organisms that live attached to a riverbed.

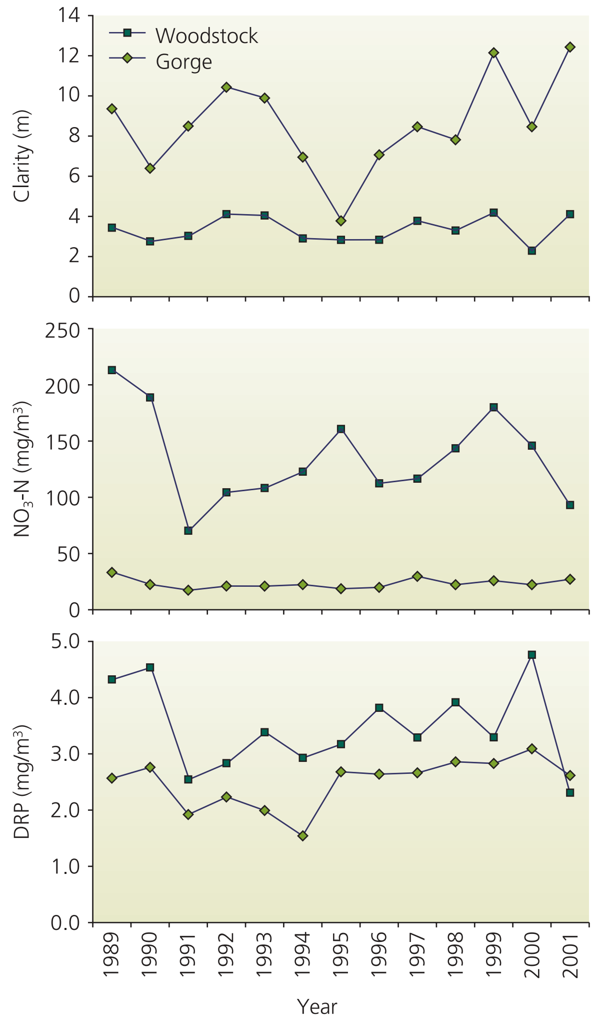


Fig. 23 Mean annual water clarity and concentrations of nitrate-nitrogen (NO_3-N) and dissolved reactive phosphorus (DRP) in the Motueka River at the Gorge and Woodstock 1989–2001 (data from NIWA National River Water Quality Network).

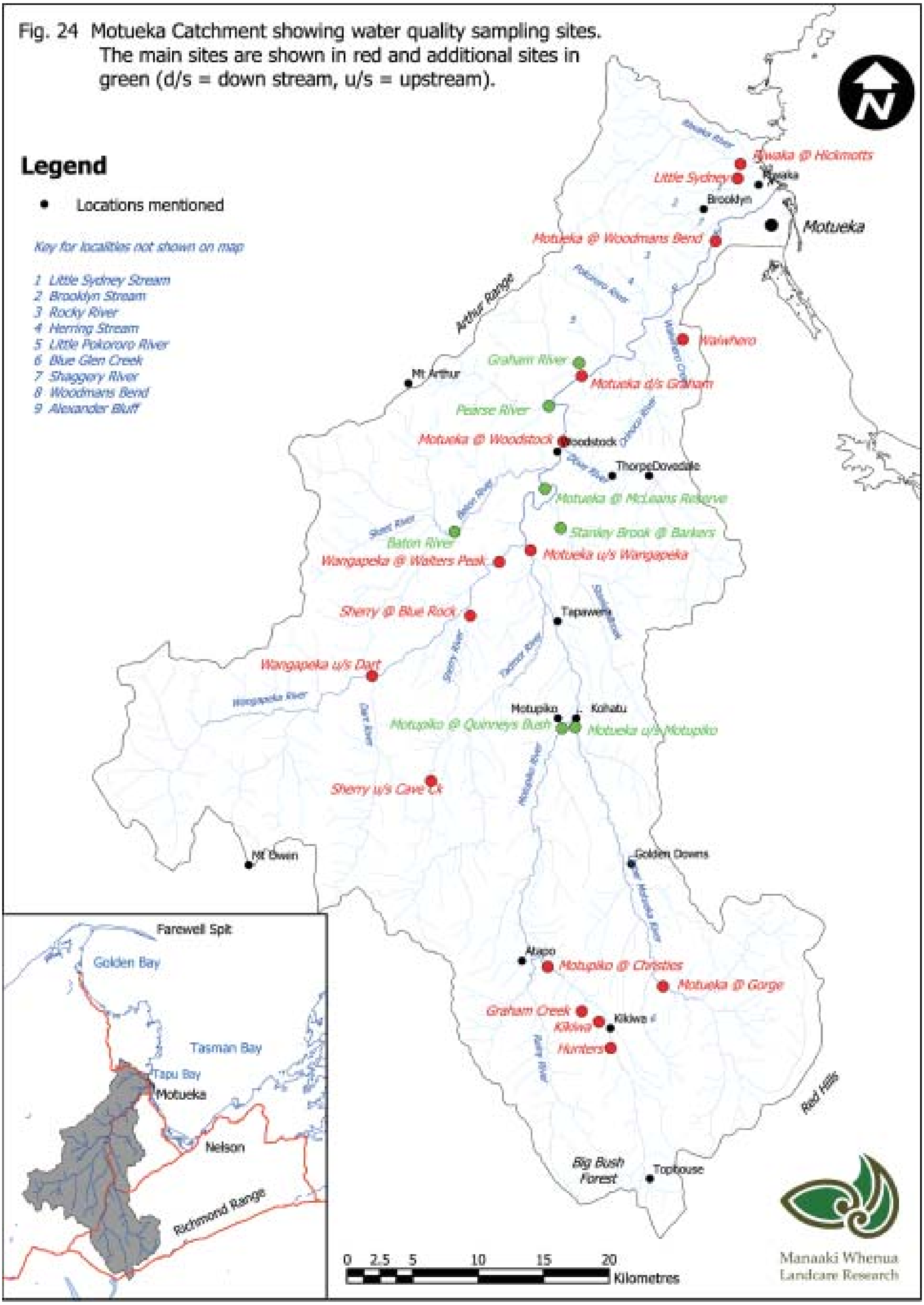
suspended solids (as inorganic and organic fractions), conductivity, pH, dissolved reactive phosphorus, total phosphorus, nitrogen (as ammonia, nitrate, total nitrogen), *Enterococci coli*, total faecal coliforms, and *Campylobacter*). The network continues to be monitored quarterly as part of the Tasman District Council's State of the Environment monitoring. Sixteen main sites and seven additional sites were chosen to cover a longitudinal profile of the river, and sample the key geological types (ultramafic rocks, basement rocks, Moutere gravels, Separation Point granite, marble), land uses (native forest, production forest, mixed agriculture, dairying, horticulture) and stream sizes found throughout the catchment. The sites and their key characteristics (size, land use, geology, location) are given in Table 5 and their location is shown in Fig. 24.

Preliminary analyses of the results (Roger Young, unpublished) have shown marked differences among sites. Some variables appeared to be primarily linked with geology (e.g., conductivity), some were related primarily to land use (e.g., bacteria, nutrients), and others were strongly controlled by both geology and land use (e.g., temperature,

Table 5 List of sites in the Motueka environmental sampling network 2000–2001, and their environmental characteristics

SITE	LOCATION	GEOLOGY	DOMINANT VEGETATION
Motueka River (at Gorge)	Main stem, upper catchment	Ultramafics and old sediments	Native forest, scrub
Motueka River (upstream of Motupiko)	Main stem, upper and middle catchment	Ultramafics, old sediments, Moutere gravel	Native and exotic forest
Motueka River (upstream of the Wangapeka)	Main stem, upper and middle catchment	Moutere gravel, ultramafics, old sediments	Native and exotic forest, pasture
Motueka River (at McLeans Reserve)	Main stem, upper and middle catchment	Complex basement rock, Moutere gravel, ultramafics, old sediments, granite	Native and exotic forest, pasture
Motueka River (at Woodstock)	Main stem, middle and lower catchment	Moutere gravel, complex basement rock, ultramafics, old sediments, granite	Native and exotic forest, pasture
Motueka River (downstream of the Graham)	Main stem, middle and lower catchment	Moutere gravel, complex basement rock, ultramafics, old sediments, granite	Native and exotic forest, pasture
Motueka (at Woodmans Bend)	Main stem, lower catchment, closest site to the coast	Moutere gravel, complex basement rock, ultramafics, old sediments, granite	Native and exotic forest, pasture
Wangapeka (at Walters Peak)	Major tributary	Complex basement rock and granite	Native forest, exotic forest, scrub
Wangapeka River (upstream of the Dart)	Medium/large catchment	Complex basement rock	Native forest
Baton River	Major tributary	Complex basement rock	Native and exotic forest, scrub
Pearse River	Major tributary	Karst (marble), complex basement rock, granite	Native and exotic forest, scrub
Graham River	Major tributary	Karst (marble), complex basement rock, granite	Native and exotic forest, scrub
Motupiko River (at Christies)	Major tributary	Moutere gravel	Pasture, exotic forest
Motupiko River (at Quinneys Bush)	Major tributary	Moutere gravel	Pasture, exotic forest
Stanley Brook (at Barkers)	Major tributary	Moutere gravel	Exotic forest, pasture
Sherry River (upstream of Cave Creek)	Small/medium catchment	Granite and mudstone	Exotic forest
Sherry River (at Blue Rock)	Medium-sized catchment	Granite and mudstone	Pasture (dairying), exotic forest
Lower Riwaka (at Hickmotts)	Medium-sized catchment	Marble and complex basement rock	Horticulture, pasture, native forest
Kikiwa Stream	Small catchment	Moutere gravel	Pasture
Hunters Gully	Small catchment	Moutere gravel	Native forest
Graham Creek	Small catchment	Moutere gravel	Exotic forest
Waiwhero Creek	Medium-sized catchment	Moutere gravel	Pasture
Little Sydney Stream	Small catchment	Complex basement rock and granite	Horticulture, scrub, native forest

Fig. 24 Motueka Catchment showing water quality sampling sites. The main sites are shown in red and additional sites in green (d/s = down stream, u/s = upstream).



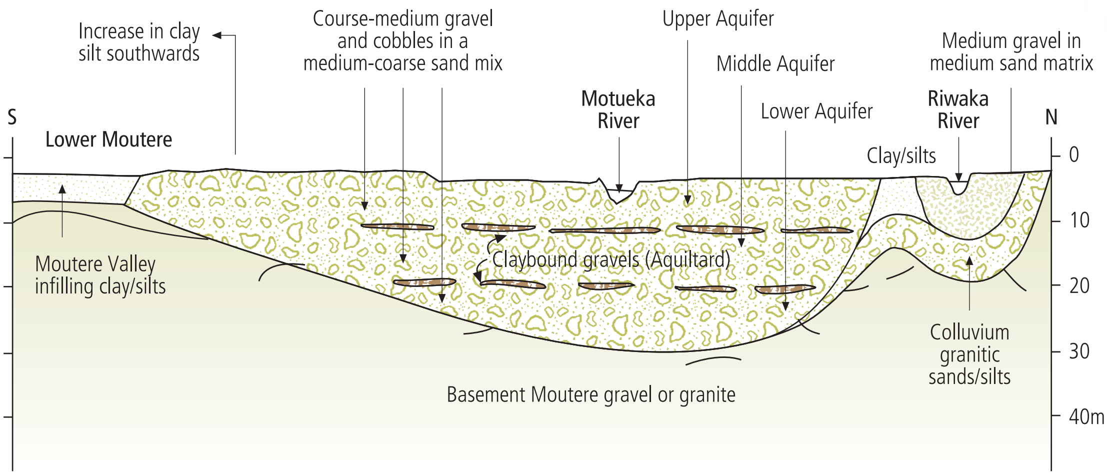


Fig. 25 Schematic cross-section through the Motueka–Riwaka Plains aquifers (from Thomas 2001).

suspended sediment, water clarity). Longitudinal patterns, in response to changing proportions of the catchment in different land use and/or geology, were also evident. Nutrient and suspended sediment concentrations in the Motueka Catchment appeared to be relatively low compared to other parts of the New Zealand. However, relatively high concentrations of harmful bacteria were found associated with dairy farming and horticulture (the latter influenced by a leaky septic tank). Conductivity of the water was much higher in the streams draining parts of the catchment with marble geology. Water clarity tended to be lower in the small streams draining pasture and horticultural land than in those draining native forest or pine forest. Water clarity also tended to be lower in the streams draining granite catchments. The highest clarity water was found in the upper parts of the Motueka and Wangapeka rivers, and water clarity tended to decrease downstream. Some water clarities recorded at the Motueka Gorge are amongst the highest recorded at any wholly riverine site in the country. Nutrient concentrations were relatively low in the Motueka Catchment compared with some other parts of the country, but within the catchment were highest in the small streams draining pasture and horticultural land.

2.8.4 Groundwater

There are three main groundwater systems exploited within the Motueka Catchment:

- the floodplain and fans of the Motueka Plains near the coast (Thomas 1991a; Robb 1999; Tasman District Council 1995a, 2000b)
- the terraces and floodplains in the upper Motueka around Tapawera (Tasman District Council 2000c)
- parts of the Waiwhero, Orinoco and Dove catchments that form the recharge zone for the Moutere groundwater system (Thomas 1989, 1991b, 1992; Tasman District Council 2000d)

Thomas (2001) summarises the characteristics of all three groundwater systems.

Groundwater in the Motueka Plains groundwater system is contained within alluvial gravels (known as the Motueka gravels) forming the coastal delta of the Motueka and Riwaka rivers (Fig. 25). This system is the principal source of water for irrigation, industrial and domestic use on the Motueka Plains, supplying 85% of the current water used (Thomas 1991a). The Motueka gravels are thinnest (c. 6 m) at the inland margins of the plains, and thicken to 30 m in the central plains area. They are underlain by granite in the west and north, and by Moutere gravels in the south. The gravels are cleanest and most permeable in the central plains, and become less permeable where mixed with fines (from Moutere gravels) to the south and with colluvium and organic materials to the west and north.

Three water-bearing units occur within the Motueka gravels (Fig. 25), with some leakage of water between them:

- the upper aquifer lies between 1 and 10 m below ground surface and has a transmissivity of 2000 m^2/day;
- the middle aquifer lies between 10 and 16 m depth and has a transmissivity of >4000 m^2/day. This is the main water-bearing unit and the most exploited;
- the lower aquifer lies below 16 m, has a transmissivity of >2500 m^2/day, and is the least-exploited aquifer.

The groundwater system is strongly connected hydraulically to both the Motueka and Riwaka rivers, and is weakly connected to the Moutere River. The principal recharge to the Motueka gravel aquifers is directly from the Motueka River downstream of Woodmans Bend, from the Riwaka River, and from rainfall on the plains. Flow from the aquifers occurs along the coast, through springs in the lower plains, or back into the Motueka River.

Groundwater quality is generally good, with low quantities of dissolved solids and a chemical composition similar to river water. However, elevated nitrate levels occur in the southern Motueka Plains (as a result of leaching of fertiliser and animal waste), and areas in the west towards the foothills of Riwaka have high iron, manganese, and sulphate levels (typical of a swampy environment). Pesticides (simazine, diazinon, terbuthylazine) have been detected in groundwater on the Motueka–Riwaka Plains but at concentrations well below the Ministry of Health maximum acceptable value for drinking water (Tasman District Council 2000e)

Tasman District Council (1995a, 2000b) has established seven zones (Riwaka, Swamp, Umukuri, Central Plain, King Edward, Hau, Transition) for groundwater management. In the Tasman Resource Management Plan (Tasman District Council 2001a) Hau and Transition have been merged into a Hau Plains Zone. The zones are based on hydrogeology and aquifer yields, and Tasman District Council's aim is to manage the zones in an integrated manner. Groundwater levels are monitored at six sites on the Motueka–Riwaka Plains to assist management. In 1999, the council allocated a total of 1298 L/s for abstraction from groundwater (Tasman District Council 2000b). Irrigation represents >96% of the pumping demand on these aquifers – with a total allocation of 110,000 m^3/day in the irrigation season, compared with 3000m^3/day for industrial use and 3000m^3/day for domestic use (Robb 1999; Fenemor et al. 1999). Much (63%) of the irrigation water re-enters the aquifers in an average year, but only 3% does so in a 1-in-20-yr drought. The water allocated for irrigation is greater than predicted irrigation demand (in a 20-yr drought this averages 65,500 m^3/day with a maximum demand of 105,000 m^3/day). Irrigation pumping has little influence on river flows in the Motueka and Riwaka rivers. Its major effect is significant lowering of groundwater levels in the Hau Plains Zone during droughts, which increases the likelihood of saltwater intrusion in this zone. Similarly, drying up of springs or flows in the Little Sydney and Brooklyn streams is more likely to be due to naturally low aquifer levels in drought years than to irrigation pumping.

Modeling of this groundwater system (Robb 1999) established that:

- most of the water entering the system from the Motueka River stays within the Central Plains Zone and exits to the sea;
- the amount of water pumped from the aquifer represents <10% of the total water flowing through the aquifer system in an average year. However, in the summer months during a 20-yr-drought simulation, pumping extracted 20% of

the water flowing through the system (and 13% in a 10-yr drought);

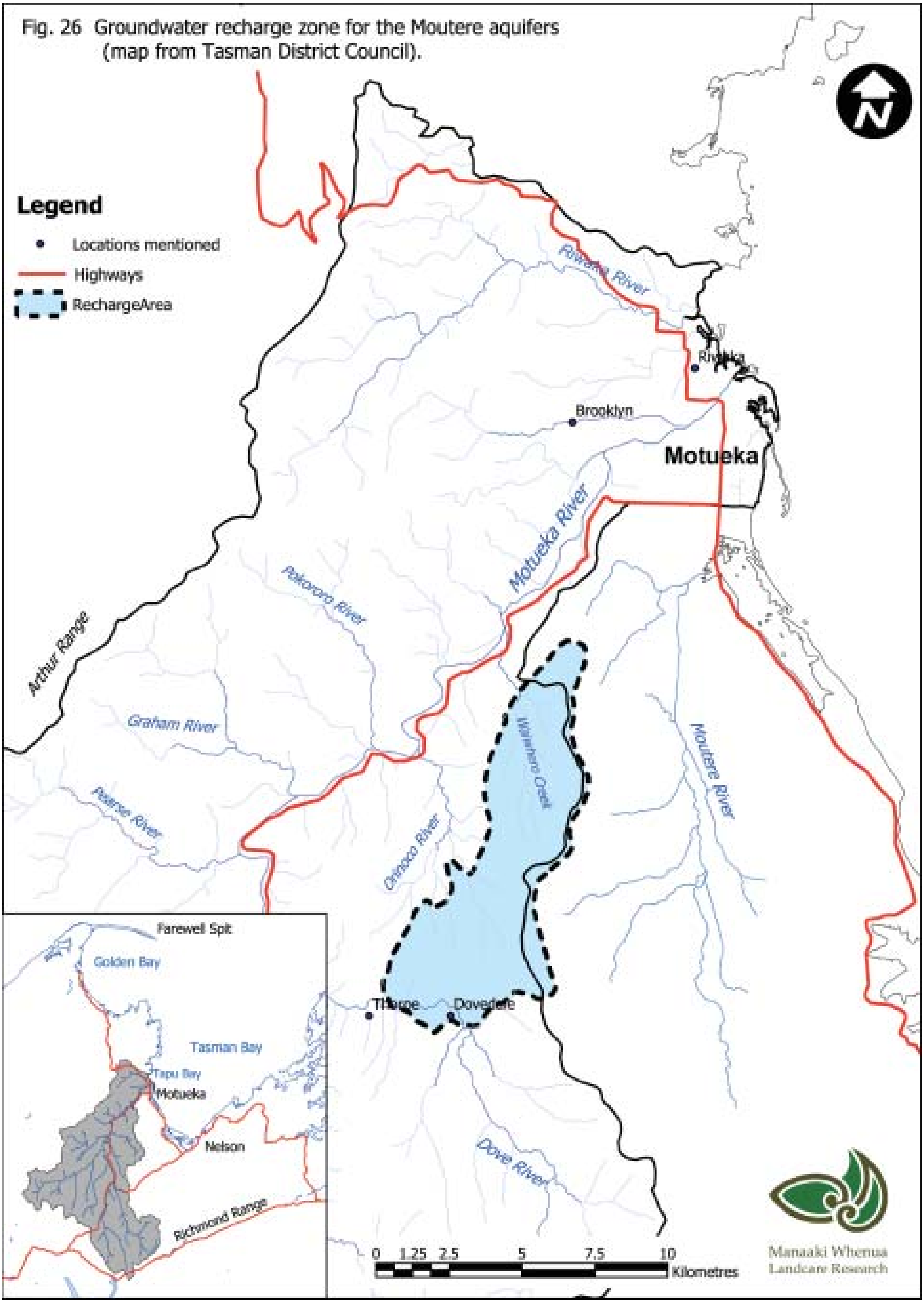
- pumping demand and recharge flows cause variation in groundwater levels on a day-to-day scale, but the base groundwater level is set by the Motueka River;
- the natural variation between years in average summer values of spring flows, aquifer–river flows, and sea outflows is greater than the variation caused by irrigation pumping;
- if the Motueka riverbed level lowered, summer recharge to the aquifers would reduce significantly (a 0.5-m lower riverbed would reduce summer recharge by 24%).

Significant groundwater resources also occur in the terraces and floodplains of the upper Motueka, especially around Tapawera, although the characteristics of the aquifers are poorly known (Tasman District Council 2000c). Historically groundwater in this area has been extracted from the lower alluvial terraces, which are believed to be recharged primarily from the Motueka River, with some direct rainfall input. However, little information is currently available on the size and character of the aquifers or on the relationship between river flow and groundwater levels. Current investigations are aimed at determining groundwater availability and recharge sources by mapping the aquifers, determining their characteristics, measuring groundwater levels in existing wells, dating the groundwater, and analysing the effect of groundwater abstraction on river flow. Initial results show significant groundwater resources beneath both the high and low terraces, and indicate that the water is older than previously thought. The latter suggests flow through the aquifer is reasonably slow or that the river is not well connected to the groundwater nearby, and may indicate it is safe to pump the groundwater during low-flow periods without major reductions in river flows. As at March 2002, Tasman District Council allocated 455 L/s for abstraction from groundwater above Woodstock (Fenemor 2002b).

In addition to these two groundwater systems, the upper reaches of the catchments of Waiwhero Stream and Orinoco Creek, and the middle reaches of the Dove River (Fig. 26) are important for recharge of deep aquifers in the adjacent Moutere Valley (Thomas 1989, 1991b, 1992). Rain falling in the recharge area moves through unconfined aquifers in the Moutere gravels underlying the eastern margin of the Motueka Catchment to confined aquifers underlying the Moutere Valley (Fig. 27). Water from these aquifers provides the major source of irrigation water for land users in the adjacent Moutere Valley. The location of the recharge zone is controlled by the outcropping of a more permeable unit within the Moutere gravels at the surface in the recharge zone.

The amount of recharge occurring through this precipitation–infiltration–recharge process is thought to be affected by vegetation cover. For rainfall to percolate into the aquifers, any soil moisture deficit needs first to be overcome before surplus water becomes available to run off or to recharge groundwater. Changes from short to tall vegetation reduce the total surface water yield (as outlined in section 2.8.2), and this same effect is likely to apply to the amount of water available for groundwater recharge. Hence, Tasman District Council has instituted land-use controls within the recharge area (Fig. 26) to limit afforestation and protect recharge of the Moutere aquifers (Tasman District Council 2000d, 2001). However, it is not clear whether recharge occurs uniformly across the recharge zone or whether there are preferred pathways for infiltration recharge. The recharge zone mainly comprises hilly terrain underlain by soils and regolith that have very slow permeability, and there may be a slow rate of recharge through these soils. Alternatively losses of water from streamflow in the valley bottoms, or from soils in lower slopes, may be the preferred pathway since these areas tend to be underlain by more-permeable soils than the hilly terrain, and by more freely draining gravels. Current research aims to answer these questions.

Fig. 26 Groundwater recharge zone for the Moutere aquifers (map from Tasman District Council).



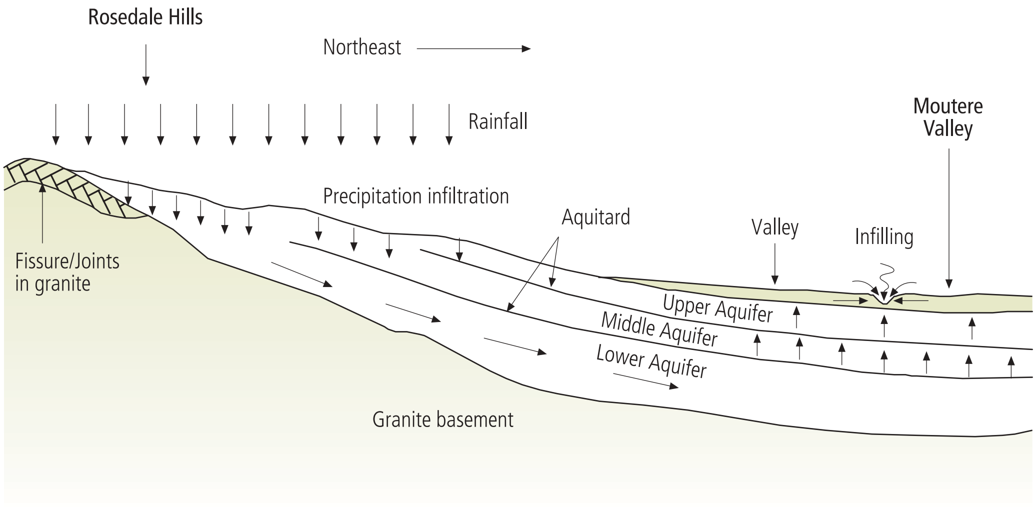


Fig. 27 Schematic recharge model for the Moutere aquifers (from Thomas 2001).

2.9 FRESHWATER ECOLOGY

2.9.1 Native fishes

The distribution and abundance of native fish species in the catchment were initially described by Bruce et al. (1987) and Ward (1990). The distribution of selected native fish species, derived from the New Zealand Freshwater Fisheries database (July 2002), are shown in Figs 28–31. The Motueka has a moderately diverse range of native fish species (as a function of the diversity of habitats and relatively unpolluted water) with 14 of New Zealand's approximately[25] 40 native fish species (Table 6). These include three migratory (kōaro, giant kōkopu, inanga) and two non-migratory (Canterbury galaxias, dwarf galaxias) galaxiids, common smelt, three migratory (bluegill, redfin, common) and one non-migratory (upland) bully, torrentfish, two eels (longfin and shortfin), and the lamprey. Five estuarine and marine species (black flounder, kahawai, yellow-eyed mullet, stargazer, cockabully) have also been reported in lower reaches of the river (Deans 2002).

Both species of eel are strong migrants and are found throughout the catchment (Fig. 28). Non-migratory species such as the dwarf galaxias (Fig.29) and upland bully (Fig. 30) tend to be found in the upper parts of the catchment, while many of the other species are only found in the lower reaches of the catchment. The Canterbury galaxiid has been reported once in the catchment, and if still present represents one of only two populations of this species found west of the Main Divide (McDowall 2000). The dwarf galaxias population found in the Motueka has been discovered to be genetically distinct from other *Galaxias divergens* populations (Allibone 2002). The Motueka is an important recreational and commercial fishery for whitebait (inanga), and would have supported a larger fishery before drainage of the wetlands between the Motueka and Riwaka rivers (Kelly 1988).

2.9.2 Introduced fish species

Until recently, brown trout were the only introduced species recorded in the catchment, and are widespread and abundant (Fig. 32). Brown trout were released in the Motueka River

[25] Genetic studies of our native freshwater fish are still in progress therefore the total number of species present is dependent on the results of these studies.

	SCIENTIFIC NAME	COMMON NAME
Native freshwater fishes	*Anguilla australis*	Shortfin eel
	Anguilla dieffenbachii	Longfin eel
	Cheimarrichthys fosteri	Torrentfish
	Galaxias argenteus	Giant kōkopu
	Galaxias brevipennis	Kōaro
	Galaxias divergens	Dwarf galaxias
	Galaxias maculatus	Inanga
	Galaxias vulgaris	Canterbury galaxias
	Geotria australis	Lamprey
	Gobiomorphus breviceps	Upland bully
	Gobiomorphus cotidianus	Common bully
	Gobiomorphus hubbsi	Bluegill bully
	Gobiomorphus huttoni	Redfin bully
	Paranephrops planifrons	Kōura (freshwater crayfish)
	Retropinna retropinna	Common smelt
Introduced fishes	*Salmo trutta*	Brown trout
	Carassius auratus	Goldfish
	Gambusia affinis	Western mosquitofish
	Scardinius erthropthalmus	Rudd
	Tinca tinca	Tench
Estuarine and marine fishes	*Aldrichetta fosteri*	Yellow-eyed mullet
	Arripis trutta	Kahawai
	Forsterygian nigripenne	Cockabully
	Leptoscopus macropygus	Stargazer
	Rhombosolea retiaria	Black flounder

Table 6 Fish species found in rivers of the Motueka Catchment and the estuary

before 1879, and releases of fish continued until the early 1960s. Since then the fishery has been supported by natural wild stock replacement. The Motueka River is recognised as a nationally important recreational fishery for brown trout and is renowned for the abundance and size of the trout (Richardson et al. 1984). In a national survey of drift-dived rivers in New Zealand, the Motueka River ranked very highly for trout numbers and biomass (Teirney and Jowett 1990). The Motueka at Woodstock had the highest trout biomass of all purely riverine sites surveyed in New Zealand. The Wangapeka is recognised as a regionally important river and is noted for relatively abundant trophy-sized trout (Richardson et al. 1984).

Food (primarily invertebrates) and availability of suitable physical habitat are the primary controls on trout biomass (Jowett 1992); therefore, maintaining high-quality fish and invertebrate habitat is fundamental to maintaining the fishery. Critical factors for fish habitat in the Motueka include:

- maintenance of adequate flow of high-quality water;
- natural fluctuations in river form creating:
  - a sequence of runs (the feeding areas for adult fish), riffles (where most of the invertebrates live, and which provide cover and habitat for small fish), and pools (provide cover and resting areas for larger fish),
  - natural cover in the form of boulders or bedrock, submerged logs, overhanging

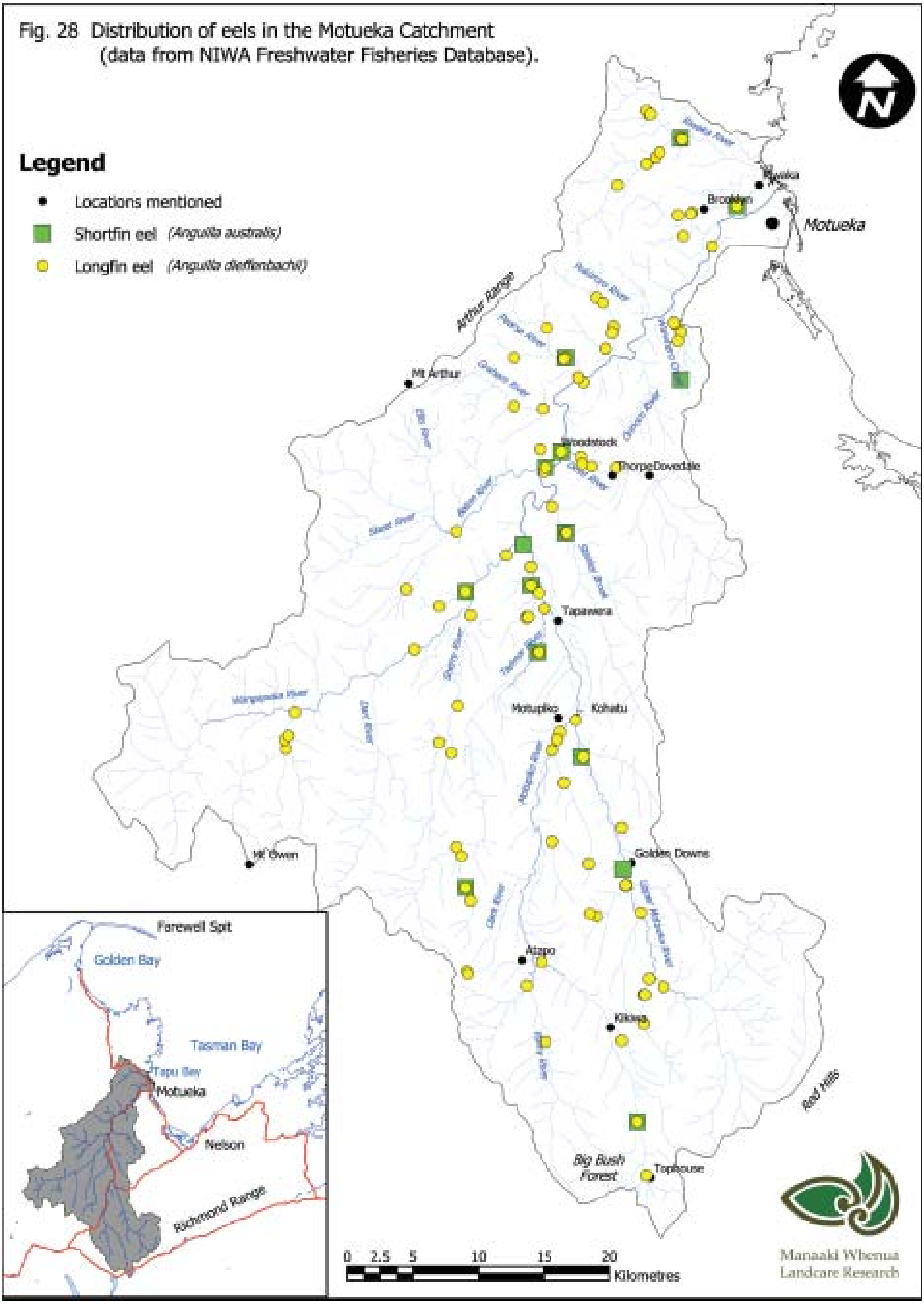
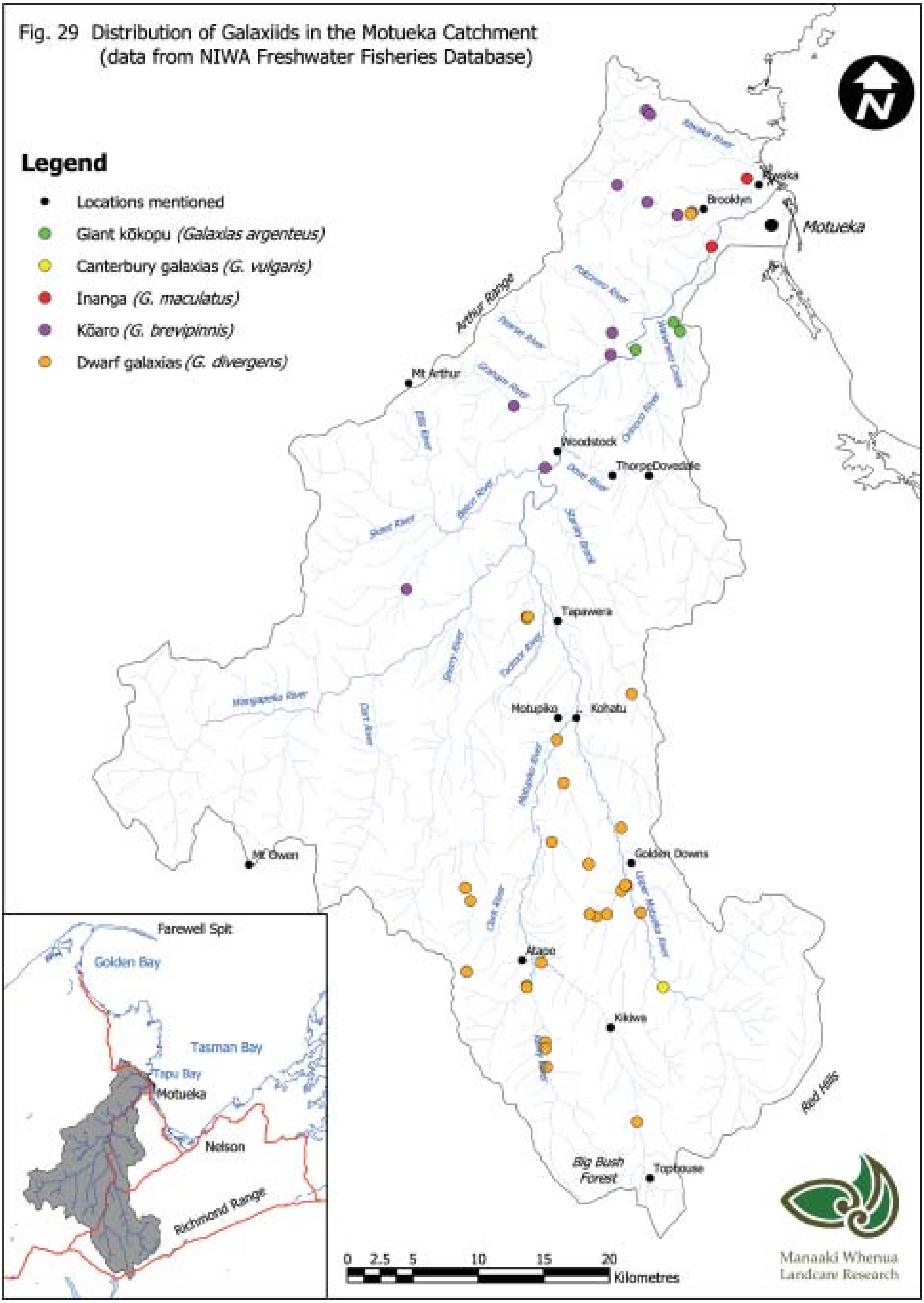


Fig. 28 Distribution of eels in the Motueka Catchment (data from NIWA Freshwater Fisheries Database).

Fig. 29 Distribution of Galaxiids in the Motueka Catchment
(data from NIWA Freshwater Fisheries Database)



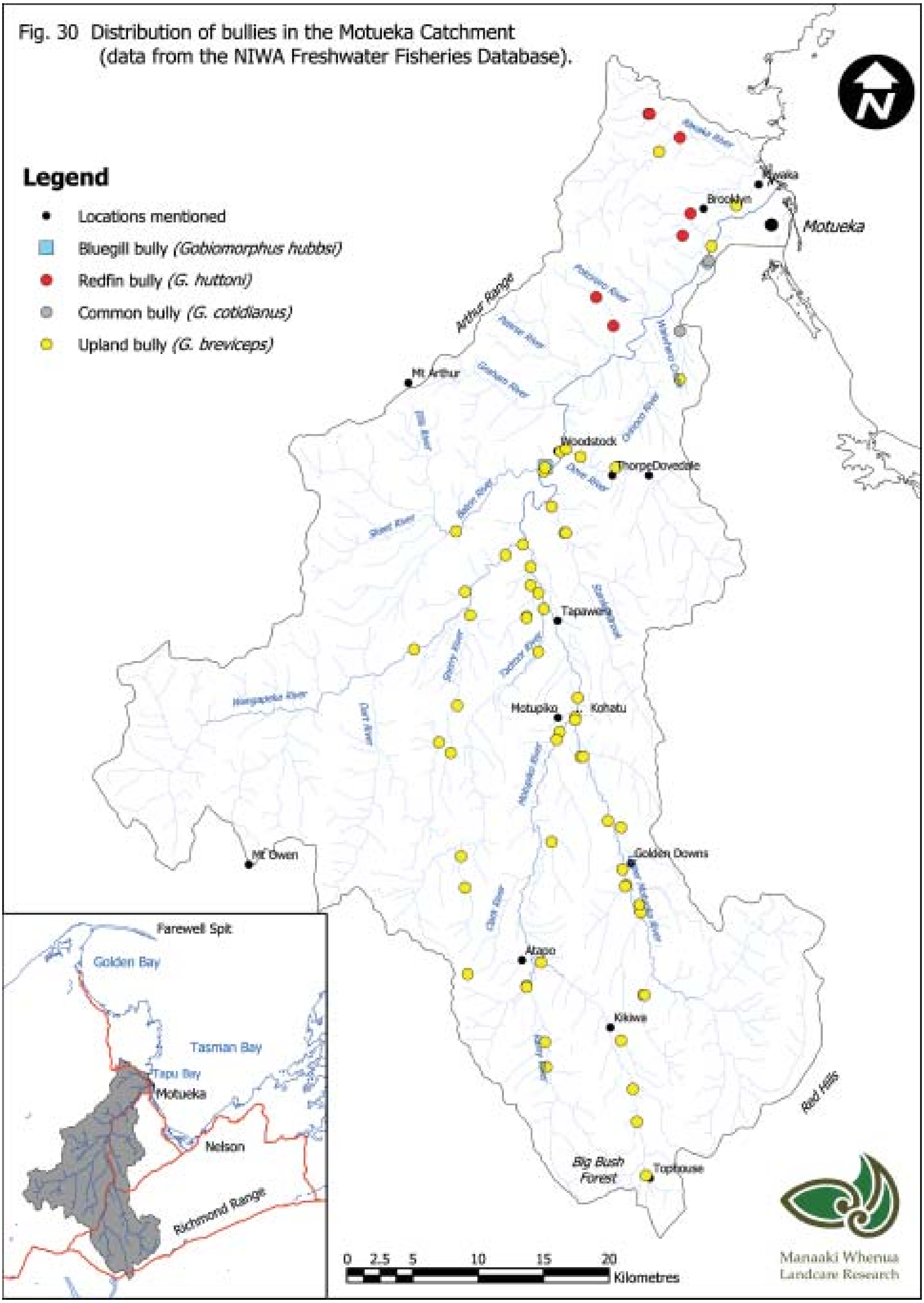


Fig. 30 Distribution of bullies in the Motueka Catchment (data from the NIWA Freshwater Fisheries Database).

Manaaki Whenua
Landcare Research

Fig. 31 Distribution of kōura, torrentfish and lamprey in the Motueka Catchment (data from the NIWA Freshwater Fisheries Database).

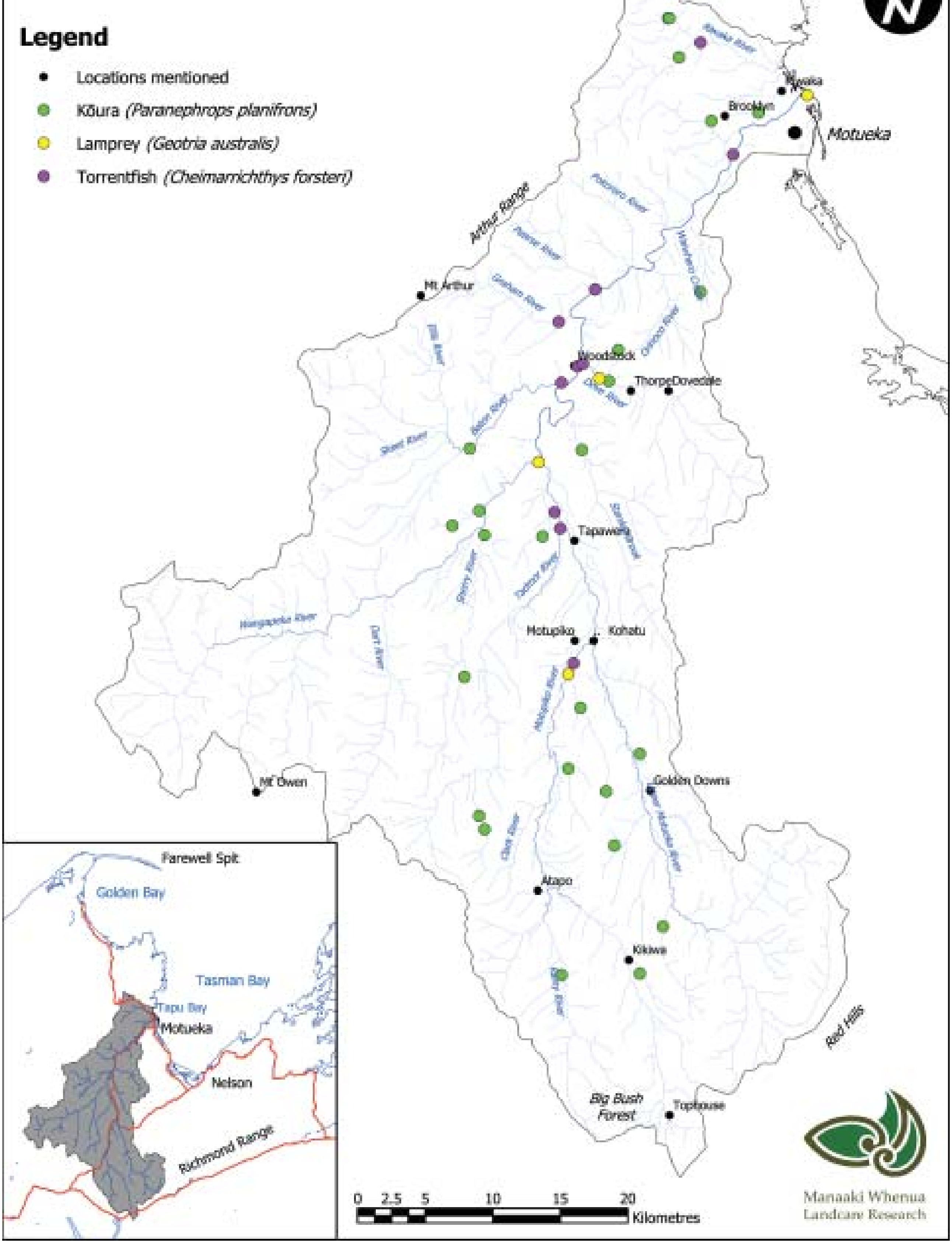
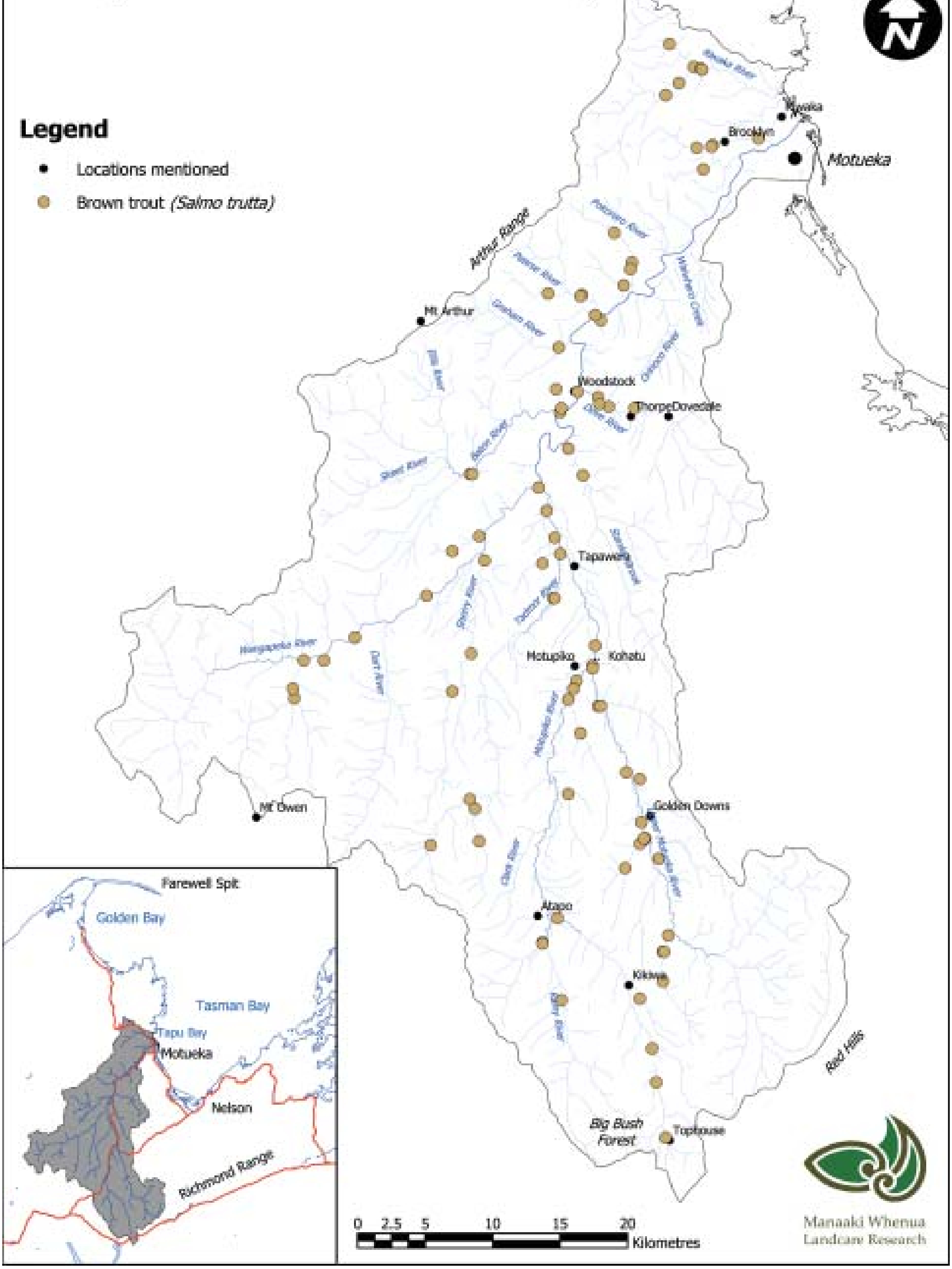


Fig. 32 Distribution of brown trout in the Motueka Catchment (data from the NIWA Freshwater Fisheries Database).



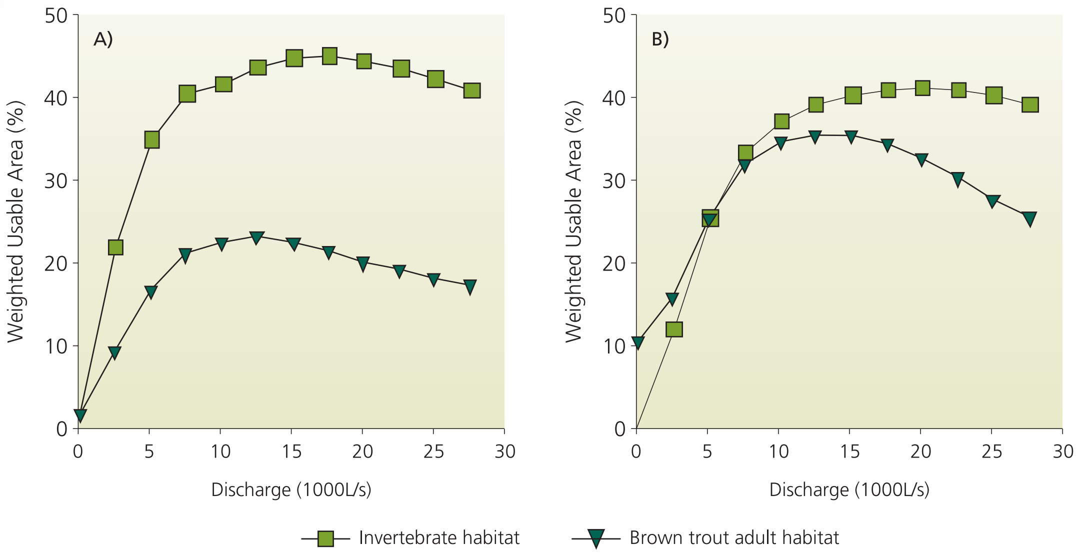


Fig. 33 Relationship between river flow and habitat for adult trout and trout food (invertebrates). Analysis for the Motueka River at (a) Woodstock and (b) Woodmans Bend, using Instream Flow Incremental Methodology (unpublished data provided by John Hayes, Cawthron Institute). Weighted usable area (WUA) is an index of habitat suitability for adult trout and invertebrates.

vegetation, or white water (which enable fish to avoid predators);

- unimpeded fish passage for spawning or to avoid floods, high water temperatures, low flows, or poorer water quality;
- the amount of fine sediment on the riverbed or in the water column[26], which has effects on both trout and invertebrate abundance;
- maintenance of spawning tributaries (including the Blue Glen, Motupiko, Rainy, Tadmor, lower Stanley Brook, lower Dove, lower Graham, Pokororo and Little Pokororo, and Motueka upstream of the Wangapeka confluence) with good water quality, cool water (<10.5ºC), high oxygen levels, low sediment levels, stable flow, and protection from predators (such as eels and shags).

The impact of variation in water depth and water velocity with flow has been evaluated at Woodstock and Woodmans Bend using the Instream Flow Incremental Methodology (IFIM), which analyses the relationship between trout and invertebrate habitat (expressed as weighted usable area, WUA) and flow (Fig. 33). At both sites the river ranks very highly for trout and invertebrate habitat (Hayes 2002). A special characteristic of the lower Motueka River is that optimal trout habitat occurs at the mean annual low flow (MALF). The amount of available trout habitat at the MALF is thought to be critical for trout population abundance (Jowett 1992); therefore, it is not surprising that the Motueka River has a very good trout population.

The trout fishery has been assessed by drift diving since 1985. At the main reference site at Woodstock there was a reduction in trout biomass around 1995 (Fig. 34a), possibly as a result of a severe flood in the upper Motueka in February 1995 and subsequent sedimentation from a large slip (Deans pers. comm. 1992). The fish population has remained reduced, possibly exacerbated by

[26] Vertical section through a water body.

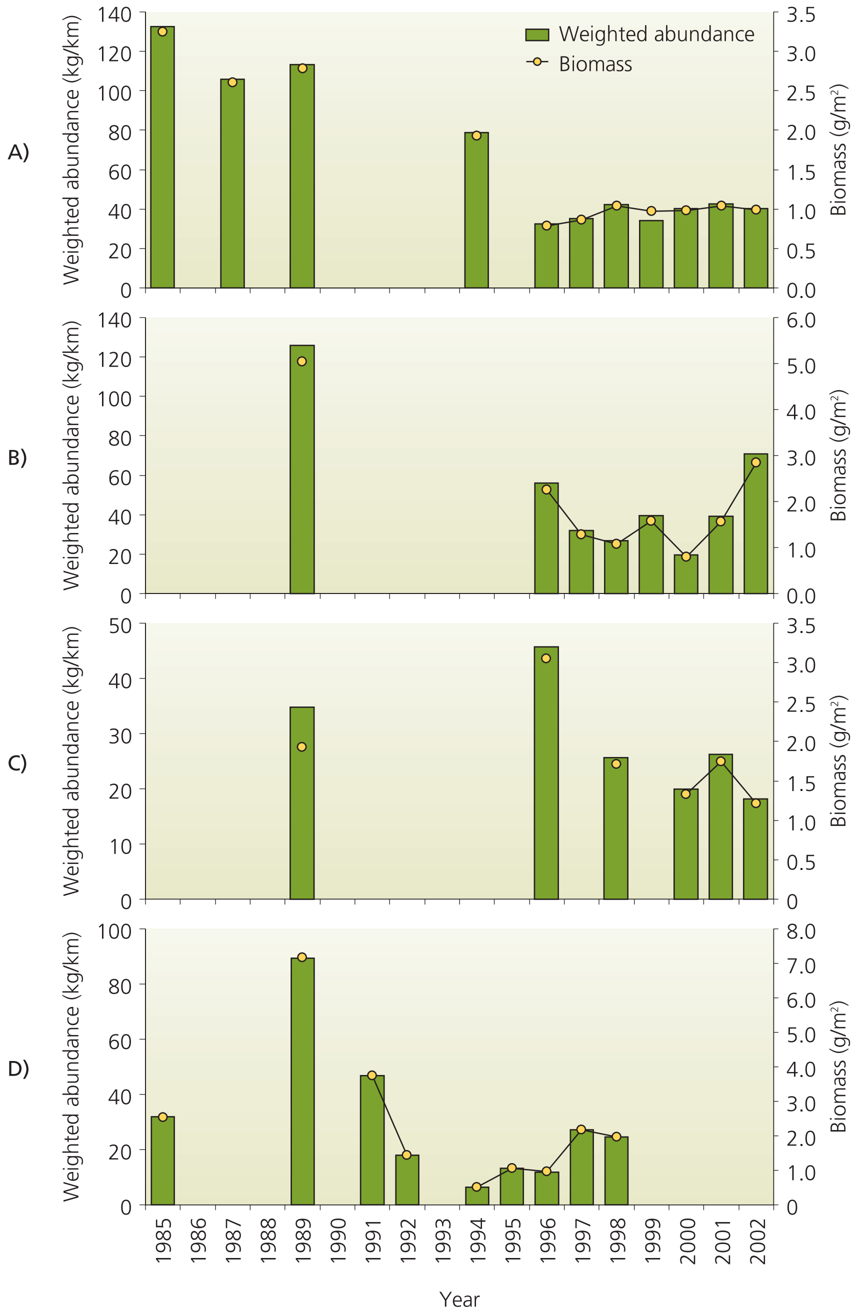


Fig. 34 Changes in weighted abundance and biomass of trout over time at (a) Woodstock, (b) Wangapeka River at Walters Peak, (c) Wangapeka River at Chummies Creek (above the Dart River), and (d) Riwaka River at Moss Bush (data provided by Neil Deans, Nelson Marlborough Region, Fish & Game New Zealand). Note different scales on the *y* axes.

winter floods affecting spawning or low river flows over subsequent summers. A similar decline is seen in the lower Wangapeka (at Walters Peak – Fig. 34b), but is not so marked in the upper Wangapeka (at Chummies Creek above the Dart confluence – Fig. 34c). It is also evident in the Riwaka River (Fig. 34d).

Recently four other species of introduced fish have been recorded in the Motueka River catchment (Table 6). These include four populations of Western mosquitofish, and single populations of the carp species tench, rudd, and goldfish. Western mosquitofish, in particular, presents a significant threat to native fish populations and the Department of Conservation has been attempting to exterminate any populations found in the South Island.

2.9.3 Macroinvertebrates

Macroinvertebrates[27] are key indicators of water quality and provide the key food source for trout. Macroinvertebrate communities are generally dominated by animals characteristic of unpolluted habitats, unmodified streams, and high aquatic habitat quality (Bruce et al. 1987; Stark 1990a,b). At least 119 taxa (dominated by caddisflies, true flies, mayflies, and stoneflies) have been recorded, with 15 of these contributing more than 90% of the community composition. Most common are the mayfly *Deleatidium*, the hydropsychid caddisfly *Aoteapsyche*, orthoclad midges, the cased caddisfly *Pycnocentria evecta,* and elmid (riffle) beetles. Most of the abundant taxa are widely distributed through the catchment. Species richness is generally high (average >28 taxa per site), with smaller headwater streams having a greater variety of taxa than the main stem. Macroinvertebrate densities average 3600 animals/m^2, with a range from <200 to >12,000 animals/m^2. Smaller rivers and headwater streams have the highest densities. Macroinvertebrate community index values (Stark 1985) range from 107 to 135, and are generally >120, which is indicative of unpolluted conditions.

As part of the National River Water Quality Network, macroinvertebrate samples were collected at Woodstock and the Gorge annually from 1989 to 1996 (Scarsbrook et al. 2000). The only trend present in the data from these sites was a weak decline in the proportion of mayflies, stoneflies, and caddisflies in the macroinvertebrate community at Woodstock.

As part of the ICM project macroinvertebrates have been sampled at 43 sites covering the range of combinations of land use, geology, and stream sizes found throughout the catchment. Results will be used to assess how land use, geology, and sediment influence stream health in the Motueka Catchment. A survey of hyporheic[28] invertebrates has also been carried out at five sites (Motueka at Gorge and Woodstock, Motupiko at Christies, Wangapeka at Walters Peak, Riwaka at Hickmotts) as part of a national survey.

2.9.4 Algae/Periphyton

At least 30 taxa of algae[29] have been recorded from the Motueka Catchment (Bruce et al. 1987). Four genera (*Oscillatoria*, *Stigeoconium*, *Oedogonium*, *Spirogyra*) are widely distributed in the lower reaches of the main stem and tributaries. Algal growth is prolific during periods of low flow and approaches nuisance levels in the lower reaches at times. Biggs and Gerbeaux (1993) sampled water quality and periphyton monthly for a year at five sites down the Motueka River and one site in the Riwaka River. They found the periphyton community was dominated by diatoms[30] (*Gomphoneis herculeana, Synedra ulna, Cymbella kappii*). *Melosira varians* was also common and more prominent at the Riwaka site. Filamentous algae (*Stigeoclonium* sp., *Ulothrix zonata*) were also common. Periphyton biomass (measured as chlorophyll-*a* levels) after an extended period of low flows ranged from 30 mg/m^2 in the upper reaches of the river to 355 mg/m^2 at Woodstock.

[27] Animals that have no backbone and are visible without magnification.

[28] The zone below the bed of the river containing water.

[29] Algae are plant-like organisms that live in water and lack stems, roots or leaves. May be single cells or multicellular.

[30] Single-celled algae.

Mean monthly periphyton biomass was higher in the lower reaches of the river than the upper reaches, and appeared to be nitrogen-limited for much of the year, but phosphorus-limited during periods of low flow (Biggs and Gerbeaux 1993).

As part of the ICM programme rates of algal production have been measured at 10 sites from the headwaters of the Motupiko and Wangapeka rivers, down to Woodmans Bend near the coast. Preliminary analyses (Young 2002) indicate that the lower reaches of the river have very high rates of algal production compared with other rivers around the country, while algal production in the forested headwaters is limited by shading from streamside vegetation. The high rates of algal production in the lower reaches may be a mixed blessing. During long periods of low flow, algal biomass may reach nuisance levels and degrade the habitat quality for macroinvertebrates. However, high rates of production (particularly of diatoms) will provide a large source of high-quality food for macroinvertebrates, thus fuelling abundant macroinvertebrate and fish populations in the river, and perhaps also shellfish off the coast.

2.9.5 *Land-use effects on freshwater ecology*

Graynoth (1979, 1992) described the short- and long-term effects of forest harvesting on stream environments and faunas at Golden Downs Forest. Comparisons were made between a control stream with an unmodified forest catchment and three streams whose catchments had been affected by different logging practices. Measurements were made of streamflow, water temperature, streambed sedimentation, suspended sediment and dissolved solids concentrations, and the abundance of benthic[31] invertebrates and fish.

Clearfelling to the stream's edge, together with inappropriate roading and bridging techniques, caused large changes in stream environments and faunas. Excessive amounts of waste timber and soil had entered streams, with stream bedloads, suspended sediment and dissolved solid concentrations increasing. In comparison to the control stream, water temperatures increased in summer by up to 6.5ºC and decreased in winter by as much as 2.5ºC. As a consequence the benthic invertebrate fauna was greatly modified (with a reduction in the abundance of Plecoptera and certain Ephemeroptera nymphs, and an increase in the abundance of oligochaetes, chironomids, and *Deleatidium* nymphs) and fish numbers were reduced. In January 1971 numerous brown trout and other fishes died in the Motueka River, and there are indications that this was due in part to low dissolved oxygen concentrations following excessive sedimentation of the riverbed caused by unsatisfactory logging practices. Where a riparian buffer strip of unlogged vegetation was left alongside one stream and the remainder of the catchment was clearfelled, there was relatively little change in the aquatic environment and fauna.

Sixteen years after the original survey, brief surveys were undertaken to collect samples of fish and invertebrates from the original study sites. At this time streamflows in the previously logged catchments were exceptionally low and long sections of the streambeds were dry, probably because of increased transpiration and interception rates from maturing pine forest. Low streamflows probably accounted for the lack of upland bullies and juvenile brown trout, and influenced the distribution and abundance of dwarf galaxias. Provided flows were satisfactory, streams in the logged catchments generally had similar invertebrate species and numbers to pre-logging populations. Graynoth (1992) suggests that on the Moutere gravels reduced streamflows caused by forest regrowth may have more serious impacts on the aquatic fauna than the

[31] Refers to the bed of a river, lake or sea.

short-term changes caused by road construction, timber harvesting, and other logging practices, and the short cutting cycle (25–30 years) makes it unlikely that any stable equilibrium will be established in either physical or biotic conditions.

At Donald Creek in Big Bush Forest similar results were found by Cowie (1984) and Anthony and Winterbourn (1998). Invertebrate faunas in three streams whose catchments had been logged in different ways (clearfelling and skidder logging, clearfelling and skyline hauler logging, selection felling and skidder logging) were compared with an undisturbed control catchment. In each catchment forest was left as riparian strips and/or in the lower reaches of the catchment. Little effect of logging and subsequent afforestation was found and this was ascribed to the lack of large storms following logging, and the retention of riparian strips and unlogged forest in the lower reaches of each catchment.

2.10 MARINE HYDROLOGY AND WATER QUALITY

Tasman Bay is a shallow, open embayment with a low seafloor gradient and dominantly silty bottom (Mitchell 1986, 1987). The delta region off the Motueka River mouth has a relatively steep gradient down to a water depth of 10–20 m, and has a sandy and gravelly bottom. Beyond the delta, water depth increases offshore to a depth of 40–60 m, the seafloor has a very low gradient and is dominantly silty. The fine-grained nature of bottom sediment reflects the relatively low wave and current activity in the bay. Under some wind conditions (particularly northerly) sediment may be resuspended and transported laterally by weak tidal and oceanic currents. Circulation patterns in Tasman Bay are influenced by circulation in both Golden Bay and Cook Strait, with strong hydrological linkage between the two bays.

Current flows in the Tasman Bay – Golden Bay system are primarily forced by tidal processes and local winds. Typical speeds for tidal flows are 2–5 cm/s in the bays, although significantly stronger currents occur in shallower regions. There is no general consensus on the direction of tidal residual flows[32] in the Tasman Bay – Golden Bay system. Heath (1976) suggested that a residual anticlockwise circulation in Tasman Bay exists; however, the limited data used in that study do not support any general conclusions about residual circulation in the bays.

The speed and direction of local winds over the Tasman Bay – Golden Bay system varies considerably as a result of the system's large spatial scale and the high mountains on adjacent land. The predominant pre-frontal north-westerly and post-frontal south-westerly winds observed over the West Coast of the South Island can be considerably modified over the Bay system. In particular, weaker-gradient winds from the west and south-western quadrants often end up as winds from the north in the southern part of Tasman Bay. This is reflected in the often-significant differences in wind speed and direction from the meteorological stations located at Farewell Spit and Nelson Airport.

In Tasman Bay in summer, water temperature and salinity values are typically 20ºC and 35 PSU (practical salinity units), respectively, and the water is normally thermally stratified. In winter, water temperatures fall to 11ºC and surface salinities are periodically reduced by freshwater runoff, producing vertical salinity and density gradients (water column stratification – see Fig. 35). As a result of the influence of freshwater runoff, nutrient levels often increase towards the shore, while salinity decreases (Fig. 36). These differences are heightened during floods, particularly during the winter when nutrient uptake by phytoplankton[33]

[32] The long-term mean flow generated by the tides.

[33] Microscopic plants.

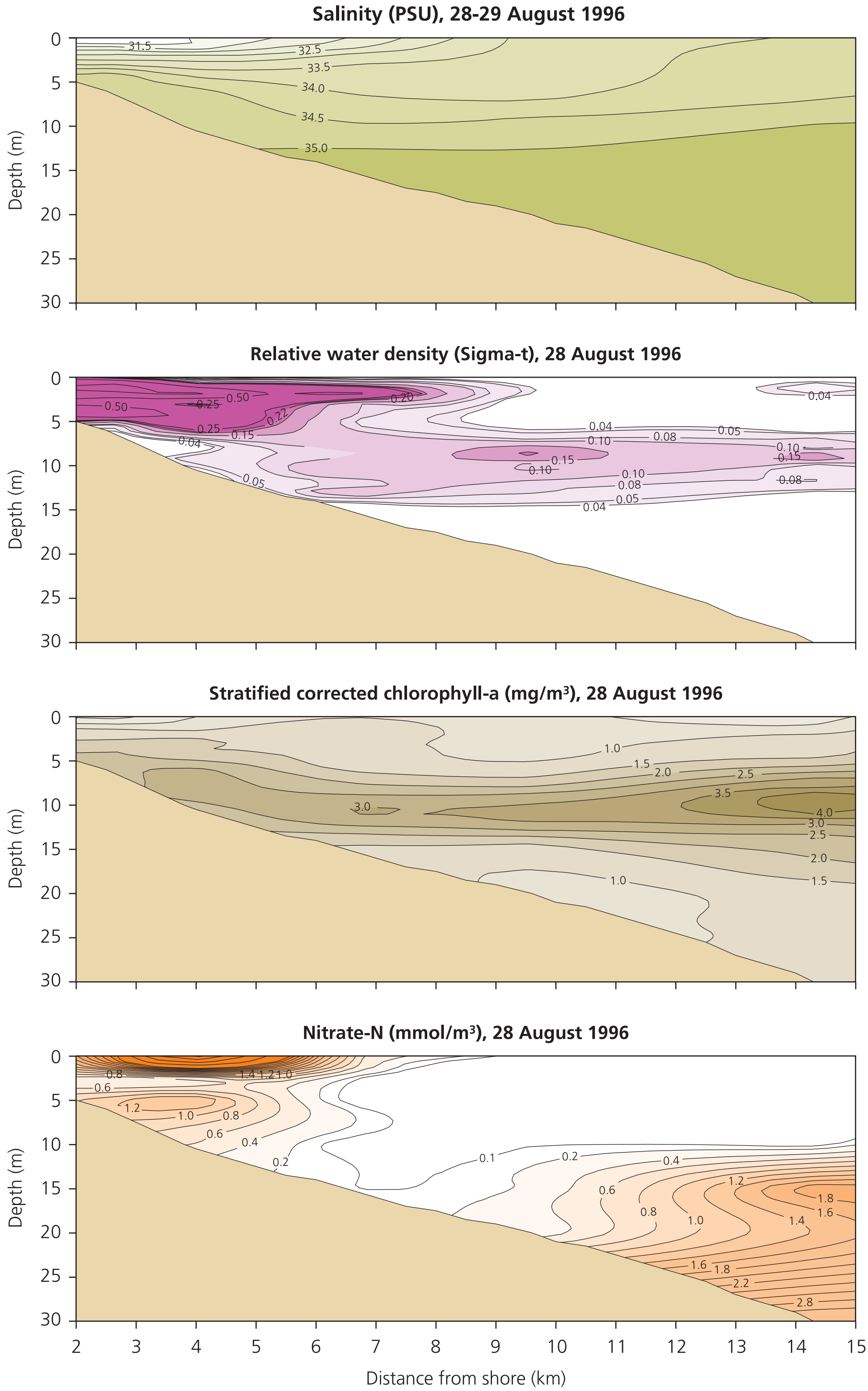


Fig. 35 Offshore transects of physical and chemical characteristics illustrating water column stratification in Tasman Bay (Lincoln MacKenzie, Cawthron Institute, unpublished data).

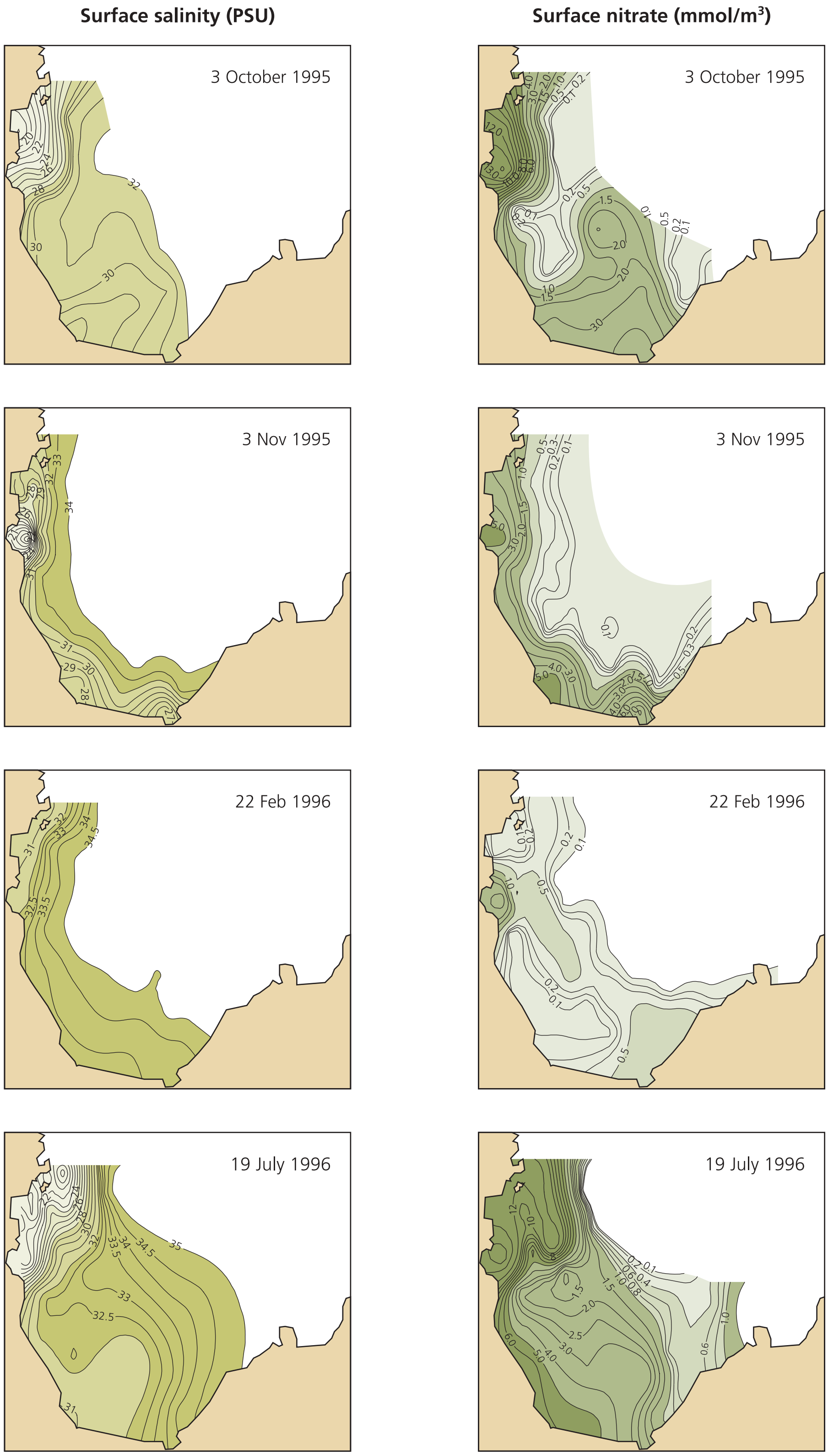


Fig. 36 Seasonal patterns of salinity and nitrate in Tasman Bay illustrating the influence of freshwater inflow from the Motueka and Riwaka rivers (maps provided by Lincoln MacKenzie, Cawthron Institute, unpublished data).

may be limited by light and river flow is greatest (Mackenzie and Gillespie 1986).

About 62% of the total freshwater inflow to Tasman Bay is provided by the Motueka River. Following heavy rainfall, the Motueka freshwater plume covers nearly the entire western side of Tasman Bay, extending more than 18 km offshore. It is a major contributor of sediment and nutrients into the bay, causing stratification of the water column and spatial and temporal variation in nutrient concentrations. Surface salinities, water column stratification characteristics and nutrient concentrations (Fig. 36), and consequently phytoplankton production, are affected to various distances seaward from the Motueka rivermouth. As the river waters flow into Tasman Bay, they spread out in a surface layer of low-salinity water over the more dense seawater below (Fig. 35). This density stratification stabilises the water column and reduces the vertical mixing processes that keep nutrients well distributed for phytoplankton nourishment. Uptake by phytoplankton can then result in a depletion of nutrients in surface waters. This is typical in mid- to late summer.

The delivery of sediment by the river also affects light penetration, photosynthetic activity. and seabed animal communities in a variety of ways. Past work has led to the discovery of a near-bottom layer of high turbidity within the Motueka plume, which could have profound ecological implications. Sediment input provides a dynamic delta region of sandspit development that is habitat for a variety of shellfish.

2.11 COASTAL AND MARINE ECOLOGY

The Motueka River flows into highly productive coastal and shallow marine ecosystems in Tasman Bay, providing a major source of freshwater and nutrients and influencing the ecology of a large area of western Tasman Bay. The estuarine and coastal area around the mouth of the Motueka River is an important area for a range of fish and shellfish, with cockles being commercially harvested near the mouth of the Riwaka River. Tasman Bay supports a wide variety of planktonic and benthic organisms and fish. Scallop harvesting is a major recreational activity and commercial industry in Tasman Bay, and there have been recent applications to establish mussel farms. The location of existing and proposed new aquaculture areas near the Motueka rivermouth is shown in Fig. 37. The Abel Tasman National Park and associated Tonga Island Marine Reserve, which supports significant fish stocks and marine mammals (seals and dolphins), are relatively close to the mouth of the Motueka River and are influenced by the Motueka River plume. A comprehensive review by Bradford-Grieve et al. (1994) provides an overview of knowledge of primary production in Tasman Bay, from plankton ecology and the benthic food web to the scallop and snapper commercial fisheries. Much of the information presented here is derived from that review.

The phytoplankton community is typical of a shallow-water, temperate environment (Bradford-Grieve et al. 1994) and is the main contributor to primary production in Tasman Bay. It is dominated for much of the year by dinoflagellates[34], with considerable seasonal and annual variation in species composition and productivity. These variations are controlled by changes in light and air and sea temperatures, which affect rates of photosynthesis and water column stratification, and by floods introducing nutrients into the bay. Diatoms are almost completely absent for considerable periods of time, and are usually only dominant during a late winter to spring bloom, coincident with maximum concentrations of dissolved inorganic nutrients. The sedimentation of diatoms following this bloom provides the main annual nutritional input for benthic fauna. Potentially toxic and

[34] Single-celled marine organisms.

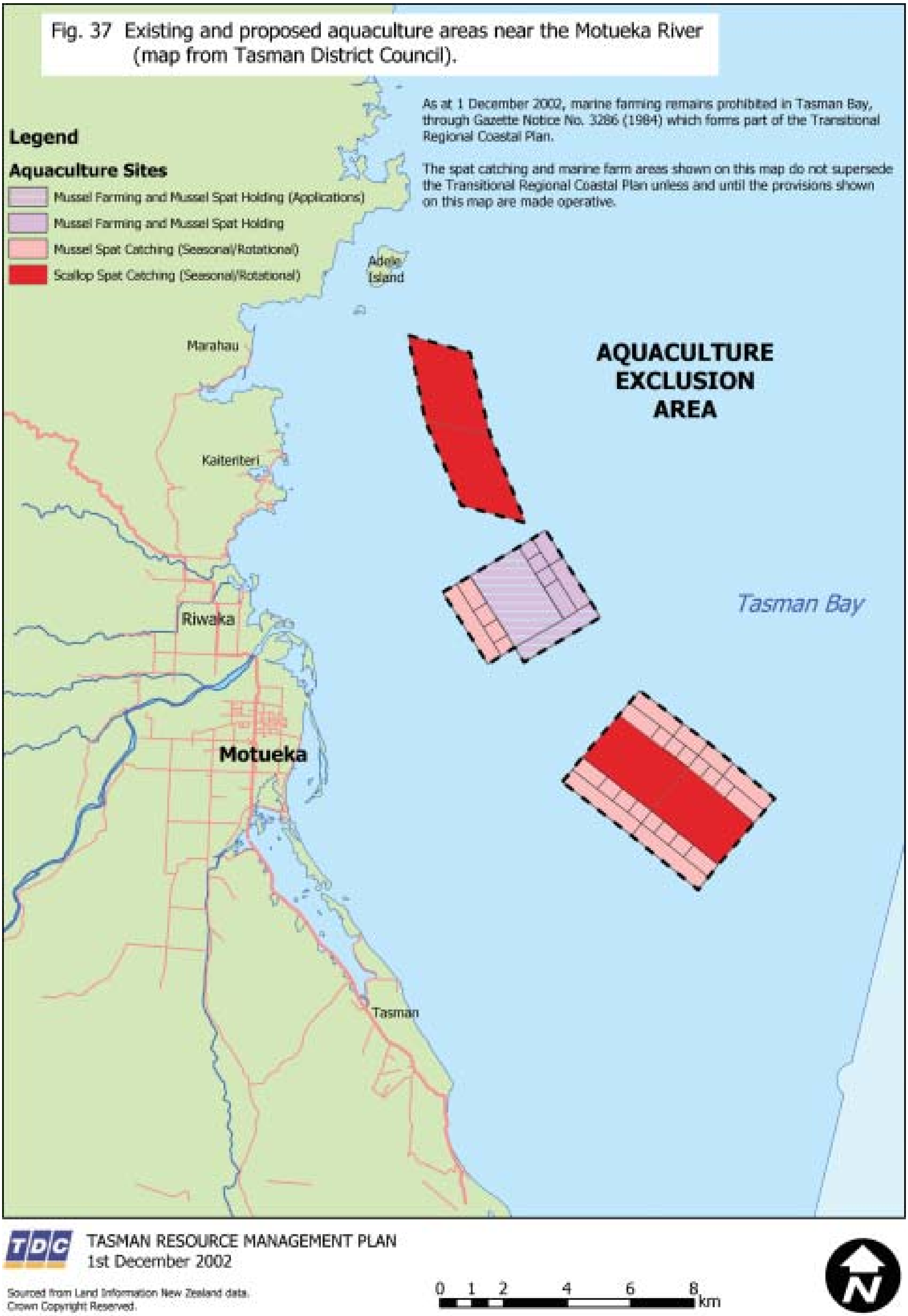


Fig. 37 Existing and proposed aquaculture areas near the Motueka River (map from Tasman District Council).

noxious phytoplankton blooms occur periodically in Tasman Bay, and may occasionally create problems for aquaculture. Their origin and causes are poorly known at present. Little is known of the ecology and productivity of the zooplankton[35] (Bradford-Grieve et al. 1994), and there is some indication of a link between phytoplankton and zooplankton productivity (Mackenzie and Gillespie 1986).

MacKenzie and Gillespie (1985, 1986) describe plankton ecology and productivity from intensive sampling of the water column at a single nearshore location in Tasman Bay between April 1982 and March 1984. The phytoplankton community structure and phenology (seasonal and cyclic patterns) was typical of a temperate shallow-water environment, though considerable year-to-year variations occurred in the composition of species and magnitude of production. Periods of relative abundance of some potential nuisance species were documented. Small nanoplanktonic (<10 µm) species were always an important and frequently dominant component of the photosynthetic community. The winter–spring diatom bloom was the most productive event. In surface waters, phytoplankton biomass ranged from 19 to 208 mg C/m^3. *In situ* rates of photosynthesis ranged from 202 to 1981 mg C/m^2/d. The magnitude of phytoplankton blooms appeared to be related to preceding high-rainfall events. Unusually large floods during the winter of 1983 led to a major peak in productivity by a mixed diatom–*Mesodinium rubrum* bloom. Annual net productivities of 121 g C/m^2/yr and 171 g C/m^2/yr during 1982 and 1983, respectively, were estimated.

Benthic organisms in Tasman Bay reflect the relatively shallow water (<60 m), grain size of sea-floor sediments (dominantly terrigenous mud and sandy mud, with isolated patches of calcareous gravel in areas such as the Motueka delta), and primary production. The benthic fauna is a soft-bottom fauna characterised by bivalves (molluscs such as scallops, oysters and mussels) and echinoderms (e.g., starfishes, sea urchins). Although its composition and distribution is relatively well known, except for sponges and cnidarians (e.g., jellyfish, sea anemones), quantitative data are limited and little is known about the species that make up the microfauna[36] and meiofauna[37] (Bradford-Grieve et al. 1994). Faunal associations comprise assemblages of both deposit and suspension feeders. Small crustaceans (e.g., crabs, barnacles) have been poorly studied even though they are a significant part of the diet of juvenile fish such as snapper. Probert and Anderson (1986) provide limited data on the biomass, faunal density, and faunal composition of the benthic macrofauna in Tasman Bay. Gillespie et al. (2000) describe microphytobenthic communities from intertidal and shallow-water environments in Tasman Bay and comment on their important contribution to the benthic food web. Bryozoan coral are present off Abel Tasman National Park.

There is a large population of scallops (*Pecten novae zelandiae*) and a smaller population of oysters (dredge oyster or Bluff oyster, *Tiostrea chilensis*), both of which support dredge fisheries. The scallop fishery is particularly important, having been commercially dredged since 1959. Scallops are suspension-feeding bivalves that rely on suspended detrital material and phytoplankton as their food source. Initially (until 1980) managed as a natural fishery, the fishery is now enhanced by reseeding scallop spat to maintain desired harvest densities. Spat catching for scallops (and mussels) has been conducted off the Motueka rivermouth for about 8–10 years. Bradford-Grieve et al. (1994) suggest that although scallop population dynamics have

[35] Plankton consisting of microscopic animals.

[36] Microscopic animals.

[37] Tiny animals living on the sea bed.

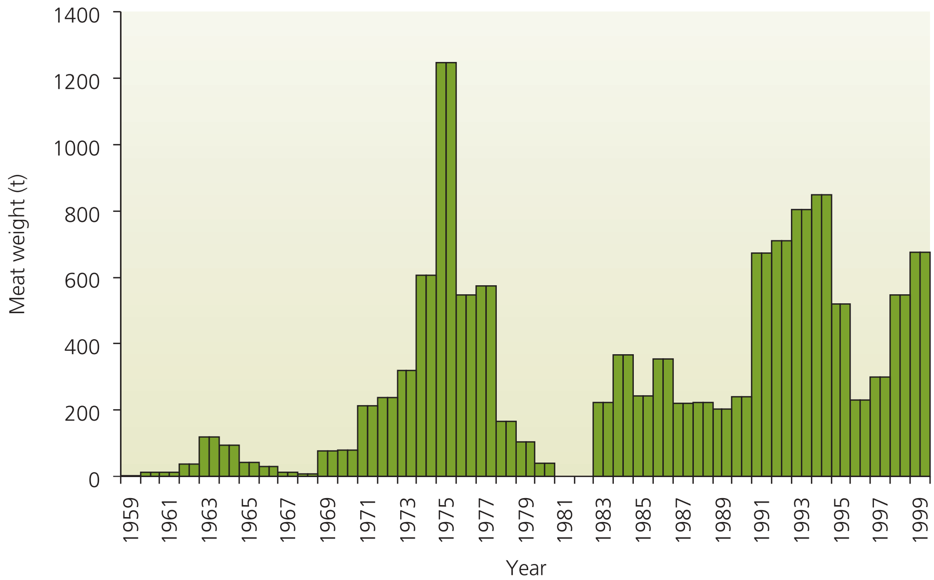


Fig. 38 Scallop harvest figures for Tasman Bay 1959–1999 (data provided by Russell Mincher, Challenger Seafoods).

been well established and shellfish stocks are regularly assessed, little is known about the life and requirements of scallops, and how they interact with their environment (e.g., sediment and nutrient inputs into the bay). The scallop fishery experiences large variations in both numbers and condition of scallops harvested (Fig. 38) and food availability is probably a major cause (Gillespie 1987). During a good year, winter–spring phytoplankton blooms may provide food for scallop growth. Later on, when food in the water column becomes scarce, microscopic algae living on the seabed seem to be a critical part of their diet. Scallop biomass may be linked to variation in production from these two main food sources. High sediment loads during floods in the Motueka River are believed to be associated with poor recruitment and growth of scallops in the plume of the river. Conversely, organic matter and other nutrients from terrestrial sources may play an important role in shellfish nutrition.

The other major commercial fishery in Tasman Bay is the snapper (*Pagrus auratus*) fishery. Snapper spawn each summer in Tasman Bay with the young fish schooling in shallow (<15 m) waters before moving to deeper water in winter and as they mature. They have been fished commercially since at least 1945, with catches increasing through to the 1970s and 1980s. Since the advent of commercial fishing, snapper numbers have been greatly reduced, resulting in reduced yields and management steps to restore the fishery. However, recovery is hampered by lack of quantitative data on key biological questions (e.g., the causes of erratic juvenile recruitment, the level of snapper biomass that can be supported, when and where juvenile snapper should be released, the requirements of post-larval snapper, and the impact on snapper of hydrological, nutrient, and primary productivity patterns in Tasman Bay).

2.12 MĀORI AND EUROPEAN HISTORY

Aspects of the Māori and European history of the Motueka Catchment are described in Peart (1937), Newport (1962), Allan (1965), Challis (1978), Motueka and District Historical Association (1982–89), and McAloon (1997).

Archaeological evidence suggests that Māori groups first settled the coastal Motueka River area before AD 1350 and more-permanent camps and fortifications (pā) were gradually established (Challis 1978). Traditional Māori tribal history depicts the Motueka – Tasman Bay area as affected by many invasions and conflicts that displaced previously occupying iwi (including Ngai Tahu, Ngai Tara Pounamu, Poutini Ngai Tahu, Ngāi Tu-Mata-Kokiri, and Ngāti Apa). Each successive iwi in turn achieved dominance and occupation over newly acquired land and resources. Intertribal conflicts decimated the local tribes in 1828–1830, about 10 years before the first European settlers arrived. Today four iwi, Ngāti Rarua, Te Ati Awa, Ngāti Tama, Ngāti Kuia, and their respective hapū, claim collective authority, significant cultural values, and an intimate spritual and physical relationship with the Motueka – Tasman Bay area.

Settlement was largely restricted to the coastal areas, although Māori travelled through the catchment in search of valued greenstone (pounamu) and argillite, and to hunt and fish. The Motueka Valley via Motupiko was a well-used inland route to the Wairau and Buller catchments for transport of greenstone and gathering of argillite washed downriver from the Motueka headwaters. The sea provided ample kaimoana (seafood) including fish and shellfish, the rivers and streams provided eels, kōkopu, and whitebait, and the bush and swamp provided materials for building, weaving, food, medicines, and a plentiful supply of birds. The better coastal areas were cultivated and soils were enriched for growing kūmara (and later potato) by addition of charcoal, fine gravel, and coarse sand (Challis 1976). In the early 1840s, 200–300 Māori were cultivating potato gardens between the Motueka and Moutere rivers (Challis 1978). Māori settlements were typically sited near the sea or river channels for access by canoe. Coastal camps were gradually replaced by fortified coastal pā following raids by displaced North Island tribes.

There is little evidence of Māori settlement inland in the Motueka Catchment except at Pokororo and the Sherry–Wangapeka confluence, although there are many records of argillite working sites, middens, burial sites, ovens and other artefacts (Challis 1978). Parts of the catchment had already been burned by Māori when European settlers arrived, but little is known of the extent of pre-European forest removal.

Europeans visited the Motueka area as early as 1840, and by 1842 sections were being surveyed at the Motueka township and the first settlers had arrived (McAloon 1997). At the end of 1847 the European population was about 100 (Allan 1965). The first European house in the Motueka Valley was built at Little Pokororo River in 1853. Planned settlements at Stanley Brook, Dovedale, and other sites in the Motueka Valley began in the 1860s, and at this time much of these areas were covered in tōtara, rimu, kahikatea, and beech forest. Gold and grazing were the main reasons behind European exploration of the Motueka Catchment. Graziers were running stock in the upper Motueka by 1843, the Wangapeka by 1846, the upper Motupiko and Baton by 1855 (Newport 1962), and would have deforested large areas to support grazing. By 1878 there were about 70 permanent settlers in the Motueka Catchment above Woodstock. Major gold finds at Baton Flats in 1855 and in the Wangapeka at Rolling River in 1859 (Newport 1962) caused a short-term influx of people. Gold mining continued in the area until the early 1900s and evidence of tailings, machinery, and house sites remain today.

Flooding of the larger rivers was a considerable hazard for transport, and establishment and maintenance of the roading network was a major cost to local government in the early days of settlement. The Motueka River was first bridged at Motupiko in 1887 and at Pokororo in the 1890s. The village of Tapawera originated as a railway camp for the Nelson–Buller railway connection in the 1890s, with the Tapawera road-rail bridge completed by 1906.

The early settlers cleared and burnt large areas of bush, which caused erosion and worsened flooding. The worst flood thought ever to have occurred in the catchment was the "Great Flood" that peaked on 7 February 1877. The Motueka River is reported to have covered the entire area between the hills and Pokororo. The flood was described as an "earth flood" rather than a water flood because of the slips that blocked tributaries then broke releasing torrents of mud, rock and trees (Brereton 1947; Fenemor 1989; Beatson and Whelan 1993). The sediment brought down by this flood is said to have raised riverbed levels by more than 3 metres in the lower Motueka. The earliest stopbank on the Motueka River was built in 1889 on the west side of the Motupiko River at the Motueka confluence to protect the road and now there is an extensive stopbanking system on the river.

First World War provided an impetus to pastoral farming with soldiers returning from the war being settled on farm blocks in the upper Motueka; but many of these farms were unsuccessful. The difficulties of farming included poor soil fertility, scrub reversion, low and unreliable rainfall, and steep slopes (Nelson Catchment Board 1952; Rigg et al. 1957). As a result the Government purchased land and planted exotic trees to begin what is now Golden Downs Forest and other forests. Golden Downs Forest began with the planting of about 10,000 hectares in 1926–27 and the planted area expanded rapidly (Ward and Cooper 1997). By the 1950s forestry was a major land use in the Motueka Catchment. Plantation forests were stocked primarily with exotic species such as Monterey pine (*Pinus radiata*) and Douglas fir (*Pseudotsuga menziesii*) and were established on less-fertile steeplands and hill country, particularly on Moutere gravel and Separation Point granite. Forestry remains a major land use, with some forests into their third rotation.

Horticulture (particularly hops and tobacco) has long been an economically important land use in the catchment, although it occupies a relatively small area of land. Tobacco began to be planted in the more fertile valleys in the 1920s and very soon Motueka became the centre of tobacco growing in New Zealand (O'Shea 1997). By 1941 tobacco accounted for 40% of Motueka's horticultural income (McAloon 1997). The area in tobacco production peaked in the mid-1960s (at c. 2500 hectares) and declined rapidly from the mid-1970s, before ceasing in 1995. Much of the land formerly used for tobacco growing is now used for fruit trees (apples, kiwifruit), berry fruit, and hops. More recently, vineyards, marine farming, and tourism have added substantially to the diversity and productivity of the local economy.

2.13 RECREATION

The Motueka Catchment is widely used for recreational activities. These include trout fishing, eeling, whitebaiting, tramping, canoeing, rafting, hunting, jet boating, swimming, picnicking, camping, caving, rock and fossil hunting, and scenic drives. Kahurangi National Park, Mt Richmond Forest Park and the Motueka River itself are especially important recreational areas. Many thousands of people visit and enjoy the river and its catchment each year.

The Motueka River is a nationally important recreational fishery for brown trout, with a reputation for producing high numbers and large size of trout, while the Wangapeka is notable for producing relatively abundant trophy-sized trout (Photo 7). A survey of angler numbers showed that the Motueka River was by far the most popular fishing river in the Nelson region, with of the order of 18,000 visits per year at that time (Richardson et al. 1984). The most heavily fished reach of the Motueka is from the confluence of the Wangapeka to the sea and this reach is considered a nationally important recreational fishery (Richardson et al. 1984). The Wangapeka is regarded as a regionally

A)

B)

Photo 7 The Motueka River is an important fishery noted for the quality of (a) the fishing experience and (b) the fish caught (photos courtesy of Terry Duval).

important fishery, being highly rated for its scenic beauty, easy access, large area of fishable water, and a high level of solitude. There have been no creel surveys conducted on the Motueka River to determine exactly how many trout are taken by anglers. Nevertheless, indications from angler surveys are that most anglers catch few fish and the ones that do, release a fairly large proportion of the ones that they catch. The general view among fisheries scientists is that anglers, and predators like shags, are unlikely to limit population size given the potential overwhelming natural production of trout in most river systems (R. Young pers. comm. 2002). Habitat degradation is much more likely to be the cause of trout population declines.

Recreation has had negligible impact on water quality and no effect on water quantity. Although there are occasional conflicts between uses such as boating and angling, recreational uses have not reached a point where controls on access to the catchment need consideration. However, recreation activity in the Motueka is increasing and there is scope for much greater usage of some areas.

2.14 HERITAGE AREAS

There are a wide variety of heritage areas within the Motueka Catchment. These include areas of significant native vegetation and habitats for native fauna, freshwater ecosystems (rivers, wetlands and their fauna), riparian zones, outstanding natural features and landscapes, and historic sites (Tasman District Council 1993b, 1995b).

Large areas of native vegetation are currently protected (c. 55% of the catchment area), primarily in Kahurangi National Park, Mt Richmond Forest Park, and Big Bush Forest. A few lowland sites with remnant native vegetation are protected in reserves (e.g., Thorp Bush, Fearon's Bush, Kumeras wetland, Moss Bush, Quinneys Bush), but many significant sites are not currently protected (see Park and Walls 1978; Walls 1985). Walker (1987) provides an inventory of both protected and unprotected sites for native fauna (Appendix 2).

Davidson et al. (1993) list and rank important coastal sites, based on ecological and geomorphic criteria. The Motueka delta (see Photo 1a), from Tapu Bay to Motueka wharf, is rated as having national importance. It is notable for its large delta and intertidal area, rich biodiversity (plant and animal), and archaeological/cultural/spiritual significance. The intertidal area is rich in shellfish (mostly cockles) and is an important feeding area for birds (particularly for wading birds and migratory birds). The Motueka sandspit is the largest in Tasman Bay and has >10,000 birds present in summer. It also has a large area of rushland and is thought to be an important whitebait spawning ground. Saltmarsh occurs around the river and creek mouths. There is a small area of pīngao (*Desmoschoenus spiralis*).

The Motueka has a rich and complex geological heritage. Consequently Kenny and Hayward (1993) list a relatively large number of sites in the catchment that are significant for protecting outstanding natural features and landscapes. Six of the listed sites are internationally important (Nettlebed Cave, the Pearse Resurgence, Mt Owen karst, Baton River Devonian fossil fauna, Tomo Thyme cave system, Bulmer caverns), seven are nationally important, and thirteen are regionally important (Appendix 3).

The Motueka also has a rich archaeological heritage. Tasman District Council (1995b) summarises the archaeological resource (using the Historic Places register, NZ Archaeological Association records, consultation with iwi) and sites of significance to Māori, from a computer database, but comments on the limitations of this database both for archaeological and Māori sites. Challis (1978) lists a large number of archaeological sites within the Motueka. However, few of these have any form of protection and most are not listed on the Historic Places Act register of historic places. Fenemor (1989) suggests a number of sites that are worthy of preservation.

2.15 SOCIO-ECONOMIC CHARACTERISTICS

There are approximately 12,000 people living in the Motueka Catchment (2001 Census). The largest town is Motueka with a population of about 7000 people (2001 Census) and there are small villages at Tapawera, Brooklyn, and Riwaka. Rural population density is about 2/km^2. Population growth is estimated at about 2% per annum. Figures for the whole of Tasman District (2001 Census) show:

- a male/female ratio of 1001 females per 1000 males;
- a median age of 37.8 years, with 13.1% of the population >65 years and 12.1% <15 years;
- a life expectancy of 77.6 years;
- 96.2% of the population identify themselves as European and 7.0% as Māori[38];
- a median income of $16,100;
- primary sources of income were from salary and wages (57%), 23% were self-employed, and 23% received some form of benefit;
- an unemployment rate of 3.7%;
- of those people over 15 years, 53% are married, 24% have never married, 7% are divorced, 3% are separated and 6% are widowed.

[38] Some of the population identify themselves as having dual ethnicity.