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Infiltration Characteristics of Soils Under Forestry and Agriculture in the Upper Waikato Catchment

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Table of contents

Acknowledgement **i**

List of Tables **iii**

List of Figures **iii**

Executive summary **v**

1 Introduction **1**

2 Infiltration **1**

3 Field Investigation **4**

4 Mapping **7**

5 Discussion **13**

6 Conclusions **14**

References **16**

List of tables

Table 1: Infiltration measurement sites 5
Table 2: Infiltration into Soil under Agriculture and Forestry 5
Table 3: Hydrological Land Use Classes 7
Table 4: Breakdown of Soil Types and Land Use within the Upper Waikato by Percentage of Total Area (based on LDCB2, 2001 and NZLRI, 1995) 8
Table 5: Soil Macroporosity Data by Soil Type and Land Use 8

List of figures

Figure 1: Upper Waikato River Catchment Location Map 3
Figure 2: Infiltration – Macro-porosity Relationships 6
Figure 3: Upper Waikato Land Use 9
Figure 4: Upper Waikato Soils 10
Figure 5: Upper Waikato Soil Macro-porosity at the Surface 11
Figure 6: Upper Waikato Soil Infiltration Capacity 12

Executive summary

There has been increasing pressure for conversion of forest to agricultural land within the upper Waikato catchment. Much of the soil mantle of this area consists of hydrological and erosion sensitive pumice soils. Changes in land use can impact on hydrological processes, e.g. interception losses from forest canopy are significantly greater than from pasture, resulting in significant changes to the overall water balance. Conversion from forest to pasture may also result in significant changes in the infiltration characteristics of the soil surface layer. These changes in infiltration characteristics may affect the frequency and magnitude of surface runoff generation under high intensity rainfalls, and thus may impact on the flooding characteristics of catchments subject to land use change. To enable a better understanding the impacts of land use change on flood risk, an assessment of the infiltration characteristics of soils in the upper Waikato under both pine forest and agriculture has been undertaken.

Infiltration characteristics of soil have been characterised by in situ measurements using a double ring infiltrometer at five paired sites, under agriculture and forestry, for 5 soils typical of the upper Waikato catchment. In addition to infiltration, the macroporosity of the soil surface layer was also measured in the laboratory from samples taken at each site.

The results from the in situ infiltration measurements showed infiltration capacity of soil under grazed pasture (between 3 and 99 mm h^{-1}) was an order of magnitude less than that under pine forest (121-1207 mm h^{-1}). Similar differences were observed for soil macroporosity, however total porosity does not seem to be greatly affected by land use. This suggests that intensified land use results primarily in a change in soil structure, rather than soil compaction.

The conversion of forest to agricultural land within the upper Waikato catchment is likely to result in increased flooding, with increased flood peak and intensity, and erosion and sedimentation. The degree of effect is yet to be quantified, but it is expected that the greatest effects will be felt for small catchments in high intensity, short duration storms, especially in summer due to dry antecedent conditions. Consequently there is likely to be a need for increased spending on soil conservation and river maintenance work. There are also potential effects on flood protection and drainage works downstream of Karapiro Dam, which require further investigation.

Infiltration measurements in this study were similar to literature values.

Texture class did not have a major influence on the infiltration rate for the soils used in this study, although the texture range is very narrow: (silt – sand).

Macroporosity appears to be a good predictor of infiltration capacity for the allophanic and pumice soils. It may also be a predictor for infiltration capacity of podzolic soils, although these soils often have a sub-surface pan restricting water movement. Macroporosity of any restricting pan or soil horizon may be a better predictor for infiltration capasity for podzolic soils though this requires more data to confirm.

Land use has a greater impact in determining soil infiltration capacity than soil type has within the Upper Waikato Catchment.

Recommendations:
1. Afforestation be encouraged, especially in erosion prone areas or to protect particularly sensitive areas.
2. Management techniques which maximise soil infiltration and minimise surface runoff from agricultural land are reported in the international literature, though their applicability to the Upper Waikato Catchment may require further investigation.

Some examples are:

a. New Zealand data on reducing hydrophobicity.
b. Investigate use of effluent irrigation to reduce hydrophobicity.
c. New Zealand data for Canterbury cropping land relief.
d. New Zealand data for relief of compaction in pumice soils.

1 Introduction

There has been increasing pressure for conversion of forest to agricultural land within the upper Waikato catchment (defined as the Waikato catchment between Karapiro Dam and Lake Taupo, see Figure 1, in recent years). A significant amount of conversion is already currently underway. Much of the soil mantle of this area consists of hydrological and erosion sensitive pumice soils. Jackson (2007) reported a loss of 30% volume with the removal of trees seen in the Puruki catchment.

Changes in land use can impact on hydrological processes in a number of ways. For example it is known that interception losses from forest canopy are significantly greater than from pasture, resulting in significant changes to the overall water balance (Fahey and Rowe, 1992). The dominant mechanisms by which land use change effects flooding are less widely accepted, however researchers such as Selby (1972) and Jackson (2007) have reported that conversion of pumice soils from forest to pasture results in significant changes in the infiltration characteristics of the soil. Infiltration is the process of water entering the soil. Changes in infiltration characteristics may affect the frequency and magnitude of surface runoff generation under high intensity rainfalls, and thus may impact on the flooding characteristics of catchments subject to land use change. To enable a better understanding the impacts of land use change on flood risk, an assessment of the infiltration characteristics of soils in the upper Waikato under both pine forest and agriculture has been undertaken.

2 Infiltration

Infiltration is the movement of water into the soil profile, and can occur both under unsaturated and saturated conditions. The process is controlled by many factors including gravity, capillary action, and the properties of the soil. The generalised mechanics of unsteady flow (both saturated and unsaturated) in a porous medium are governed by the Richards equation (Richards, 1931). This equation in one dimensional form is:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K(\psi)\left(\frac{\partial \psi}{\partial z} + 1\right)\right]$$

where :

θ = water content of the soil

K = hydraulic conductivity of the soil

ψ = pressure head of water in the soil

Solution of the Richards equation requires that the soil moisture content and hydraulic conductivity are defined as functions of pressure head. In general however, during a high intensity rainfall event, the infiltration capacity will reduce over time as soil moisture content increases, and in the limiting case if the soil becomes saturated, the infiltration capacity becomes constant at the saturated hydraulic conductivity.

If rainfall intensity is greater than the potential infiltration rate, water will accumulate on the soil surface and overland flow of runoff will begin. The soil surface under forest has greater water detention or retention due to its micro-topography of humps and hollows. Where runoff occurs, less water may be stored in the soil for plant growth or transported by subsurface flow to provide baseflow for streams. Surface runoff can cause soil erosion, and carry nutrients, sediment, organic matter and other contaminants to waterways. These contaminants reduce water quality in streams, rivers, lakes and estuaries. Sedimentation reduces the capacity of reservoirs and dams to store water and encourages mangrove growth in estuaries (Swales et al. 2007, Singleton 2006).

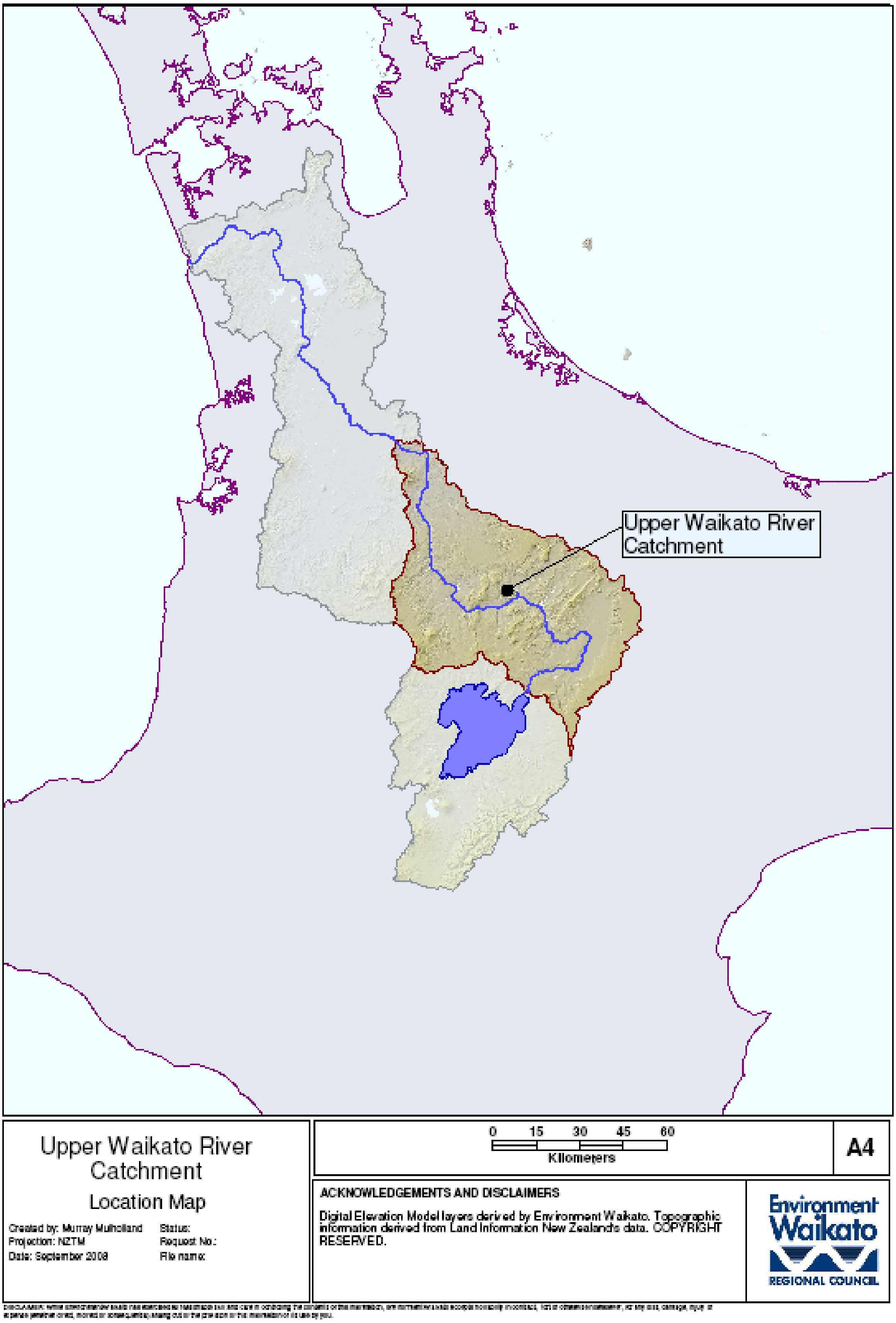

Figure 1: Upper Waikato River catchment location map

Excessive runoff can cause flooding, with high flow and high velocities that can cause streambank erosion (Boardman et al. 2003, Schnug & Haneklaus 2002). Therefore, changes in soil infiltration capacity under changing land-use are of concern to resource management agencies.

3 Field investigation

For the purpose of this study, infiltration characteristics of soil have been characterised by in situ measurements using a double ring infiltrometer (Gradwell, 1972, Klute and Dirksen 1986). The apparatus consists of an inner 300 mm diameter ring and an outer 500 mm diameter ring inserted into the ground. A constant head of water (75 mm) is then applied to each ring and the infiltration rate in the inner ring measured when the water flow rate reaches a steady state (indicating the soil is saturated). Using two rings eliminates the problem of overestimating the infiltration rate due to three dimensional flows. The outer ring supplies water which contributes to lateral flow so that the inner ring is contributing only to the vertical flow.

The method described above is a way of measuring the saturated hydraulic conductivity of the topsoil, and thus provides a measure of its minimum infiltration capacity. It does not however provide a full characterisation of the soil infiltration parameters in terms of the Richards equation, as it does not provide information about how infiltration capacity changes with soil moisture content.

An additional factor which also has to be considered is the hydrophobic nature of some soils. This tends to result in decreased infiltration capacity when the soil is very dry. This issue has been raised by Selby (1972) in regard to pumice soils. Hydrophobicity reduced short-term infiltration of water by approximately an order of magnitude for a range of New Zealand soils (Wallis et al. 1991). Waikato Valley Authority (1978) noted dry Pumice Soils with moisture content <16% v/v had negligible infiltration but infiltration rates were >30 mm/hour when moisture content was more than 60%v/v. Changing infiltration rate with wetting may also be due to several other factors. During rainfall, water repellency of the soil surface is first overcome. Then small pores on the soil surface fill with water, reducing the ability of capillary forces to actively move water into the soil. As the soil moistens, some types of clay absorb water causing them to expand, reducing the size of soil pores. Raindrop impact breaks unprotected soil peds into smaller particles, which can clog soil surface pores reducing the movement of water into the soil, while vegetation protects the soil surface from direct impact. To minimise hydrophobic effects, infiltrations measurements were carried out while the soil was still moist, after rain. Layers of plastic gauze were used to protect the soil surface from direct impact of added water.

Infiltration measurements were undertaken at five paired sites, well established under agriculture and forestry, for 5 soils typical of the upper Waikato catchment (Table 1). All agricultural sites were pastoral on flat to rolling country (< 10 degrees) and grazed by cattle. Pasture age was probably 5 years or more. The Tihoi sand land use was beef farming and the other 4 sites were dairy farming. All forestry sites were under mature Pinus radiata. In addition to infiltration, the macroporosity at -5 kPa of the soil surface layer (0-80 mm depth) was measured in the laboratory from 3 intact core samples taken at each site. Pastoral sites were selected to avoid gateways, fence-lines, stock camps and trails, and were 100% covered in pasture.

Table 1: Infiltration measurement sites

Soil	Classification	Texture Class	General Location
Tirau	Typic Orthic Allophanic Soil	Silt Loam	South of Tirau
Tihoi	Humose Orthic Podzol	Sand	East of Benneydale
Taupo	Immature Orthic Pumice Soil	Sandy Loam	East of Tokoroa
Ngakuru	Typic Orthic Allophanic Soil	Sandy Loam	North of Mokai
Waipahihi	Immature Orthic Pumice Soil	Sand	Tahora

The pasture sites were more difficult to insert rings compared to their respective forestry sites, probably due to compaction of the soil. Compaction could be due to both wheel and foot/hoof traffic on the soil surface (Selby 1972). Studies' investigating the effect of wheel tracks (Basher & Ross 2001) and cattle treading (Tian et al 2006, Pietola et al. 2005, McDowell et al. 2003; Nguyen et al, 1998) on soil infiltration rate indicate that both these decrease infiltration; However, cattle treading usually has the greater impact due to much higher ground pressure.

Infiltration measurements in this study were similar to literature values for a wide range of soil texture (clay – coarse sand). The infiltration rates for the forestry soils (121-1207 mm h^{-1}) were similar to those measured at Acacia Bay, Taupo (220-330 mm h^{-1}) by Simcock (2006). Likewise, the infiltration rates for the agricultural soils (between 3 and 99 mm h^{-1}) were similar to those measured on Whatawhata Research Farm (5 – 90 mm h^{-1}) by Tian et al. (2006), infrequently mown or grazed pasture at Acacia Bay (<10-40 mm h^{-1}) by Simcock (2006), under beef cattle in Arkansas (3-80 mm h^{-1}) by Sauer et al (2005) and those measured during a grazing trial in Texas (72 – 100 mm h^{-1}) by Pluhar et al. (1987).

The results from the in situ infiltration measurements showed infiltration under grazed pasture was an order of magnitude less than that under pine forest for all 5 sites (Table 2). This is in agreement with the results of a study at Acacia Bay by Simcock (2006) who showed infiltration rates of pumice soils are decreased by 5 to 10 times when vegetation is changed from native shrub land to pasture, and decreases again when vegetation is changed from pasture to cropped, or sites earthworked or recontoured, due largely to compaction. Similarly, measured macroporosities for the samples in this study were on average about five times less for pasture than for forest.

A 5 times difference in infiltration was reported for Midwestern United States soils under pasture and riparian buffers (Bharati et al 2004). Pitt et al (1999) analysed 153 urban soils and showed typical values for clays and silts were 170 mm h^{-1} for non-compacted and 10 mm h^{-1} for compacted soils, while typical values for sands were 380 mm h^{-1} for non-compacted and 46 mm h^{-1} for compacted soils.

Table 2: Infiltration into soil under agriculture and forestry

Soil	Infiltration Rate (mm h^{-1}) ± 1 Standard Deviation		Macroporosity (%)		Total Porosity (%)	
	Agriculture	Forestry	Agriculture	Forestry	Agriculture	Forestry
Tirau	31 ± 23	489 ± 165	4.9	25.7	65.3	67.9
Tihoi	3 ± 2	121 ± 89	4.9	41.0	78.1	79.4
Taupo	17 ± 5	409 ± 75	4.5	20.7	71.8	77.5
Ngakuru	86 ± 65	1130 ± 209	6.4	37.5	65.3	74.9
Waipahihi	99 ± 54	1207 ± 691	8.4	33.3	67.3	72.7
Average	**47±39**	**671±335**	**5.8**	**31.6**	**69.6**	**74.5**

The high average infiltration capacities measured for soils under forest suggest that very high rainfall intensities are required to generate surface runoff. (Typical rainfall intensity values for a 100 year storm of 10 minute duration are approximately 140 mm/hr within the study area compared to the range of infiltration capacities for forest soils of 120-1200 mm/hr). Also, the influence of interception by vegetation and the large surface detention capacity of forest soils reduce the likelihood of surface runoff from this land use. Because the values in Table 2 are means however, it is possible that spatial variability in infiltration capacity may result in surface runoff from some parts of a catchment but not others.

It might be expected that texture class should have a significant influence on the infiltration rate, as coarse textured soils have larger pores and fissures than fine-grained soils and therefore should allow for more water flow (Godwin & Dresser 2003). Sands are also considered to have lower compaction risk compared to sandy loams and silt loams (USDA 2001). Average finial infiltration rates for un-degraded UK soils, were in the order of: sands (800 mm h^{-1}), sandy loams (150 mm h^{-1}), silt loams (40 mm h^{-1}), and clays (20 mm h^{-1}, Berryman 1974). However, in this study, the order from lowest to highest infiltration rate, both under agriculture and forestry, was Tihoi sand < Taupo sandy loam < Tirau silt loam < Ngakuru sandy loam < Waipahihi sand indicating, over this narrow textural range, soil texture had little impact. It should be noted that allophanic soils, such as the Tirau silt loam, are very well structured and soil structure may be the dominant influence on infiltration for these soils. Low infiltration rates for sands and for pumice soils, due to hydrophobicity, have been measured in New Zealand (Vogeler 2008, Simcock 2006). As the soils in this study were allowed to come to steady state infiltration to avoid hydrophobic effects, it is likely that the low infiltration rate was due to low macro-porosity.

A strong correlation was found between measured infiltration capacities and measured macro-porosity values for the pumice and allophanic soils. The best fit was a power relationship (R^2=0.91) as shown in Figure 2. The podzolic (Tihoi) soils did not fit this relationship, probably because formation of these soils often results in a low permeability layer or pan in the subsoil. It is postulated that the podzolic soils exhibit a distinct and separate relationship between infiltration and macro-porosity which is about an order of magnitude lower than the relationship for allophonic soils, however with only 2 sample points available, such a relationship can not be confirmed at this time.

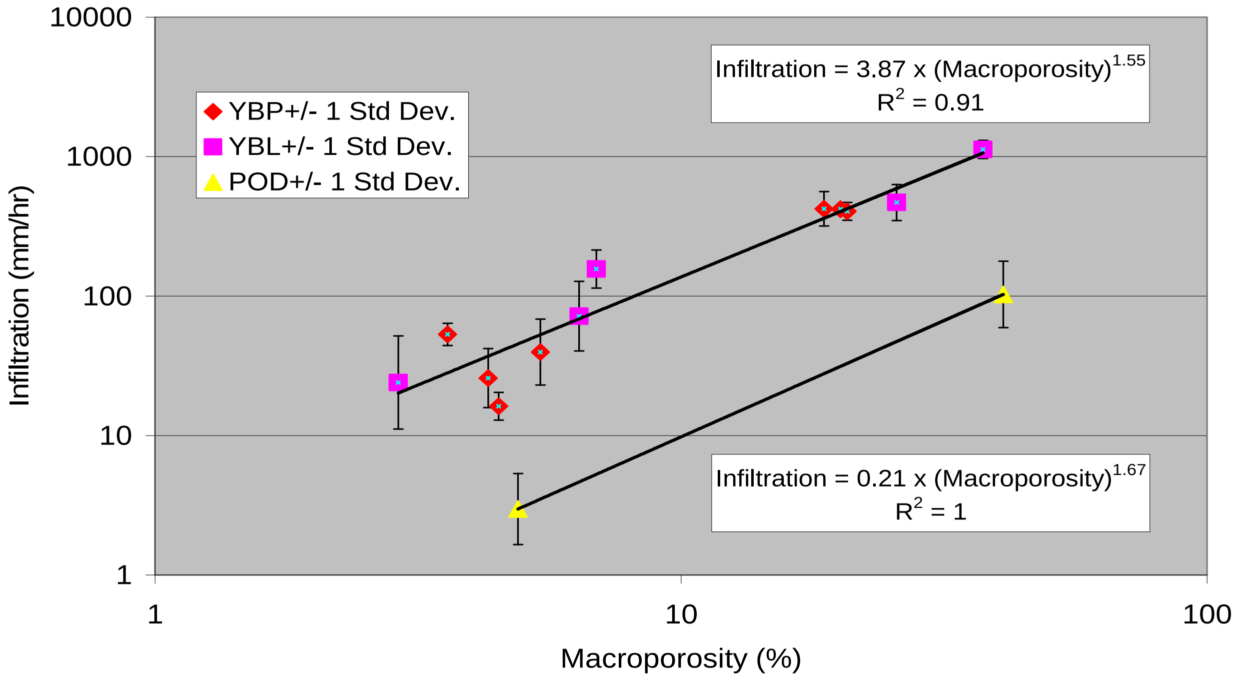

Figure 2: Infiltration – macro-porosity relationships

In comparison to macro-porosity, total porosity shows only relatively small differences between the two land uses (Table 2). This indicates that the changes that are occurring between forest and pasture are not predominantly compaction (involving a reduction in total voids) but that pore spaces, which under forest are large enough to allow free passage of water, are being converted or changed to smaller pore spaces that are less efficient at passing water, and do not allow free drainage. The predominant feature of the change in land use therefore seems to be one of loss in soil structure rather than true compaction (i.e. increase in soil density). The above observations are supported by the results of Zegwaard (2006) who reported a decrease in macroporosity of the soil surface layer, and a corresponding increase in microporosity for the same layer in a study of the effect of cattle treading on soil physical properties. This reinforces the inference that stock treading of soil results in conversion of macropores to micropores.

4 Mapping

A method has been developed to map both average soil macro-porosity and infiltration capacity throughout the Upper Waikato Catchment. The macro-porosity data obtained from the 5 paired sites has been supplemented with additional macroporosity data from Environment Waikato's soil quality database, Landcare Research's National Soil Database, and Jackson (2007). Using this data, average (geometric mean) macroporosity values were assigned to assumed homogeneous units based on the soil classification and the land use class.

Five land use classes have been used as a base to characterise the hydrological response of soils under different land uses at field capacity. These are a simplification of the land use classes contained within the LCDB2 database, which is based on satellite imaging taken in the summer of 2001-2002 (Table 3). Land use classes for the Upper Waikato catchment are shown mapped in figure 2.

Table 3: Hydrological land use classes

Land use class
1. Agricultural and horticultural surfaces
2. Bare and impervious surfaces
3. Plantation forest
4. Indigenous vegetation, scrub and unmanaged areas
5. Open water and wetland surfaces

For the purpose of this exercise, classes 2 and 5 are considered impervious (with macro-porosity values of zero). Additionally, plantation forest and indigenous vegetation etc are considered to be similar, and are considered within a single forest category.

Soils within the gauged catchments have been classified based on the NZSOILGRP (Group) and SERIES (Series) parameters of the New Zealand Land Resource Inventory Database (Newsome, 1995). A map of soils within the Upper Waikato catchment is shown in figure 3. The breakdown of the total catchment area by the soil types and key land use classes is shown in Table 4. The macro-porosity data broken down by soil group, soil series, and land use is shown in Table 5.

The data in Table 5 represents 85% coverage of the soils within the Upper Waikato catchment by area. A spatial intersection of the GIS layer for soil group and series, derived from the NZLRI database (Newsome, 1995), and the GIS layer for land use class, derived from the LCDB2 database (Ministry for the Environment, 2001), has been used to define homogeneous areas in terms of soil type and land use. Average macroporosity values have then been assigned to each homogeneous area based on the data set out in Table 5. For soils where no data is available for a specific series, but data is available for the group, the average macroporosity value for the group has been assigned. For non-podzolic soils where no data is available for either the group or the series, the overall average for all the non-podzolic soil data is used. Macro-porosity values have then been mapped spatially on the GIS (Figure 4).

The relationships between macro-porosity and infiltration capacity shown in Figure 2 has then been used to assign infiltration capacities to the different soils within the homogeneous areas based on the estimated macro-porosities for each homogeneous area. These are shown mapped in Figure 5.

Examination of the maps and the data suggests that land use has a greater impact in determining both soil macro-porosity and infiltration capacity than soil type has.

Table 4: Breakdown of soil types and land use within the upper Waikato by percentage of total area (based on LDCB2, 2001 and NZLRI, 1995)

Percentage of total area		Land use class			
Soil group	**Series**	**Pasture**	**Forest**	**Impervious**	**Total**
Pumice	Atiamuri	0.95%	0.86%	0.03%	**1.84%**
	Kaingaroa	0.76%	5.49%	0.03%	**6.28%**
	Mamaku	0.53%	2.86%	0.01%	**3.39%**
	Ngaroma	1.80%	4.75%	0.02%	**6.57%**
	Oruanui	5.90%	3.71%	0.03%	**9.64%**
	Tauhara	0.72%	2.49%	0.01%	**3.22%**
	Taupo	16.17%	16.26%	0.26%	**32.69%**
	Waipahihi	1.06%	1.17%	0.03%	**2.26%**
	Wharepaina	0.33%	0.01%	0.00%	**0.34%**
	Whenuaroa	1.08%	0.71%	0.11%	**1.90%**
	Other*	1.43%	1.70%	0.04%	**3.17%**
Allophanic	Maroa	0.70%	1.57%	0.00%	**2.26%**
	Motumoa	0.70%	2.31%	0.02%	**3.03%**
	Ngakuru	3.44%	1.55%	0.01%	**4.99%**
	Tirau	2.98%	0.17%	0.02%	**3.17%**
	Other	2.30%	3.30%	0.03%	**5.62%**
Podzol	Tihoi	1.01%	3.01%	0.00%	**4.02%**
Other		2.02%	2.26%	0.07%	**4.36%**
Rivers, Lakes & Urban		0.15%	0.13%	0.97%	**1.24%**
Total		**44.02%**	**54.30%**	**1.68%**	**100.00%**

Table 5: Soil macroporosity data by soil type and land use

Soil group	Soil series	Macroporosity			
		Pasture		Forest	
Pumice	Atiamuri	21%	(1)	32%	(1)
	Kaingaroa	18%	(1)	34%	(1)
	Mamaku			31%	(2)
	Ngaroma			35%	(1)
	Oruanui	6%	(4)	23%	(3)
	Tauhara	14%	(1)	41%	(1)
	Taupo	8%	(3)	29%	(5)
	Waipahihi	11%	(3)	33%	(3)
	Wharepaina	4%	(1)		
	Whenuaroa	20%	(2)	33%	(1)
Pumice average		**10%**	**(16)**	**30%**	**(18)**
Allophanic	Maroa	5%	(1)	46%	(1)
	Motumoa	10%	(1)	46%	(1)
	Ngakuru	7%	(3)	38%	(3)
	Tirau	4%	(3)	21%	(2)
Allophanic average		**5%**	**(8)**	**34%**	**(7)**
Podzol	Tihoi	9%	(3)	34%	(4)
Podzol average		**9%**	**(3)**	**34%**	**(4)**

Note. The number of samples are shown in brackets.

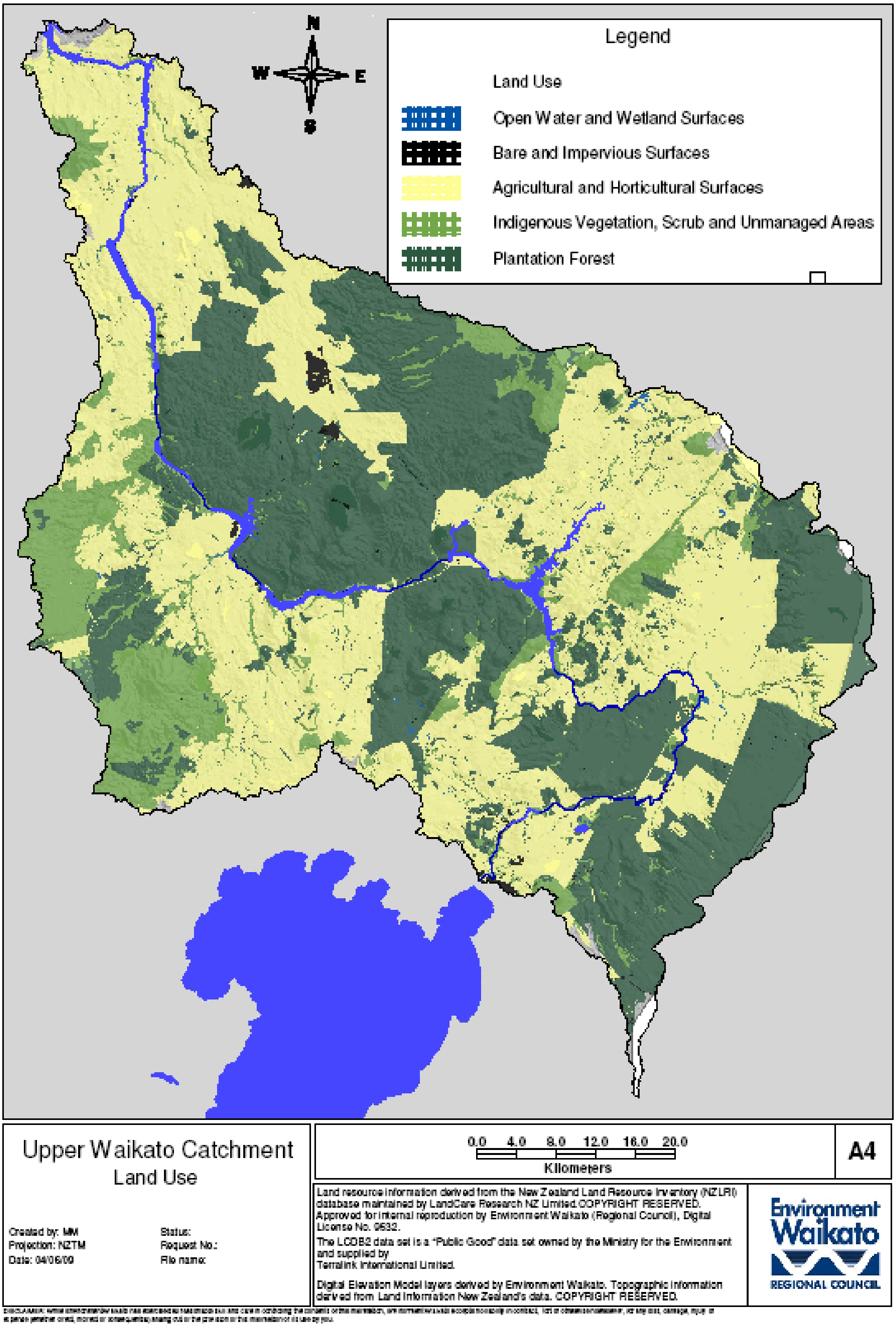

Figure 3: Upper Waikato land use

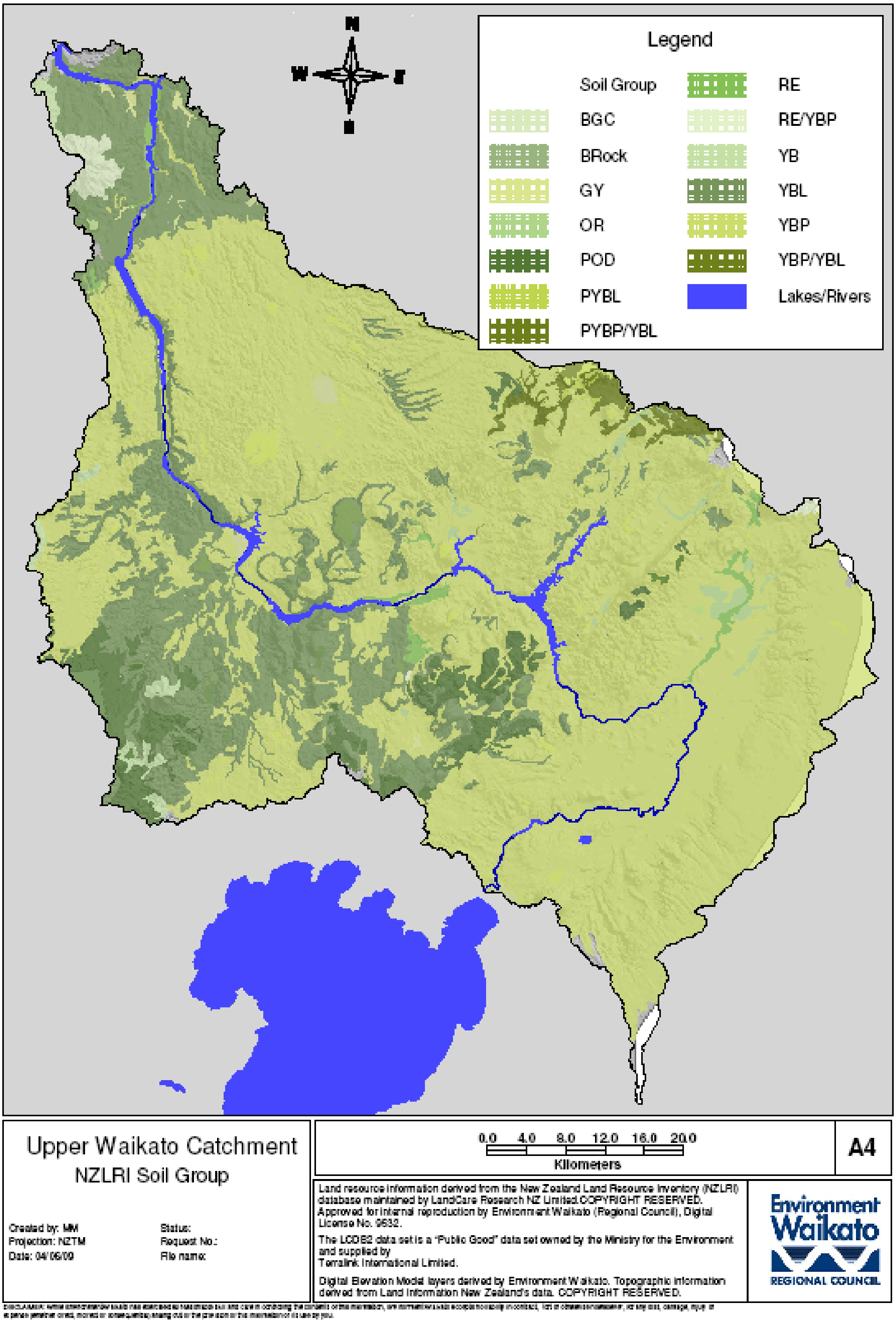

Figure 4: Upper Waikato soils

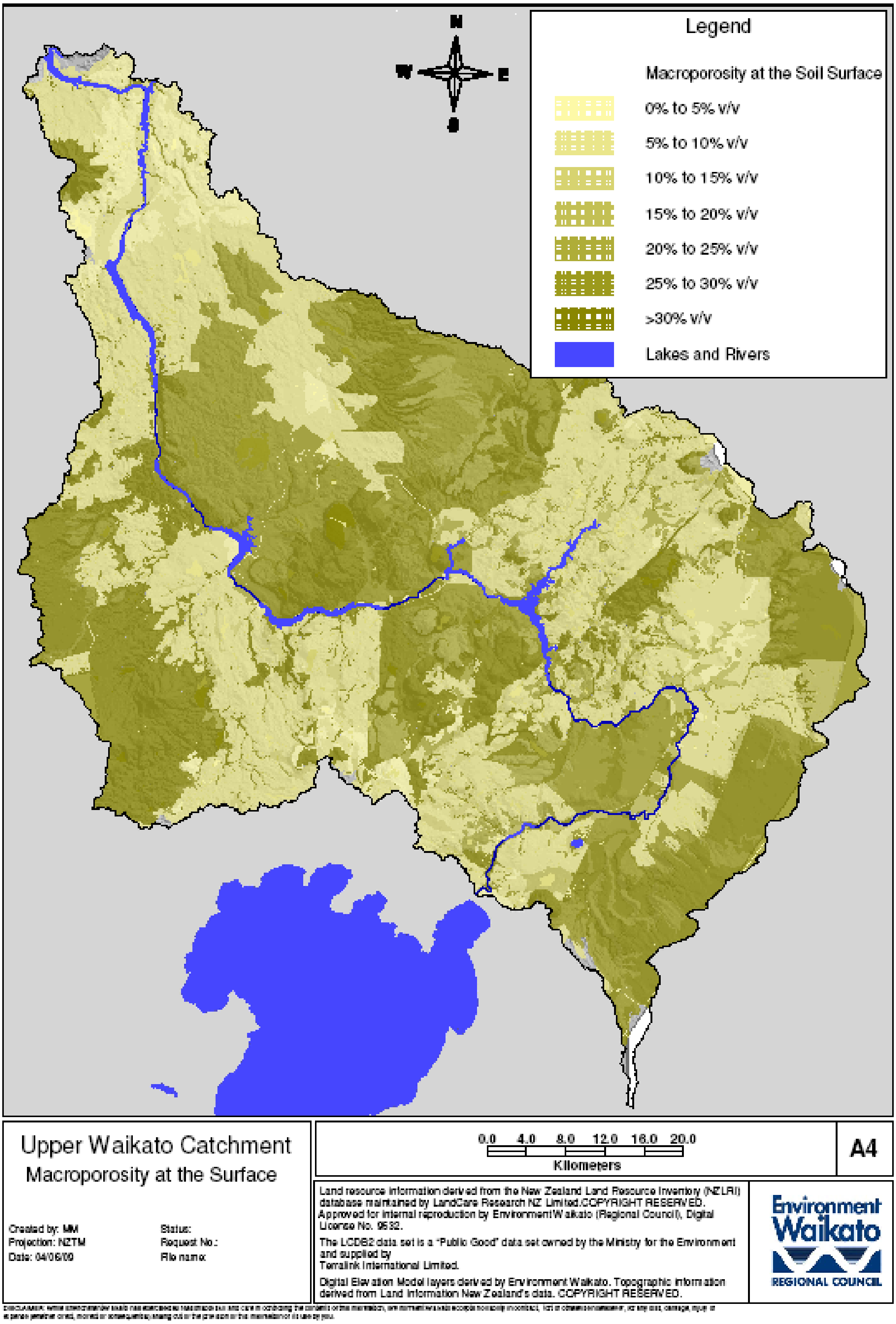

Figure 5: Upper Waikato soil macro-porosity at the surface

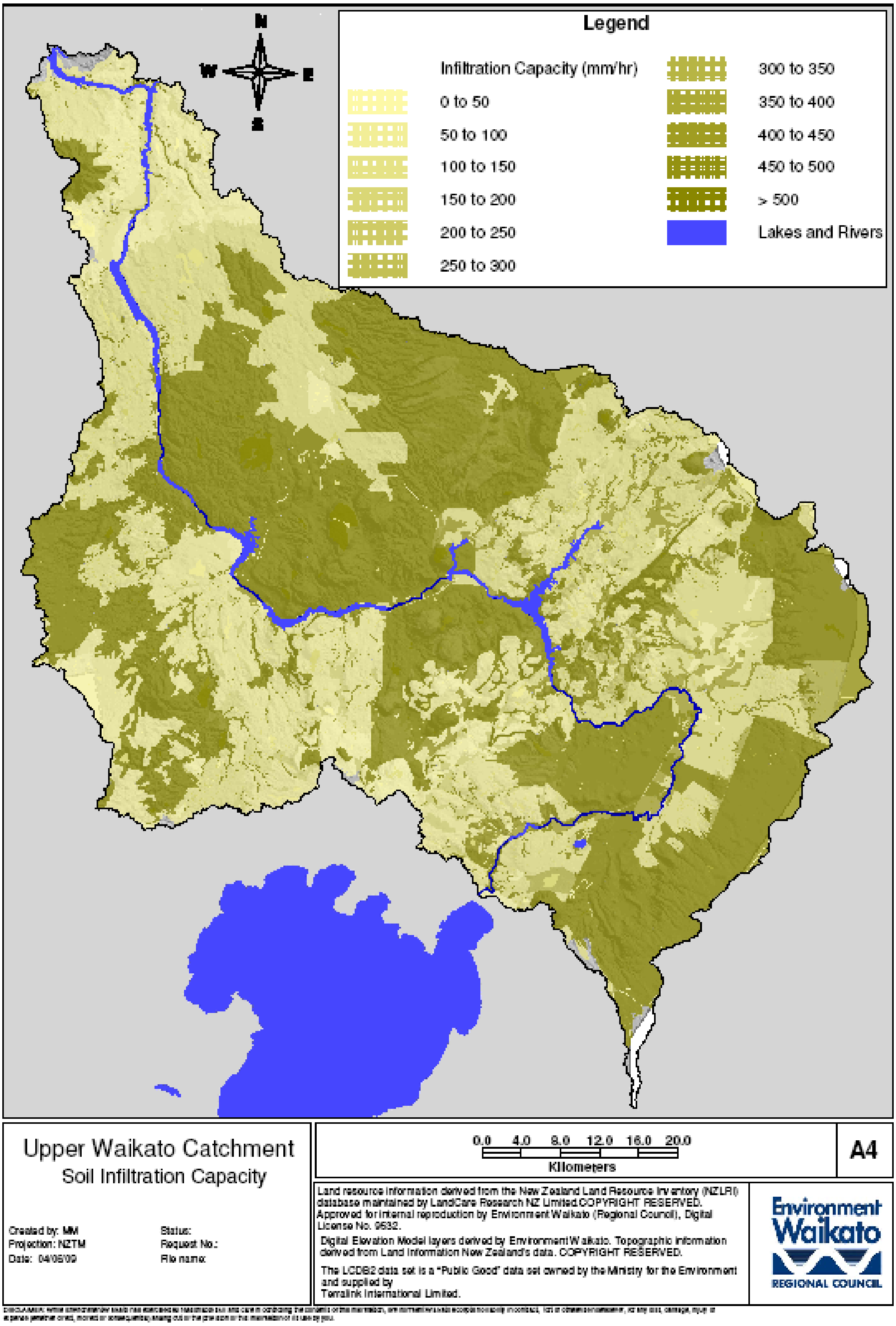

Figure 6: Upper Waikato soil infiltration capacity

5 Discussion

Bradshaw et al. (2007) showed global-scale patterns in mean forest trends and flood dynamics are meaningful, in 56 developing countries. Localised increases in stream power have been associated with heavily grazed hills with short vegetation cover in North-West England (Orr & Carling 2006), while flood intensity decreased due to farm abandonment and reforestation in the central Spanish Pyrenees (Lopez-Moreno et al. 2006). Similarly, Bradshaw et al. (2007) showed flood frequency and flood duration are negatively correlated with the amount of remaining natural forest and positively correlated with natural forest area loss. Dons (1987) recorded that the geometric mean surface runoff yield, as a percentage of gross rainfall, from pasture was significantly greater (3.6%) than that from either native forest (0.25%) or pine (1.3%) for 69 storms within the Purukohukohu experimental basement suite of catchments in the central North Island.

A decrease in infiltration capacity as a result of changing land use can be expected to result in increased flooding frequency and intensity as it is more likely for rainfall intensity to exceed soil infiltration capacity. International literature shows land use impacts flood dynamics and is most pronounced on small catchments (Tollan 2002). Small catchments are more responsive to short duration, high intensity rainfall events, and this study indicates that it is in these type of events that are likely to generate the biggest differences in actual infiltration (and consequently surface runoff) between pasture and forest catchments. Therefore it can be expected that converting forest to agricultural land in the upper Waikato catchment is likely to result in increased flooding, with increased flood peak and intensity. The impact will probably be greatest on small catchments which are more susceptible to short duration high intensity storms, especially in summer due to dry antecedent conditions.

In addition to increased flood risk, the decrease in infiltration may be expected to result in increased erosion and transport of sediment and nutrients to downstream river channels. Overland flow is a key driver for soil erosion, and if the frequency of surface runoff events is increased by a reduction in infiltration soil capacity, it follows that the erosion due to this mechanism must also increase. Niyogi et al. (2007) have shown streams flowing though agricultural land undergoing intensification usually had fine sediment on the stream bed and lower biotic indices for invertebrates compared to those flowing though land with intact riparian zones. Environment Waikato has invested heavily in soil conservation capital works and ongoing maintenance in the upper Waikato catchment. Any increased erosion could pose a threat to these investments, impact maintenance requirements, or destabilise currently stabilised catchments.

Pumice soils and allophanic soils respond differently to the stressors that lead to compaction. Pumice soils are very sensitive to load but not to moisture content. Protection of the soil surface is very important for these soils, e.g. by growing vegetation or cushioning the surface with organic matter, such as straw. Conversely, allophanic soils, which are considered “physically ideal soils”, are significantly affected by moisture content (Bell 2000) and are susceptible to physical decline due to treading damage (Singleton et al 2000). Gley Soils were not sampled in this study but these are even more vulnerable to moisture affects and treading damage than allophanic soils (Singleton et al 2000). The different responses of different soil groups to environmental stressors suggest different management techniques are required to control runoff on different soil types. However, the aim of all management techniques would be to control runoff by increasing infiltration and retaining water within small catchments. The international literature suggests that several management techniques are available to ensure that infiltration rate is maximised and profitability maintained on agricultural land.

These management strategies include:

- Afforestation.

- Avoid cropping as tillage leads to loss of soil organic matter, structural breakdown of the soil and areas of bare soil that are vulnerable to wind and water erosion.

- A less intense grazing regime so that compaction is reduced, plant cover is increased, return of residual organic matter is increased and there are no bare areas of soil.

- Avoid grazing animals and using machinery when soils are wet.

- Increase the amount of soil organic matter. Pit et al (1999) showed adding compost increased infiltration rate by between 1.5 and 10.5 times that of the unamended soil. Organic farms have been found to have improved macroporosity compared to conventional farms, resulting in a doubling of soil infiltration rates (Schnug and Haneklaus 2002).

- Imitate nature by riparian planting and baffle planting to break natural flow paths, develop wetlands to act as detention areas.

- Decrease hydrophobicity in critical catchments (e.g. sand country) using irrigation techniques (including effluent irrigation) or application of detergents.

- For soils with an appreciable amount of clay, application of lime may be helpful. Spavorek et al (2002) report that a decrease in the lime balance of soils and increased discharge of agricultural waste can contribute to degradation in soil structure and reduced soil infiltration rates. The correct balance between calcium, magnesium, potassium and sodium in the soil is important for soil structure. If the proportion of exchangeable sodium (ESP) exceeds 15% (w/w), it can cause soil clays to deflocculate (Sparling 2005). Calcium is the most common cation present and has a strong influence on the ESP (Lambert et al. 2000).

6 Conclusions

The results from the in situ infiltration measurements showed infiltration capacity of soil under grazed pasture was an order of magnitude less than that under pine forest. Similar differences were observed for soil macroporosity, however total porosity does not seem to be greatly affected by land use. This suggests that intensified land use results primarily in a change in soil structure, rather than soil compaction.

The conversion of forest to agricultural land within the upper Waikato catchment is likely to result in increased flooding and flood intensity, and erosion and sedimentation. The degree of effect is yet to be quantified, but it is expected that the greatest effects will be felt for small catchments in high intensity, short duration storms. Consequently there is likely to be a need for increased spending on soil conservation and river maintenance work. There are also potential effects on flood protection and drainage works downstream of Karapiro Dam, which require further investigation.

Infiltration measurements in this study (Table 2) were similar to literature values.

The narrow range of soil texture (silt-sand) in this study did not have a major influence on the infiltration rate.

Macroporosity appears to be a good predictor of infiltration capacity for the Allophanic and Pumice soils. It may also be a predictor for infiltration capacity of podzols, though this requires more data to confirm.

Land use has a greater impact in determining soil infiltration capacity than soil texture or group has within the Upper Waikato catchment.

Management techniques which maximise soil infiltration and minimise surface runoff from agricultural land are reported in the international literature, though their applicability to the Upper Waikato catchment may require further investigation.

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