Otago Regional Council

SUBMISSION FORM

Proposed Plan Change 1C Water Allocation and Use

to the Regional Plan: Water for Otago

Form 5, Clause 6 of the First Schedule, Resource Management Act 1991

1

Office use only

OTAGO REGIONAL COUNCIL
RECEIVED DUNEDIN
22 DEC 20
FILE No. RI241
DIR TO

Full name of submitter: Alan Grant Macgregor

Name of organisation *(if applicable)*:

Postal address: State Highway 1 1 K.R.D
Oamaru

Postcode:

Telephone: 034371653

Fax:

Email:

Contact Person: Self

I wish / do not wish *(circle preference)* to be heard in support of my submission.

If others made a similar submission, I will consider presenting a joint case with them at a hearing.
(Cross out if you would not consider presenting a joint case).

Signature of submitter: Grant Macgregor Date: 16th December 2008
(or person authorised to sign on behalf of person making submission).

Please note that all submissions are made available for public inspection.

The parts of the proposed plan change that my submission relates to are:
(Give clear references if possible e.g. reference number, policy x, rule y)

1 B Minimum Flows – 3 mentioned catchment
1 C Water allocation + use – " "

My submission is:
(Include whether you support, oppose, or wish to have amended the parts identified above, and give reasons)

I am a farmer
I am an irrigator (Lower Waitaki Irrigation Scheme)

I beleive the water flows, ecosystems and natural environment within the three mentioned water systems are too fragile to allow any water take for irrigation. Yes they could

Please turn over

I seek the following decision from the local authority:
(Give precise details e.g. changes you would like made)

support a drinking water residenial take from their upper reaches without much impact. Differed with a major river like the Waitaki where a CONTROLLED take can benfit mankind.

I sit in on irrigators meetings and believe me THEY DONT CARE more especially the dairy farmers.

We dont have much left in North Otago as regards clean water. The upper reaches of the Waianakarua, Marawhenua and Kauru is about it in the summer. The Kakanui is a disgrace. I drift dive most local rivers in th summer. I have seen them sterilized in some places even in my lifetime.

Please be sensible with your decisions.

We once called our country "God's Own"

SUBMISSIONS MUST BE RECEIVED BY 5.00 PM, MONDAY 9 MARCH 2009.

Please do your best - it is the responsibility of us all.

Please fold and secure with a small piece of tape.

FreePost Authority ORC 1722

Otago Regional Council
Private Bag 1954
Dunedin 9054

Attention Policy Team

⑥

Otago Regional Council

SUBMISSION FORM
Proposed Plan Change 1C Water Allocation and Use
to the Regional Plan: Water for Otago

Form 5, Clause 6 of the First Schedule, Resource Management Act 1991.

2

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OTAGO REGIONAL COUNCIL
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23 DEC 2008
FILE No. RI241
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Full name of submitter: ALI KINGAN

Name of organisation *(if applicable)*:

Postal address: 47 HULL ST

OAMARU

Postcode: 9400

Telephone: 0274339805

Fax:

Email:

Contact Person:

I ~~wish~~ / do n wish *(circle preference)* to be heard in support of my submission.

If others ma similar submission, I will consider presenting a joint case with them at a hearing.
(Cross out if u would not consider presenting a joint case).

Signature of submitter:

Date: 17/12/08

(or person authorised to sign on behalf of person making submission).

Please note that all submissions are made available for public inspection.

The parts of the proposed plan change that my submission relates to are:
(Give clear references if possible e.g. reference number, policy x, rule y)

GENERAL SUPPORT FOR O.R.C PROPOSED PLAN CHANGE.
1 a b c d 2, 3, 4, 6 a b c

My submission is:
(Include whether you support, oppose, or wish to have amended the parts identified above, and give reasons)

I SUPPORT THE PROPOSED PLAN CHANGE. THE WATER ALLOCATION POLICY NEEDS CAREFUL ADJUSTMENT, AND ON-GOING MONITORING. WE ARE MEDDLING WITH NATURE TOO MUCH, AND FUTURE GENERATIONS WILL PAY THE PRICE OF OUR MISADVENTURE, OFTEN FUELLED BY GREED. IT CONCERNS ME THAT NATURAL SPRINGS THAT HAVE RUN IN THE PAST, NO LONGER DO SO.

Please turn over

I seek the following decision from the local authority:
(Give precise details e.g. changes you would like made)

OUR RIVERS ARE SUFFERING BECAUSE OF WATER HARVESTING, AND MINIMUM FLOWS SET TOO LOW.

PLEASE TAKE EVERY STEP POSSIBLE, TO RETAIN SOMETHING THAT WE ARE ONLY GUARDIANS OF.

SUBMISSIONS MUST BE RECEIVED BY 5.00 PM, MONDAY 9 MARCH 2009.

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Otago Regional Council
Private Bag 1954
Dunedin 9054

Attention Policy Team

Otago Regional Council

SUBMISSION FORM
Proposed Plan Change ~~1B~~ 1C Minimum Flows
to the Regional Plan: Water for Otago

Form 5, Clause 6 of the First Schedule, Resource Management Act 1991

3

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OTAGO REGIONAL COUNCIL
RECEIVED DUNEDIN
23 JUL 2008
FILE No. RI 241
DIR. TO.

Full name of submitter: Turvey   [illegible] Weaving   Sth Dunedin

Name of organisation *(if applicable)*: NA

Postal address:

Postcode: 9012

Telephone: 03) ~~4~~455 2915

~~Fax:~~

~~Email:~~

Contact Person:

I ~~wish~~ / [✓ do not wish] *(circle preference)* to be heard in support of my submission. It can stand by itself

If others made a similar submission, I will consider presenting a joint case with them at a hearing.
(Cross out if you would not consider presenting a joint case). A Good all-round Geographer plus more specialist academics could be usefully consulted, in addition to locals

Signature of submitter: J. Turvey
(or person authorised to sign on behalf of person making submission).

Date: 2/ /08

[illegible] no goats on [illegible]

Please note that all submissions are made available for public inspection.

The parts of the proposed plan change that my submission relates to are:
(Give clear references if possible e.g. reference number, policy x, rule y)

in general
- locals know best what to what and should/shouldn't change
- any differences from near-enough-unanimous decisions should be given sensible consideration and even tolerance where possible / for time being
- preserve pastoral and agricultural landuse of present unless better is clear — any housing/tourist developments to be restricted as to space and effects, especially water use [illegible]!

My submission is:
(Include whether you support, oppose, or wish to have amended the parts identified above, and give reasons)

Apart from any grossly anomalous differences at present or intended, maintain the status quo. Any proposal to substantially alter present shares, from especially outsiders, to be disallowed. Present or future uses of pollution removed or prevented, beyond treated-water and/or filtered drinking or [illegible] standard (taste also critical). Temporary excesses of water from atmospheric precipitation desirably to be captured in part in tanks or other devices, especially domestic. Research (further?) into xerophytic alternative flora, fauna substitutes for [illegible] use — those antagonistic to irrigation (evaporation and salination). No goats (in any large number [illegible])

Please turn over

I seek the following decision from the local authority:

(Give precise details e.g. changes you would like made)

Not really my business in so specific a case, so
"See overleaf"

P.S. re irrigation — halophytes might refer

SUBMISSIONS MUST BE RECEIVED BY 5.00 PM, MONDAY 9 MARCH 2009.

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Attention Policy Team

Otago Regional Council

SUBMISSION FORM

Proposed Plan Change 1C Water Allocation and Use

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Form 5, Clause 6 of the First Schedule, Resource Management Act 1991.

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OTAGO REGIONAL COUNCIL
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23 DEC 2008
FILE No. RI241
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Full name of submitter: Lesley Warwood

Name of organisation *(if applicable)*: —

Postal address: 14 Wyre Street
Kaitangata South Otago

Postcode: 9210

Telephone: 03 4139845

Fax:

Email:

Contact Person: Lesley.

I wish / do not wish *(circle preference)* to be heard in support of my submission.

If others made a similar submission, I will consider presenting a joint case with them at a hearing.
(Cross out if you would not consider presenting a joint case).

Signature of submitter: L Warwood
(or person authorised to sign on behalf of person making submission).

Date: 20-12-08

Please note that all submissions are made available for public inspection.

The parts of the proposed plan change that my submission relates to are:
(Give clear references if possible e.g. reference number, policy x, rule y)

My submission is:
(include whether you support, oppose, or wish to have amended the parts identified above, and give reasons)

Why don't you large companys get water from the ocean

Generate power — distill water etc

Spend money now and you have it for the rest of our lives

3-4 around NZ and you ~~g~~ have got it made. (We would have it for ever) FUTURE

We have water all around us — Use it

Please turn over

I seek the following decision from the local authority: [redacted]
(Give precise details e.g. changes you would like made)

SUBMISSIONS MUST BE RECEIVED BY 5.00 PM, MONDAY 9 MARCH 2009.

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Dunedin 9054

Attention Policy Team

Otago Regional Council

SUBMISSION FORM

Proposed Plan Change 1C Water Allocation and Use

to the Regional Plan: Water for Otago

Form 5, Clause 6 of the First Schedule, Resource Management Act 1991.

5

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OTAGO REGIONAL COUNCIL
RECEIVED DUNEDIN
23 DEC 2008
FILE No. RI241
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Full name of submitter: [Clyde Watson]

Name of organisation *(if applicable)*:

Postal address: [71 Macandrew Road,
South Dunedin]

Postcode:

Telephone:

Fax:

Email:

Contact Person:

~~I wish~~/ do not wish *(circle preference)* to be heard in support of my submission.

If ~~others made a similar submission, I will consider presenting a joint case with them at a hearin~~g.
(Cross out if you would not consider presenting a joint case).

Signature of submitter:

Date: [21-12-08]

(or person authorised to sign on behalf of person making submission).

Please note that all submissions are made available for public inspection.

The parts of the proposed plan change that my submission relates to are:
(Give clear references if possible e.g. reference number, policy x, rule y)

I would like the rivers cleaned with no pollution, and water with no chemicals.

My submission is:
(Include whether you support, oppose, or wish to have amended the parts identified above, and give reasons)

I would like water clean for when we're Cooking and washing etc.

Please turn over

I seek the following decision from the local authority: [redacted]

(Give precise details e.g. changes you would like made)

I would like tosee that we will have plenty of water to last us, and not waste water at all

SUBMISSIONS MUST BE RECEIVED BY 5.00 PM, MONDAY 9 MARCH 2009.

Please fold and secure with a small piece of tape.

FreePost Authority ORC 1722

Otago Regional Council
Private Bag 1954
Dunedin 9054

Attention Policy Team

Sarah Valk

1C

6

From: Dale Meredith
Sent: Wednesday, 24 December 2008 09:17
To: Sarah Valk
Subject: FW: Proposed plan Change: Regional Water Plan

OTAGO REGIONAL COUNCIL
RECEIVED DUNEDIN
2[illegible] 2008
FILE No. RI241
DIR TO

-----Original Message-----
From: Fraser McRae
Sent: Wednesday, 24 December 2008 9:13 a.m.
To: Dale Meredith
Subject: FW: Proposed plan Change: Regional Water Plan

Dale

treat this as a submission.

Fraser
-----Original Message-----
From: Alan Mark [mailto:alan.mark@botany.otago.ac.nz]
Sent: Tuesday, 23 December 2008 9:55 a.m.
To: Fraser McRae
Cc: amark@otago.ac.nz
Subject: Proposed plan Change: Regional Water Plan

Hi Fraser,

Thanks for your notice received in the mail yesterday. I expressed my concerns with the current ORCs Water Plan at one of the evening sessions chaired by Michael Deaker and I also talked personally to the ORCs Chair who was present at this meeting and received some acknowledgment for my concerns and an undertaking to look that this in relation to the review of the Water Plan. I certainly can't see any sign of it in the two pages you sent me so I'll try again and make the case on the basis of the following statement:

Objective: "To ensure the important water supply catchments in Otago have adequate protection of vegetation cover to optimise the quantity, quality and sustained low flows of the water they produce."

Note that considerable research has shown that the type of vegetation cover can have a major effect on all these aspects of water yield and thus the availability of water, even groundwater (see Mark & Dickinson 2008, and Ingraham, Mark & Frew 2008, references therein).

This being the case the Water Programme of Action and the new NPS on water, derived from it, should recommend that all important water supply catchments be adequately protected in terms of their vegetation cover so as to retain (or regain) the maximum quantity, quality, and low-flow aspects of their water yield (see Mark & Dickinson 2008 [esp. page 30, col. 2, para 3] and Ingraham, Mark & Frew 2008). In particular, there should be protection in such catchments against afforestation with exotic conifers which are known to significantly reduce water yield (both maximum and low-flow yields) compared with most other types of plant cover, particularly indigenous tall tussock grassland (see Mark & Dickinson 2008). Necessary protection could be provided outside areas of conservation land through the use of both district plans (which control land use) and regional policy statements and water plans which are the responsibility of regional councils. I will attach the two references for your further information (you will see that we specifically mention our concerns with the ORCs position in the Frontiers paper).

References:

Ingraham NL, Mark AF, Frew RD. 2008. Fog deposition by snow tussock grassland on the Otago uplands: response to a recent review of the evidence. Journal of Hydrology (NZ) 47: 107-122.

Mark AF, Dickinson KJM. 2008. Maximizing water yield with indigenous non-forest vegetation: a New Zealand perspective. Frontiers in Ecology and the Environment 6 (1): 25-34.

Maximizing water yield with indigenous non-forest vegetation: a New Zealand perspective

Alan F Mark* **and Katharine JM Dickinson**

Provision of clean freshwater is an essential ecosystem service that is under increasing pressure worldwide from a variety of conflicting demands. Water yields differ in relation to land-cover type. Successful resource management therefore requires accurate information on yields from alternative vegetation types to adequately address concerns regarding water production. Of particular importance are upper watersheds/catchments, regardless of where water is extracted. Research in New Zealand has shown that, when in good condition, indigenous tall tussock grasslands can maximize water yield relative to other vegetation cover types. A long-term hydrological paired-catchment study revealed reductions (up to 41% after 22 years) in water yielded annually from an afforested catchment relative to adjacent indigenous grassland. Furthermore, a stable isotope assessment showed that water from fog may substantially contribute to yield in upland tussock grasslands. The tall tussock life-form and its leaf anatomy and physiology, which minimize transpiration loss, appear to be the differentiating factors. Thus, maintaining dominance of such cover is important for water production, especially in upland catchments. Ecological analogues and integrated land-use planning are discussed in the context of this essential ecosystem service. Water management programs in other countries are reviewed and that of South Africa is commended as a model.

Front Ecol Environ 2008; 6(1): 25–34, doi:10.1890/060130

There is an increasing call for economic models and land-management frameworks to incorporate the value of ecosystem services into their accounting, planning, and decision making (Prato 1999). These services, such as the provision of clean water, are becoming increasingly vulnerable worldwide, as demand increases and environments degrade (Körner *et al.* 2006; Metzger *et al.* 2006). This vulnerability is made more acute by competing and often conflicting demands, and the complexity of associated ecological, social, and political issues (Bohensky and Lynam 2005). Water is essential to human life and welfare, and demand is increasing. Many people worldwide are already living in conditions of serious water scarcity, and with increasing concentration of populations in urban areas, future supply and availability is a globally sensitive issue (Bolund and Hunhammar 1999; Vörösmarty *et al.* 2000; Jenerette and Larsen 2006). Estimates indicate that nearly half of humanity depends directly or indirectly on water yield from mountain catchments (Körner *et al.* 2006).

In a nutshell:

- Provision of clean freshwater is an essential ecosystem service which is becoming less available globally due to increasing demand
- Different land-cover types can substantially affect water yields; these effects can be important in upland catchments/watersheds, where the potential for water production is usually greatest
- Trade-offs between wood production/carbon sequestration and water production should be carefully evaluated through integrated land-use planning, particularly in important water-supply areas
- Many countries, including New Zealand, are addressing water-supply, allocation, and quality problems with varying degrees of success; we commend the comprehensive South African National Water Act of 1998 as a model

Ecosystems, the services they provide, and the people who use and manage them, form complex adaptive systems (Bohensky and Lynam 2005). Resolution of system-wide problems involves a combination of behavioral, institutional, and technical factors, and an integrated approach, very likely including trade-offs, is needed to achieve desired benefits (Bohensky and Lynam 2005; Jackson *et al.* 2005). Those factors related to the supply of freshwater include draw-off for domestic use versus storage for hydro-electricity or irrigation, often with associated displacement of people and downstream effects on biological conservation and other ecosystem services. Tree plantations for carbon sequestration, which cause reduction in water yield, may present a similar situation. Such matters offer considerable challenges to societies. Global climate change introduces additional complexity, with many scenarios projecting major shifts in precipitation and temperature regimes (Beniston 2003; Giorgi 2006; IPCC 2007). Development of frameworks for integrating ecosystem services with socio-economic benefits are therefore essential for sustainable

Department of Botany, University of Otago, Dunedin, New Zealand
*(amark@otago.ac.nz)

Listen to Alan Mark discussing this research on the new *Frontiers* monthly podcast, at www.frontiersinecology.org.

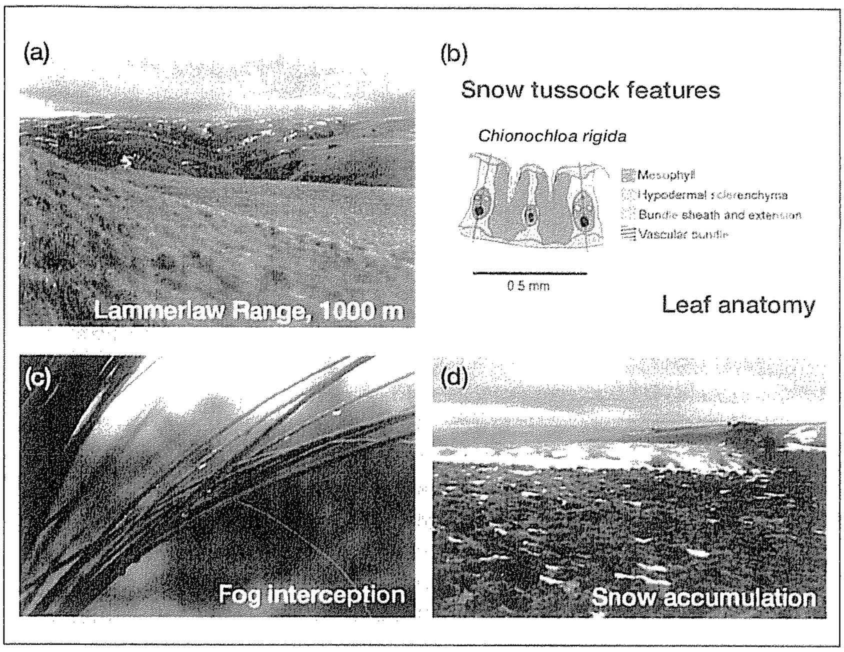

Figure 1. *(a) Special features of narrow-leaved snow tussock* (Chionochloa rigida) *grassland (pictured here in Dunedin City's water supply catchment) make it particularly efficient for water yield, yielding its leaf anatomy. (b) A camera lucida outline of a cross section of part of a mature leaf. The stomata (not shown) are adjacent to the photosynthetic mesophyll tissue and confined to the innermost reaches of the furrows on the concave side of the leaf. These furrows tend to close when the leaf rolls in response to low humidity, thus further reducing water loss. Adapted from Mark (1975) and reproduced with permission. (c) The diffuse, fine, elongated leaves of tussock allow them to intercept water droplets from fog, up to 0.5 L hr^{-1} by a single tussock in dense fog without measurable rain. (d) An area of snow tussock planted in 1974, on the crest of the Old Man Range in south–central New Zealand, showing their ability to accumulate snow on this highly exposed site.*

landscape planning and maintenance of natural capital (de Groot 2006), as well as for societal well-being (MA 2005).

■ Issues

Land use, vegetation cover, and water production

The links between land use and water production, and the contribution of a particular vegetation cover to runoff and groundwater supplies, have been studied most convincingly through the use of paired catchments, with one of the pair undergoing treatment (eg planted or cleared) and the other remaining as a control or reference (Brown *et al.* 2005). New Zealand has a history of paired catchment studies, which are now being integrated into global syntheses of the effects of vegetation change on water yield (Brown *et al.* 2005; Farley *et al.* 2005; Adams and Fowler 2006). These syntheses have confirmed that different land covers usually deliver different water yields, seasonally and annually, as well as in times of high and low flows. Achieving an understanding of catchment hydrodynamics and the inter-relationship with vegetation type is therefore essential to developing an integrated approach to land-use planning aimed at maximizing water yield at the catchment level. Influences of changing land use and vegetation cover on water yield are particularly important in the upper source areas, where environmental changes may result in reduced downstream flows and groundwater availability.

Tall tussock (bunch) grassland ecosystems

Ecosystems dominated by tall tussock (bunch) grasses occur in various parts of the world, particularly in oceanic temperate conditions such as may be found in New Zealand (Figure 1a), the tropical high mountains, and sub-Antarctic regions, but are much less common in temperate continental areas (Mark *et al.* 2000). In New Zealand, upland indigenous tall tussock grasses are resistant to wind and snow cover. In comparison to most other dominant plants here, these grasses also have relatively low water loss (transpiration), because their stomata are located in deeply incised furrows on the concave side of the rolled leaves (Mark 1975; Figure 1b). Moreover, the degree of rolling increases in response to desiccation (Clearwater 1999). These attributes, combined with the plant's morphology, render them efficient traps for precipitation in the form of rain (Pearce *et al.* 1984), snow, or fog (Ingraham and Mark 2000; Figure 1 c, d). These grasses are thus important for regional hydrology (Holdsworth and Mark 1990; Fahey and Jackson 1997).

Ecologically, there are some useful analogies that can be made with the New Zealand situation. In Ecuador, for example, research has shown that the *páramo* tall bunch grass ecosystems (Hofstede *et al.* 2003) are ecologically equivalent to those in New Zealand (Mark *et al.* 2000). As with the upland tall tussock grassland catchments in New Zealand (Webb *et al.* 1999), the *páramo* of the tropical high Andes plays an important role in maintaining soil moisture (Farley *et al.* 2004). Elsewhere in the tropics, such as on Mount Kenya in East Africa, where water supply is also critical, studies of the effects of fire on Afro-alpine vegetation, which includes tussock grassland ("moorland") have focused on plant diversity rather than ecosystem function (eg Wesche 2006). To date, the adjoining forests have received more attention in relation to resource-management conflicts (Kiteme and Gikonyo 2002).

Ecological trade-offs between afforestation and tall tussock grasslands

Since the creation of the Clean Development Mechanism (CDM) under the Kyoto Protocol, understanding the role of tree plantations in carbon sequestration has become increasingly important (Farley *et al.* 2004). The CDM enables developed countries to offset their emissions with afforestation or reforestation in developing countries. Such planting has occurred in Ecuador, and while carbon sequestration has not been the primary motivation for exotic tree plantations in New Zealand, carbon offset procedures have now been introduced. In the Ecuadorian *páramo*, bioclimatic conditions lead to slow rates of decomposition and high carbon storage. Here, following afforestation with *Pinus radiata*, soil-water retention declined with stand age, with an associated loss in soil carbon (Farley *et al.* 2004). Losses were linked to changes in soil organic matter and moisture retention (Hofstede *et al.* 2002), in addition to water losses attributed to greater canopy interception and evapotranspiration of trees when compared with grasslands (Fahey and Jackson 1997; Engel *et al.* 2005). Such decreases in soil carbon may not be solely a result of afforestation; previous land use, site preparation, species planted, climate, and soil type all influence water retention (Farley *et al.* [2004] and references therein). However, there are important issues to be addressed in balancing afforestation/reforestation with maintenance of a vegetation cover that maximizes water yield. Some strategies to address global climate change and the increase in greenhouse gases may be fundamentally at odds with water yield considerations (Jackson *et al.* 2005), with the loss of vegetation types that maximize water yield and provide substantial carbon storage having important consequences.

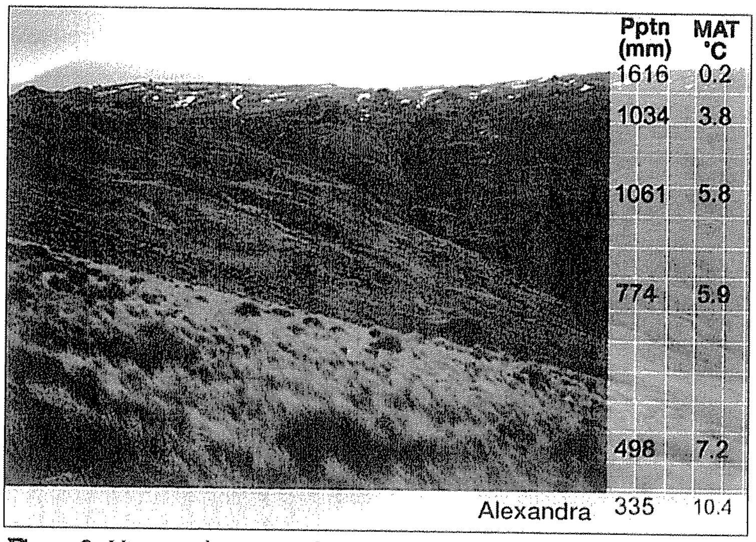

Figure 2. *View up the eastern slope of the Old Man Range (1650 m), south-central New Zealand, from 750 m on the lower slopes, showing mixed fescue–snow tussock montane grassland (foreground), which gives way to pure snow tussock sub-alpine grassland above ~900 m. Snow-lie areas in the high-alpine zone on the upper slopes above ~1300 m have remnant slim snow tussock, blue tussock, herbfield, and cushionfield. Values for mean annual precipitation (Pptn) and mean annual air temperature (MAT) are shown (right) for five sites (610 m, 910 m, 1220 m, 1380 m, and 1590 m) up this altitudinal sequence, with those for the town of Alexandra (150 m) on the valley floor (bottom values) indicating the importance of the upper slopes for water yield.*

Water yield issues in New Zealand's upland indigenous tussock grasslands

New Zealand is relatively well endowed with natural water. Precipitation is generally evenly distributed seasonally, with annual falls varying regionally from 330 to > 10 000 mm (Mark 1993). Most urban areas depend on clean, freshwater either directly from catchments or indirectly from groundwater. Furthermore, much of this water comes from upland catchments, where precipitation is generally higher and evapotranspiration is less than at lower altitudes (Figure 2). Thus, land uses in these uplands may have considerable bearing on water yield, as well as on low and high flows. Though the term "ecosystem services" is relatively new to the natural resource vocabulary, their value is not. Rivers were singled out as important resources throughout human occupation in New Zealand, first by Māori in pre-European times, and soon after European settlement in the 1840s, when river boards were established. This mainly reflected concerns about land stability and erosion. Although the importance of guaranteed water supply and quality was appreciated, the record of integrated management is patchy, with many substantial challenges still to be faced (Memon 1997; Memon and Selsky 2004).

Temperate native grasslands are considered to be the world's "most beleaguered biome" (Henwood 1998). In the New Zealand uplands, their cover, composition, and structure have been variously transformed by pastoral farming (burning and grazing, mostly by introduced sheep) during the European phase of settlement, with some associated adverse impacts on soil, water, and biodiversity values. Although reasonably substantial areas remain (Mark and McLennan 2005), there is cause for concern. Degradation or loss of these ecosystems is not easily remedied. Successions within the tall tussock grasslands are prolonged because of the slow growth rates and long life spans of individual tussocks (Mark 1993). These features led to the observation that the tussock grassland "has many of the characteristics of a forest and few of those of a short rotation pasture, it is the product of a long, slow development and, like a forest, it is much

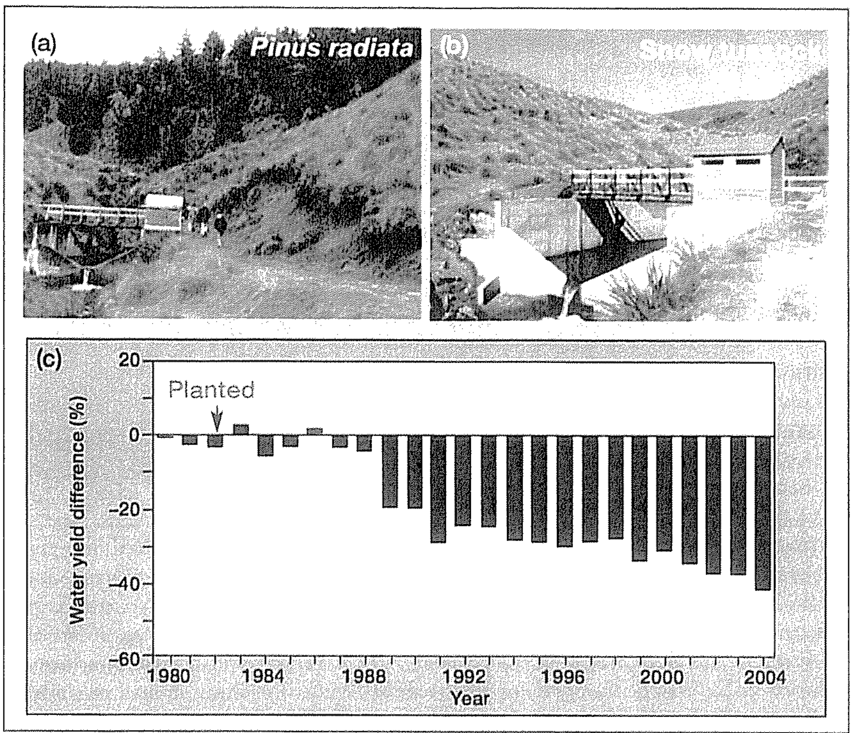

Figure 3. *V-notch weirs recording water yield from each of the adjacent Glendhu paired catchments at 460–670 m, Lammerlaw Range, south-central New Zealand. (a)* Pinus radiata *was planted in 1982 over 67% of the 310-ha catchment at 1250 stems ha^{-1} (b) while the adjoining lightly grazed (~ 1 sheep per ha) reference 218-ha catchment remains dominated by narrow-leaved snow tussock* (Chionochloa rigida) *grassland. (c) The annual water yield difference (pine–snow tussock) between the two catchments up to 2004 is shown at the base. Data provided by B Fahey.*

easier to destroy than to rebuild" (Moore 1954). Tall tussock grasses increase in basal area through vegetative tillering, and their sparse mortality emphasizes their longevity. Once lost, re-establishment is very slow, even where a seed source is available (Mark 1993).

Research focusing on transformation of tall tussock grassland to exotic afforestation has revealed important effects. A paired-catchment study (Glendhu), in south-central South Island (Fahey and Jackson 1997) has shown a continuing and increasing reduction in annual water yield from a 310-ha catchment planted in *Pinus radiata* relative to an adjacent 218-ha reference catchment of lightly grazed tussock grassland (up to 41% after 22 years; Figure 3). Such results confirm the potential trade-offs involved with afforestation for carbon sequestration or other purposes.

Other research highlights the importance of the indigenous tall tussock grassland (at most, lightly grazed) in maximizing water yield in comparison with a range of other vegetation types. Lysimeter (device used to measure the water balance of an area of vegetation) studies of water yield in relation to upland plant cover in south-central South Island begun in 1966 were later extended to six other sites in the same and nearby regions (Figure 4). Results from snow tussock grassland in non-weighing lysimeters indicated that a mean annual rainfall of 1348 mm returned 63% of this as water yield, surplus to evaporative losses (Mark and Rowley 1976). These figures were consistent with subsequent results from similar upland grassland in the nearby Glendhu catchment (see Figure 3), where a yield of 64% was recorded from a mean annual precipitation of 1305 mm (Pearce *et al.* 1984). The lysimeter-based water yields from upland tussock grassland were consistently greater than from the four other cover types studied. The yield from this grassland reached as much as 80% of the measured 1372 mm annual precipitation (and 86% for the snow-free 6 months) at one of the seven study sites (from 490 to 1340 m altitude); this was more than from a short turf of blue tussock (*Poa colensoi*) or even bare soil (Figure 4). Further, short, exotic pasture grassland at the lowest site (490 m; not shown in Figure 4), yielded < 1% of measured precipitation (Holdsworth and Mark 1990).

In another paired upland catchment study nearby, 75% of the treated snow tussock grassland catchment was burned in 1988 (Figure 4). When compared with the unburned reference catchment, a significant reduction in summer flows was measured in the early post-fire years (Duncan and Thomas 2004), with a 32% reduction in summer runoff in the second year and 19% in the third year. As tussocks recovered from the fire, relative water yield from the burned catchment gradually increased. A similar pattern was found with an earlier lysimeter study, and was explained by low transpiration of mature tussocks compared with young regrowth foliage, plus reduced interception of fog by the shorter canopy (Mark and Rowley 1976).

The entrapment (interception gain) of fog and its importance for water yield is well documented and accepted outside New Zealand (eg Bruijnzeel 2001; Olivier and Rautenbach 2002; Beiederwieden *et al.* 2005) but its role has been a source of controversy here (Holdsworth and Mark 1990). A stable isotope study (Ingraham and Mark 2000) provided further evidence that fog may contribute substantially to water yield in the upland tussock grasslands of south-central South Island. In this study, the isotopic composition of rain, fog, and groundwater was established for three upland sites (Figure 4) over two consecutive snow-free seasons. Fog, as an early-stage condensate from saturated air relatively close to the ground, had been shown to have a higher proportion of the heavy stable isotopes (of oxygen and hydrogen) than rain, which is a later-stage condensate (Ingraham 1998). In the upland study, fog was consistently more enriched in the heavy isotopes than rain, and the isotopic composition of the groundwater indicated a mixture of fog and rain in subequal proportions (Ingraham and Mark 2000; Figure 5). Such results reinforce the importance of intact tall tussock grasslands in delivering water, particularly from fog-prone upland ecosystems.

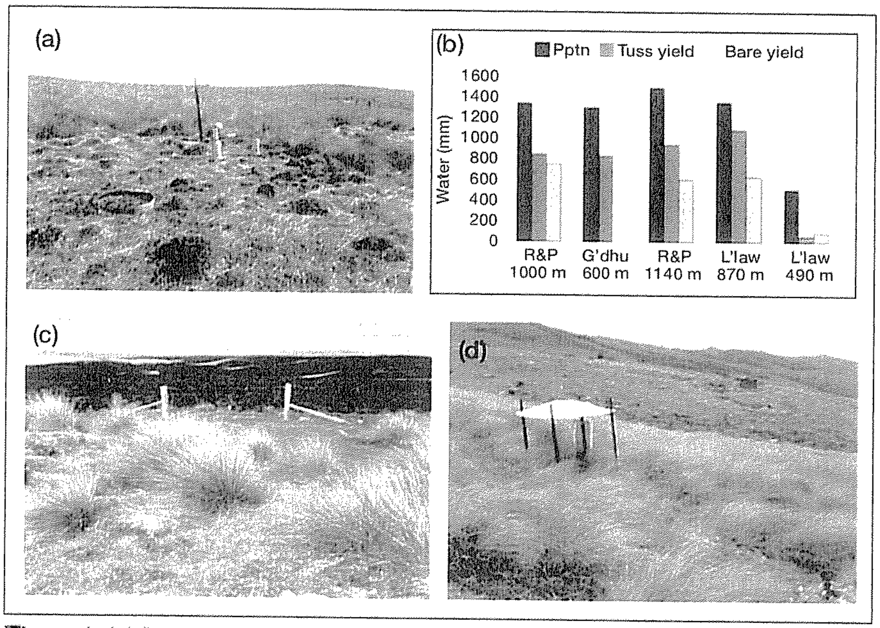

Figure 4. *(a) Lysimeter in snow tussock grassland on the Lammerlaw Range, measuring water yield associated with bare soil. Sheltering tussock has been cut. Other lysimeters are located in the undisturbed tussock grassland beyond. (b) Annual water yields associated with snow tussock grassland and bare soil in relation to precipitation at five sites on the Otago uplands: lysimeters at 1000 m on the Rock and Pillar Range; the weir measurements from the Glendhu catchment at ~600 m (G'dhu; Pearce* et al. *1984); lysimeters at 1140 m on the Rock and Pillar Range (R&P), 870 m and 490 m on the Lammerlaw Range (L'law; Holdsworth and Mark 1990). (c) Deep Creek catchment, 1120 m, soon after burning in 1988, where summer flows in the post-burn period were significantly reduced in relation to that in the nearby unburned catchment (Duncan and Thomas 2004). (d) The devices installed to catch water derived from either fog (fine nylon mesh screen, oriented normal to the prevailing fog-bearing wind and mounted under a large metal umbrella) or rain (red funnel in right foreground). Water was collected in bottles beneath paraffin, for later analyses of heavy isotopes (Ingraham and Mark 2000).*

Securing essential water supplies in New Zealand

Recognizing the importance of a secure water supply in relation to land-use decisions is not without precedent (Bohensky and Lynam 2005), including in New Zealand. For example, the Dunedin City Council acknowledged the importance of tall tussock grassland cover by purchasing an upland property in its water supply catchment in the 1980s (Dunedin City Council 2006). Furthermore, the Council's involvement in the review of the lease on an adjacent, government-owned 12 000-ha property in 2001 was aimed at obtaining long-term security of water supply by ensuring retention of tall tussock grassland in good condition. Indeed, the economic value of the water resource from this area was confirmed with the recent establishment of the Te Papanui Conservation Park (approximately 22 000 ha), which is dominated by tall tussock grassland (see Mark *et al.* 2003). The economic study (Butcher Partners Ltd 2006) assessed the value of water produced from the Park to be about NZ$136 million (US$92.8 million), in relation to providing an alternative supply.

Under New Zealand's Resource Management Act of 1991, regional councils must seek to protect and enhance the environment, and safeguarding water supply and quality is an important component of these responsibilities (Memon 1997). Councils can develop regional water plans to establish objectives and criteria for water management (Snelder and Hughey 2005). The Otago Regional Council, whose area of jurisdiction covers one of New Zealand's driest regions, has an operational Water Plan which includes an overview of catchment hydrology through a monitoring network. However, this plan does not address water production from important supply catchments, nor is there a land plan which could have addressed vegetation cover in relation to its effect on water production. Dunedin City obtains more than 60% of its water supply from upland sources, where indigenous tall tussock cover still remains. However, land-management history and contemporary pressures for land-use intensification, combined with exotic afforestation and hydro-electric development, are leading to increasing conversion from this indigenous cover, despite rising demands for water. Such developments have consequences, particularly in relation to water yield and carbon storage (Farley *et al.* 2005; Jackson *et al.* 2005), and an explicit recognition and economic evaluation of such trade-offs seems essential. The situation may be further aggravated by global warming and the predicted redistribution of precipitation. Such evaluations appear not to have featured in the policy-making processes to date. However, a potentially important precedent was established by local government in New Zealand in 1998,

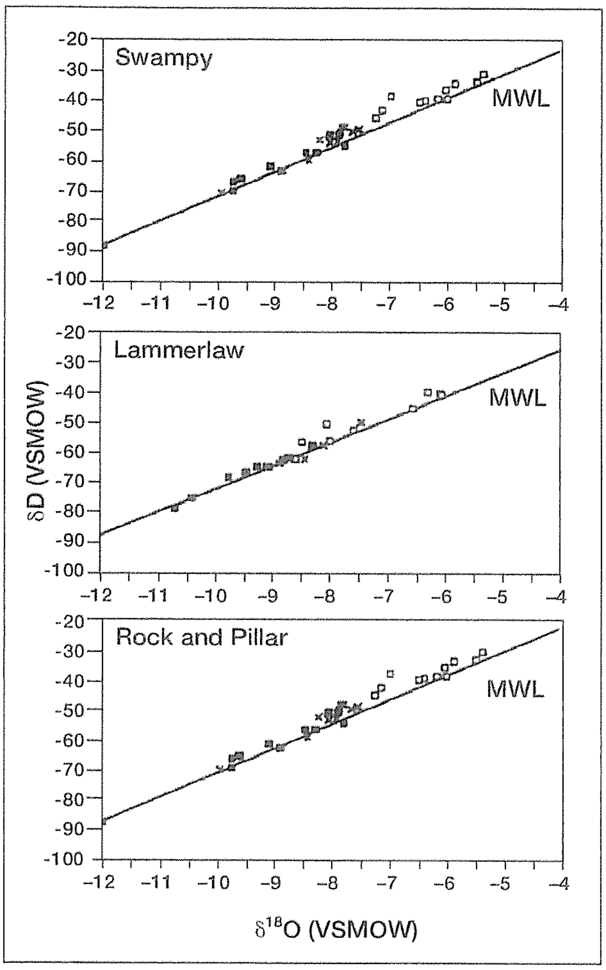

Figure 5. *Stable isotope (oxygen and hydrogen) composition of the fog (□), rain (■), and groundwater (x) samples collected at each of three sites on the Otago uplands, south–central New Zealand: Swampy Summit (736 m asl), Lammerlaw Range (870 m asl), and Rock and Pillar Range (1140 m asl), are shown with the meteoric water line (MWL). The isotope values are presented in delta (δ) notation, which expresses the difference between the measured ratios of a sample and a world standard reference, over the measured ratio of the reference, as follows:* $\delta_{sample} = (1000\ ratio_{sample} - ratio_{reference})\ /\ ratio_{reference}$. *δ values are expressed as parts per thousand. Negative δ values indicate that the sample has less of the heavier isotope than the reference Vienna Standard Mean Ocean Water (VSMOW). Reproduced courtesy of Ingraham and Mark (2000).*

under the Resource Management Act. The Tasman District Council refused to grant a resource consent for exotic afforestation of a water supply catchment on the basis that this would reduce the quantity of water downstream for an established horticultural use. The decision was subsequently appealed in, but upheld by, the Environment Court. We are not aware of subsequent legal challenges, despite comparable situations in other parts of the country.

■ Discussion and conclusions

A New Zealand perspective

An integrated approach to land-use planning, evaluating ecosystem services, recognizing trade-offs, and incorporating the need to protect water supply and quality is needed (Prato 1999; de Groot 2006) in New Zealand (Memon 1997) and elsewhere (Farley *et al.* 2005). Land-cover type clearly affects the quantity of water yield, as has been shown for upland snow tussock grassland regions in New Zealand. It is critical that governments – locally, regionally, and nationally – integrate these considerations into their planning responsibilities. Ecosystem services require careful evaluation in conjunction with the development of economic incentives. In this context, management of upland water supply catchments to maximize water production is crucial. Reliance on the Resource Management Act (RMA) requirement to protect outstanding natural landscapes and/or key indigenous vegetation through district (local government) plans is too ad hoc to safeguard water yield in supply catchments. Similarly, the outcomes of the current tenure review of the South Island pastoral leasehold lands cannot be relied upon to secure protection of important upland water supply catchments.

There is a need to ensure that land-use planning in New Zealand recognizes the role of different vegetation cover types in catchment/watershed areas important for water supply. There are some encouraging initiatives. The Government recently launched a Water Awareness Campaign and the New Zealand Landcare Trust, with funding from the Ministry for the Environment, is administering an Integrated Catchment Management Project. This aims to integrate the management of land, water, and other biological resources in order to achieve sustainable and balanced use. The Government's current Sustainable Water Programme of Action is a major initiative, but at this stage it addresses neither the general issue of water yield nor the specific effects of land cover on water production in upland catchments (Ministry for the Environment 2006).

Retention or restoration of tall tussock grassland cover, where it exists in water supply catchments, could be a specific requirement under the RMA. Given the increasing demands on the country's freshwater resources, this requirement could be linked explicitly to securing maximum water yield. Guidelines could incorporate the effects of land use on water production and water quality from upland supply catchments. Such guidelines should be added to the current Sustainable Water Programme of Action, which is intended as the basis of a new National Policy Statement and National Environmental Standard under the RMA (Ministry for the Environment 2006).

International perspectives

Many other countries have also introduced programs aimed at understanding and managing freshwater resources. One of the earliest and best known initiatives, and one which serves as a model, is South Africa's Working for Water program. Launched in 1995, this initiative integrates environmental, economic, and social–cultural aspects. Invading alien woody species, mostly of *Pinus*, *Eucalyptus*, and *Acacia*, are removed using local and otherwise unemployed, disadvantaged groups. Restoration of the rich indigenous biodiversity of the shrubby *fynbos* and other natural ecosystems is achieved while substantially increasing water yield (van Wilgen 2004; Figure 6). The program now operates within the context of the National Water Act of 1998, arguably the most comprehensive water legislation in the world. The Act mandates the Department of Water Affairs and Forestry to manage land so as to ensure there is a "reserve" (a baseline water flow for domestic and ecological uses) at all times. There is also great interest in levying major extractors of water.

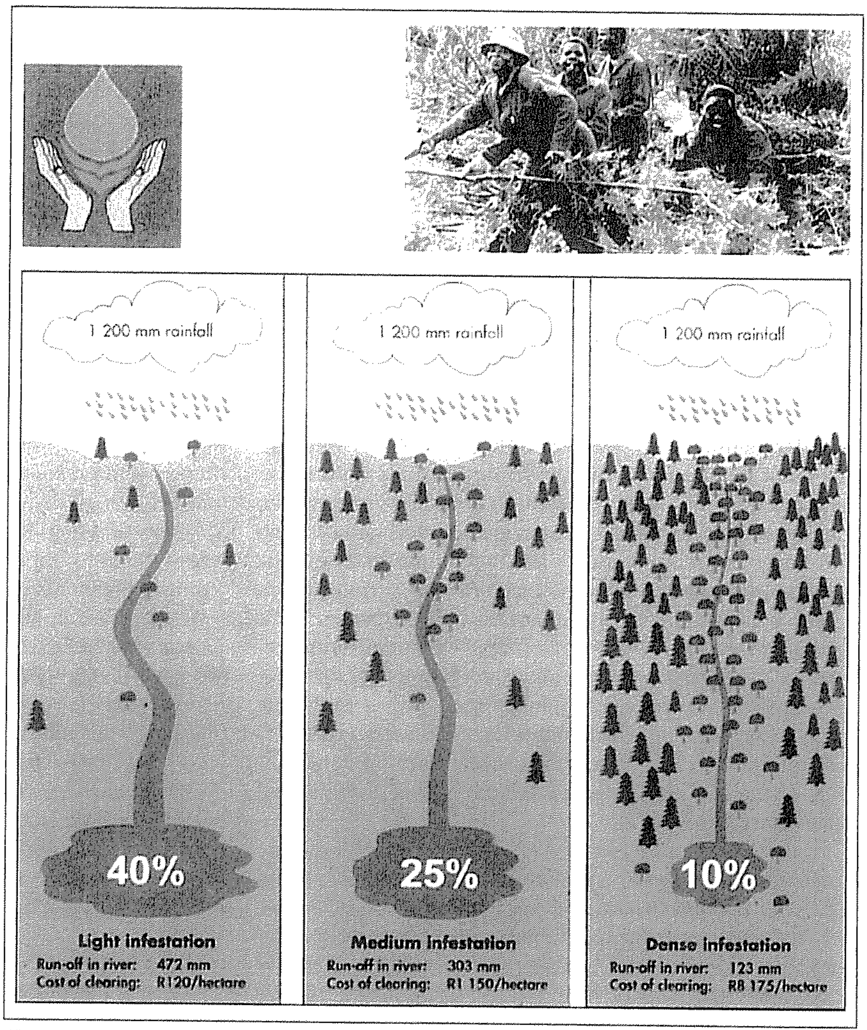

Figure 6. *Promotional material for the South African Working for Water program. This poster emphasizes the degree to which invading alien woody species reduce water yield (from a 1200 mm annual rainfall) as the invasive trees gain increasing dominance in the system (percentages indicate water yields). The photo at top shows local people employed in the clearing of invasive species from the land. Adapted and reproduced with permission from Department of Water Affairs and Forestry (1996).*

Considerable overseas funding supports the program, which, in 2002, had an annual budget exceeding 400 million rand (US$54.1 million). This investment is considered cost-effective in relation to the alternative of dam construction for increased water retention. The program has recently been reviewed through a special symposium (Macdonald 2004), which identified several research challenges. Almost 1.2 million ha of invasive alien vegetation had been cleared by the end of 2003, or about 12% of the infested areas, which is a major achievement. However, existing knowledge needs assessment, so that clearing operations can be more effectively prioritized in relation to water-related benefits (Görgens and van Wilgen 2004). Elsewhere in Africa, there are other initiatives. For instance, prevention and resolution of water supply and use conflicts in the Mount Kenya Highland–Lowland System are being addressed by catchment-based stakeholder groups and Water Users' Associations, with the support of the Ministry of Water Development (Kiteme and Gikonyo 2002).

Australia, the world's driest continent, has experienced serious water problems, in particular agrochemical pollution and increasing salinization from clearance and irrigation. The country has recently suffered its most severe drought on record. Tension has been increased by recent wildfires and by the predicted, prolonged El Niño weather pattern. Prime Minister John Howard recently announced an AU$300 million (US$232.6 million) aid package for the rural sector, stating that more would be available if necessary. Major water reform in Australia was initiated in 2004, with the establishment of a National Water Commission under Federal Government legislation (www.nwcgov.au/water_fund). The Commission is an independent statutory authority of seven commissioners, appointed for their expertise in water-related fields, and reports directly to the Prime Minister. Its main functions are to administer two programs under an Australian Government Water Fund – the AU$1.6 billion (US$1.2 billion) Water Smart Australia and the AU$200 million (US$155.1 million) Raising National Water Standards programs. The latter is directed at implementing the National Water Initiative (water accounting, emerging water markets, water planning and management), improving integrated water management across Australia (irrigation and other rural water, water-dependent ecosystems, integrated urban water management) and improving knowledge and understanding of Australia's water resources. Australia also has a Community Water Grants program that funds communities to encourage the wise use of water. Another major development is an AU$10 billion (US$7.8 billion), 10-point plan, announced by Prime Minister Howard in January 2007. This initiative aims to improve water-use efficiency and to address the serious over-allocation and overuse of water in rural Australia. Emphasis is on the country's largest river basin, the Murray-Darling, which occupies about 15% of Australia's land mass. This "National Plan for Water Security" includes improvements in governance, technology, irrigation, the distribution network, security, and imposition of a sustainable cap on water use, while improving the health of rivers and wetlands. The Plan will also accelerate implementation of the National Water Initiative (Prime Ministerial Press Statement 2007).

In the US, there has been a long history of sub-alpine forest manipulation to enhance water production, particularly in the central and western mountains (Kittredge 1948), but issues remain. Controversy surrounds water yield from the semi-arid bunch grass and sagebrush rangeland communities, and the role of encroaching woody vegetation (Wilcox 2002). Much of the information is anecdotal or speculative, but recent results from monitoring stream flow in a series of small (first order) experimental and reference watersheds in the Texas Hill Country indicated "little or no effect...except where springs are present" (Wilcox *et al.* 2005). Since then, Wilcox *et al.* (2006) have reported that, for upland sites with deep drainage, conversion from woody to herbaceous vegetation may result in annual water savings of 40–80 mm. Such swings have been observed only in small catchments to date, and confirmation at larger scales awaits further research. However, some integrated catchment planning initiatives have been suggested. For example, along the US–Mexico border, a watershed approach has been advocated for intergovernmental coordination and management of sensitive areas to help ensure maintenance of natural functions, including water supply (Steiner *et al.* 2000).

China is currently implementing a sustainable water resource strategy (Yang and Pang 2006), considered vital to addressing water-related issues that have hampered recent economic development. With a per-capita availability of freshwater only about one quarter of the world average, China faces a serious imbalance between supply and demand. Several factors exacerbate the problem: poor water-resource development, wasteful usage, and pollution. China's central government initiated several studies and reports in the early 1990s, considering sustainable water-resource development, relationships among water supplies, the economy, and society, water financing, and water conservation. Based on these studies, "Water Agenda 21" was formulated in 1998, to develop a sustainable water-resource strategy for the country. Yang and Pang (2006) discuss the implementation of this strategy, particularly the approaches used to address water problems, to meet the basic needs of urban inhabitants, agriculture, and the environment. Emphasis is on improved water allocation, more efficient use, and stronger protection of water resources. Protection plans have been developed that include monitoring and alarm systems for water quantity and quality, the protection of wetlands and other water sources, and integrated resource management. Action plans have been formulated for several major watersheds: the Yangtze, Yellow, Huai, Hai and Luan, Songua and Liao, and the Pearl. Yang and Pang (2006) also describe progress toward improving urban living standards, balancing economic development and poverty alleviation, securing food supplies, conserving water and soil, and protecting ecosystems. The national plan encourages the general public to become more aware of the need for water conservation and recommends that traditional methods for conserving water be replaced with new technologies and institutional arrangements to facilitate a holistic approach to water management (Yang and Pang 2006).

At a transboundary level, the Water Governance Reform of the Mekong Region is based on a 1995 agreement between Thailand, Laos, Cambodia, Myanmar, and the Yunan province of China. Here, a range of political, economic, environmental, social, and administrative systems have been introduced at different levels of society. These are to regulate development and management of water resources and provide water services, along with protected area management, in headwater regions (Hirsch 2006). Considerable foreign financial aid characterizes this attempt at holistic management of a finite water resource.

A major recent development has been the release of the Millennium Ecosystem Assessment (MA 2005). This promotes interaction among economists, social scientists, and ecologists, allowing tests of frameworks in practical situations (eg Nkomo and van der Zaag 2004; Bohensky and Lynam 2005). Overall, however, the MA found that the challenge of reversing the degradation of ecosystems while meeting increasing demands for their services will involve far-reaching changes in policies, institutions, and practices that are not currently underway. The MA indicated that many options exist to conserve or enhance ecosystem services in ways that can reduce negative trade-offs or provide positive relationships with other ecosystem services. For water, the options presented are: payments for ecosystem services provided by watersheds, improved allocation of freshwater resources to align incentives with conservation needs, increased transparency of information regarding water management and representation of marginalized stakeholders, development of water markets, increased emphasis on the use of the natural environment and measures other than dams and levees for flood control, and investment in science and technology to increase the efficiency of water use in agriculture.

In the context of the MA, considerable challenges remain for water resource planning in New Zealand, especially in relation to the application of responsibilities under the Resource Management Act 1991 (Memon and Selsky 2004; Snelder and Hughey 2005), and in the integration of ecosystem services into economic models and decision making. Beyond New Zealand, national and international agreements dealing with ecosystem services and human well-being, and emphasizing the critical importance of freshwater, could be implemented, as recommended in the Millennium Ecosystem Assessment (MA 2005). From our perspective, the South African National Water Act of 1998 provides a positive integrated model for future action. As the world's "water towers", mountains are of critical importance and there is a great need to improve current management and monitoring of upland water (Viviroli *et al.* 2003), particularly in relation to land cover and condition.

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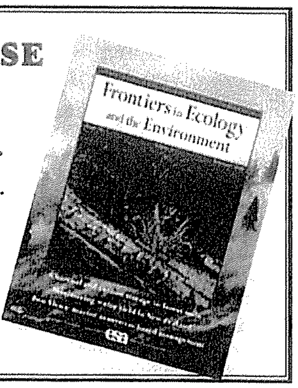

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Fog deposition by snow tussock grassland on the Otago uplands: response to a recent review of the evidence

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Abstract

We challenge a recent, rather selective 'review of the evidence' by Davie *et al.* (2006) explaining the recorded high water yields from snow tussock grasslands on the Otago uplands. We refute their dismissal of the importance to water yield of fog deposition on the fine wispy foliage of the dominant tall tussock plant cover. We stand by the results of our previous study on the stable isotope ($\delta^{18}O$ and $\delta^{2}H$) values of fog-, rain- and groundwater from three upland snow tussock grassland sites. We also provide evidence from several direct measures using natural or simulated tussocks at three fog-prone upland locations which the reviewers ignored. Overall and importantly, the value of upland snow tussock grassland in maximising water yield is not in dispute, and we continue to endorse the relevance of low evapo-transpiration from the dominant tussock cover. The water production capability of the upland snow tussock grasslands is a sufficiently important ecosystem service to justify formal recognition in land-use planning responsibilities of local authorities. Further, this important ecosystem service of upland tall snow tussock grasslands should also feature in central government's current Sustainable Water Programme of Action and in the development of National Policy Statement and National Environmental Standard for water under the Resource Management Act.

Keywords

Fog deposition, stable isotope analyses, evapo-transpiration, interception gain, upland snow tussock grassland, water yield, ecosystem service.

The issues

The high water yield from snow tussock grasslands, relative to yields from alternative types of cover on the Otago uplands, measured by several researchers in different locations and using a range of methods, is an important and undisputed ecosystem service, with relevance to land-use planning. A recent 'review of the evidence' explaining the consistently high water yields measured from these upland grasslands (Davie *et al.*, 2006) dismisses one of two major hypotheses proposed to account for these high yields, that is the significant fog deposition gains made by the fine wispy foliage of the dominant tall tussock grasses. Instead, these authors attribute the recorded high water yields to relatively low evapo-transpiration from these dominant snow tussock grasses. Not only is the information presented by the critics highly selective, but the case they make in dismissing the evidence from a stable isotope study of the importance of fog deposition gains to water yield (Ingraham and Mark, 2000) is fundamentally flawed.

Davie *et al.* (2006) claim there are 'two camps' providing explanations for the high water yields from these upland grasslands, one which supports low evapo-transpiration of the dominant snow tussocks and the second invoking significant gains of water from fog deposition on the snow tussock canopies. This either/or assertion is incorrect, as those proposing gains from fog water deposition have also given credence to low evapo-transpiration, as the following three quotations indicate:

1) 'The increased water yield associated with snow tussock grassland is only partly related to its relatively low AE [Actual Evapo-transpiration] values. It also reflects interception gains [deposition] from wind-driven fog (and rain) by the tall caespitose habit and linear leaves of the dominant tussocks' (Holdsworth and Mark, 1990; Abstract);
2) the 'significantly greater yields of water .. from ... *Chionochloa* grassland than from a range of modified types ... is because of relatively low transpiration rates of *Chionochloa*, combined with interception gains [deposition] from frequent fog and light rain ... by the tall, fine foliage of the *Chionochloa* spp.' (Mark, 1993; p. 400); and
3) 'given the relatively low rates of evapo-transpiration from the snow tussock grasslands on the Otago uplands ....' (Ingraham and Mark, 2000; p.406).

Indeed, it was the research by one of us (AFM) that established the low evapo-transpiration rates of *Chionochloa rigida* and its significance with respect to water yield (Mark, 1975). There is now a considerable body of work that confirms the importance of low evapo-transpiration of the dominant snow tussock species, *Chionochloa rigida*, involving whole catchments (Pearce *et al.,* 1984; Duncan and Thomas, 2004), weighing (Campbell, 1987, 1989; Campbell and Murray, 1990; Fahey *et al.*, 1996) and non-weighing (Mark and Rowley, 1976; Holdsworth and Mark, 1990) lysimeters, plus direct measurements (Mark *et al.*, 1980; Espie and Grau, 1994, 1995; Mark, 1998) and eco-physiological aspects (Mark, 1975; Pollock, 1979).

Three major issues are in dispute: fog deposition (interception gains) by the tussock canopy, aspects of the isotopic analyses made by Ingraham and Mark (2000), and discharge rates and age of the lysimeter/groundwater they sampled. These issues will be dealt with in turn, followed by additional relevant published information that was not discussed by the critics.

Interception: losses and gains

The term interception describes the moisture which is caught and stored on the leaves and stems of plants. Interception loss, which occurs through evaporation of water from damp vegetation, is well documented as a valid component of a water balance. However, the ability of vegetation to intercept wind-driven fog droplets that contribute to the water input through fog deposition is less generally accepted, as such a function relates to regional climate. Such fog deposition (or 'interception gains') might be considered as stemflow and/or throughfall, technical terms which generally refer to the dispersal of rain-water in woody vegetation. It has also been referred to as interception gain (Mark and Rowley, 1976; Holdsworth and Mark, 1990; Mark, 1998) or fog deposition (Ingraham and Mark, 2000) and we will continue with the preferred latter term in this paper.

There is a continuum of droplet sizes between fog and rain, and we accept Fahey *et al.*'s (1996) definition of fog in this context, that it is 'any liquid water which collects on a tussock canopy but is not caught in a rain gauge' and further, that 'fog water droplets are generally smaller than 20 μm diameter while the conventional size separation between fog and rain droplets is 100 μm diameter'. Water derived from fog deposition on vegetation has been shown to be important in a wide range of ecosystems outside New Zealand, a point freely acknowledged by Davie *et al.* (2006). For instance, the significance of fog has been documented in Australia (Costin and Wimbush, 1961; Edwards, 1973), coastal California (Azevedo and Morgan, 1974; Ingraham and Matthews, 1988b, 1990, 1995; Dawson, 1998; Corbin *et al.*, 2005), and in tropical and subtropical montane cloud forests (Weaver, 1972; Zadroga, 1981; Bruijnzeel and Proctor, 1995; Juvik and Nullet, 1995; Hutley *et al.*, 1997; Holder, 1998; Field and Dawson, 1998; Bruijnzeel, 2001), as well as other mountain regions including Taiwan (Chang *et al.*, 2006), China (Liu *et al.*, 2004), Mexico (Vogelmann, 1973), the Andes (Biederwieden *et al.*, 2005; Buytaert *et al.*, 2006), Chile (Ingraham and Cereceda, 2001), East Africa (Ingraham and Matthews, 1988a) and the French Alps (Herckes *et al.*, 2002). Moreover, fog deposition with specially built structures can provide significant amounts of water for various human uses (Schemenauer and Cereceda, 1994). Such structures are used, particularly in arid and semi-arid coastal (Schemenauer and Cereceda, 1991; Jaén, 2002) and/or mountain (Schemenauer and Cereceda, 1992; Olivier and Rautenbach, 2002) locations in many regions of the world.

Given this world-wide understanding, it is puzzling that the significance claimed for fog deposition in contributing to water yield on fog-prone uplands in New Zealand has been challenged (McSaveney and Whitehouse, 1988; Davie, *et al.*, 2006). The contribution of water from fog deposition on vegetation to a site's water yield has generated controversy in New Zealand since it was first proposed by Rowley (1970), even though its importance is accepted elsewhere in the world. Studies of the ecological significance of fog, and particularly gains of water through fog deposition, have mostly involved forested regions and have been widely accepted. Grasslands and other indigenous non-forest ecosystems have received much less attention and, given their lower stature and often smoother canopies, might be expected to be much less efficient in intercepting wind-driven fog, even in fog-prone regions. Grasslands are not homogeneous in structure or composition, and it is the tall tussock life form that is particularly significant for fog deposition in New Zealand and elsewhere.

Such a life form also prevails in the alpine páramo tall tussock grasslands of the northern Andean highlands. Buytaert *et al.* (2006) describe the páramo as 'the major water provider for the Andean highlands of Venezuela, Colombia and Ecuador, extensive parts of the adjacent lowlands, and the coastal plains of North Peru. The water quality is excellent, and the rivers descending from the páramo provide a high and sustained base flow.' Also relevant are the comments: 'While the total amount of rainfall is not particularly high in most páramos, the region is known as very cold and wet, because it is almost continuously covered with fog and drizzle.... The water balance of the páramo is subject to large uncertainties. In particular, the role of the natural páramo vegetation in the water cycle is unknown. This role extends beyond water consumption, as evidence and observations suggest that interception and microclimate regulation may be important as well.' According to Buytaert *et al.* (2006) water production from a series of small catchments in Ecuador was found to range from 600 to 1000 mm yr^{-1}, or about two-thirds of the annual rainfall, while conversion of the natural grass vegetation to either cultivation or *Pinus radiata* reduced water yield from natural catchments, by up to 70% for a *Pinus* catchment. This is generally consistent with the situation recorded for the Otago uplands.

The dominant snow tussock cover on the Otago uplands is ideally suited for fog deposition in terms of its fine wispy and aerated foliage, and the associated high above-ground biomass (Mark, 1993). The earlier 'review of the evidence' by McSaveney and Whitehouse (1988) attributed the relatively high runoff and sustained moderate flows in these upland regions to low evapo-transpiration losses and the presence of 'many bogs and ponds, and the widespread coarse debris mantle' but did admit that snow tussock grasses do collect water from fog. They claimed, however, that 'the amounts appear to be very small' and that much more is collected from wind-driven rain since 'all of the rain and probably much of the fog would fall on the ground if not first caught on tussocks.' We accept the importance of low evapo-transpiration and also the case made for rain. However, we reject the comment on fog since, in the uplands it is associated with often fast-moving air masses and may dissipate beyond the mountain mass, or be at a higher elevation, as described by Cameron *et al,* (1997). Relatively few of the fog droplets appear to fall directly on the ground and the water retained on the tussock foliage runs down the snow tussocks' furrowed leaves during a heavy fog, even in the absence of obvious accompanying rain (Fig. 1).

Isotopic analyses

Davie *et al.* (2006) criticised the study by Ingraham and Mark (2000), who collected lysimeter/groundwater samples concurrently with rain- and fog-water from three snow tussock grassland sites on the Otago uplands over two snow-free periods. The rain-water was consistently more depleted in the stable heavy isotopes of oxygen (^{18}O) and hydrogen (D) than the fog, while the groundwater had compositions usually between those of the fog and rain samples (see Figs. 2 and 3). These results were interpreted as the groundwater being a mixture of the two 'in sub-equal proportions'. Ingraham and Mark (2000) therefore proposed that interception gains through fog deposition on the foliage of the dominant snow tussock cover make a 'substantial contribution to the water yield from these uplands'.

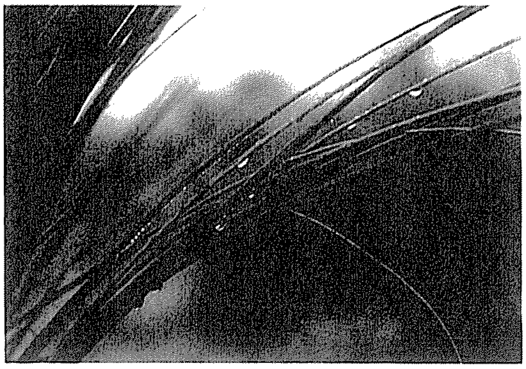

Figure 1 – Water droplets intercepted from fog on the fine foliage of narrow-leaved snow tussock, *Chionochloa rigida.*

Davie *et al.* (2006), however, have two major criticisms of the stable isotope data presented by Ingraham and Mark (2000) and offer 'two other equally plausible explanations' for the groundwater results: '1) enrichment of the isotope ratio through evaporation and/or isotopic exchange, and/or 2) the water was resident in the soil profile for longer than the rainfall collection period.' Each of these is addressed below.

Stable isotopes and the effects of evaporation

Regarding criticism of the interpretation of the isotopic composition of the lysimeter/groundwater by Davie *et al.* (2006), they are correct in their statement that the process of evaporation will cause a water to become more enriched in its stable isotopic composition.

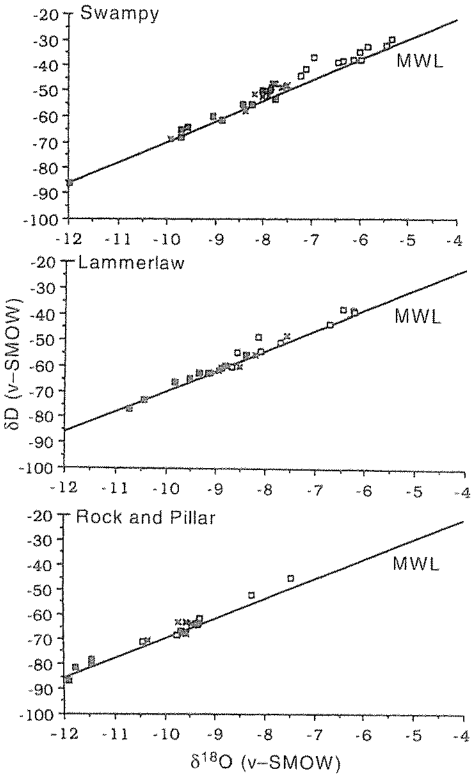

Figure 2 – Stable isotope (δ18O and δD) composition of the fog (□), rain (■) and lysimeter/ground-water (x) samples collected at each of three sites on the Otago uplands: Swampy Summit (736 m. a.s.l.), Lammerlaw Range (870 m) and Rock and Pillar Range (1140 m), are shown with the meteoric water line (MWL). Reproduced, with permission, from Ingraham and Mark (2000).

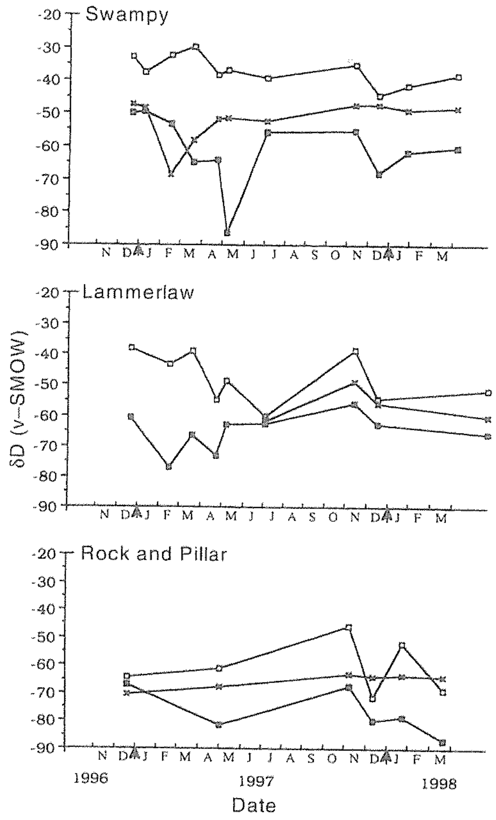

Figure 3 – The time series of the δD values of the fog (□), rain (■) and lysimeter/ground-water (x) samples collected at (top) the Swampy Summit site; (middle) the Lammerlaw Range site and (bottom) the Rock and Pillar site. The δD values of the contemporaneous rain and fog vary through time but fluctuate in unison. The groundwater fluctuates less and only appears to parallel the rain and fog at the Lammerlaw site. However, at all three locations, the groundwater commonly has a composition between that of fog and rain, and probably is a mixture of the two in subequal proportions. Reproduced, with permission, from Ingraham and Mark (2000).

They also state that enrichment by evaporation would produce a characteristic δD–δ^{18}O slope of about 4. Equilibrium fractionation is accompanied by an additional kinetic fractionation during evaporation. The value of the kinetic addition is mostly dependent on the relative humidity during evaporation and, at any given relative humidity, the additional kinetic factor is near equal for both hydrogen and oxygen (Stewart, 1975). However, the kinetic addition affects the oxygen isotopic ratios commensurably more, since the equilibrium fractionation factor for oxygen is about 12% that of hydrogen. Gonfiantini (1986) gives the mathematical basis for this relationship. At low humidity, the kinetic addition is greater and the remaining water will plot on a δD–δ^{18}O slope of less than 4.

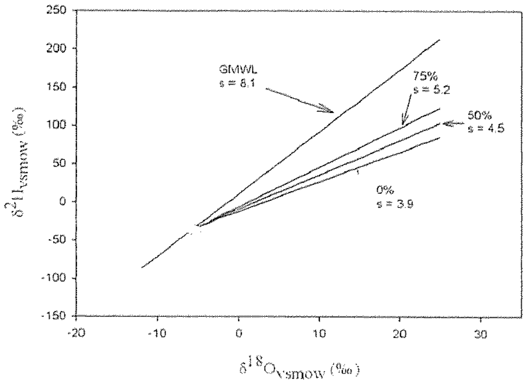

Figure 4 – Isotopic enrichment of evaporating water and the effect of humidity. The slopes are approximations from Gonfiantini (1986) of the early portion of each curve for waters evaporating under the different relative humidities. Note the regression line for the meteoric water line (MWL) of near 8 is reduced by evaporation to near 4.

At higher relative humidities the remaining water will plot on a δD–$\delta^{18}O$ slope of greater than 4, perhaps as high as 7; depending on the relative humidity (see Fig. 4). The slope of 4 proposed by Davie *et al.* (2006) is simply an arbitrary chosen value of the resultant kinetic enrichment along the continuum (Ingraham, 1998; Ingraham *et al.*, 1998; Kendall and Caldwell, 1998). Davie *et al.* (2006) themselves acknowledge that all of the data presented in Ingraham and Mark (2000) plot along a slope of 8 and not along a slope of 4. In fact, the specific samples that would be required to partake in evaporation (rain and lysimeter) plot along a slope of 8.15. Thus, the stable isotopic compositions simply do not display the isotopic effects of evaporation under ambient relative humidities, which previous records indicate are generally high at all three sites (see Holdsworth and Mark, 1990; Fahey *et al.*, 1996). To argue that a shift in the isotopic composition along a slope of 8 was the result of evaporation would require an extreme loss of water by evaporation during a very short period of time under relatively high humidity. These conditions are simply mutually exclusive. Moreover, the isotopic composition of the soil water is not affected by the transfer of water from the soil to the plant. That is, plant roots cannot discriminate between the heavy and light isotope (White *et al.*, 1985; Ingraham *et al.*, 1993). Only in the foliage, where transpiration occurs, can the isotopic compositions be affected.

Davie *et al.* (2006) refer to a study of summer water use by coastal prairie grasses in California by Corbin *et al.* (2005) who 'were able to make a specific correction in the isotopic analysis to account for evaporation from the soil because of the much drier conditions and therefore the characteristic isotopic enrichment due to evaporation'. Davie *et al.* (2006) are correct in stating that coastal California has 'much drier conditions' than the Otago uplands in southern New Zealand. Had the characteristic enrichments due to evaporation been observed by Ingraham and Mark (2000), a specific correction in the isotopic analysis to account for it could also have been made. However, as Davie *et al.* (2006) state, such an isotopic enrichment was not observed.

The study by Corbin *et al.* (2005) of water relations in coastal prairie grasses in northern California, although apparently not involving measurements of the amount of moisture deposited from fog, did use the same stable isotopic method as Ingraham and Mark (2000) and obtained ratios for water from several perennial grass species and the soil. Their results indicated that 28–66% of the water taken up by the plants during summer was sourced as fog rather than residual soil water from winter rain. One of the co-authors of this study, Dr T. Dawson (pers. comm., 2007), commented that 'these grasses do intercept the fog directly. These are advection fogs that move each evening off the Pacific Ocean and 'through' the vegetation of grasses, shrubs and redwood trees. Then early in the morning as the fog dissipates we see a marked 'evaporation effect' as evidenced by the evaporation regression we highlight in the 2005 paper.'

As Davie *et al.* (2006) explain, Corbin *et al.* (2005) made a specific correction in the isotope analysis to allow for evaporation from the soil, and they also claim that similar evaporative enrichment could have explained the results of Ingraham and Mark (2000) for their lysimeter/groundwater samples. We reject this criticism by Davie *et al.* (2006), given that the isotope ratios for all of the lysimeter/groundwater samples were close to the meteoric water line and not on evaporation lines resulting from isotopic enrichment, as recorded by Corbin *et al.* (2005). Moreover, Ingraham and Mark (2000) showed that the timing of the fog and rain depositions was immaterial to the current argument since, as expected, their rain and fog samples fluctuated isotopically at all sites, representing variations in the weather patterns at the time (Fig. 3). This figure shows the lysimeter/groundwater values, on average, balanced between them (hence 'sub-equal') and showed considerably less fluctuation as it was more homogenised through time (Fig. 3).

Discharge rates and the age of groundwater

Another concern of Davie *et al.* (2006) relates to the time taken for water to move through the soil profile. Indeed, they indicate that the interpretation by Ingraham and Mark (2000) of the lysimeter/groundwater they analysed was unlikely to have been from the same storm events as the water collected as rain and fog. Rather, they claim that this water 'was most likely old water pushed out the bottom as piston flow as the rainfall infiltrates at the surface.' We accept this interpretation but note that 'old' water is not defined and, moreover, they refer to a residence time of 3 to 6 months (average 4 months) for lysimeters of 80 cm depth, admitting 'that the piston flow mechanism predominated at greater depths' (note, the lysimeters used by Ingraham and Mark were <80 cm deep). Assuming the lysimeter drainage water analysed by Ingraham and Mark (2000) was no older than 6 months (the isotope ratios obtained for the water from the small (first-order) stream at their Lammerlaw site indicates that all such samples were of generally similar age). These would likely be equivalent to the ' "new" water from saturated overland flow' as opposed to the 'old' water in the context of that 'from a shallow, unconfined groundwater reservoir' measured by Bonell *et al.* (1990) from the Glendhu catchment.

Assuming the soil water is a partially homogenized mixture of rain and fog, we question why the actual age of the water is relevant. We assume small amounts of fog-water would be frequently admixed into the system, while rain would occasionally add measurable amounts of water that would mix with existing water in the soil. If the soil water is not at field capacity there would be none draining out and the rain and fog would mix and become more homogenized, whereas if at field capacity, as we assume it was, the rain-water could create a pressure pulse and push the lower water out below and replace it in the soil. A possible hystoresis effect may be an issue but the age of the water should be irrelevant; it is still a mix of rain and fog.

Davie *et al.* (2006) suggest that the isotopic values recorded in the lysimeter/groundwater could have been the result of isotopic exchange. This shift would require an enrichment in δD of about 10 per mil, and 1 per mil in δ^{18}O. Shifts in stable isotopic composition by exchange are possible if two waters are in vapour communication in a closed system (Ingraham and Criss, 1993, 1998). Under these conditions, the degree to which the waters can shift may be calculated, based on their mass balances. Davie *et al.* (2006) do not suggest any water in the proximity that might partake in this process. However, there is a water in the proximity with an isotopic composition sufficiently enriched that could produce the observed values in the lysimeter/ groundwater. That is the water derived from fog. By whatever method, isotopic exchange or direct mixture, fog-water appears to be important in explaining the observed stable isotopic composition of the lysimeter/ groundwater recorded by Ingraham and Mark (2000).

Comments on scientific, semantic and isotopic criticism

Stable isotope analysis allows differentiation of various sources of water (Ingraham and Matthews, 1988a, 1988b, 1990, 1995; Ingraham, Matthews and Casas, 1993; Ingraham and Cereceda, 2001). It is a powerful technique which surmounts the difficulty of designing a fog collector that has the direct collection capabilities of a tussock leaf. Nevertheless, knowing the general wind strength in the region, serious consideration was given to collecting separate samples of fog- and rain-water, as described by Ingraham and Mark (2000). However, the actual volumes of water collected were not specified, given the difficulty of accurately measuring the amount of rain reaching the ground beneath a tussock, and considering the possibility of interception, throughfall and stemflow. Davie *et al.* (2006) had no criticism of the methods used to collect the rain and fog samples, and thus the stable isotopic compositions of these samples apparently are not in question.

Regarding semantic criticism, the term 'sub-equal' was used by Ingraham and Mark (2000) to indicate the relative contributions of fog and rain present in the lysimeter/ groundwater as recorded by the stable isotope data. This term appeared to confuse Davie *et al.* (2006) who state (p. 89), 'the authors never clarify what they mean by the term sub-equal' but this can be readily determined by perusal of the hard data. Ingraham and Mark (2000) took a conservative approach when reporting the results. The actual proportions of fog- and rain-water were not quantified in the paper to preclude any incorrect interpretations. Published percentages tend to take on a life of their own and, while we believe the contribution of fog-water is significant as identified by the stable isotope values for the lysimeter/groundwater, there are minor factors controlling these actual values other than the direct influence of rain and fog. Moreover, there was no way to accurately determine the relative proportions of rain- and fog-water collected to calculate an accurate mass balance. We considered that readers of the paper would peruse the data as well as read the prose. As such, they could make their own judgments concerning the relative proportions of the isotopic compositions of rain and fog needed to produce that recorded in the lysimeter/groundwater, since delta (δ) units are conservative. However, since it appears that Davie *et al.* (2006) were confused by the data and the word 'sub-equal', we have calculated from the raw data the ratio of fog and rain that would need to be mixed in order to obtain the isotopic composition recorded for the lysimeter/groundwater (not an accurate mass balance). The Lammerlaw site would require 47% fog- and 53% rain-water, the Swampy Summit site 37% fog- and 63% rain-water, and the Rock and Pillar site 65% fog- and 35% rain-water. The sum total of all three sites (again not considering strict mass balance calculations) would require 49.6% fog- and 50.4% rain-water; that is sub-equal or near-equal amounts of each in the lysimeter/groundwater samples.

Additional information

There is also a considerable amount of relevant information obtained since the mid 1960s from the Central and eastern Otago uplands, which lends credence to the likely importance of interception gains from fog deposition in contributing to water yield, although this research was not discussed by Davie *et al.* (2006). The initial attempt to record fog deposition with the first study (Rock and Pillar Range, 1000 m) used 32 mature snow tussock tillers mounted on a coarse wire mesh inside the rim of a standard rain gauge, and a similar arrangement with tillers clipped to 20 cm. Both were placed adjacent to a standard rain gauge. This set-up, which was repeated near the summit of Mt Cargill (676 m; a coastal fog-prone site near Dunedin), clearly indicated the importance of fog deposition by snow tussock leaves to gain water from wind-driven fog (Rowley, 1970). This was later confirmed at the Rock and Pillar site with the addition of a Grunow fog catcher, and using three recording gauges (Mark and Rowley, 1976; Mark *et al.*, 1980).

The problem of over-exposure inherent in these early studies was later corrected. Twelve whole snow tussocks were transplanted to the Mt Cargill site and, with soil and most roots removed, mounted singly over a wire mesh frame in 10 litre polythene buckets which were buried to their rims and spaced 3 m apart in a line perpendicular to the prevailing fog-bearing northeasterly wind. The tussocks were deployed only during days with fog (observable from the base in Dunedin); otherwise they were cached together in a moist depression. Up to 0.5 litres per hour of water was deposited on individual tussocks from dense fog during periods with negligible recordable rain. Moreover, increasing tussock density up to 5 m^{-2} (note: 3–4 m^{-2} occur in intact snow tussock stands: see Rowley, 1970), with additional plantings showed that, although the catch per tussock declined as tussock density increased, catch per unit area (equivalent to *c.* 0.5 mm h^{-1}) did not (see Mark *et al.*, 1980; Fig. 9).


Figure 5 – The fog interception set-up at 1100 m in the upper Deep Creek catchment, showing the 40 snow tussock tillers from the site, mounted on a recording rain gauge (lower centre) among otherwise undisturbed narrow-leaved snow tussock grassland.

A later fog deposition study at 1100 m in the upper Deep Creek catchment on the Lammermoor Range, eastern Otago, associated with a lysimeter study here (see below), used a simulated snow tussock (40 mature tillers coated in silicone to hold them erect in a coarse wire mesh), mounted at canopy level on a recording rain gauge within an area of intact grassland (Fig. 5). Results confirmed the importance of fog deposition gains during the frequent periods of fog (Mark, 1998). Here a recording rain gauge, monitored hourly with a data logger over two snow-free (Nov.-April, 1988–90) periods, together with humidity, wind speed and direction, solar radiation, air and soil temperatures, indicated that fog occurred on *c.* 29% of the 306-day recording period. Most fogs were associated with cold fronts from the west-southwest and were separated into ‘light’ and ‘heavy’ on the basis of the rain gauge catch. Light fogs (defined as periods with saturated air when the standard rain gauge recorded <0.1 mm h^{-1}), contributed 50% of the recorded fog events and lasted 61% of the time when fog occurred. During these times, the simulated tussock deposited 1.54–4.00 mm h^{-1} of water. This result was equivalent to a total of 123 mm of water input to a unit area of ground during the study. Heavy fogs (defined as saturation events which deposited 0.1–1.0 mm h^{-1} of rain), were less common but represented 35% of the fog events and 30% of the fog duration period. These events contributed 154 mm of deposited water over the 306-day study period. Rain events (defined as contributing >1 mm h^{-1}, with or without fog, were excluded from the analysis. Therefore, the water derived from fog deposition by the simulated tussock over the recording period (277 mm over 306 days) would represent 166 mm input over a 6-month snow-free period. Put another way, it would provide a 22% addition to the mean precipitation recorded with a standard rain gauge for the same 6-month period at this site (755 mm) over the 4-year period of measurement (Mark, 1998) and, as explained, this is likely to be a minimal value.

Results from a 4-year lysimeter study (1988-92) in the same upper Deep Creek and nearby Elbow Stream catchments at 900–1120 m (Mark, 1998) are also relevant, particularly in relation to a concurrent paired catchment study here. The latter began in 1980 (Duncan and Thomas, 2004) and Davie *et al.* (2006) refer to this study in relation to the water yield responses following the burning of 70-80% of the Deep Creek catchment in September 1988. The burned catchment showed reduced yields of water during the first three years (consistent with prior lysimeter results from the Rock and Pillar Range by Mark and Rowley, 1976). This result was interpreted by Duncan and Thomas (2004) as being due to increased transpiration by the new foliage and 'greater loss of intercepted moisture because of increased air circulation through the less dense tussock canopy.' The statement that 'summer low flows were barely changed by burning the tussock' was interpreted by Duncan and Thomas (2004) and by Davie *et al.* (2006) to be unrelated to 'a decrease in fog deposition' even though Duncan and Thomas (2004) also state that 'the mean trend was for most months in 1989 to 1991 (the post-burn period) to have ... smaller flows than would have been expected'. The lysimeter study described by (Mark, 1998) was located in the upper reaches of both these catchments, using duplicate tanks, set up as in the Holdsworth and Mark (1990) study, with three cover types: bare soil, blue tussock and snow tussock (those in the burnt Deep Stream catchment were also burned). Operated for four years following the fire, there was little difference between the two catchments in mean yields from the lysimeters over the four snow-free periods from bare soil (43 and 45%) and the short blue tussock (*Poa colensoi*) grassland (both 56%). The snow tussock grassland, however, yielded 92% of the 622 mm precipitation with little yearly variation from the unburned tall snow tussock grassland in the Elbow Stream catchment, but with the burned tussock grassland in Deep Creek the yield increased steadily as the tussocks recovered their canopies, from 62% in the summer following the fire to 84% four years later (Mark, 1998). Neither these results nor those for the substantial fog deposition gains recorded from the upper Deep Creek catchment were discussed by Davie *et al.* (2006) even though they referenced this paper.

Davie *et al.* (2006), however, do refer to the study of Cameron *et al.* (1997) which attempted to estimate fog deposition in the tall tussock grassland at the Swampy Summit study site used by Ingraham and Mark (2000). Cameron *et al.* (1997) examined fog droplet size and density with a forward scattering spectrometer probe placed about 1.0 m above the tussock canopy, which was 80 cm tall, with a one-sided leaf area index of 3.0. They also measured horizontal and vertical wind speeds at 3.5 m above the canopy over four summer months. Deposition rates of 0.02–0.26 mm h^{-1} (mean 0.05 mm h^{-1}) of water were recorded, based on their fog deposition model. These results showed the contribution of fog represented 20% of the average rainfall rate for the same period. Notwithstanding, they concluded that such interception gains were unlikely to be a significant component of the water balance of a tall tussock grassland catchment.

Value and limitations of lysimeters

As discussed by Holdsworth and Mark (1990), similar water balance results were obtained with snow tussock grassland on the Otago uplands from Mark and Rowley's initial study using small non-weighing lysimeters containing a unit area of snow tussock grassland, and from the catchment study by Pearce *et al.* (1984), as well as the one-year weighing lysimeter study at Glendhu by Campbell (1987). We remain confident that the lysimeter approach is capable of providing reliable information on water yields, despite some early criticisms (Gillies, 1978; McSaveney and Whitehouse, 1988).

As Holdsworth and Mark (1990; p. 2) stated, 'reliable measurements of water yield in the South Island high country pose problems with the logistics of equipment operation and servicing, and in locating areas which meet the requirements of both water-tight and adequately defined catchments.... An alternative is lysimetry, the use of appropriately sized tanks that can be precisely monitored and adequately replicated.' Davie *et al.* (2006) also discuss some problems associated with lysimeters, including the single large weighing type used by Campbell (1987), Campbell and Murray (1990), and Fahey *et al.* (1996). Interestingly, this concern was not for the lack of replication but for assessment of fog deposition. Similar criticism was also applied by Davie *et al.* (2006) to the non-weighing lysimeters used, in replicate, at nine sites on the upland snow tussock grasslands of eastern and Central Otago.

Two additional issues which Davie *et al.* (2006) raise with the non-weighing lysimeters are over-exposure producing an 'edge effect' and ecological representation, particularly with inter-tussock cover. They then follow this comment with another: 'Care was taken in the Holdsworth and Mark study to ensure the single tussock lysimeters were surrounded by similar vegetation.' They also repeat a concern of McSaveney and Whitehouse (1988) that a single plant may cause a 'fog-drip shadow surrounding it' .... a 'situation less critical with larger lysimeters', even though this issue had been addressed and dismissed with a detailed assessment in the earliest publication on the use of non-weighing lysimeters in Otago by Rowley (1970). We believe that the series of about 90 non-weighing lysimeters, with a range of replicated, representative cover types, in the snow tussock grasslands on the Otago uplands has shown statistically significant differences in water yields between cover types, with different simulated management regimes, and with location. Some of these results have been confirmed by catchment studies. Exceptionally high water yields from certain particularly fog-prone sites such as the southern Lammerlaw Range are further reflected in the podsolised nature of the yellow brown earth soils, as determined by pedologist Dr J. Churchman at the highest yielding site (Site 4) and reported by Holdsworth and Mark (1990; p. 21).

There are undoubtedly problems associated with the use of catchments and lysimeters, both the weighing and non-weighing types, in differentiating between rain and fog as to the source of the water inputs in water budget studies. Direct measurements of fog deposition on the dominant snow tussock foliage, using the relevant actual or simulated vegetation cover, as has been attempted several times on the Otago uplands (Mark *et al.*, 1980; Mark, 1998), are more robust. The use of stable isotope analyses of relevant components of the water balance, as by Ingraham and Mark (2000), we believe, have provided a more critical and thorough approach to assessing this issue.

Conclusions

We concur with the findings of several other researchers that the upland tall snow tussock grasslands of Otago provide a valuable ecosystem service in producing very high yields of water, relative to any alternative type of ground cover (Mark and Dickinson, 2008). However, we reject the recent claim by Davie *et al.* (2006) that the stable isotope study of Ingraham and Mark (2000) was defective in confirming earlier claims from lysimeter studies that deposition of water on tussock leaves from not-infrequent fog makes a significant contribution to these high yields.

We find the criticism of Davie *et al.* (2006) of the interpretation of the stable isotopic data by Ingraham and Mark (2000) to be burdened by prior commitment. While Davie *et al.* (2006) may not accept the simple, straightforward hydrologic interpretations presented by Ingraham and Mark (2000) we fail to see why arguments were proposed that contained a complete disregard of the understanding of the systematics of stable isotopic fractionation.

Concern expressed by Davie *et al.* (2006) that prolonged residence of water in the soil profile could have resulted in that sampled by Ingraham and Mark (2000) as lysimeter/groundwater having originated from rainwater collected from an earlier period, by perhaps 'several months', seems irrelevant to the results obtained from the isotopic analysis by Ingraham and Mark (2000). The generally freely available soil moisture in the solum of the upland snow tussock grasslands at the relevant study sites, including within the lysimeters, together with the lysimeter designs, plus information from other studies cited by Davie *et al.* (2006), make it unlikely that the age of the lysimeter/ground water sampled was more than six months old and thus not a factor in the results obtained by Ingraham and Mark (2000). This conclusion is in the context of the isotope study by Bonell *et al.* (1990) which showed water discharged in some streams at Glendhu to be a mixture of 'old' water sourced from a shallow, unconfined groundwater reservoir, and 'new' water from saturated overland flow.

The relatively high water yields from upland tall tussock grassland systems and the contribution of low evapo-transpiration by the dominant snow tussock grasses are not in dispute, as Davie *et al.* (2006) state. Neither are the relatively low interception losses from this vegetation type (Pearce *et al.*, 1984; Campbell and Murray, 1990), nor the low canopy water-storage capacity of the grassland, of *c.* 0.5 mm (Campbell and Murray, 1990) being questioned. It is important in this context, however, to distinguish between the **upland tall snow tussock grasslands** and tussock grasslands generally, which Davie *et al.* (2006) often fail to do. We maintain that gains of water by fog deposition on the dominant tall snow tussock cover, which still persists over much of the Otago uplands, and elsewhere in New Zealand, is both real and an important ecosystem service, as Mark and Dickinson (2006; 2008) have emphasised.

Ecological trade-offs involving snow tussock grasslands and other upland land-use options, including pasture grassland development and afforestation, must be carefully addressed in any planning exercise (Mark and Dickinson, 2008). Provision of clean fresh water is an essential ecosystem service. The maintenance and/or restoration of upland tall tussock grassland vegetation cover in good condition in order to maximise water yield is a highly significant issue to be addressed in important water supply catchments. This is regardless of whether the water is being extracted in-stream or as groundwater. Given the increasing demands for fresh, clean water for a range of human uses, including retention of minimum flows adequate for conservation and recreation needs, the valuable ecosystem service of water production provided by upland indigenous snow tussock grasslands, in good condition, should be formally recognised in land-use planning responsibilities of local authorities. Such formal recognition is generally lacking at present, even within Otago, which contains the country's most water-short region and where most of the relevant research has been conducted. Such recognition would be an important component of central government's current Sustainable Water Programme of Action and should also be incorporated into a National Policy Statement and National Environmental Standard, now being considered under the Resource Management Act.

Acknowledgments

We thank Todd Dawson, Director of the Center for Stable Isotope Biogeochemistry, University of California, for additional information from his water relations study of the Californian coastal grasslands, and similarly, Robert Hofstede, Director Regional (ad interim) UICN – SUR, Quito, Ecuador, for further information on water yields from the Andean páramos. We thank Karl Auerswald, Professor, Chair of Grassland Science, Technical University of Munich, Munich, Germany, for his independent endorsement of our interpretation of the isotope information. Katharine Dickinson, Botany Department and James Maclaurin, Philosophy Department, University of Otago, provided helpful comments on a draft of the paper.

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Otago Regional Council

SUBMISSION FORM

Proposed Plan Change 1C Water Allocation and Use

to the Regional Plan: Water for Otago

Form 5, Clause 6 of the First Schedule, Resource Management Act 1991.

7

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Full name of submitter: Ruhxia Clark

Name of organisation *(if applicable)*:

Postal address: 46 TURNBULL STREET, BROCKVILLE, Dunedin.

Postcode: 0161

Telephone: None

Fax: None

Email: As Above

Contact Person:

[✓ I wish] / do not wish *(circle preference)* to be heard in support of my submission.

If others made a similar submission, I will consider presenting a joint case with them at a hearing. ✓
(Cross out if you would not consider presenting a joint case).

Signature of submitter: R Clark

Date: 23.12.08

(or person authorised to sign on behalf of person making submission).

Please note that all submissions are made available for public inspection.

The parts of the proposed plan change that my submission relates to are:
(Give clear references if possible e.g. reference number, policy x, rule y)

My submission is:
(Include whether you support, oppose, or wish to have amended the parts identified above, and give reasons)

I Support your decision's

Please turn over

I seek the following decision from the local authority:

(Give precise details e.g. changes you would like made)

I follow decision from the local Authority.

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4

Otago Regional Council

SUBMISSION FORM

Proposed Plan Change 1C Water Allocation and Use to the Regional Plan: Water for Otago

Form 5, Clause 6 of the First Schedule, Resource Management Act 1991

8

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Full name of submitter: Magaret (Maggie) Elizabeth Oakley

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Contact Person: Maggie

I wish / [✓ do not wish] *(circle preference)* to be heard in support of my submission.

If others made a similar submission, I will consider presenting a joint case with them at a hearing.
(Cross out if you would not consider presenting a joint case).

Signature of submitter: ML Oakley, Date: 2/1/09.
(or person authorised to sign on behalf of person making submission).

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The parts of the proposed plan change that my submission relates to are:
(Give clear references if possible e.g. reference number, policy x, rule y)

My submission is:
(Include whether you support, oppose, or wish to have amended the parts identified above, and give reasons)

I support the proposed changes. It would seem sensible to have linked surface and groundwater together.

Please turn over

I seek the following decision from the local authority:
(Give precise details e.g. changes you would like made)

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Proposed Plan Change 1C Water Allocation and Use to the Regional Plan: Water for Otago

Form 5, Clause 6 of the First Schedule, Resource Management Act 1991.

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Full name of submitter: ALISTAIR BROOKS (CHAIRMAN/DIRECTOR)

Name of organisation *(if applicable)*: FOREST HILL SERVICE COMPANY LIMITED

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Contact Person: RAY O'MEARA

I wish / do not wish *(circle preference)* to be heard in support of my submission.

If others made a similar submission, I will consider presenting a joint case with them at a hearing.
(Cross out if you would not consider presenting a joint case).

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12 JAN 2009
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Signature of submitter:
(or person authorised to sign on behalf of person making submission).

Date: 6th January 2009

Please note that all submissions are made available for public inspection.

The parts of the proposed plan change that my submission relates to are:
(Give clear references if possible e.g. reference number, policy x, rule y)

That part related to "What change is proposed?" under Section 6 relating to "New Provisions for Groundwater"

Section 6b. Managing takes that have some effect on surface water.. etc

My submission is:
(Include whether you support, oppose, or wish to have amended the parts identified above, and give reasons)

For a number of years the Forest Hill Service Co Ltd (FHSC) has been operating a properly licensed small rural water supply system, which is fed by a natural spring in the vicinity of Seven Mile Creek, west of Queenstown.

At this stage it is, or at least it seems unlikely that the proposed changes will influence FHSC's take of the small amount of water

Please turn over

I seek the following decision from the local authority:

(Give precise details e.g. changes you would like made)

we currently require. However, as stated in the section: "who may be affected?" "Ultimately, everyone taking water will be affected by this change. The FHSC acknowledges this probability.

It is therefore requested that FHSC be formally noted as an "Interested Party" to be kept informed of progress made by the Otago Regional Council in its consideration of submissions and of any changes that may result and that could affect our access to our potable water supply.

Fol

Thank you.

FHSC Chairman.

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to the Regional Plan: Water for Otago

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Full name of submitter: MICHAEL RAMSAY

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Email: michaelramsay1226@yahoo.com

Contact Person: MICHAEL RAMSAY

I wish / [✓ do not wish] *(circle preference)* to be heard in support of my submission.

If others made a similar submission, I will consider presenting a joint case with them at a hearing.
(Cross out if you would not consider presenting a joint case).

Signature of submitter:

Date:

(or person authorised to sign on behalf of person making submission).

Please note that all submissions are made available for public inspection.

The parts of the proposed plan change that my submission relates to are:
(Give clear references if possible e.g. reference number, policy x, rule y)

Item 6 in the proposed plan change is already covered in the existing Regional water plan: clause 12.1.2.5

My submission is:
(Include whether you support, oppose, or wish to have amended the parts identified above, and give reasons)

- I oppose the proposed change noted as item 6.
- I neither support, nor oppose the remaining items, but reserve the right to do so, after the next call for submissions at end of MARCH 2009.

Please turn over

I seek the following decision from the local authority:

(Give precise details e.g. changes you would like made)

I wish to see more specific details on the proposed changes (eg.) Defining actual minimum flows, and how these will be achieved, and who will be penalised, and via what rules process, should these minimum flows be breached.
Especially as it will relate to surface water.

Fol

SUBMISSIONS MUST BE RECEIVED BY 5.00 PM, MONDAY 9 MARCH 2009.

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