The Hydrology of *Pinus radiata* Plantations:

An Annotated Bibliography

SMF2167: Report No 1

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Introduction

Project 2167: Land Cover Effects on Water Availability is funded by a grant from the Ministry for the Environment's Sustainable Management Fund. The purpose of the project is to provide information and tools that will assist water and land managers in making the best allocations of water resources for all end-users.

A series of bibliographies are planned as part of the project to provide information on hydrological data for *Pinus radiata (*radiata pine) plantations, Douglas fir (*Pseudotsuga menziesii)* forests and plantations, and New Zealand land-use studies.

This report contains information pertaining primarily to *P. radiata* plantations and is divided into four sections:

- Section 1 provides the background to the project.

- Section 2 (the coloured section) is designed to be a quick reference point to any topic. It lists keywords under four topic areas (hydrological topics, vegetation comparisons, land-use changes, and country of origin) and includes citations relevant to each keyword.

- Section 3 is the bibliography of relevant scientific papers and reports. Each citation generally includes an abstract and further comment on the information presented. Citations are presented in alphabetical order of authors, and then by year of publication.

- Section 4 is a reference list of: (a) citations referred to in the document but not included in Section 3; (b) unpublished contract reports; and (c) territorial authority reports. These references are not annotated but are included for completeness.

Section 1: Background

There are worldwide concerns that increased establishment of plantations of exotic forest species for wood fibre production, either as a result of conversion of native forests and scrublands or afforestation of pasture and native grasslands, may have a detrimental effect on the environment. New Zealand is no different to most other countries in this regard. Attention has focused on the following concerns:

- harvesting trees will cause accelerated erosion and sedimentation problems
- plantations are a monoculture, which decreases biodiversity
- acidification and compaction will degrade soil quality
- streams will dry up after planting forests, especially in the low-flow season.

However, there is evidence to show that for forest management in general:

- erosion and sedimentation issues are short term only, and when taken over the full rotation, plantation forests are often less damaging than other land uses (e.g., McLaren 1996, Phillips et al. 1990)
- plantations do sustain a wide-ranging biological diversity (e.g., Allen et al. 1995; Ledgard 1995)
- changes to soil quality may be positive (e.g., Davis & Lang 1991) and may often lead to improvements in hydrological properties (R.J. Jackson, unpublished data).

The main concern raised when proposals are made to establish plantation forests in the headwaters of catchments is that there could be diminished water yields. In water-short areas, conflicts can then arise between foresters who need to 'use' rain water to meet the biological needs of trees for growth, and downstream-users who require water for municipal, stock-water and irrigation supplies, or to sustain minimum levels in rivers for recreation, or to maintain in-stream habitats, especially at times of seasonally low flows. Water managers then have the unenviable task of allocating scarce resources to all users. Conflicts in the allocation process can lead to litigation in the Environmental Court.

The draft National Agenda for Sustainable Management Action Plan (MfE 1999) states 'There has been a substantial research effort in New Zealand and overseas on studying the impacts of changing land use on water yield, such as afforestation. This research is at a point where a guideline needs to be produced.' This document, and others in the series, while aimed at providing a foundation to reduce conflicts between land and water managers, could assist in the preparation of such a guideline.

SMF Project 2167: Land Cover Effects on Water Availability

Workshops in Nelson (March 1999 sponsored by Tasman District Council, Landcare Research, New Zealand Hydrological Society; Rowe 1999) and Rotorua (May 1999, New Zealand Forest Research Institute, Site Management for Sustainable Forestry) identified that water resource issues were still in the forefront of the list of concerns held by land managers (foresters, agriculturalists, etc.), water resource managers (regional and district councils) and other water users (recreationalists, environmentalists, etc.). Discussion with people outside these workshops indicated that these concerns were highly relevant. The principal questions confronting water resource managers were:

- What is the effect of a particular land use on useable water resources?
- How do I allocate scarce water resources when land-use change affects availability?
- What information, resources, and tools are available to help me with these questions?

In 1999, Tasman District Council and Landcare Research applied to the Ministry for the Environment's

Sustainable Management Fund for funding to undertake a review of available literature, gather hydrological and land-use data from New Zealand catchments, and to develop a decision support resource to enable water and land managers to make more informed decisions on water resource allocations. The successful application resulted in this project, SMF2167: Land Cover Effects on Water Availability.

The New Zealand plantation forest estate

At 1 April 1999, the New Zealand exotic forest estate covered 1.73 m ha, 6% of New Zealand's land area. *Pinus radiata* D. Don is the number one plantation species grown comprising more than 1.56 m ha, over 90% of the total plantation area (NZFI undated). *Pinus radiata* is commercially grown mainly in rainfall regimes between 600 mm and 2500 mm/year, and below about 1000 m altitude. Douglas fir (*Pseudotsuga menziesii*) is the next most significant species planted, 86 000 ha, and is found mainly in the lower South Island or at higher altitudes, often above 1000 m. About 82 000 ha of other species are grown, including eucalypts (NZFI undated).

Between 1992 and 1999, new plantations were being established at over 60 000 ha per year, peaking in 1994 when about 96 000 ha were planted. Rates have dropped, however, and the provisional estimate for 1999 was about 25 000 ha (NZFI undated). Most of the new plantings are on pasture land both improved (about 45%) and unimproved (about 45%), with the balance in scrubland (12%) (MAF 2000).

Sources of hydrological data

Catchment studies at Glendhu (Otago), Maimai (West Coast), Donald Creek and Moutere (Nelson), Ashley (Canterbury) and Purukohukohu (Central North Island) provide the bulk of the information on the hydrology of New Zealand forests, but for *Pinus radiata* plantations or native forests, not Douglas fir plantations. Apart from Moutere and Ashley, these are higher rainfall areas where concerns about water yields are not high. This is in contrast to, say, Nelson and the east coasts of both islands where water is often scarce in summer and the most relevant data comes from studies at Donald Creek, Moutere and Ashley. Hydrological studies at Makara (Wellington), Puketurua (Northland), Ashley, Moutere and Purukohukohu are the main sources of pasture catchment data while Glendhu provides information about native tussock grasslands. Reviews by Fahey & Rowe (1992), McLaren (1996) and Rowe et al. (1997) summarise some of these studies.

This bibliography

This bibliography focuses on *P. radiata* and is one of a series being prepared for the project. Further reports in this series pertain to other land covers. Report No. 2 (Rowe et al. 2001a) is a bibliography of the hydrology of Douglas fir (*Pseudotsuga menziesii*). New Zealand studies on the hydrology of other land uses can be found in Report No. 3 (Rowe et al. 2001b).

Plantations of *P. radiata* are also grown extensively in Australia (Boorsma & Hunter, 1990), south-west South Africa, and Chile. In Chile, for example, there were 2 m ha in *P. radiata* in 1995 (Huber & Iroume 2001). To a lesser extent plantations have been established in Spain and around the Mediterranean. Thus, there is potentially a wealth of information to supplement that found from New Zealand sources. Therefore, the bibliography has been compiled from papers and reports obtained from searches of the literature in worldwide databases, mainly using CAB Abstracts, to supplement those available from New Zealand research, including those in the authors' archives.

Some studies report on the differences in water yield between pine-covered catchments and those with other vegetation covers, e.g., indigenous forests, grasslands, and pasture, while others focus on processes such as interception or transpiration. The bibliography's focus is hydrology; water quality and other aspects are listed only when these accompanied useful hydrological data.

Section 2: Keyword Indices

Keywords have been used to provide a quick reference to relevant citations Their selection carries a degree of subjectivity, and they have been kept to a minimum to avoid a proliferation of terms.

Hydrological Topics:

Evaporation	Total evaporation, i.e., evapotranspiration
Groundwater	
Interception	Rainfall and snowfall interception including all or some of throughfall, stemflow and interception loss = wet weather evaporation
Low flow	
Model	Used when the focus is on modelling
Nutrient cycling	Mainly canopy interactions but includes some soil-related work
Review	Used when the focus of a report is a review of many studies
Soil water	
Stemflow	
Storm flow	Includes peak flow and quickflow
Stream hydrographs	Parameters other than low flow and storm flow
Throughfall	
Transpiration	Dry canopy evaporation
Tree growth	
Water balance	Studies where the water balance is determined
Water quality	Used when this is a major focus of the paper
Water yield	Total streamflow for a given period

Species (or Vegetation Class) Comparisons:

Pinus radiata only	
Conifers	Does not include pine species/Douglas fir
Crops	
Douglas fir	
Eucalypt	Natural forest or plantations
Native deciduous forest	
Native evergreen forest	Does not include eucalypt species
Native grassland	
Pasture	
Pine species	
Scrubland (or shrubland)	

Land-use Changes:

Afforestation (includes from scrubland)	
Conversion from one forest to another	
Fire	
Forest management	
Harvesting	Of *P. radiata* plantations only, otherwise in Conversion
Irrigation	
Reforestation	Of *P. radiata* plantations only, otherwise in Afforestation

Country of Origin:

Australia
Chile
New Zealand

South Africa
Spain
United States
Worldwide

Hydrological Topics Index

Turner, J.; Lambert, M.J. 1987
Wells, L.P.; Blake, G.J. 1972
Whitehead, D.; Kelliher, F.M. 1991b
Whitehead, D. et al. 1989
Yunusa, I.A.M. et al. 1995

Low flow
Banks, C.H. 1961
Banks, C.H.; Kromhout, C. 1963
Black, R.D 1990
Black, R. 1992
Cornish, P.M. 1989
Dons, A. 1987
Duncan, M.J. 1980
Duncan, M.J. 1983
Duncan, M.J. 1995a
Duncan, M.J. 1995b
Fahey, B. 1994
Fahey, B.D.; Jackson, R.J. 1995
Fahey, B.D.; Jackson, R.J. 1997a
Fahey, B.; Jackson, R.; Rowe, L.K. 1998a
Fahey, B.; Jackson, R.; Rowe, L.K. 1998b
Fahey, B.D.; Watson, A.J. 1991
Rowe, L. et al. 1997
Scott, D.F.; Smith, R.E. 1997
Smith, R.E.; Scott, D.F. 1992

Model
Dewar, R.C. 1997
Le Maitre, D.C.; Versfeld, D.B. 1997
McMurtrie, R.E.; Landsberg, J.J. 1992
McMurtrie, R.E. et al. 1992
McMurtrie, R.E. et al. 1990
Miller, B.J. 2000
Myers, B.J. 1992
Sheriff, D.W. et al. 1996
Whitehead, D. 1987
Whitehead, D.; Kelliher, F.M. 1991a
Whitehead, D.; Kelliher, F.M. 1991b
Whitehead, D. et al. 1989
Wronski, E. 1984

Nutrient cycling
Amezaga, I. et al. 1997
Baker, T.G.; Attiwill, P.M. 1987
Baker, T.G.; Hodgkiss, P.D.; Oliver, G.R. 1985
Baker, T.G.; Oliver, G.R.; Hodgkiss, P.D. 1986
Crockford, R.H.; Khanna, P.K. 1997
Crockford, R.H. et al. 1996
Levett, M.P. 1978
Onaindia, M. et al. 1994
Smethurst, P.J.; Nambiar, E.K.S. 1990
Will, G.M. 1959a

Review
Aguilar, J.G.; Arrau, A.I. 1995
Boomsma, D.B.; Hunter, I.R. 1990
Bosch, J.M.; Hewlett, J.D. 1982
Cornish, P.M. 1989
Dye, P.J. 1996
Fahey, B. 1994
Fahey, B.D.; Rowe, L.K. 1992
Huber, A.; Iroume, A. 2001
Jackson, R.J. 1992
Langford, K.J.; O'Shaughnessy, P.J. 1977a
Rowe, L. et al. 1997
Waugh, J.R. 1980
Wicht, C.L. 1949

Soil water
Duncan, M.J. 1993
Feller, M C. 1978
Huber, A.; Lopez, D. 1993
Huber, A.; Oyarzun, C.; Ellies, A. 1985
Jackson, D.S. et al. 1983
Jackson, R.J. 1985a
Jackson, R.J.; Marden, M.; Payne, J. 1987
Jackson, R.J.; Rowe, L.K. 1997a
Kelliher, F.M. et al. 1992
Knight, P.J.; Will, G.M. 1977
McMurtrie, R.E.; Landsberg, J.J. 1992
McMurtrie, R.E. et al. 1992
McMurtrie, R.E. et al. 1990
Mitchell, B.A.; Correll, R.L. 1987

Stemflow
Baker, T.G.; Attiwill, P.M. 1987

Bell, F.C.; Gatenby, M.T. 1969
Blake, G.J. 1972
Blake, G.J. 1975
Crockford, R.H.; Khanna, P.K. 1997
Crockford, R.H.; Richardson, D.P. 1987
Crockford, R.H.; Richardson, D.P. 1990b
Crockford, R.H.; Richardson, D.P. 1990c
Crockford, R.H. et al. 1996
Duncan, H.P. et al. 1978
Duncan, M.J. 1980
Duncan, M.J. 1995a
Fahey, B.D. 1999
Fahey, B.; Watson, A.; Payne, J. 2001
Feller, M.C. 1981
Huber, A.; Iroume, A. 2001
Huber, A.; Oyarzun, C. 1983
Huber, A.; Oyarzun, C. 1990
Kelliher, F.M. et al. 1992
McGregor, K.R. 1983
Langford, K.J.; O'Shaughnessy, P.J. 1977b
Oyarzun, C.E. et al. 1985
Pienaar, L. V. 1964
Pilgrim, D.H. et al. 1982
Putuhena, W.M.; Cordery, I. 2000
Smith, M.K. 1974
Smith, M.K.; Watson, K.K.; Pilgrim, D.H. 1974
Thistlethwaite, R.J. 1970
Turner, J.; Lambert, M.J. 1987

Storm flow

Cornish, P.M. 1989
Dell, P.M. 1982
Dons, A. 1981
Dons, A. 1987
Duncan, M.J. 1980
Duncan, M.J. 1983
Duncan, M.J. 1995a
Fahey, B.D. 1990
Fahey, B. 1994
Fahey, B.D.; Jackson, R.J. 1995
Fahey, B.D.; Jackson, R.J. 1997a
Fahey, B.D.; Rowe, L.K. 1992
Fahey, B.D.; Watson, A.J. 1991
Hewlett, J.D.; Bosch, J.M. 1984
Hicks, D.M. 1988
Jackson, R.J. 1985b
Jackson, R.J.; Fahey, B.D. 1993
Jackson, R.J.; Rowe, L.K. 1996
Leitch, C.J.; Flinn, D.W. 1986
Rowe, L. et al. 1997
Scott, D.F. 1993
Scott, D.F. 1997
Smith, P.J.T. 1987

Streamflow

Forrer, J.B. 1974

Throughfall

Baker, T.G.; Attiwill, P.M. 1987
Baker, T.G.; Hodgkiss, P.D.; Oliver, G.R. 1985
Baker, T.G.; Oliver, G.R.; Hodgkiss, P.D. 1986
Bell, F.C.; Gatenby, M.T. 1969
Blake, G.J. 1972
Blake, G.J. 1975
Crockford, R.H.; Khanna, P.K. 1997
Crockford, R.H.; Richardson, D.P. 1990a
Crockford, R.H.; Richardson, D.P. 1990c
Davidson, J. 1967
Duncan, H.P. et al. 1978
Duncan, M.J. 1980
Duncan, M.J. 1995a
Fahey, B.D. 1964
Fahey, B.D. 1999
Fahey, B.; Watson, A.; Payne, J. 2001
Feller, M.C. 1981
Huber, A.; Iroume, A. 2001
Huber, A.; Oyarzun, C. 1983
Huber, A.; Oyarzun, C. 1990
Jackson, R.J. 1985b
Kelliher, F.M. et al. 1992
Langford, K.J.; O'Shaughnessy, P.J. 1977b
Levett, M.P. 1978
McGregor, K.R. 1983
Millet, M.R.O. 1944
Oyarzun, C.E. et al. 1985
Pienaar, L. V. 1964
Pilgrim, D.H. et al. 1982
Putuhena, W.M.; Cordery, I. 2000
Ruiter, J.H. 1964
Smethurst, P.J.; Nambiar, E.K.S. 1990
Smith, M.K. 1974
Smith, M.K.; Watson, K.K.; Pilgrim, D.H. 1974
Thistlethwaite, R.J. 1970

Turner, J.; Lambert, M.J. 1987
Will, G.M. 1955
Will, G.M. 1959a
Will, G.M. 1959b
Will, G.M. 1962

Transpiration

Arneth, A. et al. 1998
Dunin, F.X.; Mackay, S.M. 1982
Greenwood, E.A.N. et al. 1981
Fahey, B.; Watson, A.; Payne, J. 2001
Hatton, T.J.; Vertessy, R.A. 1990
Henrici, M. 1947?
Hicks, B.B.; Hyson, P.; Moore, C.J. 1975
Holmes, J.W.; Olszyczka, B. 1982
Kelliher, F.M. et al. 1990
McMurtrie, R.E.; Landsberg, J.J. 1992
McMurtrie, R.E. et al. 1992
Miller, B.J. et al. 1998
Pearce, A.J. et al. 1987
Sheriff, D.W. et al. 1996
Swanson, R.H. 1981
Teskey, R.O.; Sheriff, D.W. 1996
Whitehead, D.; Kelliher, F.M. 1991b
Whitehead, D. et al. 1989
Whitehead, D. et al. 1994

Tree growth

Boomsma, D.B.; Hunter, I.R. 1990
Brownlie, R.K.; Kelliher, F.M. 1989
Cromer, R.N.; Tompkins, D.; Barr, N.J. 1982

Water balance

Dons, A. 1987
Fahey, B.D.; Rowe, L.K. 1992
Fahey, B.D.; Watson, A.J. 1991
Fahey, B.; Watson, A.; Payne, J. 2001
Feller, M.C. 1981
Myers, B.J. 1992
Whitehead, D.; Kelliher, F.M. 1991a
Whitehead, D.; Kelliher, F.M. 1991b
Whitehead, D. et al. 1989

Water quality

Cooper, A.B.; Thomsen, C.E. 1988
Cornish, P.M. 1989
Fahey, B.D.; Jackson, R.J. 1997b
Graynoth, E. 1992
Hicks, D.M. 1988
Hopmans, P.; Flinn, D.W.; Farrell, P.W. 1987
Iroume, A. 1990
Iroume, A. 1992
Otero, D.L. et al. 1994
Richmond, I.C. 1980
Rowe, L.K.; Fahey, B.D. 1988
Rowe, L.K.; Fahey, B.D. 1991
Smith, C.M. 1992

Water yield

Aguilar, J.G.; Arrau, A.I. 1995
Bands, D.P.; et al. Undated
Banks, C.H. 1961
Banks, C.H.; Kromhout, C. 1963
Barton, I.L; Card, J.H. 1979
Bell, F.C.; Gatenby, M.T. 1969
Borg, H.; Bell, R.W.; Loh, I.C. 1988
Bosch, J.M.; Hewlett, J.D. 1982
Bosch, J.M.; von Gadow, K. 1990
Bren, L.J.; Papworth, M. 1991
Bren, L.J.; Papworth, M. 1993
Calder, I.R. 1996
Cooper, A.B.; Thomsen, C.E. 1988
Cornish, P.M. 1989
Dell, P.M. 1982
Dons, A. 1980
Dons, A. 1981
Dons, A. 1985
Dons, A. 1986
Dons, A. 1987
Duncan, M.J. 1980
Duncan, M.J. 1983
Duncan, M.J. 1995a
Dye, P.J. 1996
Fahey, B.D. 1990
Fahey, B. 1994
Fahey, B.D.; Jackson, R.J. 1995
Fahey, B.D.; Jackson, R.J. 1997a
Fahey, B.D.; Jackson, R.J. 1997b
Fahey, B.; Jackson, R.; Rowe, L.K. 1998a
Fahey, B.; Jackson, R.; Rowe, L.K. 1998b
Fahey, B.D.; Rowe, L.K. 1992
Fahey, B.D.; Watson, A.J. 1991

Graynoth, E. 1992
Herald, J. 1978
Herald, J. 1979
Hewitt, A.M.; Robinson, A. 1983a
Hewitt, A.M.; Robinson, A. 1983b
Holmes, J.W.; Sinclair, J.A. 1986
Hopmans, P.; Flinn, D.W.; Farrell, P.W. 1987
Iroume, A. 1990
Iroume, A. 1992
Jackson, R.J. 1983
Jackson, R.J. 1985b
Jackson, R.J. 1992
Jackson, R.J.; Payne, J. 1995
Jackson, R.J.; Rowe, L.K. 1997b
Langford, K.J.; O'Shaughnessy, P.J. 1977a
Leitch, C.J.; Flinn, D.W. 1986
Le Maitre, D.C.; Versfeld, D.B. 1997
Lesch, W.; Scott, D.F. 1997
McKerchar, A.I. 1980
Nandakumar, N.; Mein, R.G. 1993
Nandakumar, N.; Mein, R.G.; Dunin, F.X. 1991
Otero, D.L. et al. 1994
Pearce, A.J. et al. 1987
Pilgrim, D.H.; Doran, D.G.; Rowbottom, I.A.;
Mackay, S.M.; Tjendana, J. 1982
Putuhena, W.M.; Cordery, I. 2000
Richmond, I.C. 1980
Riddell, J.M.; Martin, G.N. 1982
Rowe, L.K. 1998
Rowe, L.K.; Fahey, B.D. 1988
Rowe, L.K.; Fahey, B.D. 1991
Rowe, L.K.; Pearce, A.J. 1994
Rycroft, H.B. 1952
Scott, D.F. 1993
Scott, D.F. 1997
Scott, D.F.; Smith, R.E. 1997
Smith, C.M. 1992
Smith, J.L.H. 1946
Smith, P.J.T. 1987
Tsykin, E.; Laurenson, E.M.; Wu, A.Y.K. 1982
van der Zel, D.W. 1970
van Wyk, D.B. 1987
Waugh, J.R. 1980
Whitehead, D.; Kelliher, F.M. 1991a
Wicht, C.L. 1949
Wicht, C.L. 1972?

Species (or Vegetation Class) Comparisons Index

Bari, M.A.; Schofield, N.J. 1991
Bell, F.C.; Gatenby, M.T. 1969
Bell, R.W. et al. 1990
Borg, H.; Bell, R.W.; Loh, I.C. 1988
Bosch, J.M.; Hewlett, J.D. 1982
Bren, L.J.; Papworth, M. 1991
Bren, L.J.; Papworth, M. 1993
Cornish, P.M. 1989
Crockford, R.H.; Richardson, D.P. 1987
Crockford, R.H.; Richardson, D.P. 1990a
Crockford, R.H.; Richardson, D.P. 1990b
Crockford, R.H.; Richardson, D.P. 1990c
Crockford, R.H. et al. 1996
Davidson, J. 1967
Duncan, H.P. et al. 1978
Dunin, F.X.; Mackay, S.M. 1982
Dye, P.J. 1996
Feller, M C. 1978
Feller, M.C. 1981
Henrici, M. 1947?
Hewlett, J.D.; Bosch, J.M. 1984
Holmes, J.W.; Sinclair, J.A. 1986
Hopmans, P.; Flinn, D.W.; Farrell, P.W. 1987
Huber, A.; Iroume, A. 2001
Langford, K.J.; O'Shaughnessy, P.J. 1977b
Leitch, C.J.; Flinn, D.W. 1986
Le Maitre, D.C.; Versfeld, D.B. 1997
Lesch, W.; Scott, D.F. 1997
Nandakumar, N.; Mein, R.G
Nandakumar, N.; Mein, R.G.; Dunin, F.X. 1991
Pilgrim, D.H. et al. 1982
Pook, E.W.; Moore, P.H.R.; Hall,T. 1991a
Pook, E.W.; Moore, P.H.R.; Hall,T. 1991b
Putuhena, W.M.; Cordery, I. 1996
Putuhena, W.M.; Cordery, I. 2000
Richmond, I.C. 1980
Scott, D.F. 1993
Smith, M.K. 1974
Smith, M.K.; Watson, K.K.; Pilgrim, D.H. 1974
Smith, R.E.; Scott, D.F. 1992
Tsykin, E.; Laurenson, E.M.; Wu, A.Y.K. 1982

Native deciduous forest
Amezaga, I. et al. 1997
Bosch, J.M.; Hewlett, J.D. 1982

Native evergreen forest (excluding eucalypt species)
Beets, P.N.; Brownlie, R.K. 1987
Blake, G.J. 1972
Blake, G.J. 1975
Bosch, J.M.; Hewlett, J.D. 1982
Brownlie, R.K.; Kelliher, F.M. 1989
Cooper, A.B.; Thomsen, C.E. 1988
Dell, P.M. 1982
Dons, A. 1981
Dons, A. 1987
Fahey, B. 1994
Fahey, B.D.; Jackson, R.J. 1995
Fahey, B.D.; Jackson, R.J. 1997a
Fahey, B.D.; Jackson, R.J. 1997b
Fahey, B.D.; Rowe, L.K. 1992
Graynoth, E. 1992
Hewitt, A.M.; Robinson, A. 1983a
Hewitt, A.M.; Robinson, A. 1983b
Huber, A.; Iroume, A. 2001
Jackson, R.J. 1985a
Jackson, R.J.; Fahey, B.D. 1993
Jackson, R.J.; Payne, J. 1995
Jackson, R.J.; Rowe, L.K. 1996
Levett, M.P. 1978
McKerchar, A.I. 1980
Otero, D.L. et al. 1994
Riddell, J.M.; Martin, G.N. 1982
Rowe, L.K.; Fahey, B.D. 1988
Rowe, L.K.; Fahey, B.D. 1991
Rowe, L. et al. 1997
Rowe, L.K.; Pearce, A.J. 1994
Rowe, L.K. et al. 1994
Waugh, J.R. 1980

Native grassland
Calder, I.R. 1996
Fahey, B.D. 1990
Fahey, B. 1994
Fahey, B.D.; Jackson, R.J. 1995
Fahey, B.D.; Jackson, R.J. 1997a
Fahey, B.; Jackson, R.; Rowe, L.K. 1998a
Fahey, B.; Jackson, R.; Rowe, L.K. 1998b
Fahey, B.D.; Rowe, L.K. 1992
Fahey, B.D.; Watson, A.J. 1991
Hewlett, J.D.; Bosch, J.M. 1984
Huber, A.; Lopez, D. 1993

Huber, A.; Oyarzun, C.; Ellies, A. 1985
Putuhena, W.M.; Cordery, I. 1996
Rowe, L. et al. 1997

Pasture
Allison, G.B.; Hughes, M.W. 1972
Bari, M.A.; Schofield, N.J. 1991
Beets, P.N.; Brownlie, R.K. 1987
Borg, H.; Bell, R.W.; Loh, I.C. 1988
Brownlie, R.K.; Kelliher, F.M. 1989
Colville, J.S.; Holmes, J.W. 1972
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Dye, P.J. 1996
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Le Maitre, D.C.; Versfeld, D.B. 1997
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Huber, A.; Lopez, D. 1993
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Lesch, W.; Scott, D.F. 1997
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Pilgrim, D.H. et al. 1982
van der Zel, D.W. 1970
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Fahey, B. 1994
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McGregor, K.R. 1983
McKerchar, A.I. 1980
McMurtrie, R.E. et al. 1990
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Scott, D.F.; Smith, R.E. 1997
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Calvo, R.N.; Paz, G.A.; Diaz-Fierros, V.F. 1979
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Bosch, J.M.; Hewlett, J.D. 1982
Cornish, P.M. 1989
Langford, K.J.; O'Shaughnessy, P.J. 1977a
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Wicht, C.L. 1972?

Section 3: Bibliography

Citations are listed in alphabetical order of author(s), then by date. If a citation has no annotations, the paper may or may not have been scanned but is still listed as being of possible relevance to the subject.

Many of the abstracts included here come directly from literature searches, but they can be different from the abstracts in the papers. Where known, CAB Abstracts Accession (AN) numbers are given. Other annotations extracted from the papers, indicated by '*Comment*', are considered by the authors of this report to be important relevant information. Abstracts may have been shortened to only include information of relevance to this study.

Where a physical copy of a paper has been obtained, a location reference such as R1234 or LKR indicates the reference number in the collection of Lindsay Rowe. 'Not sighted' means the report was not found in the New Zealand library system.

Tables in this report are LKR's version of data extracted from the papers listed and may not be the same as those found in the original papers. In the absence of tables, data have sometimes been extracted from figures and, therefore, may not be entirely accurate. While care has been taken to ensure the information presented here is accurate, it is the responsibility of the user to ensure that the transcriptions and interpretations made are correct, and relevant to a particular situation. Only publications in English or English annotations, abstracts and captions have been scrutinised fully.

A summary table modified from that below has been used with many citations to provide a quick reference to the thrust of the report, and a guide to the plantation parameters. A negative age implies pre-planting or calibration data are available.

Country:	Duration:	Report Location:
Species Comparison:		
Land-Use Change:		
Stand Type: Plantation	Stand Density:	Basal Area:
Height:	Diameter:	Rainfall:
Keywords:		

Where necessary, imperial units have been converted to metric equivalents.

Abbreviations

Abbreviations used by LKR in the tables and *Comments* (may be in lowercase or uppercase)

BA	Basal area	RO	Runoff (= streamflow = water yield)
DBH	Diameter at breast height	SF	Stemflow
E	Evaporation	SM	Soil moisture
ET	Evapotranspiration	SPH	Number of stems per hectare
IL	Interception loss	TF	Throughfall
LAI	Leaf area index	TRANS	Transpiration
MAP	Mean annual precipitation	Yr	Year(s)
PTTN	Precipitation		

Aguilar, J.G.; Arrau, A.I. 1995: Impacto del manejo de plantaciones sobre el ambiente fisico. Effect of plantation management on the physical environment. Bosque 16: 3–12.

Country: Chile	Report Location: LKR
Species Comparison: Eucalypt plantations	
Land-Use Change: Forest management	
Stand Type: Plantation	
Keywords: Evaporation; Interception; Review; Water yield	

CAB Abstracts AN 980606829

This review summarises the main environmental impacts of *P. radiata* and eucalypt (*Eucalyptus* spp.) plantation projects in Chile on the physical environment, and proposes some guidelines for mitigation. Site preparation, road construction, and ground-based logging (including log skidding and machinery displacements) are the operations that cause the major impacts on the physical environment. The main impacts on soil are compaction, displacement, erosion by water, and nutrient depletion. Major impacts on hydrology are disturbances in the hydrologic balance as a consequence of changes in interception, evapotranspiration and surface runoff, and physico-chemical water quality. Mitigation guidelines according to the fragility of the regional terrain are oriented toward comprehensive planning and the use of more appropriate establishment and harvesting techniques.

Comment

Quotes some annual percentage interception data (18.7%, 25%, 35%) but no rainfall or stand data to go with it, so the data are of limited use.

Allison, G.B.; Hughes, M.W. 1972: Comparison of recharge to groundwater under pasture and forest using environmental tritium. Journal of Hydrology 17: 81–95.

Country: Australia	Duration: October 1970 & February 1971	Report Location: R1389
Species Comparison: Pasture		
Stand Type: Plantation 30–40 yr	Stand Density: Various	Rainfall: MAP 600–700 mm
Keywords: Groundwater		

CAB Abstracts AN 721901242

Comment
Same location, Gambier Plains, southern Australia, as Holmes & Colville (1968). Used tritium content of the upper 20 cm of the groundwater aquifer to estimate groundwater recharge. There is virtually no recharge to groundwater under forest in this locality, < 13 mm/yr; under pasture recharge is 63 mm/yr.

Amezaga, I.; Arias, A.G.; Domingo, M.; Echeandia, A.; Onaindia, M. 1997: Atmospheric deposition and canopy interactions for conifer and deciduous forests in northern Spain. Water, Air, and Soil Pollution 97: 303–313.

Country: Spain	Duration: 1 yr	Report Location: R395
Species Comparison: Native deciduous forest/plantation (Oak)		
Stand Type: Plantation 15 yr	Stand Density: 1025 or 1750 SPH	
Height: 7 and 10 m		Rainfall: 1000–1500 mm/yr
Keywords: Interception; Nutrient cycling		

CAB Abstracts AN970608408

The effect of forest canopy on the chemical composition of throughfall was studied in four forests: two 15-yr-old coniferous plantations of *P. radiata* (at Posadero and Manzanal) and two 100-yr-old deciduous forests (*Quercus robur* at Durango, and *Q. rubra* at Orobio) near Bilbao (Bizkaia), in the Basque Country of northern Spain during 1 yr (July 1993 – June 1994). The study areas are subject to different levels of pollution: Manzanal suffers from industrial pollution mainly of $SO_4$2- and NO_3-, and Durango has industrial and agricultural pollution mainly of NH_4+ and $SO_4$2-, while the other two sites are not near pollutant sources.

The study presents data on bulk precipitation and throughfall, and on the quantities of inorganic N (NH_4+ + NO_3-), $SO_4$2-, Ca2+, Mg2+, Na+, K+ and Cl- reaching the forest floor. The nutrient input to the forest floor differed within the study sites. The capacity for neutralisation of the deposition was better in deciduous forest than in coniferous forest. Leaching in association with the canopy washoff were the most significant sources of base cations in throughfall in both types of forest. Despite the pollution levels in Manzanal and Durango no effect on tree leaves was observed during the study period.

Comment

Pines

Posadero:	Age	15 yr	1750 SPH	mean height 7 m	90% of ground cover
Manzanal:		15 yr	1025 SPH	10 m	90%
Oaks		100 yr			

Interception data

	PTTN (mm)	TF (mm)	TF (%)
P radiata Posadero	1427	904	63
P radiata Manzanal	1071	747	70
Oak Durango	1304	1011	78
Oak Orobia	1584	1450	92

Conifers have greater interception (i.e., less throughfall) than oaks.

Arneth, A.; Kelliher, F.M.; McSeveny, T.M.; Byers, J.N. 1995: Water use efficiency of a dryland *Pinus radiata* plantation. New Zealand Meteorological and Hydrological Symposium, Christchurch 1995. (Unpublished)

Country: New Zealand	Duration: 18 days in 1 yr	Report Location: LKR
Stand Type: Plantation 8 yr	Stand Density: 1250 SPH	
Height: 9 m		Rainfall: 665 mm
Keywords: Evaporation		

Comment

During the course of the study, the forest evaporation rate declined from 3.7 mm/day (17–26 November) to 2.9 mm/day (12–13 January) to 2.2 mm/day (18–27 March) to 1.0 mm/day (14–20 July). Ground evaporation was 20–25% of the total except when the ground was frozen in winter.

Arneth, A.; Kelliher, F.M.; McSeveny, T.M.; Byers, J.N. 1998: Fluxes of carbon and water in a *Pinus radiata* forest subject to soil water deficit. Australian Journal of Plant Physiology 25: 557–570.

Country: New Zealand	Duration: 6–9 d, 7 times over 18 months	Report Location: R1346
Stand Type: Plantation 8+ yr	Stand Density: 1220 SPH thinned to 860 SPH	
Height: 8.5 m		Rainfall: 658 mm/yr
Keywords: Evaporation; Transpiration		

CAB Abstracts AN 980612668

Seasonal CO2 (FCO2) and water (E) fluxes were measured by eddy covariance, in an 8-yr-old *P. radiata* plantation in New Zealand subject to growing season soil water deficit. Average rates of FCO2 and E were highest in spring (324 mmol/m^2/d and 207 mol/m^2/d, respectively) when the abiotic environment was most favourable for surface conductance and photosynthesis. During summer, fluxes were impeded by soil water (theta) deficit and were equal to or smaller than during winter (FCO_2 = 46 mmol/m^2/d in summer and 115 mmol/m^2/d in winter; E = 57 and 47 mol/m^2/d, respectively). On particularly hot and dry days, respiration exceeded photosynthetic uptake and the ecosystem was a net carbon source. Portraying the underlying biochemistry of photosynthesis, daytime half-hourly FCO_2 increased with quantum irradiance absorbed by the canopy (Qabs) following a non-saturating, rectangular hyperbola. Except for winter, this relation was variable, including hysteresis attributable to diurnal variation in air saturation deficit (D). Daily ecosystem , FCO_2 /Qabs and/E were inversely proportional to maximum daily D, but in the cases of FCO_2 and FCO_2/Qabs only after soil moisture deficit became established. Consequently, as the tree growing season progressed, ecosystem carbon sequestration was strongly limited by the co-occurrence of high D at low theta.

Comment
Balmoral Forest, North Canterbury. Start: 8-yr-old, HT 8.5 m, 1200 SPH, LAI 6.5. Finish: 10-yr-old, 860 SPH, LAI 5.6. Closed canopy throughout. Very stony sandy loam soils. MAP 658 mm; Dec.–Mar. 203 mm.

For well-watered soils, the total forest evaporation rate was 0.8 mm/d in winter; 3.7 mm/d in summer; range 0.4 to 4.8 mm/d. As the soil dried out and atmospheric demand increased, E declined to 1 mm/d.

There was considerable evaporation from the ground. Of total E, it was 24% in late spring, 42% in dry summer; 12% in winter; and 15% in early spring.

Baker, T.G.; Attiwill, P.M. 1987: Fluxes of elements in rain passing through forest canopies in South-Eastern Australia. Biogeochemistry 4: 27-39.

Country: Australia	Duration: 2 yr	Report Location: R457
Species Comparison: Eucalypt (forest and plantation)		
Stand Type: Plantation 18–22 y	Stand Density: Varies	Basal Area: Varies
Height: Varies		Rainfall: 1000 mm/yr
Keywords: Interception; Nutrient cycling; Stemflow; Throughfall		

CAB Abstracts AN S203790/Authors' Abstract

The elemental content of rainfall (bulk deposition), throughfall and stemflow was measured in *P. radiata* and *Eucalyptus* forests in Gippsland, Victoria. Accessions in rainfall (mg/m^{-2}/yr) averaged: organic-C 551, NO_3^--N 96, NH_4^+-N 62, total-N 303, K^+ 382, Na^+ 2250, Ca^{2+} 1170, and Mg^{2+} 678. The mean pH of rainfall was 5.9. Concentrations of all elements were greater in throughfall than in rainfall, and generally greater in stemflow than in throughfall. However, pH of pine throughfall was higher than that of rainfall, and pH of eucalypt throughfall was lower than that of rainfall. There was a net efflux of inorganic-N from pine crowns to rainfall, whilst in eucalypts there was generally net sorption of inorganic-N from rainfall. In both species organic-N was leached from the crowns and the net efflux of total-N from eucalypt crowns (50 mg/$m^{2/}$yr) averaged one-quarter of that in pines. Increases in the organic-C content of throughfall relative to rainfall in eucalypts were 2–4 times those in pines. Increases in the content of other elements in throughfall were comparable in pines and eucalypts and within the ranges K+ 615–1360, Na+ 480–1840, Ca2+ 123–780 and Mg2+ 253–993 mg/m$^{2/}$ yr. However, enrichment of Ca2+ may have been due to dust trapped in the canopies. Stemflow contributed significantly to the total amounts of elements reaching the forest floor in water.

Comment
Gippsland, Australia. Fully stocked, closed canopy. *E. obliqua* and *E. sieberi* stands were native forest, *E. regnans* was a plantation.

Interception data for SE Australia

Site	Species	Age	SPH	BA (m^2/ha)	HT (m)	PTTN (mm)	TF (mm(%))	SF (mm(%))	IL (mm(%))
A	*P. radiata*	18	870	38	28	942	552 (58.6)		
A	*E. regnans*	19	560	41	38	942	678 (72.0)		
B	*P. radiata*	22	610	42	31	892*	448*(50.2)	52 (5.8)	392 (44.0)
B’	*E. obliqua*	70–80	380	54	38	1028*	740*(72.0)	3.5 (0.3)	284 (27.7)
C	*P. radiata*	20	560	41	28	980	605 (61.7)		
C	*E. sieberi*	60	1190	47	26	980	670 (68.4)		
D	*P. radiata*	18	1400	44	25	902*	542*(60.1)	57 (6.3)	303 (33.6)
D	*E. obliqua*	80–90	650	48	25	902*	671*(74.4)	6.4 (0.7)	225 (24.9)

* = mean of 2 yr of measurements

At similar locations, *P. radiata* had lower throughfall, higher stemflow and higher interception loss than eucalypts

Baker, T.G.; Hodgkiss, P.D.; Oliver, G.R. 1985: Accession and cycling of elements in a coastal stand of *Pinus radiata* D.Don in New Zealand. Plant and Soil 86: 303–307.

Country: New Zealand	Duration: 1 yr	Report Location: R12
Stand Type: Plantation 14 yr	Stand Density: 2100 SPH	Basal Area: 42 m^2/ha
Height: 19 m		Rainfall: MAP 1000 mm
Keywords: Nutrient cycling; Throughfall		

CAB Abstracts AN S083515/Authors’ abstract

The accession and cycling of elements in a 14-year-old coastal stand of *P. radiata* was measured for 1 yr. The element contents (mg/m$^{2/}$yr) of bulk precipitation and throughfall respectively were: NO_3-N 41, 12; NH_4-N 133, 154; organic-N 157, 396; Na 4420, 9700; K 387, 2900; Ca 351, 701; Mg 486, 1320. Of the increase in elemental content of rainwater beneath the forest canopy 20% (NH_4-N), 70% (organic-N), 3% (Na), 90% (K), 20% (Ca) and 30% (Mg) was attributed to leaching; the remainder to washing of aerosols filtered from the atmosphere by the vegetation. The canopy absorbed approximately

40 mg/$m^{2/}$yr of NO_3-N. Litterfall was the major pathway for the above-ground biogeochemical cycle of N (93%), Ca (96%) and Mg (74%), and leaching was the major (73%) pathway for K.

Comment
Woodhill Forest, Auckland. Monthly samples, throughfall gauges moved each month. One year of data.

PTTN = 895 mm, TF = 512 ± 10 mm (57% of P).
Stemflow was not measured.

Baker, T.G.; Oliver, G.R.; Hodgkiss, P.D. 1986: Distribution and cycling of nutrients in *Pinus radiata* as affected by past lupin growth and fertilizer. Forest Ecology and Management 17: 169–187.

Country: New Zealand	Duration: 1 yr	Report Location: R1579
Stand Type: Plantation 14 yr	Stand Density: 2000 SPH	Basal Area: See below
Height: See below		Rainfall: 822 mm/yr
Keywords: Nutrient cycling; Throughfall		

Comment
Woodhill Forest, Auckland. 14-yr-old, 2000 SPH; stabilised sand dune. Study period 12 months.

Stand characteristics

	Control plot	Lupin	Fertiliser	Lupin+fertiliser
Ht (m)	16.4	18.2	19.8	20.0
BA m^2/ha	29.9	36.1	38.9	47.5

PTTN = 822 mm
Throughfall:
Control 551 mm (67%)
Lupin 484 mm (59%)
Fertiliser 484 mm (59%)
Lupin+fertiliser 459 mm (56%) This plot had greater needle mass

Bands, D.P.; Bosch, J.M.; Lamb, A.J.; Richardson, D.M.; van Wilgen, B.W.; van Wyk, D.B.; Versfield, D.B. Undated: Jonkershoek Forestry Research Centre. Forestry Branch, Department of Environment Affairs pamphlet 384.

Country: South Africa	Report Location: R1298
Species Comparison: Scrubland (fynbos)	
Land-Use Change: Afforestation	
Stand Type: Plantation age varies	
Keywords: Water yield	

Comment
Gives a description of Jonkershoek research and the following summary

Streamflow reduction at Jonkershoek, various-aged stands

Catchment	Area (ha)	Rainfall (mm)	Natural runoff (mm)	Afforestation (year (%))	Streamflow reduction (mm/yr)
Bosboukloof	200	1300	600	1940 (57)	330 @ 23 yr 200 = mean to 23
Biesievlei	27	1430	660	1948 (98)	400 @ 15 yr 313 = mean to 15
Tierkloof	157	1800	1000	1956 (36)	500 @ 16 yr 171 = mean 16–24
Lambrechtsbos B	65	1500	530	1961 (84)	170 = mean 8–16

Banks, C.H. 1961: The hydrological effects of riparian and adjoining vegetation. Forestry in South Africa 1: 31–45.

Country: South Africa	Duration: 14 yr	Report Location: R 1570
Species Comparison: Scrubland (fynbos)		
Land-Use Change: Afforestation		
Stand Type: Plantation age varies		
Keywords: Low flow; Water yield		

Part Author's Abstract

Details are given of the method employed in analysing the diurnal fluctuations from the streamflow records in conjunction with temperature records to obtain correlated data on the consumptive use of water by the natural vegetation and riparian and adjoining plantings of *P. radiata* as it affects discharge. Evidence of a reduction in summer baseflow and a decrease in absolute daily vapour losses due to afforestation is given.

Comment
Afforestation at Jonkershoek with *P. radiata* from fynbos = sclerophyll scrub

Catchment details with age of plantations

Catchment	1940	1948	1956	1964	1972	1980	*P. radiata* Forest (%)	Area (ha from various sources)
Bosboukloof	0	8	16	24	32	40	57	200 (208)
Biesievlei		0	8	16	24	32	98	27
Tierkloof			0	8	16	24	36	157
Lambrechtsbos B				0	8	16	84	65
Lambrechtsbos A					0	8	94	31
Langrivier						0	0	246

Notes:
Biesievlei has afforestation to rivers edge. Rest have a 20-m (1-chain) riparian reserve.
Langrivier was to be a control catchment but was swept by wildfire in 1942
Areas in parentheses come from different sources and were not used in the calculations

In the summer dry period get diurnal fluctuations in streamflow — 4-hour lag between highest daytime temperature and lowest streamflow and between minimum temperature and maximum streamflow. Suggests that the diurnal variation is due to use of riparian zone water by vegetation — usually fynbos scrub.

Presented data for differences in flow levels. Differences in the flow vs temperature regressions, his Table 3 and Figure 3, indicate changes on flow between 1945–8 and 1956–9. Note the control catchment's flow had increased. Thus, on a 100% planted basis, these differences show that for January rainless days daily flow dropped 0.27 mm/d at Bosboukloof and 0.39 mm/d at Biesievlei — less at the older catchment although here the diminishing flow effect may have already begun.

Changes in low flow with afforestation at Jonkershoek

Catchment	% *P. radiata* forest	Age 1945–8	Age 1956–9	Area (ha) (various sources)	Change in flow (cusecs)	Change in flow (mm)	Change for 100% forest (mm)
Bosboukloof	57	4.5–7.5	15.5–18.5	200 (208)	−0.05	−0.06	−0.11
Biesievlei	98	0	7.5–10.5	27	−0.03	−0.23	−0.23
Tierkloof	0		0	157	0.1	0.16	
Langrivier	0		0	246	0.125	0.12	

Notes:
Biesievlei has afforestation to rivers edge. Rest have 20-m (1-chain) riparian reserve.
Areas in parentheses come from different sources and were not used in the calculations
Calculations in the last column are by LKR.

Banks, C.H.; Kromhout, C. 1963: The effect of afforestation with *Pinus radiata* on summer baseflow and total annual discharge from Jonkershoek catchments. Forestry in South Africa 3: 43-65.

Country: South Africa	Duration: 14 yr	Report Location: R1427
Species Comparison: Scrubland (fynbos)		
Land-Use Change: Afforestation		
Stand Type: Plantation age varies		
Keywords: Low flow; Water yield		

Authors' Abstract

Streamflow data from two afforested and four unafforested experimental catchments at Jonkershoek Forest research station are used in a covariance analysis to determine the effect on summer baseflow and total annual discharge of replacing the natural cover by afforestation with *P. radiata.*

The results show a significant, progressive decrease in the stream discharge from the afforested catchments. The decrease occurs from years 4 to 12 after afforestation, and subsequently the flow remains relatively constant but at a lower level than prior to afforestation.

There is also some evidence that complete protection of the unafforested catchments may lead to a change in their streamflow regime. The conclusions support the general hypothesis that the hydrological effect of vegetation is proportional to its density.

Comment

This paper reports some of the data presented in Banks (1961) but in different form. Changes in Jan. baseflow on dry days for the two periods have been adjusted to a constant level for Tierkloof.

Changes in low flow with afforestation

Catchment	% *P. radiata* forest	Age 1945–8	Age 1956–9	Area (ha) (various sources)	Change in flow (cusecs)	Change in flow (mm)	Change for 100% forest (mm)
Bosboukloof	57	4.5–7.5	15.5–18.5	200 (208)	−0.156	−0.19	−0.33
Biesievlei	98	0	7.5–10.5	27	−0.05	−0.41	−0.41
Tierkloof	0		0	157	0	0	
Langrivier	0		0	246	0	0	

Note: Calculations in the last column are by LKR

Monthly flows grouped by 4-yr periods and regressed against Tierkloof showed trends of decreasing flow at Bosboukloof, and Biesievlei but not at Langrivier The decrease is mainly between years 4 and 12 after afforestation and remains steady thereafter at a lower level than prior to afforestation. There were complications in that the two catchments at Lambrechtsbos showed changes as well—increased flow compared to Tierkloof. Perhaps the inclusion of rainfall data may have helped to elucidate some of the differences.

Annual flows (in millimeters calculated using areas from various sources) show marked differences between catchments, which are in different states of afforestation.

Annual flows

	Langrivier	Biesievlei	Tierkloof	Bosboukloof	Lambrechtsbos A	Lambrechtsbos B
Mar. '45	2127	781	1369	727		
Mar. '46	1779	827	1280	716		
Mar.'47	1341	522	898	468		
Mar. '48	1443	539	866	405		
Mar. '49	1517	588	935	455	95	461
Mar. '50	1092	404	646	275	374	304
Mar.'51	1434	540	877	380	493	424
Mar. '52	2188	806	1419	655	840	720
Mar. '53	1299	476	825	343	556	415
Mar. '54	1918	648	1294	561	793	679
Mar. '55	2395	754	1555	659	880	794
Mar, '56	1839	678	1210	523	793	634
Mar. '57	1628	495	1025	452	675	559
Mar. '58	1970	608	1309	532	844	696
Mar. '59	1362	360	895	382	605	478
Mar. '60	1393	357	915	373	559	497

Bari, M.A.; Schofield, N.J. 1991: Effects of agroforestry-pasture associations on ground-water level and salinity. Agroforestry Systems 16: 13–31.

Country: Australia	Duration: 12 yr	Report Location: R394
Species Comparison: Eucalypt plantations; Pine species; Pasture		
Land-Use Change: Afforestation		
Stand Type: Plantation 3+ yr	Stand Density: Various	Rainfall: 717 mm/yr
Keywords: Groundwater		

CAB Abstracts AN920656774

Stream and land salinisation brought about by rising groundwater levels due to the clearing of native forest for agricultural development is a major environmental and resource problem in Western Australia and several other semiarid regions of the world. One potential approach to reclamation with simultaneous economic benefits is the establishment of a silvopastoral system. To determine the effects of such a system on groundwater level and salinity, two experiments were carried out in Western Australia. In Experiment I the silvopastoral system studied was of mixed pine species (*P. radiata* and *P. pinaster*) planted as six blocks and *Eucalyptus camaldulensis* planted as one block in 1978. The trees covered 58% of the cleared area and after three thinnings had a final stem density of 75-225/ha in 1985. Over the period 1979–89, groundwater levels declined by 1.0 m relative to groundwater levels beneath a nearby pasture site. In Experiment II the silvopastoral system studied was of mixed eucalypt species (*E. sargentii*, *E. wandoo*, *E. camaldulensis* and *E. calophylla*) planted as four blocks in 1978. The trees covered 57% of the farmland and after two thinnings had a final density of 150–625 stems/ha in 1982. Over the period 1981–89, the yearly minimum groundwater level declined by 2.0 m relative to a nearby pasture site. The salinity of the groundwater beneath the silvopastoral treatments decreased by 9 and 6%, respectively, in Experiments I and II, which was contrary to some early expectations. It is suggested that the design of silvopastoral plots for controlling saline groundwater tables needs further evaluation with respect to species, stem densities and proportion of cleared area planted.

Barton, I.L; Card, J.H. 1979: A comparison of vegetation mass, species and runoff on three experimental catchments in the Hunua Ranges Auckland Regional Authority Forestry Section Water Department Technical Report No G/3, (unpublished).

Country: New Zealand	Duration: 10 yr	Report Location: R1481
Species Comparison: Conifer; Scrubland		
Land-Use Change: Afforestation (scrub to plantation)		
Stand Type: Plantation −1 to +8 yr		
Keywords: Water yield		

Comment
An experimental programme was established in the Hunua Ranges near Auckland in 1969 when monitoring began on three catchments in native scrub. In 1970, two were cleared and burned and then planted in *Cupressus japonica* or *P. radiata*. There are small wetlands in the lower part of the catchment, which were not planted.

Catchment parameters

Catchment	Vegetation	Area (ha)	Wetland (ha)
North	Control scrub	8.84	0.17
Central	*C. japonica*	11.42	0.40
South	*P. radiata*	14.98	0.81

The following table does not take into account the unplanted area and assumes the wetland performs the same before and after planting (flow calculated from total volumes by LKR).

Water yield at Hunua

	Control		*P radiata*	
	Precipitation (mm)	Streamflow (mm)	Precipitation (mm)	Streamflow (mm)
1969	1580	756	1515	646
1970	1786	989	1712	978
1971	2046	1154	1961	1048
1972	1698	829	1627	743
1973	1382	500	1325	386
1974	1563	600	1498	414
1975	1922	907	1842	614
1976	2014	919	1930	591
1977	1794	868	1720	458
1978	1661	766	1592	357

Beets, P.N.; Brownlie, R.K. 1987: Puruki experimental catchment: site, climate, forest management, and research. New Zealand Journal of Forestry Science 17: 137–160.

Country: New Zealand	Duration: 15 yr	Report Location: R102
Species Comparison: Native evergreen forest; Pasture		
Land-Use Change: Afforestation		

CAB Abstracts AN900646467

Multidisciplinary research has been undertaken at the Purukohukohu experimental basin, particularly in the Puruki catchment over the past 15 yr. This period covers the conversion of Puruki from pasture to *P. radiata*, the development of the trees to canopy closure, and the effects of differential intensities of thinning on growth to the middle of the rotation. Puruki is a 35-ha catchment located at the southern end of the Paeroa Range in the central North Island of New Zealand, at 600 m altitude. The rhyolitic pumice soil, previously under rye grass/clover pasture and regularly treated with fertiliser, provides ample moisture and nutrients for *P. radiata* growth under the climatic conditions: 1500 mm of evenly distributed rainfall annually, 5 GJ/m^2 of solar irradiance annually, and average monthly temperatures of between 5° and 15°C. Puruki was uniformly planted with *P. radiata* at 2200 stems/ha in 1973, and trees in the individual subcatchments (Tahi, Rua and Toru) were progressively pruned to 2.2 m height and thinned to 160, 550 and 290 stems/ha respectively by 1985, with further thinning intended. A part of Rua was left unthinned as a control. In closed canopy stands periodic volume increment attains 52 m^3/ha p.a. The removal of between half and three-quarters of the tree basal area every 3 to 4 yr reduced volume increment to between 25 and 30 m^3/ha p.a., but this is likely to increase when management thinning is completed and the stand leaf area can increase uninterrupted to unthinned levels.

Comment

Provides forest stand and climate information relevant to the hydrological studies made by others.

Bell, F.C.; Gatenby, M.T. 1969: Effects of exotic softwood afforestation on water yield. Water Research Foundation of Australia Bulletin No. 15. 93 p.

Country: Australia	Duration: 1 yr	Report Location: R1502
Species Comparison: Eucalypt forest/plantation		
Stand Type: Plantation 30+yr or 1–6 yr	Stand Density: Varies	Basal Area: Varies
Keywords: Interception; Stemflow; Throughfall; Water yield		

Comment
West of Sydney 11 catchments at Lidsdale State Forest ranging in area from 5.5 to 308 ha.
Planted 1932 or 1935, hence 30–33 year old. BA 18.6–30.5 m^2/ha; height 24–27 m.
Young pines = mix 1961 planting 3.3 m high

Interception 1965–66 (12 months)

	Rainfall (mm)	Stemflow (mm)	Throughfall (mm)	Interception loss (mm)
Eucalypt	360	7	317	36
%	100	2	88	10
Pines	402	12	293	97
%	100	3	73	24

Interception storage capacity for both vegetation classes was estimated at 2.5 mm.

Total runoff December 1963 – March 1996

Rainfall (mm)	Mean runoff pines (4 catchments) (mm)	Mean runoff eucalypts (4 catchments) (mm)	Runoff young pines (1 catchment) (mm)
1592	272	302	408
Runoff/rainfall (%)	17	19	26

Bell, R.W.; Schofield, N.J.; Loh, I.C.; Bari, M.A. 1990: Groundwater response to reforesta-tion in the Darling Range of Western Australia. Journal of Hydrology 115: 297–317.

Country: Australia	Duration: 8 yr	Report Location: R110
Species Comparison: Eucalypts; Pines		
Land-Use Change: Afforestation		
Stand Type: Plantation −4 to +3 yr	Stand Density: Varies	Rainfall: 720 mm/yr
Keywords: Groundwater		

CAB Abstracts AN911952283/*Authors' Abstract*

Replacement of deep-rooted perennial vegetation with annual crops and pastures has led to rising groundwater tables and transport of previously stored salts to streams in south-west Western Australia. Trials to determine the potential of reforestation strategies to reverse this process by lowering the groundwater table were commenced in 1976.

Results are reported from six experimental sites for the period 1979–86. The six sites were at two locations, Flynn's Farm and Stene's Farm, each established with three types of plantings. Flynn's Farm had (1) a landscape planting of *Eucalyptus wandoo*, *E. camaldulensis*, *P. pinaster* and *P. radiata* established in 1977 at 670 stems/ha, (2) a hillslope planting of *E. wandoo* and *E. camaldulensis* established in 1978–79 at 1200 stems/ha, and (3) an agroforestry (silvopastoral) planting with *P. radiata*, *P. pinaster* and *E. camaldulensis* established at 380/760/1140 stems/ha in 1978, and grazed by sheep. Stene's Farm had (1) strip plantings of *E. camaldulensis*, *E. globulus*, *E. wandoo*, *P. radiata* and *P. pinaster* established in 1976–78 at 1200 stems/ha, (2) valley plantings of *E. wandoo*, *E. rudis* and *E. camaldulensis* established in 1979 at 625 stems/ha, and (3) an arboretum of 63 *Eucalyptus* and 2 *Pinus* spp. established in 1979 at 625 stems/ha. Different proportions of the areas were cleared and planted at each site, and thinning was done over the course of the study. Despite the mean annual rainfall of the experimental period being 10% below the 1926–86 mean, groundwater levels under pasture rose by up to 1.2 m. The change in groundwater levels beneath reforestation ranged from a 0.6 m increase to a 3 m decrease relative to the ground surface. Groundwater levels under reforestation in all cases decreased relative to groundwater levels under pasture. The magnitude of this reduction increased with the proportion of cleared area reforested and with the crown cover of the reforestation. The salinity of the water table decreased by 12% under reforestation and by 32% under pasture over the period 1979–86.

Comment

Planting was carried out in areas likely to have the greatest effect — intensively near and upslope of streamlines or extensively as agroforestry.

Black, R.D. 1990: Esk catchment. Forest development and its effect on the water resource. New Zealand Hydrological Society Symposium, Taupo 1990. (Unpublished)

Country: New Zealand	Report Location: LKR
Land-Use Change: Afforestation (reverting pasture)	
Keywords: Low flow	

Comment
Complements Black (1992) in that there is a diagram of annual plantings in the Esk catchment. Hydrological data limited to monthly discharge/rainfall (in L/s/mm) ratio for Dec.–Jan. each year.

Black, R. 1992: Esk River catchment — the influence of lithology and land use on water yield. In: Henriques, P. (Ed.) Sustainable Land Management. The Proceedings of the International Conference on Sustainable Land Management, Napier, November 1991. p259–267.

Country: New Zealand	Report Location: R1573
Land-Use Change: Afforestation (reverting pasture)	
Keywords: Low flow	

Comment
Shows geology has a significant effect on catchment low flow.
States that vegetation (afforestation, 21% of the catchment) has no effect on baseflow. Does not provide the time frame and extent of afforestation given and how it changes and overlaps with the hydrological data to back up that statement. Plantations had been established by 1943 but the flow data are from 1967. Tabulates minimum summer month flows but presents no trend analyses.
See Black (1990) for some forest planting data.

Blake, G.J. 1972: Interception and phytomorphology. New Zealand Ministry of Works, Water and Soil Conservation Hydrological Research Progress Report No.9. 27p. (Unpublished)

Country: New Zealand	Duration: 1 yr	Report Location: R1322
Species comparisons: Evergreen native forest; Scrubland		
Keywords: Interception; Stemflow; Throughfall		

Comment
Gives data as storm-based regression relationships for a number of New Zealand sites.

Whakarewarewa, Rotorua — *P. radiata*
interception loss = 0.274 × precipitation + 1.454 r = 0.801

Puketurua Basin, Northland. — Manuka — storms > 4 mm.
throughfall = 0.441 × precipitation + 0.037 r = 0.981
stemflow = 0.425 × precipitation − 0.050 r = 0.967
net precipitation = 0.847 × precipitation − 0.073 r = 0.964
interception loss = 0.155 × precipitation + 0.072 r = 0.548

Otutira, Taupo — regenerating native forest
interception loss = 0.060 × precipitation + 1.568 r = 0.513

Moutere, Nelson — gorse

interception loss = 0.454 × precipitation + 1.520 'Fitted by eye'

Blake, G.J. 1975: The interception process. In: Chapman, T.G. (Ed). Prediction in catchment hydrology. Australian Academy of Sciences. Pp. 59–81.

Country: New Zealand	Report Location: R1509
Species comparison: Evergreen native forest; Scrubland	
Keywords: Interception; Stemflow; Throughfall	

Comment
Gives data as regression relationships for a number of New Zealand sites, both Water and Soil Division projects and published data (Aldridge 1968; Aldridge & Jackson 1968, 1973; Fahey 1964; Jackson & Aldridge1973; Rowe 1975). The assumption is that these are storm-based but this needs to be verified by looking at the original studies, where possible.

The Water & Soil Division data are an update of Blake (1972):

Trounson Park, Northland — kauri forest
throughfall = 0.60 × precipitation − 3.71 r = 0.971
stemflow = 0.04 × precipitation − 0.15 r = 0.938
interception loss = 0.43 × precipitation + 1.01 r = 0.877

Puketurua Basin, Northland. — Manuka — storms > 4 mm.
throughfall = 0.44 × precipitation − 0.10 r = 0.973
stemflow = 0.38 × precipitation − 0.01 r = 0.971
interception loss = 0.18 × precipitation + 0.1.19 r = 0.877

Whakarewarewa, Rotorua — *P. radiata* planted 1948
throughfall = 0.71 × precipitation − 0.66 r = 0.988
stemflow = 0.07 × precipitation − 0.19 r = 0.948
interception loss = 0.20 × precipitation + 0.94 r = 0.801

Whakarewarewa, Rotorua — *P. radiata* planted 1968
throughfall = 0.84 × precipitation − 3.21 r = 0.984
stemflow = 0.17 × precipitation − 0.52 r = 0.950
interception loss = 0.23 × precipitation + 0.05 r = 0.893

Otutira, Taupo — regenerating native forest
throughfall = 0.47 × precipitation − 0.09 r = 0.989
stemflow = 0.30 × precipitation − 0.56 r = 0.969
interception loss = 0.14 × precipitation + 0.66 r = 0.857

Moutere, Nelson — gorse
throughfall = 0.59 × precipitation − 1.88 r = 0.990

stemflow = 0.07 × precipitation − 0.28 r = 0.929
interception loss = 0.33 × precipitation + 2.57 r = 0.971

Attempted to give an estimate for interception by tussock grassland using artificial wetting techniques.

Boomsma, D.B.; Hunter, I.R. 1990: Effects of water, nutrients and their interactions on tree growth, and plantation forest management practices in Australasia: a review. Forest Ecology and Management 30: 455–476.

Country: New Zealand, Australia	Report Location: R78
Keywords: Review; Tree growth	

CAB Abstracts AN91064869/Authors' abstract

The amount and distribution of rainfall throughout the year is used to highlight climatic differences between Australia and New Zealand. Plantation forest growth (predominantly *P. radiata*) is strongly influenced by both available moisture and nutrients. Practices such as cultivation and mounding (bedding) are used on wet sites, whereas cultivation, ripping, weed control, mulching and heavier thinning regimes are recommended for dry sites.

Management of nutrients to improve growth includes some of the practices listed above, which enhance moisture relationships. Nutrient conservation measures and selection of planting stock with better root systems to explore the soil are suggested as methods to improve growth, along with direct application of nutrients in fertiliser, sewage effluents and wastes.

Responses to a questionnaire distributed to the major forestry enterprises in Australasia showed that practices with very conspicuous benefits (e.g., weed control) had generally been accepted, but the lead-time for implementation of positive research and development was still excessive. A number of other promising practices (e.g., mycorrhizal inoculation of nurseries) had only received minimal or at best a moderate acceptance by managers.

In reviewing the positive effect of recent research on management practices, it is suggested that more information on the interaction of moisture availability and nutrition along with detailed research on both positive and negative effects of cultivation is required. Potential benefits from use of wastes and effluents within forests to supply both water and nutrients will ensure the development of this practice. Experiments should be designed to explore the interactions between genetically improved stock, sites and cultural treatments, as well as physiological processes determining growth.

Comment

Useful information on distribution of plantations and requirements for successful growth.

Borg, H.; Bell, R.W.; Loh, I.C. 1988: Streamflow and stream salinity in a small water supply catchment in Southwest Western Australia after reforestation. Journal of Hydrology 103: 323–333.

Country: Australia	Duration: 8 yr	Report Location: R43
Species Comparison: Eucalypt plantation; Pasture		
Land-Use Change: Afforestation		
Stand Type: Plantation 1–7 yr	Stand Density: Various	Rainfall: MAP 880 mm/yr
Keywords: Water yield		

CAB Abstracts AN F309550

In the mid-1970s, high salinities developed in the Padbury reservoir as a result of conversion of 80% of its 196-ha catchment from native forest to farmland in previous decades. Between 1977 and 1983 some 70% of the farmland was planted with *P. radiata* and *Eucalyptus globulus*. Most of the slopes were reforested but only some of the valleys. Gauging station studies from 1978 to 1986 are reported. Reforestation resulted in substantial reductions in streamflow and in salt discharge from the catchment; however, reduction in streamflow outweighed that of salt and stream salinity increased. Annual rainfall for the study was less than the long-term average. It is suggested that in catchments where areas that discharge most water are different from those that discharge most salt, reforestation of the latter could reduce overall stream salinities.

Comment

Study within the 194.6-ha Balingup Brook catchment, south-west Western Australia. Area above the gauging station was 93.3 ha.

About 10% of the catchment was in native forests at the start of the project (1976), approximately 55% of the catchment was planted in 1977/78 with another 10% in 1980; about 2% was cleared in 1982 and replanted in 1983. About 25% of the plantings were eucalypt but, for the purposes of these comments, are considered to have similar influences on streamflow to *P. radiata.*

Pines were planted at 1100–1300 SPH and thinned after 6 yr to 500–700. Eucalypts were planted at 625 SPH. Valleys were not planted.

Although streamflow measurements did not begin until 1978, streamflow seemed to be stable with respect to Thomson Brook (10 200 ha) or rainfall data as shown by regression relationships (although only 3 data pairs). Borg et al. predictions were an average from these relationships and that from another stream (Ludlow River, 1010 ha). There are signs that flow was decreasing about 1981, 4 yr after planting. Rainfall over the period was below average (770 mm) so the difference could be larger than shown here. If weight is given to the relationship with Balingup rainfall, planting 55% of the catchment with *P. radiata* has decreased flow by about 75 mm. (Extrapolating this to a year of normal rainfall gives an decrease of 115 mm, and further to 100% planting gives an estimated decrease of about 200 mm. LKR)

Bosch, J.M.; Hewlett, J.D. 1982: A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology 55: 3–23.

Country: Worldwide	Report Location: R34
Species Comparison: Conifers; Eucalypt forests; Native deciduous forests; Native evergreen forests; Scrubland	
Land-Use Change: Afforestation; Conversion	
Keywords: Evaporation; Review; Water yield	

CAB Abstracts

This summary and review of 94 catchment experiments shows that accumulated information on the effect of vegetation changes on water yield can be used for practical purposes. The direction of change in water yield following forest operations can be predicted with fair accuracy since no experiments, with the exception of perhaps one, have resulted in reductions in water yield with reductions in cover, or increases in yield, with increases in cover. The approximate magnitude of changes can also be estimated. Pine and eucalypt forest types cause on average 40 mm change in water yield per 10% change in cover and deciduous hardwood and scrub ~25 and 10 mm, respectively. Maximum changes of 660 mm were experienced at Coweeta, North Carolina. An assimilation of the collective experimental results shows that more careful design and expansion of experiments to certain rainfall regions would augment statistical inference.

Bosch, J.M.; von Gadow, K. 1990: Regulating afforestation for water conservation in South Africa. South African Forestry Journal 153: 41–54.

Country: South Africa	Report Location: R1585
Land-Use Change: Afforestation	
Keywords: Water yield	

CAB Abstracts AN 910652553

Comment

Jonkershoek: Change in evaporation (= rainfall − runoff) with time is expressed by a Chapman–Richards equation, which is a sigmoidal function.

$E = A(1-e^{-kt})^m$ where t is time in years and A, k and m are parameters defining the relationship. A, the amplitude, will depend on the original vegetation before afforestation. Parameters determined by curve fitting and can differ markedly as shown by

Bosboukloof	A	350	k	0.542	m	95.75
Lambrechtsbos-B		255		0.455		22.83
Biesievlei		238		0.276		5.52

When E was plotted against years after planting, all three catchments tended to an upper limit (the asymptote) of 1200 mm suggesting an upper limit for evapotranspiration.

Goes on to use linear programming to optimise annual streamflow and mean annual timber yields from subcatchment as a tool for water management. This can involve choice of species, rotation, allowable reduction in flow etc.

Bren, L.J.; Papworth, M. 1991: Early water yield effects of conversion of slopes of a eucalypt forest catchment to radiata pine plantation. Water Resources Research 27: 2421–2428.

Country: Australia	Duration: 12 yr	Report Location: R8
Species Comparison: Eucalypt forest		
Land-Use Change: Conversion		
Stand Type: Plantation −4 to +7 yr		Rainfall: MAP 1400 mm
Keywords: Water yield		

CAB Abstracts AN 921966133

Authors' Abstract

Between 1975 and 1987 the water yield from three small, contiguous, forested catchments carrying similar vegetation in south-eastern Australia was measured. These were located in humid, steep foothill areas subject to a major plantation programme. At the project start all catchments carried mature, natural eucalypt forest. In their natural state the catchments exhibited similar annual hydrologic variation and water yields, with a pronounced low-flow period in summer and autumn, and high flows in winter and spring. One catchment, Clem Creek, was converted from native eucalypt forest to *P. raidata* by clearing, burning, and planting in December 1979. A 30-m buffer was retained along the stream. The treatment increased the water yield of the catchment by up to 3.5 ML/ha, a 47% increase on average. The actual yield increase varied from year to year, and appeared to decline slowly with time from the conversion. Most of the increase was as increased storm flow in the early part of winter. The relation between the storm flow, causal rainfall, and antecedent flow did not appear to be changed by the treatment, suggesting that most of the storm flow response is attributable to increased catchment wetness at the end of the dry summer period.

Comment

In April 1980 *P. radiata* was planted in the 46-ha Clem Creek after native eucalypts had been cleared and burned, except for a riparian strip. Weed control after planting was with hexazinone. Annual rainfall = 1400 mm. Data from planting to May 1987; control = eucalypt catchments (Betsy and Ella). During 1980–87, after the initial increase in streamflow after harvesting, streamflow seemed to diminish as the trees grew (calculated by regression from a control catchment). There was also a trend in decreasing annual rainfall over this period but this may not be a factor in the decreasing streamflow. There was no clear trend in storm flow reduction with growth of the pines. Early winter storms were larger after harvesting; wetter soil conditions and the differential disappeared as winter progressed.

Daily regression of Clem Creek on Ella Creek streamflow used to get total increase at Clem following harvesting. However not given, only the increase in flow.

Bren, L.J.; Papworth, M. 1993: Hydrologic effects of conversion of slopes of a eucalypt forest catchment to radiata pine plantation. Australian Forestry 56: 90–106.

Country: Australia	Duration: 12 yr	Report Location: R7
Species Comparison: Eucalypt forest		
Land-Use Change: Conversion		
Stand Type: Plantation −4 to +7 yr		
Keywords: Water yield		

CAB Abstracts AN 950607342

Between 1975 and 1987 a multiple catchment project was conducted in the headwaters of Cropper Creek, 22 km south-west of Myrtleford (Victoria). This used three catchments ranging in size from 44 to 113 ha. During summer and autumn the streams carried a low (or zero) flow. Normally, heavy rains in late autumn or early winter led to higher flows until mid-spring. Flows then receded to low summer flows. In summer a clear diurnal variation was apparent. Flows reached a maximum about midnight and a minimum about midday. All three streams had similar water yields while their catchment carried native forest and when stream flows were high. During summer and autumn two of the streams would dry up, limiting their utility as ‘control catchments’. Clem Creek was converted from native eucalypt forest to *P. radiata* in December 1979. A 30-m buffer was retained along the stream. The water yield of the treated catchment increased by up to 400 mm per annum and varied from year to year. Most of this increase was as increased storm flow in the early part of the high-flow period. This was due to greater slope water storage because of reduced evapotranspiration from the slope vegetation. The treatment caused a small increase in the amplitude of the observed diurnal variation. This suggested enhanced transpiration from the stream vegetation due to increased groundwater recharge to the bottom-land of the catchment. After 8 yr the response is diminishing. The project was ended as an economy measure in 1987.

Comment

In April 1980 *P. radiata* was planted in the 46-ha Clem Creek after eucalypts had been cleared and burned, except for a riparian strip. Weed control after planting was with hexazinone. Annual rainfall = 1400 mm. Data from planting to May 1987; control = eucalypt catchments (Betsy and Ella). During 1980–87, after the initial increase in streamflow after harvesting, streamflow seemed to diminish as the trees grew (calculated by regression from a control catchment). There was also a trend in decreasing annual rainfall over this period but this may not be a factor in the decreasing streamflow. There was no clear trend in storm flow reduction with growth of the pines.

Main water yield story as for Bren & Papworth (1991) and no more data as the experiment was stopped. Provides residuals after harvesting and shows decrease with plantation establishment. Does look at: recessions; diurnal variation; storm flow effects—mass curves and histograms of % of total R.

Same diagrams as for Bren & Papworth (1991).

Brownlie, R.K.; Kelliher, F.M. 1989: Puruki forest climate. Measurement techniques. Data base. Preliminary analyses. New Zealand Forest Research Institute-Bulletin No. 147. 48 pp.

Country: New Zealand	Report Location: R1571
Species Comparison: Native evergreen forest; Pasture	
Land-Use Change: Afforestation	
Keywords: Tree growth	

CAB Abstracts AN 910647288

A meteorological database was constructed from measurements made in the Puruki-Rua subcatchment of the Purukohukohu Experimental Basin, New Zealand, between 1976 and 1987. Between 1986 and 1978 the vegetation changed from tall coarse pasture with widely spaced *P. radiata* seedlings to a closed canopy forest. The trees were thinned and pruned in 1980, with canopy closure being obtained again in 1983. Measurement techniques and data processing and retrieval are described.

Comment

Provides forest stand information relevant to the hydrological studies made by others.

Calder, I.R. 1996: Water use by forests at the plot and catchment scale. Commonwealth Forestry Review 75: 19–30

Country: New Zealand	Duration: 18 yr	Report Location: R85
Species Comparison: Native tussock grassland		
Land-Use Change: Afforestation		
Stand Type: Plantation −3 to +14 yr		
Keywords: Water yield		

Comment

Presents the results of using an Institute of Hydrology, U.K., model to predict the changes in flow that were observed as a result of afforestation of tussock grassland at the Glendhu catchments.

Calvo, R.N.; Paz, G.A.; Diaz-Fierros, V.F. 1979: Nuevos datos sobre la influencia de la vegetacion en la formacion del suelo en Galicia. I. Interceptacion de la precipitacion. Anales de Edafologia y Agrobiologia XXX: 1151–1163.

Country: Spain	Duration: 1 yr	Report Location: Cited in Turner & Lambert (1987)
Stand Type: Plantation — 20 yr	Basal Area: 48.0 m^2/ha	Rainfall: 1360 mm
Keywords: Interception		

Comment

Precipitation 1360 mm, Throughfall 862 mm, Stemflow 109 mm, Interception loss 397 mm

Colville, J.S.; Holmes, J.W. 1972: Water table fluctuations under forest and pasture in a karstic region of southern Australia. Journal of Hydrology 17: 61–80.

Country: Australia	Duration: 3 yr	Report Location: R1390
Species Comparison: Pasture		
Stand Type: Plantation Varies		
Keywords: Groundwater		

CAB Abstracts AN 721901241

Comment
Now determines that at sites in southern Australia there is recharge under both pasture and forests but that the latter is half the former.

Year	Rain: May–Dec. (mm)	Lysimeter recharge (grass) (mm)	Recharge under forest (mm)
1963	463	40	19
1964	805	134	73
1965	617	72	40

Contrasts with work by Holmes & Colville (1970) and that of Allison & Hughes (1972), which indicated that there would be no recharge under either land cover.

Cooper, A.B.; Thomsen, C.E. 1988: Nitrogen and phosphorus in streamwaters from adjacent pasture, pine, and native forest catchments. New Zealand Journal of Marine and Freshwater Research 22: 279–291.

Country: New Zealand	Duration: 2 yr	Report Location: LKR
Species Comparison: Native evergreen forest; Pasture		
Stand Type: Plantation 10–11 yr	Stand Density: 550/275 SPH	
Keywords: Water quality; Water yield.		

Comment
Primarily a paper on water quality of streams draining three differing land uses at Purukohukohu catchments in the central North Island. Does contain limited water balance information. Storm flow yields lowest under native forest but total yield lowest under pine.

Streamflow summary

	1983	1984

	Pasture	Pine	Native forest	Pasture	Pine	Native forest
PTTN (mm)	1492	1437	1676	1468	1467	1556
Storm flow (mm)**	319	120	69	162	45	18
Base flow (mm)	259	146	296	280	170	282
Quickflow (mm)	147	67	21	40	14	2
Total flow (mm)	578	266	355	442	215	300

** Storm flow determined by Hewlett & Hibbert (1967) separation.

Cornish, P.M. 1989: The effects of radiata pine plantation establishment and management on water yields and water quality—a review. Technical Paper Forestry Commission of New South Wales No. 49.

Country: World wide	Report Location: R1286
Species Comparison: Many species; Eucalypts; Pasture	
Land-Use Change: Afforestation; Conversion from one forest to another; Forest management	
Keywords: Evaporation; Interception; Low flow; Review; Storm flow; Water quality; Water yield	

CAB Abstracts AN 920663059

A comprehensive review of the effects of *P. radiata* establishment and management on water yield and water quality in Australia. The most important hydrologic processes that contribute to ultimate hydrologic differences between vegetation types are outlined. The processes that determine the relative hydrological behaviour of pine plantations (*P. radiata* in Australia and New Zealand and *P. patula* in South Africa), eucalypt (*Eucalyptus* spp.) forests in Australia and grasslands in Australia are considered in more detail. Recent research suggests that the complete afforestation with *P. radiata* of cleared pasture areas in Australia is likely to result in maximum reductions in annual water yield of >400 mm where annual precipitation >1300 mm; actual reductions will depend on precipitation received and the age of the stands. Baseflow in streams in such afforested areas may decrease significantly, and some perennial streams may become ephemeral, particularly in dry years. Suspended sediment and turbidity are the most widespread pollutants of streamwater in *P. radiata* plantations, particularly in areas of higher precipitation such as the New South Wales tablelands. The imposition of various controls to minimise streamwater sediment increases is now standard practice in many plantations, but turbidity levels remain greater than in managed broadleaved forests.

Comment

Amongst the many graphs/tables, two show the trends of larger decreases in streamflow with increasing annual precipitation in pasture afforestation studies and the change in water yield with plantation age. This includes a reduction of the decrease in streamflow once South African plantations grow past the mid-rotation age of 20 yr (rotations here are often greater than 40 yr).

Crockford, R.H.; Khanna, P.K. 1997: Chemistry of throughfall, stemflow and litterfall in fertilized and irrigated *Pinus radiata*. Hydrological Processes 11: 1493–1507.

Country: Australia	Duration: 2 yr	Report Location: R4
Land-Use Change: Irrigation		
Stand Type: Plantation 12–14 yr	Stand Density: Varies	Basal Area: Varies
Keywords: Interception; Nutrient cycling; Stemflow; Throughfall		

CAB Abstracts AN 970610252/Authors' Abstracts

The chemical inputs by rainfall, throughfall and stemflow were studied in a pine plantation in Pierces Creek Forest, Canberra, Australia. Three treatments were included in the study: a control (C) and two fertiliser treatments: F—two applications of mixed fertilisers at high rates; and IL—application of a complete liquid fertiliser with irrigation, so as to remove nutrient and water restrictions to growth. The application rates of nutrients were higher for IL than F. Net inputs of elements in throughfall and stemflow, obtained by subtracting the amounts in the rainfall, were compared for different treatments. For cations (Ca, Mg, Na and K), the treatment effect on leaching by throughfall and stemflow was IL > F > C; but the F to C differences were greater for throughfall than stemflow. The effects were almost entirely due to increases in concentration, rather than the amount of rainfall becoming throughfall or stemflow. The concentration of N (as NH_4 or NO_3) in throughfall or stemflow could be lower or higher than in rainfall, indicating net removal or leaching, respectively. Net removal occurred for most rainfall events for the control treatment, for a substantial number of events for treatment F, but for few events for treatment IL. The ammonium ion was preferentially removed from throughfall, and nitrate from stemflow. Transfers of K and total N by litterfall, throughfall and stemflow were also studied. The proportions of K and N being transferred by these processes showed little difference between treatments; the overall values for K being 60% by throughfall, 4% by stemflow and 36% by litterfall. In contrast the transfer of N was dominated by litterfall (81%), with 18% by throughfall and 1% by stemflow.

Comment:

Planted 1973; treated since 1983; study period June 1985 – July1987

Sampled 44 events = 75% of rainfall between June 1985 and July 1987.

It is unclear what the rainfall regime was, but from statements in the paper it appears to have averaged 578 mm a year.

Stand characteristics

	Control (C)	Fertilised (F)	Irrigated and fertilised (IL)
1983			
SPH	625	599	746
Mean height (m)	9.4	9.5	9.5
BA (m^2/ha)	12.5	12.1	13
Foliage (t/ha)	4.98	4.89	4.9
1987			
Mean height (m)	14.5	13.8	15.8
BA (m^2/ha)	24	24.7	38.2

	Control (C)	Fertilised (F)	Irrigated and fertilised (IL)
Foliage (t/ha)	11.1	12.2	13.9

Interception balance

Treatment	Throughfall (%)	Stemflow (%)	Interception (%)
C	75	3.8	21.2
F	76	3.1	20.5
IF	67	3.9	29.4
If we assume rainfall 578 mm/yr then:**			
Treatment	Throughfall (mm)	Stemflow (mm)	Interception (mm)
C	434	22	122
F	442	18	118
IF	385	23	170

**Calculations by LKR

Crockford, R.H.; Richardson, D.P. 1987: Factors affecting the stemflow yield of a dry sclerophyll eucalypt forest, a *Pinus radiata* plantation and individual trees within the forests. CSIRO, Institute of Natural Resources and Environment, Division of Water Resources Research, Technical Memorandum 87/11. 27p.

Country: Australia	Duration: 4 yr	Report Location: R1287
Species Comparison: Eucalypt		
Stand Type: Plantation 16+yr	Stand Density: 1708 SPH but thinned	Basal Area: 35 m^2/ha
Diameter: 15.6 cm		
Keywords: Stemflow		

CAB Abstracts AN F208010

A 4-yr study was made of stemflow in a eucalypt forest (main species *Eucalyptus rossii*, *E. mannifera*, *E. macrorhyncha* and *E. melliodora*) and an adjacent *P. radiata* plantation in the Upper Yass Representative Basin, New South Wales. The stemflow yield of *P. radiata* was 2.3 times that of the eucalypts, and was not related to stand density orDBH, which were similar for the two stands. *E. macrorhyncha* had a low yield due to its thick absorptive bark, while the low yield of *E. mannifera* was due to the drip points caused by detaching bark. It is suggested that *P. radiata* has a higher yield as it has fewer trunk drip points, due to the more vertical trunks, coupled with less hydrophobic bark.

Comment

Upper Yass Valley, near Canberra.

General stand characteristics: Pine planted in 1962. In 1978 there was 1708 SPH, BA 35.2 m^2/ha, DBH 15.6 cm. Pruned to 2 m prior to 1978; thinned late 1982.
Three plots, 20 ×20 m.

Stemflow under the pine was 11.2% of 798 mm but this is only a fraction of the storms over the 3.5 yr of the study.

Crockford, R.H.; Richardson, D.P. 1990a: Partitioning of rainfall in a eucalypt forest and pine plantation in Southeastern Australia: I Throughfall measurement in a eucalypt forest: effect of method and species composition. Hydrological Processes 4: 131–144.

Country: Australia	Duration: 7 yr	Report Location: R52
Species Comparison: Eucalypt		
Stand Type: Plantation 16+yr		
Keywords: Throughfall		

CAB Abstracts AN 901946991/Authors' Abstracts

A 7-yr event-based study of partitioning of rainfall into throughfall, stemflow, and interception was conducted in a dry sclerophyll eucalypt forest (major species *Eucalyptus rossii*, *E. mannifera*, *E. macrorhyncha* and *E. melliodora*) and *P. radiata* plantation. The resulting information will be of use for process modelling. Stemflow was influenced by event type, rain angle having a major effect; and the yields of the different species are compared. Tree characteristics that influenced stemflow yields are outlined and discussed. The canopy storage capacity of the eucalypt forest was determined and the influence of species composition is shown. The likely influence of climate variation is discussed. The canopy storage capacity is compared with the interception values estimated for continuous events of various sizes. The interception of the eucalypt forest and the pine plantation are compared on an event basis for event size classes and on an annual basis. The comparative interceptions for continuous events are also discussed, while the effect of thinning the pine plantation on throughfall, stemflow, and interception is shown. The hydrological consequences of this study are that more informed judgement can be made about techniques for measurement of throughfall, tree structural characteristics (species related) can more adequately be considered when selecting trees for measurements of stemflow, and the stemflow yields can in some cases be better understood from the information about effect of event type. This paper deals with the influence of measurement method, species composition, and tree characteristics on the estimation of throughfall in the eucalypt forest. The site is near Canberra (35°S, 145°E), with annual rainfall about 650 mm. Two methods of measuring throughfall are compared: randomly placed, 200-mm-diameter cylindrical (standard) and 50-mm -square opening wedge type (plastic) gauges, and randomly placed 5 × 0.22-m troughs. Despite the high placement density (150–225/ha), throughfall estimates from gauges had high variance and were consistently less than those of the troughs, which had a total opening equivalent to 2325 standard raingauges per hectare. Local concentration of stemflow into drip points provided by detaching bark pieces of one smooth-barked species, *E. mannifera*, is believed to be the principal cause of the lower collection and greater variance of the gauges. The low leaf area index (1.3) and large wood area of the forest together with pendulous vertical habit of the leaves also contributed. The presence of *E.mannifera* is shown to substantially affect the relative values of throughfall as measured by troughs and gauges. The plastic receivers were found to underestimate

rainfall or throughfall relative to the standard gauges, particularly for fine drop rainfall in multiperiod events.

Comment
This paper does not consider *P. radiata*. However, it does give stand details pertinent to other papers by the same authors. Hence, its inclusion here.

Upper Yass Valley, near Canberra.
General stand characteristics: Pine planted 1962; in 1978 have 1708 SPH, BA 35.2 m^2/ha, DBH 15.6 cm. Pruned to 2 m prior to 1978; thinned late 1982.
Three plots, 20 ×20 m

Pre-thinning data for the *P. radiata* plots

Plot	Stem Density (SPH)	Mean DBH (cm)	Mean BA (m^2/tree)
A	66	15.9	0.0204
B	73	15.3	0.0206
C	66	15.6	0.0207

Crockford, R.H; Richardson, D.P. 1990b: Partitioning of rainfall in a eucalypt forest and pine plantation in southeastern Australia: II. Stemflow and factors affecting stemflow in a dry sclerophyll eucalypt forest and a *Pinus radiata* plantation. Hydrological-Processes 4: 145–155.

Country: Australia	Duration: 4 yr	Report Location: R53
Species Comparison: Eucalypt		
Stand Type: Plantation 16+ yr	Stand Density: Varies	Rainfall: 769 mm
Keywords: Stemflow		

CAB Abstracts AN 901946992/Authors' Abstracts

Stemflow of a dry sclerophyll eucalypt forest and a nearby *P. radiata* plantation was studied on a rainfall event basis. The stemflow yields of the forests are quantified, compared, and presented on an annual basis for 4 yr. Yields of the individual eucalypt species (*Eucalyptus rossii*, *E. mannifera*, *E. macrorhyncha* and *E. melliodora*) are compared and the tree characteristics responsible for the yield differences are discussed. The influence of event size, type, and season on stemflow are also shown. Rainfall angle is shown to have a significant effect on stemflow yield.

Comment
Pine: 7 trees/plot; 3 plots. Stemflow per ha extrapolated from regression of stemflow with BA of the measured trees to all trees. Correlation coefficient of SF= fn(BA) was 0.83; 0.82 for DBH relationship.

For 55 events: PTTN = 798 mm, SF = 91.1 mm = 11.2% of rainfall and was 2.3 times that for eucalypt. Total period rainfall was 2700 mm in nearly 4 yr = ~ 720 mm/year = below average.

Calculated a stemflow factor SFF = L3 catch/m^2BA/mm rainfall = 32.6

Stemflow by storm class

Size class	Number	Mean rainfall (mm)	SF as % of rainfall
1.0–3.0	14	2.2	0.19
3.1–6.0	18	4	3.54
6.1–8.0	13	7.1	5.33
8.1–10.0	17	8.6	7.5
10.1–15.0	16	12.8	9.1
15.1–20.0	7	17.1	8.09
20.1–25.0	10	22.6	9.88
25.1–30.0	4	28.5	13.1
>30.0	9	42.3	11

Crockford, R.H.; Richardson, D.P. 1990c: Partitioning of rainfall in a eucalypt forest and pine plantation in Southeastern Australia: IV The relationship of interception and canopy storage capacity, the interception of these forests, and the effect on interception of thinning the pine plantation. Hydrological Processes 4: 169–188.

Country: Australia	Duration: 7 yr	Report Location: R55
Species Comparison: Eucalypts		
Land-Use Change: Forest management		
Stand Type: Plantation 16+ yr	Stand Density: Varies	Rainfall: 769 mm/yr
Keywords: Interception; Stemflow; Throughfall		

CAB Abstracts AN 901946994/Authors' Abstracts

A study of partitioning of rainfall into throughfall, stemflow, and interception was conducted in a dry sclerophyll eucalypt forest (*Eucalyptus rossii*, *E. mannifera*, *E. macrorhyncha* and *E. melliodora*) and an adjacent pine (*P. radiata*) plantation over a period of 7 yr, on a rainfall event basis. The following three issues are discussed:(1) the relationship between canopy storage capacity and interception of continuous events, (2) interception, throughfall, and stemflow, and (3) the effect on interception of thinning the pine plantation.

(1.) The canopy storage capacity/interception interaction for the eucalypt forest was assessed by comparing a gravimetric estimate of canopy storage with interception. The maximum possible value for canopy storage capacity was found to be a small proportion of interception for events of all sizes. This suggests that evaporation of intercepted water during the continuous events was responsible for most of the interception. This 'within event' evaporation appears to be responsible also for the net rainfall estimate of canopy storage capacity being four times the gravimetric value. For the pines the regression estimate was more closely related to interception.

(2.) Interception, throughfall, and stemflow of these forests were measured for 4 yr. Data are presented for each year with overall average interception being 11.4 % of precipitation for the eucalypt forest and 18.3 % for the pine plantation. Topography and rainfall event type are considered in the comparison. Species composition and tree type are considered when comparing these results with published studies from similar forest types in south-eastern Australia. The periodic (annual) variations of interception in this and the other studies makes comparison difficult.
(3.) The effect of thinning on the throughfall, stemflow, and interception in a *P. radiata* plantation is examined. Throughfall increased, interception decreased but not in proportion to the removed biomass; stemflow decreased on an area basis, but increased on a per tree basis. A positive relationship was established between interception and stemflow in the thinned plantation but not in the unthinned. Reasons for this are suggested. The results are compared with those reported from similar experiments in other forests. The periodic variation in interception and errors inherent in its estimation suggest that caution should be exercised when using average interception figures in water balance studies.

Comment
Using Leyton et al. (1965) and Rutter et al. (1971) method, ISC = negative intercept of regression line of gross precipitation with net rainfall for continuous events. For pine ISC = 2.0 mm, for eucalypt 1.7 mm.

Comparison with eucalypt = same events and not on an annual basis.

	Rainfall (mm)	Throughfall mm (%)	Stemflow mm (%)	Interception loss mm (%)
Pine	792	576 (73%)	71 (9%)	145 (18%)
Eucalypt	785	663 (85%)	32 (4%)	89 (11%)

Interception by *P. radiata* for storm classes

Event class	Number of events	Mean rainfall (mm)	Mean IL (mm)	Mean IL (%)
<3.0	18	2.4	1.25	52
3.1–6.0	13	4.4	1.63	37
6.1–8.0	15	7.1	2.11	30
8.1–10.0	7	8.6	1.66	19
10.1–15.0	15	13.1	2.31	18
15.1–20.0	7	16.7	2.51	15
20.1–25.0	12	24.6	2.96	12
>30.0	6	42.8	2.38	6

Effect of thinning

Pre-thinned	SPH	1708	mean DBH (cm)	15.8	BA	35.1 m^2/ha
Thinned		700		17.8		17.4

Selected 18 similar events before and after thinning = comparing data 3.5 yr apart

Pre-thinning = 6 winter, 5 spring, 7 summer events, mean event size = 11.4 mm
Post-thinning = 10 autumn, 3 winter, 2 spring, 3 summer, mean event size = 11.0 mm

Pre-thinning	RF = 164 mm	TF = 115 mm (70%)	SF = 14 mm (9%)	IL = 34 mm (21%)
Post-thinning	166 mm	135 mm (81%)	11 mm (6%)	20 mm (12%)

For over 50% reduction in biomass, (stems to 41% of original number, BA 50% but 3.5 yr later that the pre-thinned data) IL decreased only 57%, SF by 25% and TF increased by 16%.

Differences must be related to changes in method of interception. Whereas in the pre-thinning period it would have been at the canopy crown, now the crown interception (50% of original) is being supplemented by that of the sides of trees as angled rain penetrates the canopy gaps.

Crockford, R.H.; Richardson, D.P.; Sageman, R. 1996: Chemistry of rainfall, throughfall and stemflow in a eucalypt forest and a pine plantation in South-Eastern Australia: 3. Stemflow and total inputs. Hydrological Processes 10: 25–42.

Country: Australia	Duration: 4 yr	Report Location: R96
Species Comparison: Eucalypt forest		
Stand Type: Plantation 16+ yr		
Height: 10 m	Diameter: 18 cm	

Keywords: Nutrient cycling; Stemflow

CAB Abstracts AN 960603408/Authors' Abstracts

Some factors affecting stemflow chemistry were examined in a dry sclerophyllous eucalypt forest and a *P. radiata* plantation in a catchment that was part of the Upper Yass Representative Basin, ENE of Canberra. The dry sclerophyllous forest (major species *Eucalyptus rossii*, *E. mannifera*, *E. macrorhyncha*, *E. melliodora*) under study had undergone regrowth after partial clearance and severe disturbance 80–90 yr ago. The pine plantation was established in a cleared area of forest in 1962. Stemflow was collected over the period March 1978 to November 1991, after rainfall events, and covering both debarking and inter-debarking seasons. For events of similar size, the amount and frequency of antecedent rainfall were important for both forests. Bark type was important for the eucalypts, as was the debarking season for the smooth-barked species. Correlations for tree basal area vs concentration were established for the pines and three eucalypt species (*E. rossii*, *E. mannifera*, *E. macrorhyncha*). On average, stemflow was responsible for 10% of the nutrient input for the eucalypts and 11% for the pines. For the pines, the cation composition was dominated by Na and K. Eucalypt stemflow was dominated by K. The relative inputs of inorganic nitrogen and the major cations are presented for the pines and the four major eucalypt species. There was a net uptake of NH_4-N by the pines and a release of NO_3-N. For the eucalypts, both were released by all species, except for *E. melliodora* which absorbed NO_3-N. *E. rossii* dominated nitrogen release. Apart from *E. melliodora*, the pH of stemflow of all eucalypt species and pines was less than that of rainfall. The pH values for *E. melliodora* and rainfall were similar. The chemical concentration of stemflow samples taken during events was greatly influenced by the intensity and continuity of the rainfall, and different eucalypt species were influenced in different ways. The relative chemical inputs of rainfall, throughfall and stemflow of the principal cations, Ca, Mg, Na, and K, were very variable, even between events of similar total rainfall. The total cation average inputs in g/ha per mm/rainfall were: for the eucalypts, rainfall 10.7 (34%), throughfall 17.4 (55%) and stemflow 3.4 (11%); and for the pines, rainfall 10.7 (32%), throughfall 18.4 (55%) and stemflow 4.7 (14%). Thus, on average, throughfall made the major contribution, but in individual events of similar size, rainfall input could be 25–78% of the total for the eucalypts and 10–54% for the pines. There was also a substantial variation in the cation composition of all three components. It was possible to make a reasonable assessment of the probable throughfall and stemflow inputs by considering antecedent conditions, season, ad certain event characteristics such as the intensity and rain angle. For the eucalypt forest, the summer debarking of the smooth-barked species affected the concentration and volume of both throughfall and stemflow. For rainfall, however, assessment of likely inputs was not possible except for some marine-influenced easterly events.

Comments
Stemflow was 11.2 % of rainfall.

Cromer, R.N.; Tompkins, D.; Barr, N.J. 1982: Irrigation of *Pinus radiata* with waste water: Tree growth in response to treatment. Australian Forest Research 13: 57–65.

Country: Australia	Duration:	Report Location: R108
Land-Use Change: Irrigation		
Stand Type: Plantation 15 yr		
Keywords: Tree growth		

Authors' Abstract

Irrigation of a 15-yr-old stand of site quality V in south-east Victoria with sewage effluent substantially increased productivity such that the stand achieved site quality I in the second year. Each increment of 500 mm of water (between the limits of 500 and 1500 mm) produced an extra 11 m^3/ha of merchantable timber annually, the effects being attributable almost entirely to the water rather than to the nutrients present. In irrigated plots, monthly diam. increment was correlated with solar radiation and water supplied during the period. These relations were less marked in non-irrigated plots where water stored in the soil became important to subsequent growth, and periods of drought reduced the influence of solar radiation.

Comment

Included because of the response of trees to the added water.

Davidson, J. 1967: Spatial variation in soil moisture under eucalypts and pine stands. BSc(For)(Hons) Thesis, ANU, Canberra. 125 p.

Country: Australia	Duration: 9 months	Report Location: Cited in Turner & Lambert (1987)
Species Comparison: Eucalypt forest		
Stand Type: Plantation 23 yr		Basal Area: 45.6 m^2/ha
Keywords: Interception; Throughfall		

Comment

Kowan, ACT. Two sites. For *P. radiata*: Precipitation 593 mm, throughfall 350 mm (59%)

Dell, P.M. 1982: The effect of afforestation on the water resources of the Mamaku Plateau region. MSc Thesis, University of Waikato.

Country: New Zealand	Duration: 3 yr	Report Location: R1574
Species Comparison: Native evergreen forest; Pasture		
Stand Type: Plantation vary up to 10 yr		
Keywords: Storm flow; Water yield		

Comment
Presents rainfall and runoff totals for catchments in the Mamaku Plateau. Geology — ignimbrites in which the jointing controls drainage. Flow is extremely variable

	1979–80		1980–81		1981–82	
	PTTN	SF mm (%)	PTTN	SF mm (%)	PTTN	SF mm (%)
Native forest	2712	1342(50)	2050	1103(54)	2350	1175(50)
Exotic forest	2268	476(21)	1872	422(23)	1743	387(19)
Exotic+native	2227	301(14)	1820	290(16)	1485	295(20)
Pasture (66%) + forest (34%)	1880	1309(69)	1458	1079(74)	1650	1039(63)

There are questions over the geological influences on springs/groundwater flows disappearing and reappearing in the catchments. Noted that as well as for total flows, quickflow (very small) and peak flows could not be related to the differing vegetation types. Each catchment's top 10 flows were similar.

Denmead, O.T. 1969: Comparative micrometeorology of a wheat field and a forest of *Pinus radiata*. Agricultural Meteorology 6: 357–371.

Country: Australia	Duration: 2 weeks — spring	Report Location: R1396
Species Comparison: Crop		
Stand Type: Plantation 7 yr	Stand Density: 1730 SPH	
Height: 7.5 m		
Keywords: Evaporation		

Comment
LE = L latent heat of evaporation of water and E evaporation rate
wheat 7 days mean LE = 234 cal/cm^2
pine 4 days = 329 cal/cm^2

From Dunin & Mackay (1982), 329 cal/cm^2 = 5.4 mm, therefore LE on individual days ranged from 3.8 to 7.5 mm

Dewar, R.C. 1997: A simple model of light and water use evaluated for *Pinus radiata*. Tree Physiology 17: 259–265.

Country: Australia	Duration: 4 yr	Report Location: R2
Stand Type: Plantation 10 to 13 yr	Stand Density:	Basal Area:
Keywords: Model		

CAB Abstract AN 970607455/Author's Abstract

An existing model of light and water use by crops (RESCAP) was adapted and evaluated for trees. In the model, growth on any given day is determined either by the amount of intercepted radiation (by means of the light utilisation coefficient, epsilon) or by the maximum rate of water extraction by roots (a function of root biomass and soil water content). In either case, transpiration and growth are related by the water-use efficiency (q), which is inversely proportional to the daily mean saturation vapour pressure deficit (D). The model was applied to two *P. radiata* stands (control, C and fertilised, F) growing near Canberra, Australia, using data collected during the Biology of Forest Growth experiment (1983–88). For both stands, predicted and measured soil water contents were in close agreement (r2 > 0.9) over a 4-yr period involving several wet-dry cycles. The parameter combination epsilon/qD was estimated to be 0.28 and 0.26 kg H2O (MJ total)-1 kPa-1 for the C and F stands, respectively. Because of the close physiological link between water use and CO^2 uptake, the results suggest that tree growth may be realistically simulated by simple models based on conservative values for epsilon and qD.

Comment

Uses the RESCAP model (RESource CAPture, Monteith (1986)) to predict tree growth. Combined with a water balance model it has soil moisture as a controlling factor. Predicted soil water close to measured soil water values.

Dons, A. 1980: Purukohukohu land use basin — a report on the effects of afforestation on water yield. New Zealand Hydrological Society Symposium 1980. (Unpublished).

Country: New Zealand	Duration: 11 yr	Report Location: LKR
Land-Use Change: Afforestation		
Stand Type: Plantation −4 to +6 yr	Stand Density: Various	
Keywords: Water yield		

Comment

Shows in figures the change in annual and seasonal water yield at Puruki determined by regression relationship from a pasture control catchment. Decreases started as early as the year after release spraying the pasture and planting the *P. radiata* seedlings (a reflection of the recovery of the grass — LKR).

By year 5, the annual reduction was as much as 2 L/s (44%). Winter reductions were 4 L/s (20%) and in summer were less than 2L/s but 70% of flow.

Dons, A. 1981: Results from the Purukohukohu land-use basin and their application to water and soil management. In: Waters of the Waikato. University of Waikato. Pp. 43–62.

Country: New Zealand	Duration: 11 yr	Report Location: R1575
Species Comparison: Native evergreen forest; Pasture		
Land-Use Change: Afforestation		
Stand Type: Plantation −4 to +7 yr	Stand Density: Various	
Keywords: Storm flow; Water yield		

Author's Abstract

The Purukohukohu land-use basin, situated midway between Rotorua and Taupo is described, together with an outline of some results concerning the hydrological effect of afforestation of pasture. After 7 yr of tree growth there have been substantial reductions in the annual, seasonal and peak flows from the small afforested catchment, which indicate beneficial effects of afforestation on gully erosion, sheet erosion and soil creep but detrimental effects on summer water supply and pollution dilution.

Comment

Planted 1973 at 2450 SPH but there had been vigorous regrowth of grasses and weeds. Thinning began April 1979 with the eastern subcatchment down to 550 SPH and pruned to 2 m. Central subcatchment was similarly treated in May 1980.

Flow reduction 7 yr after planting was 4.5 L/s = 47% of the predicted yield = 410 mm of ~1700 mm 1980 rainfall. Winter showed the greatest absolute decrease but summer the greatest proportional decrease.

Peak flows (based on those from the control catchment that were greater that 44 L/s/ha) had decreased by 90% by 1978, and after thinning in 1980 by 70%.

Dons, A. 1985: The effect of large-scale afforestation on Tarawera River flows. New Zealand Hydrological Society Symposium, Christchurch 1985. (Unpublished).

Country: New Zealand	Duration: 17 yr	Report Location: LKR
Land-Use Change: Afforestation		
Stand Type: Plantation — variable ages		
Keywords: Water yield		

Comment

Over 250 km^2 of the Tarawera catchment (906 km^2) in the central North island, New Zealand, was planted in pine forest between 1964 and 1981. This change has affected flow of the River Tarawera. Between 1964 and 1981 annual, summer and winter Tarawera flows showed significant reductions of 10.9

m^3/s, 11.4 m^3/s and 9.6 m^3/s respectively. Simple flow models for the Tarawera, and two neighbouring catchments that had undergone little land-use change, showed that about 4.5 m^3/s of these reductions, 13% of the mean flow over the calibration period, could be attributed to afforestation, while the remainder was due to decreased rainfall. The reduction attributed to afforestation was in accord with the results of small catchment studies.

Does not show data.

Dons, A. 1986: The effect of large-scale afforestation on Tarawera River flows. Journal of Hydrology (New Zealand) 25: 61–73.

Country: New Zealand	Duration: 17 yr	Report Location: LKR
Land-Use Change: Afforestation		
Stand Type: Plantation — variable ages		
Keywords: Water yield		

Author's Abstract

Over 250 km^2 of the Tarawera catchment (906 km^2) in the central North island, New Zealand, was planted in pine forest between 1964 and 1981. This change has affected flow of the River Tarawera. Between 1964 and 1981 annual, summer and winter Tarawera flows showed significant reductions of 10.9 m^3/s, 11.4 m^3/s and 9.6 m^3/s respectively. Simple flow models for the Tarawera, and two neighbouring catchments that had undergone little land-use change, showed that about 4.5 m^3/s of these reductions, 13% of the mean flow over the calibration period, could be attributed to afforestation, while the remainder was due to decreased rainfall. The reduction attributed to afforestation was in accord with the results of small catchment studies.

Comment

The only large scale study of land-use change in New Zealand. Afforestation has taken place between 1964 and 1981. Streamflow records were available for comparison for up to 15 yr pre-planting.

Dons, A. 1987: Hydrology and sediment regime of a pasture, native forest, and pine forest catchment in the Central North Island, New Zealand. New Zealand Journal of Forestry Science 17: 161–178.

Country: New Zealand	Duration: 3 yr	Report Location: R9
Species Comparison: Native evergreen forest; Pasture		
Stand Type: Plantation 8 to10 yr	Stand Density: 640 SPH	
Height: 13 m		Rainfall: 1550 mm/yr
Keywords: Low flow; Storm flow; Water balance; Water yield		

CAB Abstracts AN 900646468/Author's Abstract

The hydrology and sediment regime of a 0.10-km^2 pasture, 0.34-km^2 pine (*P. radiata*) forest, and 0.28-km^2 native (podocarp/broadleaved) forest catchment were compared. The highly permeable pumice soils of these catchments resulted in generally low annual stormflow yields (0.54–5.2% of gross rainfall) and consequently low annual sediment yields (4.0–27.0 t/km^2 p.a.). The pasture catchment had the highest average flows, highest peak flow rates, and greatest stormflow yields, but lowest evaporative losses. The pasture catchment also recorded the maximum instantaneous sediment concentrations and the maximum instantaneous sediment discharges. The pine forest catchment had the lowest annual average flows, lowest low flows, and lowest instantaneous sediment concentrations and discharges, but evaporative losses were similar to those from the native forest catchment. The native forest catchment had the lowest stormflow yields, lowest peak flows, and highest low flows. Some of the differences in hydrologic responses from the native forest catchment could be explained by drainage density rather than land use.

Comment

Puruki at Purukohukohu. Closed canopy by 1981.

Some problems with delineating catchment boundaries in this volcanic terrain. There is some doubt over the area of pasture catchment as it has been adjusted to 44% of the topographic area to meet similar RO/RF ratios for other pasture catchments for estimating water yields, but not for storm flows. It should be noted that in this region, streamflows are extremely variable in proportion to rainfall as the pumice country surface topography may bear little relationship to the hydrologic boundaries with transfers from catchment to catchment—there is evidence for fractured basement rock in the pasture catchment.

There are no comparable data given in this study for the pre-planting period to enable changes in the regimes to be estimated/compared. It is a straight comparison between differing land uses.

Interception loss assumed to be 26% (unpublished data). From flow duration curves, afforestation of a pasture catchment appears to have resulted in lower peak flows and low flows—a result of increased interception and decreased net rainfall. Storm flows were 2.2% and 5% of rainfall for the pine and pasture catchments, respectively.

Water balance—mean of 3 yr

	Pasture	Pine	Native forest
Area (ha)	10*	34	28
Pttn (mm)	1427	1398	1484
Storm flow (mm) (H&H)**	74 (5.2%)	31(2.2%)	8 (0.54%)
Delayed flow (mm)	469	223	331
Total flow (mm)	543	254	339
Evapotranspiration (mm)	784	1044	1045
Groundwater loss (mm)	100	100	100
Interception***	N/A	0.26 × P = 365 mm	0.26 × P = 385 mm

* Problems with delineating the catchment hydrologic boundary

** Hewlett & Hibbert (1967) separation; Values in parentheses are percentages of precipitation

*** Interception by pine from unpublished data (New Zealand Forest Research Institute) and assumed to be the same for native forest.

Duncan, H.P.; Langford, K.J.; O'Shaughnessy, P.J. 1978: A comparative study of canopy interception. Institution of Engineers, Australia, National Conference Publication 78/9: 150–154.

Country: Australia	Duration:	Report Location: R1586
Species Comparison: Conifers; Douglas fir; Eucalypt		
Stand Type: Plantation unknown age		
Keywords: Interception; Stemflow; Throughfall		

Comment

Coranderrk, Victoria. See Langford & O'Shaughnessy (1978) for stand information.

Weekly sampling:
TF = PTTN × 0.695 − 0.45
SF = PTTN × 0.141 − 1.04
IL = PTTN × 0.164 + 1.49

Interception summary

	Throughfall (%)	Stemflow (%)	Interception loss (%)
Mixed species	75.4	1.3	23.3
Hazel	73.2	12	14.8
Mature ash	72.5	4.3	23.2
Regrowth ash	76	5.3	18.7
Musk	75.1		
Redwood	59.8	1.1	39.1
P. radiata	68	10.6	21.4
Douglas fir	58	14.1	27.9

Note:
Rainfall amounts are not given in this paper.
Throughfall is greater for *P. radiata* than under redwood and Douglas fir but less than the eucalypt species.
Stemflow by pines was greater than all species except Douglas fir.
Interception loss by pines was half that of redwood, 2/3 that of Douglas fir, lower than two and higher than two eucalypt stands.

Duncan, M.J. 1980: The impact of afforestation on small catchment hydrology in Moutere Hills, Nelson. *In*: Land use in relation to water quantity and quality. Nelson Catchment Board, Nelson. Pp. 61–90.

Country: New Zealand	Duration: 15 yr	Report Location: R1479
Species Comparison: Pasture; Scrubland (Gorse)		
Land-Use Change: Afforestation		
Stand Type: Plantation −7 to 8 yr	Stand Density: Various	Rainfall: 1105 mm
Keywords: Interception; Low flow; Stemflow; Storm flow; Throughfall; Water yield		

Author's Abstract
.... In 1970 *P. radiata* were planted:
(a) directly on a pasture catchment
(b) in another catchment after gorse was burnt and linedozed, and
(c) in a further catchment after gorse was burnt, later disced and 9 months had elapsed.
Three control catchments remained in pasture in 1963–78.

For the12 months following burning there was an increase of 53% (184 mm) and 167% (236 mm) from the catchments previously in gorse (b and c above, respectively) and increase flow persisted 3 and 5 yr after planting respectively. There was no increase from the pasture after planting. However, by 1978

the runoff from the two catchments previously on gorse had reduced by 65% (64 mm) and 5% (2 mm) respectively, and from the catchment previously in pasture had reduced by 76% (56 mm).

The mean runoff from the three pine catchments was compared with the mean runoff from the three pasture catchments on a quarterly basis over the period 1973 to 1978 and the runoff from the pine catchments was almost invariably less than half that from pasture catchments. The greatest difference in runoff between pines and pasture catchments occurred in the July–September quarters because most runoff occurs then. However, when this difference is expressed as a percentage of runoff from pasture catchments, the greatest percentage difference occurs in other quarters.

During 1975 and 1976 there was no difference in the number of days of zero flow, but in 1977 and 1978 there was no flow from pine catchments for 2½ and 1 month, respectively, while there was still flow from the pasture catchments. For most of the low flow period runoff from pine catchments was half that from pasture.

Flood peaks and volumes from the pine catchments in 1978 were on average 73% lower than those from pasture catchments. Flood peaks from gorse catchments before they were burnt (1968 and 1969) were on average 78% lower than those from the pasture catchments. In the same years, flood peaks from the pasture catchments that were later planted in pines were 9% greater that the average from the other pasture catchments. Thus the gorse and pine reduced flood peaks by a similar amount.

Precipitation gauges under the pine canopy show that the difference between runoff from pine and pasture catchments is equal to the amount of precipitation intercepted by the pine trees.

Comment

Same catchments as in Duncan (1995a,b) with the addition of catchment 15, another pasture catchment. Covers seasonal runoff, flood peaks, low flow, and interception (including changes due to thinning)

An interception study was located in catchment 14: Planted after pasture disced in1970 at 1500 SPH; thinned 1975 (5-yr-old trees) to 500 SPH and pruned to 2.5 m. Canopy closure by 1978

Pre-thinning (5-yr-old trees)	IL = 20% of PTTN (= 220 mm of MAP)
Post-thinning	IL = 8% of PTTN = 60% reduction in IL for 60% reduction in stem numbers.

Data below is off Figure 15 for trees up to aged 8 yr

Moutere catchment 14 interception data

Age	TF%	SF%	IL%
4	86	5	9
5 Pre-thinning	74	3	23
5 Post thinning	88	3	9
6	83	3	14
7	80	3	17
8	76	4	20

Duncan, M.J. 1983: The effects of planting pines on water yield in Nelson. New Zealand Hydrological Society Symposium, Dunedin, 1983. (Unpublished).

Country: New Zealand	Duration: 18 yr	Report Location: LKR
Species Comparison: Pasture; Scrubland (Gorse)		
Land-Use Change: Afforestation		
Stand Type: Plantation −7 to 11 yr	Stand Density: Various	Rainfall: 1105 mm
Keywords: Low flow; Storm flow; Water yield		

Comment
Moutere, Nelson. An update of Duncan (1980) with an additional 3 yr of data.

In 1970 *P. radiata* were planted:
(a) directly on a pasture catchment
(b) in another catchment after gorse was burnt and linedozed, and
(c) in a further catchment after gorse was burnt, later disced and 9 months had elapsed.
Three control catchments remained in pasture in 1963–81.

Since 1978 water use by the pines had leveled off. By 1981, runoff reduction from the two catchments previously in gorse, 51% and 2%, and from the one previously in pasture, 60%, were smaller than given in Duncan (1980). Notes that for 1975–1981 the seasonal yield from the pine catchments was invariably less than half that from the pasture catchment, the magnitude being greater in the July–September quarter when flow is greatest but other quarters had the greatest percentage change.

Five and 6 years after planting there was no difference in the number of days of zero flow in the pine and pasture catchments. For the years 8 to 11 after planting, there were 82 days with no flow in the pine and pasture catchments with an extra 52 days without flow in the pine catchments.

Between 1978 and 1981, flood peaks and quickflow volumes from the pine catchments were only 27% and 14% of that from the pasture catchment. Notes that before being burned, flood peaks in the gorse catchments were 22% of those in the pasture catchment, a similar effect to that of the pines.

Duncan, M.J. 1993: Does planting pines reduce groundwater recharge? New Zealand Hydrological Society Symposium, Nelson, 1993. (Unpublished).

Country: New Zealand	Duration: 11 yr	Report Location: LKR
Species Comparison: Pasture; Scrubland (Gorse)		
Land-Use Change: Afforestation		
Stand Type: Plantation 4–15 yr	Stand Density: Various	Rainfall: 1105 mm
Keywords: Soil water		

Comment
Moutere catchments, Nelson.

Monitored soils moisture from 1974 (trees age 4 yr) to 1986. Used a neutron probe and had three access tubes in each of the pasture and two pine catchments.

There were no data from the pretreatment period or for the first 4 yr of tree growth so the reference point was 1974. Soil moisture from the pines catchment 8 was always below that of the pasture, got larger until age 6 yr and tended to remain at a constant lower level thereafter. In pines catchment 14, the soil moisture deficits were similar at the start of the sampling period and declined up until year 7 to a constant deficit except for marked responses to thinning.

A plot of mean monthly soil water potential deficits for 1974–1986 shows the pine catchments to be in deficit longer (December to June compared to February to May) and by a greater amount. When there was a surplus, that in the pines was smaller than for the pasture catchment.

Duncan, M.J. 1995a: Hydrological impacts of converting pasture and gorse to pine plantation, and forest harvesting, Nelson, New Zealand. Journal of Hydrology (New Zealand) 34: 15–41.

Country: New Zealand	Duration: 28 yr	Report Location: R30
Species Comparison: Pasture; Scrubland (gorse)		
Land-Use Change: Afforestation		
Stand Type: Plantation − 7 to 20 yr	Stand Density: Various	Rainfall: 1018 mm
Keywords: Interception; Low flow; Stemflow; Storm flow; Throughfall; Water yield		

CAB Abstracts AN 950619305/Author's Abstract

The hydrological impacts of converting hill country pasture and tall dense gorse [*Ulex europaeus*] to *P. radiata* plantation and subsequent felling of the mature forest are examined using data collected from five small (4.0–7.7 ha) catchments in Moutere Gravel hill country near Brightwater, Nelson, New Zealand. After a 6-yr calibration period one pasture catchment and two tall dense mature gorse catchments were planted at a density of 1500 trees/ha in 1970/71. The trees were pruned and thinned at various times until in 1981 all catchments were stocked at 300 trees/ha. The trees were felled in the winter of 1991. Annual water yield increased by 219–358 mm/yr in the 3 yr after the gorse catchments were cultivated or line dozed for planting. Water yield reduced to preplanting values 4–5 yr after planting. Over the next 2–3 yr annual water yield continued to decline, as the canopy closed. Thereafter annual water yields were relatively constant with some response to annual rainfall variation and silvicultural practices. These water yields averaged 63 mm/yr less than would be expected from gorse. Water yields in the former pasture catchment started to reduce 3 yr after planting and beyond 7 yr averaged 167 mm/yr less than expected from pasture. Four months after clear-felling, when soil moisture levels had been replenished, runoff rates had increased and were greater than those from pasture. In the first and second years after harvest flows increased 0–60 mm/yr and 226–343 mm/yr, respectively, above those expected from *P. radiata*, to yield in the second year flows similar to those expected from bare land.

The small catchments were all ephemeral, and those with gorse or *P. radiata* cover can be expected to be dry for 3 months per year more than pasture catchments. When all catchments are flowing, *P. radiata* or gorse catchments have less than half the flow expected from pasture catchments.

Peaks of freshes from *P. radiata*/gorse catchments are 20% of those from pasture catchments. As annual flood exceedance probability (AEP) decreases the difference in flood size also decreases until for AEPs of 0.02 flood peaks from *P. radiata*/gorse catchment average half of those from pasture catchments.

The differences in runoff between *P. radiata* and pasture catchments are primarily attributed to greater interception by the *P. radiata* trees and greater soil moisture storage potential under *P. radiata* because of their greater rooting depth.

Comment
Moutere: study covers a full rotation although there are a couple of gaps in the record. Pines were planted in land from pasture or gorse. MAP 1018 mm, and ranges from 53 mm in February to 103 mm in August.

Runoff for various periods

Period	Rainfall (mm)	C2 pasture	C5 pasture	C8 pines x gorse	C13 pines x gorse	C14 pines x pasture
Control 1964–1970	1032	258	284	242	128	258
1971–1975	1013	203	278	378	228	172
1976–1981	986	158	213	67	56	40
1982–1987	1015	223	289	108	87	57
1991/92–1992/93	989		216	298	148	136

Interception data
Post-thinning here is after the second thinning to 300 SPH in March1981, Moutere C14 x Table 3
First thinning/pruning was July 1975 when the trees were reduced to 500 SPH

Moutere catchment 14 interception data

Year	Age (yr)	PTTN (mm)	C14 IL Pre-thinning (mm (%))	C14 IL Post-thinning (mm (%))
1975	4	1167	130 (11)	
1976	5	1300	307 (24)	
1977	6	963	177 (18)	
1978	7	855	236 (28)	
1979	8	1028	284 (28)	
1980	9	1082	491 (45)	
1981	10	938		134 (14)
1982	11	834		183 (22)
1983	12	1284		179 (14)
1984	13	1027		273 (27)
1985	14	1214		259 (21)

Seasonal effect: IL Autumn 24% Winter 27% Spring 20% Summer 18%. Note: this trend is opposite to Donald Creek, South Nelson, data for native evergreen forest (Rowe 1985).
Stemflow 5.5% for 1500 SPH, 3.1% for 500 SPH, and 0.1% for 300 SPH.

Duncan, M.J. 1995b: Predicting the effects of afforestation on low flows in the Mangakahia catchment, Northland. New Zealand Meteorological and Hydrological Symposium, November 1995, Christchurch. 2 p. (Unpublished).

Country: New Zealand	Duration: 14 yr	Report Location: LKR
Land-Use Change: Afforestation (pasture/scrub)		
Keywords: Low flow		

Comment
Mangakahia above Titoki—809 km^2. Between 1980 and 1995, 24% underwent afforestation from undeveloped pasture and scrub to *P. radiata*—mostly before 1988.

To quote:

"An annual low flow series (1982–1995) without pines was constructed by increasing flow on a pro-rata basis based on the area of pines and the original vegetation and the percentage change in flow associated with that landuse change. Minimum series were constructed in a similar way on the basis of the current level of pine planting and/or future predicted levels of pine planting to give a list of estimated mean annual minima from catchments with current and predicted areas of pine forest.

Flow has been measured at Mangakahia at Gorge site since 1961 and not until 1983 could the flows have been affected by converting catchment cover to pines. The mean annual low flow 1961–1982 was 1447 L/s and for 1983–1995 was 10.3% less at 1298 L/s. Annual rainfall data indicates that rainfall differences between the periods are unlikely to be the cause of this reduction in minima. Calculation of the minima since planting based on the area and landuse of land converted to pines and the New Zealand wide average hydrological effects of those changes, estimates the 1983–1995 mean annual low flow to be 1315 L/s (9/1% less than the pre-planting minima of 1447 L/s). This estimate is close to(17 L/s different) the measured mean annual minima for the same period."

Dunin, F.X.; Mackay, S.M. 1982: Evaporation of eucalypt and coniferous forest communities. *In*: O'Loughlin, E.M.; Bren, L.J. (Eds.), First National Symposium on Forest Hydrology. Institute of Engineers Australia, National Conference Publication 82/6: 18–25.

Country: Australia	Report Location: R1358
Species Comparison: Eucalypt	
Stand Type: Plantation Ages vary	
Keywords: Evaporation; Interception; Transpiration	

CAB Abstracts AN S849216/Authors' Abstract

Interception and transpiration losses from eucalypt and coniferous forest systems were reviewed as a basis to compare evaporative losses by the different communities. Interception losses from coniferous forest under normal management were greater than those from eucalypt forest due mainly to the larger leaf area associated with conifers. The difference in interception loss was estimated as being equivalent to being about 10% of annual rainfall. Similarity in transpiration between communities was observed both on an hourly and annual basis. However, on the annual scale, differences can exist in the patterns of transpiration even though annual totals were comparable. This occurred in subhumid environments with periods of soil water stress. The leaf area of eucalypt communities fluctuated on a seasonal scale resulting in a different pattern of transpiration dynamics from that of *P. radiata* plantations with a characteristically high and stable leaf area. The implications of the differing patterns were explored to explain greater plant production in pine plantations than in eucalypt communities. A model of vapour loss from *P. radiata* was developed to stimulate the consequences of converting eucalypt forest to pine plantation. Realistic solutions for increased vapour loss from pine over eucalypt communities were claimed with an estimated difference between 35 and 100 mm per year in two case studies at Lidsdale and Batemans Bay, N.S.W.

Comment

Discusses a number of Australian studies already covered in this bibliography.

Dye, P.J. 1996: Climate, forest and streamflow relationships in South African afforested catchments. Commonwealth Forestry Review 75: 31–38.

Country: South Africa	Report Location: R1572
Species Comparison: Eucalypts; Pines; Scrubland (fynbos)	
Land-Use Change: Afforestation	
Stand Type: Plantation Various ages	
Keywords: Evaporation; Review; Water yield	

Comment

Reviews information from Jonkershoek (in other references here), Cathedral Peak and other South African studies. No detail on interception losses.

Fahey, B.D. 1964: Throughfall and interception of rainfall in a stand of radiata pine. Journal of Hydrology (New Zealand) 3: 17–26.

Country: New Zealand	Duration: 9 months	Report Location: R226
Stand Type: Plantation—30 yr	Stand Density: 340 SPH	
Height: 21 m	Diameter: 25 cm	
Keywords: Interception; Throughfall		

Author Abstract

Some interception values are determined for *P. radiata* in the Silverstream catchment, Otago. Both net rainfall and pattern of throughfall are correlated with a number of factors. Individual storm total appears to be the main factor in determination of throughfall and interception loss.

Over the 9-month recording period a total rainfall of 920 mm was measured in the open. Of this total, on the average, only 48% (440 mm) reached the forest floor as throughfall; 49% (450 mm) being attributed to the average interception loss. Stemflow was accounted for by the 3% (30 mm estimate) deficit.

Comment

Throughfall was higher in storms with no wind, and in larger rainfall events.

Throughfall and interception loss with storm size

Storm size (mm)	Throughfall %	Interception loss %
0–2.5	22	78
2.6–7.6	40	60
7.7–19.8	54	46
19.9–32.8	56	44
37.5–85.6	62	38

Fahey, B.D. 1990: Hydrological impacts of afforestation of tussock grasslands, Glendhu Forest, Otago. New Zealand Hydrological Society Symposium, Taupo 1990. (Unpublished).

Country: New Zealand	Duration: 10 yr	Report Location: LKR
Species Comparison: Native grassland		
Land-Use Change: Afforestation		
Stand Type: Plantation −2 to 7 yr	Rainfall: MAP 1350 mm/yr	
Keywords: Storm flow; Water yield;		

Comment

Describes the Glendhu catchments and treatments. In the first 6 yr after planting 67% of GH2, the only hydrological change noticed was a reduction in the proportion of quickflow. From about 6 yr after planting, monthly streamflow yields from GH2 were less than from the control catchment in tussock grassland amounting to a reduction of about 130 mm/yr or 25% of the flow.

Peak flows were reduced in the 7th year. For the flow class 5–10 L/s/ha, the average peak flow from the planted catchment was 50% lower than from the tussock catchment compared to 7% less in the pretreatment period. A smaller reduction was noted in the flow class > 10 L/s/ha, 22% compared to 5% in the pretreatment period.

Fahey, B. 1994: The effect of plantation forestry on water yield in New Zealand. New Zealand Forestry 39: 18–23.

Country: New Zealand	Duration:	Report Location: R35
Species Comparison: Native evergreen forest; Native grassland; Pasture; Scrubland		
Land-Use Change: Afforestation; Conversion from native forest; Forest management; Harvesting		
Stand Type: Plantation ages vary		
Keywords: Low flow; Review; Storm flow; Water yield		

CAB Abstracts AN 950606094

Author Abstract

This paper discusses the hydrological consequences of converting land in native forest, scrub, tussock grassland, and pasture to plantation forestry, and the impacts of harvesting and re-establishing a tree crop. Forests influence water yield and associated streamflow responses through increased canopy interception of rainfall. Thus afforestation of pasture may reduce water yield by 30–50% 5–10 yr after planting. For tussock grasslands the reduction is between 25 and 30%. A similar percentage reduction can be expected in low flows. Storm quickflows and flood peaks can fall by over 50%. Silvicultural practices, such as understorey control and spreading the time of planting, have the potential to augment water yield.

Forest harvesting in moderate-to-high rainfall areas can cause a 60–80% increase in water yield for 3–5 yr after clearfelling. Yields should return to pre-harvesting levels within 6–8 yr, depending on the silvicultural regime adopted. Mean flood peaks can rise by up to 50%. However, the hydrological impact must be viewed within the context of the area harvested compared with the total forest area. If the former is small in comparison, any local increases in water yield and flood response may be quickly attenuated.

Comment

Reviews a number of New Zealand studies discussed elsewhere here.

Fahey, B.D. 1999: Interception loss by stands of Douglas fir and radiata pine near Hororata, Mid-Canterbury. New Zealand Hydrological Society Symposium, Napier 1999. (Unpublished).

Country: New Zealand	Duration: 9 months	Report Location: LKR
Species Comparison: Douglas fir		
Stand Type: Plantation: 17 yr		
Keywords: Interception; Stemflow; Throughfall		

Comment

Interception by *P. radiata* and Douglas fir stands

	P. radiata 17 yr	Douglas fir 18 yr	Douglas fir 54 yr
Stand density (SPH)	654	1360	570
Rainfall (mm)	712	712	648
Throughfall (mm)	495	455	399
Stemflow (mm)	55	32	33
Interception loss (%)	23	33	34

Fahey, B.D. 2000: Interception loss by stands of Douglas fir and radiata pine, South Island, New Zealand. IUFRO World Congress 2000, August 2000, Kuala Lumpur. Forests and Society: The Role of Research Poster Abstracts Vol. 3: 454–455.

Country: New Zealand	Duration: 9 months	Report Location: LKR
Species Comparison: Douglas fir		
Stand Type: Plantation: 17 yr		
Keywords: Interception		

Comment
Rainfall for the 9 months was 700 mm.

Interception loss for *P. radiata* and Douglas fir stands

	P. radiata 17 yr	Douglas fir 18 yr	Douglas fir 54 yr
Stand density (SPH)	654	1360	570
Interception loss (%)	23	33	34

Fahey, B.; Jackson, R. 1995: Hydrological effects of converting indigenous forests and grasslands to pine plantations, Big Bush and Glendhu experimental catchments. New Zealand Meteorological and Hydrological Symposium, Christchurch 1995. (Unpublished).

Country: New Zealand	Duration: 13/15 yr	Report Location: LKR
Species Comparison: Native evergreen forest; Native grassland		
Land-Use Change: Afforestation; Conversion from one forest to another		
Stand Type: Plantation −2 to 10 yr		
Keywords: Low flow; Storm flow; Water yield		

Comment
Big Bush Forest, Nelson.
In the 4 yr after harvesting native forest in two catchments, average annual yields increased by 310 (61%)and 342 (68%). Peak flows in all storm classes increased after harvesting: 2–5 L/s/ha by 77% and 52%; 8–15 L/s/ha by 16% and 0%. Quickflows responded similarly but were more subdued. Yields were back at pretreatment levels after 8 yr, this being delayed by increases after thinning operations. Storm peak flows and quickflows took 10 yr to return to pretreatment levels. In the 5 yr after harvest, lowflows were 2–3 times that of the control catchment but had returned to pretreatment levels after 5 yr.

Glendhu, Otago—67% planted.
There was no difference in yield for the 6 yr after planting a tussock catchment. In the 8–12 year period after planting yields were reduced by 231 mm (27% of the runoff at the control catchment. The mean minimum 7-day low flows showed a reduction of 0.18 mm/day and peak flows had reduced by 55–65% depending on the flow class size.

Fahey, B.; Jackson, R. 1997a: Hydrological impacts of converting native forests and grasslands to pine plantations, South Island, New Zealand. Agricultural and Forest Meteorology 84: 69–82.

Country: New Zealand	Duration: 13/17 yr	Report Location: R32
Species Comparison: Native evergreen forest; Native grassland		
Land-Use Change: Afforestation; Conversion from one forest to another		
Stand Type: Plantation −2 to 15 yr	Rainfall: Big Bush 1530 mm/yr; Glendhu 1350 mm/yr	
Keywords: Low flow; Storm flow; Water yield		

CAB Abstracts AN 970605082/Authors' Abstract

Changes in water yield, flood hydrology, and low flow caused by replacing indigenous forests and grasslands with commercial softwoods have been investigated in New Zealand since the mid-1970s. The long-term results of two of these studies are discussed here.

The first deals with the conversion of mixed evergreen forest to pine plantation in the northwestern South Island. After a 2-yr calibration period one catchment was left as the control (DC2) and the other two catchments were harvested in 1981, one by skidder (DC1) and the other by hauler (DC4), and planted in pines shortly thereafter. For the first 4 yr after harvesting the average annual difference in water yields between DC1 and DC2 was 352 mm (69%), and between DC4 and DC2 was

463 mm (90%), which equates to an annual increase of 312 mm (68%), respectively, when compared with the calibration period. Planting the harvesting areas caused the water yield from both catchments to return to pre-harvesting levels within 8 yr, and an estimated reduction in runoff of 340 mm within 5 yr at DC4. Mean flood peaks increased after harvesting, especially for small and medium storms on the skidder-logged catchment (75–100%). The response of the storm quickflows to harvesting was similar but much more subdued. Low flows also increased after harvesting. Tree growth brought storm peak flows, quickflows, and low flows back to the levels of those in the original beech forest within 10 yr.

The second study examines the impact of converting tussock grasslands to pine plantations using data collected from two catchments in the eastern uplands of southern New Zealand. After a 3-yr calibration period (1980–1982) one catchment was planted in pines over 67% of its area and the other was left in tussock. By 1989 the difference in annual water yield from the planted catchment was 130 mm, and between 1991 and 1994 it averaged 260 mm (27% of total runoff from the control). Differences in low flows (represented by the minimum annual 7-day mean) showed a similar trend, and suggest that in dry periods, afforestation of tussock grasslands can reduce water yields by 0.18 mm/day. Higher interception losses from increased canopy evaporation is believed to be the main reason for the reduction in water yield. After 10–12 yr of tree growth mean flood peaks had fallen between 55 and 65%, and quickflows had decreased by about 50%.

Comment

Gives changes in water yields but no data on annual flows under any of the vegetation regimes.

Big Bush—Conversion of native forest to pine plantation

Low flows, peakflows and yields all increased after harvesting the native forest. In the 4 yr after 83% clearfelling of DC1 streamflow increased 312 mm/year (61%) and at the 94% cleared DC4 the yield was 344 mm/year higher (90%). (These are proportionally equivalent to 375 and 365 mm on a 100% clearfelling basis—LKR). After this, there was a decline in flows to pre-harvest levels after about 8 yr.

Low flow comparison are difficult as DC2, the control catchment, dries up in some years. However there were increases in the 7-day minimum flow up to 0.05 mm/day at DC4 after harvesting and this had declined to native forest levels by about 10 yr after planting.

Glendhu—Afforestation of tussock grassland at GH2

Annual flows began to diminish about 5 yr after planting and seemed to approach a stable level of about 250 mm lower than the tussock catchment after about 8 yr. This was for a catchment planted over 67% of its area.

Low flows: Between 1992 and 1994, the minimum 7-day low flow at GH2 averaged 0.18mm/day lower (0.13 to 0.33 mm range); GH1 range was 0.5 to 1 mm/day in nearly all years.

Peakflows: Four size classes (> 2 L/s/ha). 1991–1993 had fewer storm at GH2 than at GH1. For comparable storms in the size classes at GH1 storms were reduced at GH2 by an average 57% in 2–5, 58% in 5–10 (15 storms), 65% in 10–15, and 55% in >15 L/s/ha size classes.

Storm quickflow: in four classes above 5 mm, mean yields were reduced 40 to 57% compared to GH1, and there were lesser events in each size class.

Fahey, B.D.; Jackson, R.J. 1997b: Environmental effects of forestry at Big Bush Forest, South Island, New Zealand: I. Changes in water chemistry. Journal of Hydrology (New Zealand) 36: 43–71.

Country: New Zealand	Duration: 7 yr	Report Location: R36
Species Comparison: Native evergreen forest		
Land-Use Change: Conversion from one forest to another		
Stand Type: Plantation −2 to +5 yr		
Keywords: Water quality; Water yield		

CAB Abstract/Author abstract

This study considers short-term (immediate post-harvesting) and long-term (forest establishment) changes in water chemistry (base cations, total N, and total P) in streamflow from three experimental catchments in Big Bush Forest, central Nelson. One (DC2) has been left in beech/podocarp forest as the control (4.77 ha). In 1980 catchment DC1 (8.57 ha) was skidder-logged and DC4 (20.19 ha) was hauler-logged. In DC1, concentrations of the dominant cation (Na+) rose from a pretreatment mean of 2.83 mg/L to a maximum of 5 mg/L, then declined to 3.82 mg/L, 4 yr after harvesting. For K+, the pre-treatment mean concentration was 0.75 mg/L, rising to a maximum of 5.4 mg/L, but 1 yr later had fallen to a mean of 0.90 mg/L. Fluctuations in concentrations of Ca2+ and Mg2+ were smaller. Similar patterns of change were recorded at DC4. Total N concentrations at DC4 increased 10–12 times compared with the control, but seldom exceeded 1 mg/L, and were close to pretreatment levels 4 yr after harvesting. The response of total P was similar but more subdued. Cation yields over the period 1980–1986 for DC1 and DC4 were double that of the control (22.4 kg/ha/yr). Total N yields (0.18–0.44 kg/ha at the control) were much lower than those for cations. At DC4 they increased by up to an order of magnitude after harvesting, and were still 3–5 times higher than the control 4 yr later. Total P (0.08–0.14 kg/ ha/yr at the control) increased 2–3 times after harvesting. Rainfall chemistry data from other sites suggest an approximate balance between cation and nutrient inputs and outputs for undisturbed beech/podocarp forest. Recent short-term monitoring suggests that cation and nutrient yields in streamflow from pine plantations at mid-rotation will be comparable to those from mature beech/podocarp forest. Yields of total N in the first few years after harvesting were comparable to or less than those recorded for pasture.

Comment:
Shows annual water yields for the three catchments for 1980–1986 (their Fig. 2). Increase in water yield after clearfelling the native forest are apparent and this begins to decline after about 3 yr as the *P. radiata* crop grows. However, the main thrust of the paper discusses water quality changes.

Fahey, B.; Jackson, R.; Rowe, L.K. 1998a: Hydrological effects of land-use change in the upper Waipori catchment, east Otago. Meteorological Society of New Zealand and New Zealand Hydrological Society Symposium, Dunedin, 1998. (Unpublished).

Country: New Zealand	Duration: 18 yr	Report Location: LKR
Species Comparison: Native grassland; Pasture		
Land-Use Change: Afforestation		
Stand Type: Plantation −3 to 15 yr		
Keywords: Low flow; Water yield		

Comment
At Glendhu, between 8 and 14 yr after planting 67% of a tussock catchment streamflow yields had fallen by an average of 270 mm (31%) of streamflow from the control catchment. Minimum annual 7-day low flows had fallen 0.13 mm/day, 16% of that at the control catchment.

Data from Glendhu was used in a daily water balance model to show that if the plantation area of the upper Waipori catchment was converted to pasture or returned to tussock grassland, water yields would increase by 5% and 8%,respectively.

Fahey, B.; Jackson, R.; Rowe, L.K. 1998b: Hydrological effects of afforestation and pasture improvement in montane grasslands, South Island, New Zealand. *In*: Sassa, K. (Ed.) Environmental Forest Science. Kluwer Academic Publishers. Dordrecht. P 395–404.

Country: New Zealand	Duration: 18 yr	Report Location: LKR
Species Comparison: Native grassland; Pasture		
Land-Use Change: Afforestation		
Stand Type: Plantation −3 to 15 yr		
Keywords: Low flow; Water yield		

Comment
At Glendhu, 7 years after planting 67% of GH2, annual streamflow had fallen by 130 mm and between 9 and 15 yr after planting yields had fallen by an average of 270 mm (31%) of streamflow from the control catchment.

Minimum annual 7-day low flows had fallen 0.11 mm/day, 15% of that at the control catchment, between 12 and 15 years after planting.

A model was used to estimate changes likely to occur if there were land use changes in the Waipori catchment—30000 ha of which 49% is in tussock grassland, 34% in pasture/depleted tussock land, 17% plantation forest. If the forest was not present, runoff would be 5% higher if the land had been originally in pasture and 8% higher if originally in tussock.

Fahey, B.D.; Rowe, L.K. 1992: Land-use impacts. Ch. 15 in Mosley, M.P. (Ed.) Waters of New Zealand. New Zealand Hydrological Society, Wellington. Pp. 265–284.

Country: New Zealand	Report Location: R1603
Species Comparison: Native evergreen forest; Native grassland; Pasture; Scrubland	
Land-Use Change: Afforestation; Conversion from one forest to another	
Keywords: Review; Storm flow; Water balance; Water yield	

Comment
Reviews many of the New Zealand studies on the effects of land-use change on the hydrology of catchments.

Fahey, B.D.; Watson, A.J. 1991: Hydrological impacts of converting tussock grassland to pine plantation, Otago, New Zealand. Journal of Hydrology (New Zealand) 30: 1–15.

Country: New Zealand	Duration: 11 yr	Report Location: R31
Species Comparison: Native grassland		
Land-Use Change: Afforestation		
Stand Type: Plantation −3–8 yr	Stand Density: Initially 1250 SPH	
Keywords: Low flow; Storm flow; Water balance; Water yield		

CAB abstracts AN 920662839/Authors' Abstract

The hydrological impacts were studied of converting lightly grazed mid-altitude tussock grassland to *P. radiata* plantation, using data collected from two medium-sized catchments in upland east Otago. After a 3-yr calibration period, 207 ha of one catchment (310 ha) were planted at 1250 stems/ha in 1982. No change in water yield was observed until late 1988. In 1989, annual runoff from the planted catchment was 100 mm less than that from the adjacent control tussock catchment (218 ha). The same was true in 1990, representing a 20% reduction in water yield each year. Site preparation before planting had a much earlier effect on the quickflow component of annual runoff, causing it to decrease by about 9% in 1983. The peak flow rates of small storms (<10 L/s/ha) were most affected by afforestation and showed an average reduction of up to 50% for the 1988–90 period. Storm quickflow volumes showed a 29% reduction over the same period. Flow-duration curve analysis suggested that less water is now being released as low flow storage in the planted catchment than in the control catchment. Greater interception loss through increased evaporation rates from a wetted forest canopy is believed to be the main reason for reduced water yields after almost 8 yr of tree growth.

Comment
A 200-ha tussock grassland catchment was ripped and planted with *P radiata* seedlings in 1982 after 3 yr of calibration data. 67% of the catchment was planted—riparian areas and wetlands were excluded. The decline in flow became manifest in 1987.

Water yield changes at Glendhu for 67% afforestation of GH2

Year	Precipitation (mm)	GH1 (mm)	GH2 (mm)	Difference (GH1−GH2)	Reduction (%)
1980	1555	911	907	4	1
1981	1265	728	707	21	3
1982	1482	837	825	12	1
1983	1572	1115	1145	-30	-3
1984	1388	946	883	63	7
1985	958	488	476	12	2
1986	1487	799	810	-11	-1
1987	1591	1008	959	49	5
1988	1321	718	681	37	5
1989	1222	705	574	131	19
1990	1063	533	428	105	20
Mean	1355	799	761		

Comparison between storm flows in the >10 L/s/ha size class at the control catchment showed a reduction in the planted catchment.

Low flows may be showing signs of reduction in flow.

Fahey, B.; Watson, A.; Payne, J. 2001: Water loss from plantations of Douglas fir and radiata pine on the Canterbury Plains, South Island, New Zealand. Journal of Hydrology (New Zealand) 40: 77-96.

Country: New Zealand	Duration: 20 months	Report Location: LKR
Species Comparison: Douglas fir		
Stand Type: Plantation 18 yr	Stand Density: 650 SPH	Basal Area: 46 m^2/ha
Height: 20 m	Diameter: 30 cm	Rainfall: MAP 850 mm
Keywords: Evaporation; Interception; Stemflow; Throughfall; Transpiration; Water balance		

Comment

In addition to the interception measurements made, eight months (October to May) of transpiration data derived from sapflow measurements are available.

Stand parameters and interception values, Canterbury, New Zealand

	P. radiata	Douglas fir	Douglas fir
Age (years)	18	18	54
Height (m)	20	11	28
Stocking (SPH)	650	1350	550
Mean DBH (cm)	30	19	38
Basal area (m^2/ha)	46	38	67
Sapwood area (m^2/ha)	14	14	9
Gross precipitation (mm)	1586	1586	1397
Throughfall (mm)	1195	1064	920
Throughfall (%)	75	67	66
Stemflow (mm)	90	61	70
Stemflow (%)	5.7	5	3.9
Interception loss (mm)	301	461	407
Interception loss (%)	20	29	28

Estimated water balance (mm), *P. radiata* and Douglas fir, October to May

	18-yr-old *P. radiata*	18-yr-old Douglas fir	54-yr-old Douglas fir
Gross rainfall	816	816	700
Interception	155	219	170
Transpiration	341	382	406
Understory evaporation	41	0	35
Total losses	536	601	611
Available for recharge	280	215	89

Feller, M C. 1978: Nutrient movement into soils beneath eucalypt and exotic conifer forests in southern central Victoria. Australian Journal of Ecology 3: 357–372.

Country: Australia	Duration: 2 yr	Report Location: LKR
Species Comparison: Eucalypts; Douglas fir		
Stand Type: Plantation 32 yr	Stand density: 1200 SPH	
Height: 40 m	Diameter: 30.9 cm	
Keywords: Soil water		

CAB Abstracts AN: 791951505

Above-ground nutrient return to the soil was estimated by studying forest floor leachates for 2 yr in two eucalypt forests (*Eucalyptus obliqua*) and *E. regnans*) and two nearby conifer plantations (*P. radiata* and *Pseudotsuga menziesii*) near Narbethong in southern central Victoria. Forest floor leachate volumes were recorded and samples were analysed for pH and potassium, sodium, magnesium and calcium concentrations. The volume of forest floor leachate was greater in the eucalyptus. This was attributed to greater interception losses of water by the conifers. In each of the four forest types, leachate acidity was highest in spring and autumn and lowest in summer. Cation concentrations were highest in autumn and lower in spring. This behaviour was attributed to changes in climate and in rates of litter decomposition. Cation quantities entering the soil in leachates showed no pronounced seasonal variations but were significantly higher in *E. obliqua* than in *P. radiata*. Greater quantities of acid were added to the soil under *P. radiata*. The *P. radiata* soil contained lower quantities of exchangeable cations than the *E. obliqua* soil but the *P. menziesii* soil did not appear to be depleted in exchangeable cations.

Comment:

Forest floor leachate, Victoria

	May–Dec. 1976	1978	Jan–Jul. 1977
Rain (mm)	608	927	820
E. regnans (?)	123	134	143
E obliqua (?)	118	130	154
P. radiata (?)	88	97	123
P. menziesii (?)	75	–	–

Rainfall site is 5 km away.
Leachate values were given as volumes in centimetres but this is inconsistent with the rainfall.
Trend is: ER ~ EO > PR > PM.

Feller, M.C. 1981: Water balances in *Eucalyptus regnans, Eucalyptus obliqua*, and *Pinus radiata* in Victoria. Australian Forestry 44: 153–161.

Country: Australia	Duration: 2 yr	Report Location: R109
Species Comparison: Eucalypts		
Stand Type: Plantation 37–38 yr	Stand Density: 670 SPH	Basal Area: 51.2 m^2/ha
Height: 25–30 m	Diameter: 29 cm	
Keywords: Interception; Stemflow; Throughfall; Water balance		

CAB Abstracts AN 820676672

Comment
SF is not a function of DBH - took average volume of stemflow per tree and multiplied it by SPH. Sampling was monthly when the collectors were relocated. Forest floor leachate 66 and 70%, forest floor interception 5 and 9%.

Interception

	Year 1		Year 2	
	mm	%	mm	%
Rainfall	1150		1147	
Throughfall	791	69	893	78
Stemflow	12	1	16	1
Interception loss	347	30	238	21
Forest floor interception	54	5	106	9
Forest floor leachate	759	66	803	70

Throughfall is less than for eucalypt and stemflow is greater.

Forrer, J.B. 1974: The effects of afforestation on the streamflow spectra of Jonkershoek streams. Forestry in South Africa No.15: 71–79.

Country: South Africa	Duration: 20 yr	Report Location: LKR
Species Comparison: Scrubland (fynbos)		
Land-Use Change: Afforestation		
Stand Type: Plantation Up to 20 yr		
Keywords: Streamflow		

CAB Abstracts AN 750627221

Comment
Jonkershoek
This highly mathematical paper purports to show that the streamflow spectrum for Bosboukloof when trees are 12–20 yr is similar to that for Biesievlei (4–12 yr) but differs from that at Tierkloof (−4 to +4 yr old, i.e., more or less in fynbos scrub).

Grah, R.F.; Wilson, C.C. 1944: Some components of rainfall interception. Journal of Forestry 42: 890–898.

Country: United States	Report Location: R1411
Species Comparison: Shrub	
Stand Type: Potted seedlings	
Keywords: Interception	

Comment
Sprayed water on potted *P. radiata* seedlings to determined interception storage capacity (ISC) which ranged between 0.25 and 1 mm.

Graynoth, E. 1992: Long-term effects of logging practices in streams in Golden Downs State Forest, Nelson. *In:* Hayes, J.W.; Davis, S.F. (Eds). Proceedings of the Fisheries/ Forestry Conference, February 1990. MAF Freshwater Fisheries Centre, New Zealand Freshwater Fisheries Report No 136. Pp 52–69.

Country: New Zealand	Report Location: LKR
Species Comparison: Douglas fir; Native evergreen forest; Pines	
Landuse change: Forest management	
Stand Type: Plantation	
Keywords: Water quality; Water yield	

Comment
This is an update of Graynoth (1979) in which four catchments were studied in Golden Downs Forest, Nelson. Comparisons are made between visits in 1973–74 and January and March 1990, the 1990 visits being during a drought beginning in November 1989.

Makes a comment that in January 1990 streamflows in Long Gully, a gauged control catchment, were similar to those in 1973–1974, but observed that in Rough'ns and Gilbert Creek long sections of the streambed were dry.

Greenwood, E.A.N.; Beresford, J.D.; Bartle, J.R. 1981: Evaporation from vegetation in landscapes developing secondary salinity using the ventilated-chamber technique. III. Evaporation from a *P. radiata* tree and the surrounding pasture in an agroforestry plantation. Journal of Hydrology 50: 155–166.

Country: Australia	Duration: 21 months	Report Location: R1596
Species Comparison: Pasture		
Stand Type: Single tree 16 yr	Stand Density: 200 SPH	Basal Area: 8 m^2/ha
Height: 16 m		Rainfall: MAP 900 mm
Keywords: Evaporation; Transpiration		

Comment
PTTN mainly winter. Pasture in winter and grazed over dry summer. Sampled one 16-m tree and enclosed in a ventilated chamber and a pasture plot (also within a chamber) for one 24-hour period every month. Evaporation ranged from 0.6 mm/day in April–June to 3.3 mm/day in September. Cf pasture 0.0 in the dry season to 1.4 mm/day in October. Total evaporation from the tree, pasture and soil can account for all precipitation.

Hatton, T.J.; Vertessy, R.A. 1990: Transpiration of plantation *Pinus radiata* estimated by the heat pulse method and the Bowen ratio. Hydrological Processes 4: 289–298.

Country: Australia	Duration: 4 days	Report Location: R10
Stand Type: Plantation 8 yr		
Height: 10.5 m		
Keywords: Transpiration		

CAB Abstracts AN 910648660/Authors' abstract

The heat pulse method was used to estimate stand transpiration from a *P. radiata* plantation in southeastern Australia over a period of 4 days. The diurnal pattern of sapflow was related to net radiation with a time lag of about 1.5 hours. Despite high soil moisture levels, sapflow did not keep up with evaporative demand in the afternoon. Sapflow estimates of transpiration exceeded estimates for evaporation based on Bowen ratio measurements for all 4 days of the study.

Comment
Thinned 8-yr-old *P. radiata*; mean height 10.5 m; sparse ground cover. Average ground area per sampled tree = 8.01 m^2. Sampled 4 days, 16–20 October 1998. Sapflow transpiration at 3.06 to 5.31 mm/day compared to Bowen ratio estimates of 2.26 to 4.09 mm/day

Herald, J. 1978: The influence of afforestation in radiata pine on the runoff of a small catchment in the Hunua Ranges, Auckland. New Zealand Hydrological Society Symposium 1978. 20 p.

Country: New Zealand	Duration: 8 yr	Report Location: LKR
Species Comparison: Scrubland		
Land-Use Change: Afforestation (scrub to plantation)		
Stand Type: Plantation −3 to +5 yr		
Keywords: Water yield		

Comment
Presents data for the control and *P. radiata* catchments at Hunua. This is a shorter data set than in Barton & Card (1979) and the values are slightly different - possibly adjusted for climate and wetland areas. The afforested catchment was part-cleared 1968, burnt 1970 and planted in 1971.

Precipitation and runoff for Moumoukai catchments.

Year	Precipitation (mm)	Control catchment runoff (mm)	Afforested catchment runoff (mm)	Control-afforested runoff (mm)*
1968	2162	1264	1230	36
1969	1539	846	736	110
1970	1880	1034	1058	-24
1971	2090	1287	1186	101
1972	1614	903	789	114
1973	1321	534	416	118
1974	1441	629	439	190
1975	1853	973	680	297
1976	1993	1054	671	383

* Calculated by LKR

The last column in the table indicates that flows were diminishing 3 yr after planting the pine seedlings. There are also graphs of seasonal changes in flow with time but no data are provided to verify the trends and conclusions.

Some of the adjustments made to the flow data for climate and time trends may need to be revisited.

Herald, J.R. 1979: Changes in streamflow in a small drainage basin following afforestation in radiata pine. MSc. Thesis. University of Auckland.

Country: New Zealand	Duration: 10 yr	Report Location: LKR
Land-Use Change: Afforestation (scrub to plantation)		
Stand Type: Plantation −3 to +6 yr		
Keywords: Water yield		

Comment
Same dataset as Herald (1978). Presents monthly data as well as annual water balance.

Streamflow increased 19% following clearing of the vegetation in preparation for planting. After afforestation streamflow decreased 68 mm/year until after 7 years of forest growth streamflow had decreased to 70% of that in the calibration period. At the same time summer streamflow had decreased to 50% of the pre-harvest period.

Henrici, M. 1947? The transpiration of South African plant associations. Part III. Indigenous and exotic trees in the Drakensberg area. Scientific Bulletin of the Department of Agriculture, South Africa No. 247. 43 p.

Country: South Africa	Duration:	Report Location: R1583
Species Comparison: Conifers; Eucalypt		
Keywords: Transpiration		

Comment
Paper not sighted but the abstract implies that pines did not use as much water by transpiration as other introduced trees and that they could not affect water supplies.

Hewitt, A.M.; Robinson, A. 1983a: Moutere gravels land use. A study of comparative water yields. New Zealand Hydrological Society Symposium, Dunedin, 1983. (Unpublished).

Country: New Zealand	Report Location: LKR
Species comparison: Native evergreen forest; Pasture	
Land-Use Change: Afforestation	
Stand Type: Plantation 3 to 8 yr	
Keywords: Water yield	

Comment
Presents data from the Kikiwa suite of catchments, Nelson.

Graham Creek	planted in exotics from pasture
Hunters Creek	beech forest control
Kikiwa Creek	pasture control

On an annual basis there was no major change in streamflow yield at Graham Creek in the period when trees were aged 3 to 7 yr. However, over a 4-month summer period Graham streamflow declined from 112% of Hunters to 55% of Hunters while at Kikiwa the summer flow remained in the 80–90% of Hunters range. No data given to back up these statements.

Hewitt, A.M.; Robinson, A. 1983b: Moutere gravels land use. A study of comparative water yields. Unpublished typescript.

Country: New Zealand	Report Location: LKR
Species comparison: Native evergreen forest; Pasture	
Land-Use Change: Afforestation	
Stand Type: Plantation 3 to 8 yr	
Keywords: Water yield	

Comment
A more extensive version of Hewitt & Robinson (1983a).

Presents data from the Kikiwa suite of catchments, Nelson.

Graham Creek	474 ha	planted in exotics from 1974
Hunters Creek	502 ha	beech forest
Kikiwa Creek	285 ha	pasture

Paper includes some of the forest management history.
Most of the forest was planted in 1974 and 1975 and thinning occurred in some compartments in 1980 and 1981.
The data in these tables begin 3 yr after the majority of the Kikiwa was planted. Therefore there is no effective calibration period. Changes in the flow regime should be apparent in the last part of the data set but there is no certain reference point to indicate the comparative situation when planting occurred.

Annual runoff (mm) from Kikiwa suite, Nelson

	Hunters	Graham	Kikawa	Rainfall*
1978	416	510	440	1000
1979	532	600	568	1210
1980	643	646	722	1310
1981	498	548	569	1070
1982	395	390	416	1050
Mean	497	539		

* Rainfall data were extracted off a graph by LKR so there will be some error in these numbers.

Trends in annual runoff after planting are not conclusive.

Summer (December–March) runoff (mm) from Kikiwa suite, Nelson

	Hunters	Graham	Kikawa
1977–1978	71	78	58
1979	76	82	63
1980	144	140	110
1981	13	8	12
1982	56	44	40
1983	67	36	58

No summer-only rainfall data are given. There appears to be a downwards trend in summer flow in the planted catchment.

Hewlett, J.D.; Bosch, J.M. 1984: The dependence of storm flows on rainfall intensity and vegetal cover in South Africa. Journal of Hydrology 75: 365–381.

Country: South Africa	Duration:	Report Location: R26
Species Comparison: Conifers; Eucalypt; Native Grassland; Scrubland (fynbos)		
Land-Use Change: Afforestation		
Stand Type: Plantation 21 to 38 yr	Rainfall: MAP 1400 and 2000 mm	
Keywords: Storm flow		

Comment
Presents data for Bosboukloof and Langrivier.

Storm flows in scrub and forest catchments

	Vegetation	MA PTTN (mm)	MA RO (mm)	Events > 20 mm	Mean storm (mm)	Mean storm flow (mm)	Mean peakflow L/s/ha
Bosboukloof	21-38yr *P. radiata*	1400	430	204	37	1	0.4
Langrivier	Fynbos	2000	1500	286	57	22.4	4.8

Notes:
Langrivier has upper 30% occupied by precipitous sandstone cliffs with little or no vegetation or water storage, is very responsive, and is atypical compared to the other seven catchments studied.
Storm flow = Hewlett & Hibbert (1967) quickflow
Storm flows = fn (Storm rainfall, initial flow rate, storm duration, max. 60-min rainfall intensity)
Peakflows = fn (Storm rainfall, initial flow rate, max. 60-min rainfall intensity)
Carried out linear regression analysis on the logarithms of the variables.

Concluded:
Hourly rainfall intensity accounted for 5% of total variation in storm flow and ~20% in peak flows
Afforestation had little importance on flood water discharge.
Storm flow low % of rainfall

Hicks, B.B.; Hyson, P.; Moore, C.J. 1975: A study of eddy fluxes over a forest. Journal of Applied Meteorology 14: 58–66.

Country: Australia	Duration: 2 days in May & October	Report Location: LKR
Stand Type: Plantation 9 yr		
Height: 13 m		
Keywords: Evaporation; Transpiration		

CAB Abstracts AN 780646450
Comment
Measured fluxes of heat and water above a *P. radiata* canopy. For the October measurement period, the average evaporation was equivalent to 2.31 mm (my calculations)

Hicks, D.M. 1988: Differences in suspended sediment yield from basins established in pasture and exotic forest. New Zealand Hydrological Society Symposium, Dunedin, 1988. (Unpublished)

Country: New Zealand	Report Location: LKR
Species Comparison: Pasture	
Stand Type: Plantation	
Keywords: Stormflow; Water quality	

Comment
Whilst a paper about sediment yields, gives the following for Northland catchments:

Topuni (88 ha) in exotic forest	For 1981–1986, MAP = 1334 mm & Quickflow = 199 mm.
Kokopu (308 ha) in pasture	For 1981–1986, MAP = 1351 mm & Quickflow = 281 mm.

Holmes, J.W.; Colville, J.S. 1968: On the water balance of grassland and forest. Transactions, 9th International Congress of Soil Science, Adelaide, Australia. Vol. I: 39–46.

Country: Australia	Duration: 3 yr	Report Location: R1405
Species Comparison: Pasture		
Stand Type: Plantation	Stand Density: 2200 & 450 SPH	
Keywords: Evaporation; Groundwater		

Comment
Presents data on water use by *P. radiata* forest and grassland but no rainfall information is given. Data averaged for two forest stands, 2200 SPH closed canopy and a thinned stand of 450 SPH. Drainage to water table under grassland ranges between 25 and 134 mm per year; under forest was nil.

Evaporation (in mm) calculated using a water balance equation for the winter period

Year	Grassland	Forest	Evaporation equivalent of radiation over grassland.
1963	110	260	160
1964	240	420	267
1965	212	305	228

Holmes, J.W.; Colville, J.S. 1970: Forest hydrology in a karstic region of southern Australia. Journal of Hydrology 10: 59–74.

Country: Australia	Duration: 4 yr	Report Location: R1587
Species Comparison: Pasture		
Stand Type: Plantation 33 to 37 yr	Stand Density: 2200 & 450 SPH	
Keywords: Evaporation: Groundwater		

Part Authors' Abstract
Evaporation was measured in stands of *P. radiata* in southern Australia ...... The predominantly winter rainfall of about 600 mm was almost all evaporated by early summer and therefore no recharge of the local aquifer, by deep infiltration, occurred beneath the forest.

The evaporation from forest during winter and spring was up to 2.2 times that from grassland. There was no soil moisture stress during this period but an explanation is needed for the supply of energy used in forest evaporation.

The forest albedo is less than that of the pasture but the extra radiation energy absorbed by the forest is insufficient to explain all the increase of evaporation.

Advection of sensible heat from the neighbouring grassland is sometimes sufficient to explain the greater evaporation from the forests. It is thought that subsidence of continental air masses supplies an appreciable component of the energy budget. Also, advection from the Southern Ocean may supply energy to this part of southern Australia during winter and early spring.

Holmes, J.W.; Olszyczka, B. 1982: Evaporation of surface water from the foliage of an isolated pine tree. The First National Symposium on Forest Hydrology, 1982, Melbourne., Institution of Engineers, Australia, National Conference Publication 82/6: 7–11.

Country: Australia	Duration: Aug & Dec 1980	Report Location: R1357
Stand Type: Single 7-yr-old tree in weighing lysimeter pot		
Height: 5.5 m		
Keywords: Evaporation; Transpiration		

CAB Abstracts AN S849194

Authors' Abstract

The rate of evaporation, when the foliage was wet, and the transpiration alone, during dry weather, were measured with the aid of a weighing lysimeter. The tree was a solitary pine (*P. radiata*) that had grown in a lysimeter pot for about 7 yr. The water loss rate was up to three times greater, when the canopy was wet, than the transpiration rate when the canopy was dry. Three dendrometers attached to the stem of the tree gave diurnal shrinking and swelling records that can be used to derive indirect assessments of transpiration rate and to partition evaporation between loss of surface water and transpiration.

Comment

Used a single, isolated, tree on a weighing lysimeter: 7 yr old; 5.5 m tall; unlimited available soil moisture.

Single tree evaporation

	August 1980	December 1980
Daily evaporation	0.8–3.8 mm	3.3–6.2 mm
Mean	1.98	4.7

Holmes, J.W.; Sinclair, J.A. 1986: Water yield from some afforested catchments in Victoria. Hydrology & Water Resources Symposium, Brisbane, November 1986. Pp. 214–218.

Country: Australia		Report Location: R1590
Species Comparison: Eucalypt; Pasture		
Stand Type: Plantation Various	Rainfall: 460 to 2600 mm	
Keywords: Water yield		

Comment:
Uses plot of evaporation (= rainfall-runoff) versus rainfall to delineate an envelope with forested catchments at the upper bound and grassland catchments the lower bound. Mainly eucalpyt catchments although some have extensive pasture. Data set includes values for two *P. radiata* studies with evaporation derived from water balances. This provides an opportunity to make an assessment of the likely effects of afforestation on streamflow. Is light on detail of the land cover for many of the catchments used.

Hopmans, P.; Flinn, D.W.; Farrell, P.W. 1987: Nutrient dynamics of forested catchments in southeastern Australia and changes in water quality and nutrient exports following clearing. Forest Ecology and Management 20: 209–231.

Country: Australia	Duration: 6 yr	Report Location: R57
Species Comparison: Eucalypt		
Land-Use Change: Conversion from one forest to another		
Stand Type: Plantation −4 to 2 yr		
Keywords: Water quality; Water yield		

CAB Abstracts AN F213510

Authors' Abstract
Nutrient inputs in rainfall, and streamwater chemistry and quality, were measured from May 1976 to April 1982 at three forested catchments in Victoria. Streamwater chemistry was influenced by strong seasonal fluctuations in streamflow. Yearly input-export balances for Na, K, Ca, Mg and Cl varied substantially and were highly correlated with runoff. This underlines the importance of sampling a wide range of climatic variation to derive meaningful balances. Clearing native eucalypt forest for the establishment of *P. radiata* was found to have little effect on streamwater quality, thus demonstrating the effectiveness of a 30-m-wide buffer strip retained on both sides of the stream channel. Only minor changes in streamwater chemistry were observed; however, exports of nutrients and suspended solids were significantly higher because of increased discharge following clearing. Exports of most nutrients returned to pretreatment levels within 18 months after clearing. Nutrient losses in streamwater were small when compared with losses due to burning the cleared vegetation. Balances for Na were used to estimate nutrient inputs from geological weathering. It was concluded that inputs of Ca are probably too low to ensure adequate supply of Ca for successive rotations of *P. radiata*, and future management practices should aim at conserving this nutrient.

Comment

Reports 4 yr pre-harvest and 2 yr post-harvest annual runoff from the Cropper Creek experiment. Notes substantial increases in yield at Clem Creek compared to Ella Creek after harvesting.

Cropper Creek catchments

Water year to 30 April of	Precipitation (mm)	Ella runoff (mm)	Clem runoff (mm)	Clem-Ella (mm)
1977	1029	40	79	39
1978	1065	99	148	49
1979	1478	348	485	137
1980	1511	486	620	134
*1981	1402	330	797	467
*1982	1976	919	1335	416

* Post-harvest

Huber, A.; Ellies, A.; Oyarzun, C. 1990: Comparative research on the water balance between a *Pinus radiata* stand (D. Don) and pasture land in southern Chile. (Vergleichsuntersuchung uber die Wasserbilanz eines *Pinus radiata* Bestandes und einer Weidelandflache in Sudchile). Zeitschrift fur Kulturtechnik und Landentwicklung 31: 184–190.

Country: Chile	Duration:	Report Location: Not Sighted
Species Comparison: Pasture		
Stand Type: Plantation		
Keywords: Evaporation		

CAB Abstracts AN 901944479

The water balance of a *P. radiata* stand was compared with that of a pasture on an (Andeptic) Orthoxic Palehumult in southern Chile. Water potential was measured up to a depth of 2.7 m and related to input from precipitation to obtain the water content. Evapotranspiration and infiltration were calculated from the water balance. The annual water consumption of the pasture was 946 mm compared with 1190 mm under forest. While the root zone under pasture dried out completely during the vegetation period, no drying out occurred in any soil layer under forest. Groundwater recharge was less under forest than under pasture.

Huber, A.; Iroume, A. 2001: Variability of annual rainfall partitioning for different sites and forest covers in Chile. Journal of Hydrology 248: 78–92.

Country: Chile	Report Location: LKR
Species Comparison: Conifers; Douglas fir; Eucalypts; Native evergreen forest	
Stand Type: Plantations various ages	
Keywords: Interception; Review; Stemflow; Throughfall	

Comment

Data from 29 research plots at nine research sites throughout Chile are summarised. It includes data presented in papers included in this bibliography, some that were unobtainable, together with new data. Data are presented on an annual basis, not always a calendar year, and for each year studied.

The following table summarises parts of their tables 1 and 2.

Location Forest type	Density SPH	BA m^2/ha	Age (Yr)	PTTN (mm)	Throughfall mm (%)	Stemflow mm (%)	Interception loss mm (%)
Valdivia *P. radiata*	733	60	25	2389	1226 (76)	311 (13)	254 (11)
			26	1628	1226 (75)	202 (12)	199 (12)
			27	2059	1477 (72)	241 (12)	346 (17)
			28	2295	1651 (72)	253 (11)	291 (17)
			29	2341	1697 (73)	237 (10)	408 (17)
			30	1841	1386 (75)	159 (93)	296 (16)
			31	1364	654 (70)	108 (8)	303 (22)
	973	65.9	18	2925	2083 (72)	302 (10)	540 (18)
			19	2075	1459 (70)	187 (9)	429 (21)
	467	51.6	18	2925	2204 (75)	228 (8)	494 (17)
			19	2075	1525 (74)	165 (8)	385 (18)
			20	2394	1766 (74)	186 (8)	442 (18)
			21	2574	1988 (77)	208 (8)	378 (15)
			22	1676	1314 (78)	139 (8)	222 (13)
	194	34.9	17	2925	2311 (79)	171 (6)	443 (15)
				2075	1639 (79)	97 (5)	339 (16)
				2394	1929 (81)	108 (5)	357 (15)
				2574	2091 (81)	134 (5)	349 (14)
				1676	1377 (82)	92 (6)	207 (12)

Location Forest type	Density SPH	BA m^2/ha	Age (Yr)	PTTN (mm)	Throughfall mm (%)	Stemflow mm (%)	Interception loss mm (%)
	467	33.2	23	2373			367 (16)
	1250	58	20	2648			579 (22)
	426	35	20	2648			538 (20)
	217	32	20	2648			515 (19)
Hueicolla 1 Alerce	1100	58	~600	4603	3662 (80)	403 (9)	537 (12)
Hueicolla 2 Broadleaf	530	99.6	~200	3563	2650 (74)	131 (4)	782 (22)
Mariquina Broadleaf	335	n.a.	~150-200	2973	1829 (62)	46 (2)	1097 (37)
				2268	1404 (62)	29 (1)	835 (37)
				1538	956 (62)	18 (1)	564 (37)
				1643	985 (60)	107 (7)	550 (34)
				2287	1652 (72)	27 (1)	608 (27)
				2355	1490 (63)	23 (1)	843 (36)
				2690	2161 (80)	25 (1)	505 (19)
Nacimiento *P. radiata*	2000	n.a.	23	1971	1359 (69)	88 (5)	523 (27)
	443		13	1971	1557 (79)	68 (3)	338 (17)
Nacimiento *Nothofagus obliqua*	3500	n.a	~15-25	1971	1697 (86)	49 (3)	225 (10)
Collipulli *P. radiata*	460	19.5	15	1039	667 (64)	28 (3)	344 (33)
			16	1858	1268 (68)	49 (3)	540 (29)
	220	12	15	1039	706 (68)	15 (1)	318 (31)
			16	1858	1311 (71)	37 (2)	510 (28)
	833	13.4	8	1039	690 (66)	22 (2)	326 (31)
			9	1858	1347 (73)	40 (2)	471 (25)
			10	734	505 (69)	17 (2)	212 (29)
	395	6.8	8	1039	758 (73)	12 (1)	268 (26)
Collipulli *E.nitens*1	1560	29.6	8	1039	670 (65)	41 (4)	328 (32)
			9	1858	1197 (65)	67 (4)	593 (32)
			10	734	472 (64)	28 (4)	182 (32)

Location Forest type	Density SPH	BA m^2/ha	Age (Yr)	PTTN (mm)	Throughfall mm (%)	Stemflow mm (%)	Interception loss mm (%)
	850	19.5	8	1039	716 (69)	28 (3)	295 (28)
			9	1858	1252 (67)	55 (3)	551 (30)
			10	734	508 (69)	22 (3)	260 (28)
	633	15.9	8	1039	755 (73)	20 (2)	264 (25)
Malalcaheullo Douglas fir	1143	97	27	1346	812 (60)	81 (6)	452 (34)
Malalcaheullo Broadleaf	367	47	~80	1346	891 (66)	105 (8)	350 (26)
Los Angeles 1 *P. radiata*	1206	27.1	12	1005	562 (56)	54 (5)	389 (39)
	549	13.7	12	1005	721 (72)	44 (4)	240 (24)
	143	22.1	16	1005	550 (55)	64 (6)	391 (39)
	417	8.8	16	1005	677 (67)	12 (2)	306 (30)
Los Angeles 2 *P radiata*	926	11	6	1038	745 (72)	14 (1)	280 (27)
	1087	16.5	10	1038	721 (69)	25 (3)	292 (28)

Analyses were carried out on conifers (*P. radiata*, Douglas fir and Alerce) and broadleaved forests. Throughfall for conifers was between 55% and 82% of precipitation; for broadleaves the range was 60% to 86%. Throughfall was, on average, higher for conifers than for broadleaves but the differences were not statistically different.

All data	Throughfall = −132.48 + 0.795 × PTTN	r = 0.958
Conifers	Throughfall = −162.18 + 0.823 × PTTN	r = 0.993
Broadleaves	Throughfall = − 65.25 + 0.733 × PTTN	r = 0.953

Stemflow ranged between 1 and 13% of precipitation for conifers, between 1 and 8% for broadleaves with the differences being significant.

Conifers	Stemflow = −72.29 + 0.106 × PTTN	r = 0.839
Broadleaves	Stemflow = −20.65 + 0.014 × PTTN	r = 0.333

Interception loss was up to 1097 mm in a broadleaved forest, with the conifers having a maximum of 579 mm. The range was 11–39% of precipitation for conifers and 10–37% for broadleaves. The difference between the two stands was statistically significant.

Conifers	Interception loss = 222.76 + 0.081 × PTTN	r = 0.596
Broadleaves	Interception loss = 44.61 + 0.253 × PTTN	r = 0.731

Huber, A.; Lopez, D. 1993: Changes in the moisture balance caused by clear felling an adult stand of *Pinus radiata* in Valdivia, Chile. (Cambios en el balance hidrico provocados por tala rasa de un rodal adulto de *Pinus radiata* (D. Don), Valdivia, Chile). Bosque 14: 11–18.

Country: Chile	Duration: 3 yr	Report Location: R1423
Species Comparison: Native grassland		
Land-Use Change: Forest management; Harvesting		
Stand Type: Plantation 32 yr	Stand Density: 733 SPH	Basal Area: 60 m^2/ha
Height: 32 m	Diameter: 35 cm	Rainfall:
Keywords: Evaporation; Interception; Soil water		

CAB Abstract AN 950617339

Comparisons were made of the seasonal and spatial variation of soil moisture content (m.c.) and water consumption in an adult stand (plantation) of *P. radiata* 32 yr old, before and after clear-felling in June 1989, and also in natural grassland (*Agrostis capillaris* and *Holcus lanatus*). Soil m.c. was determined by a neutron probe to a depth of 300 cm, and evapotranspiration was calculated by the moisture balance equation. Water reserves in the soil during summer changed to a depth of 280 cm in the stand, but only to 100 cm in the grassland and in the felled area. Between July 1988 and May 1989, evapotranspiration and interception was 1031 mm in the stand; this was 80% greater than in grassland, which in turn was 13% more than in the felled area. Evapotranspiration during this period was equivalent to 96.6% of the total precipitation for the stand and 57.7% for the grassland. Annual percolation in the period July 1989 to June 1990 was 257 mm for the stand, and 1549 and 1041 mm for the 2 yr after felling, as against 686, 1533 and 1056 mm, respectively, in the grassland.

Comment

According to table 3 in the paper, PTTN = 1023 mm, which does not compute with the numbers given above. However, 1989 and 1990 rainfalls were 1769 and 2184 mm, and the zone average is 2367 mm. Gives tables of monthly precipitation, and water consumption by ET for the *P. radiata* forest and for a prairie.

Huber, A.; Oyarzun, C. 1983: Net precipitation and interception in a mature forest of *Pinus radiata*. (Precipitacion neta e intercepcion en un bosque adulto de *Pinus radiata* (D.Don)). Bosque 5: 13–20.

Country: Chile	Duration: 1 yr	Report Location: R1419
Stand Type: Plantation 26 yr	Stand Density: 733 SPH	Basal Area: 52 m^2/ha
Height: 32 m	Diameter: 32 cm	Rainfall: MAP 2000mm
Keywords: Interception; Stemflow; Throughfall		

CAB Abstracts AN 900643709/*Authors' Abstract*

The monthly, seasonal and annual distributions of the interception, net precipitation, throughfall and stemflow was studied in an adult forest of plantation *P. radiata*, in the proximity of Valdivia (Chile) during 1981–82.

The rainfall intercepted by the crowns and stems reached an annual average of 10.3%. The water that reached the surface of the forest soil is constituted 87% by throughfall and 13% by stemflow. These values fluctuated monthly depending on the rainfall characteristics. The interception decreases to values lower than 10% when the precipitation reach values over 40 mm.

It was established that approximately 0.9 mm of rain are necessary to saturate the capacity of water retention of the crowns. Besides, it was determined that the stemflow manifest itself after 6 mm of precipitation, which is a quantity necessary to saturate with water the stem barks.

Regression equations were calculated for net precipitation, throughfall and stemflow on a weekly basis.

Comment

Interception 10.3% PTTN, 87% by throughfall and 13% by stemflow.
If PTTN > 40 mm, then I < 10%
Crown saturation needs 0.9 mm of rain, stem saturation 6 mm.

PTTN net	= 0.925 × PTTN − 1.554	r = 0.996
SF	= 0.127 × PTTN − 0.806	r = 0.981
TF	= 0.799 × PTTN − 0.748	r = 0.995

PTTN = 1769 mm; TF = 1379 mm, SF = 208 mm, PTTN net = 1588 mm, IL = 182 mm

Has tabulated monthly totals as well.

Huber, A.; Oyarzun, C. 1984: Factors regulating interception in a mature *Pinus radiata* stand. (Factores reguladores de la interceptacion en un bosque adulto de *Pinus radiata* (D. Don)). Bosque 5: 59–64.

Country: Chile	Report Location: R1420
Stand Type: Plantation 26 yr	
Keywords: Interception	

CAB Abstracts AN 900643713

The influence of intensity and duration of precipitation, wind speed and saturation deficit of the air on interception was studied in a 26-yr-old stand near Valdivia, Chile. The amount of water necessary to saturate the crowns of the trees showed variation between 0.6 and 1.5 mm, depending on the value of the rainfall intensity.

Comment
Relationships between interception and precipitation intensity

I = 0.142 × PTTN + 1.610	r = 0.809	PTTN = 0.0 to 1.0 mm/hour	35 events
I = 0.074 × PTTN + 1.295	r = 0.811	PTTN = 1.1 to 2.0 mm/hour	24
I = 0.041 × PTTN + 1.096	r = 0.873	PTTN = 2.1 to 3.0 mm/hour	15
I = 0.033 × PTTN + 0.626	r = 0.869	PTTN = > 3.0 mm/hour	6

Wind speed was also a factor. At high wind speeds, interception was reduced.

Huber, A.W.; Oyarzun, C.E. 1990: Annual variations in precipitation, stemflow and interception in a mature *Pinus radiata* stand. (Variaciones annuales en precipitacion, escurrimiento e intercepcion en un bosque adulto de *Pinus radiata*). Turrialba 40: 503–508.

Country: Chile	Duration: 7 yr	Report Location: R1354
Stand Type: Plantation 25–32 yr	Stand Density: 733 SPH	Basal Area: 60 m^2/ha
Height: 32 m	Diameter: 35 cm	Rainfall: MAP 2500 mm
Keywords: Interception; Stemflow; Throughfall		

CAB Abstracts AN 910656300/Authors' Abstract

Temporal variations of the different components of the redistribution of rainfall in throughfall, stemflow and interception were quantified and analysed in a mature *P. radiata* stand in southern Chile. During the period studied (1982–88), water input due to throughfall and stemflow represented 73.9±2.6% and 10.8±1.9% respectively of the incidental precipitation. Interception loss was estimated as 15.3±4.0%. Therefore, the amount of water effectively reaching the surface was equivalent to 84.7±4.9% of the total annual precipitation. Losses due to interception showed a large variation, with values fluctuating from 10.6 to 22.1% of the annual precipitation. The interception by the forest was, therefore, mainly regulated by temporal distribution and by the amount and intensity of precipitation.

Comment

Interception in a mature *P. radiata* stand, Chile

Year	PTTN	TF	SF	IL
1982	2389	1824	311	254
1983	1628	1229	202	196
1984	2059	1472	241	346
1985	2165	1651	253	261
1986	2341	1697	237	408
1987	1841	1386	159	296
1988	1364	954	108	303
Mean	1970	1459	216	295

Annual relationships:

TF = 0.784 × PTTN − 84.53

SF = 0.156 × PTTN − 92.26

Huber, A.; Oyarzun, C.; Ellies, A. 1985: Water balance in three *P. radiata* plantations and a meadow. II. Soil moisture and evapotranspiration. (Balance hidrico en tres plantaciones de *Pinus radiata* y una pradera. II: Humedad del suelo y evapotranspiracion). Bosque 6: 74–82.

Country: Chile	Duration: 1 yr	Report Location: R1422
Species Comparison: Native grassland		
Stand Type: Plantation 9 & 26 yr	Stand Density: Various	Rainfall: MAP 2000 mm
Keywords: Evaporation; Interception; Soil water		

CAB Abstracts AN 900644397

In continued work in Chile, it was found that during the summer soil water reserves were considerably depleted down to a depth of 250 cm in the plantations, and down to 100 cm in a natural *Agrostis tenuis/Holcus lanatus* meadow. Evapotranspiration (10 Oct. 1982 to 21 Apr. 1983) was 1057, 1009 and 999 mm respectively in the three plantations, and 501 mm for the meadow (28 Oct. to 21 Apr.). Evapotranspiration amounted to 76% of the net annual precipitation in the 26-yr-old and 9-yr-old plantations, and to 63% in a 9-yr-old silvopastoral plantation; for the meadow it was only 29%.

Comment

P radiata 26 yr, 733 SPH; 32 m tall; BA 57.1 m^2/ha and average diameter 32 cm

P radiata 9 yr, 443 SPH; farm management (= agro-forestry); BA 10.5 m^2/ha and DBH 17 cm

P radiata yr, 1392 SPH; BA 19.8 m^2/ha and average diameter 14 cm

MAP = 2000 mm

Has soil moisture data so used in ET calculations as ET = net PTTN + change in SM

***P. radiata* Interception and evaporation - Chile**

	PTTN (mm)	PTTN net (mm)	INTN (mm)	ET (mm)
2 September 1982 to 1 September 1983				
26 yr	1717	1473	243	
9-yr traditional	1717	1394	322	
9-yr agro-forestry	1717	1578	139	
meadow	1717	1717	0	
1 October 1982 to 21 April 1983				
26 yr	513	409	103	1057
9-yr traditional	513	402	110	1010
9-yr agro-forestry	513	427	86	999
meadow	513	513	0	501++

Showed soil water content profiles for the three forestry stands were similar to each other throughout the year, but were lower than the meadow from November to April, reaching a maximum 300–350 mm lower in February–March.

Iroume, A. 1990: Assessment of runoff and suspended sediment yield in a partially forested catchment in southern Chile. Water Resources Research 26: 2637–2642.

Country: Chile	Duration: 1 yr	Report Location: R1595
Stand Type: Plantation -partly forested with 1–7 yr trees		Rainfall: 2170 mm
Keywords: Water quality; Water yield		

Comment
The basic data were 132 spot measurements of stream stage at 5-day intervals during rainless periods and 1–2 days during the rainy season and then converted to discharge using stage–discharge relationship. There was no continuous recording.

93 ha, 27% native forest, 33% *P. radiata*, 40% grassland
Runoff for 1983–84 was estimated to be 1150 mm of 2170 mm PTTN — monthly yields are given. There is also information on estimated sediment yields.

Iroume, A. 1992: Precipitation, runoff and suspended sediment yield in a catchment near Valdivia, Chile. (Precipitacion, escorrentia y produccion de sedimentos en suspension en una cuenca cercana a Valdivia, Chile). Bosque: 13: 15–23.

Country: Chile	Duration: 1983–4 & 1988–9	Report Location: R1424
Stand Type: Plantation -partly forested		Rainfall: 2170 mm
Keywords: Water quality; Water yield		

CAB Abstracts AN 940606214
A comparative analysis was made of precipitation, runoff and suspended sediment yield for two 12-month periods (representing an average year and a dry year) in a catchment of 93 ha near Valdivia, Chile. The catchment area consisted of 27% native forest (*Nothofagus obliqua, N. dombeyi, Drimys winteri*), 33% *P. radiata* (planted 1976–82), and the remaining 40% meadowland. The results are presented in tables and graphs.

Comment
Updates Iroume (1990). The 1982–1984 data are 132 spot measurements of stage height at 5-day intervals during rainless periods and 1–2 day-intervals during the rainy season. From July 1988, measurements are continuous. 1983–84 was an average year, 1988–1989 a dry year.

Runoff for 1983–84 was 1150 mm of 2170 mm PTTN; for 1988–1989, 655 mm of 1485 mm PTTN. Monthly mean stream discharges and sediment yields are given.

Jackson, D.S.; Jackson, E.A.; Gifford, H.H. 1983: Soil water in deep Pinaki sands: some interactions with thinned and fertilised *Pinus radiata*. New Zealand Journal of Forestry Science 13: 183–196.

Country: New Zealand	Duration: 10 yr	Report Location: R750
Land-Use Change: Forest management		
Stand Type: Plantation 4–13 yr	Stand Density: Various	
Keywords: Soil water		

CAB Abstracts AN F922694

In an experiment in Woodhill State Forest, New Zealand, studying the effects of thinning, fertiliser application and the presence of *Lupinus arboreus*, plots treated with both lupin and fertiliser had much greater vol. increment than controls (60–70% more over 13 yr). Depletion of soil water by these stands was also much greater, and could cause critically low soil water potential (-5 bars or less) throughout the profile during late summer and autumn. Critical depletion did not occur in plots without lupin or fertiliser.

During the first 7 yr (up to canopy closure) differences in stocking produced the most significant differences in soil moisture, but only in the top metre. Thinning greatly reduced soil water depletion, particularly in plots with fertiliser, but these effects diminished after 2–3 yr and were insignificant after 5 yr. After canopy closure the effects of fertiliser began to overide those of stocking and produced soil moisture differences down to 3–4 m. Differences in soil water storage between extremes of treatment amounted to approx. 134 mm of rainfall at midwinter.

Comment

Initial stocking 2224 SPH with some plots thinned to 1483, 741 and 371 SPH.

Jackson, R.J. 1983: Evaporation from pasture and radiata pine forest at Ashley, Canterbury. New Zealand Hydrological Society Symposium, Dunedin, 1983. (Unpublished)

Country: New Zealand	Duration: 2 yr	Report Location: LKR
Species Comparison: Pasture		
Stand Type: Plantation		
Keywords: Evaporation; water yield		

Comment

1981: Precipitation 750 mm; Pine catchment runoff 30 mm; Pasture catchment runoff 120 mm.
1982: Precipitation 600 mm; No significant runoff from either catchment.

Pasture catchment: When soil moisture was adequate, evaporation followed Penman PE - 2 mm/day September to 4.5 mm/day in December. Declined rapidly when soil moisture deficit reached 80 mm. Maximum SWD = 120 mm.

Pine catchment: Transpiration 2-2.5 mm/day in November/December falling to 0.5 m/day in late summer; Winter rates 0.5 to 1.0 mm/day. Interception contributed 1/3 of the total evaporation.

Jackson, R.J. 1985a: The effects on soil water of conversion from beech/podocarp forest to pine plantation. Proceedings, Soil Dynamics and Land Use Seminar, Blenheim, 1985. New Zealand Society of Soil Science and New Zealand Soil Conservators Association. Pp. 230–242.

Country: New Zealand	Duration: 3 yr	Report Location:
Species Comparison: Native evergreen forest		
Land-Use Change: Conversion from one forest to another		
Stand Type: Plantation 0–3 yr	Stand Density:	Basal Area:
Keywords: Soil water		

Author's Abstract

At Big Bush State Forest, south Nelson, the hydrological regime of small catchments is being investigated to assess the impact of conversion from beech/podocarp forest to plantations of *P. radiata*. Soil water measurements were made in undisturbed beech/podocarp forest and in a nearby catchment that had been clearfelled and recently planted with *P. radiata*. Whereas transpiration by the undisturbed forest caused depletion of soil water storage by almost 100 mm in summer, in the first year after clearfelling little soil drying occurred. Except on the first day after wetting by rainfall, rates of evaporation from bare forest soil were low as a result of restricted water movement through the upper organic soil horizons. Low summer evaporation results in a much larger surplus of water draining to streams in summer from clearfelled catchments than from undisturbed forest catchments. After the first year, regrowth of vegetation increased summer soil drying, initially at only a small proportion of sites, but at all sites by the 4th year after clearfelling.

Jackson, R.J. 1985b: Hydrology of radiata pine and pasture catchments, Ashley, Canterbury. New Zealand Hydrological Society Symposium, Christchurch, 1985. (Unpublished)

Country: New Zealand	Duration: 5 yr	Report Location: LKR
Species Comparison: Pasture		
Stand Type: Plantation - mixed ages 36–40, 11–16, 6–11 yr		
Keywords: Stormflow; Throughfall; Water yield		

Comment

Throughfall measured over 4 year was 65% of precipitation.

Annual rainfall and runoff for Ashley catchments

Year	Rainfall (mm)	Runoff (mm)		Quickflow (mm)	
		Pasture	Pines	Pasture	Pines
1981	770	122	32	40	10
1982	610	0	2	0	0
1983	930	157	79	84	39
1984	1110	180	89**	96	53**
1985*	475	8	2	n.a.	n.a.

* Until October 1995
** Includes an estimate for missing data in the largest event.

Jackson, R.J. 1992: Forest management effects on stream flow and water quality in New Zealand. In: Hayes, J.W.; Davis, S.F. (Eds) Proceedings of the Fisheries/Forestry Conference, Christchurch, February 1990. New Zealand Freshwater Fisheries Report No. 26: 45–51.

Country: New Zealand	Report Location: LKR
Keywords: Review; Water yield	

Comment
Briefly reviews work carried out in New Zealand

Jackson, R.J.; Fahey, B.D. 1993: Forest harvesting and flood hydrology of small catchments. New Zealand Hydrological Society Symposium, Nelson, 1993. (Unpublished).

Country: New Zealand	Duration: 17 yr	Report Location: LKR
Species Comparison: Native evergreen forests		
Land-Use Change: Conversion from one forest to another		
Stand Type: Plantation −4 to 12 yr		
Keywords: Stormflow		

Comment
Harvesting beech/hardwood forest gave increases in both flood peaks and quickflow depths. In the 5 yr after harvesting there was a 3-fold increase in the number of flood peaks > 8 L/s/ha. In winter, when soils were wet in all catchments, differences in flood peaks and quickflow between the undisturbed native forest and the harvested catchments were small, but there were significant differences at the end of a dry summer, the differences depending on the antecedent csoil conditions.

Jackson, R.J.; Marden, M.; Payne, J. 1987: Impact of clearfelling radiata pine forests on soil water at Ashley and Mangatu. New Zealand Hydrological Society Symposium, Gisborne, 1987. (Unpublished).

Country: New Zealand	Duration: 18 yr	Report Location: LKR
Land-Use Change: Harvesting		
Stand Type: Plantation 45 and 25 yr		
Keywords: Soil water		

Comment
Discusses the impact of dry summer pre-harvest conditions on the recharge of soil moisture stores in the winters following harvesting, and how low winter rains after harvesting may not recharge the soil moisture store with the result that the deficit can carry on to the next spring/summer.

Notes that rainfall interception by the forest canopies was about 35% of precipitation.

Jackson, R.J.; Payne, J. 1995: Hydrology of beech and pine forest catchments, Big Bush, Nelson. New Zealand Hydrological Society Symposium, Christchurch, 1995. (Unpublished).

Country: New Zealand	Duration: 18 yr	Report Location: LKR
Species Comparison: Native evergreen forests		
Land-Use Change: Conversion from one forest to another		
Stand Type: Plantation −3 to 14 yr		
Keywords: Water yield		

Comment
The water balance for the native beech forest is:

Precipitation 1550 mm; Runoff 530 mm; Interception 450 mm; Transpiration 430 mm; Groundwater loss 100 mm.

Annual water yield increase for the first 4 yr after harvesting was 375 mm/yr. There was a decline between years 5 and 9 with a temporary increase as a result of thinning. For years 9–14 after harvesting the water yield and flood responses were close to that expected from the pretreatment data indicating evaporation is about the same for the two forest types. Over the 15 yr since harvest, the additional runoff due to harvesting is 2500 mm. It would require greatly increased evaporation over the rest of the rotation (165 mm/yr) for the overall yield of the pine plantation to fall below that of the undisturbed beech forest.

Jackson, R.J.; Rowe, L.K. 1996: Flood hydrology of small catchments in *Nothofagus* forests and *Pinus radiata* plantations, South Island, New Zealand. Hydrology and Water Resources Symposium 1996 "Water and the Environment", Wrest Point Hotel Casino Hobart, Tasmania 21-24 May. Pp. 727–728.

Country: New Zealand	Duration:	Report Location: R1483
Species Comparison: Native evergreen forests		
Land-Use Change: Conversion from one forest to another		
Stand Type: Plantation		
Keywords: Stormflow		

Authors' abstract

Catchment experiments assessing forest harvesting at two sites with similar natural forest and soils, but differing in annual rainfall (1500 and 2400 mm) are compared. Data for storm events smaller that the mean annual flood provide direct evidence of the contributions of soil water storage and interception to the differing losses when vegetation cover changes. Interception is always important, but soil water storage is important in large events only in a few summer months at the drier site.

Jackson, R.J.; Rowe, L.K. 1997a: Soil water deficit effects on water use and growth of *P. radiata* in Canterbury, New Zealand. IUFRO.

Country: New Zealand	Report Location: LKR
Stand Type: Plantation	
Keywords: Evaporation; Soil Water	

Comment

Compares low rainfall, eastern South Island sites at Ashley, Eyrewell and Chaneys Forest sites. Transpiration at Ashley Forest is low in winter (<0.7 mm/day) and reaches 3.0 mm/day in summer of soil water is not limiting. Transpiration is usually limited by soil moisture supply late in the summer, but the limitations can be in force as early as September if winter rainfall fails to recharge the soil water storage.

At Eyrewell, extraction of soil water was in the top 60 cm with smaller contributions from as far as 1.5 m deep. Total water extraction was in the range 80–100 mm.

At Chaneys Forest where tree growth and transpiration are unrestricted by water supply, 250 mm of moisture was extracted between September and December 1966. Most of the water supply uptake was from just above the water table as the upper 1.5 m of sand retains only 75 mm of available water for the trees.

Jackson, R.J.; Rowe, L.K. 1997b: Effects of rainfall variability and land use on streamflow and groundwater recharge in a region with summer water deficits, Canterbury, New Zealand. 5th Scientific Assembly of the International Association of Hydrological Sciences, Rabat, Poster Proceedings. Pp. 53–56.

Country: New Zealand	Duration: 6 yr	Report Location: LKR
Species Comparison: Pasture		
Stand Type: Plantation - mixed ages 36–41, 11–17, 6–12 yr		
Keywords: Evaporation; Water yield		

Comment
Maximum evaporation values for the pasture catchment were close to Penman PE values. Monthly maximum values for closed canopy pine forests approximated 0.7 × PE (Penman). For much of the time in summer transpiration is controlled by soil water supply and Egrass and Eforest are similar.

Annual rainfall and runoff for Ashley catchments

Year	Rainfall (mm)	Runoff (mm)		Quickflow (mm)	
		Pasture	Pines	Pasture	Pines
1981	770	122	32	40	10
1982	610	0	2	0	0
1983	930	157	79	84	39
1984	1110	180	89	96	53
1985	830	123	40	64	25
1986	1260	499	398	280	250

This table shows that in an environment such as Ashley, variations in water yield associated with variations in rainfall are much greater than the reductions in water yield when grassland is converted to forest. Constraints on land use offer resource managers only a limited opportunity to influence water yield — management of water storage is required to better utilise winter runoff.

Kelliher, F.M.; Whitehead, D.; McAneney, K.J.; Judd, M.J. 1990: Partitioning evapotranspiration into tree and understorey components in two young *Pinus radiata* D.Don stands. Agricultural and Forest Meteorology 50: 211–227.

Country: New Zealand	Duration: 2 days, March 1986	Report Location: R51
Stand Type: Plantation 4 & 7 yr	Stand Density: See below	
Keywords: Evaporation; Transpiration		

CAB Abstracts AN 900643574/Authors' Abstract

The tree and understorey components of latent heat flux density (LE) in two young *P. radiata* stands in Kaingaroa Forest, near Rotorua, New Zealand, were measured on 18 and 19 March 1986, when there was no soil water deficit. Contributing LE from understorey (LEu) and trees (LEt) was estimated using small weighing lysimeters and the Penman-Monteith equation, respectively. In both stands, the daily contribution of LEu to forest LE was considerable. LEu was nearly equal to LEt in the 4-yr-old stand (which had not been pruned or thinned since establishment), but in the nearby 7-yr-old stand, LEu was 30% less than LEt. In the 7-yr-old stand, the presence of woody debris from pruning and thinning operations covering approx. 60% of the understorey was responsible for the comparative reduction in LEu. Equilibrium LEu was estimated in the 7-yr-old stand and overall was 43% less than measured LEu. Vertical wind statistics, determined near ground level in the relatively open 7-yr-old stand, indicated that gusts regularly penetrated from above the forest to the understorey. These results suggest that forest management effects on the available energy and turbulence regimes below the tree canopy can be important determinants of LEu.

Comment
Haupapa, Kaingaroa Forest:
P. radiata, 7 year old, 9 m tall, 450 SPH, pruned to 5 m.
P. radiata, 4 year old, 2.5 m tall, 2900 SPH; tree crown area fraction 0.2, non-evaporative surface 0.1, open understorey 0.7.
Soil water not limiting.
4-yr-old: clear day transpiration from trees = 1.60 mm, understorey = 1.56, total = 3.16
7-yr-old: clear day transpiration from trees = 1.02 mm, understorey = 0.86, total = 1.88

Kelliher, F.M.; Whitehead, D.; Pollock, D.S. 1992: Rainfall interception by trees and slash in a young *Pinus radiata* D.Don stand. Journal of Hydrology 131: 187–204.

Country: New Zealand	Duration: 13 months	Report Location: R228
Stand Type: Plantation 7 yr	Stand Density:450 SPH	
Height: 9 m		
Keywords: Interception; Soil water; Stemflow; Throughfall		

CAB Abstracts AN 930665137

Rainfall interception was measured from November 1986 to December 1987 in a 7-yr-old *P. radiata* stand in New Zealand pruned and thinned in 1985 to 450 stems/ha. Two-thirds of the trees were high-pruned to 4–5 m in July 1986, with slash from pruning and thinning covering about 60% of the ground. A total of 1154 mm of rain was recorded in 163 days. Canopy and slash throughfall and stemflow for high- and low-pruned trees were measured. The predominance of convective rather than radiative energy determining wet canopy evaporation rates was indicated by the duration times of canopy wetness and evaporation being divided almost equally between day and night. The effect of rainfall interception on the forest water balance was examined using a biophysical water balance model with parameters derived from stand measurements. Annual evaporation of rainfall intercepted by the tree canopy modelled with the Penman equation was only 9% (100 mm) of rainfall. This was attributed largely to an underestimation of wet tree canopy evaporation during 15 days of higher-intensity rain when daily falls exceeded 20 mm. For the remaining 148 rain days, modelled wet tree canopy evaporation was generally close to the measured 19% of rainfall. Modelled annual wet canopy evaporation emanating from slash was 116 mm (10% of rainfall). Modelled annual tree transpiration and understorey evaporation during fine periods were 367 and 328 mm, respectively. Annual soil drainage/water yield was 270 mm. These results suggest a possible increase in annual water yield of the order of 6% of rainfall (69 mm for the modelling period) in the second year after thinning and pruning.

Comment
Haupapa, Kaingaroa Forest. Trees pruned to 5 m; canopy occupied 24 % of ground area. Thinned at age 5 and pruned to 2 m. At age 6 two-thirds were high pruned to 4–5 m.

PTTN 1154 mm; 336 events, 163 days (864 hours = 10% of the study period). Tree interception was 19%. Slash covered 60% of ground and intercepted 11% of rainfall. One-sided LAI 1.7.

Wetness sensors showed the canopy was wet for 26% of the time. There was an equal probability of rainfall for any hour and emphasised importance of nighttime interception and evaporation.

Canopy storage capacity: trees 0.4 mm (ground area basis) and 0.24 mm(leaf area basis); 0.7 and 0.1 mm for slash

Stemflow = 0.05 × PTTN − 0.18	low pruned trees	r^2 = 0.87; PTTN > 7 mm
Stemflow = 0.08 × PTTN − 0.16	high pruned trees	r^2 = 0.86; PTTN > 7 mm

From Fig. 4, we can get an approximate estimate (by LKR) for:
Canopy throughfall TFc = 0.74 × PTTN + ??
Slash throughfall TFs = 0.72 × TFc + ??
= 0.53 × PTTN + ??
Intercepts ?? were not determined by LKR

Canopy Interception = 0.19 × PTTN − ?? r^2 = 0 .90
Slash interception = 0.11 × PTTN − ?? r^2 = 0.57
Intercepts ?? were not given.

Slash interception = 37% of total interception

Shows 1 yr of trends of soil water status - fluctuations ranged about 110 mm

Knight, P.J.; Will, G.M. 1977: A field lysimeter to study water movement and nutrient content in a pumice soil under *Pinus radiata* forest. II Deep seepage and nutrient leaching in the first 12 years of tree growth. New Zealand Journal of Forestry Science 7: 274–296.

Country: New Zealand	Duration: 12 yr	Report Location: R1597
Stand Type: One tree from age 0 in a field lysimeter		Stand Density: Varies
Keywords: Soil water		

Comment
One tree in a draining lysimeter surrounded by plantation. Planted 1962 (2500 SPH ??). Canopy closure by 1967. In 1971 low pruned and thinned to 1340 SPH. In 1973: BA 42 m^2/ha, mean diameter 18.6 cm, 18 m tall.

Why such big losses when there was no vegetation in years 1–3 - evaporation from bare soil and substantial surface runoff???

Noted in years 6–12 seepage averaged 164 mm less than the earlier period. If assume IL = 30% of rain, TRANS calculated as 890 mm/year. Drainage generally begins May and continues through to November.

Drainage from lysimeter

	Precipitation	Drainage	Losses
1961	1231		
1962	2150	573	1577
1963	1179	206	973
1964	1606	354	1252
1965	1444		
1966	1628		
1967	1673	118	1555
1968	1440	211	1229
1969	1370	54	1316
1970	1616	214	1402
1971	1891	385	1506
1972	1315	110	1205
1973	1195	77	1118

Langford, K.J.; O'Shaughnessy, P.J. 1977a: Some effects of forest change on water values. Australian Forestry 40: 192–218

Country: Worldwide	Report Location: R921
Keywords: Review; Water yield	

Comment
Reviews a lot of worldwide data and that in Australia - mainly eucalypts.
Reports data from F&TB (1975) for the Cotter River near Canberra.

Study 1:
Compt 97: 27 ha, clearfelled *P. radiata* stand, PTTN 1066 mm, Streamflow 337 mm = 31.5% of PTTN
Compt 99: 11 ha, 39-yr-old, PTTN 1066 mm, Streamflow 199 mm = 18.5% of PTTN
Stated that streamflow increases from 20% of rainfall to 30% of rainfall - I have to assume that pre-harvest streamflow were similar for Compartments 97 and 99 - not stated.

Study 2:
Streamflow from 13- and 22-yr-old pines catchments (3.5% of PTTN) were lower than for eucalypt catchments. Throughfall in the dense unthinned stands showed interception could be 50–70% of rainfall. In thinned stands , interception losses were lower and streamflow was 12% of rainfall - higher than from a similar catchments in eucalypts.

Langford, K.J.; O'Shaughnessy, P.J. (Editors) 1977b: A study of canopy interception in native forests and conifer plantations. Melbourne and Metropolitan Board of Works, Victoria Report No. MMBW-W-0007.

Country: Australia	Duration: 8 yr	Report Location: Landcare Library
Species Comparison: Conifers; Douglas fir; Eucalypt; Scrub		
Stand Type: Plantation 10–18 yr	Stand Density: 1745 SPH	Basal Area: 58 m^2/ha
Keywords: Interception; Stemflow; Throughfall		

CAB Abstracts AN F255876

In Victoria, Australia, no significant differences in interception were found between old growth *Eucalyptus regnans*, mixed eucalypt forest and *P. radiata*. Interception of 1939 regrowth *E. regnans* was lower than that of mature *E. regnans*. Interception of *Pomaderris aspera* was significantly lower while that of *Sequoia sempervirens* and *Pseudotsuga menziesii* was significantly higher than that of mature *E. regnans*.

Comment

Same stands as for Duncan et al. (1978).
Planted 1960; Measured 1976: 29 m tall; BA 58 m^2/ha; 1745 SPH, pruned to 1.8 m.
377 observations for TF: Data collection weekly and the last day of the month - early 1970 to May 1978.
TF = PTTN × 0.695 − 0.45
SF = PTTN × 0.141 − 1.04
IL = PTTN × 0.164 + 1.49

Interception results from Victoria

	Throughfall (%)	Stemflow (%)	Interception loss (%)
Mixed species	75.4	1.3	23.3
Hazel	73.2	12	14.8
Mature ash	72.5	4.3	23.2
Regrowth ash	76	5.3	18.7
Musk	75.1		
Redwood	59.8	1.1	39.1
P. radiata	68	10.6	21.4
Douglas fir	58	14.1	27.9

Turner & Lambert (1987) give the following attributed to this paper possibly from the microfiche.

Age 15, PTTN 1600mm; TF 957 mm (59.8%); SF 170 mm (10.6%). TF+SF 70%, IL 342 mm (21.4%)

This does not compute with the above table. Indications from Duncan et al. (1978) is that TF should be1088 mm = 68%. (And 1600 × 0.695 − 52 × 0.45 = 1088. LKR). Are these the same stands??

Leitch, C.J.; Flinn, D.W. 1986: Hydrological effects of clearing native forest in Northeast Victoria: the first 3 years. Australian Forest Research 16: 103–116.

Country: Australia	Duration: 8 yr	Report Location: R160
Species Comparison: Eucalypt		
Land-Use Change: Conversion from one forest to another		
Stand Type: Plantation −5 to 3 yr		Rainfall: MAP 1400 mm
Keywords: Storm flow; Water yield		

Authors' Abstract

A small, steeply sloping, forested catchment (46.4 ha) in north-east Victoria was cleared of its native vegetation (except for a 30-m strip on either side of the perennial stream) and the debris was broadcast burnt before planting with *P. radiata* . Clearing caused variable increases in annual runoff in the first 3 yr after treatment, with the magnitude of the increases dependent on the amount and distribution of the rainfall. Annual runoff was 365 mm or 85% higher than expected in the first year after clearing, 210 mm (19%) higher in the second year and 33 mm (73%) higher in the third year. In this locality, therefore, initial increases in annual runoff of between 30 and 400 mm can be expected, with increases of c.250 mm being most likely in years of average rainfall (c.1400 mm). Analysis of pre- and post-treatment storm hydrograph data showed that the clearing caused a significant overall increase in peak flows, with the size of the increase dependent on the moisture status of the catchment soils. Substantial increases (two-fold) in peak flows were measured during the post-summer recharge phase. However, when catchment soils were moist in winter-spring, the period when most flooding occurs, peak flows of cleared catchments were not substantially different (+30%) from undisturbed catchments. The

results indicate that overland flow had little influence on the storm hydrographs of these steeply sloping catchments either before or after clearing. These results are specific to sites with similar characteristics to those of the study area.

Comment
For this bibliography, the first 3 yr of data following planting *P. radiata* in Clem Creek, which had been clearfelled from native eucalypt forest, are given. Slight variations on data in Hopmans et al. (1987)

Clem Creek

Year	Rainfall (mm)	Runoff (mm)	Predicted RO (mm)	Deviation (%)
1975–76	1951	953	966	−1.3
1976–77	1015	79	89	−11.2
1977–78	1055	148	159	−6.9
1978–79	1492	486	452	7.5
1979–80	1532	621	615	1
Post-treatment				
1980–81	1448	797	432	84.5
1981–82	2018	1337	1127	18.6
1982–83	843	78	45	73.3

Peak flows increased markedly in summer but not substantially in winter — soil moisture differences in that under forest in winter was still wet.

Le Maitre, D.C.; Versfeld, D.B. 1997: Forest evaporation models: relationships between stand growth and evaporation. Journal of Hydrology 193: 240–257.

Country: South Africa	Report Location: R5
Species Comparison: Eucalypts; Pines; Scrubland (fynbos)	
Land-Use Change: Afforestation	
Keywords: Model; Water yield	

CAB Abstracts AN 980600907/Authors' Abstract

The relationships between forest stand structure, growth and evaporation were analysed to determine whether forest evaporation can be estimated from stand growth data. This approach permits rapid assessment of the potential impacts of afforestation on the water regime. The basis for this approach is that (a) growth rates are determined by water availability and limited by the maximum water extraction potential, and (b) stand evaporation is proportional to biomass and biomass increment. The relationships between stand growth and evaporation were modelled for sets of data from eight afforested catchments in South Africa where estimates of both growth and evaporation were available. The species planted were *P. radiata* and *P. canariensis* (1 catchment), *P. radiata* (4), *P. patula* (1) and *Eucalyptus grandis* (2). The

predicted mean evaporation, over periods of several years, was generally within 10% of the measured mean annual evaporation (rainfall minus streamflow) when the model from one catchment was applied to other catchments planted with the same species. The residual evaporation, after fitting the models, was correlated with rainfall: above-average rainfall resulted in above-average evaporation. This relationship could be used to derive estimates for dry and wet years. Analyses using the models provided additional evidence that *E. grandis* may be depleting groundwater reserves in catchments where its roots can reach the water table. The models are designed to be integrated into a plantation management system, which uses a geographic information system for spatial analysis and modelling. The use of readily available growth parameters as predictor variables may reduce dependence on intricate process-based models. This is seen as an efficient way of extrapolating existing catchment data — reflecting the impacts of forestry on water supplies across a range of sites, climatic zones and species. The approach has the potential for further development, especially in dealing with low flows and faster growing species.

Comment
Stands from four regions.
Predicts evaporation = rainfall less runoff in a water year from stand growth. Utilises site index (SI) = fn(age, height) or stand growth (volume, SV or basal area, BA) = fn(SI, height, age, stand density). Total stand evaporation = transpiration and interception for the hydrological year. Rainfall was taken from the most representative gauge.
Models were different from region to region. Could also be used to calculate evaporation for a given year on the basis of deviation from mean rainfall. Models are to project mean evaporation from a plantation, not evaporation for a particular year. Potential for evaluating differing plantation regimes but note that there may be better stand variables than, for example height and BA, which will reflect the main drivers of evaporation, e.g., leaf area and water use efficiency.

Jonkershoek *P. radiata* catchments
Strong correlations between rainfall and evaporation (= rainfall less runoff) for the four catchments analysed but does not show the data, however.
Generally poor relationships between ET and BA of the form $ET = A \times (BA+1)^n$
Better for percentage ET/rainfall of the form $PCET = A + b \times \ln(volume+1)$ or $PCEt = A + b \times (BA+1)$

Lesch, W.; Scott, D.F. 1997: The response in water yield to the thinning of *Pinus radiata*, *Pinus patula* and *Eucalyptus grandis* plantations. Forest Ecology and Management 99: 295–307.

Country: South Africa	Duration: 4 yr	Report Location: R1364
Species Comparison: Eucalypt; Pines		
Land-Use Change: Forest management		
Keywords: Water yield		

CAB Abstracts AN 980607446/Authors' Abstracts

The paired catchment method was used to test for the effects of thinning on the water yield in three afforested catchments in South Africa: Biesievlei, Jonkershoek, 98% afforested with *P. radiata* (3 thinnings); Westfalia catchment D, 100% afforested with *Eucalyptus grandis* (2 thinnings); and Cathedral Peak CII, 74% afforested with *Pinus patula* (1 thinning). During and after two separate thinnings, each of which removed roughly one-third of the stems in a maturing *P. radiata* plantation in the Biesievlei catchment, annual streamflow increased by between 10 and 71% (19–99 mm). These increases persisted for 3 and 2 yr after the thinning, respectively. A final thinning in the same catchment removed only 22% of stems at an age of 28 yr. The following years (1977 and 1978) were wetter than average, and reductions in annual streamflow of 26 and 55% were recorded in these 2 yr. At Westfalia catchment D and Cathedral Peak CII, the hydrological trends were entirely dominated by the rapidly declining streamflow caused by the developing *E. grandis* and *P. patula* plantations, respectively. Any savings in water use that may have resulted from the thinning of these plantations were insufficient to affect the downward trend in annual streamflow. Thinnings may have had a minor effect of delaying or reducing the desiccation of these catchments but such effects could not be assessed due to natural variability and the limited resolution of the paired catchment method. The trends in total water yield from the catchments were generally mirrored in the dry season streamflow, and there were no strong indications that thinning effects are linked to a particular season.

Comment
Predictions are based on weekly periods and summed for annual or low-flow season (5 months) totals. Calibration periods were 2 or 3 yr prior to thinning and changes assessed for sequential 1 year periods following thinning.

Thinning did produce additional streamflow for 2 or 3 yr after the operation but in overall yields only. Any change to the low season flow seemed to be subsumed in the change of flow caused by a rapidly growing plantation.

At Biesievlei increases in flow after thinning tended to be between 5 and 100 mm/yr. In the dry season, changes were between −40 and + 33 mm.

Levett, M.P. 1978: Aspects of nutrient cycling in some indigenous and exotic forests in Westland, New Zealand. PhD Thesis, Lincoln College, University of Canterbury

Country: New Zealand	Duration: 2 yr	Report Location: Lincoln University
Species comparison: Native evergreen forest		
Stand Type: Plantation 10 & 18 yr	Stand Density: Various	
Keywords: Nutrient Cycling; Throughfall.		

Comment
Included here for completeness but there appears to be a fundamental problem with the data, most likely the rainfall used. The results concluded that throughfall under hard beech and 18-yr-old *P. radiata* were similar and that interception by 10-yr-old *P. radiata* and podocarp/hardwood stands was 1% and 4%, respectively.

McGregor, K.R. 1983: Interception loss from the bracken and slash understory of a pine forest, Purukohukohu Basin, New Zealand. MSc Thesis, University of Auckland.

Country: New Zealand	Duration: March-August	Report Location: LKR
Stand Type: Plantation	Stand Density: 550 SPH	Height: 15 m
Keywords: Interception; Stemflow; Throughfall.		

Comment
Canopy:
Throughfall 75% of PTTN; on a storm basis TF = −0.094 + 0.82 × PTTN
Stemflow 6.4% of precipitation — stemflow based on crown projection area.; on a storm basis SF = 0.029 + 0.036 × PTTN
Interception loss 18% of PTTN; on a storm basis IL = 0.017 + 0.147 × PTTN

Understory:
Consisted of bracken (40%) and slash (60%)
Throughfall 74% of canopy throughfall; on a storm basis TF = −0.125 + 0.852 × understory PTTN
Bracken stemflow 6.75% of understory precipitation; on a storm basis SF = 0.045 + 0.015 × understory PTTN
Interception loss 18.6% of understory precipitation; on a storm basis IL = 0.073 + 0.132 × PTTN
Modelled the partitioning of rainfall using the Gash (1979) interception model.

McKerchar, A.I. 1980: Hydrological characteristics of land use catchments in the Nelson area. *In*: Land use in relation to water quantity and quality. Nelson Catchment Board, Nelson. Pp. 122–136.

Country: New Zealand	Duration: 1 yr	Report Location: LKR
Species comparison: Douglas fir , Native evergreen forest; Pasture; Pines; Scrubland		
Landuse change: Forest management		
Keywords: Water yield		

Comment
Data from five Nelson catchments are reported.

Long Gully	232-ha control catchment with, in July 1973, about 58% evergreen native forest, 31% 15-yr-old Corsican pine and 11% open areas & roads.
Rough'ns Creek	300-ha catchment; 50% in *P. radiata* in 1965; 90% by1975. Note that this is not the same sampling position used by Graynoth (1979, 1992).
Graham Creek	474 ha; Reverting pasture converted to exotic forest in 1975
Hunters Gully	483 ha; Untouched beech forest
Kikiwa	285 ha; Rough pasture with bracken and pockets of scrub

12 months of data — March 1978 to February 1979

Water balance for selected Nelson catchments, 1978–79

		March –May	June– August	September– November	December– February	Total
Rough'n	Precipitation Runoff Evaporation	250 50	355 241	278 171	318 35	1201 497 704
Graham	Precipitation Runoff Evaporation	203 26	337 221	307 187	371 78	1218 512 706
Hunters	Precipitation Runoff Evaporation	214 29	334 181	290 146	313 71	1151 427 724
Kikiwa	Precipitation Runoff Evaporation	201 25	316 211	319 150	325 61	1.161 447 714

Evaporation = precipitation − runoff

During this year, annual yields from the four catchments in differing vegetation covers were similar. Seasonally yields were more variable.

Hydrograph separation, Nelson Catchments, 1978–1979

	Streamflow (mm)	Quickflow (mm (%))	Delayed flow (mm (%))
Rough'n	499	151 (30)	348 (70)
Graham	512	141 (28)	371 (72)
Hunters	427	119 (28)	308 (72)
Kikiwa	445	110 (25)	355 (75)

Quickflow (determined using the Hewlett & Hibbert (1967) method) was similar between the catchments ranging between 25 and 30% of total streamflow.

McMurtrie, R.E.; Landsberg, J.J. 1992: Using a simulation model to evaluate the effects of water and nutrients on the growth and carbon partitioning of Pinus radiata. Forest Ecology and Management: 52:1–4.

Country: Australia	Report Location: R1399
Land-Use Change: Irrigation	
Keywords: Evaporation; Model; Soil water; Transpiration	

CAB Abstracts AN 930665763/Authors' Abstract

The model BIOMASS was developed during the 'Biology of Forest Growth' project. It calculates water and carbon balances of tree stands. Parameters for the model were estimated using data from a wide range of water and nutritional conditions which were imposed on plots in a stand of *P. radiata* growing near Canberra, Australia. The treatments caused considerable differences in tree growth. Net primary production (NPP) was estimated from total CO^2 uptake by the stand, minus respiration rates of component parts of trees. CO^2 uptake was calculated from intercepted radiation and photosynthetic properties of foliage. Because of close similarities between processes involved in transpiration and CO^2 uptake, excellent correspondence (r2=0.92–0.94) between calculated and measured daily soil water balances, over 4 yr, gave confidence in the total CO^2 uptake calculations. There were differences in relations between NPP and above-ground production in irrigated trees, where internal nutrient levels fell significantly, compared with trees in other treaments. NPP was partitioned to foliage, stems and roots using these relations to estimate partitioning coefficients. Above-ground production was 60–80% of NPP; stem growth was about 40% and root growth varied from 20 to 40% of NPP, with the higher value in the irrigated (low nutrient) treatment. Correspondence between observed and simulated growth patterns of trees - particularly those of stem and foliage — was excellent, indicating that BIOMASS can reproduce differences in growth caused by water and fertility.

Comment
Another paper describing the BIOMASS model. Provides indications on its performance by comparing measured and modelled soil moisture data. For a control plot, soil moisture in the top 2 m of the profile ranged between 150 and 370 mm. 150 mm seems to be the lower limit for soil water extraction by the trees.

McMurtrie, R.E.; Leuning, R.; Thompson, W.A.; Wheeler, A.M. 1992: A model of canopy photosynthesis and water use incorporating a mechanistic formulation of leaf CO2 exchange. Forest Ecology and Management 52: 1–4.

Country: Australia	Report Location: R1398
Stand type: Plantation	
Land-Use Change: Irrigation	
Keywords: Evaporation; Model; Soil water; Transpiration	

CAB Abstracts AN 930665764/Authors' Abstract

A model of the carbon uptake and water balance of forest stands is described, which is an enhancement of the BIOMASS model. Data are presented to support an empirical relation linking stomatal conductance, photosynthesis, relative humidity and ambient CO2 concentration. The model was applied to stands of *P. radiata* subject to extremes of water and nutrient availability. Simulated water storage in the root zone agreed with measurements conducted over a 5-yr period. Simulated and measured seasonal patterns of water use reached maximum rates of approximately 7 mm/day in summer for irrigated stands with projected leaf area indices of approximately 8. Simulated annual net photosynthesis (net photorespiration and daytime foliar respiration) ranged from approximately 17 t C/ha for control stands to approximately 45 t C/ha for irrigated and fertilised stands.

Comment

Uses the Biomass model to simulate evaporation from forest stands, some fertilised and some irrigated, in the Biology of Forest Growth experiments near Canberra.

Transpiration ranged between 500 and 600 mm for non-irrigated stands with severe water limitations to 1150 to 1400 mm for the irrigated stands with no limitations. Soil volumetric water content was simulated well and ranged from 0.18 in winter down to 0.075 in the measured 2-m soil profile.

While the irrigated stands had January mean daily transpiration rates approaching 8 mm/day, the water limited stands had values of about 0.6 mm/day. In July all stands had rates about 1 mm/day increasing to over 3 mm/day in October but divergences occurred after that as soil moisture limitations took effect.

McMurtrie, R.E.; Rook, D.A.; Kelliher, F.M. 1990: Modelling the yield of *Pinus radiata* on a site limited by water and nitrogen. Forest Ecology and Management. 30: 1–4.

Country: New Zealand	Duration: 4 yr	Report Location: R60
Stand Type: Plantation 9–12 yr	Stand Density: Various	
Height: 12–15 m	Diameter: 13–19 cm	
Keywords: Evaporation; Model; Soil water		

CAB Abstracts AN 910648965/Authors' Abstract

A process-based model is described and applied to a range of *P. radiata* stands, 9–12 yr old, growing on stabilised sand dunes in a stocking X fertiliser experiment in Woodhill State Forest, New Zealand. The model requires inputs of daily weather data (maximum and minimum air temperatures and rainfall), physical characteristics of the site (longitude, latitude, root-zone depth and relation between root-zone soil matric potential and volumetric water-content) and crop (stocking, crown dimensions and leaf area index) and crop physiological parameters (e.g., maximum stomatal conductance). The model was used to simulate components of forest water-balance and annual net photosynthesis for a defined crop canopy architecture. Simulated daily root-zone water storage in both open and closed canopy stands generally agreed with monthly measurements made over a complete year. Simulated net annual photosynthesis ranged from 23 to 33 t/ha C, and comparison with measured stem-volume annual increments of 12–38 m3/ha over the same time periods resulted in a strong positive correlation. Ratios of stem-volume increment to net photosynthesis suggested that fertilised and unfertilised stands had a 26 and 14%, respectively, allocation of C to stem growth. Simulations using weather data for a dry year with 941 mm/yr rainfall indicated that annual net photosynthesis and transpiration of fully stocked stands were reduced by 41 and 45%, respectively, compared with those in a wet year with 1553 mm/yr rainfall. Operational applications of the model to forest management in quantifying environmental requirements for stand growth and examining silvicultural alternatives are discussed.

Comment
Discussion on and an explanation of the BIOMASS model.
Data from Woodhill Forest, Auckland — “soil” is 97% sand, 3% silt. Forest stands have a range of stockings and fertiliser treatments.

Shows graphs of soil water content changes throughout 1 year in the top 3.25 m of soil. – 20 to 80 mm in March rising to about 300 mm in July with recharge.

Also predicts the effect of thinning on evaporation. In a year of average (1270 mm) rainfall, dropping the LAI from 6 to 1 reduces water use from about 1250 to 350 mm/yr (data extracted from graph so accuracy??)

Miller, B.J. 2000: Development of water use models for dryland *Pinus radiata* agroforestry systems. PhD Thesis, Lincoln University.

Country: New Zealand	Report Location: Not sighted
Stand Type: Plantation 3+ yr	
Land-Use Change: Afforestation	
Keywords: Model	

Comment
Included for completeness.

Miller, B.J.; Clinton, P.W.; Buchan, G.D.; Robson, A.B. 1998: Transpiration rates and canopy conductance of *P. radiata* growing with different pasture understories in agroforestry systems. Tree Physiology 18: 575–582.

Country: New Zealand	Duration: 4 months	Report Location: R17
Stand Type: Plantation 3 to 5 yr	Stand Density: Various	
Height: 12–15 m	Diameter: 13–19 cm	Rainfall:
Keywords: Transpiration		

Comment
Measurements were done when the trees were about 3½ yr old at Eyrewell Forest at 4444 SPH and about 4½ yr old at 400 SPH at Lincoln. Ground vegetation varied and irrigation was applied at some Eyrewell plots. Tree heights varied considerably between plots: from 1.1 m to 6.8 m at the start of the experiments. Transpiration rates varied between treatments ranging from 1 to 5 mm /day.

Millet, M.R.O. 1944: Evaporation and rainfall inside and outside a forest. Commonwealth Forestry Bureau, Australia, Leaflet No. 57. pp. 16.

Country: Australia	Report Location: R1594 (abstract only)
Stand Type: Plantation -- various	
Keywords: Evaporation; Interception; Throughfall	

Comment
The abstract notes that evaporation from a free-water surface within two forest stands was 28.5% and 33.1% of that outside the forest.

Data in abstract supplemented by the following information in Turner & Lambert (1987)

Interception data — ACT

Where	Duration yr	Age yr	BA m^2/ha	Precipitation (mm)	Throughfall (mm)	Throughfall (%)
Stromlo, ACT	1	17	49.5	34	457	62
Westbourne, ACT	6	17–23		603	367	61

Mitchell, B.A.; Correll, R.L. 1987: The soil water regime in a young radiata pine plantation in Southeastern Australia. New Forests 4: 273–289.

Country: Australia	Duration: 7 yr	Report Location: R41
Land-Use Change: Afforestation; Reforestation		
Stand Type: Plantation 0–7 yr	Stand Density: 2450 SPH	
Keywords: Evaporation; Groundwater; Soil water		

CAB Abstracts AN F327273/Authors' Abstract

The soil water regime from planting to age 7 yr beneath plantations of *P. radiata* on first- and second-rotation sites in South Australia has been studied by measuring changes in water-table depth and soil content. Both plantations received intensive management, which produced very high growth rates. Magnitude, and to a lesser extent duration, of groundwater peaks decreased from planting, and by the time plantations were 5 yr old the winter rise was negligible. Within 2 yr of planting, soil water in the upper 1 m was largely depleted during summer periods, and by the 5th summer available water to 3 m depth was exhausted. A model relating change in water content to time from planting and cumulative rainfall explained over 95% of the variation in water content. Daily changes in water content, which varied from 1.7 to 5.3 mm from winter to summer, related strongly to rainfall but weakly to pan evaporation. No relationship between evapotranspiration and soil water content was found. A rapid early depletion of soil water through vigorous plantation growth resulting from intensive silviculture was observed. This could cause problems in sustaining rapid growth rates beyond canopy closure, where access to groundwater is not possible. A judicious balance of fertilisation and crop density, related to site characteristics, would be necessary to achieve optimum productivity.

Comment
Over 100 yr, MAP 775 mm, evaporation 1350 mm. For part of the study period, 1976–1980, MAP 864 mm, pan evaporation 1170 mm.
Planting was into pasture (1R) and clearfelled plantation (2R). Groundwater table rose in the 2 yr after the older plantation was clearfelled by about 5.5 m in winter but started to fall after the next year for the next 3 yr. In the ex-grassland catchment falls were similar.

Related change in soil water content (z) as:
$z = Co + C1 \times \sin(a) + c2 \times \cos(a) + C3 \times \text{rain rate} + C4 \times \text{evaporation rate}$
a is an angular function of time of year and months since planting.
Parameters are given for two stands.

Myers, B.J. 1992: Effluent loading rates for irrigated plantations — a water balance model. Australian Forestry 55: 39–47.

Country: Australia	Report Location: R99
Keywords: Model; Water balance	

CAB Abstracts AN 950609932/Author's Abstract

Disposal of municipal and industrial effluents to rivers is a major source of river pollution in Australia. Since an increasingly popular alternative for reducing discharge of nutrients to rivers and promoting wood production is to use effluents to irrigate tree plantations, there is a strong demand for accurate information on the water and nutrient consumption of effluent-irrigated plantations. An empirical water-balance model of irrigated plantations (WATLOAD) was developed using data for growth and water-use of *P. radiata* plantations treated with a wide range of water and nutrient supplements over 4 yr in Australian Capital Territory. The central biological parameter is the amount of foliage carried by the trees, which affects throughfall and stemflow, the transpiration rate of the trees and the evapotranspiration rate of the pasture grass or understorey. The model calculates the monthly amount of effluent that can be applied to a plantation in a given climate from planting to canopy closure with minimal risk of increasing nutrient contamination to waterways. It calculates the area required to treat a given volume of effluent and the amount of winter storage required.

Comment
Describes the WATLOAD model, which has a component for estimating amounts of irrigation that can be applied. Interception for the average event is calculated as interception (%) = $-3.61 + 2.01M$ where M is the canopy mass of the forest in t/ha — this relationship can be applied on a monthly time step. The model calculates E from pan evaporation and crop factors. Effluent loading rates, canopy growth, rotation and winter storage requirements are also factored in to the model.

Myers, B.J.; Talsma, T. 1992: Site water balance and tree water status in irrigated and fertilised stands of *Pinus radiata*. Forest Ecology and Management 52: 17–42.

Country: Australia	Duration: 4 yr	Report Location: R791
Land-Use Change: Irrigation		
Stand Type: Plantation 10–14 yr		
Keywords: Evaporation; Interception		

CAB Abstracts AN 930665753/Authors' Abstract

Soil water content and pre-dawn needle water potential were measured at 2-week intervals for 4 yr in a field study of the interaction of water and nutrients in controlling growth of 10- to 14-year-old *P. radiata* near Canberra, Australia. Growth on the shallow low-fertility duplex soil was limited by both nutrient and water deficiencies. The 40-cm-deep A horizon, which contained about 85% of the fine root system, had a plant-available water (PAW) holding capacity of about 60–70 mm or about 8 days supply at peak summer transpiration rates. About 33% of total annual precipitation was unavailable to the trees because of canopy and litter interception losses (28%) and runoff (5%) resulting from dissimilarity in seasonal distribution of precipitation and potential water use. Net canopy interception was 20% of annual rainfall and litter/understorey interception was 8%. Net interception was strongly affected by size of rainfall event during individual storms, ranging from more than 55% of a 5-mm event to less than 10% of a 40-mm event. However, stand basal area was the main source of variation in annual net canopy interception, varying from 15% of total precipitation at a basal area of 20 m^2/ha to 25% at 34 m^2/ha.

Trees appeared to extract soil water below the conventionally accepted wilting point (−1.5 MPa) and progressively dried out the profile to at least 2 m depth, resulting in growth being restricted by water deficiency. Water availability was a more important determinant of water use than was canopy size, but in non-water-limited stands annual transpiration varied directly with foliage mass and varied between 0.88 to 1.19 times pan evaporation. Seventy percent of annual water use occurred in the 6 months from October to March inclusive. Differences in water use between stands were largest in summer because of maximum differences in water availability and maximum foliage mass at that time. At soil water contents above 40% PAW, pre-dawn needle water potential was independent of soil water content, but it increased with increasing soil temperature and foliar nitrogen concentration. Below 40% PAW, pre-dawn potential decreased linearly with declining soil water content.

Comment

~13-yr-old *P. radiata*, 700 SPH, > 10 m tall, > 15 cm DBH. Canopy closure not complete in two of the three stands.

Rainfall 680–1264 mm, No indication of the rainfall for the 2 yr here.

Over 2 yr, net canopy interception was 20.4% of PTTN, and ranged from 16 to 25% for three stands. Higher (31%) in intermittent and multiple events, 18.5% in single uninterrupted events.

S = 4.2% of PTTN

$I = 195 \times PTTN^{-0.81}$

$S = -2.55 + 2.14 \times \log PTTN$

For an average event, $I = 3.5 + 0.635 \times BA$

and $I = -3.61 + 2.01 \times M$ where M = annual average foliage mass.

In the irrigated stands, mean daily water use peaked in summer at 6.8 to 8.2 mm/day depending on treatment and dropped to 1.1–1.8 mm/day in winter. The non-irrigated stands peaked at about 3.5 mm/day in November and dropped to about 0.5 mm/day in late summer and winter but was controlled by soil water content. The amounts of water used by the non-irrigated stand was controlled by annual effective P. In springtime water use by irrigated stands was 3.5–5.5 mm/day.

Nandakumar, N.; Mein, R.G. 1993: Analysis of paired catchment data for some of the hydrologic effects of land-use change. Hydrology and Water Resources Symposium, Newcastle 1993, Institution of Engineers Australia National Conference Publication 93/14: 87–92.

Country: Australia	Duration: 30 yr	Report Location: R1605
Species comparison: Eucalypt		
Land-Use Change: Conversion of one forest to another		
Stand Type: Plantation − 16–22 yr		
Keywords: Water yield		

Comment
Stewarts Creek Catchment, Victoria. Catchment 4 = native forest control; catchment 5 cleared native forest in May 1969 and planted in April 1970.

There was an increase in runoff after harvesting which in their Fig. 4 is about 360 mm reached the year after harvesting (unlike a conversion from native forest to pasture in which the peak increase was 3 yr after harvesting). However, a generalised, fitted equation for the increase in flow after t yr after the maximum increase observed was

$$\Delta = I_{max} \{1 - (1/L_t) \text{ Log } t\}$$

where I_{max} is the maximum increase in flow and
L_t is the log of time in years from the year of maximum increase to the year of zero increase
and t = time in years after the maximum increase
For Stewarts Creek 5, the fitted equation gave time to maximum increase of 3 yr, maximum flow increase of 296 mm, and L_t of 1.3 and T = time between treatment and zero increase of 20 yr.

Nandakumar, N.; Mein, R.G.; Dunin, F.X. 1991: Catchment evaporation from grassland and forest. International Hydrology and Water Resources Symposium, Perth 1991, Institution of Engineers, Australia National Conference Publication: 675–680.

Country: Australia	Duration: 30 yr	Report Location: R1606
Species comparison: Eucalypt		
Land-Use Change: Conversion		
Stand Type: Plantation − 16 to 15 yr		
Keywords: Water yield		

Comment
Stewarts Creek Catchment, Victoria. Catchment 4 = native forest control; catchment 5 cleared native forest in May 1969 and planted in April 1970.

			Catchment 4		Catchment 5	
Period	Catchment 5 vegetation	Precipitation (mm)	Runoff (mm)	P−R (mm)	Runoff (mm)	P−R (mm)
1960–1969	Native forest	1129	201	928	178	951
1970–1975	Regenerating scrub with pine seedlings	1254	275	979	530	724
1976–1980	Pine	1030	173	857	258	772
1981–1985	Pine	1080	167	913	207	873
1986–1989	Pine	1230	310	920	291	939

There was an increase in runoff after harvesting which diminished back to pretreatment levels (about 10% less than catchment 4) when the trees were more than 10 yr old.

Onaindia, M.; Gonzalez, A.; Amezaga, I.; Echeandia, A.; Domingo, M. 1994: Nutrient flow in precipitation and throughfall in *Pinus radiata* forests. (Flujo de nutrientes a traves del agua de lluvia y lavado de copa en bosques de *Pinus radiata* D. Don). Studia Oecologica 10–11: 367–372.

Country: Spain	Duration: 2 yr	Report Location: Not sighted
Stand Type: Plantation 10 yr		
Keywords: Interception; Nutrient cycling		

CAB Abstracts AN 950617662
Analyses were made over 2 yr of the chemical composition of the precipitation and throughfall in two plantations of *P. radiata* 10 yr old near Bilbao. In one plantation less affected by atmospheric pollution the net inflow of nutrients in the throughfall was closely related to the amounts in the precipitation, but in the other plantation more affected by pollution this relationship applied only for Pb and NH4. Differences between the two plantations are discussed, in the light of studies elsewhere in Europe.

Otero, D.L.; Contreras, J.A.; Barrales, M.L. 1994: Environmental effects of replacing native forest with plantations (a study in four microcatchments in the Province of Valdivia). (Efectos ambientales del reemplazo de bosque native por plantaciones (estudo en cuatro microcuencas in la Provincia de Valdivia)). Ciencia e Investigacion Forestal 8: 253–276.

Country: Chile	Duration: 17 months	Report Location: R1428
Species Comparison: Native evergreen forest		
Land-Use Change: Conversion from one forest to another		
Stand Type: Plantation 8 & 16 yr		
Keywords: Water quality; Water yield		

CAB Abstracts AN 97063439

The effect on water quality and yield of replacing native forest with *P. radiata* plantations was studied in four basins in the Central Valley of Valdivia Province, Chile. Data on rainfall, discharge and sediment production were collected for 17 months (January 1993 to May 1994). Average water yield from the basin with native vegetation was up to 28% greater than the yield from basins with plantations in seasons with low rainfall, but this was reversed in seasons with high rainfall. Sediment yield was greater in basins with plantations.

Comment

Results must be treated with caution as they are based on 18 spot measurements of streamflow using floats.

PTTN in 1993 2705 mm, 1994 584 mm to May, total for 17 months 3289mm.

Native forest flow 28% greater than pines in low rainfall season, < 60 L/s/km^2
No significant difference in flows in the high flow season, >60 L/s/km^2

Low flows (< 40 L/s/km^2) more frequent (41%) in pines than natives (23%)

Oyarzun, C.E.; Huber, A.W.; Vasquez, S.G. 1985: Water balance in three *Pinus radiata* plantations. I. Redistribution of the precipitation. (Balance hidrico en tres plantaciones de *Pinus radiata* I: redistribucion de las precipitaciones). Bosque 6: 3–14.

Country: Chile	Duration: 21 months	Report Location: R1421
Stand Type: Plantation 9 & 26 yr	Stand Density: See below	Basal Area: See below
Keywords: Interception; Stemflow; Throughfall		

CAB Abstracts AN 900644306

Measurements were made of throughfall, stemflow and interception in three plantations in Chile: (1) 26 yr old, 733 stems/ha; (2) 9 yr old, conventional management, 1392 stems/ha; and (3) 9 yr old, silvopastoral management, 443 stems/ha. Precipitation reaching the soil (i.e., throughfall + stemflow) was 86, 82 and 92% respectively of the incident precipitation; interception loss was estimated at 14, 18 and

9%, respectively. Canopy storage capacity was 2.2, 1.3 and 1.1 mm respectively, and the amount of precipitation required to initiate stemflow was 5.2, 1.2 and 0.8 mm, respectively. Stemflow on individual trees was positively correlated with crown area.

Comment
21 months of data
P. radiata 26 yr old, 733 SPH; 32m tall; BA 57.1 m^2/ha and avge diameter 32 cm
P. radiata 9 yr old, 443 SPH; farm management (= agro-forestry); BA 10.5 m^2/ha and mean dbh 17 cm
P. radiata 9 yr old, 1392 SPH; BA 19.8 m^2/ha and average diameter 14 cm
Mean annual PTTN = 2000 mm
Gives data for monthly totals and for the total period.

Interception data July 1982 to March 1984

Stand	PTTN (mm)	TF (mm (%))	SF (mm (%)	INTN (mm (%))
26 yr old	3032	2256 (74)	358 (12)	417 (14)
9 yr traditional	3032	1846 (61)	621 (21)	565 (18)
9-yr agroforestry	3032	2418 (80)	367 (12)	279 (9)

Provides relationships between TF or ST or INTN and rain duration for different intensity classes
Canopy storage capacity = 2.2, 1.3 and 1.1 mm for 26, 9t & 9a stands, respectively.

Obtained a direct relationship between canopy covering and interception. In winter, when throughfall and stemflow increase, the absolute amount of interception increased but relative amounts decreased.

Pearce, A.J.; O'Loughlin, C.L.; Jackson, R.J.; Zhang, X.B. 1987: Reforestation: on-site effects on hydrology and erosion, eastern Raukumara range, New Zealand. International Association of Hydrological Sciences Publication 167: 489–497.

Country: New Zealand	Report Location: R1345
Species Comparison: Pasture	
Stand Type: Plantation 23 yr	Rainfall: MAP 1350 mm
Keywords: Evaporation; Interception; Transpiration; Water yield	

Comment
Interception 35% of rainfall = ~ 470 mm/yr.
Stand transpiration was determined as the residual of the soil water balance for 2-week periods using TF as rain input and net SM storage changes. Summer transpiration is 2.5–3.5 mm/day when SM is not limiting; c.f. Priestley Taylor 4–4.5 mm.day for pasture with SM not limited.
Transpiration from May to August was <1 mm/day.
Annual transpiration total ~550 mm.

Hence evaporation is 1020 mm for 1350 mm rain which implies streamflow = 330 mm. Pasture estimate for E using the Priestley-Taylor method is 850 mm/yr implying streamflow = 500 mm. Afforestation would therefore reduce streamflow by 170 mm ~ 30%.

Pienaar, L. V. 1964: Rainfall interception in young *Pinus radiata*. (Reenvalonderskepping deur 'n jong opstand van *Pinus radiata*, D.Don.) Bosbou in Suid-Afrika: 23–37.

Country: South Africa	Duration: 1 yr	Report Location: R1426
Stand Type: Plantation 10 yr	Stand Density:1480 SPH	Basal Area: 22.5 m^2/ha
Height:	Diameter: 14 cm (10–178 cm)	
Keywords: Interception; Stemflow; Throughfall		

Comment
Jonkershoek: MAP 1440 mm. Planted 1949; Study April 1959 to March 1960.
Gross rainfall 1400 mm on 100 raindays

Throughfall	Daily TF = 0.79 × PTTN − 0.1 mm
Interception loss	Daily IL = 0.0907 × PTTN +0.44 mm

PTTN 1400 mm = TF 1092 mm (78%) + SF 137 mm (10%) + IL 171 mm (12%)

Pilgrim, D.H.; Doran, D.G.; Rowbottom, I.A.; Mackay, S.M.; Tjendana, J. 1982: Water balance and runoff characteristics of mature and cleared pine and eucalypt catchments at Lidsdale, New South Wales. The First National Symposium on Forest Hydrology, 1982, Melbourne, 11–13 May. Institution of Engineers, Australia National Conference Publication 82/6: 103–110.

Country: Australia	Duration: 13 yr	Report Location: R1360
Species Comparison: Eucalypt		
Land-Use Change: Forest management; Harvesting; Reforestation		
Stand Type: Plantation 33 yr +	Stand Density: Varies	Rainfall: MAP 840 mm.
Keywords: Evaporation; Interception; Stemflow; Throughfall; Water yield		

CAB Abstracts AN S849330

Authors' Abstract
Results are presented of analyses of runoff characteristics and evapotranspiration estimates of two pairs of small catchments under *P. radiata* and native eucalypt forest at Lidsdale, 130 km north-west of Sydney. Three of the catchments were cleared in early 1978. Comparisons of annual and monthly runoff volumes showed that the runoff from the pine catchments was considerably less than that from the eucalypt catchments. The ratios of the average flows varied seasonally from about 0.7–0.9 in January-February to 0.1–0.4 during late autumn to early spring. The short post- clearing records indicated increases in runoff, with larger increases for the pine than the eucalypt forest. Water balance studies gave

similar evapotranspiration estimates for the two forest types, despite considerable differences in runoff and in biomass produced. Large variations in evapotranspiration from both forest types resulted from different seasonal patterns of rainfall.

Comment
Three pine catchments were planted in 1978 after clearing two catchments with 1935 planted pines and one with 33–48-year-old eucalypt stand.

Preclearing: Pine at Lidsdale 1 had streamflow 0.79 of eucalypt at Lidsdale 5.
Post-clearing: Storm runoff in larger events more than doubled after clearing.

Water balance

	P (mm)	I (mm)	Nett TF (mm)	Streamflow (mm)	E (mm)
Pre-harvest 1968–1971					
Pine L2	871	163(19%)*	708(82%)	72(8%)	627(72%)
Eucalypt L6	895	95(11)	800(90)	127(14)	638(71)
Pre-harvest 1974–1976					
Pine L1	842	183(22%)	659(78%)	190(23%)	472(56%)
Eucalypt L6	870	99(11)	771(89)	269(31)	501(58)
Post-harvest 1978–1981					
Pine L1	688	0(0%)	688(100%)	123(18%)	567(82%)
Eucalypt L6	750	0(0)	750(100)	162(22)	603(80)
Eucalypt L5	750	88(12)	662(88)	103(13)	574(77)

* Interception estimated
E is determined as the residual in the water balance equation.

Although rainfall was similar for the first two periods, the latter had greater runoff reflecting a higher incidence of large storms giving greater runoff. Soil moisture levels were also higher, and there were different time patterns of rain falling. Flow durations showed a much smaller number of zero flow days in the second period.

Difference in interception between the pines and eucalypts could explain the difference in runoff between the species for the first two periods. E is similar for the two species.

Pook, E.W.; Moore, P.H.R.; Hall,T. 1991a: Rainfall interception by trees of *Pinus radiata* and *Eucalyptus viminalis* in a 1300 mm rainfall area of Southeastern New South Wales: I. Gross losses and their variability. Hydrological Processes 5: 127–141.

Country: Australia	Duration: 18 months	Report Location: R47
Species Comparison: Eucalypt		
Stand Type: Single tree		
Keywords: Interception		

CAB Abstracts AN 910652790/Authors' Abstract

Interception loss, I, was determined by continuous concurrent measurements of canopy precipitation balances of a mature seed orchard tree of *P. radiata* and a dominant tree of *Eucalyptus viminalis* at a mountainous high rainfall site (900 m altitude) in Tallaganda State Forest of the Upper Shoalhaven Catchment. Approximate canopy storage capacity (Sc) of the pine was 54 L, and that of the eucalypt was 11.3 L. Gross pine I was 26.5% and eucalypt I was 8.3% of total incident rainfall over a period of 18 months (June 1975 to December 1976). The exponential model that provided the best fit to overall data relating I to gross rainfall was of good precision for the pine ($r^2 = 0.73$) but rather poor precision for the eucalypt ($r^2 = 0.27$). A consistent pattern in interception data of the two canopy types suggested that variation in I was related to change in pervasive conditions influencing rates of evaporation from wet canopies during rainfall. Multiple regression analyses confirmed that factors such as rainfall intensity and windspeed explained some of the variation in eucalypt I but little in pine I. Negative eucalypt I and corresponding low values of pine I over a wide range of weekly gross rainfall (up to 20 mm) suggest that capture of wind-borne precipitation (cloud, mist, or fog) had also complicated the canopy precipitation balances.

Comment

Single tree study. Relevance to a plantation is questionable as there are large differences in the aerodynamics of the two environments.

Pook, E.W.; Moore, P.H.R.; Hall, T. 1991b: Rainfall interception by trees of *Pinus radiata* and *Eucalyptus viminalis* in a 1300 mm rainfall area of Southeastern New South Wales: II. influence of wind-borne precipitation. Hydrological Processes 5: 143–155.

Country: Australia	Duration: 18 months	Report Location: R48
Species Comparison: Eucalypt		
Keywords: Interception		

CAB Abstracts AN: 910652790/Authors' Abstract

Analyses were made of the concurrent canopy precipitation balances of a seed orchard pine and a mature forest eucalypt during protracted rainfalls selected for their representation of the range of variation encountered in the two canopy types at Tallanganda State Forest (990 m altitude) in the Upper Shoalhaven Valley. Although their canopy storage capacities were widely different there was consistent interception behaviour in the pine and the eucalypt in all events. Detailed weather data and the time courses of interception loss provided circumstantial evidence for a varying and, at times, substantial

influence of cloud or mist deposition on the canopy precipitation balances during rainfall that made a significant contribution to the variation in rainfall interception data. Mean evaporation rates from the saturated canopies during rainfall varied from −0.02 mm/hr to 0.68 mm/hr in the pine; and from −0.04 mm/hr to 0.13 mm/hr in the eucalypt. The implications of cloud-capture during rainfall for studies of rainfall interception in forests of south-eastern Australia are discussed.

Comment
Single tree study. Relevance to a plantation is questionable as there are large differences in the aerodynamics of the two environments.

Putuhena, W.M.; Cordery, I. 1996: Estimation of interception capacity of the forest floor. Journal of Hydrology 180: 283–299.

Country: Australia		Report Location: R13
Species Comparison: Eucalypt; Native grassland		
Stand Type: Plantation 15 yr	Stand Density: 1024 SPH	Basal Area: 21 m^2/ha
Height: 16 m		Rainfall: MAP 890 mm
Keywords: Interception		

CAB Abstracts AN 961908991/Authors' Abstract

Methods of measuring interception capacity of the understorey (grasses) and litter layer were developed to estimate the forest floor interception capacity of a 15-yr-old *P. radiata* plantation and a native dry sclerophyll *Eucalyptus* forest in Australia. Interception by various types of forest floor were measured in the laboratory using a technique of applying artificial rain to undisturbed samples of the forest floor. These laboratory experiments separately measured the interception storage capacity of the pine needle mat, the leaf/twig/bark debris mat in the *Eucalyptus* forest, and the understorey (grasses). The results showed that the interception storage capacity of all components of the forest floor of both vegetation types were proportional to the mass per unit area of forest floor cover. It was also shown that the interception storage capacity of the pine needle mat and the leaf/twig/bark debris mat under eucalypt were proportional to the thickness of the surface debris. For standing grasses the capacity was proportional to the percentage of ground cover. These laboratory results were then used to estimate the forest floor interception storage capacity of two experimental catchments each covered by one of the two forest types. In each case the forest floor was extremely heterogeneous, and so a large number of undisturbed samples were examined. Approximate forest floor interception capacity of the pine catchment was 2.8 mm and of *Eucalyptus* was 1.7 mm. The contribution of leaf litter, stem and branch litter, and grass vegetation to the overall interception capacity was similar for both catchments at 47, 8 and 45%, respectively.

Putuhena, W.M.; Cordery, I. 2000: Some hydrological effects of changing forest cover from eucalypts to *Pinus radiata*. Agricultural and Forest Meteorology 100: 59–72.

Country: Australia	Duration: 27 yr	Report Location: R966
Species Comparison: Eucalypt		
Land-Use Change: Conversion of one forest type to another		
Stand Type: Plantation 11 to 16 yr	Stand Density: Varies	Rainfall: 775 mm
Keywords: Interception; Stemflow; Throughfall; Water yield		

Authors' Abstract

A study of the hydrological effects of clearing a catchment covered by native, dry sclerophyl eucalypt forest, and replanting it with a *P. radiata* plantation was undertaken. The purpose of this study was to examine the effects of vegetation species change and growth rates on streamflow.

The water balance of the two forests was observed for a 27-yr period; 11 yr before and 16 yr after the forest conversion. Data on precipitation, canopy interception, forest floor interception and water yield, combined with analysis of the rate of vegetative growth and development of the forest floor litter, enabled investigations of the effects of forest conversion on the water balance components for the whole period (1967–1993). The age of a *P. radiata* plantation during the first 16 yr of its growth greatly affected the streamflow and other water balance components. For the first 4 yr after forest conversion, the rate of evapotranspiration and streamflow changed completely. Transpiration and the evaporation of intercepted rainfall ceased after the forest was cleared. The changes in the first 4 yr were followed by a further transformation of the whole evapotranspiration process as the pine plantation developed. A trend of increasing evapotranspiration and canopy and forest floor interception losses as the canopy grew, with decreases in runoff, was followed by an equilibrium situation in which streamflow, and the evapotranspiration from soil water storage were smaller than for the native forest.

Comment

Lidsdale catchment L6: 1967–77 in eucalypt; 1978–1977 *P. radiata*. Cleared Feb. 1978; burnt April 1978; planted winter 1978; Pruned to 2 m late 1986.
Rainfall 775mm, 128 raindays; range 416 mm (1982) to 1124 mm (1973).

Daily stemflow	15-yr-old pine	$SF = 0.038 \times RF$	c.f. eucalypt = $0.021 \times PTTN$
Daily throughfall	15-yr-old pine	$SF = (1 - (0.47C + 0.48 \times \exp(-0.40 \times RF/C)1)) \times PTTN$	
Daily throughfall	eucalypt	$SF = (1 - (0.55C + 0.27\exp(-0.20RF/C)))PTTN$	

where C = fraction of canopy cover = 0.34 for eucalypt and 0.71 for 15-yr-old pine

Canopy interception in figure. Gives a forest floor interception as well — rises to 13%.
Canopy interception reaches about 28% for dry year = 650 mm at year 14

Lidsdale Annual Data

Year	Rainfall (mm)	Eucalypt Streamflow measured (mm)	Eucalypt Streamflow estimated (mm)	*P. radiata* Streamflow measured (mm)	Difference *P. radiata* - Eucalypt (mm)
1967	663	75			
1968	679	29			
1969	893	165			
1970	816	97			
1971	852	215			
1972	696	133			
1973	1124	336			
1974	893	281			
1975	630	64			
1976	908	260			
1977	268	29			
1978	961		189	386	197
1979	583		39	143	104
1980	494		17	46	29
1981	812		81	148	67
1982	416		12	24	12
1983	835		52	99	47
1984	901		133	155	22
1985	719		32	25	-7
1986	938		257	235	-22
1987	859		96	39	-57
1988	787		64	17	-47
1989	804		57	6	-51
1990	910		121	74	-47
1991	530		15	1	-14
1992	649		30	5	-25
1993	608		11	1	-10

Richmond, I.C. 1980: Streamflow and water quality following pine establishment in the Donnybrook Sunkland. Forests Department Western Australia Research Paper No. 58. 6 pp.

Country: Australia	Report Location: Not sighted
Species Comparison: Eucalypt	
Land-Use Change: Conversion of one forest to another	
Keywords: Water quality; Water yield	

CAB Abstracts an F894127

Streamflow increased after clearing of *Eucalyptus marginata* and planting of *P. radiata*, but there were no significant changes in water quality.

Riddell, J.M.; Martin, G.N. 1982: Estimating annual water yields from forest and pasture catchments. New Zealand Hydrological Society Symposium, Auckland, 1982. (Unpublished).

Country: New Zealand	Report Location: LKR
Species Comparison: Native evergreen forest; Pasture	
Keywords: Water yield	

Comment

Used annual water yield data from 38 pasture, 32 native forest and 20 pine forest catchments.

Concluded from mean runoff versus mean precipitation plots that:
Pasture catchments have a greater runoff than forested catchments.
In the rainfall range where native forest and pine plantation catchments overlap, relationships between runoff and rainfall were indistinguishable.

For pasture catchments

$RO = 0.60 \times PTTN - 267$	$P < 1400$ mm	$n = 28$	$r = 0.758$
$RO = 1.4 \times PTTN - 1477$	$P >= 1400$ mm	$n = 20$	$r = 0.938$

For forested catchments

$RO = 0.68 \times PTTN - 605$	$P < 1600$ mm	$n = 12$	$r = 0.797$
$RO = 1.24 \times PTTN - 1537$	$P >= 1600$ mm	$n = 40$	$r = 0.985$

Rowe, L.K. 1998: Forestry and water resources. Catchment Connections (Landcare Research, Lincoln) 3: 7–8

Country: New Zealand	Report Location: LKR
Species Comparison: Pasture	
Keywords: Water yield	

Comment
Presents data and discusses in general terms observed changes in streamflows following afforestation in the following regions: Waiwhiu (Northland), Otago, Canterbury, and East Coast North Island. Notes that in regions with annual rainfall about 600 mm, there will be little difference in flows from pasture and pine forested catchments. In fact, there may be no flow from either. Also changes in flows as parts of large catchments are planted may not be detectable.

Rowe, L.K.; Fahey, B.D. 1988: The Maimai hydrological study: Some conclusions ten years after harvesting indigenous forests. New Zealand Hydrological Society Symposium, Dunedin, 1988. (Unpublished).

Country: New Zealand	Duration: 11 yr	Report Location: LKR
Species Comparison: Native evergreen forest		
Land-Use Change: Conversion from one forest to another		
Stand Type: Plantation −1 to +10 yr		Rainfall: MAP 2450 mm
Keywords: Water quality; Water yield		

Comment
Mean annual rainfall: LM 2400 mm; UM 2330 mm.
Mean annual runoff: M6 1320 mm; M15 1270 mm for native forest = 54% of rainfall.

After harvesting, first year increases for the four treated catchments were generally in the range 400–600 mm. Three was a rapid decrease in the extra runoff in the 3 yr after harvesting with prolific regrowth and after 6 yr it was back to pretreatment levels.

Also presents data on water quality aspects.

Rowe, L.K.; Fahey, B.D. 1991: Hydrology and water chemistry changes after harvesting small, indigenous forest catchments, Westland, New Zealand. International Association of Hydrological Sciences Publication No. 203: 259–266.

Country: New Zealand	Duration: 10 yr	Report Location: LKR
Species Comparison: Native evergreen forest		
Land-Use Change: Conversion from one forest to another		
Stand Type: Plantation −3 to +7 yr		Rainfall: MAP 2450 mm
Keywords: Water quality; Water yield		

CAB Abstracts AN 920663081/Authors' Abstract

After a 2- to 3-yr calibration period, four of six small (1.63 to 4.62 ha) catchments on the west coast of New Zealand's South Island were subjected to various harvesting treatments (clear-felling ± riparian reserve, burning or spraying with desiccant) and then were planted with *P. radiata*. Streamflow yields increased after treatment up to 550 mm/yr, but increases were not in the order expected from a ranking of treatment severity. After about 7 yr of vegetation regrowth, streamflow seemed to stabilise at a level about 200 mm/yr less than that before treatment. The burnt catchments had the largest initial increases in streamwater electrical conductivity and cation and NO^3 concentrations, but, apart from K, these returned to pre-treatment levels in about 2 yr. Unburnt catchments with riparian reserves were least affected. After treatment, cation yields were highest for the catchment with the largest runoff amounts.

Rowe, L.; Fahey, B.; Jackson, R.; Duncan, M. 1997: Effects of land use on floods and low flows. Ch. 6 in Mosley, M.P.; Pearson, C.P. (Eds.) Floods and Droughts: the New Zealand Experience. New Zealand Hydrological Society, Wellington. Pp. 89–102.

Country: New Zealand	Report Location: R1602
Species Comparison: Native evergreen forest; Native grassland; Pasture; Scrubland	
Land-Use Change: Afforestation; Conversion from one forest to another	
Keywords: Low flow; Review; Storm flow	

Comment

Reviews many of the New Zealand studies on the effects of land-use change on the hydrology of New Zealand catchments.

Rowe, L.K.; Pearce, A.J. 1994: Hydrology and related changes after harvesting native forest catchments and establishing *Pinus radiata* plantations. Part 2. The native forest water balance and changes in streamflow after harvesting. Hydrological-Processes 8: 281–297.

Country: New Zealand	Duration: 12 yr	Report Location: LKR
Species Comparison: Native evergreen forest		
Land-Use Change: Conversion from one forest to another		
Stand Type: Plantation −3 to 9 yr		Rainfall: MAP 2450 mm
Keywords: Water yield		

CAB Abstracts AN 950611743/Authors' Abstract

Six small, steep, south-west facing catchments (1.63–4.62 ha) have been monitored in Westland, New Zealand since 1974. Two catchments were retained as native mixed evergreen forest and the rest were subjected to various harvesting and land preparation techniques (clear- felling, slash burning, herbicide treatment, riparian protection) before being planted with *P. radiata* between 1977 and 1980. The 11-yr water balance for the native forest catchments was: rain = stream flow + interception loss + transpiration + seepage (2370 mm = 1290 mm + 620 mm + 360 mm + 100 mm). In the year after treatment stream flow generally increased by 200–250 mm, except for one treatment (clear-felling, herbicide application, no riparian reserve) where the increase was 550 mm. The catchments were planted with *P. radiata*, but rapid colonisation by bracken (*Pteridium esculentum*) and Himalayan honeysuckle (*Leycesteria formosa*) led to a rapid decline in stream flow, which returned to pre-treatment levels after an average of about 5 yr. Stream flow yields then continued to decline for another 2–3 yr before stabilising at a level about 250 mm/yr lower than pre-treatment levels. At this time the catchments had a dense bracken/honeysuckle understorey beneath 5-m-tall *P. radiata*.

Comment

Data from the Maimai catchments, near Reefton, West Coast.
M6 and M15 were retained in native beech/podocarp/hardwood forest, the others were clear-felled, and cable logged with (M8, M13) or without riparian reserves, and burned (M8, M14) or not burned before planting.

Rainfall (UM & LM) and runoff for Maimai catchments (mm)

Year	M5	M6	M8	M13	M14	M15	LM	UM
1977	1306	913				806	1888	1840
1978		1075				1069	2138	2087
1979	2441	1419		2040		1297	2625	2462
1980	2624	1775	2029	2216		1538	2827	2711
1981	2058	1363	1687	1779	1615	1323	2482	2356
1982	1745	1070	1414	1522	1335	1119	2253	2144
1983	2322	1688	1991	2082	1863	1633	1996	2735
1984	1919	1324	1597	1636	1417	1261	2468	2303

Year	M5	M6	M8	M13	M14	M15	LM	UM
1985	1374	1130	1229	1324	1325	1160	2193	2107
1986	1418	1250	1250	1396	1334	1167	2247	2133
1987	1818	1554	1654	1731	1674	1446	2668	2461
Mean		1324				1256	2435	2304

Control catchments M6 and M15

Regression relationship determined using the above data were:

M15 = −630 (± 330) + 0.82 (± 0.14) × UM $r^2 = 0.95$

M6 = −620 (± 400) + 0.80 (± 0.16) × LM $r^2 = 0.93$

M15 = 170 (± 230) + 0.82 (± 0.17) × M6 $r^2 = 0.95$

Water balance in mm:

	Rainfall =	Runoff +	Interception +	Transpiration +	Seepage
M6	2435	1320	635	380	100
M15	2300	1260	600	340	100

Determined a water balance model with:

IL% = 7.1 × [sin(0.0172 × D + 90)] + 26.4

where IL% = interception loss as a percentage of rainfall for a given month, D is the number of days since 1 January (15 for January, 46 for February,......) and 90 is the value of the phase shift of the calculated sine wave.

Trans = 1.2 × [sin(0.0172 × D + 90)] + 1.8

where trans = transpiration for a rainfree day (<1.0 mm of rain).

Harvesting:

After harvesting, streamflow increases were variable and not that expected from the perceived severity of the operations. In the first year after harvesting the increases were generally in the range 200–260 mm, but was 550 mm at M5, the most severe treatment. Varying annual rainfall in the year following treatment did affect the magnitude of the increases. Because rainfall is high (~2400 mm/yr), reduction of interception alone can easily account for these increases.

Significant regression relationships were developed for determining the expected diminishing yields as the catchments recovered after treatment, but these were variable and inconsistent with the severity of treatment. Annual runoff yields from the catchments were generally back to pretreatment levels after 3–6 yr and did decline to about 20 mm/month lower than pretreatment levels. This was attributed to dense bracken/honeysuckle regrowth as well as tree growth.

Rowe, L.K.; Pearce, A.J.; O'Loughlin, C.L. 1994: Hydrology and related changes after harvesting native forest catchments and establishing *Pinus radiata* plantations. Part 1. Introduction to study. Hydrological-Processes. 8: 263–279

Country: New Zealand	Report Location: LKR
Species Comparison: Native evergreen forest	
Land-Use Change: Conversion from one forest to another	

CAB Abstracts AN*: 950601150/Authors' Abstracts*

The hydrology of eight small catchments (1.63–8.26 ha) has been monitored in Westland, New Zealand since 1975. Two of these catchments were left in indigenous beech-podocarp- hardwood forest and the rest were subjected to various harvesting and land preparation treatments before being planted with *P. radiata*. This paper introduces a series of papers on the hydrology of the indigenous forest catchments and the changes that occurred after treatment. The catchments, experimental programme, climate of the area and the rainfall regime experienced between 1975 and 1987 are described.

Comment

Provides background information on the Maimai catchments in North Westland, New Zealand.

Ruiter, J.H. 1964: The water relations of *Pinus radiata* (D Don) in the lower south east of South Australia. MSc Thesis, University of Adelaide.

Country: Australia	Duration: 3 yr	Report Location: Cited in Turner and Lambert (1987)
Stand Type: Plantation 16 to 18 yr		Basal Area: 37.9 m^2/ha
Keywords: Interception; Throughfall		

Comment

There were 10 stands, therefore the data must be averages.
16–18 yr old stands; average PTTN 658 mm, TF 478 mm

Rycroft, H.B. 1952: Hydrological research in South African forestry 1947 to 1951. Government Printer, Pretoria. Pp.13.

Country: South Africa	Report Location: R1591 (Abstract only)
Species Comparison: Scrubland (fynbos)	
Land-Use Change: Afforestation	
Stand Type: Plantation 12 yr	
Keywords: Water yield	

CAB Abstracts

General progress in hydrological research in South Africa is reported. The influence of replacing native sclerophyll shrubs by a plantation of *P. radiata*, now 12 yr old, is examined, and it is shown that stream discharge has not been significantly affected by the treatment. A critical review of the methods of investigation leads to the conclusion that these are satisfactory, but it is considered that the influence of variations in rainfall on streamflow should in future be studied more intensively.

Saunier, R.; Burschel, P.; et al. 1969: Effect of a stand of *Pinus radiata* on some ecological factors: I. Solar radiation, light, and soil temperature. II. Air temperature, soil moisture, and evaporation. III. Interception and stemflow. In Actas V Jornadas Forestales, Los Angeles 1969. Asociacion Chilena de Ingenieros Forestales, Santiago. [1970]. Pp. 31–48.

Country: Chile?	Report Location: Not Sighted
Keywords: Interception	

Scott, D.F. 1993: The hydrological effects of fire in South African mountain catchments. Journal of Hydrology 150: 409–432.

Country: South Africa		Report Location: R1372
Species Comparison: Eucalypt; Scrubland		
Land-Use Change: Fire		
Stand Type: Plantation 5 & 31 yr	Stand Density: Varies	Rainfall: Varies
Keywords: Storm flow; Water yield		

CAB Abstracts/Author's Abstract

Streamflow and its storm-flow elements in four catchments were analysed by the paired catchment method for a response to fire. Prior to burning, two of the catchments were vegetated with over-mature fynbos (the indigenous scrub vegetation of the south-western Cape, South Africa), one was afforested with *P. radiata* and the fourth with *Eucalyptus fastigiata*. One of the fynbos catchments was burned in a prescribed fire in the late dry season. The other catchments burned in wildfires.

Neither of the fynbos catchments showed changes in stormflow. Annual total flow increases of around 16% were in agreement with model predictions, being related to the reductions in transpiration and interception. The manner of streamflow generation appeared to have remained unaltered despite the presence of some water repellency in the soils and consequent overland flow in some steep midslope sites.

The two timber plantation catchments experienced large and significant increases in stormflows and soil losses, while total flow increased by 12% in the pine catchment and decreased marginally in the eucalypt catchment. The pattern of the stormflow increases was similar in both cases. After fire, storm hydrographs were higher and steeper though their duration was little changed. The respective first year increase in the pine and eucalypt catchments were 290% and 1110% for peak discharge, 201% and 92% for quickflow volume, and 242% and 319% for storm response ratio. These fire effects are considered to be due to changes in stormflow generation consistent with an increased delivery of overland flow (surface runoff) to the stream channel. This was caused, in part, by reduced infiltration resulting from water repellence in the soils of the burned catchments. Overall the hydrological effects of fire are related

to numerous interactive factors, including the degree of soil heating, the vegetation type and soil properties.

Comment
At Bosboukloof after the 5-yr-old *P. radiata* was burned, annual water yield increased by 70 mm in the first year.

Scott, D. F. 1997: The contrasting effects of wildfire and clearfelling on the hydrology of a small catchment. Hydrological Processes 11: 543–555.

Country: South Africa	Duration:	Report Location: R3
Land-Use Change: Fire; Harvesting		
Stand Type: Plantation ages vary		
Keywords: Storm flow; Water yield		

CAB Abstracts/Author's Abstract
A wildfire in an afforested research catchment presented the rare opportunity to compare the hydrological effects of wildfire with the effects of clear-felling in the same catchment in the Jonkershoek Valley, in the south-western Western Cape Province of South Africa. The timber plantation, which occupies 57% of the 2 km^2 catchment, had been clear-felled and replanted to *P. radiata* roughly 5 yr before the fire. The effects of the two treatments on total flow, storm flow and quick-flow volumes, peak discharge and storm response ratio were determined by means of multiple regression analysis, employing the dummy variable method to test for the significance of treatments. Both clear-felling and wildfire caused significant increases in all the stream flow variables analysed. But the clear-felling effect was dominated by large increases in total flow (96% over 3 yr), of which storm flow and quick-flow volumes formed only minor parts. After the wildfire, by contrast, increases in total flow were small (12%) but the storm flow increases were three- to four-fold in the first year and roughly double in the second year. The wildfire caused fire-induced water repellency in the soils, which led to overland flow on mid-slope sites, where soil infiltrability normally far exceeds local rainfall intensities. It is argued that these results support the hypothesis that stream-flow generation processes were changed by the wildfire in that overland flow made a direct contribution to storm flows, but that clear-felling had no such effect.

Comment
Bosboukloof (57% plantation) was harvested at 39–42 yr. The catchment was replanted but was burned by wildfire in 1986 at tree ages 4–7 yr. The control catchment is Lambrechtsbos-B at age 22 yr when the fire took place.
In the following figure, evaporation is PTTN − RO
Harvesting effects:
Clearfelling occurred 1979–1982; planting took place within 12 months; pretreatment period was chosen as 1977–78, post-treatment was after 70% cleared = 1981–1982.

Storm flow volumes increased (quickflow+baseflow), quickflow volumes and peakflows increased.

Harvesting effects

	1977–1978	1981	Increase (%)	1982	Increase (%)
Weekly RO (mm)	11.1	8.9	97	6.8	102
Storm flow (mm)	6.9	2.7	25	1.8	18
Quickflow (mm)	1.8	0.9	62	0.6	37
Peak flow (mm/day)	6.8	5.8	53	3.1	30

Noted that an increase in streamflow was first observed when less than half the plantation had been felled, i.e., about 25% of the catchment. Between 1981 and 1983, the average annual increase was 237 mm (96%). By 1985, water yield was approaching pretreatment levels but was still greater.

Fire effects:
The pre-fire calibration period was selected as the 3 yr before the burn and the treatment period was the 2 yr after the burn.

Wildfire effects

	Pre-fire	1986	Increase (%)	1987	Increase (%)
Weekly RO (mm)	9.9	14.1	12	11.4	11
Storm flow (mm)	3.7	6.4	62	5.1	20
Quickflow (mm)	1.4	3.6	201	2.2	47
Peak flow (mm/day)	6.6	22.5	290	12 0	108

Annual streamflow increased 70 mm (12%) and 61 mm (11%) in the 2 yr after burning.

Scott, D.F.; Smith, R.E. 1997: Preliminary empirical models to predict reductions in total and low flows resulting from afforestation. Water SA 23: 135–140.

Country: South Africa	Duration: 17 yr	Report Location: R15
Species Comparison: Scrubland (fynbos)		
Land-Use Change: Afforestation		
Stand Type: Plantation 0–17 yr		
Keywords: Low flow; Water yield		

CAB Abstracts AN97190783/Authors' Abstract

Mathematical models to predict runoff reductions due to afforestation are presented. The models are intended to aid decision makers and planners who need to evaluate the water requirements of competing land uses at a district or regional scale. Five afforestation catchment experiments were analysed by the paired catchment method to determine the reductions in both total (annual) and low flows. The percentage reduction in flow after afforestation with both *Eucalyptus grandis, Pinus patula*, or *P.*

radiata was determined for each post-treatment year relative to the expected flow based on a calibration relationship with an untreated (control) catchment. Curves were fitted to these data points to predict the effects of afforestation under optimal and sub-optimal growing conditions. Eucalypt plantations depleted both total and low flows sooner and in larger quantities than pine stands.

Comment
Presents, amongst other studies, data from the Jonkershoek Lambrechtsbos-B catchment (65.5 ha; 82% *P. radiata*) for flow reductions in the 17 yr after planting — Bosboukloof (200.9 ha; 57% mature *P radiata*) is the control.
MAP 1473 vs 1296 mm; MAR 531 vs 593 mm.
Gives sigmoidal relationships for the % reduction in flow (and low flow) with time since planting.
$Y = A/(1+Be^{nX})$ where Y = % flow reduction, A = asymptote = maximum Y, B intercept, X = plantation age in years, n = exponent. Also splits land into two classes: optimal (deep soils and tropical climate) vs sub-optimal (shallow soils, less favourable climate)

Obvious precipitation effect but no data given to isolate this. The low flow period is those months below the 75th percentile of monthly flows — none in some years.

Sheriff, D.W.; Mattay, J.P.; McMurtrie, R.E. 1996: Modeling productivity and transpiration of *Pinus radiata*: climatic effects. Tree Physiology 16: 183–186.

Country: Australia	Duration: 10 yr	Report Location: R88
Stand Type: Plantation various		
Keywords: Model; Transpiration		

CAB Abstracts AN 969694261

It has been reported that stem volume growth of *P. radiata* increased 1.8 times as fast in trees located near Mt Gambier (south-eastern South Australia) than in trees located in other parts of southern Australia (e.g., Canberra) receiving similar amounts of rainfall: it was further hypothesised that this difference may be due to access to aquifer water. An alternative hypothesis is that the variation results from differences in temperature and humidity of the two regions. In order to distinguish between these two hypotheses, an estimate was made of net carbon assimilation and transpiration for the two regions with two models, BIOMASS Model 1, and a modified version, Model 2, in which response functions for carbon assimilation and leaf conductance were replaced with those derived from field gas exchange data collected at Mt. Gambier. Simulated carbon gain was compared with the *P. radiata* data for Mt Gambier. Regional differences in climate resulted in a 20% greater simulated annual transpiration at Canberra than at Mt Gambier but only small differences in simulated productivity, indicating that climatic differences did not account for the reported differences in productivity. With Model 1, simulated annual net carbon gain and annual increase in stem biomass were greater at Canberra than at Mt Gambier, whereas Model 2 indicated a similar annual net carbon gain and annual stem biomass increase in both regions.

Comment
Used two versions of the Biomass model to simulate transpiration for sites at Mt Gambier and Canberra using 10 yr of climate records.

Simulated transpiration

	MAP (mm)	Transpiration (mm)
Mt Gambier	669	601 or 612
Canberra	798	500 or 517

Smethurst, P.J.; Nambiar, E.K.S. 1990: Distribution of carbon and nutrients and fluxes of mineral nitrogen after clear-felling a *Pinus radiata* plantation. Canadian Journal of Forest Research 20: 1490–1497.

Country: Australia	Duration: 1 yr	Report Location: R105
Land-Use Change: Harvesting		
Stand Type: Plantation 37 yr	Stand Density: 162 SPH	Basal Area: 33.9 m^2/ha
Height: 34–40 m	Diameter: 31–71 cm	
Keywords: Nutrient cycling; Throughfall		

CAB Abstracts AN 910653943

The effects of clear-felling and slash removal on the distribution of organic matter and nutrients, fluxes of mineral N, and soil water and temperature were studied in a 37-yr-old *P. radiata* plantation on a sandy podzol near Mount Gambier, South Australia, from 1984 to 1987. Slash, litter and the top 30 cm of soil combined contained 1957 kgN/ha, of which slash and litter contained 12 and 25%, respectively. During the first 18 months after clear-felling, soil water content in the clear-felled area was up to 50% greater than in the uncut plantation, but there were only minor differences in soil temperature. Slash removal decreased the water content of litter, but had little effect on soil water content or temperature. In the uncut plantation, N mineralised in litter and soil was completely taken up by the trees. Following clear-felling, rates of N mineralisation increased in litter after 4 months, and in soil after 12 months, but changes were less pronounced with slash removal. After clear-felling, increased mineralisation and the absence of trees (no uptake) led to increased concentrations of mineral N in both litter and soil, 64-76% of which was leached below 30 cm soil depth prior to replanting. Despite leaching, concentrations of mineral N after clear-felling remained greater than those in the uncut plantation for at least 3 yr.

Comment

South Australia

OP = old plantation with a significant understorey of *P. radiata* seedlings.

In the following table, IL was calculated by LKR as PTTN − Throughfall − 0.02 × PTTN as an allowance for stemflow

Interception

PTTN (mm)	TF OP (mm)	IL OP (mm)	E OP (mm)	E Cleared (mm)
754	517	231	323	914

Evaporation — what is it? Does it include soil evaporation, interception loss, or is it estimated transpiration?

Smith, C.M. 1992: Riparian afforestation effects on water yields and water quality in pasture catchments. Journal of Environmental Quality 21: 237–245.

Country: New Zealand	Duration: 18 yr	Report Location: LKR
Species Comparison: Pasture		
Land-Use Change: Afforestation		
Keywords: Water quality; Water yield		

Comment

Moutere catchments 2 (6.95 ha), 3 (2.80 ha) and 5 (2.71 ha).
From 1970 to 1978 the three catchments were grazed. After 1979, C2 continued to be grazed as a control catchment. In August 1978, a 25–35-m strip enclosing the stream channel and lower slopes was fenced off in C3 and C4 and planted at 1400 SPH in *P. radiata*. In late 1983 the trees were thinned to 500 SPH — light grazing was allowed under the trees until mid-1986.

Precipitation and runoff (mm) at Moutere, Nelson

		Catchment C2			Catchment C4		
	Precipitation	Runoff	Quickflow	Delayed flow	Runoff	Quickflow	Delayed flow
1970–1978	1032	271	97	175	214	76	138
1979–1987	1010	266	97	169	161	70	91

Hydrograph separation used the method of Hewlett & Hibbert (1967). The original Table 3 by Smith also gives the range and standard deviations. Streamflow is reduced after pine establishment in the riparian zone. Quickflow was only slightly lower but was an increased proportion of total flow as delayed flow decreased more. Note that the post-treatment period includes a few years when no effects will be noticeable as the pines will be too small and the use of means could be misleading with respect to the actual change.
The paper does show that in some years between 1982 and 1987: annual runoff was reduced, QF declined by between 52 and 59%, and delayed flow was reduced. Peak flows were reduced in small events, but medium-sized storm peaks were not affected.

Gives the deviations of C4 seasonal data from that predicted from C2 using regression relationships. The seasonal rainfall is given but no flow data for either catchment.

Smith, J.L.H. 1946: Exotic forests and runoff. New Zealand Journal of Forestry 5: 231–232.

Country: New Zealand	Report Location: R1393
Land-Use Change: Afforestation	
Keywords: Water yield	

Comment
Earliest reference in this bibliography on the effects of forests on water yield in New Zealand
Maramarua exotic forest with 4040 ha in *P. radiata* of 5650 ha total. Notes experience of farmers that a creek in this forest used to flood regularly washing out bridges while in manuka scrub, the floods are getting progressively smaller.
Also in Tairua, a water supply put in 15 yr previously in bracken and manuka is almost completely dried up. *P. radiata* was planted about the same time.

Smith, M.K. 1974: Throughfall stemflow and interception in pine and eucalypt forest. Australian Forestry 36: 190–197.

Country: Australia	Duration: 2 ½ yr	Report Location: R56
Species Comparison: Eucalypt		
Stand Type: Plantation 33+ yr		Basal Area: 31 m^2/ha
Height: 27 m		
Keywords: Interception; Stemflow; Throughfall		

CAB Abstracts AN 740616688

Comment
Lidsdale
Pine: catchment 2, crown density index =63%
Eucalypt: catchment 6, mature native eucalypt forest, 12.5 m tall, BA 26.5 m^3/ha

Weekly measurements (converted from inches to mm)
Pine:
TF = −1.45 + 0.837 × PTTN
SF = −0.23 + 0.036 × PTTN
PTTN = 2210 mm   TF+SF = 1795 mm   IL=415 mm =18.7% of PTTN

Eucalypt:
TF = −0.43 + 0.889 × PTTN
SF = 0.00 + 0.019 × PTTN

PTTN =2270 mm   TF+SF = 2025 mm   IL=245 mm =10.6% of PTTN

Analyses with storm duration, mean monthly air temp., monthly pan evaporation in multiple regressions were non- or just significant.

Smith, M.K.; Watson, K.K.; Pilgrim, D.H. 1974: A comparative study of the hydrology of radiata pine and eucalypt forests at Lidsdale, New South Wales. Civil Engineering Transactions, Institution of Engineers, Australia 16: 82–86.

Country: Australia	Duration: 31 months	Report Location: R1592
Species Comparison: Eucalypt		
Stand Type: Plantation 33+ yr		Basal Area: 31 m^2/ha
Height: 27 m		
Keywords: Interception; Stemflow; Throughfall		

CAB Abstracts AN 759\0626022

Comment

Study area as for Smith (1974). Interception relationships as for Smith (1974)
Pine/eucalypt throughfall relationships are significantly different at 0.1% probability.

Water balance 31 months at Lidsdale

	Pine Catchment 2	Eucalypt Catchment 3
P (mm)	2207	2268
IL (mm)	414	242
Net P (mm)	1793	2026
RO (mm)	183	322
SM change (mm)	23	89
ET (mm)	1587	1615

Smith, P.J.T. 1987: Variation of water yield from catchments under introduced pasture grass and exotic forest, East Otago. Journal of Hydrology (New Zealand) 26: 175–184.

Country: New Zealand	Duration: 8 yr	Report Location: R11
Species Comparison: Pasture		
Stand Type: Plantation 14–22 yr	Stand Density: Varies	Rainfall: MAP 1000 mm
Keywords: Storm flow; Water yield;		

CAB Abstracts AN S267845/Author's Abstract

Eight years' data from catchments in Otago, two under introduced grass cover and two under exotic forest cover (*P. radiata* alone and *P. radiata* with *P. nigra*), were analysed for net differences in annual yields, quickflow volumes, delayed flow and recessions. Pasture catchments consistently yielded more water in all facets of the flow regime when compared to exotic forest catchments. Even for storms with high return periods (up to 100 yr) causing simultaneous rainfall over all catchments, the forest

catchments yielded less runoff. Recession curves of all catchments showed similar characteristics, but grass catchments consistently yielded more water during recession periods because they always commenced at higher discharges.

Comment
Water year Sept.–Aug. Low intensity (2–3mm/hour) long duration (2–3 days) storms.
Comparative study as no control period data.

Annual yields at North Otago

		Kintore		Vollweillerburn			Jura		Storm	
		Pasture		Pasture			*P radiata & P. nigra*		*P radiata*	
		292 ha		163 ha			192 ha		115 ha	
	PTTN	RO	E	RO	E	PTTN	RO	E	RO	E
1/9/78–79	1061	451	610			1076	196	880	143	933
80	1129	538	591			1106	331	775	205	901
81	885	312	573	273	612	812	221	591	146	666
82	824	237	587	196	628	946	174	772	113	833
83	1165	569	596	574	591	1250	347	902	261	989
84	1033	474	559	410	623	1185	314	871	226	959
85	724	216	508	192	532	771	177	594	96	675
86	1003	374	629	351	652	1178	315	863	131	1047

Quickflow

Pasture: Kintore 601 mm = 28% of RO or 11% of PTTN; Vollweillerburn 640 mm = 32 % RO and 11% of PTTN
Forest: Jura 164 mm = 12% of RO ns 3% of PTTN; Storm 139 mm = 14% of RO and 2% of PTTN.
Flow duration curves higher for pasture that forest as are master recession curves

Smith, R.E.; Scott, D.F. 1992: The effects of afforestation on low flows in various regions of South Africa. Water SA 18: 185–194.

Country: South Africa	Duration:	Report Location: R14
Species Comparison: Eucalypt; Pines; Scrubland (fynbos)		
Land-Use Change: Afforestation		
Stand Type: Plantation Various		
Keywords: Low flow		

CAB Abstracts/Authors' Abstract

It may be expected that afforestation has the greatest relative impact on annual streamflow during the low flow periods prior to the first rains of the next season. A paired catchment approach was used to quantify the effect of afforestation with both pines and eucalypts on the low flows of five catchments in the winter and summer rainfall regions of South Africa. Dummy variable analyses were used to test the significance of afforestation on low flows during each year after treatment. Afforestation was found to have a highly significant effect on low flows in all five catchment experiments, with low flows being reduced by up to a 100% in some cases. The effect of afforestation generally appeared to be more marked for eucalypt plantings than for pines, and was manifest at an earlier stage after afforestation. For some catchments (Mokobulaan A and B) these differences became irrelevant as afforestation with both pines and eucalypts eventually caused the streams to dry up.

Comment

Refers to other indices of low flow: 50-day period of lowest flow in a year (Bosch 1979); days below a fixed level of 0.2 mm/day (Harr et al. 1982). Took a different approach. Monthly low flow cutoff was chosen to include 2–3 of the driest months each year = 13 mm for Lambrechtsbos-B and Bosboukloof (= control and 57% in *P. radiata*, respectively). 82% planted; stand thinned three times, 5-yr calibration period. MAP 1440 mm, 85% between April and September.

Low flow model used was : $\ln Y = \ln(a) + b(\ln X)$

Y = predicted flow in treated catchment, X = monthly flow in control catchment

For Lambrechtsbos-B $\ln(a) = 1.07$, $b = 0.748$

Reductions given for each year are slightly different to Scott & Smith's values.

Significant flow reduction from 5th year of treatment; 40% or 29 mm lower in 7–8 yr; at 16 yr was 78% lower than predicted flows. The question not answered is 'over how many months?' 1 or 2 or 3? The inference from their Fig. 3 is that at age 16 the flow reduction is about 15 mm/month or 0.5 mm/day; at age 8 it is about 7 mm/month = 0.25 mm/day.

Swanson, R.H. 1981: Transpiration potential of contorta, radiata pine and Douglas fir for de-watering in mass wasting control. International Association of Hydrological Sciences Publication 132: 558–575.

Country: New Zealand	Duration: 1 yr	Report Location: R1598
Species Comparison: Douglas fir; Pines		
Stand Type: Plantation various ages	Stand Density: Various	
Keywords: Transpiration		

Comment
Transpiration measured by sapflux in *P. radiata*, *P. contorta* and Douglas fir at Whakarewarewa and for a number of age and density classes — based on one set of morning and afternoon measurements each month for a year.
Assumed only had transpiration on days with < 1 mm precipitation

Monthly transpiration

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Year
P. radiata													
5 yr 1600 SPH	63	29	21	55	35	48	124	78	148	194	92	109	996
5 yr 1100 SPH	44	17	13	45	31	36	96	60	104	148	68	82	744
17 yr 1500 SPH	75	36	21	42	31	34	104	64	130	169	78	87	871
26 yr 600 SPH	72	34	18	30	38	38	95	55	101	114	58	65	718
Douglas fir													
15 yr 1600 SPH	42	12	8	18	17	42	140	66	130	202	91	75	843
66 yr 100 SPH	7	3	1	4	3	2	14	10	22	34	20	15	135
P. contorta													
15 yr 2037 SPH	38	12	7	16	9	20	69	36	84	128	63	76	558
31 yr 598 SPH	19	4	4	7	5	9	28	19	39	60	31	39	264
65 yr 321 SPH	26	7	4	11	7	9	27	19	40	61	34	39	258
PTTN	138	81	149	51	161	228	31	122	110	11	190	68	1340
Rainfree days	22	17	19	26	16	14	26	17	23	28	21	25	

Note: 1100 SPH stand was part of 2200 SPH but thinned in March prior to measurements
P. radiata 700–1000 >> *P. contorta* 350–560 >< Douglas fir 140–850.

The sap flux of the thinned trees exceeded that of the unthinned as greater SM available - but total yield in mm was still less.

Comments that sap flux in *P. radiata* decreases with age and stabilises at 13–16 $cm^3/cm^2/hr$. This rate was also found for *P. contorta* and possibly with Douglas fir. Might be a function of growth rate such as the point of inflexion of the sigmoidal growth curve.

Teskey, R.O.; Sheriff, D.W. 1996: Water use by *Pinus radiata* trees in a plantation. Tree Physiology 16: 273–279.

Country: Australia	Duration: 4 months	Report Location: R1
Stand Type: Plantation 16 yr		Rainfall: MAP 714 mm
Keywords: Transpiration		

CAB Abstracts AN 960604271

The relationship between soil water availability and transpirational water loss was examined, in the case of a plantation in which trees could potentially be penetrating to an (unconfirmed) aquifer at depths of 8–10 m. It was hypothesised that a close relation between soil water availability and transpirational water loss would indicate that most transpired water was coming from the soil rather than groundwater, whereas a poor correlation would be indicative of substantial water use from lower soil depths. The heat-pulse velocity technique was used to estimate transpirational water use of trees in an experimental 16-year-old *P. radiata* plantation near Wandilo, about 10 km N. of Mt Gambier, South Australia during a 4-month period from November 1993 to March 1994 (spring-summer). Fertiliser application and other silvicultural treatments during the first 8 yr of the plantation produced trees varying in DBH from 0.251 to 0.436 m, with leaf areas ranging from 83 to 337 m^2. Daily water use was greater for large trees than for small trees, but transpiration per unit leaf area was nearly identical. Daily transpiration was highly correlated with available soil water in the upper 1 m of soil and weakly correlated with irradiance and air temperature. For the stand (0.4 ha), estimated rates of transpiration ranged from 6.8 to 1.4 mm/day in wet and dry soil conditions, respectively. Total water use by the plantation during the 4-month study period was 346 mm. Water transpired by the trees was about three times that extracted from the upper 1 m of soil. Large trees extracted water from the same soil volume as small trees and did not exhibit a greater potential to extract water from deeper soil when the upper horizons become dry.

Comment

Near Mount Gambier, South Australia. LAI 6.6.

Transpiration was not related directly to diameter; large trees did use more water though. For different-sized trees transpiration was proportional to leaf area. Soil moisture, not PAR or air temperature, was the most important factor affecting transpiration.

Transpiration range was 6.82 mm/day in late spring to 1.41 mm/day at the end of summer. Total water use over the 120 days was 346 mm and 110 mm was withdrawn from the top 1 m of the soil. Therefore 235 mm had to come from soil water below 1-m depth or the aquifer or both.

Suggests that water available at depth is only used when that in the top 1 m is limited. At the end of summer the soil was very dry $<0.02\ m^3/m^3$. If mean minimum transpiration of 1.7 mm/day is taken as the daily contribution from below 1 m or the aquifer, this would account for 204 of the 235 mm extra water extracted.

Thistlethwaite, R.J. 1970: Forests and water supply in the Cotter catchment. PhD Thesis, ANU, Canberra.

Country: Australia	Duration: 9 months	Report Location: Cited in Turner and Lambert (1987)
Stand Type: Plantation 24 yr		Basal Area: 43.8 m^2/ha
Keywords: Interception; Stemflow; Throughfall		

Comment
Three Cotter River catchments, ACT.
PTTN = 1231 mm; TF = 804 mm (Corrected from other data - was given as 304 mm) (65%); SF 81 mm, (6.8%), IL 346 = 28%

Tsykin, E.; Laurenson, E.M.; Wu, A.Y.K. 1982: Hydrologic effects of replacement of eucalypt forest by pasture and pines. The First National Symposium on Forest Hydrology, Melbourne, 11–13 May. Institution of Engineers Australia National Conference Publication 82/6 Pp. 124–131.

Country: Australia	Duration: 18 yr	Report Location: R1361
Species Comparison: Eucalypt		
Land-Use Change: Conversion of one forest to another		
Stand Type: Plantation −10 to +8 yr	Stand Density:	Rainfall: 1000–1280 mm
Keywords: Water yield		

CAB Abstracts AN S849364/Authors' Abstract

Hydrologic data have been collected on four small catchments at Stewarts Creek, Victoria, since 1960 in an experiment to examine the hydrologic effects of replacing eucalypt forest by pasture and by pine forest. Analyses of monthly runoff were undertaken using a conceptual statistical modelling method. It was determined that monthly runoffs more than doubled for the first 4 yr after the land-use change while the vegetation cover was sparse. In the next 3–5 yr, as the vegetation on cleared areas became better established, a reduction of the runoff occurred to a level about 25% above the original, pretreatment level.

Comment
Catchments established in 1959. Treatments implemented on CA2 and CA5 in 1969; CA2 from eucalypt to bare ground/poor grass cover and to pasture in 1975 and CA5 planted after ploughing in 1970. CA1 and CA4 in eucalypt forest.

Model used is a statistical function to calculate monthly runoff based on the monthly rainfalls in up to 5 preceding months. Although useful for stable vegetation conditions, the technique is not really applicable for changing land use such as clearing and afforestation, but will provide a prediction for the original cover from which change can be assessed by difference with real measured data. For the eucalypt to pines change, the average annual difference was an increase of 170 mm/yr over the 9 yr since clearing.

Turner, J.; Lambert, M.J. 1987: Forest water usage and interactions with nutrition of *Pinus radiata*. Acta Ecologica/Ecologia Plantarum 8: 37–43.

Country: Worldwide	Report Location: R46
Stand Type: Plantation Various	
Keywords: Interception; Stemflow; Throughfall	

CAB Abstracts AN F160964/Authors' Abstract

Rainfall interception studies in *P. radiata* plantations have been reviewed and a model developed to relate the percentage of intercepted rainfall to stand density and annual precipitation. It was estimated from this model that in marginal rainfall areas, where phosphatic fertiliser treatments have greatly stimulated growth, rainfall reaching the forest floor was reduced from 812 mm per annum to 632 mm per annum in an average rainfall year. In the fertilised stand, thinning allowed a further 120 mm per annum to reach the forest floor. It was concluded that studies on the impact of intensive forest management on *P. radiata* water usage are required.

Comment

Reviews 15 studies, all referenced here but many papers/theses unobtainable.

Determined the relationship:

$$I(\%) = 8.7517 + 0.4551 \times BA \qquad r^2 = 0.606,\ n = 23$$

and

$$I(\%) = 14.752 + 0.48854 \times BA - 0.008575 \times PTTN \qquad r^2 = 0.669,\ n = 24$$

van der Zel, D.W. 1970: The effect of a thinning on flow in a Jonkershoek stream. Forestry in South Africa 11: 41–45.

Country: South Africa	Duration: 7 yr	Report Location: R 1425
Species Comparison: Scrubland (fynbos)		
Land-Use Change: Forest management		
Stand Type: Plantation 16 yr	Stand Density: 740 to 440 SPH	
Height: 18.6 m	Diameter: 25.6 cm	Rainfall: MAP 1340 mm
Keywords: Water yield		

CAB Abstracts/Authors' Abstract

Analysis of stream flow figures show a 50% increase in flow after 33% of the *P. radiata* trees in a fully afforested catchment were removed 16 yr after planting. Study of annual vapour losses indicates that most of the increase in flow is due to less transpiration taking place. This effect is maintained for at least 3 yr after the thinning process.

Comment

Biesievlei; 98% planted in *P. radiata* at 1320 SPH in 1948. Thinned 1954 to 740 SPH, and in 1964 to 444 SPH. Lambrechtsbos-A = control in fynbos

Determined a monthly streamflow relationship B = 18.9 + 0.6853(LA − 42.9) mm

and found for the immediate period after thinning that there were significant deviations from this regression.

Also a comparison of the 2-hourly average streamflows for January over 1961–64 was vastly different from that for 1965 and that there was an average nett increase in streamflow of 50.8%.

On an annual basis, there was a decrease in annual vapour losses of 35%.

van Wyk, D.B. 1987: Some effects of afforestation on streamflow in the Western Cape Province, South Africa. Water SA 13: 31–36.

Country: South Africa	Duration: 40 yr	Report Location: R16
Species Comparison: Scrubland (fynbos)		
Land-Use Change: Afforestation		
Stand Type: Plantation - Varies	Stand Density: 1330 SPH, thinned 3 or 4 times to final 150 to 175 SPH	
Keywords: Water yield		Rainfall: 1300 – 2260 mm

CAB Abstracts AN S158647

Results of a multiple catchment experiment are reported in which the influence of afforestation with *P. radiata* on streamflow was monitored from 1940 to 1980. Where 98% of the catchment was afforested streamflow decreased by 313 mm from an initial 663 mm/a over a period of 12 to 32 yr. With 57% afforestation, streamflow declined by 200 mm from 593 mm/a over a period of 16 to 40 yr. Area afforested, total biomass and rainfall appear to have influenced the magnitude of reductions.

Comment

Jonkershoek catchments.

Estimated the reduction in streamflow by subtracting an adjusted value from the mean before treatment.

Qadj = Qt − b × [(PTTN−PTTNmean) or (Qc − Qcmean]

where	Qadj	adjusted streamflow
	Q	annual streamflow of treated catchment
	b	regression constant
	PTTN	annual weighted catchment precipitation
	PTTNmean	annual mean weighted catchment precipitation
	Qc	annual streamflow from the control
	Qcmean	annual mean streamflow from the control

Decreases in streamflow were noted (in years after afforestation): 7 Bosboukloof (57% afforested), 4 Lambrechtsbos-B (82%), 3 Biesievlei (98%), 3 Tierkloof (36%) and 3 Lambrechtsbos-A (89%). Seems as though the bigger the treatment the sooner you see an effect — Tierkloof the exception but there was 2 yr of unusually heavy rain after treatment.

Reductions peaked at 19 yr for Bosboukloof and 14 yr for Biesievlei and remained steady apart from annual variation due to annual rainfall variation. Sample periods too short at the other catchments to define this.

Mean decrease between16 and 40 at Bosboukloof = 197 mm/yr (of 663 mm) (= 346 for 100%, LKR)
Mean decrease between16 and 32 at Biesievlei = 313 mm/yr (of 663 mm) (= 320 for 100%, LKR)
Mean decrease stabilised after 16 yr at Tierkloof at 171 mm/yr = 475 for 100%
Mean decrease stabilised after 16 yr at Lambrechtsbos-B at 185 mm/yr (of 532mm) (= 225 for 100%, LKR)
Annual reductions can be variable in an individual year, and the reduction can be over 500 in wetter yr (~3000 mm rainfall).

Waugh, J.R. 1980: Hydrological effects of the establishment of forests. In: Land use in relation to water quantity and quality. Nelson Catchment Board. Pp. 218–249.

Country: New Zealand	Report Location: R1480
Species Comparison: Native evergreen forest; Pasture;	
Land-Use Change: Afforestation	
Stand Type: Plantation Various — young	
Keywords: Review; Water yield	

Comment
Reviews preliminary findings of a number of studies presented in this bibliography. Also includes scrubland to pasture conversions and the effects of different pasture grazing options.

Moutere: Gorse to *P. radiata* Catchments 8 and 13 vs 5 as control. Moutere 14 *P. radiata* planted into pasture. These are updated by Duncan (1995a,b).

Waiwhiu in Northland: 50% of a native evergreen forest/pasture/scrub catchment was converted to *P. radiata* forest . 5 yr under forest/pasture; 18 months scrub clearing and burning; 3 yr of pines and rank grass.
Destocking lead to an decrease in runoff and this continued through the early years of pine growth - attributed to increased interception by rank grass.

Purukohukohu/Puruki: A similar story to that for the Waiwhiu — rank grass in the young pines was the probable cause of the initial flow decreases.

Wells, L.P.; Blake, G.J. 1972: Interception characteristics of some central North Island vegetation and their geographical significance. Proceedings, Seventh Geography Conference, Hamilton. Pp. 217–224.

Country: New Zealand	Report Location: LKR
Species Comparison: Scrubland (native)	
Stand Type: Plantation 25 yr	
Keywords: Interception	

Comment
Provides graphs of interception loss in the first 15 minutes of a storm (a measure of interception capacity) against rainfall intensity and percentage interception loss vs accumulating storm precipitation for a number of storms for both the 25-yr-old pines at Whakarewarewa (near Rotorua) and native scrub at Otutira.

Whitehead, D. 1987: WATMOD - a means of predicting water use by forests. What's New in Forest Research No. 154. 4 pp.

Country: New Zealand	Report Location: R1599
Keywords: Model	

CAB Abstracts AN 900644299
WATMOD is a computer model being developed by the Forest Research Institute of New Zealand to predict the effects of a wide variety of management proposals on water availability from forest catchments. The model can already be used to simulate long-term water use and drainage from *P. radiata* forests for many different management prescriptions. Because WATMOD has been based on the processes which affect the overall water balance within a forest, its use is not restricted to a particular site.

Whitehead, D.; Kelliher, F.M. 1991a: Modeling the water balance of a small *Pinus radiata* catchment. Tree Physiology 9: 17–33.

Country: New Zealand	Duration: 1 yr	Report Location: R832
Stand Type: Plantation 13 yr	Stand Density: 575 SPH	Basal Area: 30 m^2/ha
Height: 20 m		Rainfall: 1403 mm
Keywords: Model; Water balance; Water yield		

CAB Abstracts AN 920656647/Authors' Abstract
An hourly biophysical model was used to calculate water balance over a period of 1 yr for an 8.7-ha 13-yr-old *P. radiata* forest in central North Island, New Zealand. Components of the model were transpiration from the dry tree canopy, evaporation from the partially wet tree canopy and stems, evaporation from the understorey and soil, and drainage from a single-layer root zone. Model inputs were

hourly weather data (net radiation, air and wet bulb temperatures, windspeed, and rainfall), tree stand characteristics (average height, tree number, leaf area index), physical characteristics of the site (root zone depth, relation between root zone matric potential and volumetric water content, relation between rate of drainage from the root zone and volumetric water content, and area of open-stream channels). A submodel of the response of stomatal conductance to air saturation deficit and root zone matric potential was also required. Tree transpiration (704 mm/yr, or 50% of annual rainfall) was a dominant component of the catchment water balance. Estimated evaporation from wet tree canopy was 203 mm/yr (15%). Evaporation from the understorey was much less, amounting to 94 mm/yr (7%) and an increase in water storage for the 3.5 m root zone depth was estimated to be 53 mm/yr (4%). Estimated daily rates of drainage generally agreed well with measurements of streamflow, although estimated annual drainage (349 mm/yr, 24%) exceeded measured streamflow (234 mm/yr). Significance of the results is discussed in relation to closure of the hydrologic balance.

Comment
Puruki - Rua 8.7 ha; LAI all surfaces 15.5.
PTTN 1403 mm on 155 days;
Model requires hourly climate data, tree stand characteristics, and soil physical data
Streamflow was measured and used to check the other modelled outputs — interception, transpiration, drainage.

Water balance of 13-yr *P. radiata* at Puruki

Month	PTTN	Interception	Tree transpiration	Understorey evaporation	Soil Drainage	Streamflow
8	173	24	32	4	40	56
9	134	17	49	6	75	66
10	133	28	58	9	42	22
11	59	13	81	12	18	12
12	40	11	103	14	5	2
1	179	24	104	15	5	4
2	73	15	82	12	3	1
3	154	16	67	9	6	5
4	174	15	47	5	18	13
5	129	15	30	3	32	15
6	111	18	22	2	56	25
7	44	7	29	3	50	14
Total	1403	203	704	94	350	235
% rain	100	15	50	7	24	

Evaporative losses = 1000 mm, drainage 350 mm cf. streamflow of 235 mm; rain = 1403

Whitehead, D.; Kelliher, F.M. 1991b: A canopy water balance model for a *Pinus radiata* stand before and after thinning. Agricultural and Forest Meteorology 55: 109–126.

Country: New Zealand	Duration: 3 yr	Report Location: R236
Land-Use Change: Forest management		
Stand Type: Plantation 11–13 yr	Stand Density: 754 SPH thinned to 334 SPH	
Height: 17+ m		
Keywords: Interception; Model; Transpiration; Water balance		

CAB Abstracts AN 920661462/Authors' Abstract

A model of water balance for a coniferous forest canopy is described which combines the Penman–Monteith equation to estimate transpiration from the dry canopy (Et) and the Rutter model of interception to estimate evaporation from the canopy and stems wetted by rainfall (Ei). Evaporation from the understorey and forest floor (Eu) estimated from the available energy determined from radiation attenuation by the tree canopy, is also included. The model was applied to an 11-yr-old *P. radiata* stand at Longmile, Rotorua, New Zealand, before and after thinning in 1984. Parameters in the model were determined for the unthinned stand, and changes in the parameters following thinning were estimated from changes in tree number per unit area and leaf area index (LAI). The model was validated using (i) independent measurements of Et from trees growing in weighing lysimeters within the stand, (ii) estimates of evaporation from the canopy, not including the stems (Eic) from measurements of rainfall, throughfall and stemflow, and (iii) measurements of Eu. The model also shows good agreement with measurements of the duration of tree canopy wetness and Et from a drying canopy after rainfall. The model was used to estimate the annual components of canopy water balance for the unthinned and thinned stands during a year with high, well distributed rainfall (1623 mm), when there was no summer drought period. For the unthinned stand, modelled annual Et, Ei and Eu were 636, 268 and 93 mm, respectively, with the net amount of water added to the soil storage (N) being 626 mm. Thinning resulted in a significant reduction (36%) in modelled annual Et, slightly less than the decrease in LAI (42%). The decrease in modelled annual Ei (27%) was much smaller than the decrease in LAI. These results are discussed in relation to the significance of canopy structure in determining evaporative losses from forest canopies and the net addition of water to storage in the soil. During the year following thinning, the model indicated an increase in N of 201 mm (13% of gross rainfall). Implications for managing the water yield from forest catchments are discussed.

Comment

This paper is an update of Whitehead et al. (1989) below but a different rainfall period was used for the model output.

Combines Penman–Monteith with Rutter and Gash model components.

Models differences but no apparent validation by field measurement.

Whakarewarewa (Longmile), Rotorua. Planted 1973;

In 1983 754 SPH; 17-m tall, LAI (all surfaces) 15.5; no understorey; closed canopy

Sept 1984, thinned to 334 SPH, 21 m tall; LAI 9, crown cover 46% of ground. 60% ground covered by debris. Well watered.

Modelled canopy water balance

	Unthinned	Thinned
Precipitation (mm)	1623	1623
Tree transpiration (mm (%))	636 (39)	410 (25)
Tree interception (mm (%))	268 (17)	195 (12)
Understorey interception (mm (%))	93 (6)	191 (12)
Balance to Soil Moisture (mm (%))	626 (38)	827 (51)
Losses (mm (%))	997 (62)	796 (49)

Whitehead, D.; Kelliher, F.M.; Hobbs, J.F.F.; Brownlie, R.K.; Godfrey, M.J.S. 1989: A model of the canopy water for a *Pinus radiata* stand before and after thinning. Proceedings, Fourth Australasian Conference on Heat and Mass Transfer, Christchurch, May 1989. Pp. 467–475.

Country: New Zealand	Duration: 3 yr	Report Location: R1190
Land-Use Change: Forest management		
Stand Type: Plantation 11–13 yr	Stand Density: 754 SPH thinned to 334 SPH	
Height: 17+ m		
Keywords: Interception; Model; Transpiration; Water balance		

Comment
Longmile stand at Whakarewarewa, Rotorua.
Storm stemflow: SF = 0.11 × PTTN − 0.22
Storm throughfall (guesstimated from eyeballed . fit through graphed data by LKR)
TF = 0.76 × PTTN − 1
Interception storage capacity estimated to be 0.6 mm.

Selected transpiration values for 1 dry day in given months:

Pre-thinning:	December 3.4 mm	April 2.5 mm	July 1.4 mm	September 2.1 mm
Post-thinning:	January 2.4 mm	April 2.0 mm	July 1.2 mm	October 1.6 mm

The model is shown to work well for both pre- and post-thinning wet and dry canopy evaporation when adjusted for the decrease in leaf area.

Simulated water balance 1985 with annual rainfall of 1347 mm

	Unthinned		Thinned	
	mm	%	mm	%
Tree canopy transpiration	763	57	461	34
Tree canopy evaporation	240	18	187	14
Understorey evaporation	62	4	161	12
Net addition to soil moisture	283	21	539	40

Whitehead, D.; Kelliher, F.M.; Lane, P.M.; Pollock, D.S. 1994: Seasonal partitioning of evaporation between trees and understorey in a widely spaced *Pinus radiata* stand. Journal of Applied Ecology 31: 528–542.

Country: New Zealand	Duration: 1 yr	Report Location: R100
Stand Type: Plantation 7 yr	Stand Density: 450 SPH	
Height: 7.5 m		Rainfall: 1154 mm
Keywords: Transpiration		

CAB Abstracts AN 940608405

Tree transpiration, Et, and understorey evaporation, Eu, were measured hourly on 2–3 fine days during 12 periods throughout a year in a *P. radiata* plantation in Kaingaroa Forest, New Zealand. There were 450 stems/ha and 60% of herbaceous understorey vegetation and forest floor was covered by dead stems, branches and foliage from earlier thinning and pruning operations. Annual rainfall was 1154 mm and trees and understorey vegetation were supplied adequately with water throughout the year. Data are presented and discussed on relations between stomatal conductance, air saturation deficit above the forest canopy, incident quantum flux density, foliage development, night frost, tree canopy leaf area index, canopy conductance, and average daily transmittance of shortwave radiation through the tree canopy. The combination of weather variables, changes in stomatal conductance, increasing leaf area index and the relation between Eu and available energy led to the fraction Et/(Et + Eu) remaining roughly constant throughout the year with an average of 0.52.

Comment

Same stand as Kelliher et al. (1992) at Haupapa.
Transpiration ranged between 0.5 mm/day winter and 1.3 mm/day late summer
Understorey evaporation ranged from 0.3 mm to 1.6 mm in early summer

Wicht, C.L. 1949: Forestry and water supplies in South Africa. Bulletin, Department of Agriculture, South Africa No 33.

Country: South Africa	Report Location: R1593 - Abstract only
Keywords: Review; water yield	

Comment
A comprehensive review of the hydrology of South Africa, the influence of land management on hydrology, and specific studies on forestry and the effects on water supplies.

Wicht, C.L. 1972? Timber and water. South African Forestry Journal 85: 3–11.

Country: Worldwide	Report Location: R1584
Keywords: Water yield	

Comment
Reviews a number of studies on the effects of forestry on water yield.
Notes that at Jonkershoek, 16 yr after converting a fynbos covered catchment to *P. radiata*, water yield had decreased by 342 and 362 mm, rainfall about 1500 mm.

There were restrictions on afforestation within 20 m of streambanks and 90 m of the margins of marshes. Points out that this measure becomes ineffective if dense vegetation is allowed to develop naturally in these areas.

Will, G.M. 1955: Removal of mineral nutrients from tree crowns by rain. Nature, London 1955: 1880.

Country: New Zealand	Duration: 6.25 months	Report Location: R1600
Stand Type: Plantation 30 yr		
Keywords: Throughfall		

Comment
PTTN 687mm, TF 420mm, TF% 61%. November 1954 to June 1955

Will, G.M. 1959a: Nutrient return in litter and rainfall under some exotic conifer stands in New Zealand. New Zealand Journal of Agricultural Research 2: 719–734.

Country: New Zealand	Duration: 2 yr	Report Location: R434
Species Comparison: Conifers; Douglas fir; Pines		
Stand Type: Plantation 28 & 29 yr	Stand Density: 300 SPH	Height: 36.5 m
Keywords: Nutrient cycling; Throughfall		

Comment
Kaingaroa Forest: Two rain collectors (5.5 in glass funnels) at each site.
P. radiata, 65–70% crown cover
Douglas fir, 33 yr old, 27 m tall, 1240 SPH, 100% crown cover.

Throughfall at Kaingaroa

	Rainfall (mm)	Throughfall (mm)	Throughfall (%)
P. radiata year 1	1854	1346	73
P. radiata year 2	1168	800	68
Douglas fir year 1	1448	800	55
Douglas fir year 2	1930	927	48

Will, G.M. 1959b: Soil-moisture and soil-temperature studies under radiata pine, Whakarewarewa Forest, 1954–1955. New Zealand Journal of Agricultural Research 2: 184–193.

Country: New Zealand	Duration: 1 yr	Report Location: LKR
Stand Type: Plantation 7 yr regeneration & 39 yr		
Keywords: Throughfall		

Comment
Whakarewarewa, Rotorua.

7-yr-old regenerating stand after clearfelling, 3700 SPH; 10.7 m tall.
39-yr-old stand with no management but mortality reduced stocking to 250 SPH; 35 m tall.

Precipitation for 1 yr was 1510 mm; 7yr throughfall 905 mm, 39 yr throughfall 980 mm.

Will, G.M. 1962: Soil moisture and temperature studies under radiata pine, Kaingaroa Forest, 1956–1958. New Zealand Journal of Agricultural Research 5: 111–120.

Country: New Zealand	Duration: 2 yr	Report Location: LKR
Stand Type: Plantation 28 to 30 yr	Density 300 SPH	
Keywords: Throughfall		

Comment
Kaingaroa Forest
This appears to be the same stand but with slightly different sampling periods as for the Kaingaroa *P. radiata* stand in Will (1959a).

Throughfall under *P. radiata* at Kaingaroa

	Precipitation (mm)	Throughfall (mm)
1956	1855	1525
1957	1105	885

Wronski, E. 1984: A model of canopy drying. Agricultural Water Management 8: 243–262.

Country: Australia	Duration:	Report Location: R62
Stand Type: Plantation 8 yr	Stand Density: 2000 SPH	
Height: 8.5 m		
Keywords: Evaporation; Model		

CAB Abstracts AN S028387/Authors' Abstract

A one-dimensional diffusion model of canopy drying applied to a *P. radiata* forest in South Australia yielded evapotranspiration rates lower than those observed. The discrepancy indicated either that there was greater interchange between the above- and within-canopy airflow than calculated assuming local diffusion, or that stomatal resistance was reduced when the canopy was wet. It was concluded that the net interception loss during canopy drying was approx. 60% of the total loss.

Yunusa, I.A.M.; Mead, D.J.; Pollock, K.M.; Lucas, R.J. 1995: Process studies in a *Pinus radiata*-pasture agroforestry system in a subhumid temperate environment. I. Water use and light interception in the third year. Agroforestry Systems 32: 163–183.

Country: New Zealand	Duration: 15 months	Report Location: R111
Stand Type: Plantation 2 yr	Stand Density: 1000 SPH	
Keywords: Interception		

CAB Abstracts AN 969602621

Soil moisture storage, evapotranspiration (ET) and light interception were determined in an agroforestry trial near Lincoln, New Zealand, consisting of *P. radiata* grown over (1) control (bare ground), (2) ryegrass/clovers *(Lolium perenne/Trifolium* spp.), (3) lucerne (*Medicago sativa*), and (4) ryegrass only, during the third growing season between 1992 and 1993. In the period when rainfall was frequent and exceeded the evaporative demand (Epot), ET and depletion of soil moisture were not affected by the ground cover treatments. During summer when rainfall was less frequent, but with moisture readily available in the soil profile, ET was associated with the plant canopy, and was significantly higher for the pasture ground covers than for the control. The more rapid growth by lucerne caused higher ET in this ground cover than in the ryegrass/clover ground cover in which the pasture was slow growing. At the end of the study period, total ET was in the following order: lucerne (757 mm) > ryegrass/clover (729 mm) > control (618 mm). ET was dominated by pasture transpiration (Ep) during most of the growing season, but by tree transpiration (Et) in winter when large parts of the pasture canopy was shaded. Ep was always at least 16% higher for lucerne than for ryegrass/clover as a result of a greater radiation intercepted by the former. The fraction of incoming radiation intercepted by the tree crowns was in the following order: control > ryegrass > ryegrass/clover > lucerne. At the end of the 1-yr period, the fraction of intercepted radiation was 140% greater for control than for the lucerne ground cover. The control produced the largest tree crowns - these were almost twice the size of the tree crowns in the lucerne ground cover, which had the smallest trees. Accordingly, the trees in the control intercepted more radiation and rainfall, with the former being lost to evaporation, than the trees in the pasture. The fractions of radiation intercepted and ET accounted for by the trees and pastures were associated with the proportion of the plot area they occupied.

Comment

Agro-forestry trial -pasture with *P. radiata* at 1000 SPH.

Precipitation (14 months) = 915 mm

Interception by trees 8 to 13.7 % but relative to what — tree area or plot area?

Section 4: Additional References

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