Water sampling by Forestry Tasmania to determine presence of pesticides and fertiliser nutrients, 1993–2003

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Abstract

Since 1993, Forestry Tasmania has conducted pre- and post-operational water sampling in areas where broadacre application of pesticides (herbicides and insecticides) or fertilisers has been employed to increase or maintain the productivity of eucalypt, pine and blackwood plantations.

The operational methods used by Forestry Tasmania for applying pesticides and fertilisers and for monitoring water quality are described. The health and guideline values for drinking water prescribed by the National Health and Medical Research Council (NHMRC) for a range of pesticides are used as the standards for determining the need for investigation and corrective action when these pesticides are detected in water samples. Where no guideline values are prescribed for particular pesticides, Forestry Tasmania uses any detection of the pesticide in water samples as the trigger for investigation.

In the 10 years to July 2003, a total of 5227 water samples were taken and analysed in association with herbicide, insecticide and fertiliser applications. Pesticide operations covering the application of 14 herbicides and five insecticides accounted for 4396 of these samples. Three samples (0.07%) contained pesticide in excess of the NHMRC health values and 87 (2%) exceeded the guideline values. Eighty-eight per cent of these high readings resulted from the use of the herbicides atrazine (48%) (not used by Forestry Tasmania since 1995) and hexazinone (40%).

A further 831 water samples were analysed for total nitrogen (506 samples) and total phosphorus (325 samples) in conjunction with later age fertilising operations in eucalypt, pine and blackwood plantations. Guideline values set by Forestry Tasmania were exceeded in 25% and 7% of the samples analysed for total nitrogen and total phosphorus respectively. Some of these samples exceeded the guideline values prior to any application of fertiliser, and the results are discussed in relation to the natural baseline levels of nutrients in forest streams and the factors affecting the pattern of total nitrogen and phosphorus levels in water samples from individual fertilised coupes. Future research which will assist continuous improvement in water quality management in commercial forests is discussed.

Introduction

Effective weed control is an essential component of plantation establishment in Tasmania. A wide variety of chemical and non-chemical weed-control regimes are

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applied by Forestry Tasmania to reduce competition between weeds and the young seedlings so that early seedling growth can be maximised. These regimes vary according to the soil types, weed species, terrain and other factors encountered when establishing plantations. Until the early 1990s, the most common pre-planting herbicide application for eucalypt and pine plantations was a broadacre treatment with a standard recipe of amitrole / atrazine. Other herbicides were used for some specific weed situations such as hexazinone application against eucalypt and acacia weeds in *Pinus radiata* plantations (Neilsen 1990). Forestry Tasmania ceased using the triazine herbicides atrazine and simazine in 1995 and 1997 respectively. In addition to changes in the types of herbicides used, there have been significant changes in weed-control practices for plantation establishment such as strip spraying and more intensive site preparation.

Currently, the most common weed-control regime is aerial application by helicopter of herbicides such as glyphosate and / or metsulfuron-methyl to the plantation area following site preparation and prior to planting (Hodgson 2003).

Insecticide application is less common and mostly occurs in young eucalypt plantations as part of an integrated pest management program for the eucalypt leaf beetles *Chrysophtharta bimaculata* (Olivier) and *C. agricola* (Chapuis) (Elliott *et al.* 1992; Elek *et al.* 2000). When insecticide application is required, synthetic pyrethroids are commonly used, although a considerable research effort over the last 10 years has resulted in the registration of some biological insecticides for control of eucalypt-defoliating insects (J. Elek, pers. comm.)

In addition to fertilising individual seedlings at planting time, there is a significant program of broadacre application of fertilisers (later age fertilising) in State forests to increase the productivity of plantation crops, principally *Eucalyptus nitens*, *E. globulus* and *Pinus radiata*. A range of nitrogen (N) and phosphorus (P) fertilisers has been used in the ten-year period, 1993–2003, but current applications use nitrogen as urea (NPK 46:0:0) applied at 200 kg / ha, and a blend of N and P (urea + di-ammonium phosphate, UDAP, 24:16:0) at 400 kg / ha (A. Muirhead, pers. comm.).

Pinus radiata growth has been shown to increase substantially from multiple later age fertilising (Neilsen *et al.* 1992; Neilsen and Lynch 1998) and this is a routine operation in some plantations. Fertiliser regimes have been developed for application to some eucalypt sawlog plantations in Tasmania (P. Adams and W. Neilsen, unpublished data). These regimes vary according to site and other factors but can involve one application of phosphorus and up to three applications of nitrogen in the first 2–5 years of the plantation, followed by maintenance applications of nitrogen at three-yearly intervals.

Prior to the early 1990s, *ad hoc* water sampling was conducted after some herbicide spraying operations. A formal water quality sampling system was established in 1993, and water quality monitoring in areas where broadacre application of pesticides and fertilisers was conducted became an integral part of Forestry Tasmania's water quality policy in 1994. This system has been continually refined in the last decade based on operational experience and research findings. The water sampling system is a quality control procedure to check that operational practices place pesticides and fertilisers on the target areas and to facilitate corrective action if contamination of watercourses is detected.

A key part of the standard procedures was the introduction of prescriptions for protective buffers along streams in the areas where treatments were conducted. This initiative was adopted because at the time there were no legislative requirements for buffer zones when using pesticides, apart from the streamside reserve provisions in the 1993 Forest Practices Code (Forestry Commission 1993). An early benefit from the introduction of water sampling in the 1990s was the provision of data on contamination of some streams by atrazine. The development of water sampling practices paralleled the upgrading of chemical application training for forestry personnel. A three-level training program was developed by Forestry Tasmania for the forest industry in the mid 1990s in response to the increasing use of aerial application methods, which had the potential to result in more off-site contamination than ground-based applications.

Forestry Tasmania's water quality management is guided by the State Policy on Water Quality Management (DPIWE 1997) and the Forest Practices Code (Forest Practices Board 2000). The principal objectives of the State Policy are to:

- Focus water quality management on the achievement of water quality objectives which will maintain or enhance water quality and further the objectives of Tasmania's Resource Management and Planning System (RMPS). This System was established in 1994 to ensure that the State's planning systems provide a sustainable basis for development. Several pieces of legislation make up the RMPS, the principal one being the *Land Use Planning and Appeals Act 1993.*
- Ensure that diffuse source and point source pollution does not prejudice the achievement of water quality objectives, and that pollutants discharged into waterways are reduced as far as possible by the use of best practice environmental management.
- Ensure that efficient and effective water quality monitoring programs are carried out and that the responsibility for monitoring is shared by those who use and benefit from the resource, including polluters, who should bear an appropriate share of the costs arising from their activities, water resource managers and the community.
- Facilitate and promote integrated catchment management.
- Apply the precautionary principle in actions to achieve water quality objectives.

At the forest operations level (individual harvesting unit, i.e. the coupe), the use of pesticides and fertilisers must comply with the environmental protection measures prescribed in the Forest Practices Code (Forest Practices Board 2000). Section E2 of the Code contains specific prescriptions covering watercourse protection. Forestry Tasmania's water quality sampling program monitors compliance with the Forest Practices Code when using pesticides and fertilisers. An operational manual on water sampling techniques was developed in the mid 1990s in the absence of legislative requirements, and is regularly updated (Hodgson 2002). The manual states that sampling for evidence of chemical movement into water will be mandatory where there is:

- Broadacre application of pesticides or fertilisers either by ground or air;

and in other circumstances as follows:

- In areas or under conditions where there is a risk of off-site movement following strip or spot application;
- In coupes within water catchments with known domestic supply intakes;
- Where adjacent neighbours have expressed a concern or are known to be growing crops that may be affected by agricultural pesticides.

In operational practice, District managers have to take account of local conditions when planning water sampling. These conditions include situations where coupes are not sampled because there is no running water flowing from the coupe, or where extra sampling is done to clarify local issues. Thus, not all coupes where pesticides or fertilisers are applied are sampled because of the discretionary approach required at the local District level.

Water quality management is an important part of Forestry Tasmania's Environmental Management System and the organisation's annual Sustainable Forest Management Report (Forestry Tasmania 2004) includes results of water sampling as a measure and indicator under Objective 5: *Conserve and maintain soil and water resources*.

This paper describes the current water sampling practices used by Forestry Tasmania to monitor the presence of fertilisers and pesticides in watercourses after broadacre applications and presents the results of water sampling between 1993 and 2003.

Application of pesticides and fertilisers

Pesticide applications on Forestry Tasmania plantations from 1999 / 2000 to 2002 / 2003 are summarised in Table 1. Data for these years only are presented because in prior years there was no centralised database for these operations and data were fragmented and recorded with different systems at District level. Total pesticide usage is reported annually in relation to indicators and targets as part of the Sustainable Forest Management Report (Forestry Tasmania 2004).

The data on fertiliser applications presented in Table 2 relate to eucalypt plantations managed by Forestry Tasmania. Later age fertiliser applications to eucalypt plantations

Table 1. Pesticide usage in plantation management on State forest (from Forestry Tasmania 2004). (a.i. = active ingredient)

Year	Approximate planted area (ha)	Total pesticide (kg) Schedule 5 / Schedule 6[1]	Pesticide rate (kg a.i. / ha) Schedule 5 / Schedule 6[1]
1999 / 2000	8100	4067 / 15	0.50 / 0.002
2000 / 2001	7000	6929 / 42	0.99 / 0.006
2001 / 2002	8000	4849 / 29	0.61 / 0.004
2002 / 2003	6000	4719 / 10	0.78 / 0.002

[1] Schedule 5 and 6 poisons cover the herbicides and insecticides used in plantation management on State forest but not 1080 (a Schedule 7 poison).

Table 2. Later age fertilising of eucalypt plantations by Forestry Tasmania.

	Nitrogen				Phosphorus			
Year	Area (ha)	Fertiliser	Bulk rate (kg / ha)	Nutrient (%)	Area (ha)	Fertiliser	Bulk rate (kg / ha)	Nutrient (%)
2000 / 2001	360	Urea	200	46	60	TSP[1]	320	21
2001 / 2002	1252	Urea	200	46	902	TSP[1]	300	21
2002 / 2003	2730	UDAP[2]	400	24	2730	UDAP[2]	400	16
	1181	Urea	200	46				

[1] Triple superphosphate.
[2] A blend of urea and di-ammonium phosphate.

commenced in 2000 / 2001 and the areas treated are expanding significantly as the estate increases and results from research trials on likely responses to fertiliser are becoming available. Later age fertilising has also been used in some *Pinus radiata* plantations, but the plantations where this occurs are now managed by Rayonier Tasmania and their water sampling data are not recorded on the Forestry Tasmania database.

Most pesticide and fertiliser applications are conducted aerially, usually with helicopters. Hodgson (1998, 2003) describes the procedures and responsibilities required by Forestry Tasmania for aerial applications of pesticides and fertilisers. A spray plan is prepared for each application. This plan includes a 1:10 000 scale map which delineates streams, wet areas and restricted areas, indicates locations of known domestic water supply intakes within 2 km of the operation, and shows mandatory buffer strips and their widths. An aerial photo of the coupe to be treated is marked with the buffer zones and other areas not to be treated, and this photo is also used during the operation by the spray supervisor when communicating with the pilot (e.g. Figure 1).

Forestry Tasmania's Geographic Information System is used to compile polygon shapes of areas to be treated and these data are electronically transferred and entered into the Global Positioning System of the aircraft. In the aircraft, the pilot has a screen depicting the location of the treatment area and, as the treatment proceeds, a pictorial image of the aircraft moves across the treatment area on the screen. As the delivery systems on the aircraft for chemical or fertiliser application are opened and shut, these points are indicated by a line equivalent to the predetermined swathe. During the operation, the pilot is able to check progress and take suitable action to correct gaps in the flight path and subsequent coverage of the area. The post-flight printout (e.g. Figure 2) shows when the delivery equipment was activated on each flight line, in addition to the actual flight paths in relation to the coupe boundary. Thus, the supervising aerial co-ordinators are able to check where pesticide or fertiliser was applied.

In a small number of cases where application of chemicals or fertilisers by aerial means is not appropriate due to small coupe size, numerous watercourses, flight hazards or other factors, ground application methods can be used. These operations have a high cost compared with aerial methods but there is a potentially lower risk of contamination of watercourses.

The use of buffers within and around coupes is essential for minimising any direct application of fertilisers / pesticides to watercourses. Streamside reserves of varying widths according to stream class are prescribed for watercourse protection under the Forest Practices Code (Forest Practices Board 2000). For operations involving application of pesticides, the width of buffers is related to the method of application as prescribed in the Pesticide Application Manual (Hodgson 2003; Table 3).

Following a recent review of water sampling protocols, additional Forestry Tasmania prescriptions for buffers to be used in pesticide applications will be introduced in 2004 as follows:

- All roads forming the coupe boundaries should be buffered (10 m) to minimise any treatment of edge roads and tracks. Internal roads should also be buffered where District officers consider these could make a substantial contribution to contamination from runoff.
- Classified Class 4 streams (Forest Practices Board 2000) with running water at the time of fertilising or chemical application should be buffered and buffer width should be a minimum of 10 m. Forest Practices Code requirements for individual coupes must override any other considerations.

Figure 1. A marked-up aerial photo of Coupe SO018B, showing coupe boundary and areas not to be treated.

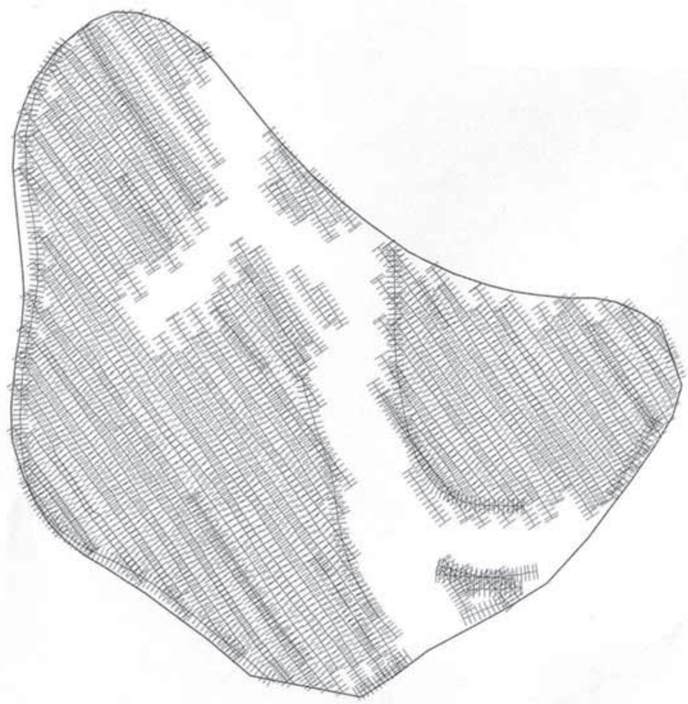

Figure 2. The post-flight printout for Coupe SO018B, showing the flight path and where the delivery equipment for chemical application was activated on each flight line.

- It is recognised that local decisions will be required on a coupe-by-coupe basis in relation to location and extent of buffers, flying direction and use of ground application within buffers.

Prior to applications of pesticides or fertilisers, the spray supervisor makes a field reconnaissance with water sampling staff to identify potential sampling sites and to obtain information used to develop emergency plans for accidental chemical spills.

Water sampling practices

Water sampling is conducted in accordance with the manual on water sampling techniques (Hodgson 2002). The sampling sites are selected to be downstream of all watercourses flowing from the treated area and they must always be well above any points where water is drawn from the stream for beneficial uses such as domestic water supplies. In practice, most sample points are between 20 and 50 m (occasionally up to 250 m if access is difficult) downstream from the treated area. In summary, a balance has to be obtained between proximity to the treated area and allowing some distance for mixing of water leaving the site so that reasonably representative values for any contamination can be obtained.

When sampling for herbicides or insecticides, samples are collected in amber glass, solvent-rinsed, one-litre bottles. For fertiliser detection, plastic, acid-rinsed, 250 ml bottles are used. Analysis of all samples is undertaken by an independent laboratory and to a standard accredited by the National Association of Testing Authorities. Both types of bottles are supplied by the analytical laboratory.

Field blanks (bottles containing distilled water supplied by the laboratory) are used as a quality control measure for sampling associated with pesticide applications. Field blanks are opened and exposed for the time it takes to collect the water samples and then sealed and returned to the laboratory with the samples. The field-blank bottle must be the same type as that used for the water sampling.

Table 3. Recommended buffer widths for Forestry Tasmania pesticide application operations (from Hodgson 2003).

Application method	Buffer width (m)
Fixed-wing aircraft	50
Helicopter	30
Tractor and boom	20
Hand application	5

Staff who carry out the water sampling are trained to a standard acceptable to the responsible Government Authority, the Department of Primary Industries, Water and Environment. To minimise the potential for contamination of samples, the sampler is not involved with any other aspect of the treatment operation such as the handling of chemicals or nutrients, or travel in any vehicles involved in the operation.

Water samples are collected as nearly as practicable from the middle of the stream at half depth without stirring up bottom sediments or introducing surface debris and avoiding eddies and backwaters. Samples are taken by slowly lowering the bottle at an angle upstream of the sampler into the main flow of the stream so water does not contact clothing or skin of the sampler. After collection and labelling, the samples and field blanks are kept cool and forwarded within 24 hours to the laboratory. The results of the analysis are entered on a database at Forestry Tasmania and any values above the guideline levels are discussed with the Districts concerned to identify possible causes of contamination and implementation of improved procedures where required. Some of the improvements which have been implemented include changes in buffer width, more targeted training programs and better handling procedures for water samples.

One water sample is taken at each sampling site on each sampling occasion and at least three samples are recommended to be taken in association with each application as follows:

1. 15–60 minutes before the application. This sample is used to establish if any background contamination existed in the stream.
2. 30–120 minutes after the application to determine if any direct contamination occurred during the operation.
3. Just following the first significant rain event after spraying to detect any contamination due to runoff and leaching.

'Significant' rainfall varies considerably from site to site, but a level of 20 mm is commonly used as the trigger for conducting this third stage of the sampling. Depending on the treatment product used and any specific factors in the area of application, the third sample may not be taken if no significant rainfall occurs in the first four weeks after the application. If treatment products are detected in samples after significant rain, further sampling may occasionally be required until sample readings have reduced to a level which is at or near the guideline value for that particular product at each sampling point.

Water quality standards

There are prescribed limits set for contamination of drinking water for a range of chemical and radiological substances and physical properties which affect water quality to ensure that drinking water does not pose any significant health risk to the consumer and is aesthetically of good quality (NHMRC 1996; ANZECC and ARMCANZ 2000). The National Health and Medical Research Council (NHMRC) sets guideline and health values as the standards for monitoring the presence of pesticides and other parameters affecting the quality of drinking water. The guideline values for pesticides are generally based on the levels at which the particular pesticide can be reliably detected using readily available and validated analytical methods. Health values are based on 10% of the Acceptable Daily Intake and water containing this level of pesticide could be safely consumed over a lifetime without adverse effects (NHMRC 1996). The NHMRC recommends that if pesticide contamination reaches the guideline value then action should be taken to determine the source and corrective measures taken. Exceeding the guideline value does not necessarily indicate a hazard to public health but it does indicate that undesirable contamination has occurred (NHMRC 1996).

Official guideline values and / or health values for drinking water are currently available for 10 of the 19 pesticides used in broadacre applications by Forestry Tasmania between 1993 and 2003 (NHMRC 1996). For pesticides which have no official guideline or health values, Forestry Tasmania has adopted a policy that any presence of the applied pesticide in water samples is a trigger for further investigation and corrective actions where these are required. For fertilisers, there are no official guideline or health values. However, interim trigger values for total N and total P are available for several ecosystem types (e.g. upland rivers, lowland rivers, lakes) (ANZECC and ARMCANZ 2000). These values have a wide range according to the ecosystem type and, in 1997, Forestry Tasmania adopted a trigger level of 800 µg / l and 100 µg / l for total N and total P respectively after discussions with the Department of Primary Industries, Water and Environment.

Results from water sampling, 1993–2003

In the 10 years to July 2003, some 5227 water samples have been taken and analysed and the results are summarised in Tables 4 and 5. The majority of samples (4236) were taken in association with herbicide applications to control weeds in eucalypt and pine plantations. Fourteen herbicides were used in the 10-year period but the main ones were glyphosate (Roundup®), metsulfuron-methyl (Brushoff®), atrazine (Gesaprim®) and hexazinone (Velpar®).

Table 4 shows that 90 samples (2%) exceeded guideline or health values (NHMRC 1996) from 4396 samples covering 19 pesticides over the 10 years that sampling has been conducted. The triazine herbicides, atrazine and simazine, were responsible for 51 of these high readings prior to their withdrawal by Forestry Tasmania in 1995 and 1997 respectively. Hexazinone caused most of the remaining high level readings (36 samples). Thirty of these samples were taken between 1993 and 1999 when hexazinone was used at the highest approved rate on areas of very advanced weed competition. Since then, treatment at lower concentrations and at an earlier stage of weed development has lowered the number of high readings. The high terbacil reading was detected after heavy rain resulted in some surface runoff from a coupe in north-eastern Tasmania in 2001. Follow-up sampling for this coupe showed that the readings had subsequently dropped to trace levels, below both health and guideline values for this pesticide (Forestry Tasmania 2002). The two instances where glyphosate exceeded the guideline level were traced to accidental contamination of the samples by contact with traces of the pesticide from operators and equipment.

The herbicide sulfometuron-methyl, for which there are no official guideline or health values, was recorded at the trace level of 0.2 µg/l in one sample (0.6% of the total samples for this herbicide).

Table 4. Summary of water sampling results for pesticides, 1993–2003.

Pesticide	Registered trade name	Total samples	Guideline Value (GV) (µg/l)	Health Value (HV) (µg/l)	No. sample readings > GV	HV
Herbicides						
Atrazine	Gesaprim	647	0.5	20	41	2
Clopyralid	Lontrel	106	1000	1000	0	0
Dicamba	Banvel	9	N/A[1]	100	0	0
Diquat	Regione	2	0.5	5	0	0
Glyphosate	Roundup	1590	10	1000	2	0
Haloxyfop-methyl	Verdict	62	N/A	N/A	ND[2]	ND
Hexazinone	Velpar	509	2	300	36	0
MCPA	MCPA	4	N/A	N/A	ND	ND
Metosulam	Eclipse	6	N/A	N/A	ND	ND
Metsulfuron-methyl	Brushoff	1032	N/A	30	N/A	0
Simazine	Simazine	36	5	20	8	0
Sulfometuron-methyl	Oust	177	N/A	N/A	N/A	N/A
Terbacil	Sinbar	44	10	30	0	1
Triclopyr	Garlon	11	N/A	10	N/A	0
Insecticides						
Alphamethrin	Alphamethrin	86	N/A	N/A	ND	ND
Alpha-cypermethrin	Dominex	19	N/A	N/A	ND	ND
Chlorpyrifos	Chlorpyrifos	1	N/A	N/A	ND	ND
Cypermethrin	Cypermethrin	23	N/A	N/A	ND	ND
Spinosad	Success	32	N/A	N/A	ND	ND

[1] N/A = no value specified in the Australian Drinking Water Guidelines (NHMRC 1996).
[2] ND = no pesticide detected when the sample was analysed.

Table 5. Summary of water sampling results for fertilisers, 1993–2003.

Treatment	Total no. samples	No. sample readings > GV[1]	Total no. sampling sites	No. sites with readings > GV
Total nitrogen	506	129	207	66
Total phosphorus	325	23	140	18

[1] Forestry Tasmania's guideline values (GV): N = 800 µg / l; P = 100 µg / l.

Table 5 summarises the results of water sampling for total N and total P for all samples and sampling sites in relation to the guideline values set by Forestry Tasmania.

Most fertilising operations did not increase the total N levels above Forestry Tasmania's guideline levels. However, Table 5 shows that 25% and 7% of samples for total N and total P respectively taken following fertiliser operations exceeded these levels. Thirteen of the 129 samples which exceeded the 800 µg / l guideline value for total N were taken prior to the fertilising operation; that is, these readings represented the natural background levels in the streams draining the areas to be fertilised. At nine of these thirteen sites (one pre-fertilising sample is taken per site), the post-fertilising readings remained above the guideline levels whereas at the other four sites the levels dropped below the guideline value. At the other 194 sites (94%), the guideline value for total N was exceeded only in post-fertilising samples, either soon after the fertilising operation and / or after significant rainfall. A total of 16 extra samples (beyond the usual three samples) were required across nine of the sites to check that levels returned to below or near the guideline value. A breakdown of all total N samples by concentration is shown in Figure 3.

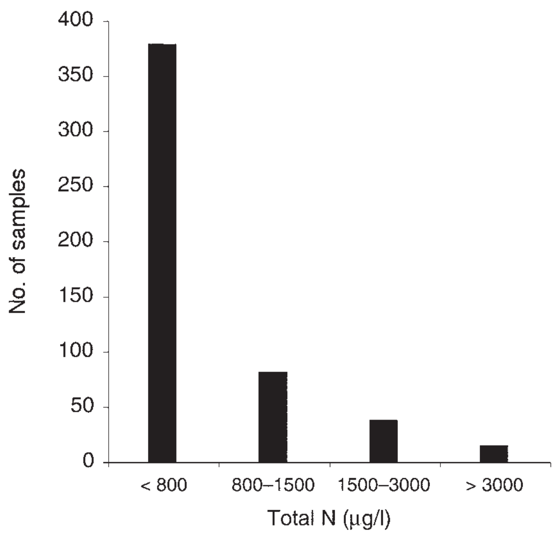

Figure 3. Total N concentrations in water samples.

At sites where high levels of total N were recorded, the pattern of readings in consecutive water samples varied considerably from coupe to coupe. Examples from operational information obtained for three coupes with different patterns of sample readings are shown in Figure 4 and discussed below.

Coupe GC035A shows a low pre-fertilising level followed by a significant increase in total N after fertilising and then a decrease to pre-fertilising levels at the third sample after rainfall three weeks later. In coupe RU001C, the pre-fertilising level of total N was above the guideline value of 800 µg / l and it increased slightly following fertilising. After significant rainfall five days later, the level increased markedly, probably due to runoff and leaching, and then decreased to below the pre-fertilising level at the next sample 23 days later. Coupe EP102A shows a very low pre-fertilising level which increased markedly following fertilising, decreased sharply at the next sample and then gradually decreased in subsequent samples (two and eight weeks after fertilising) to pre-fertilising levels.

A much lower proportion of samples for total P (7%) had readings that exceeded the guideline level of 100 µg / l (Table 5, Figure 5). All high readings for total P were from post-fertilising samples except for one site where the pre-fertilising reading exceeded the guideline value.

Table 6 shows the annual breakdown of all water samples taken in association with pesticide and fertiliser applications from 1993–2003 and the numbers exceeding guideline and health values. The number of samples has varied widely from year to year depending on the number and type of operations and local situations. For example, most of the samples in 1994 were taken in response to local concerns about atrazine, and this herbicide was responsible for some 80% of the samples exceeding guideline and health levels in that year. The general increase in the number of samples from 1998 onwards is a reflection of the increased plantation program, particularly hardwoods, following the signing of the Regional Forest Agreement.

Discussion

Most of the operations where guideline levels have been exceeded involved application of nitrogen fertilisers. High readings of nutrients in forest streams can occur due to several factors such as high natural background levels, direct deposition of fertiliser on watercourses, application of fertiliser to saturated soils, and runoff and leaching following significant rainfall after fertilising. The multiple N application strategy being implemented in some of Forestry Tasmania's eucalypt sawlog plantations (P. Adams and W. Neilsen, unpublished data) has some potential to produce high levels of N in some circumstances, but no data are yet available for analysis. Granulated fertilisers, flight guidance technology and appropriate buffering of watercourses and tracks where practical significantly reduce the potential for direct deposition on waterways and / or runoff. Continuous refinement of these techniques will be very important for maintaining water quality in forest streams as later age fertilising expands along with an increasing plantation area in Tasmania.

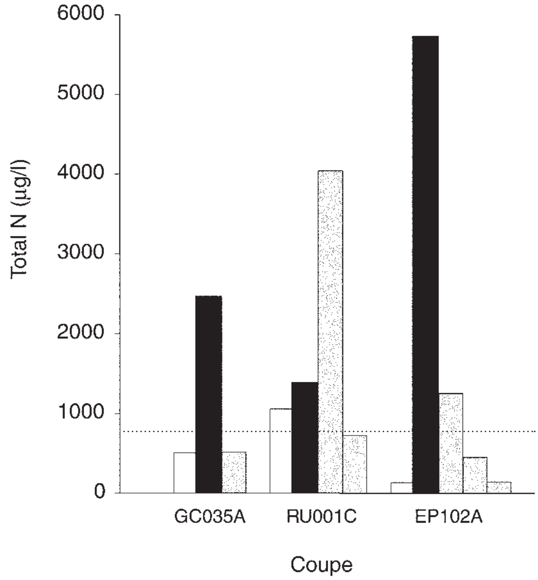

Figure 4. Examples from three coupes of consecutive readings of total N at sampling points where high levels were recorded. (□ = pre-fertilising, ■ = post-fertilising, ▩ = post-fertilising and after rain; dotted line shows guideline value)

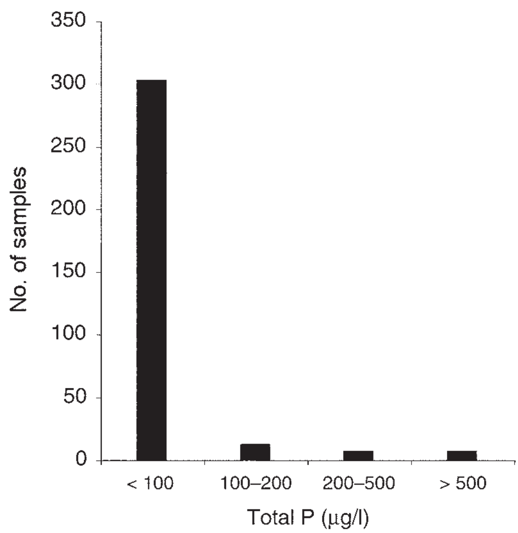

Figure 5. Levels of total P in water samples.

Table 6. Annual breakdown of pesticide and fertiliser sampling, 1993–2003. (GV = guideline value, HV = health value)

	Pesticide			Fertiliser	
Year	No. samples	No. sample readings > GV	No. sample readings > HV	No. samples	No. sample readings > GV
1993 (part)	85	13			
1994	527	38	2	8	4
1995	241	4			
1996	129	3			
1997	104	1		24	3
1998	236	3		120	28
1999	1052	18		148	29
2000	428	4		16	4
2001	761	1	1	18	
2002	527			140	12
2003 (part)	306	2		357	72
Total	**4396**	**87**	**3**	**831**	**152**

The use of fixed guideline values for total nitrogen and phosphorus is problematic because, as reported in this paper, natural background levels of these elements in some Tasmanian streams can sometimes be higher than the guideline values. Currently, the 800 µg / l guideline value for total N and 100 µg / l for P are not related to measured natural background ranges in the Tasmanian streams draining the specific areas where individual treatments are applied. Therefore, assessment of water sampling results against these fixed values can be misleading and natural background levels are the appropriate standards against which to evaluate the results of water sampling.

Establishment of background data on nutrient levels in forest streams is important because it is difficult to generalise about the effects of fertilising when other factors such as fire, erosion and harvesting also affect many parts of the nitrogen cycle (MacDonald *et al.* 1991). Evaluation of the effects of various land uses on water quality within individual catchments is also very important. Thompson *et al.* (2002) collected data on total N and total P as part of a study of the effects of forest harvesting on water quality and yield at Musselboro Creek in northern Tasmania. In this study, sampling stations were located before the stream entered the harvesting area, after it left the area, and after it had flowed through an agricultural area. Levels of total N and P ranged up to 1400 and 230 µg / l respectively, with the highest values and largest range recorded at the agricultural station at the bottom of the catchment.

There is limited information on water quality monitoring for nitrogen and phosphorus in forest streams managed by other Australian land managers. Turner *et al.* (1996) reported wide variation in total N and P concentrations in the course of testing water quality monitoring strategies in Bago State Forest in New South Wales. Across some 89 sampling sites in the Bago forest, total N and total P concentrations were 150–1370 µg / l and 4–321 µg / l respectively, with the variation related to land use and geology. These values are similar to the range of readings recorded across the Tasmanian sampling sites, although the high levels of N and P recorded in some of the Tasmanian samples could not generally be related to previous land use or geology.

In the United States, the Environmental Protection Agency (EPA) proposed water quality criteria for total N and total P in rivers and streams across 13 ecoregions, with ranges of 120–2180 μg / l and 10–128 μg / l respectively (EPA 2002). However, Ice and Binkley (2003) reviewed 300 streams draining small forested watersheds and found that the EPA's criteria for nutrient concentrations were often exceeded, including in some undisturbed forested catchments. Their studies emphasised the wide natural variability in stream nutrient concentrations as affected by factors such as underlying geology, season of sampling and forest species composition. Their overall conclusion was that water quality standards will be acceptable only when they reflect what is physically achievable and biologically relevant.

MacDonald *et al.* (1991) state that intense monitoring for four days after fertiliser application will usually detect peak concentrations of nitrogen due to direct application into the fluvial system but monitoring plans should recognise that a second increase in nitrate concentration occurs during the first runoff events following fertilising. The current sampling system used by Forestry Tasmania does allow for this second flush. However, determining the duration of any high levels of pesticide and fertiliser at individual sampling points after applications is critical to evaluating their effects on water quality and there is a need to conduct more intensive sampling to address this aspect. The current sampling system does not take into account any variations in nutrient concentrations caused by natural changes in stream hydrology (e.g. during periods of high flow) which may confound post-application sample readings, and this needs to be considered when interpreting sampling results and in any refinements of the sampling system.

At the Warra Long-Term Ecological Research Site in southern Tasmania, a major hydrology and water quality program has been established. One objective of this study is to characterise the variability of water quality, including total N and P levels, in a pristine stream (Ringrose *et al.* 2001). Expansion of this work to characterise major streams in all forest Districts would provide data for a more representative standard against which water sampling results could be assessed. An independent hydrologist is currently investigating approaches for Forestry Tasmania to develop a cost-effective Statewide baseline monitoring system for forest streams.

Other priority research areas associated with improved water quality management by forest land managers are to continue refinement of delivery and tracking systems for pesticides and fertilisers, design of protective buffer strips, studies of alternative methods of weed control and pest management, frequency and intensity of water sampling, and developing improved understanding of hydrological processes such as leaching of applied pesticides and fertilisers. A program of regular regional sampling of background water quality parameters would enable consideration of specific local sample data in a spatial and temporal context, thus aiding the overall management of water quality in Tasmanian forests.

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