The effects of aerial and hand fertiliser applications on water quality in sub-catchments of the River Oykel and Loch Shin – update report

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Summary

Many of Scotland’s forests are growing on upland soils with low nutrient content and require fertilisation to improve tree establishment and growth. Fertilisation often has the desired effect of increasing forest productivity but it can have an adverse impact on the water environment if nutrient runoff enriches watercourses. This risk prompted the Scottish Environmental Protection Agency (SEPA) to express concerns over Forestry Commission Scotland’s (FCS) aerial and hand phosphorus fertilisation application programme in the North Highland District, particularly in sensitive water body catchments. Whilst past evidence suggests that the applications would not impair water quality, both SEPA and FCS agreed that it would be prudent to undertake water quality monitoring in a few sensitive catchments to ensure that water quality is not adversely affected and to check the effectiveness of current good practice measures.

A programme of water quality monitoring was established in 2014 in a few selected sub-catchments around Loch Shin and the River Oykel to determine the phosphorus response to aerial and hand fertiliser treatments. Aerial fertiliser applications were carried out in the Craggie and Inveroykel sub-catchments of the River Oykel in May 2014, followed by a second application to another site at Craggie in May 2015. A hand fertiliser application was undertaken in a sub-catchment of Loch Shin at South Dalchork in August-September 2014.

The results show that both orthophosphate (the reactive form) and total phosphorus concentrations in stream waters increased following the aerial fertiliser applications with annual mean concentrations of orthophosphate <7 µg P l⁻¹ at the Craggie streams and <12 µg P l⁻¹ at the Inveroykel streams, well below the 28 µg l⁻¹ good ecological status standard for annual mean reactive phosphorus in upland, low alkalinity waters (UKTAG, 2013). In contrast, it was difficult to discern any response in phosphorus levels to the hand fertiliser application in the S. Dalchork sub-catchment, confirming that this method of treatment poses a much smaller risk of fertiliser runoff; however, phosphorus levels increased at mid-Dalchork in September 2015 and may be related to forest felling.

At all sites, the absence or short length of baseline data makes it difficult to separate out the effect of the fertiliser application from the background variation in phosphorus concentrations. Data from the few pre-fertiliser samples collected, together with the results for the River Tirry control stream, indicate a considerable background level of both orthophosphate and total phosphorus in the streams, which is subject to marked variation in response to weather (particularly storm events) and seasonal factors. The source of this phosphorus could be natural (weathering), historic fertiliser applications or due to forest felling activity. Further investigation of the soils and past land use and management would be needed to help identify the main cause.

It is recommended that water sampling continues at Craggie, and possibly also at Inveroykel, to capture any lag effects of the aerial fertiliser applications and planned forestry operations within the catchments. However, consideration should be given to transferring the sampling at Inveroykel to an
upcoming fertiliser treatment site where baseline date collection would help to separate the background effect from the fertiliser application. The sampling of the hand fertiliser application at Loch Shin should be continued to monitor the effects of the felling in the mid-Dalchork catchment.

1. Objective

To monitor the effects of aerial and hand forest fertiliser applications on water quality in sensitive water catchments.

2. Background

Many of Scotland’s forests are growing on upland soils with low nutrient content therefore forest fertilisation is undertaken to improve tree establishment and growth. Fertilisation often has the desired effect of increasing forest productivity but it can have an adverse impact on the water environment if nutrient runoff, especially of phosphate, enriches local watercourses. This nutrient transport, a form of diffuse pollution, can in extreme cases result in eutrophication where algal growth depletes oxygen eventually leading to death of fish and other organisms. More commonly, a relatively small rise in phosphate concentrations causes unwelcome ecological changes that disturb the ecosystem balance, especially within oligotrophic (nutrient-poor) standing waters such as lochs and reservoirs. Many of our forests are planted in upland catchments that drain to oligotrophic waters supporting sensitive Priority Species such as the freshwater pearl mussel. Therefore, careful land-use management is required to ensure that water quality remains high.

Forest phosphate fertilisation has been an issue of concern in the UK since the late 1970’s (Harriman, 1978). Fertiliser losses have been shown to be greatest during the first six months after an application but can continue for up to five years or longer (Swift, 1987). The method of application is an important factor, with greater losses from aerial compared to hand fertiliser treatments. Improvements to fertiliser practice following the introduction of the Forests & Water Guidelines in 1988, including better helicopter targeting systems and the use of buffer areas, succeeded in reducing phosphate losses to water (Binkley et al., 1999; Nisbet, 2001; Nisbet et al., 2002), although some concerns remain, particularly involving fertiliser applications to deep peat.

Although hand fertiliser applications present less risk, in some areas aerial treatments are necessary due to issues of accessibility, scale and cost, particularly on second and third rotation restocking sites. A number of these sites occur in Forestry Commission Scotland’s (FCS) North Highland Forest District who consulted the Scottish Environmental Protection Agency (SEPA) about their 2014-15 aerial and hand fertiliser programme. SEPA expressed concerns over the aerial applications and the
hand fertiliser application in the catchment of the highly sensitive waters of Loch Shin. Whilst past evidence suggests that the applications could be undertaken without impairing water quality, both SEPA and FCS agreed that it would be prudent to undertake water quality monitoring in a few selected sub-catchments around Loch Shin and the River Oykel to check that this was the case. The results would inform FCS’ ongoing fertiliser application programme and test the efficacy of the water guidelines and General Binding Rules related to fertiliser applications (GBR 18); any lessons learned would be incorporated into future revisions of best practice guidance.

This report presents the results of 16 months of monitoring on the partnership project, where FCS sample the watercourses and provide field-based support, SEPA analyse the water samples in their laboratory and Forest Research manage the project, process and interpret the data and describe the results.

3. Methods

3.1 The sites

Three sites were identified for monitoring from N. Highland Forest District’s fertiliser application programme. Two were to receive aerial fertiliser applications, both in the River Oykel catchment, and a third a hand application in the Loch Shin catchment (Figure 1). The Oykel is a famous salmon fishing river and designated a Special Area of Conservation (SAC) for both Atlantic salmon and freshwater pearl mussels. Loch Shin is also an SAC and a Special Protection Area (SPA); in 2013 the water body was classified overall as bad for ecological status and poor for water quality (moderate for total phosphorus). Phosphorus is a long-standing issue in the loch, leading to concerns about any land use activities in the catchment that could contribute additional nutrients, hence SEPA’s interest in monitoring the effects of the planned hand fertiliser application.
Figure 1 The three study catchments are indicated by the red stars; the two to the west lie within the River Oykel catchment and received aerial fertiliser applications, while the northernmost site is in the Loch Shin catchment and received a hand fertiliser application.

Craggie and Inveroykel – aerial fertiliser applications

The Craggie and Inveroykel sites are located within the River Oykel catchment. Soils at both sites belong to the Arkaig soil association and are peaty gleys with dystrophic blanket peat and peaty gleyed podzols; the parent material consists of drifts derived from schists, gneisses, granulites and quartzites principally of the Moine Series (Soil Survey of Scotland Staff, 1981).

The Craggie site was ploughed and planted in 1972/73, mainly with Lodgepole pine but also Sitka spruce. The site was fertilised with phosphorus around the time of planting and most likely received a second application to achieve establishment; the site was felled in 2009. The site lay fallow until 2014 when it was mounded, restocked with a Lodgepole pine/Sitka spruce mix and fertilised with an aerial PK (phosphorus-potassium) application on 31st May 2014; another aerial fertiliser application was made on 12th May 2015, north of the 2014 treatment (Figure 2). Three sites were identified for sampling following the 2014 application: the Craggie Road Drain (CRD), which drains from the north-eastern part of the fertilised area; the Allt Ruchain, which captures drainage from the north-western
treated section; and the River Chonachair, which receives the Allt Ruchain and waters that drain to the south-east of the fertilised area, before flowing for some 3.5 km directly into the River Oykel. These three sampling points also collect much of the water draining from the 2015 fertiliser application.

![Figure 2](image-url)

Figure 2 The Craggie site with the three sampling points indicated by red circles, the fertiliser storage area by the green circle, the 2014 fertilised area by orange shading and the 2015 fertilised area by yellow shading; the River Oykel can be seen to the east.

The Inveroykel site was ploughed and planted in 1970 with mostly Lodgepole pine but also a mixture of Sitka spruce/Scots pine/Japanese larch. The site was fertilised with phosphorus around the time of planting and probably received a second application thereafter; it was felled in 2009/10. A fallow period was followed by mounding in 2013/14, restocking with mixtures of Lodgepole pine/Sitka spruce and Japanese larch/Sitka spruce, and an aerial PK fertiliser application on 30th May 2014. Two sites were identified for sampling (Figure 3): the Allt a Charraigh burn that captures most of the drainage from the fertilised area, and the Kilmachalmack Burn, which drains a strip running the full length of the southern end of the fertilised area; the Kilmachalmack Burn meets the River Oykel around 2.5 km downstream of the sampling point.
South Dalchork – hand fertiliser application

The S. Dalchork site is located within the Loch Shin catchment (Figure 4). The soils belong to the Arkaig soil association and comprise peaty gleyed podzols with dystrophic semi-confined peat and peaty gleys; the parent material consists of drifts derived from schists, gneisses, granulites and quartzites principally of the Moine Series (Soil Survey of Scotland Staff, 1981).

The S. Dalchork site was ploughed and planted in 1964, mostly with Lodgepole pine but also some Sitka spruce and Scots pine. The site was fertilised with phosphorus around the time of planting and probably received a second application to achieve establishment; the crop was felled in 2009. Following a fallow period the site was mounded and planted in 2014 with a Japanese larch/Sitka spruce mix in the mid-Dalchork catchment and Lodgepole pine/Sitka spruce and Japanese larch/Sitka spruce mixes in the Allt Bhreac Lethaid catchment; native broadleaves were planted adjacent to watercourses and both catchments were fertilised with PK in August 2014.

Three sampling points were identified for monitoring (Figure 4): two downstream of fertilised areas, the Allt Bhreac Lethaid and a burn that we named mid-Dalchork, and one point on the River Tirry that acts as a control; the Tirry flows into Loch Shin about 4 km downstream of the sampling point.
3.2 Fertiliser applications

The Craggie and Inveroykel sites received an aerial fertiliser application of granular PK at 650 kg ha\(^{-1}\), the former on the 31\(^{st}\) May 2014 and the latter on the 30\(^{th}\) May 2014. Figure 5 shows the fertiliser spread patterns recorded by the helicopter guidance system in 2014.

The Craggie site received another aerial application on the 12\(^{th}\) May 2015, to the north of the 2014 application; again with granular PK at 650 kg ha\(^{-1}\) (Figure 2).

The S. Dalchork site was fertilised by hand with standard non-granular PK at 500 kg ha\(^{-1}\), with the application beginning on the 1\(^{st}\) August 2014 and ending on the 8\(^{th}\) September 2014.
3.3 Sampling and chemical analysis

Water samples were collected fortnightly from planned sampling locations in iodised polycarbonate bottles, pre-washed in the laboratory with deionised water. Collected samples were posted on the day of sampling to SEPA’s Eurocentral laboratory. Total and ortho phosphorus determinations were carried out on the samples using a manual colorimetric analysis technique, with a limit of detection 2 µg/l. The testing technique involves reacting orthophosphate ions with acidic molybdate reagents to form a reduced phosphomolybdenum blue complex. The intensity of the blue complex colour formed is proportional to the concentration of orthophosphorus present, the absorbance of which is measured on a spectrophotometer at 882 nm. In the determination of total phosphorus, which includes all inorganic and organic forms of phosphorus, an initial sulphuric acid-persulphate digestion was carried out to convert all forms of phosphorus to the orthophosphate form.

The storage, handling and analysis of samples at the SEPA laboratory was carried out in accordance with the laboratory’s ISO 17025 (UKAS accredited) quality assurance procedures, unless otherwise stated. Analysis results associated with samples collected on 22nd May 2014, and 27th March 2015 were not reported as UKAS accredited since the test-specified storage conditions were not maintained. However the impact on data quality is regarded as minimal and is not expected to have affected the results.
4. Results and Discussion

Aerial fertiliser applications

Craggie

Following the aerial fertiliser application at Craggie in May 2014, total P and orthophosphate concentrations increased at the Allt Ruchain, the Craggie Road Drain (CRD) and, to a lesser extent, the River Chonachair (Figure 6). At the Allt Ruchain, concentrations peaked some five weeks after the fertiliser application at 31.6 µg P l⁻¹ and 10.8 µg P l⁻¹ for total P and orthophosphate, respectively. At the CRD concentrations peaked around 7 weeks after the application at 62.2 µg P l⁻¹ and 14.8 µg P l⁻¹ for total P and orthophosphate, respectively, whilst at the River Chonachair concentrations peaked at 12.7 µg P l⁻¹ and 7.5 µg P l⁻¹, respectively. The variation in response of the concentrations between the three watercourses is thought to mainly reflect the scale of the fertiliser application in each catchment; the CRD is the smallest watercourse with the highest percentage of the catchment area treated (~26%), followed by the Allt Ruchain with around 3% of the catchment fertilised and the River Chonachair with less than 2% of the catchment treated. Research shows that the impact of fertiliser applications is often directly related to the proportion of a catchment treated (Nisbet, 2001).

After peaking, total P and orthophosphate concentrations decreased at all sites to <9 µg P l⁻¹ and <4 µg P l⁻¹, respectively, by January 2015. Baseline, pre-fertilisation monitoring was not possible but samples taken at the CRD and the River Chonachair one week before the fertiliser application show that orthophosphate and total P concentrations were higher than the low levels reached in winter 2015, suggesting that concentrations were above background levels prior to the fertiliser application. Elevated levels could have occurred due to the meteorological conditions in the period leading up to the May 2014 fertiliser applications; precipitation in the River Oykel area was high in February (~200 mm), March (~160 mm) and April (~140 mm) when compared with the 1910 to 2014 North of Scotland long-term averages for these three months of 125 mm, 119 mm and 99 mm, respectively (Met Office, 2015). Phosphorus is known to increase in watercourses during and after rainfall events (Hutton et al., 2008; Swift, 1987), being carried in surface runoff or in subsurface drainage due to leaching from soil horizons that are enriched naturally or by historic phosphate fertiliser applications (Sims et al., 1998; Domagalski and Johnson, 2011).
Total P and orthophosphate concentrations increased again following the second fertiliser application in May 2015, with concentrations reaching their highest levels in July and August 2015 (Figure 6); simultaneous increases at the Inveroykel and Loch Shin sites in summer 2015 indicate that some of the rise reflects increases in background phosphorus levels. As with the 2014 application the increase is not immediate with the first sign of increase in early June, almost 4 weeks after the application. The delayed release seen after both applications may be due to the granular nature of the fertiliser, which takes time to break down release phosphorous into the soil and water. It is worth noting that after rainfall the total P concentration increases more relative to orthophosphate, which could be due to physical washoff of the granular fertiliser, indicating that the particulate P fraction is more responsive compared to dissolved P, something we would expect in erosion-prone soils following heavy rainfall.

Importantly, after the May 2014 fertiliser application, the concentration of orthophosphate at both the Allt Ruchain and River Chonachair never exceeded 11 µg P l⁻¹, with a one year mean of <4 µg P l⁻¹ (Figure 6 and Table 1); concentrations would be further diluted as the River Chonachair flows further downstream into the Oykel. At the CRD, the maximum recorded orthophosphate concentration was 44.8 µg l⁻¹ (in September 2015), with a one year mean of 6 µg P l⁻¹ (Figure 6 and Table 1). The CRD drains into a field below the road where it flows for a distance of at least 600 m to the River Oykel; this will provide some buffering ability and is likely to reduce phosphorus transfer to the River Oykel.
At all of the Craggie sampling sites the annual mean orthophosphate concentration is well below the 28 µg l⁻¹ good ecological status standard for reactive phosphorus in upland, low alkalinity waters (UKTAG, 2013).

**Inveroykel**

Very little if any increase in orthophosphate was seen at the Allt a Charraigh following the aerial fertiliser application and the total P concentration increased only slightly to 45.7 µg P l⁻¹ (Figure 7). Concentrations were lower at the Kilmachalmack Burn (maximum of 16.2 µg P l⁻¹ for orthophosphate and 27.8 µg P l⁻¹ for total P) and both orthophosphate and total P again increased only slightly after the fertiliser application. The period following the application was characterised by a series of peaks and troughs but concentrations did not display any sustained rise; orthophosphate and total P concentrations never exceeded 23 µg P l⁻¹ and 65 µg P l⁻¹, respectively, in either of the burns until after a year when, as with the Craggie site, both orthophosphate and total P increased during summer 2015, beginning in early June. It is unlikely that this represented a lag effect from the 2014 fertiliser application, although the absence of baseline data or an adjacent control catchment makes it difficult to rule this out. There appears to be a strong link with rainfall as the June increases were preceded by heavy rainfall in May 2015, which continued into June; orthophosphate and total P concentrations reached highs of 52.5 µg P l⁻¹ and 97.3 µg P l⁻¹, respectively, at the Allt a Charraigh in early July.

Again, the important point is that with the exception of the July 2015 peak at the Allt a Charraigh, concentrations remained overall low with annual means of 11.2 µg P l⁻¹ at the Allt a Charraigh and 6.8 µg P l⁻¹ at the Kilmachalmack Burn, well below the 28 µg l⁻¹ good ecological status standard for annual mean reactive phosphorus in upland, low alkalinity waters (UKTAG, 2013).

The presence of a natural vegetated buffer (flush) at the eastern end of the fertilised area, before the Allt a Charraigh burn flows under the forest road, is likely to have intercepted some of the fertiliser runoff and thus have helped to reduce the phosphorus loading to the Allt a Charraigh burn.

![Figure 7 Total P and orthophosphate concentrations at Inveroykel; the arrow indicates the date of the fertiliser application](image-url)
S. Dalchork (Loch Shin)

Both total P and orthophosphate showed a small increase during the fertiliser application period at the Mid-Dalchork site (Figure 8), although a similar rise also occurred at the River Tirry control, indicating that the rise was not due to the hand fertiliser application. The cause is thought to be a natural response to the period of heavy rainfall that occurred in the week before the measured peak, when the highest daily rainfall total (41 mm) of 2014 was recorded. Orthophosphate levels proceeded to decline during the following months after the fertiliser application, as with the Oykel sites, reaching minimum values in early 2015. Two baseline samples were taken at the S. Dalchork sites prior to the hand fertiliser application and the results indicate that total P and orthophosphate concentrations were elevated prior to the fertiliser application and return to what appear to be natural winter background levels by January 2015, similar to the trend at the Craggie and Inveroykel sites.

![Graphs showing total P and orthophosphate concentrations at S. Dalchork, Mid-Dalchork, and Tirry upstream - control.](image)

Figure 8 Total P and orthophosphate concentrations at S. Dalchork; the black, dashed rectangle demarcates the fertiliser application period; the green, dashed rectangle indicates the felling period in the mid-Dalchork catchment.

Both total P and orthophosphate increased in summer 2015 at the two fertilised sites and in the River Tirry control, suggesting a natural seasonal response. However, the increase at mid-Dalchork in September 2015 is larger than at the River Tirry control and could be related to felling that took place in the catchment at the end of August and early September; however the peak is short-lived and since concentrations were increasing prior to felling further monitoring is needed to determine the relative
contribution of the felling versus the background concentration increases. Hand fertiliser applications, which are targeted to the base of individual trees, have generally been shown to result in little or no fertiliser loss to runoff (Roberts et al., 1986 in Nisbet, 2001), and with the possible exception of this peak, our results support this conclusion.

The source of the increases in P concentration recorded in summer 2015 at all three sites could be rainfall-runoff induced soil or bank erosion, generating particulate P, as well as increased phosphorus leaching from soil horizons. This could involve both natural P (weathering) and losses from previous fertiliser treatments as well as forest felling activity. Further investigation of the soils and past land use activities in the Loch Shin catchment would be required to try and separate these contributions.

Table 1 Orthophosphate and total phosphorus data with the latter given in parentheses

<table>
<thead>
<tr>
<th>Sample site (fertilised area)</th>
<th>Pre-fertiliser (µg P l⁻¹)</th>
<th>Post-fertiliser annual mean¹ (µg P l⁻¹)</th>
<th>Maximum (µg P l⁻¹)</th>
<th>Minimum (µg P l⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Craggie (57 ha)</td>
<td>n/a</td>
<td>3.8 (11.8)</td>
<td>10.8 (31.6)</td>
<td>&lt;2 (4)</td>
</tr>
<tr>
<td>Allt Ruchain</td>
<td></td>
<td>6 (18.8)</td>
<td>44.8 (134)</td>
<td>&lt;2 (5.1)</td>
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<td>Craggie Road Drain (CRD)</td>
<td>2.4 (8.9)</td>
<td>3.4 (7.7)</td>
<td>7.5 (18.4)</td>
<td>&lt;2 (3.4)</td>
</tr>
<tr>
<td>River Chonachair</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inveroykel (75 ha)</td>
<td></td>
<td>11.2 (28.3)</td>
<td>52.5 (100)</td>
<td>2.9 (9.8)</td>
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<td>Allt a Charraigh</td>
<td>17.9 (34.4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kilmachalmaack Burn</td>
<td>5.8 (17.6)</td>
<td>6.8 (17.1)</td>
<td>16.2 (27.8)</td>
<td>3 (7.2)</td>
</tr>
<tr>
<td>S. Dalchork (37 ha)</td>
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<tr>
<td>Allt Bhreac-Lethaid</td>
<td>9.6 (29.4)</td>
<td>4.4 (15.5)</td>
<td>10.3 (33.1)</td>
<td>2.3 (7.9)</td>
</tr>
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<td>Mid-Dalchork</td>
<td>4.5 (12.8)</td>
<td>4.1 (10.1)</td>
<td>18.2 (31.5)</td>
<td>2.3 (4.4)</td>
</tr>
<tr>
<td>River Tirry</td>
<td>5 (20)</td>
<td>5.7 (16)</td>
<td>10.8 (27.3)</td>
<td>2.3 (7.1)</td>
</tr>
</tbody>
</table>

¹ One year from June 2014
5. Findings thus far

- Aerial fertiliser applications were followed by increases in both orthophosphate (the reactive form) and total P concentrations in waters draining the fertilised areas; however, stream water concentrations remained overall low with annual means of orthophosphate of <7 µg P l\(^{-1}\) in the Craggie streams and <12 µg P l\(^{-1}\) at the Inveroykel streams, well below the 28 µg l\(^{-1}\) good ecological status standard for annual mean reactive phosphorus in upland, low alkalinity rivers (UKTAG, 2013).

- Very little if any phosphorus increase can be attributed thus far to the hand fertiliser application around Loch Shin; however, a peak at the mid-Dalchork site in September 2015 may be related to forest felling within the catchment.

- The lack of baseline data makes it difficult to apportion the phosphorus concentrations between natural sources and the fertiliser treatments, although data from the few pre-fertilisation samples collected, together with the results from the River Tirry control site, indicate that most of the P results from background contributions, particularly associated with rainfall events. The source of the background phosphorus could be natural (weathering), historic fertiliser additions or forest felling, and further investigation of the soils and past land use activities would be needed to confirm this.

6. Recommendations

- Continue sampling and analysis at Craggie to capture the effects of the 2015 aerial fertiliser application and forestry operations within the catchment.

- Continue sampling and analysis in the Loch Shin catchment to look at the effects of the felling within the mid-Dalchork catchment.

- Baseline data is needed to apportion the changes in phosphorus to the fertiliser applications and background levels, therefore consider transferring the sampling from Inveroykel to an upcoming fertilisation site that is conducive to baseline data collection prior to fertilisation.
7. References


Met Office (2015) Climate summaries; download regional values
http://www.metoffice.gov.uk/climate/uk/summaries/datasets


Acknowledgements

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SEPA provided rainfall data from their Loch Ailsh rainguage © Scottish Environment Protection Agency and database right [2015]. All rights reserved.