BEFORE THE HEARINGS PANEL

IN THE MATTER of hearings on submissions concerning the Proposed One Plan notified by the Manawatu-Wanganui Regional Council

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SECTION 42A REPORT OF DR ROGER LYNDHURST PARFITT

ON BEHALF OF HORIZONS REGIONAL COUNCIL

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1. INTRODUCTION

1. My full name is Roger Lyndhurst Parfitt. I have a PhD in Soil Chemistry from Adelaide University and am a Fellow of the New Zealand Society of Soil Science. I have over 40 years of postgraduate work experience, and have been involved in research on carbon, nitrogen and phosphorus in soils and water since 1972, at the University of Papua New Guinea (1969-1976), at DSIR Soil Bureau (1977-1992), and at Landcare Research (1992-2009). I have published over 140 scientific papers on soil science and biogeochemistry.

2. I have worked on five projects on phosphorus (P) and nitrogen (N) for Horizons since 2004 (see Appendix 1).

3. The first two projects measured and modelled P in soils and waters in the Manawatu-Wanganui Region. The second project estimated the loads of dissolved P and N in streams flowing into the Manawatu River between Dannevirke and Hopelands. This identified the major sources of dissolved P in the Manawatu River in late spring and early summer.

4. The last three projects were directly involved with the Proposed One Plan (POP) and I was the leader of the project on P. I have been involved with research on P in soils and in soil solution since 1972. Four of my international publications on this topic have been cited over 100 times (see Appendix 2).

5. I have led work on N and P budgets at both the national and the regional scale since 2004. This work is published in three publications (Parfitt *et al.* 2006, 2008a, b). Parfitt *et al.* (2008a), involves various scenarios for growth in agricultural products from pastoral farming.

6. I have read the Environment Court's practice note 'Expert Witnesses – Code of Conduct' and agree to comply with it.

7. I have been asked to give evidence about a) possible scenarios for N losses in New Zealand for the next 50 years, and b) the sources of P losses in the Upper Manawatu and possible mitigation strategies, based on recent research projects within SLURI – New Zealand's multi-crown research institute (CRI) Sustainable Land Use Research Initiative.

2. EXECUTIVE SUMMARY OF EVIDENCE

8. My evidence is in two parts. The first presents scenarios of future N inputs and outputs for New Zealand. The evaluated scenarios are intended to represent projections of plausible, simple and transparent assumptions. Individual scenarios constructed in this context should not be interpreted as predictions of the future. The second part presents models for P loss in the Upper Manawatu Water Management Zones. A Glossary is provided at the end of this report.

Nitrogen (N) scenarios for New Zealand:

9. Scientists who work on N inputs and outputs are becoming increasingly alarmed about the N load to parts of the planet. In many parts of the world, losses of reactive N to the environment disturb the N cycle and increase the probability of N induced problems such as pollution of waters. The Nanjing Declaration on Nitrogen Management (2004) calls for governments to optimise N management by several strategies including assessments of N cycles.

10. In New Zealand, reactive N continues to be added to the environment mainly by biological N fixation, and also from N fertiliser additions. Dr Morgan Williams - The Parliamentary Commissioner for the Environment (PCE, 2005, executive summary) called for immediate action to remedy the pollution from farms, to manage the use of N fertilisers, and to deal with contamination of waterways.

11. My colleagues and I (Parfitt *et al*., 2008a) extended our work on N budgets in 2001-02 for New Zealand, at both national and regional scales, out to 2020 and 2050, using a scenario where the growth in animal production was 3% per year, and using a "cap-and-trade"[1] scenario. The 3% growth scenario warns of ever-increasing N loads on the environment. In this scenario, the N intake by farm animals would increase by 426% within 50 years. Within 20-40 years the land cannot provide enough feed for the animals, and feed has to be imported from overseas. In this scenario N leaching increases by 420%.

12. The Strategy Framework for New Zealand's Future Dairy and Farming Industry 2005-15 (DairyNZ, 2005) sets a target of 3% growth per year in milk-solids; by 2015 this is 35% growth. To achieve this, feed for the cows must increase by about 3% per year. If the

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1 Cap-and-trade refers to emissions trading and is an administrative approach used to control pollution by providing economic incentives for achieving reduction in the emission of pollutants.

concentration of N in feed remained the same, the N excreted by cows would also increase by about 3% per year.

13. The Draft Strategy for New Zealand Dairy Farming (page 10, DairyNZ, 2009) reports that processed milk solids increased by 4.4% per year from 1988-89 to 2008. However, from 2001 to 2007, total productivity gains in the dairy industry (feed consumed, cow productivity, labour efficiency) averaged 1%. If the growth in milk solids was 1% per year, this would become 163% within 50 years, and about 60% extra feed would be required. N excreted by animals would increase by about 60%. For 2% per year growth in milk solids, this would become 264%, and about 160% extra feed would be required within 50 years. Nitrogen excreted by animals would increase by about 160%.

14. The cap-and-trade scenario supports the development of a mechanism by which farmers might constrain N losses.

Phosphorus (P) losses from Upper Manawatu Water Management Zones:

15. The phosphorus (P) cycle is complex and varies from soil to soil. It is different from the N cycle because the inorganic (mineral) component is much larger than for N. Most fertiliser P becomes a) adsorbed and fixed by iron oxides and aluminium hydrous oxides in soils b) incorporated into soil organic matter, and P is concentrated in the top 5 cm of soil.

16. A small part of the P is soluble (dissolved reactive P (DRP) and dissolved organic P (DOP)) and can move from soil to waters. In winter some P can be leached to ground water. Phosphorus can also move as runoff when there is intense rainfall. In major storms P can move from soil to rivers by erosion from hill soils and P is carried in suspended sediment particles (particulate P).

17. The P cycle under dairying is generally similar except that there is less erosion on flatter land.

18. My SLURI colleagues and I estimated both the total and dissolved P losses (for the first time in New Zealand) for a large catchment (Upper Manawatu Water Management Zones (UMWMZ) above Hopelands) by using the OVERSEER® model and the New Zealand Empirical Erosion Model (NZEEM) together. These are estimates and there is some uncertainty in these numbers. The uncertainly can be reduced by further monitoring both on farms and in the river.

19. Using these models for this catchment (126,669 ha), which has 77% sheep and beef, 16% dairy and 6% forest, and data for the catchment above Weber Road (near Dannevirke), we were able to assess the likely sources of these losses.

20. Most P comes down the rivers in particles of eroded sediment from steeper land during major floods – about 511 tonnes of P per year, attached to particles of sediment, goes under the bridge at Hopelands. Ninety percent of the erosion occurs under pastures on steep land and 10% under forest.

21. These particle P losses could be reduced from 511 to 280 tonnes by targeted planting of trees on land subject to an elevated risk of accelerated erosion (Figure 2A).

22. During low flows sediment particles on the bed of the river release about 4 tonnes of dissolved P per year. This could be halved by reducing erosion.

23. Dissolved P contributes to blooms of periphyton, and they appear to strip both DRP and nitrate from the Manawatu River in summer.

24. Most dissolved P, however, comes from pastures. For sheep and beef farms this could be reduced from 12 tonnes P per year down to 9 tonnes P per year with targeted planting of trees and riparian zones.

25. For dairy farms dissolved P could be reduced from 7 tonnes P down to 3 tonnes P per year with changes to management of effluent, excluding cows from streams and limiting soil P fertility to the optimum agronomic range (Figure 2B).

26. Dissolved P from point sources at Dannevirke and PPCS Oringi could be reduced from 7 to 2 tonnes per year with changes to management of effluent.

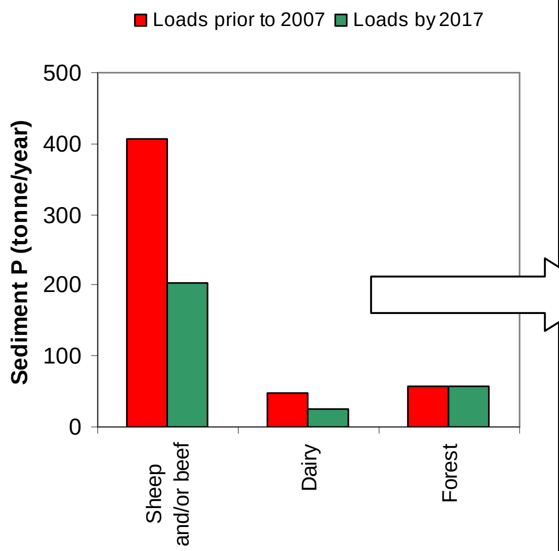	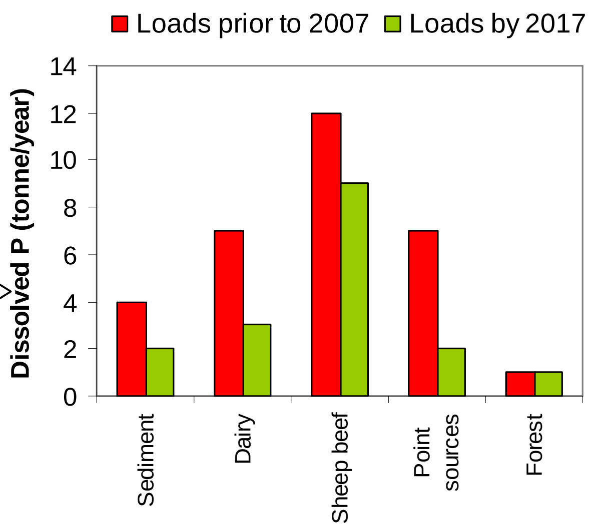
Figure 2A. Estimates of sources of the 511 tonnes of particulate phosphorus (P) in the Manawatu River at Hopelands in 2007, and loads achievable by 2017 if our recommendations are implemented (tonnes P per year)	**Figure 2B.** Estimates of sources of dissolved phosphorus (P) in the Manawatu River at Hopelands in 2007, and loads achievable by 2017 if our recommendations are implemented (tonnes P per year). Note: Some of the 511 tonnes of particulate P remains on the bed of the river and generates about 4 tonnes of dissolved P per year

3. EVIDENCE

27. My evidence is in two parts. The first presents scenarios of future N inputs and outputs for New Zealand. Scenario approaches are now well known in the context of IPCC assessments, and the evaluated scenarios are intended to represent projections of plausible, simple and transparent assumptions. Individual scenarios constructed in this context should never be interpreted as predictions of the future. The second part presents models for P loss in the Upper Manawatu Water Management Zones (UMWMZ) and is largely taken from Parfitt *et al.* (2007, Appendix 1). A Glossary is provided at the end of this report.

Nitrogen (N) scenarios for New Zealand:

28. Scientists who work on N inputs and outputs are becoming increasingly alarmed about the N load on parts of the planet. At a meeting in Nanjing in October 2004, they signed The Nanjing Declaration on Nitrogen Management (2004), which states that in many parts of the world the anthropogenic production of reactive N exceeds natural production, while other areas suffer from the opposite problem. In many parts of the world, losses of reactive N to the environment disturb the N cycle and increase the probability of N induced problems such as pollution of waters. The Declaration calls for national governments to optimise N management by several strategies including assessments of N cycles.

29. In New Zealand, reactive N continues to be added to the environment mainly by biological N fixation, and also from N fertiliser additions. For the 2001-02 year, inputs by biological N fixation were 461,000 tonnes, and N fertiliser additions were 309,000 tonnes; the N lost by leaching was 304,000 tonnes (Table 4, Parfitt *et al*., 2008a).

30. For the Manawatu-Wanganui Region, inputs from biological N fixation were 68,000 tonnes, and from N fertiliser were 31,000 tonnes; the N lost by leaching was 29,000 tonnes (Table 4, Parfitt *et al*., 2008a).

31. Leaching losses for North Island Regional Councils are mainly from pasture land and range from 83 to 97% of the total leaching losses.

32. The average N leaching losses for New Zealand are 11 kg N/ha, and for the Manawatu-Wanganui Region are 13 kg N/ha with 93% coming from pastures. For North Island Regional Councils losses by leaching range from 9 kg N/ha (Gisborne) to 27 kg N/ha (Taranaki). Large losses also occur in Northland (15 kg N/ha), Auckland (15 kg N/ha), and Waikato (20 kg N/ha).

33. N fertiliser sales peaked in 2005-06 at 350,000 tonnes; in 2007-08 they were 312,000 tonnes (Figure 3).

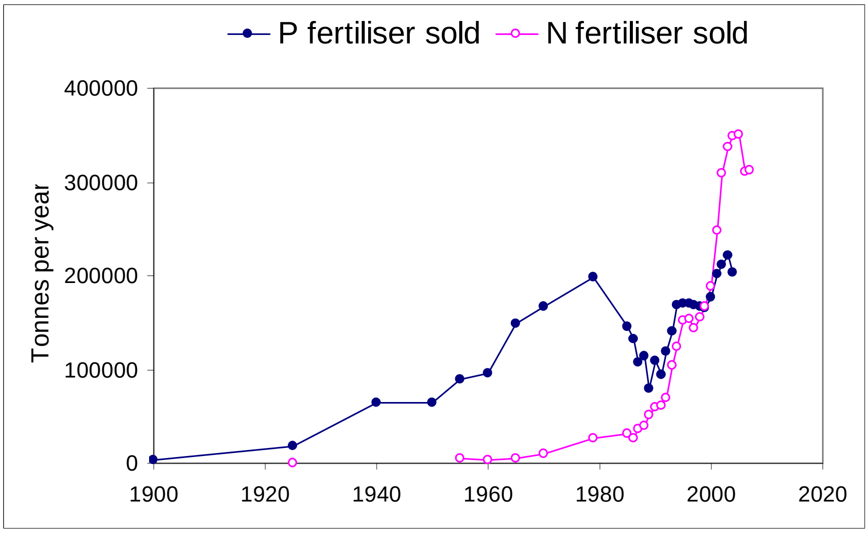

Figure 3. Fertiliser sold in New Zealand from 1900 to 2007 (from H. Furness, FertResearch)

34. The Strategy Framework for New Zealand's Future Dairy and Farming Industry 2005-15 (page 2, DairyNZ, 2005) set a target of 3% growth per year in milk-solids; by 2015 this will be 35% growth. To achieve such growth, feed for the cows must increase by about 3% per year. If the feed contains the same concentration of N, then N excreted by cows would also increase by about 3% per year.

35. My colleagues and I (Parfitt *et al.*, 2008a) assessed N budgets (inputs from biological N fixation, N fertiliser additions, atmosphere, and imports; outputs in produce, waters, gases, and erosion) for New Zealand in 2001-02 at both national and regional scales. We used the OVERSEER nutrient model to estimate the N lost by leaching from soil profiles for each region and each animal type, and we estimated losses by leaching from crops, forests and point sources (Parfitt *et al.*, 2008a) (see the evidence of Dr Ledgard). The dominant sources of N leaching were diffuse sources under pasture, arising mainly from N excreted by animals. Total losses of N from soils by leaching were greater for sheep and beef than from dairying (Figure 4), because, although average losses for sheep and beef were 9-22 kg N/ha/year and for dairy were 25-58 kg N/ha/year, the area of pasture under sheep and beef is 8.5 million ha, whereas the area under dairy cows is 2 million ha.

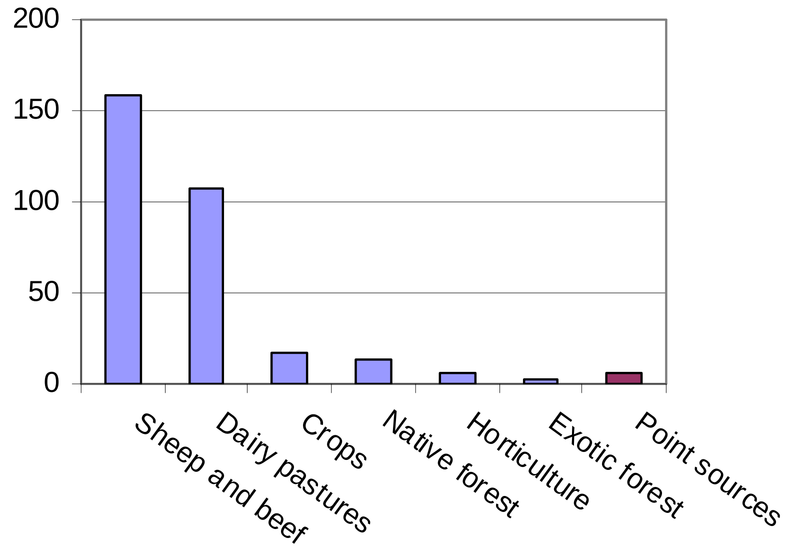

Figure 4. Leaching of soluble nitrogen (N) (1,000 tonnes) from soil to waters in 2001-02, estimated using OVERSEER.

36. My colleagues and I extended our work on N budgets in 2001-02 for New Zealand, at both national and regional scales, out to 2020 and 2050 (Parfitt *et al*.,2008a). We adopted two scenarios to assess the future pathways of reactive N in New Zealand: agricultural production increasing at 3% per year, and a cap-and-trade scheme for N. These scenarios provide instructive results by projecting two very different potential policy directions into the future; they do not represent predictions. The 3% growth scenario warns of ever-increasing N loads on the environment. In this scenario the N intake by farm animals would increase by 426% within 50 years. To achieve this more N fertiliser would be required initially. In later years, feed would have to be imported from overseas since New Zealand does not have the land area to provide the feed required. The scenario considered sheep, beef and dairy sectors separately; feed had to be imported after 42 years for sheep, 30 years for beef, and 18 years for dairy.

37. In this scenario, the national inputs of N increased from 1,023,000 tonnes in 2001-02 to 3,565,000 tonnes in 2050. Nitrogen lost by leaching in New Zealand would increase from 304,000 tonnes to 1,279,000 tonnes after 50 years, a 420% increase (Table 8, Parfitt *et al*., 2008a).

38. The Strategy Framework for New Zealand's Future Dairy and Farming Industry 2005-15 (page 2, DairyNZ, 2005) set a target of 3% growth in milk-solids by 2015 (35% growth). To achieve this, feed for the cows must increase by 3% per year.

39. The Draft Strategy for New Zealand Dairy Farming (page 10, DairyNZ, 2009) reports that processed milk solids increased by 4.4% per year from 1988-09 to 2008. However, the Draft Strategy for New Zealand Dairy Farming also reports total productivity gains in the dairy industry (feed consumed, cow productivity, labour efficiency) averaged 1% from 2001 to 2007 (Figure 5). I have calculated two scenarios, using 1% per year and 2% per year growth in milk solids. If the growth in milk solids was 1% per year, this would become 163% within 50 years, and about 60% extra feed would be required. If the N concentration in feed remains unchanged, the N excreted by animals would increase by about 60%. For 2% per year growth in milk solids, this would become 264% within 50 years, and about 160% extra feed would be required. The N excreted by animals would increase by about 160%. This would become an increasing load on the environment.

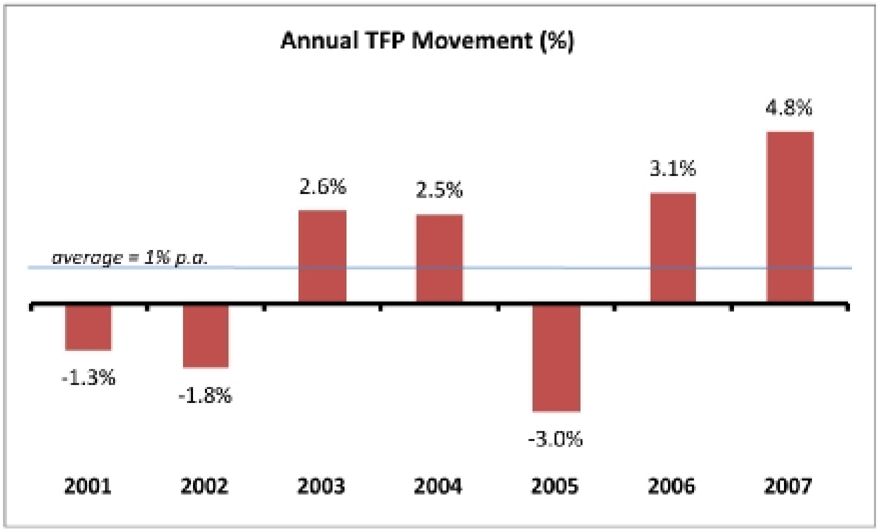

Figure 5. Productivity gains and losses since 2001. TFP stands for Total Factor Productivity.

40. Generally little consideration has been given to the effects of increasing N loads as a result of the ongoing lift in total cow and per cow production, and the trend of bringing more imported feed onto the milking platform. Our paper highlighted the urgency with which primary industry must address the issue of N loads on the environment, and move away from continued increase in production *per se* to systems where value is added to products. Indeed, the annual growth model appears to be unsustainable in the long term unless there are radical changes in the farming systems (PCE, 2005).

41. Dr Morgan Williams -The Parliamentary Commissioner for the Environment in “Growing for Good” (page 127, PCE, 2005) expressed concern about waterways and lakes becoming nutrient enriched and degraded, and called for immediate action to remedy

the pollution from farms, to manage the use of nitrogen fertilisers, and to deal with contamination of waterways.

42. We also modelled a simple cap-and-trade scenario for New Zealand, to limit the quantity of reactive N in water. We modelled a cap on N fertiliser of 472,000 tonnes N; our projections (in 2005) suggested this amount would be sold in 2011. The simple approach allows a sensible scenario to be calculated but may differ from more politically realistic cap-and-trade schemes in which adjustments to the cap can be made at regional or catchment levels based on the natural capital of the land. We make the following assumptions:

i. To reduce erosion, pine is planted on soils on soft rock with slopes >24%, so pine plantations increase from 2 million ha to 2.9 million ha, farm and pasture ha decrease by 0.9 million ha, Stock Units (SU) decrease by 5 for each ha of pine.

ii. Other animal numbers and SU stay the same as in 2001-02.

iii. Farmers will grow more maize to feed the livestock, and the N concentration in animal excreta will therefore be reduced.

iv. Most dairy farms will use winter feed pads (some of which may include a “herd home”) so N waste can be better managed, leaching of N is halved from dairy farms, and denitrification is increased from 10 (in 2001) to 20 kg N/ha.

v. Emissions of ammonia will increase from 2.1 kg N/SU to 3 kg N/SU as a result of larger concentrated areas of animal waste.

vi. N_2O emissions from animal excreta decrease by 30%.

vii. Nitrate leaching in pasture under sheep and beef increases from 2001-02 by 30% as a result of increased N inputs.

43. In the simple cap-and-trade scenario, the national inputs of N increased by about 20% from 1,023,000 tonnes in 2001-02 to 1,171,000 tonnes in 2050 (Table 9, Parfitt *et al*., 2008a). Most of this increase comes from N fertiliser and from the subsequent deposition of ammonia-N as more ammonia becomes volatilised. Clover N fixation was reduced as a result of both N fertiliser additions and the effect of the clover weevil. The national outputs of N increase by about 14% – from 1,105,000 tonnes in 2001-02 to 1,253,000 tonnes in 2050. The output of reactive N, therefore, is about the same as in 2001-02. As a result of reforestation in hill country, the loss of N by erosion is reduced by about 20% to 158,000 tonnes. Leaching of N is increased from sheep and beef farms because of the higher N status of the pastures but is reduced from dairy farms in winter as a result of using feedpads, giving a small net reduction in leaching (to 287,000 tonnes N). Although inputs of N fertiliser have actually decreased since 2005, the losses of N from pastures to rivers appear to be increasing (see evidence of Kate McArthur), and

the cap-and-trade scenario supports the development of a mechanism by which farmers might constrain N losses (see evidence of Dr Mackay).

Phosphorus (P) losses from Upper Manawatu Water Management Zones:

44. The phosphorus (P) cycle is complex and varies from soil to soil depending on the amount of iron oxides and aluminium hydrous oxides. It is different from the N cycle because the inorganic (mineral) component is much larger than for N (Figure 6).

45. Most fertiliser P becomes: a) adsorbed and fixed by iron oxides and aluminium hydrous oxides in soils; b) incorporated into soil organic matter. Phosphorus from litter and dung is returned to the soil and the P is concentrated in the top 5 cm of soil. The distribution of dung, however, is uneven and animal camp sites become enriched with P.

46. A small part of the P dissolves in water and moves (only) 2-3 mm from soil to roots whereas N is much more mobile and moves up to 10 cm from soil to roots. Nevertheless a small part of the P is soluble (dissolved reactive P (DRP), and dissolved organic P (DOP)) and can move from soil to waters. In winter some P can be leached to ground water.

47. Phosphorus can also move as runoff when there is intense rainfall, and this may account for 30% of the annual loss to waters. In major storms P can move from soil to rivers by erosion from hill soils. Phosphorus is carried in suspended sediment particles (particulate P).

48. The P cycle under dairying is generally similar except that there is less erosion on flatter land. The losses of DRP and DOP to waters are greater than for sheep because the P status of soils is usually richer under dairying.

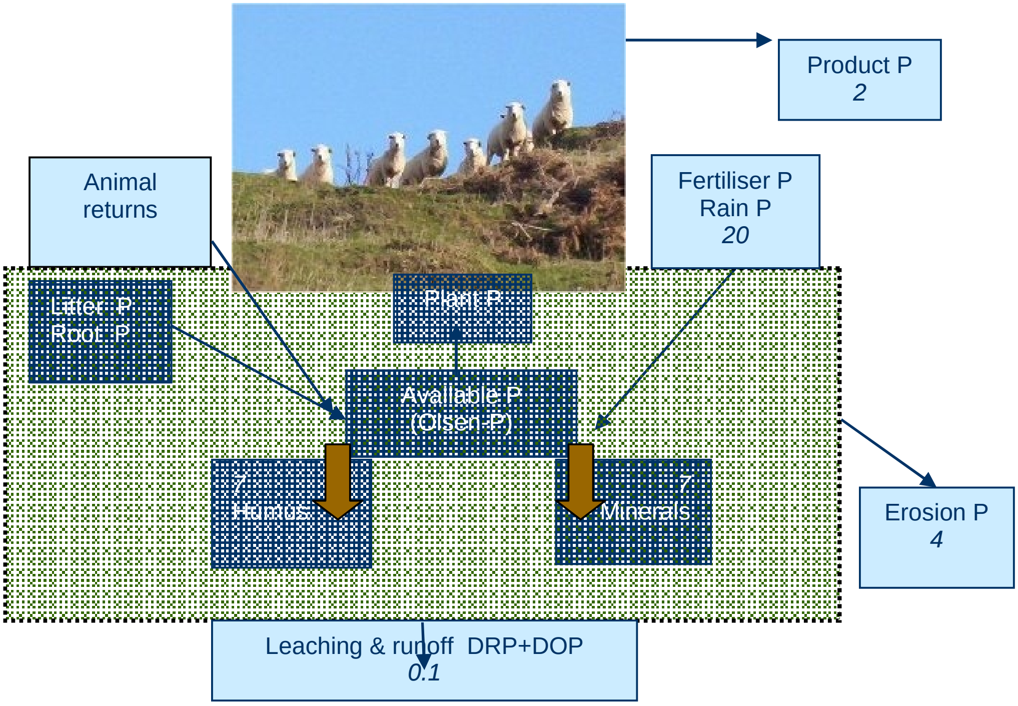

Figure 6. A simplified schematic of the flows and fate of phosphorus (P) in the root zone of pasture with 12 stock units per hectare. The organic pools are on the left and the inorganic on the right. Units are kg P /ha.

49. Horizons Regional Council is implementing the Sustainable Land Use Initiative (SLUI) to address both erosion issues on farms and issues of sediment in rivers (see evidence of Dr Roygard to the Hearing on Land). A further Horizons initiative, the proposed Farmer Applied Resource Management strategy (FARM strategy), will target reductions in contaminant loss (mainly N and P) from intensive land uses in target catchments (see the evidence of Dr Roygard). Horizons asked Landcare Research and SLURI – New Zealand's multi-CRI Sustainable Land Use Research Initiative – to develop a method to determine the potential for water quality improvement through these combined initiatives in relation to P in water-ways, and also provide an indication as to whether erosion control or nutrient management should be the priority management target in that catchment.

50. My colleagues and I (SLURI) estimated both the total and dissolved P losses (for the first time in New Zealand) for a large catchment (Upper Manawatu Water Management Zones above Hopelands) by using the OVERSEER model and NZEEM (Dymond & Betts, 2007) together (Figure 7). NZEEM is an empirical erosion model that estimates long term sediment loss for each 25 m square in New Zealand based on erosion terrain; annual rainfall; and land cover. Our results give first estimates and there is some

uncertainty in these numbers. The uncertainly can be reduced by further monitoring, both on farms and in the river.

51. Using these models for this catchment (126,669 ha), which has 77% sheep and beef, 16% dairy and 6% forest, together with data for the catchment above Weber Road (Figure 7), we were able to assess the likely sources of these P losses.

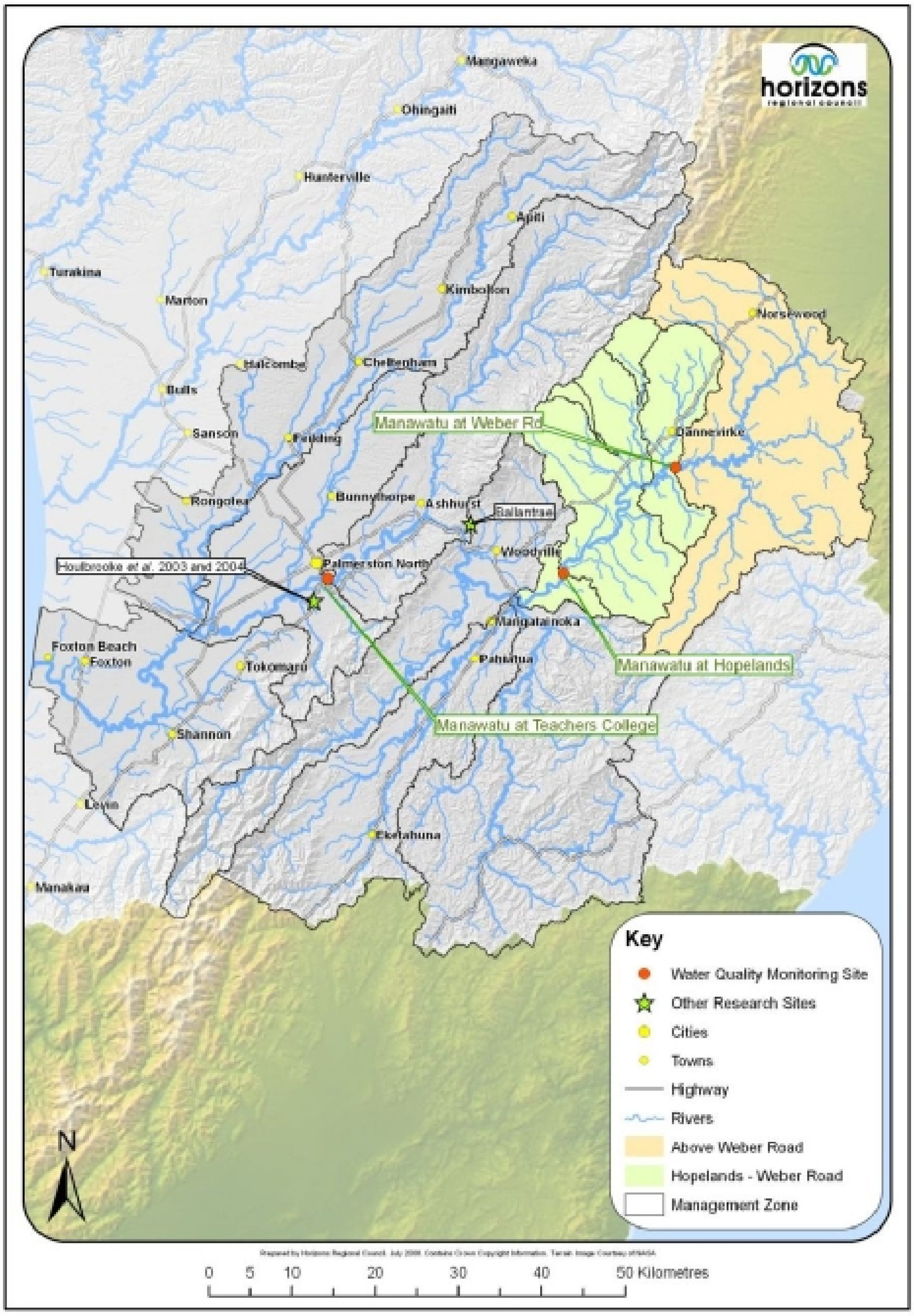

Figure 7. The Upper Manawatu Water Management Zones (UMWMZ), monitoring locations and research sites, above Weber Road (in yellow) and above Hopelands (in green).

52. Phosphorus is lost in three forms: 1) P in suspended sediment particles (particulate P); 2) DRP; and 3) DOP; with the first of these dominant (60–90%). Dissolved reactive phosphorus is readily available to periphyton; DOP is less available and requires biological energy (enzymes) to access this P and then mineralise the DOP into DRP. Dissolved P contributes to blooms of periphyton and they appear to strip both DRP and nitrate from the Manawatu River in summer (see the evidence of Kate McArthur and Dr Biggs).

53. The NZEEM was used to estimate the suspended sediment in the Manawatu River at Weber Road (641,000 tonnes per year) and at Hopelands (930, 000 tonnes per year). This is a long-term average over about the last 40 years and includes major flood events but excludes the extreme 2004 flood event. The *total-P* content of dry particles in the Manawatu River one day after flood peaks was about 550 mg/kg. Assuming this is the concentration of P in suspended sediment in UMWMZ this gives 353 tonnes per year as particulate P in the Manawatu River at Weber Road, and 511 tonnes per year at Manawatu at Hopelands. This is consistent with the Horizons estimate (that includes the aftermath of the very large 2004 flood) of 903 tonnes per year at Manawatu at Weber Rd. The average loss is 4.9 kg P/ha/year from all land above Weber Road and 4.0 kg P/ha/year from all land above Hopelands. This may be compared with the loss of 1.5 kg P/ha in just 12 hours in the flood of 16 February 2004 for the whole catchment above the Manawatu at Teachers College site.

54. The losses from different land uses above Manawatu at Hopelands were estimated using the shape files from Horizons. The losses of P from sheep and beef land were estimated at 406 tonnes per year (4.8 kg P/ha/year), losses from dairy land at 48 tonnes P per year (2.3 kg P/ha/year), and losses from other land (mainly forest on very steep slopes) at 57 tonnes per year (2.7 kg P/ha/year) (Figure 8). Total losses are 511 tonnes per year. Ninety percent of the erosion occurs under pastures on steep land and 10% under forest.

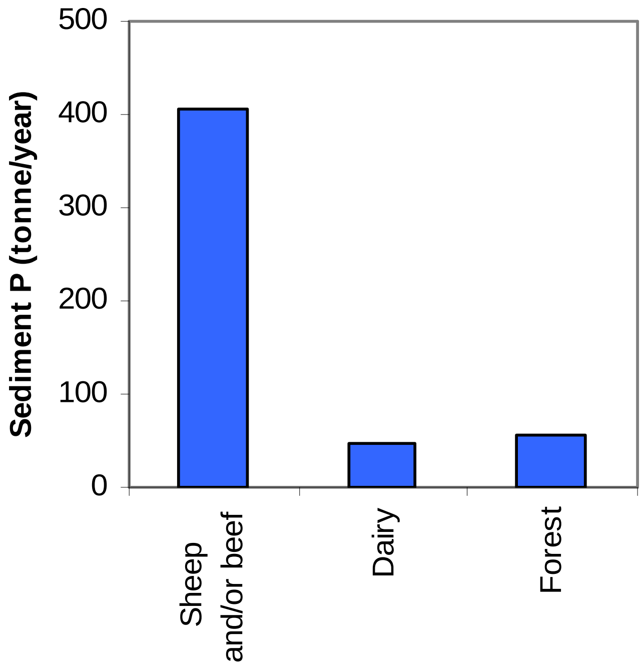

Figure 8. Estimates of sources of sediment derived phosphorus (P) (Particulate P) in the Manawatu River at Hopelands in 2007 based on the long-term average over about the last 40 years and includes major flood events but excludes the extreme 2004 flood event (tonnes P per year).

55. Target planting of trees could reduce the total losses to about 280 tonnes P per year by implementing whole farm plans on approximately 10% of farms with the highest proportion of land subject to an elevated risk of accelerated erosion. Since it takes several years for tree roots to bind the soil, the achievement of these gains may take 10-20 years should all land at risk of erosion be planted on day one. The time scales will be longer if planting of eroding land through whole-farm plans is staggered over a number of years. Targeting the SLUI whole-farm plans to the highest priority farms is the best way to achieve gains in the shortest time. By reducing the introduction of fresh sediment into the bed of the Manawatu River there would also be reductions in P released from the river bed that is available to periphyton. Losses from forests are estimated to remain at 57 tonnes P per year (Figure 9).

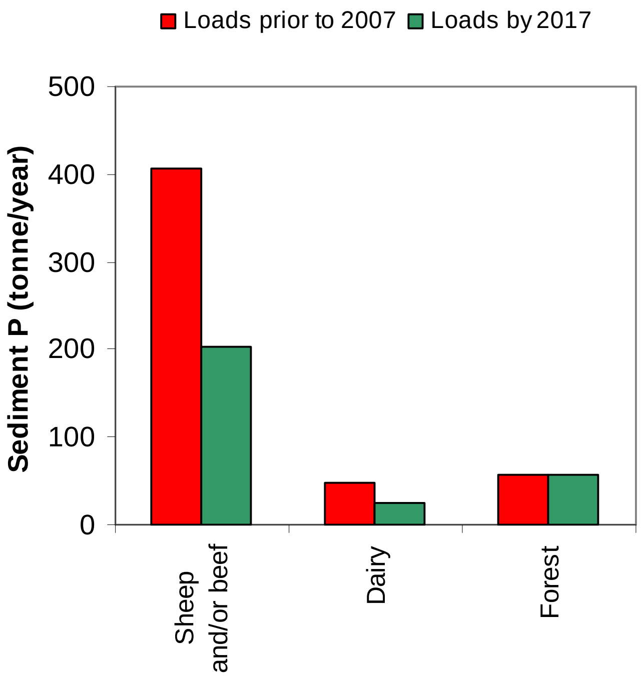

Figure 9. Estimates of sources of sediment phosphorus (P) (particulate P) in the Manawatu River at Hopelands in 2007, and loads achievable by 2017 and 2027 if our recommendations are implemented on all affected land on day 1 (tonnes P per year)

56. Assuming the area of sediment in the bed of the Manawatu River above Hopelands occupies 250 ha, and the bulk density on the river bed is 1.6 tonnes/m^3, and if the surface 100 mm of sediment (500mg P/kg) releases 2% of the P each year, then the bed releases 4 tonnes dissolved P per year. This probably occurs when temperatures are warmer and when the river is less turbulent ie. during low flows. The 4 tonnes dissolved P per year could be halved by reducing erosion. Gains can therefore be made from decreasing the sediment load “sitting” in the bed of the Manawatu River since the surface of the sediment will release DRP that is available to periphyton.

57. The amount of DRP going under the bridge at Hopelands is 21 tonnes per year (Maree Clark *pers comm.*). Our unpublished data suggest DOP is 50% that of DRP. The total dissolved P is therefore estimated at 31 tonnes per year.

58. Of these 31 tonnes, 4 tonnes comes from sediment and point sources (such as sewage effluent at Dannevirke and effluent at PPCS Oringi) produced 5 tonnes of DRP and an estimated 2 tonnes of DOP.

59. The 7672 ha of forest in the catchment produce about 0.5 tonnes of DRP and 0.5 tonnes of DOP (0.1 kg P/ha/year; McGroddy *et al*., 2008).

60. The remaining 19 tonnes is produced by diffuse sources in soils under pasture.

61. Using the OVERSEER model together with published information reviewed in Parfitt *et al*. (2009) we estimated that soils under sheep and beef yield 12 tonnes P per year to the river (0.1 kg P/ha/year), and soils under dairy yield 7 tonnes P per year (0.35 kg P/ha/year).

62. The 31 tonnes P per year is apportioned to sheep and beef = 12 tonnes P per year, dairy = 7 tonnes P per year, forest = 1 tonne P per year, dissolving sediment = 4 tonnes P per year, and point sources = 7 tonnes P per year (Figure 10). The total losses are then the sum of 511 tonnes P per year from particulate P and 31 tonnes dissolved P per year.

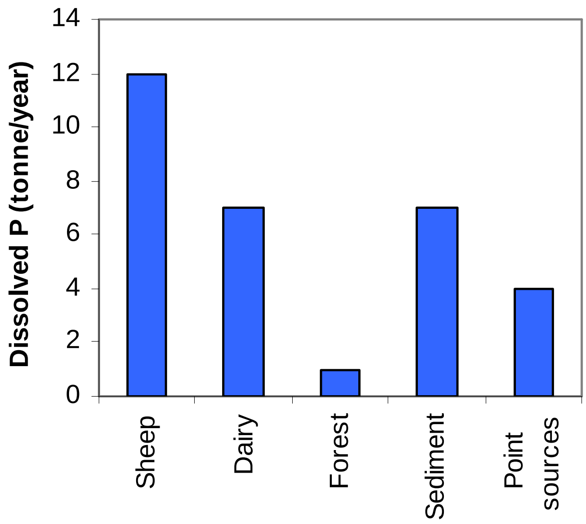

Figure 10. Estimates of sources of dissolved phosphorus (P) in the Manawatu River at Hopelands in 2007 (tonnes P per year)

63. Most gains during low flow can be made from management of dissolved P. Gains can be made from better managing point sources that add 3.5 tonnes P per year as DRP to the Manawatu River above Hopelands at low flows; this is 44% of the load at low flows (Ledein *et al*., 2007; see evidence of Kate McArthur and Dr Roygard for updated load estimates for this catchment). The load of DRP at all flows is approximately 21 tonnes P per year, and approximately 5 tonnes P per year is from point sources. The DOP loads

are estimated to be 10 tonnes P per year, with 2 tonnes P per year from point sources. With the closing of PPCS Oringi and improved management of waste using engineering and chemical technologies, the loads from point sources could be reduced. A reduction of 5 tonnes P per year would be 16% of the total load (31 tonnes P per year) (Figure 11).

64. Planting trees on steeper slopes, and riparian fencing and planting of rivers and larger streams on sheep and beef farms may reduce the DRP load by about 3 tonnes P per year. This estimate has large uncertainty and requires further study.

65. For dairy farms, cows in waterways contribute about 0.5 kg P/ha/year to rivers (McDowell, 2006). Gains can be made from removing animal stock from these waterways. If this applies to 10% of the dairy farms, this could reduce the load in the Manawatu River at Hopelands by 1 tonne P per year (see the evidence of Dr Monaghan).

66. Gains can be made from irrigating farm dairy effluent according to deferred irrigation criteria where applications are only made to soil that has a sufficient soil water deficit to store applied volumes (see the evidence of Dr Houlbrooke). Furthermore, when soil infiltration limitations exist or preferential flow of applied effluent is likely, further gains can be made using low rate irrigation technology. This could reduce the losses for dairy farms by 1kg P/ha/year on at least 10% of the milking platforms. If this applies to all dairy farms, this could reduce the load in the Manawatu River at Hopelands by 2 tonnes P per year. The consented effluent loads at Hopelands have been reduced from a peak of about 3.0 tonnes DRP per year in 1998 to 0.5 tonne DRP per year by 2006 (McArthur evidence).

67. Gains can be made from moving tracks that link to streams. For dairy farms this could reduce the losses by 0.1kg P/ha/year. If this could apply to half the dairy farms, the load in the Manawatu River at Hopelands could be reduced by 1 tonne P per year (Figure 11).

68. Parfitt *et al*. (Table 4, 2008b) estimated that P stored in soils was increasing by 20,000 tonnes P per year in the Horizons Region as a result of inputs of 33,000 tonnes P per year. Generally soil Olsen-P levels are increasing, particularly on dairy farms. Gains can be made from limiting P fertiliser inputs to maintaining the soil Olsen-P in the agronomic optimum range. When too much P fertiliser is used, the P losses increase exponentially; therefore P use (and losses) should be reduced by farmers. On the other hand, if fertiliser use is increased on less fertile land, P losses will increase. We assume these increases and reductions in P loss will cancel each other in the catchment budget, but

there is uncertainty in this assumption. If farmers use OVERSEER to assess nutrient budgets there will be more certainty in these numbers.

69. Gains can be made from using reactive phosphate rock fertiliser (RPR) rather than more soluble P fertilisers on pastures since fertilisers can fall within streams and soluble fertilisers can rapidly move short distances to streams (Allan Gillingham, unpublished data from Waipawa). The gains depend on weather conditions (such as storms shortly after applying fertiliser, and the amount of fertiliser that falls directly into waterways). Assuming that the loss from soluble P fertilisers during a large storm is an average of 1kg P/ha then the loss over 1,000 ha would be 1 tonne P. Assuming the loss from RPR is 0.5kg P/ha then the loss over 1,000 ha would be 0.5 tonnes P. Most fertiliser P, however, is retained in soils.

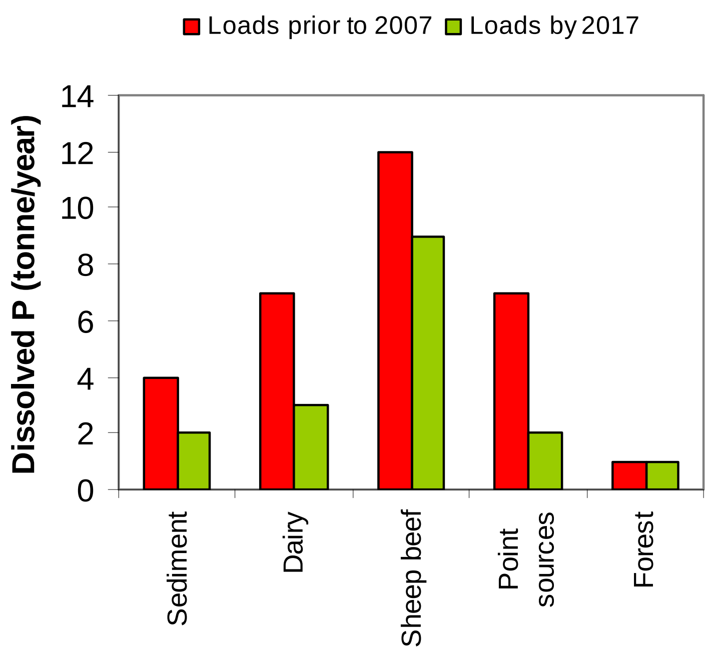

Figure 11. Estimates of sources of dissolved phosphorus (DRP+DOP) in the Manawatu River at Hopelands in 2007, and loads achievable by 2017 if our recommendations are implemented (tonnes phosphorus (P) per year). Note: Some of the 511 tonnes of particulate phosphorus (PP) remains on the bed of the river and generates about 4 tonnes of dissolved P per year.

70. The Proposed One Plan (POP) standards in schedule D recommend a DRP standard of 0.010 g P/m^3. Current concentrations at Hopelands are usually in excess of this standard (see evidence of Kate McArthur), except when periphyton are actively stripping

DRP in summer. It should be possible to reduce current DRP concentrations down towards the proposed DRP standard with our recommended mitigation measures. Since the geology of the Upper Manawatu catchment has some P rich materials it may be difficult to lower the DRP concentrations below the standard.

71. In our report to Horizons (Parfitt *et al*., 2007, Appendix 1) and in our Parfitt *et al*., (2008c) summary paper we recommended attention is paid to:

i. Point sources, since rapid gains may be possible.

ii. Animals in rivers, since rapid gains may be possible.

iii. Effluent land application, since rapid gains may be possible.

iv. Riparian fencing and planting, managing stream crossings, and other recommendations in the Clean Streams Accord as they should be implemented.

v. SLUI Farm Plans and they should be targeted on high priority farms.

vi. Both N and P, and they should be managed year round.

vii. OVERSEER nutrient budgets on farms, and they should be implemented to provide more precise numbers about nutrients under different management and for the different soils.

viii. Erosion control.

ix. Monitoring of phosphorus concentrations (DRP, DOP, PP) in the Manawatu River, and they should be carried out on a regular basis to define a more precise base line, and to monitor improvements to water quality as SLUI and the FARM strategy programmes progress.

4. REFERENCES

DairyNZ. 2005. Strategy Framework for New Zealand's Future Dairy and Farming Industry 2005–15. http://www.dairynz.co.nz/page/pageid/2145836752

DairyNZ. 2009. Draft Strategy for New Zealand Dairy Farming. http://www.dairynz.co.nz/file/fileid/13269

Dymond JR, Betts HD. 2009. An erosion model for evaluating regional land-use scenarios in New Zealand. Submitted to Environmental Modelling and Software.

Ledein E, Ausseil O, Roygard J. 2007. Identifying point source and non-point source contributions to nutrient loadings in water ways in three catchments in the Manawatu-Wanganui Region. Horizons Region Council Technical Report

McDowell RW. 2006. Phosphorus and sediment loss in a catchment with winter forage grazing of cropland by dairy cattle. J Env. Qual. 35:575–583.

McGroddy M E, Baisden WT, Hedin LO. 2008. Stoichiometry of hydrological C, N, and P losses across climate and geology: an environmental matrix approach across New Zealand primary forests, Global Biogeochemical Cycles 22: GB1026.

Nanjing Declaration on Nitrogen Management. 2004. www.initrogen.org/nanjing_declaration.0.html

Parfitt RL, and Mackay AD. 2007. Phosphorus filtering by soils, and movement from soils to waters. Occasional report to SLURI.

Parfitt RL, Baisden WT, Elliott AH. 2008b. Phosphorus inputs and outputs for New Zealand in 2001 at national and regional scales. Journal of the Royal Society of New Zealand 38: 37–50.

Parfitt R, Dymond J, Ausseil A-G, Clothier B, Deurer M, Gillingham A, Gray R, Houlbrooke D, Mackay A, McDowell R. 2007. Best practice phosphorus losses from agricultural land. Landcare Research Contract Report: LC0708/012 Prepared for Horizons Regional Council

Parfitt R, Dymond J, Mackay A, Gillingham A, Houlbrooke D, McDowell R, Clothier B, Roygard J, Clark M. 2008c. Sources of Phosphorus in the Manawatu River and Implications for the One Plan. In Carbon and Nutrient Management in Agriculture. (Eds L.D. Currie and L.J. Yates). Occasional Report No. 21. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. Pp 515-524.

Parfitt RL, Mackay AD, Ross DJ, Budding PJ. 2009. Effects of soil fertility on leaching losses of N, P and C in hill country. N. Z. Journal of Agricultural Research 52: 69-80.

Parfitt RL, Schipper LA, Baisden WT, Elliott AH. 2006. Nitrogen inputs and outputs for New Zealand in 2001 at national and regional scales. Biogeochemistry 80: 71–88.

Parfitt RL, Schipper LA, Baisden WT, Mackay AH. 2008a. Nitrogen inputs and outputs for New Zealand at national and regional scales: past, present and future scenarios. Journal of the Royal Society of New Zealand 38: 71–87.

PCE. 2005. Growing for good. Intensive farming, sustainability and New Zealand's environment. www.pce.parliament.nz/work_programme/reports_by_subject/all_reports/land_use/growing_for_good

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APPENDIX 1

Parfitt R, Sutherland A, Wilde H, Dymond J, Ausseil A-G. 2004. GIS risk layers of phosphorus loss from soil to rivers for the Manawatu-Wanganui Region. Landcare Research Contract Report

Parfitt RL. 2006. Estimates of the loads of dissolved phosphate and nitrate in streams flowing into the Manawatu River between Dannevirke and Hopelands in late spring and early summer. Landcare Research Contract Report 0506/098

Clothier B, Mackay A, Carran A, Gray R, Parfitt R, Francis G. 2007. Farm Strategies for Contaminant Management. SLURI Contract Report to Horizons

Mackay A, Clothier B, Parfitt R. 2008. Defining nitrogen loss limits within a water management zone using the natural capital of soil. Appendix to Clothier et al. 2007 SLURI Contract Report to Horizons

Parfitt R, Dymond J, Ausseil A-G, Clothier B, Deurer M, Gillingham A, Gray R, Houlbrooke D, Mackay A, McDowell R. 2007. Best practice phosphorus losses from agricultural land. Landcare Research Contract Report: LC0708/012 Prepared for Horizons Regional Council. Envirolink medium advice grant HZLC41.

APPENDIX 2

Parfitt RL. 1978. Anion adsorption by soils and soil materials. Advances in Agronomy 30: 1–50.

Parfitt RL. 1989. Phosphate reactions with natural allophane, ferrihydrite and goethite. Journal of Soil Science 40: 359–369.

Parfitt RL, Russell JD, Farmer VC. 1976. Confirmation of the surface structures of goethite and phosphated goethite. Journal of the Chemical Society Faraday 72: 1082–1087.

Parfitt RL, Atkinson RJ, Smart RStC. 1975. The mechanism of phosphate fixation by iron oxides. Soil Science Society of America Proceedings. 39: 837–841.

GLOSSARY

Anion storage capacity	this is identical to P-retention
DRP	dissolved reactive phosphorus; this is dissolved inorganic phosphorus that is readily available to plants and periphyton; measured by filtering waters and analysing for phosphorus. It is mainly in the from of the $H_2PO_4^-$ ion.
DFP	dissolved filtered phosphorus; this is similar to dissolved reactive phosphorus.
DOP	dissolved organic phosphorus; this is measured by filtering waters and analysing them for total-P and then subtracting DRP. It may be in the form of H_2PO_4 bonded to carbon.
Farm dairy effluent	the wash-down water and waste from milking parlour and yard.
Olsen-P	soil test number in µg per ml that estimates the P that is available to plants and is available to be dissolved. The quick test units are approximate to mg per kg. The agronomic optimum depends on the number of stock units per ha on a farm, etc., but is usually about 18 for sheep and beef soils in hill country, and about 30 for dairy soils.
P-retention	a number that indicates how much DRP will be chemically sorbed and stored in a soil; it is more a guide to the amount of iron and aluminium in soils that will react with DRP; it is a % between 0 and 100.
PP	particulate P (ie. P in suspended sediment particles).
RPR	reactive phosphate rock fertiliser is a slow release phosphate fertiliser that needs acid soils and moisture to dissolve and release P for plants.
Reactive N	N that is biologically active as opposed to inert N gas that makes up 80% of the atmosphere.
Shape file	popular geospatial vector (points, lines, etc.) data format for geographic information systems software.
TP	total P in a water sample. This will include dissolved and particulate, or sediment P.