**Supplement of**

**Investigating Relationships Between Nitrogen Inputs and In-Stream Nitrogen Concentrations and Exports Across Catchments in Victoria, Australia**

**Olaleye Babatunde et al.**

***Correspondence to*:** Olaleye Babatunde(olaleyejohn.babatunde.1@unimelb.edu.au)

# **Table S1:** Summary of catchment characteristics, land use, and nitrogen (N) inputs and exports for each catchment (provided as an attached Excel file).

# **Table S2.** Catchment characteristics and data Sources.

|  |  |
| --- | --- |
| **Characteristics** | **Sources** |
| Land Area Covered by Forests (%) | Victorian Land Use Information System (2017) |
| Land Area Covered by Water (%) | Victorian Land Use Information System (2017) |
| Land Area for Intensive Uses (Urban) (%) | Victorian Land Use Information System (2017) |
| Land Area Used for Cropping (%) | Victorian Land Use Information System (2017) |
| Land Area Used for Dairy Farming (%) | Victorian Land Use Information System (2017) |
| Land Area Used for Horticulture (%) | Victorian Land Use Information System (2017) |
| Land Area Used for Mixed Farming and Grazing (%) | Victorian Land Use Information System (2017) |
| Land Area Used for Livestock (Non-Dairy (%)) | Victorian Land Use Information System (2017) |
| Runoff-Area Normalized Streamflow (mm yr⁻¹) | Derived from streamflow (Victorian Water Quality Monitoring Network) and Catchment area (Geofabric tool, BoM 2012) |
| Annual Temperature (°C) | Geoscience Australia (2011) |
| Catchment Slope (°) | Geoscience Australia (2011) |
| Mean Annual Rainfall (mm yr⁻¹) | Bureau of Meteorology, 30-year mean (1991–2020) |
| Runoff Pereniality (°) | Geoscience Australia (2011) |

# **Table S3**. Summary of datasets used to estimate nitrogen fertiliser inputs.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **s/n** | **Data Source** | **Spatial Coverage** | **Temporal Coverage** | **Data Applied in the Study** | **Reference URL** |
| 1 | Australia's National Statistical Agency (ABS) | 10 CMA in Victoria | Two years (2016–2017 and 2018–2019) | Fertiliser weight` (t) and area fertilised (ha) for various land uses. | <https://www.abs.gov.au/statistics/industry/agriculture/land-management-and-farming-australia/latest-release#data-downloads> |
| 2 | Bureau of Meteorology | Whole of Victoria | 30-year mean annual rainfall (1991–2020) | Mean Annual rainfall (MAR) (mm/year) used in fertiliser-rainfall relationship. | <http://www.bom.gov.au/climate/maps/averages/rainfall/?period=an&region=vc> |
| 3 | Victorian Land Use Information System | Whole of Victoria. | 2017 (Latest Classification) | Land use categories (e.g., dairy, cropping) based on ALUMv8.  Irrigated land parcel. | https://discover.data.vic.gov.au/dataset/victorian-land-use-information-system-2016-2017 |
| 4 | Australia's National Statistical Agency (ABS) | 10 CMA in Victoria | Two years (2016–2017 and 2018–2019) | Irrigation water (mm) applied to irrigated land use specifically Dairy and Cropping. | https://www.abs.gov.au/statistics/industry/agriculture/water-use-australian-farms |
| 5 | Dairy  and Livestock  Monitoring  Program | Selected  Farms  in Northern  Victoria,  Southwest  Victoria, and  Gippsland. | Dairy: Two years (2016–2017, 2018–2019)  Livestock: (2018–2019, 2019–2020, 2020–2021, 2021–2022) | Proportion of nitrogen (N) applied to dairy and livestock in various regions. | https://www.dairyaust  ralia.com.au/industry  -reports/dairy-farm-  monitor-  project/dairy-farm-  monitor-project---vic  https://agriculture.vic  . gov.au/about/agricult  ure-in-  victoria/livestock-  farm-monitor- project#h2-3 |

# **Table S4.** Average fertiliser nitrogen (N) input at the Catchment Management Authority (CMA) level. Data sources are provided in Supplement Table S3.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Catchment Management Authority (CMA) | Area (km²) | Average N Input Grazing (kg ha⁻) (2016-17 and 2018-19) **ABS** | Average N Input (kg ha⁻) (2016-17 and 2018-19) kg/ha **Dairy Monitoring** | Average N Input (kg ha⁻) (2019-20 - 2022-23) kg/ha **Livestock Monitoring** | Proportion of N Input Livestock to **Dairy (%) Monitoring** | N Input Dairy (2016-17 and 2018-19) kg ha⁻Adjusted | N Input Livestock (2016-17 and 2018-19) kg ha⁻Adjusted | Average Cropping Input (2016-17 and 2018-19) kg ha⁻ |
| Goulburn Broken | 24,060 | 152 | 115 | 7 | 6 | 143 | 9 | 236 |
| Mallee | 39,324 | 72 | 115 | 7 | 6 | 68 | 4 | 99 |
| North Central | 29,653 | 121 | 115 | 7 | 6 | 114 | 7 | 118 |
| Northeast | 19,799 | 181 | 115 | 7 | 6 | 170 | 11 | 182 |
| Wimmera | 23,449 | 103 | 115 | 7 | 6 | 97 | 6 | 96 |
| West Gippsland | 17,236 | 269 | 193 | 13 | 7 | 251 | 19 | 382 |
| East Gippsland | 21,047 | 146 | 193 | 13 | 7 | 136 | 10 | 267 |
| Corangamite | 13,371 | 157 | 149 | 11 | 7 | 146 | 11 | 213 |
| Glenelg Hopkins | 26,729 | 220 | 149 | 11 | 7 | 204 | 16 | 183 |
| Melbourne Water | 12,783 | 216 | 149 | 11 | 7 | 201 | 15 | 236 |

# **Table S5.** Mean rainfall for each land use and average irrigation water use at the Catchment Management Authority (CMA) level. Data sources are provided in Supplement Table S3.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Catchment Management Authority (CMA) | Area (km²) | Average Cropping Rainfall (mm) | Average Dairy Rainfall (mm) | Average Livestock (Non-Diary) Rainfall (mm) | Average Mixed Farming and Grazing Rainfall (mm) | Average Irrigation Water Use (mm) |
| Goulburn Broken | 24,060 | 461 | 448 | 509 | 651 | 321 |
| Mallee | 39,324 | 314 | 310 | 268 | 301 | 355 |
| North Central | 29,653 | 389 | 374 | 485 | 493 | 291 |
| Northeast | 19,799 | 797 | 963 | 842 | 755 | 295 |
| Wimmera | 23,449 | 393 | 420 | 514 | 465 | 188 |
| West Gippsland | 17,236 | 972 | 782 | 924 | 789 | 343 |
| East Gippsland | 21,047 | 684 | 759 | 718 | 706 | 181 |
| Corangamite | 13,371 | 535 | 797 | 653 | 645 | 217 |
| Glenelg Hopkins | 26,729 | 542 | 732 | 671 | 634 | 308 |
| Melbourne Water | 12,783 | 753 | 929 | 836 | 790 | 313 |

# **Table S6.** Nitrogen (N) inputs from biological nitrogen fixation and atmospheric deposition used in this study, along with their corresponding data sources.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Farming Type** | **Mean Value (kg ha⁻)** | **Sources** |
|  |  |  |  |
| Nitrogen Fixation | Crop (Legume and Non-Legume) | 43 | Mckee & Eyre., 2000 |
|  | Horticulture | 10 |
|  | Forest | 5 |
|  | Pasture (Improved and unimproved) | 12 |
|  |  |  |  |
| Atmospheric Deposition | Dairy | 5 | Adams et al., 2014 |

# **Table S7.** Estimated total nitrogen (N) inputs, measured total nitrogen (TN) concentrations, TN exports (obtained through WRTDS), calculated Nox: TN ratio, and estimated riverine export (percentage of inputs exported)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sites ID** | **Sites name** | **Total Nitrogen Input (kg ha⁻¹)** | **Total Nitrogen Concentration (mg L⁻¹)** | **Nox: TN** | **Riverine Export (kg ha⁻¹)** | **Riverine Export (% of Inputs)** |
| 221201 | CANN RIVER (WEST BRANCH) @ WEERAGUA | 10.4 | 0.4 | 0.3 | 1.1 | 10.6 |
| 221208 | WINGAN RIVER @ WINGAN INLET NATIONAL PARK | 10.4 | 0.4 | 0.1 | 1.4 | 13.3 |
| 221211 | COMBIENBAR RIVER @ COMBIENBAR | 12.3 | 0.5 | 0.5 | 1.9 | 15.6 |
| 221212 | BEMM RIVER @ PRINCES HIGHWAY | 11.0 | 0.5 | 0.5 | 2.5 | 22.5 |
| 222217 | RODGER RIVER @ JACKSONS CROSSING | 10.0 | 0.5 | 0.4 | 2.0 | 20.1 |
| 223202 | TAMBO RIVER @ SWIFTS CREEK | 19.1 | 0.3 | 0.1 | 0.8 | 4.2 |
| 223204 | NICHOLSON RIVER @ DEPTFORD | 10.0 | 0.4 | 0.3 | 1.0 | 9.6 |
| 223214 | TAMBO RIVER @ U/S OF SMITH CREEK | 20.8 | 0.4 | 0.1 | 0.3 | 1.5 |
| 224203 | MITCHELL RIVER @ GLENALADALE | 10.8 | 0.2 | 0.1 | 0.7 | 6.9 |
| 224206 | WONNANGATTA RIVER @ CROOKED RIVER | 10.1 | 0.1 | 0.1 | 0.6 | 6.4 |
| 224213 | DARGO RIVER @ LOWER DARGO ROAD | 11.6 | 0.2 | 0.2 | 1.0 | 8.6 |
| 225201 | AVON RIVER @ STRATFORD | 27.0 | 0.4 | 0.3 | 1.2 | 4.4 |
| 226226 | TANJIL RIVER @ TANJIL JUNCTION | 12.2 | 0.4 | 0.5 | 2.7 | 22.3 |
| 227200 | TARRA RIVER @ YARRAM | 62.3 | 1.1 | 0.5 | 4.2 | 6.7 |
| 227211 | AGNES RIVER @ TOORA | 47.7 | 1.4 | 0.4 | 7.4 | 15.5 |
| 233214 | BARWON RIVER EAST BRANCH @ FORREST | 10.3 | 0.3 | 0.3 | 2.7 | 25.9 |
| 233218 | BARWON RIVER @ INVERLEIGH | 60.4 | 1.0 | 0.1 | 0.9 | 1.4 |
| 233224 | BARWON RIVER @ RICKETTS MARSH | 66.5 | 0.8 | 0.1 | 1.5 | 2.2 |
| 234203 | PIRRON YALLOCK CREEK @ PIRRON YALLOCK (ABOVE H'WY BR.) | 119.8 | 2.4 | 0.1 | 3.2 | 2.7 |
| 235203 | CURDIES RIVER @ CURDIE | 140.3 | 1.8 | 0.2 | 5.1 | 3.6 |
| 235211 | KENNEDYS CREEK @ KENNEDYS CREEK | 103.7 | 1.7 | 0.3 | 4.5 | 4.3 |
| 235224 | GELLIBRAND RIVER @ BURRUPA | 69.0 | 0.9 | 0.3 | 3.4 | 4.9 |
| 235227 | GELLIBRAND RIVER @ BUNKERS HILL | 30.0 | 0.6 | 0.4 | 3.0 | 10.0 |
| 235234 | LOVE CREEK @ GELLIBRAND | 47.1 | 0.9 | 0.2 | 1.4 | 3.0 |
| 235237 | SCOTTS CREEK @ CURDIE (DIGNEYS BRIDGE) | 154.1 | 2.4 | 0.2 | 8.7 | 5.7 |
| 237200 | MOYNE RIVER @ TOOLONG | 67.6 | 1.1 | 0.1 | 2.0 | 3.0 |
| 237207 | SURRY RIVER @ HEATHMERE | 39.2 | 0.5 | 0.1 | 1.2 | 3.2 |
| 238202 | GLENELG RIVER @ SANDFORD | 34.7 | 1.2 | 0.1 | 0.7 | 2.1 |
| 238206 | GLENELG RIVER @ DARTMOOR | 33.8 | 1.5 | 0.4 | 0.7 | 2.1 |
| 238223 | WANDO RIVER @ WANDO VALE | 33.4 | 1.1 | 0.1 | 1.5 | 4.6 |
| 238228 | WANNON RIVER @ HENTY | 38.1 | 1.3 | 0.1 | 0.9 | 2.3 |
| 238231 | GLENELG RIVER @ BIG CORD | 10.0 | 0.3 | 0.0 | 0.4 | 4.2 |
| 401203 | MITTA MITTA RIVER @ HINNOMUNJIE | 20.0 | 0.2 | 0.1 | 0.6 | 3.0 |
| 401204 | MITTA MITTA RIVER @ TALLANDOON | 19.6 | 0.3 | 0.3 | 0.6 | 2.9 |
| 401211 | MITTA MITTA RIVER @ COLEMANS | 18.5 | 0.2 | 0.2 | 0.4 | 2.4 |
| 401212 | NARIEL CREEK @ UPPER NARIEL | 10.0 | 0.1 | 0.2 | 0.8 | 7.7 |
| 401215 | MORASS CREEK @ UPLANDS | 22.1 | 0.8 | 0.0 | 0.6 | 2.7 |
| 401216 | BIG RIVER @ JOKERS CREEK | 10.8 | 0.1 | 0.1 | 1.0 | 8.9 |
| 401226 | VICTORIA RIVER @ VICTORIA FALLS | 20.4 | 0.3 | 0.1 | 0.6 | 2.9 |
| 402203 | KIEWA RIVER @ MONGANS BRIDGE | 20.1 | 0.2 | 0.3 | 2.4 | 12.1 |
| 402205 | KIEWA RIVER @ BANDIANA | 37.6 | 0.3 | 0.2 | 1.5 | 4.0 |
| 402222 | KIEWA RIVER @ KIEWA (MAINSTREAM) | 41.8 | 0.4 | 0.2 | 2.2 | 5.2 |
| 402223 | KIEWA RIVER WEST BRANCH @ U/S OF OFFTAKE | 10.0 | 0.1 | 0.2 | 1.6 | 15.5 |
| 403205 | OVENS RIVER @ BRIGHT | 15.0 | 0.2 | 0.3 | 1.1 | 7.2 |
| 403210 | OVENS RIVER @ MYRTLEFORD | 17.7 | 0.2 | 0.4 | 1.1 | 6.5 |
| 403213 | FIFTEEN MILE CREEK @ GRETA SOUTH | 45.0 | 0.4 | 0.3 | 1.3 | 2.8 |
| 403217 | ROSE RIVER @ MATONG NORTH | 28.0 | 0.3 | 0.4 | 1.1 | 3.8 |
| 403223 | KING RIVER @ DOCKER ROAD BRIDGE | 46.1 | 0.3 | 0.3 | 1.4 | 3.1 |
| 403230 | OVENS RIVER @ ROCKY POINT | 18.4 | 0.3 | 0.4 | 1.2 | 6.7 |
| 403241 | OVENS RIVER @ PEECHELBA | 37.7 | 0.4 | 0.3 | 1.2 | 3.3 |
| 403244 | OVENS RIVER @ HARRIETVILLE | 10.0 | 0.1 | 0.3 | 0.8 | 7.6 |
| 404207 | HOLLAND CREEK @ KELFEERA | 34.5 | 0.7 | 0.2 | 1.5 | 4.4 |
| 405203 | GOULBURN RIVER @ EILDON | 28.0 | 0.3 | 0.4 | 0.8 | 2.8 |
| 405205 | MURRINDINDI RIVER @ MURRINDINDI ABOVE COLWELLS | 10.0 | 0.5 | 0.4 | 2.0 | 20.5 |
| 405209 | ACHERON RIVER @ TAGGERTY | 28.5 | 0.4 | 0.4 | 1.9 | 6.6 |
| 405219 | GOULBURN RIVER @ DOHERTYS | 10.0 | 0.2 | 0.3 | 0.9 | 9.2 |
| 405251 | BRANKEET CREEK @ ANCONA | 31.6 | 0.8 | 0.3 | 0.9 | 2.9 |
| 405264 | BIG RIVER @ D/S OF FRENCHMAN CREEK JUNCTION | 10.1 | 0.3 | 0.4 | 1.8 | 18.2 |
| 415207 | WIMMERA RIVER @ EVERSLEY | 36.7 | 1.1 | 0.0 | 0.5 | 1.4 |

# **Table S8**. Trend analysis of total nitrogen flux (kg ha⁻¹ yr⁻¹) for high export sites (S = significant (*p* ≤ 0.05); NS = not significant (*p* > 0.05)).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Site ID** | **Sites Names** | **Slope** | **Intercept** | **R²** | ***P-*value** | **Significance** |
| 235237 | Scotts Creek @ Curdie | 0.002 | -4.09 | 0.42 | 0.03 | S |
| 227211 | Agnes River @ Toora | 0.001 | -2.05 | 0.15 | 0.23 | NS |
| 235203 | Curdies River @ Curdie | 0.001 | -2.79 | 0.50 | 0.02 | S |
| 235211 | Kennedys Creek @ Kennedy | 0.001 | -1.93 | 0.50 | 0.01 | S |
| 227200 | Tarra River @ Yarram | 0.000 | -0.93 | 0.02 | 0.72 | NS |
| 235224 | Gellibrand River @ Burrupa | 0.000 | -0.62 | 0.19 | 0.18 | NS |
| 234203 | Pirron Yallock Creek | 0.001 | -1.57 | 0.38 | 0.04 | S |
| 235227 | Gellibrand River @ Bunker | 0.000 | -0.03 | 0.00 | 0.95 | NS |
| 226226 | Tanjil River @ Tanjil Junction | 0.000 | -0.97 | 0.10 | 0.36 | NS |
| 233214 | Barwon River East Branch @ Forrest. | 0.000 | -0.48 | 0.03 | 0.59 | NS |
| 221212 | Bemm River @ Prince Highway | 0.000 | -0.80 | 0.06 | 0.47 | NS |
|  |  |  |  |  |  |  |

# **Table S9.** Correlation between land use and Nox: TN ratio for high (>2.5 kg ha⁻¹ yr⁻¹), low (<2.5 kg ha⁻¹ yr⁻¹) and all TN export catchments. S = significant (*p* ≤ 0.05); NS = not significant (*p* > 0.05).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **TN Export Level** | **Land Use** | **Nox: TN Correlation** | ***p*-value** | **Significance** | **Stream N Speciation** |
|  |  |  |  |  |  |
| **> 2.5 (kg ha⁻¹ yr⁻¹)** **(High Export Sites)** | Forests (%) | 0.68 | 0.032 | S | Nitrate (NOx) |
| Dairy (%) | -0.73 | 0.016 | S | Organic N/Ammonia |
| Horticulture (%) | 0.22 | 0.539 | NS | Nitrate (NOx) |
| Mixed Farming and Grazing (%) | -0.29 | 0.423 | NS | Organic N/Ammonia |
| Livestock (Non-Dairy (%)) | -0.47 | 0.174 | NS | Organic N/Ammonia |
|  |  |  |  |  |  |
| **<** 2.5 (kg ha⁻¹ yr⁻¹) **(Low Export Sites)** | Forests (%) | 0.425 | 0.002 | S | Nitrate (NOx) |
| Cropping (%) | -0.14 | 0.333 | NS | Organic N/Ammonia |
| Dairy (%) | -0.187 | 0.194 | NS | Organic N/Ammonia |
| Horticulture (%) | 0.097 | 0.503 | NS | Nitrate (NOx) |
| Mixed Farming and Grazing (%) | -0.283 | 0.046 | S | Organic N/Ammonia |
| Livestock (Non-Dairy (%)) | -0.387 | 0.005 | S | Organic N/Ammonia |
|  |  |  |  |  |  |
| **All Export Sites** | Forests (%) | 0.32 | 0.01 | S | Nitrate (NOx) |
| Dairy (%) | -0.01 | 0.95 | NS | Organic N/Ammonia |
| Cropping (%) | -0.16 | 0.22 | NS | Organic N/Ammonia |
| Horticulture (%) | 0.04 | 0.79 | NS | Nitrate (NOx) |
| Mixed Farming and Grazing (%) | -0.24 | 0.07 | NS | Organic N/Ammonia |
| Non-Dairy (%) | -0.42 | 0.00 | S | Organic N/Ammonia |

# A graph with different colored lines AI-generated content may be incorrect.

# **Figure S1.** Trend of nitrogen application to dairy farms across different regions in Victoria.

A graph with different colored lines

AI-generated content may be incorrect.

# **Figure S2.** Trend of nitrogen application to Livestock (Non-Dairy) farms across different regions in Victoria.

A graph with red dots

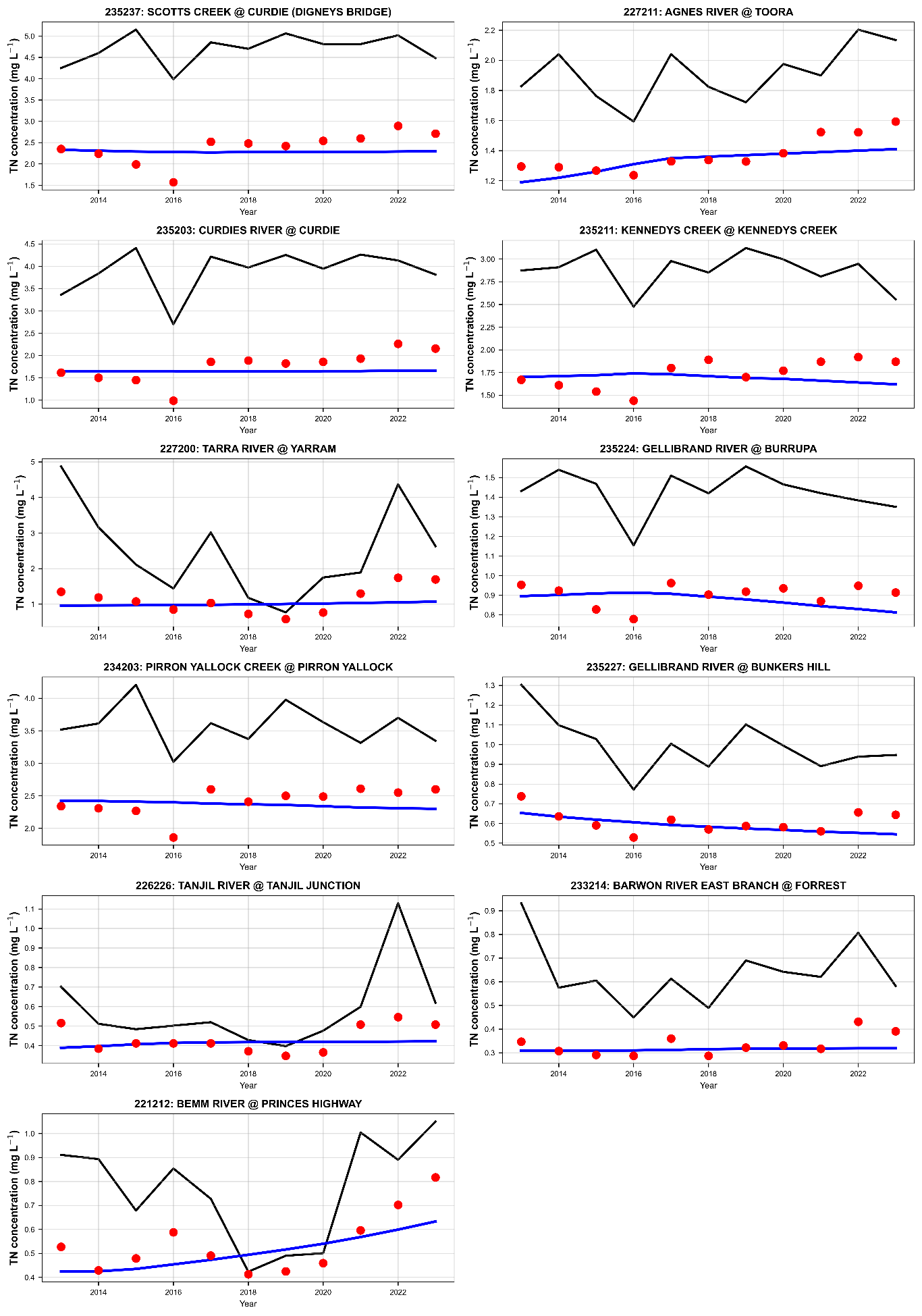
AI-generated content may be incorrect.

# **Figure S3**. Relationship between total nitrogen (N) inputs and (a) fertiliser additive land use (%), (b) dairy, and (c) forests (%).

A graph of red and grey bars

AI-generated content may be incorrect.

# **Figure S4:** Percentage change in total nitrogen (TN) export at high export sites.



# **Figure S5:** Flow-normalized concentrations are shown as blue lines, annual values as red dots, and flow-weighted concentrations as black lines for high export sites.

A graph of different colored bars

AI-generated content may be incorrect.

# **Figure S6:** Comparison of the coefficient of variation (CV) across high export sites.

A graph of different sizes and shapes

AI-generated content may be incorrect.

# **Figure S7.** Land use distributions across high export sites.