# **Supplementary Information**

Table 1 Data availability for the BBN nodes. Variables pertaining to the calculated loads and those nodes parametrized as logical Conditional Probability Tables are not reported here but specified for each catchment.

|  |  |  |
| --- | --- | --- |
| **Node or variable name** | **Data availability** | **Model structure implementing the variable** |
| Mean total monthly Q (discharge) [m3] | Catchment specific | All model structures |
| Mean total monthly Surface Flow (surface runoff) [m3] | Catchment specific | All model structures |
| Mean total monthly Sub-surface Stormflow (subsurface runoff) [m3] | Catchment specific | All model structures |
| Mean total monthly Baseflow [m3] | Catchment specific | All model structures |
| Land use | Catchment specific | All model structures |
| Buffers | Not catchment specific | All model structures |
| Buffer effectiveness for Particulate P (PP) and suspended sediments (SS) | Not catchment specific | All model structures |
| Buffer effectiveness for Total Dissolved P (TDP) | Not catchment specific | All model structures |
| Morgan P | Catchment specific | All model structures |
| Monthly Turbidity [NTU month-1] | Catchment specific | All model structures |
| Monthly Suspended Sediment concentration [mg l-1 month-1] | Catchment specific | All model structures |
| Water Extractable P (WEP) [mg l-1] | Catchment specific | All model structures |
| Sediment Water Soluble P [mg kg-1] | Only available for Ballycanew and Castledockrell | All model structures |
| Predicted Dissolved P Concentration [mg l-1] | Not catchment specific | All model structures |
| P concentration per tank [mg l-1] | Not catchment specific | All model structures |
| Direct discharge | Not catchment specific | All model structures |
| Degree of Phosphorus Saturation (DPS) [%] | Catchment specific | All model structures |
| Soil risk factor | Catchment specific | All model structures |
| Connectivity rescaled (Hydrologically Sensitive Areas, HSA) | Catchment specific | All model structures |
| Farmyard size area [m2] | Catchment specific | All model structures |
| Farmyard P concentration [mg l-1] | Catchment specific | All model structures |
| Number of Septic Tanks | Only available for Ballycanew | All model structures |
| Septic Tank Treatment | Only available for Ballycanew and Castledockrell | Structure 1 only |
| Groundwater Dissolved P Concentration [mg l-1] | Implemented for Timoleague and Castledockrell | Structure 4 and 5 (Timoleague and Castledockrell), Structure 6 (Castledockrell) |
| In-stream winter P removal | From expert elicitation, catchment specific | Structure 2 (Ballycanew and Dunleer), Structure 5 (Timoleague and Castledockrell), Structure 6 (Castledockrell) |
| In-stream spring P removal | From expert elicitation, catchment specific |
| In-stream summer P removal | From expert elicitation, catchment specific |
| In-stream autumn P removal | From expert elicitation, catchment specific |
| Sewage Treatment Works (STWs) P concentration [mg l-1] | Castledockrell only | Structure 6 (Castledockrell) |

### **Timoleague model specifications**

Table 2 Timoleague model structure (filename Ptool\_pointanddiffuse\_v7\_Timoleague.xdsl)

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable (symbol) [unit]** | **States** | **Discretisation boundaries/ Probability** | **Description** |
| **Hydrology sub-model (Drivers)** | | | |
| Month | Each month |  | Calculated as No. days in the month/ 365 |
| Calculated variables | | | |
| Mean total monthly Q (discharge) [m3] | Very Low | 0-202577 | Bootstrapped from daily total discharge observations (2009-2016) to obtain a Lognormal (µ; ơ) discharge distribution with base e for each month. Each month’s parameters are shown in the table. Discretization of states is based on percentiles calculated from the average monthly observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile).   |  |  |  | | --- | --- | --- | |  | **µ** | **ơ** | | **January** | 13.8 | 0.1 | | **February** | 13.8 | 0.1 | | **March** | 12.8 | 0.1 | | **April** | 12.6 | 0.1 | | **May** | 12.2 | 0.1 | | **June** | 12.2 | 0.2 | | **July** | 12.2 | 0.3 | | **August** | 12.1 | 0.4 | | **September** | 12.1 | 0.4 | | **October** | 12.4 | 0.2 | | **November** | 13.4 | 0.1 | | **December** | 13.6 | 0.2 | |
| Low | 202577-277340 |
| Medium | 277340-603944 |
| High | 603944-934347 |
| Very High | 934347-990000 |
| Mean total monthly Surface Flow (surface runoff) [m3] | Very Low | 0-16207 | Calculated as a portion of mean monthly runoff (8%), via hydrograph separation method described in Mellander et al., (2012). Discretization of states is based on percentiles calculated from observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). |
| Low | 16207-22188 |
| Medium | 22188-48316 |
| High | 48316-74748 |
| Very High | 74748-79070 |
| Mean total monthly Sub-surface Stormflow (subsurface runoff) [m3] | Very Low | 0-8104 | Calculated as a portion of mean monthly runoff (4%), via hydrograph separation method described in Mellander et al., (2012). Discretization of states is based on percentiles calculated from observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). |
| Low | 8104-11094 |
| Medium | 11094-24158 |
| High | 24158-37374 |
| Very High | 37374-39540 |
| Mean total monthly Baseflow [m3] | Very Low | 0-178268 | Calculated as a portion of mean monthly runoff (88%), via hydrograph separation method described in Mellander et al., (2012). Discretization of states is based on percentiles calculated from observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). |
| Low | 178268-244060 |
| Medium | 244060-531471 |
| High | 531471-822225 |
| Very High | 822225-869748 |

|  |  |  |  |
| --- | --- | --- | --- |
| **Management (Drivers)** | | | |
| Land use | Arable | 0.04 | As reported by Teagasc - Agriculture and Food Development Authority, (2018). |
| Grassland | 0.89 |
| Seminatural | 0.07 |
| Buffers | |  |  |  |  | | --- | --- | --- | --- | | **Land use** | **Arable** | **Grassland** | **Seminatural** | | **2 m** | 0.98 | 0.01 | 1.01\*10-6 | | **>2 m** | 0.019 | 0.01 | 1.01\*10-6 | | **none** | 0.001 | 0.08 | 0.999 | | | Buffer strips are defined as being 2 m in width, more than 2 m in width, or absent. Probabilities of having either type of buffer according to land use were agreed upon with one of the ACP advisors (expert) during consultation. |
| **Calculated variables** | | | |
| Buffer effectiveness for Particulate P (PP) and suspended sediments (SS) | Very Low | 0-0.2 | Dependent on the variable Buffers. For 2 m buffers, effectiveness is defined as Beta (α=2.9; β=4.5); for >2 m buffers it is defined as Beta (α=1.44; β=0.789); for no buffers, effectiveness is equal to 0. The distributions were fitted to the dataset published in Stutter et al., (2021), where negative retention data was deleted from the analysis. |
| Low | 0.2-0.4 |
| Medium | 0.4-0.6 |
| High | 0.6-0.8 |
| Very High | 0.8-1 |
| Buffer effectiveness for Total Dissolved P (TDP) | Very Low | 0-0.2 | Dependent on the variable Buffers. For Buffers 0-2 m, Buffer effectiveness is defined as Beta (α=1.8; β=2.7), for >2 m buffers it is defined as Beta (α=1; β=0.8); for no buffers, effectiveness is equal to 0. The distributions were fitted to the dataset published in Stutter et al., (2021), where negative retention data was deleted from the analysis. |
| Low | 0.2-0.4 |
| Medium | 0.4-0.6 |
| High | 0.6-0.8 |
| Very High | 0.8-1.0 |
| **Soil erosion and soil P sub-model** | | | |
| Morgan P | |  |  |  |  | | --- | --- | --- | --- | |  | **Arable** | **Grassland** | **Seminatural** | | **Morgan1** | 0.163 | 0.163 | 0 | | **Morgan2** | 0.442 | 0.225 | 0.6 | | **Morgan3** | 0.289 | 0.42 | 0.3 | | **Morgan4** | 0.106 | 0.192 | 0.1 | | | Based on land use, proportions of land for each level and in each land use category were calculated based on the soil survey carried out in 2013 in the catchment. Where the Morgan P index was unknown, that proportion of land was assigned to the dominant index category. For the interpretation of the Soil Morgan P Index, the reader is referred to Regan et al., (2012). |
| **Calculated variables** | | | |
| Monthly Turbidity [NTU month-1] | Very Very Low | 0-500 | Bootstrapped from daily average turbidity observations (2009-2016) to obtain a Lognormal (µ; ơ) turbidity distribution with base e for each month. Each month’s parameters are shown in the table. Discretization of states is based on percentiles calculated from the average monthly observations.   |  |  |  | | --- | --- | --- | |  | **µ** | **ơ** | | **January** | 5.42 | 0.17 | | **February** | 5.23 | 0.14 | | **March** | 5.07 | 0.15 | | **April** | 4.92 | 0.13 | | **May** | 4.75 | 0.17 | | **June** | 4.58 | 0.14 | | **July** | 4.32 | 0.14 | | **August** | 4.29 | 0.18 | | **September** | 3.80 | 0.16 | | **October** | 4.31 | 0.22 | | **November** | 4.71 | 0.20 | | **December** | 5.48 | 0.30 | |
| Very Low | 500-664 |
| Low | 664-946 |
| Medium | 946-1115 |
| High | 1115-2060 |
| Very High | 2060-2680 |
| Monthly Suspended Sediment concentration [mg l-1 month-1] | Very Very Low | 0-52 | Calculated as: a \* Monthly Turbidity [NTU month-1] b, where a= 0.6636, and b= 1.1045, as described in Sherriff et al., (2015). Discretization of states is based on percentiles calculated from the average monthly calculated observations. |
| Very Low | 52-73 |
| Low | 73-104 |
| Medium | 104-124 |
| High | 124-268 |
| Very High | 268-380 |
| Water Extractable P (WEP) [mg l-1] | Low | 0-3 | Based on variable “Morgan P levels” and “land use” (data from 2013) it is calculated with the equations available in (Thomas et al., 2016b): for Grassland, WEP=0.57 \* Morgan P + 0.29, for Arable: WEP= 0.36 \* Morgan P + 0.89, where Morgan P is defined as a Uniform distribution with the following parameters:   |  |  |  | | --- | --- | --- | | **Morgan P Index** | **Grassland** | **Arable** | | **Index 1** | a=0; b=3 | a=0; b=3 | | **Index 2** | a=3.1; b=5 | a=3.1; b=6 | | **Index 3** | a=5.1; b=8 | a=6.1; b=10 | | **Index 4** | a=8.1; b=30 | a=10.1; b=30 |   For the Seminatural Land use, WEP was assumed constant to 0.001. Discretization is based on Morgan P discrete levels. |
| Medium | 3-5 |
| High | 5-8 |
| Very High | 8-15 |
| Sediment Water Soluble P [mg kg-1] | Very Low | 0-0.0995 | Defined as a Lognormal distribution (µ=-0.9, ơ=1), fitted with the *SHELF* R package (version 1.8.0, Oakley, 2020) to observed Water Extractable P in the catchment sediments (Shore et al., 2016). Discretization of states is based on percentiles calculated from the observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). Based on Ballycanew data. |
| Low | 0.0995-0.2100 |
| Medium | 0.2100-0.3550 |
| High | 0.3550-0.9100 |
| Very High | 0.9100-8 |
| Predicted Dissolved P Concentration [mg l-1] | Very Very Low | 0-0.1 | Dependant on Water Extractable P, it is defined with the linear model: Predicted Dissolved P = β(WEP)+α, where β =0.08, α =0.158, derived from (Thomas et al., 2016b). This equation is derived from data gathered during the closed period only, that is, when farmers are forbidden from spreading fertilizer. An assumption is made that when the linear model yields a negative value, that is resampled as a zero. Water Extractable P is considered a good in-stream TRP/ TDP predictor in the ACP catchments by the experts, however careful consideration is needed when choosing a soil P test in a different setting. |
| Very Low | 0.1-0.5 |
| Low | 0.5-1.5 |
| Medium | 1.5-5 |
| High | 5-8 |
| Very High | 8-15 |
| Groundwater Dissolved P Concentration [mg l-1] | Very Very Low | 0-0.1 | Derived from monthly piezometer data of TDP concentrations (2009-2016) monitored in multi-level wells described in Mellander et al., (2016).   |  |  |  | | --- | --- | --- | |  | **µ** | **ơ** | | **January** | -3.00 | 0.16 | | **February** | -2.70 | 0.12 | | **March** | -2.60 | 0.12 | | **April** | -2.90 | 0.10 | | **May** | -2.45 | 0.10 | | **June** | -2.67 | 0.06 | | **July** | -2.69 | 0.06 | | **August** | -2.22 | 0.21 | | **September** | -2.62 | 0.07 | | **October** | -2.74 | 0.17 | | **November** | -2.70 | 0.20 | | **December** | -3.00 | 0.20 | |
| Very Low | 0.1-0.5 |
| Low | 0.5-1.5 |
| Medium | 1.5-5 |
| High | 5-8 |
| Very High | 8-15 |
| Sub-surface Dissolved P load  [kg month-1] | Low | 0-3 | Calculated as the product of Predicted Dissolved P concentration and Subsurface Storm-flow. |
| High | 3-200 |
| Baseflow Dissolved P load  [kg month-1] | Low | 0-3 | Calculated as the product of Predicted Dissolved P concentration and Baseflow. |
| High | 3-200 |
| Modified Dissolved P load  [kg month-1] | Low | 0-3 | Based on “Buffer effectiveness for Total Dissolved P”, for effective buffers, modified Dissolved P load= Sub-surface Dissolved P load \*(1-Buffer effectiveness for TDP). Based on expert recommendation. |
| High | 3-200 |
| Monthly Sediment P load  [kg month-1] | Low | 0-3 | Calculated as the product of Sediment Water Soluble P [mg kg-1], Monthly Suspended Sediment concentration [mg l-1 month-1] , and Mean total monthly surface flow [m3] . |
| High | 3-200 |
| Modified Sediment P load  [kg month-1] | Low | 0-3 | Based on “Buffer effectiveness for Suspended Sediments and Particulate P”, for effective buffers, Modified Sediment P load= Monthly Sediment P load [kg month-1]\*(1-Buffer effectiveness for SS and PP). Based on expert recommendation. |
| High | 3-200 |
| **Septic Tanks (ST) sub-model (Point P sources)** | | | |
| P concentration per tank  [mg l-1] | Absent (to represent 0 STs) | 0-1\*10-8 | P concentration is dependent on the treatment type. If the treatment is unknown, the concentration is defined as a Lognormal distribution (µ=2.9, ơ =1.25), based on a literature review of data available for Ireland (Environmental Protection Agency Ireland (EPA), 2003, 2000; Gill et al., 2005, 2007) (n=8). Fitting was done with R package *fitdistrplus* (version 1.1-8, Delignette-Muller et al., 2020). Otherwise, for primary and secondary treatment concentration is defined as Truncated Normal distribution (µ=10; ơ=1), and (µ=5; ơ=0.5) respectively, as described in Glendell et al., (2021) and derived from SEPA guidelines (Brownlie et al., 2014). All tanks are assumed to be maintained. Discretization was also based on the literature review. |
| Low | 1\*10-8-1 |
| Medium | 1-18 |
| High | 18-35 |
| Very High | 35-100 |
| **Management related variables** | | | |
| Direct discharge | Present | 0.16 | Probabilities are derived from the report by the Environmental Protection Agency Ireland (EPA, 2015). |
| Absent | 0.84 |
| **Connectivity related variables** | | | |
| Degree of Phosphorus Saturation (DPS) [%] | Very Low\_0-20 | 0.674 | Discretization is equal to the 20th, 40th, 60th, and 80th quantiles, however 0< DPS <60 in this catchment. Probabilities were calculated from available spatial data (Wall et al., 2012). |
| Medium\_20-40 | 0.324 |
| High\_40-60 | 0.002 |
| Soil risk factor [adimensional] | Low | 0.766 | An indicator to describe the combined risk of effluent leaching to the groundwater table with the risk of the effluent being transported with surface runoff. This approach is a simplification of the one adopted in Glendell et al., (2021). The risk factor was obtained by overlaying the soil series (Thomas et al., 2016a) with information on the position of the groundwater table (0- 2 m below ground or more than 2 m below ground). Because little is known regarding the septic tanks in the catchment (i.e. age, type of treatment, maintenance), and the groundwater table position (few datapoints within the catchment) experts recommended a precautionary principle. This meant that the the class at most risk of effluent transfer was applied when data was unavailable. The table to the left represents a synthesis of the classification approach. Probabilities are based on land cover proportion. |
| Medium | 0.118 |
| High | 0 |
| Very High | 0.116 |
| |  |  |  | | --- | --- | --- | |  | **Groundwater Table Position** | | | **Soil Series** | **0-2 m below surface** | **>2 m below surface** | | **Brown earths** | High Risk | Moderate Risk | | **Gleys** | Very High Risk | Very High Risk | | |
| Leachfield removal | |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Soil risk factor** | **DPS** | **Low** | **Medium** | **High** | | **Low** | **Very Low** | 0 | 0.3 | 0.7 | | **Medium** | 0 | 0.7 | 0.3 | | **High** | 0.3 | 0.7 | 0 | | **Medium** | **Very Low** | 0 | 0.5 | 0.5 | | **Medium** | 0 | 1 | 0 | | **High** | 0.5 | 0.5 | 0 | | **High** | **Very Low** | 0 | 0.7 | 0.3 | | **Medium** | 0.3 | 0.7 | 0 | | **High** | 0.7 | 0.3 | 0 | | **Very High** | **Very Low** | 0 | 0.5 | 0.5 | | **Medium** | 0.5 | 0.5 | 0 | | **High** | 1 | 0 | 0 | | | The node refers to P removal from septic drains. Conditional on P leaching risk from Degree of Phosphorus Saturation (DPS). The conditional probability table is a logical one. |
| Leachfield connectedness | |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **HSA rescaled** | **None** | | **Low** | | **Medium** | | **High** | | | **Direct discharge** | **pres** | **abs** | **pres** | **abs** | **pres** | **abs** | **pres** | **abs** | | **low** | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | | **medium** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | | **high** | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | | | Probabilities are conditional on the presence/absence of Direct ST discharge, and HSA (node: Connectivity rescaled HSA). Where Direct discharge is present, connectedness is assumed as ‘high’. Where Direct discharge is absent, the risk class of the HSA is assigned. |
| Septic Tank connectedness | |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **Leachfield removal** | **Low** | | | **Medium** | | | **High** | | | | | **Leachfield connectedness** | **Low** | **Medium** | **High** | **Low** | **Medium** | **High** | **Low** | **Medium** | **High** | | **Low** | 1.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 1.0 | 0.5 | 0.0 | | **Medium** | 0.0 | 1.0 | 0.0 | 0.0 | 1.0 | 0.5 | 0.0 | 0.5 | 1.0 | | **High** | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | | | Probabilities are conditional on Leachfield removal and Leachfield connectedness. Where Leachfield removal is ‘low’ or ‘High’, Leachfield connectedness remains unaltered. |
| Connectivity rescaled HSA [adimensional] | None\_0 | 0.09 | Data extracted from spatial layers of Hydrologically Sensitive Areas (HSAs) rescaled between 0 and 10 was provided by the Agricultural Catchments Programme (Thomas et al., 2016b). Discretization is also based on the spatial layers. |
| Low\_1-3 | 0.78 |
| Medium\_4-7 | 0.12 |
| High\_8-10 | 0.01 |
| **Calculated variables** | | | |
| Load per tank [kg month-1] | Absent | 0-1\*10-6 | Specified as the product of ST density [No ha-1] \* ST concentration [mg l-1] \* 120 [L] average daily water consumption per person \* 365/12 days in a month\* average No of persons per household 2.7/1\*106. Discretisation is based on interpolation to represent plausible probabilities for combination of extreme risk classes (eg. High+high=high, low+low=low). |
| Very Low | 1\*10-6-0.1 |
| Low | 0.1-0.5 |
| Medium | 0.5-1.0 |
| High | 1.0-2.0 |
| Very High | 2.0-30 |
| Total Realized load [T month-1] | Very Low | 0.0-0.1 | Calculated as the product of septic tank load and delivery factors (D) related to the connectedness of a septic tank, based on the median estimated fraction to be delivered in Table 13 of the report by Glendell et al., (2021) and the number of septic tanks present within catchment boundary (N): Realised load per tank [kg month-1] \* N \* D / 1000. In this case, N= 88. Discretisation based on interpolation to represent plausible probabilities for combination of extreme risk classes. |
| Low | 0.1-0.5 |
| Medium | 0.5-1.0 |
| High | 1.0-2.0 |
| Very High | 2.0-12 |
| |  |  |  | | --- | --- | --- | | **Septic tank connectedness** | **Delivery factor (D)** | **Reference** | | **Low** | 0.05 | “very low” category in Appendix A3, Glendell et al., (2021) | | **Medium** | 0.30 | “medium” category in Appendix A3, Glendell et al., (2021) | | **High** | 0.80 | “very high” category in Appendix A3, Glendell et al., (2021) | | |
| **Farmyards sub-model (Point P sources)** | | | |
| Farmyard size area [m2] | Very Low | 0-38 | Based on available farmyard survey, a distribution was fitted to farmyard area data: Lognormal (µ=-5.13; ơ=1.01). Discretization of states is based on percentiles calculated from the observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). |
| Low | 38-98 |
| Medium | 98-160 |
| High | 160-317 |
| Very High | 317-3100 |
| Farmyard P concentration [mg l-1] | Very Low | 0-0.01 | Using the *SHELF* R package (version 1.8.0, Oakley, 2020), a distribution was fitted to the data in Table 2 in Harrison et al., (2019): Lognormal (µ=-1.8; ơ=1.6 ). The best fit would have been the LogT distribution, however, that is not available for Genie, so we opted for Lognormal. Discretization is also based on the literature. For simplicity, here we have used SRP to mean TRP. |
| Low | 0.01-0.50 |
| Medium | 0.50-1.00 |
| High | 1.00-2.50 |
| Very High | 2.50-60 |
| Incidental losses per average yard  [kg month-1] | Very Low | 0-1\*10-9 | Based on average farmyard size, losses are calculated as Surface runoff [m3] / catchment area [m2]\* Farmyard size area [m2]\* Farmyard P concentration [mg l-1]/ 103. Catchment area is set at 758 ha. |
| Low | 1\*10-9-0.001 |
| Medium | 0.001-0.01 |
| High | 0.01-0.10 |
| Very High | 0.10-60 |
| Total incidental losses [T month-1] | Very Low | 0-1\*10-5 | Incidental losses per average yard [kg month-1] \* N, where N is the total number of yards present within the catchment boundary. In this case, N =97. |
| Low | 1e-05-0.007 |
| Medium | 0.007-0.070 |
| High | 0.07-0.700 |
| Very High | 0.700-10 |
| **Catchment outlet integration sub-model** | | | |
| Total catchment in-stream P load  [T month-1] | Low | 0-0.02 | Equal to the sum of Baseflow Dissolved P load [kg month-1], Modified Dissolved P load [kg month-1],  Modified Sediment P load [kg month-1], Total incidental losses [T month-1], and Total Realized load [T month-1], all converted to appropriate units. |
| Medium | 0.002-1 |
| High | 1-10 |
| (meteorological) Season |  |  | Based on the node “Month”. |
| In-stream winter P removal | Very Low | -1 to -0.5 | Defined as a Normal distribution (µ=0.12; ơ=0.1) derived from expert elicitation with the R package (version 1.8.0, Oakley, 2020). |
| Low | -0.5-0 |
| Medium | 0-0.5 |
| High | 0.5-1 |
| In-stream spring P removal | Very Low | 0-0.2 | Defined as a Normal distribution (µ=0.35; ơ=0.21) derived from expert elicitation with the R package (version 1.8.0, Oakley, 2020). |
| Low | 0.2-0.4 |
| Medium | 0.4-0.6 |
| High | 0.6-0.8 |
| In-stream summer P removal | Very Low | 0.1-0.3 | Defined as a Normal distribution (µ=0.43; ơ=012) derived from expert elicitation with the R package (version 1.8.0, Oakley, 2020). |
| Low | 0.3-0.45 |
| Medium | 0.45-0.6 |
| High | 0.6-0.8 |
| In-stream autumn P removal | Very Low | 0-0.2 | Defined as a Normal distribution (µ=0.25; ơ=0.07) derived from expert elicitation with the R package (version 1.8.0, Oakley, 2020). |
| Low | 0.2-0.4 |
| Medium | 0.4-0.5 |
| High | 0.5-0.65 |
| In-stream reduced P load [T month-1] | Moderate | 0-1 | Calculated as the product of Total catchment in-stream P load and the seasonal removal. |
| Bad | 1-10 |
| In-stream P concentration [mg l-1] | Good | 0-0.035 | Defined as the in-stream reduced P load [T] \* 109 / Mean total monthly Q (discharge) [m3] \* 1000, where mean monthly discharge is equal to the total catchment discharge measured at the outlet. |
| Bad | 0.035-5 |
| Environmental Quality Standard [TRP concentration mg l-1] | |  |  |  | | --- | --- | --- | | **TRP concentration** | **Good** | **Bad** | | **Good** | 1 | 0 | | **Bad** | 0 | 1 | | | Discretization of the variable “In-stream TRP concentration [mg l-1]”. For simplicity, in-stream TRP is here considered equal to in-stream Dissolved Reactive Phosphorus, as in previous studies the mean DRP accounted for 98–99% of the flow-weighted mean TRP (Shore et al., 2014). |

### **Castledockrell model specifications**

Table 3 Castledockrell model structure (filename Ptool\_pointanddiffuse\_v8\_Castledockrell)

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable (symbol) [unit]** | **States** | **Discretisation boundaries/ Probability** | **Description** |
| **Hydrology sub-model (Drivers)** | | | |
| Month | Each month |  | Calculated as No. days in the month/ 365 |
| Calculated variables | | | |
| Mean total monthly Q (discharge) [m3] | Very Low | 0-193630 | |  |  |  | | --- | --- | --- | |  | **µ** | **ơ** | | **January** | 13.9 | 0.11 | | **February** | 13.7 | 0.13 | | **March** | 12.9 | 0.11 | | **April** | 12.7 | 0.13 | | **May** | 12.2 | 0.09 | | **June** | 12.0 | 0.18 | | **July** | 11.7 | 0.21 | | **August** | 11.7 | 0.21 | | **September** | 11.7 | 0.22 | | **October** | 12.5 | 0.19 | | **November** | 13.8 | 0.19 | | **December** | 13.7 | 0.15 |   Bootstrapped from daily total discharge observations (2009-2016) to obtain a Lognormal (µ; ơ) discharge distribution with base e for each month. Each month’s parameters are shown in the table. Discretization of states is based on percentiles calculated from the average monthly observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). |
| Low | 193630-310530 |
| Medium | 310530-871120 |
| High | 871120-1080000 |
| Very High | 1080000-1200000 |
| Mean total monthly Surface Flow (surface runoff) [m3] | Very Low | 0-3873 | Calculated as a portion of mean monthly runoff (2%), via hydrograph separation method described in Mellander et al., (2012). Discretization of states is based on percentiles calculated from observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). |
| Low | 3873-6211 |
| Medium | 6211-17425 |
| High | 17425-21556 |
| Very High | 21556-24000 |
| Mean total monthly Sub-surface Stormflow (subsurface runoff) [m3] | Very Low | 0-3873 | Calculated as a portion of mean monthly runoff (2%), via hydrograph separation method described in Mellander et al., (2012). Discretization of states is based on percentiles calculated from observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). |
| Low | 3873-6211 |
| Medium | 6211-17425 |
| High | 17425-21556 |
| Very High | 21556-24000 |
| Mean total monthly Baseflow [m3] | Very Low | 0-186000 | Calculated as a portion of mean monthly runoff (96%), via hydrograph separation method described in Mellander et al., (2012). Discretization of states is based on percentiles calculated from observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). |
| Low | 186000-230000 |
| Medium | 230000-837000 |
| High | 837000-1035000 |
| Very High | 1035000-1107000 |

|  |  |  |  |
| --- | --- | --- | --- |
| **Management (Drivers)** | | | |
| Land use | Arable | 0.2 | As reported by Teagasc - Agriculture and Food Development Authority, (2018). |
| Grassland | 0.78 |
| Seminatural | 0.02 |
| Buffers | |  |  |  |  | | --- | --- | --- | --- | | **Land use** | **Arable** | **Grassland** | **Seminatural** | | **2 m** | 0.98 | 0.01 | 1.01\*10-6 | | **>2 m** | 0.019 | 0.01 | 1.01\*10-6 | | **none** | 0.001 | 0.08 | 0.999 | | | Buffer strips are defined as being 2 m in width, more than 2 m in width, or absent. Probabilities of having either type of buffer according to land use were agreed upon with one of the ACP advisors (expert) during consultation. |
| **Calculated variables** | | | |
| Buffer effectiveness for Particulate P (PP) and suspended sediments (SS) | Very Low | 0-0.2 | Dependent on the variable Buffers. For 2 m buffers, effectiveness is defined as Beta (α=2.9; β=4.5); for >2 m buffers it is defined as Beta (α=1.44; β=0.789); for no buffers, effectiveness is equal to 0. The distributions were fitted to the dataset published in Stutter et al., (2021), where negative retention data was deleted from the analysis. |
| Low | 0.2-0.4 |
| Medium | 0.4-0.6 |
| High | 0.6-0.8 |
| Very High | 0.8-1 |
| Buffer effectiveness for Total Dissolved P (TDP) | Very Low | 0-0.2 | Dependent on the variable Buffers. For Buffers 0-2 m, Buffer effectiveness is defined as Beta (α=1.8; β=2.7), for >2 m buffers it is defined as Beta (α=1; β=0.8); for no buffers, effectiveness is equal to 0. The distributions were fitted to the dataset published in Stutter et al., (2021), where negative retention data was deleted from the analysis. |
| Low | 0.2-0.4 |
| Medium | 0.4-0.6 |
| High | 0.6-0.8 |
| Very High | 0.8-1.0 |
| **Soil erosion and soil P sub-model** | | | |
| Morgan P | |  |  |  |  | | --- | --- | --- | --- | |  | **Arable** | **Grassland** | **Seminatural** | | **Morgan1** | 0.29 | 0.29 | 0 | | **Morgan2** | 0.41 | 0.34 | 0.6 | | **Morgan3** | 0.2 | 0.19 | 0.3 | | **Morgan4** | 0.09 | 0.18 | 0.1 | | | Based on land use, proportions of land for each level and in each land use category were calculated based on the soil survey carried out in 2013 in the catchment. Where the Morgan P index was unknown, that proportion of land was assigned to the dominant index category. For the interpretation of the Soil Morgan P Index, the reader is referred to Regan et al., (2012). |
| **Calculated variables** | | | |
| Monthly Turbidity [NTU month-1] | Very Very Low | 0-707 | Bootstrapped from daily average turbidity observations (2009-2016) to obtain a Lognormal (µ; ơ) turbidity distribution with base e for each month. Each month’s parameters are shown in the table. Discretization of states is based on percentiles calculated from the average monthly observations.   |  |  |  | | --- | --- | --- | |  | **µ** | **ơ** | | **January** | 5.7 | 0.19 | | **February** | 5.5 | 0.20 | | **March** | 4.9 | 0.15 | | **April** | 4.6 | 0.13 | | **May** | 4.4 | 0.13 | | **June** | 4.6 | 0.15 | | **July** | 4.5 | 0.13 | | **August** | 5.8 | 0.44 | | **September** | 4.5 | 0.13 | | **October** | 5.1 | 0.25 | | **November** | 5.7 | 0.33 | | **December** | 5.6 | 0.24 | |
| Very Low | 707-780 |
| Low | 780-1510 |
| Medium | 1510-2770 |
| High | 2770-5590 |
| Very High | 5590-8661 |
| Monthly Suspended Sediment concentration [mg l-1 month-1] | Very Very Low | 0-50 | Calculated as: a \* Monthly Turbidity [NTU month-1] b, where a= 0.4119, and b= 1.1456, as described in Sherriff et al., (2015). Discretization of states is based on percentiles calculated from the average monthly calculated observations. |
| Very Low | 50-60 |
| Low | 60-130 |
| Medium | 130-262 |
| High | 262-640 |
| Very High | 640-1050 |
| Water Extractable P (WEP) [mg l-1] | Low | 0-3 | Based on variable “Morgan P levels” and “land use” (data from 2013) it is calculated with the equations available in (Thomas et al., 2016b): for Grassland, WEP=0.26 \* Morgan P + 2.74, for Arable: WEP= 0.11 \* Morgan P + 1.12, where Morgan P is defined as a Uniform distribution with the following parameters:   |  |  |  | | --- | --- | --- | | **Morgan P Index** | **Grassland** | **Arable** | | **Index 1** | a=0; b=3 | a=0; b=3 | | **Index 2** | a=3.1; b=5 | a=3.1; b=6 | | **Index 3** | a=5.1; b=8 | a=6.1; b=10 | | **Index 4** | a=8.1; b=30 | a=10.1; b=30 |   For the Seminatural Land use, WEP was assumed constant to 0.001. Discretization is based on Morgan P discrete levels. |
| Medium | 3-5 |
| High | 5-8 |
| Very High | 8-15 |
| Sediment Water Soluble P [mg kg-1] | Very Low | 0-0.042 | Defined as a Gamma distribution ( k=1.03, ꝋ=0.44), fitted with the *SHELF* R package (version 1.8.0, Oakley, 2020) to observed Water Extractable P in the catchment sediments (Shore et al., 2016). Discretization of states is based on percentiles calculated from the observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). |
| Low | 0.042-0.720 |
| Medium | 0.720-1.570 |
| High | 1.570-3.350 |
| Very High | 3.350-7.000 |
| Predicted Dissolved P Concentration [mg l-1] | Very Very Low | 0-0.1 | Dependant on Water Extractable P, it is defined with the linear model: Predicted Dissolved P = β(WEP)+α, where β =0.08, α =0.158, derived from (Thomas et al., 2016b). This equation is derived from data gathered during the closed period only, that is, when farmers are forbidden from spreading fertilizer. An assumption is made that when the linear model yields a negative value, that is resampled as a zero. Water Extractable P is considered a good in-stream TRP/ TDP predictor in the ACP catchments by the experts, however careful consideration is needed when choosing a soil P test in a different setting. |
| Very Low | 0.1-0.5 |
| Low | 0.5-1.5 |
| Medium | 1.5-5 |
| High | 5-8 |
| Very High | 8-15 |
| Groundwater Dissolved P Concentration [mg l-1] | Very Very Low | 0-0.1 | Derived from monthly piezometer data of TDP concentrations (2009-2016) monitored in multi-level wells described in Mellander et al., (2016).   |  |  |  | | --- | --- | --- | |  | **µ** | **ơ** | | **January** | -4.3 | 0.09 | | **February** | -4.4 | 0.07 | | **March** | -5.0 | 0.06 | | **April** | -5.6 | 0.05 | | **May** | -4.8 | 0.12 | | **June** | -4.1 | 0.08 | | **July** | -4.4 | 0.03 | | **August** | -4.2 | 0.04 | | **September** | -4.4 | 0.00 | | **October** | -3.4 | 0.06 | | **November** | -3.9 | 0.17 | | **December** | -3.6 | 0.21 | |
| Very Low | 0.1-0.5 |
| Low | 0.5-1.5 |
| Medium | 1.5-5 |
| High | 5-8 |
| Very High | 8-15 |
| Sub-surface Dissolved P load  [kg month-1] | Low | 0-3 | Calculated as the product of Predicted Dissolved P concentration and Subsurface Storm-flow. |
| High | 3-200 |
| Baseflow Dissolved P load  [kg month-1] | Low | 0-3 | Calculated as the product of Predicted Dissolved P concentration and Baseflow. |
| High | 3-200 |
| Modified Dissolved P load  [kg month-1] | Low | 0-3 | Based on “Buffer effectiveness for Total Dissolved P”, for effective buffers, modified Dissolved P load= Sub-surface Dissolved P load \*(1-Buffer effectiveness for TDP). Based on expert recommendation. |
| High | 3-200 |
| Monthly Sediment P load  [kg month-1] | Low | 0-3 | Calculated as the product of Sediment Water Soluble P [mg kg-1], Monthly Suspended Sediment concentration [mg l-1 month-1] , and Mean total monthly surface flow [m3] . |
| High | 3-200 |
| Modified Sediment P load  [kg month-1] | Low | 0-3 | Based on “Buffer effectiveness for Suspended Sediments and Particulate P”, for effective buffers, Modified Sediment P load= Monthly Sediment P load [kg month-1]\*(1-Buffer effectiveness for SS and PP). Based on expert recommendation. |
| High | 3-200 |
| **Septic Tanks (ST) sub-model (Point P sources)** | | | |
| P concentration per tank  [mg l-1] | Absent (to represent 0 STs) | 0-1\*10-8 | P concentration is dependent on the treatment type. If the treatment is unknown, the concentration is defined as a Lognormal distribution (µ=2.9, ơ =1.25), based on a literature review of data available for Ireland (Environmental Protection Agency Ireland (EPA), 2003, 2000; Gill et al., 2005, 2007) (n=8). Fitting was done with R package *fitdistrplus* (version 1.1-8, Delignette-Muller et al., 2020). Otherwise, for primary and secondary treatment concentration is defined as Truncated Normal distribution (µ=10; ơ=1), and (µ=5; ơ=0.5) respectively, as described in Glendell et al., (2021) and derived from SEPA guidelines (Brownlie et al., 2014). All tanks are assumed to be maintained.  Discretization was also based on the literature review. |
| Low | 1\*10-8-1 |
| Medium | 1-18 |
| High | 18-35 |
| Very High | 35-100 |
| **Management related variables** | | | |
| Direct discharge | Present | 0.16 | Probabilities are derived from the report by the Environmental Protection Agency Ireland (EPA, 2015). |
| Absent | 0.84 |
| **Connectivity related variables** | | | |
| Degree of Phosphorus Saturation (DPS) [%] | Very Low\_0-20 | 0.88 | Discretization is equal to the 20th, 40th, 60th, and 80th quantiles, however 0< DPS <40 in this catchment. Probabilities were calculated from available spatial data (Wall et al., 2012). |
| Low 20-40 | 0.12 |
| Soil risk factor [adimensional] | Low | 0 | An indicator to describe the combined risk of effluent leaching to the groundwater table with the risk of the effluent being transported with surface runoff. This approach is a simplification of the one adopted in Glendell et al., (2021). The risk factor was obtained by overlaying the soil series (Thomas et al., 2016a) with information on the position of the groundwater table (0- 2 m below ground or more than 2 m below ground). Because little is known regarding the septic tanks in the catchment (i.e. age, type of treatment, maintenance), and the groundwater table position (few datapoints within the catchment) experts recommended a precautionary principle. This meant that the the class at most risk of effluent transfer was applied when data was unavailable. The table to the left represents a synthesis of the classification approach. Probabilities are based on land cover proportion. |
| Medium | 0.02 |
| High | 0.98 |
| Very High | 0 |
| |  |  |  | | --- | --- | --- | |  | **Groundwater Table Position** | | | **Soil Series** | **0-2 m below surface** | **>2 m below surface** | | **Brown earths** | High Risk | Moderate Risk | | **Gleys** | Very High Risk | Very High Risk | | |
| Leachfield removal | |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Soil risk factor** | **DPS** | **Low** | **Medium** | **High** | | **Low** | **Very Low** | 0 | 0.3 | 0.7 | | **Low** | 0 | 0.7 | 0.3 | | **Medium** | **Very Low** | 0 | 0.5 | 0.5 | | **Low** | 0 | 1 | 0 | | **High** | **Very Low** | 0 | 0.7 | 0.3 | | **Low** | 0.3 | 0.7 | 0 | | **Very High** | **Very Low** | 0 | 0.5 | 0.5 | | **Low** | 0.5 | 0.5 | 0 | | | The node refers to P removal from septic drains. Conditional on P leaching risk from Degree of Phosphorus Saturation (DPS). The conditional probability table is a logical one. |
| Leachfield connectedness | |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **HSA rescaled** | **None** | | **Low** | | **Medium** | | **High** | | | **Direct discharge** | **pres** | **abs** | **pres** | **abs** | **pres** | **abs** | **pres** | **abs** | | **low** | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | | **medium** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | | **high** | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | | | Probabilities are conditional on the presence/absence of Direct ST discharge, and HSA (node: Connectivity rescaled HSA). Where Direct discharge is present, connectedness is assumed as ‘high’. Where Direct discharge is absent, the risk class of the HSA is assigned. |
| Septic Tank connectedness | |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **Leachfield removal** | **Low** | | | **Medium** | | | **High** | | | | **Leachfield connectedness** | **Low** | **Medium** | **High** | **Low** | **Medium** | **High** | **Low** | **Medium** | **High** | | **Low** | 1.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 1.0 | 0.5 | 0.0 | | **Medium** | 0.0 | 1.0 | 0.0 | 0.0 | 1.0 | 0.5 | 0.0 | 0.5 | 1.0 | | **High** | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | | | Probabilities are conditional on Leachfield removal and Leachfield connectedness. Where Leachfield removal is ‘low’ or ‘High’, Leachfield connectedness remains unaltered. |
| Connectivity rescaled HSA [adimensional] | None\_0 | 0.03 | Data extracted from spatial layers of Hydrologically Sensitive Areas (HSAs) rescaled between 0 and 10 was provided by the Agricultural Catchments Programme (Thomas et al., 2016b). Discretization is also based on the spatial layers. |
| Low\_1-3 | 0.8 |
| Medium\_4-7 | 0.16 |
| High\_8-10 | 0.01 |
| **Calculated variables** | | | |
| Load per tank [kg month-1] | Absent | 0-1\*10-6 | Specified as the product of ST density [No ha-1] \* ST concentration [mg l-1] \* 120 [L] average daily water consumption per person \* 365/12 days in a month\* average No of persons per household 2.7/1\*106. Discretisation is based on interpolation to represent plausible probabilities for combination of extreme risk classes (eg. High+high=high, low+low=low). |
| Very Low | 1\*10-6-0.1 |
| Low | 0.1-0.5 |
| Medium | 0.5-1.0 |
| High | 1.0-2.0 |
| Very High | 2.0-30 |
| Total Realized load [T month-1] | Very Low | 0.0-0.1 | Calculated as the product of septic tank load and delivery factors (D) related to the connectedness of a septic tank, based on the median estimated fraction to be delivered in Table 13 of the report by Glendell et al., (2021) and the number of septic tanks present within catchment boundary (N): Realised load per tank [kg month-1] \* N \* D / 1000. In this case, N= 88. Discretisation based on interpolation to represent plausible probabilities for combination of extreme risk classes. |
| Low | 0.1-0.5 |
| Medium | 0.5-1.0 |
| High | 1.0-2.0 |
| Very High | 2.0-12 |
| |  |  |  | | --- | --- | --- | | **Septic tank connectedness** | **Delivery factor (D)** | **Reference** | | **Low** | 0.05 | “very low” category in Appendix A3, Glendell et al., (2021) | | **Medium** | 0.30 | “medium” category in Appendix A3, Glendell et al., (2021) | | **High** | 0.80 | “very high” category in Appendix A3, Glendell et al., (2021) | | |
| **Sewage Treatment Works (STWs) sub-model (Point P sources)** | | | |
| STWs P concentration [mg l-1] | Absent | 0-1\*10-8 | Based on Total P concentrations after tertiary treatment and specified as a Truncated Normal distribution (µ=1.44, ơ=1 .61, truncated at 0), as described in Glendell et al., (2022). |
| Low | 1\*10-8-1 |
| Medium | 1-18 |
| High | 18-35 |
| Very High | 35-100 |
| STWs Load [kg month-1] | Absent | 0-1\*10-6 | Specified as the product of STWs P concentration [mg l-1] \* 120 [L] average daily water consumption per person \* 365/12 days in a month\* 130 people equivalent /1\*106. |
| Very Low | 1\*10-6-0.1 |
| Low | 0.1-0.5 |
| Medium | 0.5-1 |
| High | 1-2 |
| Very High | 2-30 |
| **Farmyards sub-model (Point P sources)** | | | |
| Farmyard size area [m2] | Very Low | 0-35 | Based on available farmyard survey, a distribution was fitted to farmyard area data: Lognormal (µ=4.9; ơ=0.9). Discretization of states is based on percentiles calculated from the observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). |
| Low | 35-75 |
| Medium | 75-146 |
| High | 146-270 |
| Very High | 270-1315 |
| Farmyard P concentration [mg l-1] | Very Low | 0-0.01 | Using the *SHELF* R package (version 1.8.0, Oakley, 2020), a distribution was fitted to the data in Table 2 in Harrison et al., (2019): Lognormal (µ=-1.8; ơ=1.6 ). The best fit would have been the LogT distribution, however, that is not available for Genie, so we opted for Lognormal. Discretization is also based on the literature. For simplicity, here we have used SRP to mean TRP. |
| Low | 0.01-0.50 |
| Medium | 0.50-1.00 |
| High | 1.00-2.50 |
| Very High | 2.50-60 |
| Incidental losses per average yard  [kg month-1] | Very Low | 0-1\*10-9 | Based on average farmyard size, losses are calculated as Surface runoff [m3] / catchment area [m2]\* Farmyard size area [m2]\* Farmyard P concentration [mg l-1]/ 103. Catchment area is set at 758 ha. |
| Low | 1\*10-9-0.001 |
| Medium | 0.001-0.01 |
| High | 0.01-0.10 |
| Very High | 0.10-60 |
| Total incidental losses [T month-1] | Very Low | 0-1\*10-5 | Incidental losses per average yard [kg month-1] \* N, where N is the total number of yards present within the catchment boundary. In this case, N =86. |
| Low | 1e-05-0.007 |
| Medium | 0.007-0.070 |
| High | 0.07-0.700 |
| Very High | 0.700-10 |
| **Catchment outlet integration sub-model** | | | |
| Total catchment in-stream P load  [T month-1] | Low | 0-0.02 | Equal to the sum of Baseflow Dissolved P load [kg month-1], Modified Dissolved P load [kg month-1],  Modified Sediment P load [kg month-1], Total incidental losses [T month-1], and Total Realized load [T month-1], all converted to appropriate units. |
| Medium | 0.002-1 |
| High | 1-10 |
| (meteorological) Season |  |  | Based on the node “Month”. |
| In-stream winter P removal | Very Low | -1, -05 | Defined as a Normal distribution (µ=0.12; ơ=0.1) derived from expert elicitation with the R package (version 1.8.0, Oakley, 2020). |
| Low | -0.5-0 |
| Medium | 0-0.5 |
| High | 0.5-1 |
| In-stream spring P removal | Very Low | 0-0.2 | Defined as a Normal distribution (µ=0.08; ơ=0.06) derived from expert elicitation with the R package (version 1.8.0, Oakley, 2020). |
| Low | 0.2-0.4 |
| Medium | 0.4-0.6 |
| High | 0.6-0.8 |
| In-stream summer P removal | Very Low | 0.1-0.3 | Defined as a Normal distribution (µ=0.; 35=0.21) derived from expert elicitation with the R package (version 1.8.0, Oakley, 2020). |
| Low | 0.3-0.45 |
| Medium | 0.45-0.6 |
| High | 0.6-0.8 |
| In-stream autumn P removal | Very Low | 0-0.2 | Defined as a Normal distribution (µ=0.25; ơ=0.07) derived from expert elicitation with the R package (version 1.8.0, Oakley, 2020). |
| Low | 0.2-0.4 |
| Medium | 0.4-0.5 |
| High | 0.5-0.65 |
| In-stream reduced P load [T month-1] | Moderate | 0-0.5 | Calculated as the product of Total catchment in-stream P load and the seasonal removal. |
| Bad | 0.5-10 |
| In-stream P concentration [mg l-1] | Good | 0-0.035 | Defined as the in-stream reduced P load [T] \* 109 / Mean total monthly Q (discharge) [m3] \* 1000, where mean monthly discharge is equal to the total catchment discharge measured at the outlet. |
| Bad | 0.035-5 |
| Environmental Quality Standard [TRP concentration mg l-1] | |  |  |  | | --- | --- | --- | | **TRP concentration** | **Good** | **Bad** | | **Good** | 1 | 0 | | **Bad** | 0 | 1 | | | Discretization of the variable “In-stream TRP concentration [mg l-1]”. For simplicity, in-stream TRP is here considered equal to in-stream Dissolved Reactive Phosphorus, as in previous studies the mean DRP accounted for 98–99% of the flow-weighted mean TRP (Shore et al., 2014). |

### **Dunleer model specifications**

Table 4 Dunleer model structure (filename Ptool\_pointanddiffuse\_v7\_Dunleer)

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable (symbol) [unit]** | **States** | **Discretisation boundaries/ Probability** | **Description** |
| **Hydrology sub-model (Drivers)** | | | |
| Month | Each month |  | Calculated as No. days in the month/ 365 |
| Calculated variables | | | |
| Mean total monthly Q (discharge) [m3] | Very Low | 0-139000 | Bootstrapped from daily total discharge observations (2009-2016) to obtain a Lognormal (µ; ơ) discharge distribution with base e for each month. Each month’s parameters are shown in the table. Discretization of states is based on percentiles calculated from the average monthly observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile).   |  |  |  | | --- | --- | --- | |  | **µ** | **ơ** | | **January** | 13.4 | 0.1 | | **February** | 13.3 | 0.1 | | **March** | 12.6 | 0.1 | | **April** | 12.5 | 0.2 | | **May** | 11.9 | 0.2 | | **June** | 11.5 | 0.3 | | **July** | 11.3 | 0.3 | | **August** | 11.3 | 0.4 | | **September** | 11.7 | 0.4 | | **October** | 12.3 | 0.3 | | **November** | 13.3 | 0.2 | | **December** | 13.2 | 0.2 | |
| Low | 139000-274000 |
| Medium | 274000-596800 |
| High | 596800-697000 |
| Very High | 697000-720000 |
| Mean total monthly Surface Flow (surface runoff) [m3] | Very Low | 0-23100 | Calculated as a portion of mean monthly runoff (21%), via hydrograph separation method described in Mellander et al., (2012). Discretization of states is based on percentiles calculated from observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). |
| Low | 23100-57400 |
| Medium | 57400-125400 |
| High | 125400-147000 |
| Very High | 147000-150900 |
| Mean total monthly Sub-surface Stormflow (subsurface runoff) [m3] | Very Low | 0-5541 | Calculated as a portion of mean monthly runoff (4%), via hydrograph separation method described in Mellander et al., (2012). Discretization of states is based on percentiles calculated from observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). |
| Low | 5541-10934 |
| Medium | 10934-23870 |
| High | 23870-27860 |
| Very High | 27860-28800 |

|  |  |  |  |
| --- | --- | --- | --- |
| Mean total monthly Baseflow [m3] | Very Low | 0-103887 | Calculated as a portion of mean monthly runoff (75%), via hydrograph separation method described in Mellander et al., (2012). Discretization of states is based on percentiles calculated from observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). |
| Low | 103887-205000 |
| Medium | 205000-447565 |
| High | 447565-522370 |
| Very High | 522370-538900 |
| **Management (Drivers)** | | | |
| Land use | Arable | 0.33 | As reported by Teagasc - Agriculture and Food Development Authority, (2018). |
| Grassland | 0.49 |
| Seminatural | 0.18 |
| Buffers | |  |  |  |  | | --- | --- | --- | --- | | **Land use** | **Arable** | **Grassland** | **Seminatural** | | **2 m** | 0.98 | 0.01 | 1.01\*10-6 | | **>2 m** | 0.019 | 0.01 | 1.01\*10-6 | | **none** | 0.001 | 0.08 | 0.999 | | | Buffer strips are defined as being 2 m in width, more than 2 m in width, or absent. Probabilities of having either type of buffer according to land use were agreed upon with one of the ACP advisors (expert) during consultation. |
| **Calculated variables** | | | |
| Buffer effectiveness for Particulate P (PP) and suspended sediments (SS) | Very Low | 0-0.2 | Dependent on the variable Buffers. For 2 m buffers, effectiveness is defined as Beta (α=2.9; β=4.5); for >2 m buffers it is defined as Beta (α=1.44; β=0.789); for no buffers, effectiveness is equal to 0. The distributions were fitted to the dataset published in Stutter et al., (2021), where negative retention data was deleted from the analysis. |
| Low | 0.2-0.4 |
| Medium | 0.4-0.6 |
| High | 0.6-0.8 |
| Very High | 0.8-1 |
| Buffer effectiveness for Total Dissolved P (TDP) | Very Low | 0-0.2 | Dependent on the variable Buffers. For Buffers 0-2 m, Buffer effectiveness is defined as Beta (α=1.8; β=2.7), for >2 m buffers it is defined as Beta (α=1; β=0.8); for no buffers, effectiveness is equal to 0. The distributions were fitted to the dataset published in Stutter et al., (2021), where negative retention data was deleted from the analysis. |
| Low | 0.2-0.4 |
| Medium | 0.4-0.6 |
| High | 0.6-0.8 |
| Very High | 0.8-1.0 |
| **Soil erosion and soil P sub-model** | | | |
| Morgan P | |  |  |  |  | | --- | --- | --- | --- | |  | **Arable** | **Grassland** | **Seminatural** | | **Morgan1** | 0.224 | 0.224 | 0 | | **Morgan2** | 0.426 | 0.249 | 0.6 | | **Morgan3** | 0.142 | 0.154 | 0.3 | | **Morgan4** | 0.208 | 0.373 | 0.1 | | | Based on land use, proportions of land for each level and in each land use category were calculated based on the soil survey carried out in 2013 in the catchment. Where the Morgan P index was unknown, that proportion of land was assigned to the dominant index category. For the interpretation of the Soil Morgan P Index, the reader is referred to Regan et al., (2012). |
| **Calculated variables** | | | |
| Monthly Turbidity [NTU month-1] | Very Very Low | 0-1312 | Bootstrapped from daily average turbidity observations (2009-2016) to obtain a Lognormal (µ; ơ) turbidity distribution with base e for each month. Each month’s parameters are shown in the table. Discretization of states is based on percentiles calculated from the average monthly observations.   |  |  |  | | --- | --- | --- | |  | **µ** | **ơ** | | **January** | 5.9 | 0.23 | | **February** | 5.9 | 0.26 | | **March** | 5.3 | 0.19 | | **April** | 5.4 | 0.16 | | **May** | 5.1 | 0.14 | | **June** | 5.2 | 0.14 | | **July** | 5.1 | 0.13 | | **August** | 5.3 | 0.15 | | **September** | 5.1 | 0.14 | | **October** | 5.4 | 0.23 | | **November** | 6.1 | 0.30 | | **December** | 6.0 | 0.28 | |
| Very Low | 1312-1417 |
| Low | 1417-1792 |
| Medium | 1792-3004 |
| High | 3004-3775 |
| Very High | 3775-3810 |
| Monthly Suspended Sediment concentration [mg l-1 month-1] | Very Very Low | 0-186 | Calculated as: a \* Monthly Turbidity [NTU month-1], where a= 1.132 when the monthly turbidity is <= 432.2 NTU, a \* Monthly Turbidity [NTU month-1]+b, where a= 0.6032 and b= 228.547 when the monthly turbidity is >= 432.2 NTU, as described in Sherriff et al., (2015). Discretization of states is based on percentiles calculated from the average monthly calculated observations. |
| Very Low | 186-201 |
| Low | 201-249 |
| Medium | 249-421 |
| High | 421-527 |
| Very High | 527-531 |
| Water Extractable P (WEP) [mg l-1] | Low | 0-3 | Based on variable “Morgan P levels” and “land use” (data from 2013) it is calculated with the equations available in (Thomas et al., 2016b): for Grassland, WEP=0.57 \* Morgan P + 0.29, for Arable: WEP= 0.36 \* Morgan P + 0.89, where Morgan P is defined as a Uniform distribution with the following parameters:   |  |  |  | | --- | --- | --- | | **Morgan P Index** | **Grassland** | **Arable** | | **Index 1** | a=0; b=3 | a=0; b=3 | | **Index 2** | a=3.1; b=5 | a=3.1; b=6 | | **Index 3** | a=5.1; b=8 | a=6.1; b=10 | | **Index 4** | a=8.1; b=30 | a=10.1; b=30 |   For the Seminatural Land use, WEP was assumed constant to 0.001. Discretization is based on Morgan P discrete levels. |
| Medium | 3-5 |
| High | 5-8 |
| Very High | 8-15 |
| Sediment Water Soluble P [mg kg-1] | Very Low | 0-0.0995 | Defined as a Lognormal distribution (µ=-0.9, ơ=1), fitted with the *SHELF* R package (version 1.8.0, Oakley, 2020) to observed Water Extractable P in the catchment sediments (Shore et al., 2016). Discretization of states is based on percentiles calculated from the observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). Based on Ballycanew data. |
| Low | 0.0995-0.2100 |
| Medium | 0.2100-0.3550 |
| High | 0.3550-0.9100 |
| Very High | 0.9100-8 |
| Predicted Dissolved P Concentration [mg l-1] | Very Very Low | 0-0.1 | Dependant on Water Extractable P, it is defined with the linear model: Predicted Dissolved P = β(WEP)+α, where β =0.08, α =0.158, derived from (Thomas et al., 2016b). This equation is derived from data gathered during the closed period only, that is, when farmers are forbidden from spreading fertilizer. An assumption is made that when the linear model yields a negative value, that is resampled as a zero. Water Extractable P is considered a good in-stream TRP/ TDP predictor in the ACP catchments by the experts, however careful consideration is needed when choosing a soil P test in a different setting. |
| Very Low | 0.1-0.5 |
| Low | 0.5-1.5 |
| Medium | 1.5-5 |
| High | 5-8 |
| Very High | 8-15 |
| Sub-surface Dissolved P load  [kg month-1] | Low | 0-3 | Calculated as the product of Predicted Dissolved P concentration and Subsurface Storm-flow. |
| High | 3-200 |
| Baseflow Dissolved P load  [kg month-1] | Low | 0-3 | Calculated as the product of Predicted Dissolved P concentration and Baseflow. |
| High | 3-200 |
| Modified Dissolved P load  [kg month-1] | Low | 0-3 | Based on “Buffer effectiveness for Total Dissolved P”, for effective buffers, modified Dissolved P load= Sub-surface Dissolved P load \*(1-Buffer effectiveness for TDP). Based on expert recommendation. |
| High | 3-200 |
| Monthly Sediment P load  [kg month-1] | Low | 0-3 | Calculated as the product of Sediment Water Soluble P [mg kg-1], Monthly Suspended Sediment concentration [mg l-1 month-1] , and Mean total monthly surface flow [m3] . |
| High | 3-200 |
| Modified Sediment P load  [kg month-1] | Low | 0-3 | Based on “Buffer effectiveness for Suspended Sediments and Particulate P”, for effective buffers, Modified Sediment P load= Monthly Sediment P load [kg month-1]\*(1-Buffer effectiveness for SS and PP). Based on expert recommendation. |
| High | 3-200 |
| **Septic Tanks (ST) sub-model (Point P sources)** | | | |
| P concentration per tank  [mg l-1] | Absent (to represent 0 STs) | 0-1\*10-8 | P concentration is dependent on the treatment type. If the treatment is unknown, the concentration is defined as a Lognormal distribution (µ=2.9, ơ =1.25), based on a literature review of data available for Ireland (Environmental Protection Agency Ireland (EPA), 2003, 2000; Gill et al., 2005, 2007) (n=8). Fitting was done with R package *fitdistrplus* (version 1.1-8, Delignette-Muller et al., 2020). Otherwise, for primary and secondary treatment concentration is defined as Truncated Normal distribution (µ=10; ơ=1), and (µ=5; ơ=0.5) respectively, as described in Glendell et al., (2021) and derived from SEPA guidelines (Brownlie et al., 2014). All tanks are assumed to be maintained.  Discretization was also based on the literature review. |
| Low | 1\*10-8-1 |
| Medium | 1-18 |
| High | 18-35 |
| Very High | 35-100 |
| **Management related variables** | | | |
| Direct discharge | Present | 0.16 | Probabilities are derived from the report by the Environmental Protection Agency Ireland (EPA, 2015). |
| Absent | 0.84 |
| **Connectivity related variables** | | | |
| Degree of Phosphorus Saturation (DPS) [%] | Very\_Low\_0-20 | 0.85 | Discretization is equal to the 20th, 40th, 60th, and 80th quantiles. Probabilities were calculated from available spatial data (Wall et al., 2012). |
| Low\_20-40 | 0.117 |
| Medium\_40-60 | 0.0145 |
| High\_60-80 | 0.01 |
| Very\_High\_80-100 | 0.0085 |
| Soil risk factor [adimensional] | Low | 0.639 | An indicator to describe the combined risk of effluent leaching to the groundwater table with the risk of the effluent being transported with surface runoff. This approach is a simplification of the one adopted in Glendell et al., (2021). The risk factor was obtained by overlaying the soil series (Thomas et al., 2016a) with information on the position of the groundwater table (0- 2 m below ground or more than 2 m below ground). Because little is known regarding the septic tanks in the catchment (i.e. age, type of treatment, maintenance), and the groundwater table position (few datapoints within the catchment) experts recommended a precautionary principle. This meant that the the class at most risk of effluent transfer was applied when data was unavailable. The table to the left represents a synthesis of the classification approach. Probabilities are based on land cover proportion. |
| Medium | 0.236 |
| High | 0 |
| Very High | 0.125 |
| |  |  |  | | --- | --- | --- | |  | **Groundwater Table Position** | | | **Soil Series** | **0-2 m below surface** | **>2 m below surface** | | **Brown earths** | High Risk | Moderate Risk | | **Gleys** | Very High Risk | Very High Risk | | |
| Leachfield removal | |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Soil risk factor** | **DPS** | **Low** | **Medium** | **High** | | **Low** | **Very Low** | 0 | 0 | 1 | | **Low** | 0 | 0.1 | 0.9 | | **Medium** | 0 | 0.5 | 0.5 | | **High** | 0.1 | 0.4 | 0.5 | | **Very High** | 0.1 | 0.6 | 0.3 | | **Medium** | **Very Low** | 0 | 0.4 | 0.6 | | **Low** | 0.1 | 0.3 | 0.6 | | **Medium** | 0.1 | 0.8 | 0.1 | | **High** | 0.5 | 0.5 | 0 | | **Very High** | 0.6 | 0.4 | 0 | | **High** | **Very Low** | 0.3 | 0.7 | 0 | | **Low** | 0.4 | 0.6 | 0 | | **Medium** | 0.6 | 0.5 | 0 | | **High** | 0.7 | 0.3 | 0 | | **Very High** | 0.9 | 0.1 | 0 | | **Very High** | **Very Low** | 0.4 | 0.6 | 0 | | **Low** | 0.5 | 0.5 | 0 | | **Medium** | 0.6 | 0.4 | 0 | | **High** | 0.9 | 0.1 | 0 | | **Very High** | 1 | 0 | 0 | | | The node refers to P removal from septic drains. Conditional on P leaching risk from Degree of Phosphorus Saturation (DPS). The conditional probability table is a logical one. |
| Leachfield connectedness | |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **HSA rescaled** | **None** | | **Low** | | **Medium** | | **High** | | | **Direct discharge** | **pres** | **abs** | **pres** | **abs** | **pres** | **abs** | **pres** | **abs** | | **low** | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | | **medium** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | | **high** | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | | | Probabilities are conditional on the presence/absence of Direct ST discharge, and HSA (node: Connectivity rescaled HSA). Where Direct discharge is present, connectedness is assumed as ‘high’. Where Direct discharge is absent, the risk class of the HSA is assigned. |
| Septic Tank connectedness | |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **Leachfield removal** | **Low** | | | **Medium** | | | **High** | | | | **Leachfield connectedness** | **Low** | **Medium** | **High** | **Low** | **Medium** | **High** | **Low** | **Medium** | **High** | | **Low** | 1.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 1.0 | 0.5 | 0.0 | | **Medium** | 0.0 | 1.0 | 0.0 | 0.0 | 1.0 | 0.5 | 0.0 | 0.5 | 1.0 | | **High** | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | | | Probabilities are conditional on Leachfield removal and Leachfield connectedness. Where Leachfield removal is ‘low’ or ‘High’, Leachfield connectedness remains unaltered. |
| Connectivity rescaled HSA [adimensional] | None\_0 | 0.06 | Data extracted from spatial layers of Hydrologically Sensitive Areas (HSAs) rescaled between 0 and 10 was provided by the Agricultural Catchments Programme (Thomas et al., 2016b). Discretization is also based on the spatial layers. |
| Low\_1-3 | 0.73 |
| Medium\_4-7 | 0.2 |
| High\_8-10 | 0.01 |
| **Calculated variables** | | | |
| Load per tank [kg month-1] | Absent | 0-1\*10-6 | Specified as the product of ST density [No ha-1] \* ST concentration [mg l-1] \* 120 [L] average daily water consumption per person \* 365/12 days in a month\* average No of persons per household 2.7/1\*106. Discretisation is based on interpolation to represent plausible probabilities for combination of extreme risk classes (eg. High+high=high, low+low=low). |
| Very Low | 1\*10-6-0.1 |
| Low | 0.1-0.5 |
| Medium | 0.5-1.0 |
| High | 1.0-2.0 |
| Very High | 2.0-30 |
| Total Realized load [T month-1] | Very Low | 0.0-0.1 | Calculated as the product of septic tank load and delivery factors (D) related to the connectedness of a septic tank, based on the median estimated fraction to be delivered in Table 13 of the report by Glendell et al., (2021) and the number of septic tanks present within catchment boundary (N): Realised load per tank [kg month-1] \* N \* D / 1000. In this case, N= 88. Discretisation based on interpolation to represent plausible probabilities for combination of extreme risk classes. |
| Low | 0.1-0.5 |
| Medium | 0.5-1.0 |
| High | 1.0-2.0 |
| Very High | 2.0-12 |
| |  |  |  | | --- | --- | --- | | **Septic tank connectedness** | **Delivery factor (D)** | **Reference** | | **Low** | 0.05 | “very low” category in Appendix A3, Glendell et al., (2021) | | **Medium** | 0.30 | “medium” category in Appendix A3, Glendell et al., (2021) | | **High** | 0.80 | “very high” category in Appendix A3, Glendell et al., (2021) | | |
| **Farmyards sub-model (Point P sources)** | | | |
| Farmyard size area [m2] | Very Low | 0-99 | Based on available farmyard survey, a distribution was fitted to farmyard area data: Lognormal (µ=-5.9; ơ=0.83). Discretization of states is based on percentiles calculated from the observations (very low<= 5th percentile, low= 5th-25th percentile, medium= 25th-50th percentile, high= 50th-75th percentile, very high= 75th-100th percentile). |
| Low | 99-204 |
| Medium | 204-378 |
| High | 378-665 |
| Very High | 665-5500 |
| Farmyard P concentration [mg l-1] | Very Low | 0-0.01 | Using the *SHELF* R package (version 1.8.0, Oakley, 2020), a distribution was fitted to the data in Table 2 in Harrison et al., (2019): Lognormal (µ=-1.8; ơ=1.6 ). The best fit would have been the LogT distribution, however, that is not available for Genie, so we opted for Lognormal. Discretization is also based on the literature. For simplicity, here we have used SRP to mean TRP. |
| Low | 0.01-0.50 |
| Medium | 0.50-1.00 |
| High | 1.00-2.50 |
| Very High | 2.50-60 |
| Incidental losses per average yard  [kg month-1] | Very Low | 0-1\*10-9 | Based on average farmyard size, losses are calculated as Surface runoff [m3] / catchment area [m2]\* Farmyard size area [m2]\* Farmyard P concentration [mg l-1]/ 103. Catchment area is set at 758 ha. |
| Low | 1\*10-9-0.001 |
| Medium | 0.001-0.01 |
| High | 0.01-0.10 |
| Very High | 0.10-60 |
| Total incidental losses [T month-1] | Very Low | 0-1\*10-5 | Incidental losses per average yard [kg month-1] \* N, where N is the total number of yards present within the catchment boundary. In this case, N =70. |
| Low | 1e-05-0.007 |
| Medium | 0.007-0.070 |
| High | 0.07-0.700 |
| Very High | 0.700-10 |
| **Catchment outlet integration sub-model** | | | |
| Total catchment in-stream P load  [T month-1] | Low | 0-0.02 | Equal to the sum of Baseflow Dissolved P load [kg month-1], Modified Dissolved P load [kg month-1],  Modified Sediment P load [kg month-1], Total incidental losses [T month-1], and Total Realized load [T month-1], all converted to appropriate units. |
| Medium | 0.002-1 |
| High | 1-10 |
| (meteorological) Season |  |  | Based on the node “Month”. |
| In-stream winter P removal | Very Low | -1, -0.5 | Defined as a Normal distribution (µ=0.1; ơ=0.05) derived from expert elicitation with the R package (version 1.8.0, Oakley, 2020). |
| Low | -0.5-0 |
| Medium | 0-0.5 |
| High | 0.5-1 |
| In-stream spring P removal | Very Low | 0-0.2 | Defined as a Normal distribution (µ=0.35; ơ=0.21) derived from expert elicitation with the R package (version 1.8.0, Oakley, 2020). |
| Low | 0.2-0.4 |
| Medium | 0.4-0.6 |
| High | 0.6-0.8 |
| In-stream summer P removal | Very Low | 0.1-0.3 | Defined as a Normal distribution (µ=0.43; ơ=012) derived from expert elicitation with the R package (version 1.8.0, Oakley, 2020). |
| Low | 0.3-0.45 |
| Medium | 0.45-0.6 |
| High | 0.6-0.8 |
| In-stream autumn P removal | Very Low | 0-0.2 | Defined as a Normal distribution (µ=0.25; ơ=0.07) derived from expert elicitation with the R package (version 1.8.0, Oakley, 2020). |
| Low | 0.2-0.4 |
| Medium | 0.4-0.5 |
| High | 0.5-0.65 |
| In-stream reduced P load [T month-1] | Moderate | 0-0.5 | Calculated as the product of Total catchment in-stream P load and the seasonal removal. |
| Bad | 0.5-10 |
| In-stream P concentration [mg l-1] | Good | 0-0.035 | Defined as the in-stream reduced P load [T] \* 109 / Mean total monthly Q (discharge) [m3] \* 1000, where mean monthly discharge is equal to the total catchment discharge measured at the outlet. |
| Bad | 0.035-5 |
| Environmental Quality Standard [TRP concentration mg l-1] | |  |  |  | | --- | --- | --- | | **TRP concentration** | **Good** | **Bad** | | **Good** | 1 | 0 | | **Bad** | 0 | 1 | | | Discretization of the variable “In-stream TRP concentration [mg l-1]”. For simplicity, in-stream TRP is here considered equal to in-stream Dissolved Reactive Phosphorus, as in previous studies the mean DRP accounted for 98–99% of the flow-weighted mean TRP (Shore et al., 2014). |

### **Supplementary Results**

Supplementary results show the monthly TRP concentrations and percentage bias of the first model formulation against the final model structure per each catchment (Table 5). Additionally, supplementary results of the sensitivity analysis carried out for the final model structure for the Dunleer catchment are shown in Figure 1.

Table 5 Summary of months’ results, including Percentage Bias and P concentrations, which have been calculated excluding data outside the instrument’s limit of detection (0.01-5.00 mg l-1). Both observed and predicted TRP concentrations were log-transformed before calculating the statistics, and then converted back to normal values. For each catchment, results are reported only for Structure 1 (“Str 1”) and the best performing model structure which includes in-stream P removal. Therefore, the column “final” describes Structure 5 for Timoleague, Structure 2 for Ballycanew and Dunleer, and Structure 6 for Castledockrell. A positive bias indicates overestimation. Observations are shaded in grey to improve readability of text.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | **Percentage bias of simulations against distribution fitted to observed** | | **mean (µ)**  **concentrations** | | | **lower limit concentrations**  **(µ-1ơ)** | | | **upper limit concentrations**  **(µ+1ơ)** | | | |
| **(mg l-1)** | | | **(mg l-1)** | | | **(mg l-1)** | | | |
| **Str 1** | **final** | **Str 1** | **final** | **observations** | **Str 1** | **final** | **observations** | **Str 1** | **final** | **observations** |
| **Timoleague** | **Jan** | 28 | -20 | 0.14 | 0.05 | 0.05 | 0.05 | 0.04 | 0.04 | 0.40 | 0.06 | 0.08 |
| **Feb** | 289 | 5 | 0.14 | 0.06 | 0.05 | 0.05 | 0.05 | 0.04 | 0.41 | 0.08 | 0.08 |
| **Mar** | 281 | -10 | 0.14 | 0.05 | 0.04 | 0.05 | 0.03 | 0.03 | 0.40 | 0.08 | 0.07 |
| **Apr** | 281 | -26 | 0.14 | 0.04 | 0.04 | 0.05 | 0.03 | 0.02 | 0.40 | 0.07 | 0.07 |
| **May** | 286 | 11 | 0.14 | 0.06 | 0.04 | 0.05 | 0.03 | 0.02 | 0.41 | 0.10 | 0.06 |
| **Jun** | 283 | -12 | 0.14 | 0.05 | 0.06 | 0.05 | 0.03 | 0.03 | 0.41 | 0.07 | 0.10 |
| **Jul** | 280 | -18 | 0.14 | 0.05 | 0.06 | 0.05 | 0.03 | 0.04 | 0.40 | 0.07 | 0.12 |
| **Aug** | 290 | 20 | 0.14 | 0.07 | 0.06 | 0.05 | 0.04 | 0.03 | 0.41 | 0.10 | 0.13 |
| **Sept** | 277 | 17 | 0.13 | 0.07 | 0.05 | 0.05 | 0.04 | 0.03 | 0.40 | 0.10 | 0.08 |
| **Oct** | 286 | -1 | 0.14 | 0.06 | 0.06 | 0.05 | 0.04 | 0.04 | 0.41 | 0.08 | 0.11 |
| **Nov** | 285 | -10 | 0.14 | 0.05 | 0.06 | 0.05 | 0.04 | 0.04 | 0.40 | 0.07 | 0.10 |
| **Dec** | 286 | -19 | 0.14 | 0.05 | 0.06 | 0.05 | 0.04 | 0.04 | 0.40 | 0.07 | 0.09 |
| **Ballycanew** | **Jan** | 70 | 57 | 0.08 | 0.08 | 0.05 | 0.03 | 0.03 | 0.03 | 0.20 | 0.19 | 0.07 |
| **Feb** | 72 | 63 | 0.08 | 0.08 | 0.04 | 0.03 | 0.03 | 0.03 | 0.21 | 0.19 | 0.07 |
| **Mar** | 75 | 40 | 0.08 | 0.07 | 0.04 | 0.03 | 0.03 | 0.03 | 0.21 | 0.16 | 0.07 |
| **Apr** | 78 | 39 | 0.08 | 0.07 | 0.05 | 0.03 | 0.03 | 0.03 | 0.21 | 0.16 | 0.09 |
| **May** | 78 | 40 | 0.08 | 0.07 | 0.05 | 0.03 | 0.03 | 0.02 | 0.22 | 0.17 | 0.07 |
| **Jun** | 91 | 39 | 0.09 | 0.07 | 0.07 | 0.03 | 0.03 | 0.03 | 0.23 | 0.16 | 0.13 |
| **Jul** | 107 | 47 | 0.09 | 0.07 | 0.09 | 0.04 | 0.03 | 0.05 | 0.25 | 0.17 | 0.14 |
| **Aug** | 88 | 39 | 0.09 | 0.07 | 0.09 | 0.03 | 0.03 | 0.05 | 0.23 | 0.16 | 0.16 |
| **Sept** | 99 | 64 | 0.09 | 0.08 | 0.07 | 0.04 | 0.03 | 0.04 | 0.294 | 0.19 | 0.12 |
| **Oct** | 77 | 48 | 0.08 | 0.07 | 0.07 | 0.03 | 0.03 | 0.04 | 0.21 | 0.18 | 0.13 |
| **Nov** | 74 | 47 | 0.08 | 0.07 | 0.07 | 0.03 | 0.03 | 0.04 | 0.21 | 0.17 | 0.12 |
| **Dec** | 73 | 58 | 0.08 | 0.08 | 0.06 | 0.03 | 0.03 | 0.04 | 0.21 | 0.19 | 0.09 |
| **Castledockrell** | **Jan** | 485 | -38 | 0.12 | 0.02 | 0.02 | 0.05 | 0.01 | 0.01 | 0.29 | 0.02 | 0.02 |
| **Feb** | 485 | -36 | 0.12 | 0.02 | 0.02 | 0.05 | 0.01 | 0.01 | 0.29 | 0.02 | 0.02 |
| **Mar** | 461 | -14 | 0.11 | 0.02 | 0.02 | 0.04 | 0.01 | 0.02 | 0.29 | 0.03 | 0.03 |
| **Apr** | 471 | 10 | 0.11 | 0.02 | 0.02 | 0.04 | 0.01 | 0.01 | 0.29 | 0.04 | 0.03 |
| **May** | 413 | 31 | 0.09 | 0.02 | 0.02 | 0.03 | 0.01 | 0.01 | 0.27 | 0.05 | 0.03 |
| **Jun** | 424 | 27 | 0.09 | 0.03 | 0.03 | 0.03 | 0.01 | 0.02 | 0.27 | 0.05 | 0.05 |
| **Jul** | 437 | 57 | 0.09 | 0.03 | 0.04 | 0.03 | 0.01 | 0.03 | 0.27 | 0.06 | 0.07 |
| **Aug** | 420 | 62 | 0.09 | 0.03 | 0.04 | 0.03 | 0.01 | 0.03 | 0.26 | 0.06 | 0.07 |
| **Sept** | 430 | 61 | 0.09 | 0.03 | 0.03 | 0.03 | 0.01 | 0.02 | 0.27 | 0.06 | 0.06 |
| **Oct** | 428 | 51 | 0.09 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 | 0.28 | 0.06 | 0.05 |
| **Nov** | 499 | -27 | 0.13 | 0.02 | 0.02 | 0.05 | 0.01 | 0.01 | 0.30 | 0.03 | 0.03 |
| **Dec** | 491 | 6 | 0.12 | 0.03 | 0.02 | 0.05 | 0.02 | 0.01 | 0.29 | 0.04 | 0.03 |
| **Dunleer** | **Jan** | 98.3 | 75.4 | 0.12 | 0.11 | 0.07 | 0.04 | 0.03 | 0.05 | 0.40 | 0.35 | 0.09 |
| **Feb** | 95.6 | 74.1 | 0.12 | 0.11 | 0.06 | 0.04 | 0.03 | 0.04 | 0.39 | 0.34 | 0.09 |
| **Mar** | 96.9 | 33.8 | 0.11 | 0.08 | 0.07 | 0.03 | 0.03 | 0.04 | 0.39 | 0.25 | 0.11 |
| **Apr** | 87.5 | 31.8 | 0.11 | 0.08 | 0.08 | 0.03 | 0.03 | 0.04 | 0.37 | 0.25 | 0.13 |
| **May** | 83.6 | 34.4 | 0.11 | 0.08 | 0.08 | 0.03 | 0.03 | 0.06 | 0.36 | 0.25 | 0.12 |
| **Jun** | 94.3 | 23.9 | 0.11 | 0.08 | 0.13 | 0.03 | 0.03 | 0.09 | 0.38 | 0.23 | 0.18 |
| **Jul** | 94.9 | 31.7 | 0.11 | 0.08 | 0.15 | 0.03 | 0.03 | 0.11 | 0.38 | 0.25 | 0.20 |
| **Aug** | 97.9 | 28.3 | 0.11 | 0.08 | 0.17 | 0.03 | 0.03 | 0.12 | 0.38 | 0.24 | 0.23 |
| **Sept** | 90.3 | 54.5 | 0.11 | 0.09 | 0.15 | 0.03 | 0.03 | 0.10 | 0.37 | 0.30 | 0.23 |
| **Oct** | 91.5 | 49.6 | 0.11 | 0.09 | 0.11 | 0.03 | 0.03 | 0.08 | 0.38 | 0.29 | 0.17 |
| **Nov** | 99.7 | 50.5 | 0.12 | 0.09 | 0.09 | 0.04 | 0.03 | 0.06 | 0.40 | 0.29 | 0.12 |
| **Dec** | 92.4 | 75.4 | 0.12 | 0.11 | 0.08 | 0.04 | 0.03 | 0.05 | 0.38 | 0.34 | 0.12 |

A screenshot of a graph

Description automatically generated

Figure 1 A representation of the impact of varying both α and β parameters of Predicted Dissolved P Concentration [mg l-1] on the median log10(TRP) concentration. In order to combine the effect of both parameters, a limited number of values were tested for both α and β. The figure shows the target TRP concentration is more sensitive to the β parameter than the α.

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