PERFECT GWlag - SRG

GWlag is both a rainfall runoff model and a constituent (salt) generation model. Descriptions of both these aspects of functionality are provided in this section.
Description and rationale

Catchment models have traditionally focused on estimating total stream flows with less emphasis on modelling the groundwater component. Greater pressure on water resources and the environment, as well as the need to better model constituent generation, has led to more interest in low flow conditions, particularly how these are impacted by groundwater - surface water interactions.

GWlag is a simple delay based model to explicitly simulate groundwater movement in catchments, improving both the contributions and timing of groundwater to the stream, especially at low flows. It estimates both slow and quick groundwater contributions to stream flow at the catchment outlet. It also estimates groundwater salt load contributions to the stream. GWlag is intended to be applied across upland areas composed mainly of local and intermediate groundwater flow systems.
Scale

GWtag operates at the catchment scale and daily time-step.
Principal developer

The principal developer is eWater building on earlier work as noted below.
Scientific provenance

GWlag builds on earlier models including 2CSalt (Stenson et al., 2005; Stenson et al., 2011) and the Biophysical Capacity to Change model (BC2C) (Dawes et al., 2004; Gilfedder et al., 2009) which were developed by CSIRO and the Cooperative Research Centre for Catchment Hydrology. In addition, GWlag incorporates the 1-D PERFECT crop water balance model (Littleboy et al., 1992) developed by the Queensland Department of Primary Industries.
Version

Source v3.8.10
Dependencies

None
Availability/conditions

GWlag is a plugin, but is available in the plugin folder that accompanies Source installations.
Flow phase

The conceptual model used in the GWlag builds on the structure of the 2CSalt model (Stenson et al. 2005; 2011) and BC2C (Gilfedder et al. 2009). A gauged catchment is subdivided into sub-catchments using terrain analysis of surface topography and a knowledge of the scale of the underlying Groundwater Flow Systems (Coram et al. 2000).

Each sub-catchment is further divided into Functional Units (FUs), which are defined as areas with the same combination of soil, land-use and climate. For each of these FUs, water balances are calculated using the 1-D PERFECT crop water balance model (Littleboy et al. 1992). PERFECT (Productivity, Erosion, Runoff Functions to evaluate Conservation Techniques) considers climate, crop type, and soil parameters, and predicts surface runoff and deep drainage. The PERFECT results from all FUs are summed to the sub-catchment level.

GWlag works at a sub-catchment scale and accepts daily deep drainage which is split into recharge of groundwater (slow flow) and shallow lateral-flow (quick flow) (using the approach of Rassam and Littleboy 2003) from each FU within the sub-catchment. Groundwater and lateral flow response time scales are calculated for each sub-catchment using linear-storage-discharge relationships. In addition to the groundwater and lateral flow delays, GWlag allows for losses of groundwater recharge to deep regional groundwater, and for losses from the stream itself due to prolonged dry periods and groundwater pumping. The delayed groundwater and lateral flows, losses, and surface runoff are combined to predict the daily stream flow at the outlet of the catchment (Figure 1).

Figure 1. Simplified flowchart of the conceptual model for GWlag
Source catchments implementation

GWlag is in the form of a Rainfall Runoff model and includes the companion models SimpleGWSaltModel, PumpingImpactModel, and FlowScaledNodeLossModel.

The SimpleGWSaltModel uses estimated spatial representations of groundwater salinity to a sub-catchment scale. Salt is treated as conservative and is tightly linked to slow flow discharge to the stream. It is designed to give an estimate of groundwater concentrations of salt to upland streams.

The PumpingImpactModel simulates the impact of groundwater extraction on stream flow and loads and is applied at a catchment scale through the implementation of one or many pumps within each sub-catchment. Pumps can be either spatially implemented or behave as a simple abstract loss. Each pump has a series of pumping events where water and constituents are removed for a specified period of time at a specified rate. As each event may take many years to fully impact the stream, each event is tracked and combined with all other events for a particular sub-catchment, giving an overall impact at each time-step. The PumpingImpactModel may be applied to one or many sub-catchments within Source.

The FlowScaledNodeLossModel simulates losses from the stream that are flow weighted and constrained by actual flow in the stream. The modeller applies a single loss volume which is then scaled against flow in the stream. The scaled loss is removed at each time-step. The loss cannot be greater than the flow in the stream.
Process

GWlag generates daily time series inputs of surface runoff and deep drainage. These inputs can be scaled if required. The surface runoff contributes directly to stream flow. Deep drainage is split into a lateral (quick) and a vertical recharge (slow) component. The lateral flow pathway is delayed using a user parameterised exponential function before contributing to stream flow. The recharge component is delayed using a groundwater response time calculated from hydrogeology and topography (saturated hydraulic conductivity, storativity, aquifer thickness, aquifer flow length, and basement slope). This response time can then be scaled by a whole catchment user-defined parameter. GWlag can deal with losses by removing groundwater and/or removing stream flow.

Rainfall scaling

There can be inconsistencies in the measured rainfall data used to drive the catchment runoff model. For example, this has been shown to be a specific issue in the Namoi River catchment (Croke et al. 2006; Herron and Croke 2007). This issue can be handled by changing rainfall in the 1-D water balance model; although due to long run times this would need to be a separate exercise explored outside Source.

GWlag can allow for changes to catchment rainfall with a scaling parameter \( P \). GWlag uses \( P \) to scale deep drainage and runoff from the lumped 1-D Water balance models.

\[
DD = DD_{1D} \cdot P
\]

\[
RO = RO_{1D} \cdot P
\]

where:

- \( DD_{1D} \) lumped deep drainage output from 1-D water balance models (m\(^3\)/day)
- \( DD \) deep drainage used by GWlag (m\(^3\)/day)
- \( P \) use defined scaling parameter (0<P<2)
- \( RO_{1D} \) lumped runoff used by GWlag (m\(^3\)/day)
- \( RO \) lumped runoff used by GWlag (m\(^3\)/day)

It is likely that \( P \) will be set to 1 in most catchments but if calibration/optimisation leads to a value of \( P \) which is not close to unity, it is likely that the re-running of the 1-D Water balance model with modified rainfall would be required to be undertaken.

Sub-surface portioning factor

\( DD \) is split into lateral flow, and groundwater recharge using a partitioning fraction \( PF \). \( PF \) is determined using the method of Rassam & Littleboy (2003) (ie. calculated, not user defined), which was also used in the 2CSalt model (Stenson et al. 2005; 2011). The partitioning can also be scaled using \( PF \) (calibration parameter) if desired:

\[
R = DD \cdot \lambda \cdot PF
\]

\[
LF = DD \cdot \lambda \cdot (1 - PF)
\]

where:

- \( R \) groundwater recharge (m\(^3\)/day)
- \( DD \) deep drainage (m\(^3\)/day)
- \( LF \) lateral flow (shallow subsurface) (m\(^3\)/day)
- \( PF \) partitioning factor (0<P<1) (Rassam and Littleboy, 2003)
- calibration parameter (0 < <2)
Groundwater delay

A linear-storage-discharge relationship is used to predict groundwater response at a sub-catchment level. A groundwater storage term \( V \) is calculated for each time-step but this is used to provide the response only, and is not meant to be considered explicitly.

\[
DGW(t) = \frac{\alpha \cdot (R(t) + VGW(t-1))}{ts}, \quad (VGW \geq 0)
\]

\[
VGW(t) = VGW(t-1) + R(t) - DGW(t)
\]

where:

- \( t \) is time (days)
- \( DGW \) is the groundwater discharge to stream (m\(^3\)/day)
- \( \alpha \) is a calibration parameter (1 < \( \alpha \) < 500)
- \( R \) is Recharge (m\(^3\)/day)
- \( VGW \) is a storage term (m\(^3\))
- \( ts \) is the groundwater time scale (days)

The groundwater time scale is determined in a similar manner to the BC2C model (Gilfedder et al. 2009). This uses the idealised groundwater analogue that was developed by Walker et al. (2005) which captures some of the features of real, sloping aquifer systems (see Figure 2). It provides a simple approach for estimating the response of aquifers to changes in recharge, and for predicting the time-scale between changes in recharge and subsequent changes in discharge.

Figure 2. Idealised groundwater analogue of sloping aquifer, with surface head drop \((h_0 - h_1)\) over the flow length \(L\), and aquifer thickness at the outlet \(h_1\).

```
uniform recharge (R)

\[ h_0 \]

\[ h_1 \]

aquifer basement

\[ Q \]
```

Much of the literature on groundwater flow over sloping beds have a full-thickness seepage face as the downstream-end boundary condition (eg. Schmid and Luthin 1964; Childs 1971; Towner 1975; Verhoest and Troch 2000). This leads to a convex groundwater profile. The method in Walker et al. (2005) maintains a constant head boundary at the aquifer outlet, with the head at the elevation of the land surface - mimicking a stream overlying a thick and saturated zone. This boundary condition tends to result in a concave groundwater profile.

While the extended Dupuit-Forchheimer assumption of streamlines parallel to the bed is typically used for modelling flow over sloping beds (eg. Wooding and Chapman 1966; Childs 1971), Chapman (1980) considered that the horizontal streamline assumptions remained satisfactory up to a bed-slope of at least 10 degrees. Henderson and Wooding (1964) provided a solution for groundwater discharge from a steeply sloping aquifer using the classical Dupuit-Forchheimer assumption of horizontal streamlines. In Walker et al. (2005) the mathematics is modified to allow for the inclusion of much flatter aquifers - with a focus on estimating changes in groundwater flux to a stream.

Groundwater time scale, \( ts \), in equation 5 is calculated as follows.
where:

- $S$ is storativity (volume of water released from storage in an aquifer per unit decline in hydraulic head, per unit area of the aquifer. Storativity is a dimensionless quantity, and ranges between 0 and the effective porosity of the aquifer)
- $L$ is the groundwater flow length (m)
- $K$ is the saturated hydraulic conductivity (m/day)
- $a$ is the aquifer basement slope
- $h$ is the change in elevation of land surface (m)
- $d$ is the aquifer thickness

The calibration parameter, $(\text{in equation 5})$, is applied globally, while the groundwater time scale, $t_s$, is calculated for each individual sub-catchment. Thus, the variability of groundwater responses across the catchment is maintained, but can be adjusted to provide a better fit to gauged information.

**Lateral flow delay**

GWlag uses a linear-storage-discharge relationship to predict lateral flow response. A storage term ($V_{LF}$) is calculated for each time-step but this is used to provide the response only, and is not considered explicitly.

$$D_{LF}(t) = \beta \cdot (LF(t) + V_{LF}(t - 1)), \quad (V_{LF} \geq 0)$$

where:

- $D_{LF}$ is the lateral flow discharge to stream (m$^3$/day)
- $\beta$ is a calibration parameter (1 < 30)
- $LF$ is a lateral flow input (m$^3$/day)
- $V_{LF}$ is a storage term

**Losses**

In addition to the groundwater and lateral flow delays, GWlag can allow for three different types of "loss".

- Recharge to deep regional groundwater;
- Fixed losses from streams; and
- Variable groundwater pumping losses from streams.

Recharge to deep regional groundwater ($D$)

Not all recharge appears as stream flow, for example, some recharge provides water to the regional groundwater system which may discharge outside the catchment or directly to the ocean.
Recharge to deep regional groundwater is handled by removing a fixed daily volume from the groundwater store (VGW). In other words, Equation 6 is modified to include recharge to deeper groundwater (D):

\[
VGW(t) = VGW(t - 1) + R(t) - DGW(t) - D
\]

Fixed losses from the stream (L)

Incorporation of fixed losses can be used to improve the modelling of zero flow periods, in areas where streams are losing. It provides the capacity to model losing streams, including no-flow periods that are likely to occur after prolonged dry periods.

Loss of water from the stream is calculated using:

\[
L = REMOVE \cdot \log(Q)
\]

where:

\( L \) is the amount of water lost from the stream (m\(^3\)/day)

\( REMOVE \) is an input/calibration parameter

\( Q \) is the stream flow (prior to loss) (m\(^3\)/day)

If \( L \) is calculated as being less than zero it is set to zero.

Variable groundwater pumping losses

Variable groundwater pumping losses are additional losses that occur in areas with extensive groundwater development. These losses are calculated using classical stream depletion models (Glover and Blamer, 1954) which require knowledge of pumping rates, distance from stream/gauge and aquifer parameters (see also, Evans, 2007). GWlag will recognise both local and regional impacts of pumping, depending on the depth of the bore.

Explicit groundwater pumping capacity is included in GWlag for two reasons: (1) if significant changes in groundwater development occur in the middle of a long simulation, then the depletion losses will be time-variant and hence a constant loss term will result in inferior calibration, and (2) to allow for scenario modelling to predict the impacts of proposed groundwater development on flows.

Pumping impacts are modelled as follows:

\[
Q_p = Pr \cdot \text{Erfc} \left( \frac{a \cdot \sqrt{D \cdot t}}{2} \right)
\]

where:

\( Q_p \) is the impact of pumping (m\(^3\)/day)

\( P \) is the pumping rate (m\(^3\)/day)

\( \text{Erfc} \) is the complementary error function

\( a \) is the distance of pump from sub-catchment outlet (m)

\( D \) is the aquifer diffusivity (m\(^2\)/day)

\( K \) is the saturated conductivity (m/day)

\( d \) is the aquifer thickness (m)

\( S \) is the storativity

\( t \) is the time since start of pumping.

The impacts of groundwater pumping are calculated for each bore (or borefield). These impacts are estimated and their effect is to remove water from the gauged catchment outflow. For each pump (ie. individual bore, or borefield), the following inputs are required:
• Location (latitude/longitude); and
• Pumping regime (volume and time-step; dates of operation (eg. 1 ML/day between 1 Oct 2010 - 31 Mar 2011).

The result is that for each time-step, the sum of the impacts of pumping ($Q_p$) from all pumping events is calculated and this amount is then removed from the groundwater discharge to stream volume at the sub-catchment level. (ie the "removed volume" will be at the groundwater salinity, not stream salinity). The impact of groundwater pumping can reduce groundwater discharge to zero thus depleting stream flow from upstream catchments. The losses due to groundwater pumping will capture the groundwater discharge (base flow) and can deplete stream flow. In those situations surface flow (quick runoff) will only be available for a short period of time. Flow will soon drop to zero, when the quick runoff disappears but the flow is prevented from being negative.

**Modelled stream flow**

The modelled stream flow will be:

$$Q = D_{LF} + D_{GW} + RO - L - \sum Q_p, \quad (Q \geq 0)$$

Equation 14

where:

- $Q$ is the stream flow (m$^3$/day)
- $D_{LF}$ is discharge to stream flow from 'lateral flow' (m$^3$/day)
- $D_{GW}$ is discharge to stream from groundwater (m$^3$/day)
- $RO$ is the runoff (m$^3$/day)
- $L$ is the amount of water lost from the stream (m$^3$/day)
- $Q_p$ is the sum of the impacts of groundwater pumping (m$^3$/day)

If $Q$, in equation 14 is calculated to be less than zero, it is set to zero.

**Modelled salt export**

Note that this section is related to GWlag as a constituent generation model rather than as a rainfall runoff model. The explanation of this functionality is included here for completeness.

GWlag is capable of modelling salt generation from sub-catchments and salt exports in stream flow.

$$SALT_{gen} = D_{LF} \bullet LATPER \bullet GW_{SAL} + D_{GW} \bullet GW_{SAL} + RO \bullet RAIN_{SAL}$$

Equation 15

$$SALT = SALT_{gen} - \frac{SALT_{gen} \bullet (L + \sum Q_p)}{D_{LF} + D_{GW} + RO}$$

Equation 16

where:

- $SALT_{gen}$ is the salt generated from sub-catchments (kg/day)
- $D_{LF}$ is the discharge to stream from 'lateral flow (m$^3$/day)
\( D_{GW} \) is the discharge to stream from groundwater (m³/day)

\( LATPER \) is the 'lateral flow' salinity as a proportion of groundwater salinity

\( GW_{SAL} \) is the groundwater discharge salinity (kg/m³)

\( RO \) is the runoff (m³/day)

\( RAIN_{SAL} \) is the rainfall salinity (kg/m³)

\( SALT \) is the salt export from catchment in stream flow (kg/day)

\( L \) is the amount of water lost from the stream (m³/day)

\( Q_p \) is the sum of the impacts of groundwater pumping (m³/day)
Assumptions

The model makes the following assumptions:

- Contribution of water and constituents are calculated at a FU level and accumulated to a sub-catchment level.
- Stream losses are calculated at the catchment outlet, not at a sub-catchment level.
- Each sub-catchment is modelled as a predominantly gaining system (stream losses are only calculated for the whole catchment).
- There is no feedback between the groundwater and the 1-D Water balance models.
- All runoff makes it to the stream within the time-step.
- All deep drainage becomes recharge at the saturated zone within the time-step.
- The sub-catchment is parameterised with a single set of hydrogeological values (area weighted average).
- The groundwater response assumes that aquifers are unconfined.
- Groundwater discharge can only occur to a stream (not to the land surface).
- Salt mass balance is conserved in the surface water.
Limitations

GWlag is not applicable in areas with regulated surface flow. It is suitable for local and intermediate groundwater flow systems and is intended for areas which are drained by surface water streams.
Input data

GWlag requires the following data sets:

- Spatial representations of soil type, land use type, climate zone (based on rainfall and ET), and initial conditions including proportion of field capacity (dimensionless), crop residue (kg/ha).
- Rainfall and ET time series. These are used for climate inputs for the GWlag model that is specified for each FU.
- Spatial representations of aquifer thickness (m), aquifer hydraulic conductivity (m/day) and aquifer storativity (dimensionless).
- Information on groundwater pumping to parameterise the pumping impacts model
  - distance to local and regional impacts (m)
  - aquifer diffusivity (m²/day)
  - pumping regimes (start and end dates and pumping rate (m³/day)).
- Spatial representation of groundwater salinity (kg/m³) and rainfall salinity (kg/m³).
- Daily loss volume from the stream at the catchment outlet.
Parameters or settings

Model parameters are summarised in Table 1 and Table 2.

Table 1. Model parameters (PERFECT)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Units</th>
<th>Default</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Covm</td>
<td>Percent surface residue cover based on the crop residue value</td>
<td>-</td>
<td>n.a.</td>
<td>-</td>
</tr>
<tr>
<td>Cres</td>
<td>Crop residue – initial condition</td>
<td>-</td>
<td>n.a.</td>
<td>-</td>
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<tr>
<td>PAWCFactor</td>
<td>Plant available water capacity factor</td>
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<td>n.a.</td>
<td>-</td>
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<tr>
<td></td>
<td>Crop factor parameters</td>
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<td></td>
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<td>n.a.</td>
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<td>Maximum root depth</td>
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<td>n.a.</td>
<td>0</td>
</tr>
<tr>
<td>Cf</td>
<td>Crop factor</td>
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<td>n.a.</td>
<td>-</td>
</tr>
<tr>
<td>EtPanWUE</td>
<td>Water use efficiency</td>
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<td>n.a.</td>
<td>-</td>
</tr>
<tr>
<td>HI</td>
<td>Harvest index</td>
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<td>n.a.</td>
<td>-</td>
</tr>
<tr>
<td>EtPanDays</td>
<td>Days from crop planting to harvest</td>
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<td>n.a.</td>
<td>0</td>
</tr>
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<td>MaxResidCover</td>
<td>Maximum residual cover</td>
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<td>n.a.</td>
<td>-</td>
</tr>
<tr>
<td>Days0 … Days12</td>
<td></td>
<td>-</td>
<td>n.a.</td>
<td>0-366</td>
</tr>
<tr>
<td>Gcov0 … Gcov12</td>
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<td>-</td>
<td>n.a.</td>
<td>0-100</td>
</tr>
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<td>Ccov0 … Ccov12</td>
<td></td>
<td>-</td>
<td>n.a.</td>
<td>0-100</td>
</tr>
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<td>NumberOfSoilHorizons</td>
<td>The number of soil horizons in the soil profile</td>
<td>-</td>
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<td>1.0-3.0</td>
</tr>
<tr>
<td>Cona</td>
<td>Stage II soil evaporation</td>
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</tr>
<tr>
<td>Ch2b</td>
<td>Runoff curve number for average antecedent moisture conditions and bare soil</td>
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<td>n.a.</td>
<td>-</td>
</tr>
<tr>
<td>Conred</td>
<td>Reduction in curve number at 100% cover</td>
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<td>n.a.</td>
<td>-</td>
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<tr>
<td>Cracklimit</td>
<td>Limit of infiltration due to cracking</td>
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<td>n.a.</td>
<td>0</td>
</tr>
<tr>
<td>Crackling</td>
<td>Does cracking occur (0 - no, 1 - yes)</td>
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<td>n.a.</td>
<td>-</td>
</tr>
<tr>
<td>Conrough</td>
<td>Maximum reduction in curve number due to tillage</td>
<td>-</td>
<td>n.a.</td>
<td>-</td>
</tr>
<tr>
<td>Conrain</td>
<td>Cumulative rainfall to remove roughness</td>
<td>mm</td>
<td>n.a.</td>
<td>0</td>
</tr>
<tr>
<td>Kusle</td>
<td>MUSLE K factor</td>
<td>-</td>
<td>n.a.</td>
<td>-</td>
</tr>
<tr>
<td>Pusle</td>
<td>MUSLE P factor</td>
<td>-</td>
<td>n.a.</td>
<td>-</td>
</tr>
<tr>
<td>Slope</td>
<td>Field slope</td>
<td>%</td>
<td>n.a.</td>
<td>0-100</td>
</tr>
<tr>
<td>Length</td>
<td>Slope length or bank spacing</td>
<td>m</td>
<td>n.a.</td>
<td>0</td>
</tr>
<tr>
<td>Beta</td>
<td>Rill/inter-rill ratio</td>
<td>-</td>
<td>n.a.</td>
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<tr>
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<td>Bulk density</td>
<td>cm</td>
<td>n.a.</td>
<td>0.0-10.0</td>
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<td>Depth of soil horizon 1</td>
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<td>n.a.</td>
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</tr>
<tr>
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<td>n.a.</td>
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<tr>
<td>SoilHorizon1LowerLimit</td>
<td>Lower limit for soil horizon 1</td>
<td>%</td>
<td>n.a.</td>
<td>0-100</td>
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<tr>
<td>SoilHorizon1UpperLimit</td>
<td>Upper limit for soil horizon 1</td>
<td>%</td>
<td>n.a.</td>
<td>0-100</td>
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<tr>
<td>SoilHorizon1Saturation</td>
<td>Saturation limit for soil horizon 1</td>
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<td>n.a.</td>
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<tr>
<td>SoilHorizon1KSat</td>
<td>Saturated hydraulic conductivity of soil horizon 1</td>
<td>mm/h</td>
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<tr>
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<td>Depth of soil horizon 2</td>
<td>mm</td>
<td>n.a.</td>
<td>0</td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Units</td>
<td>Default</td>
<td>Range</td>
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<tr>
<td>--------------------------------</td>
<td>--------------------------------------------------</td>
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<td>---------</td>
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<tr>
<td>SoilHorizon2AirDry</td>
<td>Lower limit for soil horizon 2</td>
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<td>n.a.</td>
<td>0-100</td>
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<td>SoilHorizon2LowerLimit</td>
<td>Upper limit for soil horizon 2</td>
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<td>0-100</td>
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<td>Saturated hydraulic conductivity of soil horizon 2</td>
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<td>n.a.</td>
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<td>Upper limit for soil horizon 3</td>
<td>%</td>
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<td>0-100</td>
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<td>SoilHorizon3UpperLimit</td>
<td>Saturated hydraulic conductivity of soil horizon 3</td>
<td>mm/h</td>
<td>n.a.</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2. Model parameters (GWlag)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Units</th>
<th>Default</th>
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</tr>
</thead>
<tbody>
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<td>P</td>
<td>Rainfall scaling parameter</td>
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<td>0 - 2</td>
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<tr>
<td>Calibration parameter for sub-surface partitioning</td>
<td>-</td>
<td>n.a.</td>
<td>0 - 2</td>
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<tr>
<td>Calibration parameter for groundwater delay</td>
<td>-</td>
<td>n.a.</td>
<td>1 - 500</td>
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<tr>
<td>Calibration parameter for lateral flow delay</td>
<td>-</td>
<td>n.a.</td>
<td>1 - 30</td>
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<tr>
<td>D</td>
<td>Recharge to deep regional groundwater</td>
<td>m³/day</td>
<td>n.a.</td>
<td>0</td>
</tr>
<tr>
<td>REMOVE</td>
<td>Calibration parameter for loss from the stream</td>
<td>-</td>
<td>n.a.</td>
<td>1</td>
</tr>
<tr>
<td>LATPER</td>
<td>‘Lateral flow’ salinity as a proportion of the groundwater salinity</td>
<td>-</td>
<td>n.a.</td>
<td>0 - 1</td>
</tr>
</tbody>
</table>
Output data

A time series of total stream flow at the catchment outlet ($Q$), salt export from the catchment in stream flow ($SALT$), discharge to the stream from lateral flow ($DLF$), discharge to the stream from groundwater ($DGW$), and runoff from the water balance model ($RO$).

In addition, the variables listed in Table 3 can be recorded.

Table 3. Recorded variables from PERFECT

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tsevap</td>
<td>Daily soil evaporation</td>
<td>time step</td>
</tr>
<tr>
<td>Ttrans</td>
<td>Total daily transpiration</td>
<td>time step</td>
</tr>
<tr>
<td>PreRassamLittleboyRecharge</td>
<td>Recharge before Rassam-Littleboy split</td>
<td>time step</td>
</tr>
<tr>
<td>PostRassamLittleboyRecharge</td>
<td>Recharge after Rassam-Littleboy split</td>
<td>time step</td>
</tr>
<tr>
<td>PostRassamLittleboyLateralFlow</td>
<td>Lateral flow after Rassam-Littleboy split</td>
<td>time step</td>
</tr>
<tr>
<td>Swtot</td>
<td>Daily total soil water</td>
<td>time step</td>
</tr>
<tr>
<td>Tse</td>
<td>Daily PERFECT evapotranspiration</td>
<td>time step</td>
</tr>
<tr>
<td>GreenCover</td>
<td>Green cover proportion</td>
<td>time step</td>
</tr>
<tr>
<td>TotalCover</td>
<td>Total cover proportion</td>
<td>time step</td>
</tr>
</tbody>
</table>
Bibliography