# IHACRES-CMD - SRG

IHACRES-CMD is a unit hydrograph model that converts time series of rainfall and temperature into a time series of runoff. The version of IHACRES used in Source has six parameters.

# Scale

The model operates at a catchment scale and is typically run at a daily time-step. IHACRES has been used to model catchments that range from 490 $m^2$ to 10,000 $km^2$ and with time-steps from six minutes to one month (Littlewood *et al.*, 1997).

# Principal developer

The principal developers are the Integrated Catchment Assessment and Management Centre (iCAM), Australian National University, and the Institute for Hydrology, Wallingford, UK.

# Scientific provenance

IHACRES is an acronym for "Identification of unit Hydrographs And Component flows from Rainfall, Evaporation and Streamflow data". IH is also an acronym for the Institute of Hydrology (now the Centre for Ecology and Hydrology, Wallingford, UK) and CRES is an acronym of Centre for Resource and Environmental Studies, Australian National University. The original IHACRES model is described in a paper by authors from these two institutions (Jakeman *et al.*, 1990).

IHACRES model has been used in numerous applications and there are many different versions of the model (see reference list and bibliography). The IHACRES-CMD version currently implemented in Source is described in Croke and Jakeman (2004, 2005) and the references cited therein.

A version of IHACRES was included in Cooperative Research Centre for Catchment Hydrology's toolkit and is in the eWater toolkit.

# Version

Source version TBA

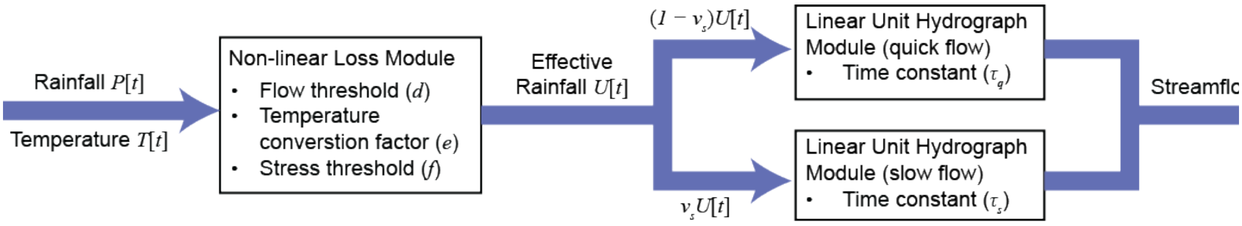
# Dependencies

Requires rainfall and maximum daily temperature or potential evapotranspiration (PET) as input. Observed streamflow is used for calibration.

# Structures and processes

IHACRES-CMD is a continuous rainfall-runoff model used to generate estimates of runoff from rainfall and temperature (or PET) data. The conceptual layout of the model is shown in Figure 1. The box on the left represents a non-linear loss module that converts rainfall, *P,* into effective rainfall, *U*. Effective rainfall is the portion of rainfall that will eventually leave the catchment as runoff. Effective rainfall is routed through two parallel stores to produce streamflow.

Figure 1. Conceptual layout of the IHACRES-CMD model.




## Non-linear Loss Module

The non-linear loss module uses a catchment moisture deficit (CMD) accounting scheme, which partitions rainfall into drainage (effective rainfall), evapotranspiration (ET) and changes in catchment moisture. Each time step the CMD is calculated as:

| | |
|---|---|
| (1) | $M[t] = M[t-1] - P[t] + E[t] + U[t]$ |

where *t* is the time step, *M* is the CMD, *P* is rainfall, *E* is actual evapotranspiration (ET), *U* is drainage (effective rainfall). Units are millimetres per time step. The minimum value of *M* is 0, which means that the catchment is fully saturated, while a value greater than 0 indicates that there is a moisture deficit.

The effective rainfall (drainage) is assumed to be an instantaneous, linear function of the CMD given by:

| | |
|---|---|
| (2) | $\frac{\mathrm{d}U}{\mathrm{d}P} = 1 - \min(1, \frac{M}{d})$ |

where *d* is a flow threshold. If the CMD is greater than the threshold, no flow is produced. The actual effective rainfall at each time step is given by the integral of equation (2). Other forms for the drainage function could be used (see Croke and Jakeman (2004) for examples) but the linear form only is currently implemented in Source.

Evapotranspiration is calculated as:

| | |
|---|---|
| (3) | $E[t] = eT[t]\exp\left(2\left(1 - \frac{M_f[t]}{g}\right)\right)$ |

where *T* is the temperature, $M_f$ is the value of the CMD before taking into account ET losses, *e* is a temperature to PET conversion factor, and is a stress threshold. The parameter *g* represents the value of the CMD above which the ET rate will begin to decline due to insufficient water availability for plant transpiration. To reduce parameter correlation, it is calculated as:

| | |
|---|---|
| (4) | $g = fd$ |

where *f* is a multiplication factor on the flow threshold *d*.

# Linear Routing Module

The Linear Routing Module translates effective rainfall into streamflow by routing it through two parallel, linear stores. It is based on the concept of the *instantaneous unit hydrograph*, which, for a drainage area, is the hydrograph of direct runoff resulting from effective rainfall of infinitely small duration. In the Linear Routing Module, instantaneous unit hydrograph theory is used to describe both direct runoff (quickflow) and baseflow (slowflow). In Figure 1, the top store represents quickflow while the bottom store represents slowflow. The sum of the quick and slow hydrographs gives the total streamflow (Figure 2). Refer to Jakeman *et al.* (1990) for a discussion of instantaneous unit hydrograph theory and Jakeman and Hornberger (1993) for a discussion of the two-store formulation of the Linear Routing Module.

The quickflow and slowflow equations are:

| | |
|---|---|
| (5) | $Q_q[t] = -\alpha_q Q_q[t-1] + (1-\alpha_q)v_q U[t]$<br>$Q_s[t] = -\alpha_s Q_s[t-1] + (1-\alpha_s)v_s U[t]$ |

where:

*t* is the time step

$Q_q$ and $Q_s$ are quickflow and slowflow, respectively. They are subject to the initial conditions $Q_q[t_0] = 0$ and $Q_S[t_0] = 0$

*U* is effective rainfall

$_q$ and $_s$ are calibration parameters, $0 < -_q < 1$ and $0 < -_S < 1$

$v_q$ and $v_s$ are the proportions of effective rainfall diverted to quickflow and slowflow, respectively, $v_q + v_s = 1$ and $v_q, v_s > 0$

Total streamflow *Q* is the sum of quickflow and slowflow:

| | |
|---|---|
| (6) | $Q[t] = Q_q[t] + Q_s[t]$ |

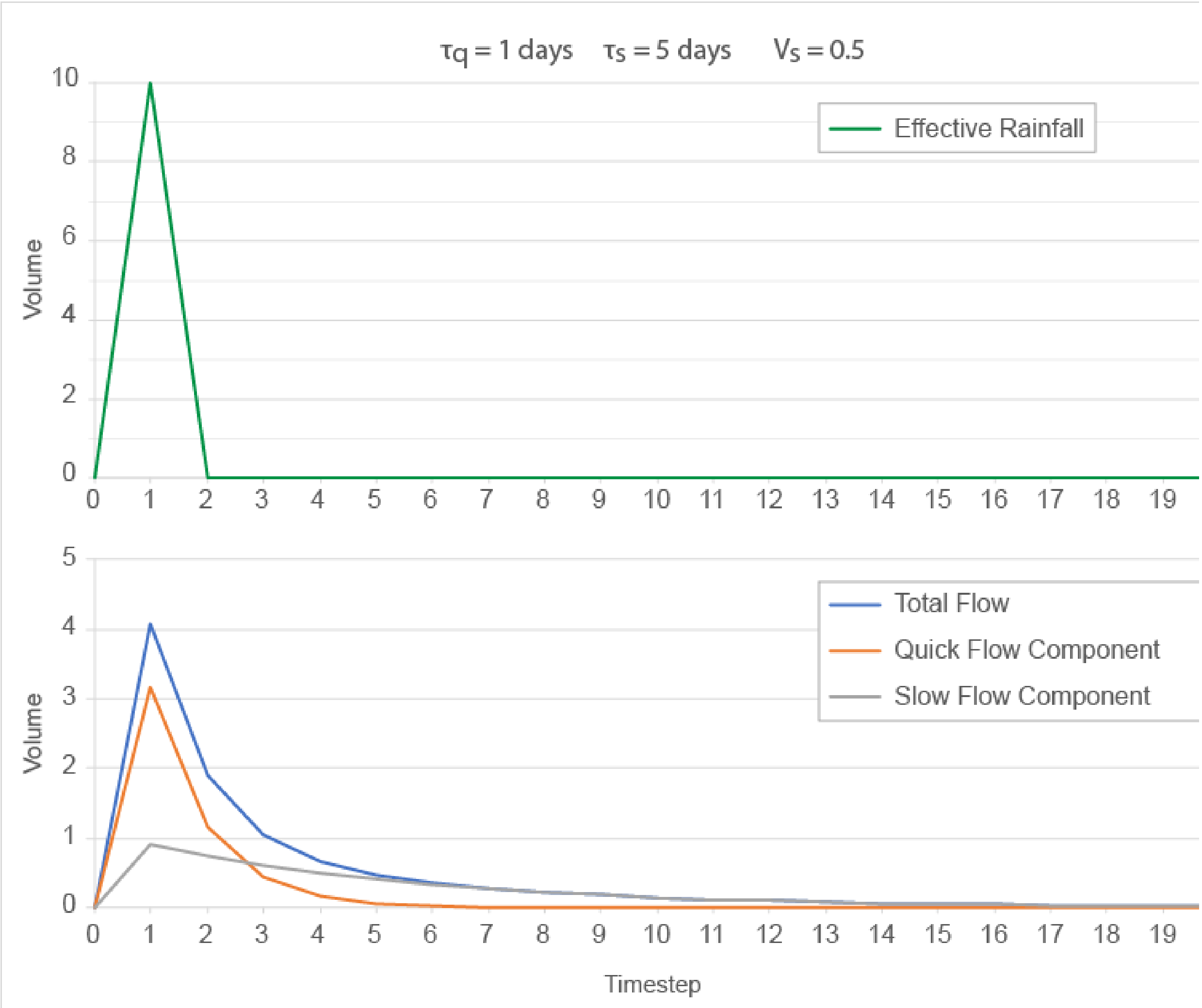
It is more intuitive to express the parameters $_q$ and $_s$ in terms of the time constants $_q$ and $_s$, respectively:

| | |
|---|---|
| (7) | $\tau_q = -\Delta t / \log_e(-\alpha_q)$<br>$\tau_s = -\Delta t / \log_e(-\alpha_s)$ |

where *t* is the time step size.

The time constants $_q$ and $_s$ represent the time required for the quickflow and slowflow responses to fall to 1/*e* of their initial values after an impulse of rainfall. They are subject to the condition $_q < _s$, which says that that quickflow should receed more quickfly than slowflow (Figure 2).

Figure 2. Linear Routing, example



τq = 1 days τs = 5 days Vs = 0.5
Effective Rainfall
Volume
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Total Flow
Quick Flow Component
Slow Flow Component
Volume
5
4
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Timestep

# Limitations

IHACRES-CMD is designed to represent the large-scale, conceptual rainfall-runoff processes occurring in a catchment. The model parameters may not be directly related to physical properties that can be measured in the field.

# Input data

IHACRES-CMD requires three sets of time series data. These are:

- Observed rainfall (expressed as a depth, e.g. mm)
- Temperature (daily maximum) in degrees Celsius or potential evapotranspiration (PET) depth (e.g. mm)
- Observed streamflow for calibration

# Parameters or settings

IHACRES-CMD has six parameters requiring calibration as described in Table 1.

Table 1. IHACRES-CMD model parameters. Feasible values are the range of theoretically possible values. Typical ranges are parameter upper and lower bounds typically used for model calibration via automatic optimisation algorithms.

| Parameter | Description | Units | Default | Feasible Values | Typical Range |
|---|---|---|---|---|---|
| *q* | Time constant governing the rate of recession of quickflow | Day | 1 | > 0 | 0.5 - 10 |
| *s* | Time constant governing rate of recession of slowflow. The slowflow time constant must always be greater than the quickflow time constant: $\tau_q < \tau_s$ | Day | 10 | > 0 | 10 - 350 |
| $v_s$ | The proportion of slow flow to total flow | Proportion | 0.5 | [0, 1] | 0 - 1 |
| *d* | Flow threshold | mm | 200 | > 0 | 50 - 550 |
| *e* | Temperature to PET conversion factor | Dimensionless | 0.1 | > 0 | 0.01 - 1.5 |
| *f* | Plant stress threshold factor (expressed as a multiplicative factor of *d*) | Dimensionless | 0.5 | > 0 | 0.01 - 3 |

# Output data

The primary output of the IHACRES-CMD model is a time series of total streamflow. It also outputs time series of quickflow and slowflow, the sum of which gives total streamflow.

In addition, the internal state variables listed in Table 2 can be recorded.

Table 2. Recorded state variables.

| State Variable | Symbol | Frequency |
|---|---|---|
| Catchment moisture deficit (CMD) | *M* | time step |
| Effective rainfall | *U* | time step |
| Evapotranspiration (ET) | *E* | time step |

## References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