Introduction

Kineros2 (KINematic runoff and EROsion) (K2) model was originated at the USDA-ARS in late 1960s and released until 1990 (Smith et al., 1995; Woolhiser et al., 1990). The spatial scales is from plot <10 m$^2$ to large watershed. However, it has only been validated for small basins (Schaffner et al., 2010). K2 simulations can fluctuate from ten minutes for small plots to more than a day for large watershed depending on the respective runoff response time. The companion ArcGIS-based Automated Geospatial Watershed Assessment (AGWA) tool (Miller et al., 2007) estimates the time-consuming task of watershed delineation into distributed model element and initial parameterization of these elements for K2.

Description

K2 model estimates runoff, erosion, and sediment transport in overland flow, channel, detention pond, urban, injection, and non-pressurized culvert model elements (Semmens et al., 2008). Precipitation inputs are in the form of rain gauge observations in either time and accumulated rainfall pairs or time intensity pairs. In K2, watershed characterization is important to estimate both the geometric characteristics of watershed modeling elements such as slope, flow, length, and area and the factors that affecting infiltration and routing, such as soil hydraulic properties, hydraulic roughness, land use, and land cover (Goodrich et al., 2012).

Model components

Fig. 1. Schematic view (Woolhiser et al., 1990).

- Rainfall and interception

Rainfall is modeled as spatially uniform over each element, but varies between elements if there is more than one rain gage. The spatial and temporal variability of rainfall is expressed by interpolation from up to twenty rain gage location to each plane, pond or urban element (Goodrich et al., 2012). In K2, interception is the portion of rainfall that initially collects and is retained on vegetation surfaces (Woolhiser et al., 1990).

- Infiltration
K2 contains a new soil infiltration model which allows more detailed specification of the soil profile for each hydrologic element, including specification of the characteristics of the bed for an infiltration channel. The new formulation allows either a one or two layer soil profile. Infiltration may occur from either rainfall directly on the soil or from ponded surface water created from upslope rainfall excess. K2 requires 3 basics parameters to describe the infiltration properties of a soil: the field effective saturated hydraulic conductivity, Ks, the integral capillary drive G, and the porosity $\phi$ (Woolhiser et al., 1990).

-Overland flow

Rainfall can produce ponding by two mechanisms, infiltration excess and saturation excess. The first mechanism involves a rate of rainfall which exceeds the infiltrability of the soil at the surface. The second mechanism a soil layer deeper in the soil restricts downward flow, and the surface layer fills its available porosity (Woolhiser et al., 1990).

-Channel flow

K2 contains the ability to route flow through channels (see fig. 2) with a significant overbank region. The compound channel algorithm is based on two independent kinematic equations, one for the main channel and one for the overbank section. The dimension of overland flow elements are chosen to completely cover the watershed, so rainfall in the channel is not considered directly (Goodrich et al., 2012).

![Fig. 2. Example of watershed discretization for parameterizing KINEROS2. Model parameters are average for each overland flow and channel element (Semmens et al., 2008).](image)

-Erosion and sedimentation

K2 accounts separately for erosion caused by raindrop energy (splash erosion) and erosion caused by flowing water (hydraulic erosion). Erosion is computed for upland, channel, and ponds elements (Semmens et al., 2008). Sediments sources are conceptualized to arise from interrill and rill erosion processes. The general equation used by K2 to describe the sediment dynamics at any point along a surface flow path is a mass balance equation similar to that for kinematic water flow (Woolhiser et al., 1990).
Inputs model

Rainfall input. Uniform rainfall input files for K2 can be created in AGWA using gridded return-period rainfall maps, a database of geographically specific return-period rainfall depths provided with the tool, or using data entered by the user. Soil parameters for upland planes as required by K2 (such as percent rock, suction head, porosity, saturated hydraulic conductivity). Land cover allows users to build management scenarios. Locations of land cover alteration specified by either drawing a polygon on the display, or specifying a polygon map (see case study 2), and topography (digital elevation model) (Semmens et al., 2008).

Output model

The model produces a variety of outputs in tables, hydrographs, and sedigraphs; which show peak runoff rate, runoff volume, sediment yield, infiltration, and peak sediment discharge (Goodrich et al., 2012; Semmens et al., 2008; Woolhiser et al., 1990).

Calibration and validation

For an ideal calibration and validation of K2, ten or more rainfall-runoff events, ranging from small to large and from dry to wet initial soil moisture conditions, would be available. It is recommended use automated calibration algorithms such as PEST, GLUE, and SCEM (Goodrich et al., 2012).

Goodrich et al. (2012), recommended that, for one or more acceptable calibrated parameter sets, a set simple observed versus simulated plots such as peak runoff, volume, and sediment yields with a 1:1 line be examined for outliers, bias or trends. Ideally, if good observation exist from nearby watershed, or within a nested calibration/validation watershed, the selected set of best model parameters should be used to evaluate model performance at the nearby or nested watershed.

Some researches recommend using Nash-Sutcliffe (N-S) efficiency statistics and watershed-wide parameter multipliers (M) on the saturated hydraulic conductivity (Ks) infiltration section term (G), and hydraulic roughness (n) for calibrating the hydrology of K2.

Case study 1

This study compares a stepwise multiscale calibration of K2 with the DWEPP erosion and sediment transport formulation at single scale. The calibration use rainfall, runoff, and sediment data collected from a rainfall simulator at the plot scale and a network of rain gauges and flumes at the hillslope and watershed scale. Stepwise calibration start at the rainfall simulator plot scale (12.2 m²), where severe key parameters for plot-scale runoff and erosion processes are calibrated and fixed. Calibrations were performed against hydrographs from 17 and 18 events observed on LH106, LH102, and LH104 respectively (see fig. 3). Results indicate that the stepwise, mulitscale calibration are able to outperform the lumped calibration for both hydrology and sediment at both the hillslope and watershed scales (Goodrich et al., 2012).
Case study 2

K2 and AGWA were applied to pre- and post-fire conditions for the largest recorded fire in New Mexico: the 2011 Las Conchas fire. Using nationally available digital datasets of topography, soils, and land cover, AGWA can be used to rapidly set up, parameterize, and simulate pre-fire watershed response. Pre-fire K2 simulation output from all the overland and channel model elements are automatically saved by AGWA, for example runoff volume, peak runoff rate, sediment yield, etc. The pre- to post-fire relative changes in peak runoff rate ($Q_p$) are illustrated in figure 4, and the pre- and post-fire hydrograph is shown in figure 5 at the Frijoles Canyon (Goodrich et al., 2012).
Fig. 4. Percent change in pre and post-fire peak runoff rates for 6-hour, 25 year simulated by K2/AGWA model (Goodrich et al., 2012).

Fig. 5. Simulated pre- and post-fire hydrograph at the Frijoles Canyon (Goodrich et al., 2012).

Limitations

K2 has a number of limitations. a) it is event-based and it does not treat snowmelt, lateral subsurface flow, or biogeochemistry (Goodrich et al., 2012), b) the model under-predicted runoff for small events and over-predicted runoff for larger storms (Hernandez et al., 2000), c) in regions without dense rain gauge networks, the lack of distributed rainfall data will be a limiting factor in model performance (Hernandez et al., 2000), d) soil particle needs to be similar for all the eroding elements (Woolhiser et al., 1990), and e) simulates runoff and erosion only for small watersheds (Schaffner et al., 2010). However, efforts to address many of these limitations are in the future directions models.

Future directions

Kineros2-Opus2 (treats of evapotranspiration and snow accumulation and melt), K2-SM-hsB couples Kineros2 (snow model and lateral saturated subsurface transport algorithms), K2-RHEM (new rangeland erosion model), and K2-STWIR (simulates the overland transport of manure-borne pathogen and indicator organisms).

References


