Streamflow characteristics in poorly gauged basins

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1. Introduction

Description of streamflow characteristics in poorly gauged basins is still an interesting challenge in hydrological modeling. Spatial climate data are often key drivers of computer models and statistical analyses, which form the basis for scientific conclusions, management decisions, and other important outcomes (Daly C., 2006). It is a common case that topographic and climatic data may not be available at the same resolution for a whole region in the entire period to be analyzed. This paper aims to evaluate the probable outcomes resulting from the application of a distributed hydrological model using input data with different resolutions, in order to describe streamflow characteristics of a poorly gauged catchment.

2. Study area and distributed model structure

A system in the transition Andean-interandean in Bolivia is selected as a case study, where heterogeneous geography and poorly gauged conditions are characteristic. Caine River basin (10214km^2) is located in the Central valley of the country (Fig. 1); altitudes vary from 2500masl to 2700masl; climate is semiarid, with average temperature of 12°C to 19°C; land use is agricultural, with urban interference in the valleys.

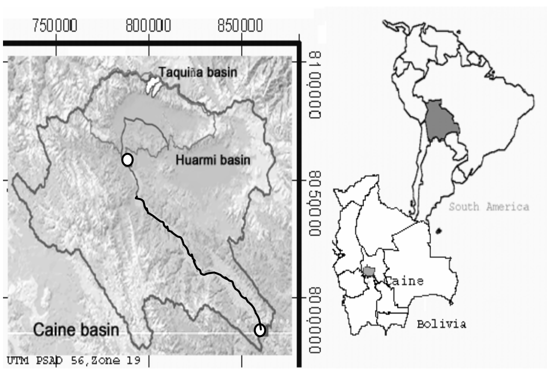

Figure 1. Geographical location

Pluviometric information from 27 stations is used for analysis in monthly resolution, and 9 stations for analysis in daily resolution. Mean monthly evapotranspiration is calculated from 9 climatic stations. Spatial distribution of variables is estimated by the inverse distance method. Records from one stream gauge station are used to evaluate model performance. Two additional stations are used for a preliminary estimation of the spatial distribution of model parameters, in monthly time resolution. Digital elevation models (DEMs) are derived for different resolutions by bilinear interpolation. Complementary minor manual corrections were made for flat areas.

The distributed model used is developed under the structure suggested by Kazama (2004). Three reservoirs account for subsurface, groundwater flow and snowmelt. Overland flow routing is described with the kinematic wave equation

$$\frac{B\Delta h}{\Delta t}+\frac{\Delta Q}{\Delta x}=(r-S_m-E)B \qquad (1)$$

where B is surface flow width, h flow depth, t time, Q discharge, x the distance along the longitudinal axis of the watercourse, r rainfall rate, S_m snowmelt rate, and E evapotranspiration rate.

Groundwater recharge is estimated considering a homogeneous soil structure with a linear infiltration rate. The storage volume S is estimated by a storage function

$$S=kq_s^{\,m} \qquad (2) \qquad\qquad \frac{dS_o}{dt}=r-q_s \qquad (3)$$

where k is a dimensional parameter, m a dimensionless, S_o storage depth, and q_s discharge rate. Maidment (1993) presents referential values for m.

Channel flow routing is described with a dynamic wave model, considering St. Venant equations of mass and momentum conservation

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}-q=0 \qquad (4)$$

$$\frac{1}{g}\frac{\partial A}{\partial t}+\frac{1}{2g}\frac{\partial v^2}{\partial x}+\frac{\partial H}{\partial x}+\frac{n^2|v|v}{h^{4/3}}=0 \qquad (5)$$

where A is flow cross-sectional area, q lateral inflow, g gravity acceleration, H water level, v flow velocity, and n Manning's friction factor.

3. Methods and results

Climatic and spatial resolution data availability, besides geographical heterogeneity in the studied watershed defined the approach considered here.

Spatial distribution of model parameter values was estimated after simulations carried on two subbasins assumed as characteristically defining dominant processes in the main watershed: a mountainous area with relatively steep slope (under surface runoff as dominant process), and a flat area (under groundwater as dominant process). Disaggregation and aggregation considerations were applied to simplify this spatial distribution (Becker et al., 1999). Climatic input data in the period 1972-1977 with monthly time step resolution was considered at this stage. A subsequent process was carried on daily input data basis for the period 1972-1973, with the same spatial distribution of model parameter values estimated at first stage. No daily discharge records for that period were available in the subbasins considered at first stage. DEMs at different resolutions were used to evaluate topographical heterogeneity influence and to simplify numerical calculations. Model performance and methodology's limitations were established based on considerations above.

Considering input data with monthly time step in a model structured for hourly climatic inputs caused surface flow spreading, decreasing its influence on total discharge, and therefore increasing the influence of groundwater flow on catchment response. Such aspect simplified the calibration at first stage. As shown in Figure 2, results were satisfactory.

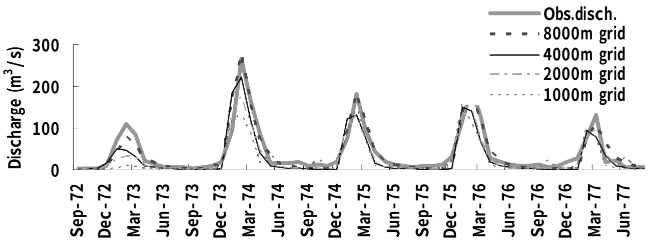

Figure 2. Graphical model performance for different grid sizes. Climatic input data with monthly resolution.

This paper expected to show how model response could change due to different climatic input resolutions. It was expected to reach a minimum agreement expressed at least on the behavior of time series, which was barely accomplished. An overview showed a general trend that seems to follow the observed one, but further evaluation showed poor model performance (Table 1). On the other hand, water level measurements showed high fluctuations within short time periods, perhaps product of human errors that difficult model performance evaluation. Finally, finer grid sizes could not be modeled (1000m grid size resolution) as done at first stage, due to an increased sensibility of the model to topographic heterogeneities.

Table 1. Model performance for various DEM resolution and climatic input data resolution.

Caine River basin		DEM spatial resolution		
	Statistics	1000m	2000m	4000m
M.res.; parameter values with u.s.d.	CE $_{SET\ 1}$	0.6548	0.8358	0.8382
(1972-1977)	RVE $_{SET\ 1}$	0.4193	0.3452	0.2874
M.res.; parameter values with u.s.d.	CE $_{SET\ 2}$	0.5809	0.7644	0.7661
(1972-1977)	RVE $_{SET\ 2}$	0.4253	0.3567	0.2877
D.res.; parameter values s.d.s	CE $_{SET\ 3\text{-}1}$	----	0.5814	0.2990
(1972-1973)	RVE $_{SET\ 3\text{-}1}$	----	-0.1388	-0.4650
D.res.; parameter values s.d.s	CE $_{SET\ 3\text{-}2,1}$	----	0.3596	0.4471
(performance sub period "1")	RVE $_{SET\ 3\text{-}2,1}$	----	0.0994	0.0092
D.res.; parameter values s.d.s	CE $_{SET\ 3\text{-}2,2}$	----	0.6258	0.3857
(performance sub period "2")	RVE $_{SET\ 3\text{-}2,21}$	----	-0.2271	-0.3602

M.res.:Climatic data with monthly resolution; D.res.:Climatic data with daily resolution
u.s.d.:Uniform spatial distribution; s.d.s.:Spatially distributed according to slope ranges

Coeff. of efficiency: $CE = 1 - \dfrac{\sum (O_i - S_i)^2}{\sum (O_i - O_m)^2}$; Relative vol. error: $RVE = \dfrac{\sum (O_i - S_i)}{\sum O_i}$

where O_i is the observed value, S_i the simulated value, and O_m is the average.

4. Conclusions

Simple assumptions (e.g. dominant processes, topographical features) to spatially distribute model parameter values are useful for preliminary estimations. Their application to finer spatial and temporal scales still requires further research to enhance simple methodologies to apply to poorly gauged scenarios. It is also evident a lack of universal spatio-temporal relationships or indices to evaluate an adequate modeling resolution environment, which is aimed to be developed as future work within this research.

5. Acknowledgements

Authors would like to thank the Ministry of Education, Culture, Sports, Science and Technology, who supported the current research work under the Japanese Government (MEXT) Scholarship funds.

6. References

1.Daly ,C.：Guidelines for assessing the suitability of spatial climate data sets, *Int J. Climatol.*, Vol.26, 707-721, 2006.

2.Becker, A., Braun, A.：Disaggregation, aggregation and spatial scaling in hydrological modelling, *J. Hydrology*, 217, 239-252, 1999.

3.Kazama, So., Hyejin, Ku., Sawamoto, M.：Uncertainty of morphological data for rainfall-runoff simulation, *Proc. Int. Conf. on Sustainable Water Resources Management in the Changing Environment of the Monsoon Region.*, 1, 400-406, 2004.

4.Maidment,D.R.:Handbook of Hydrology, McGraw-HillUSA, 9.11, 1993.