

THE EFFECT OF DEM AND LAND USE SPATIAL RESOLUTION ON SIMULATED STREAMFLOW AND SEDIMENT

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ABSTRACT

The Hydrologic Simulation Program-FORTRAN (HSPF) model is widely used to develop management strategies for water resources and to evaluate the hydrologic effect of various management scenarios. The spatial resolution of the input data used to parameterize HSPF model may induce uncertainty in model outputs. In this study, the impact of spatial resolutions of Digital Elevation Model (DEM) and land use map on the uncertainty of HSPF predicted flow and sediment were evaluated. DEM resolution can affect stream length, watershed area and average slope, whereas land use data resolution can lead to redistribution of land use information. Results showed that finer resolution DEM and land use maps can generate higher flow volumes and sediment loads compared to modelling scenarios using inputs of coarse resolution. The relative change in model performance between the baseline scenario (high-resolution) and scenarios of coarser resolution described uncertainties due to DEM and land use spatial information, and the probability density function of these uncertainties was used to estimate these uncertainties. Modelled flow and sediment uncertainty due to DEM resolution seems to follow a log-normal and a general extreme value distribution respectively, whereas modelled flow and sediment uncertainty due to land use resolution seems to both follow a general extreme value distribution. Overall, results highlight the need for a high-resolution DEM and land use maps in the application of the HSPF model while they provide useful information for reducing the model uncertainties.

Keywords: Digital Elevation Models; Hydrologic Simulation Program-FORTRAN model; land use; spatial model resolution; uncertainty

1. Introduction

Watershed models have been introduced to examine watershed-scale processes and to evaluate the hydrologic effect of various management scenarios (Beven, 2001; Pechlivanidis *et al.*, 2011). The lack of spatially and temporally adequate data, which seems to be particularly true in China and some African countries, has become one of the major limitation in the utilization of flow and sediment prediction, and as expected this can affect the watershed management. The spatial information of input data (e.g. rainfall, DEM) has long been identified as a key issue in hydrological modelling (Wilson *et al.*, 1996; Pechlivanidis *et al.*, 2010). Among others, Aronica *et al.*, (2005) studied the effect of temporal resolution of rainfall data in the modelling of an urban drainage system. Chaubey *et al.*, (1999) estimated the uncertainty in model parameters due to spatial variability in rainfall. Wagenet and Hutson, (1996) pointed out that even though the use of Geographic Information Systems (GIS) have greatly improved the capability to simulate watershed processes, the scale at which GIS data, such as soil survey, DEM and land use, should be collected and used is a major concern and needs to be studied. Fine digital elevation models (DEMs) and

detailed or high-scale land-use and soil maps (e.g. 1/25000) would generate accurate estimations. However, researchers cannot always acquire such information because of the expensive cost. It is therefore important to understand the effect of spatial data resolution on watershed model accuracy and estimate the resolution-induced uncertainties.

In previous efforts, Wolock and Price (1994) found that increasing DEM coarseness from 30×30 m to 90×90 m increased the ratio of overland flow to total flow in a study using 71 watersheds and TOPMODEL. Cho and Lee (2001) found that the SWAT simulated flow was higher for 30×30 m DEM data resolution compared to flow predicted using 90×90 m DEM. Similar conclusions were drawn by Chaubey *et al.*, (2005) and Chaplot, (2005). Cotter *et al.*, (2003) and Luzio *et al.*, (2005) concluded that the coarse DEM and land use resolution not only reduced flow but also reduced sediment. Although these studies highlighted the impact of spatial input data resolution on simulated flow and sediment, few studies estimate the probability density function (PDF) and cumulative distribution function (CDF) of these uncertainties, which is very important for the estimation of the total uncertainties, i.e. using methods based on a Bayesian approach.

In here, we investigate the impact of the mesh size of the DEM and the land use map scale on modelled flow and sediment by using HSPF model. In particular, we aim to quantify related uncertainties in the simulation flow and sediment due to DEM and land use resolution and estimate these uncertainties using PDFs and CDFs.

2. Study area and data

The study region covers an area of about 2200 km² and is located upstream of the Yixun river watershed in the northeast of the Hebei province, China (Figure 1). The selected watershed is a tributary of the Luan river watershed, which behaves as an ecological barrier of Tianjin and Beijing for the entire North Chinese zone. The elevation varies between 663 and 1814 m. The average slope is about 24% and the smoothest slope is 20%. Most of the watershed (70% of the total area) is covered by forest, whereas agriculture accounts for about 15%. Major soil in the watershed is brown forest soil (about 75%). The average annual precipitation and evaporation from water surface is about 450 mm and 900 mm respectively, and the average annual runoff and sediment is about 0.9×10^8 m³ and 3.5×10^8 kg respectively.

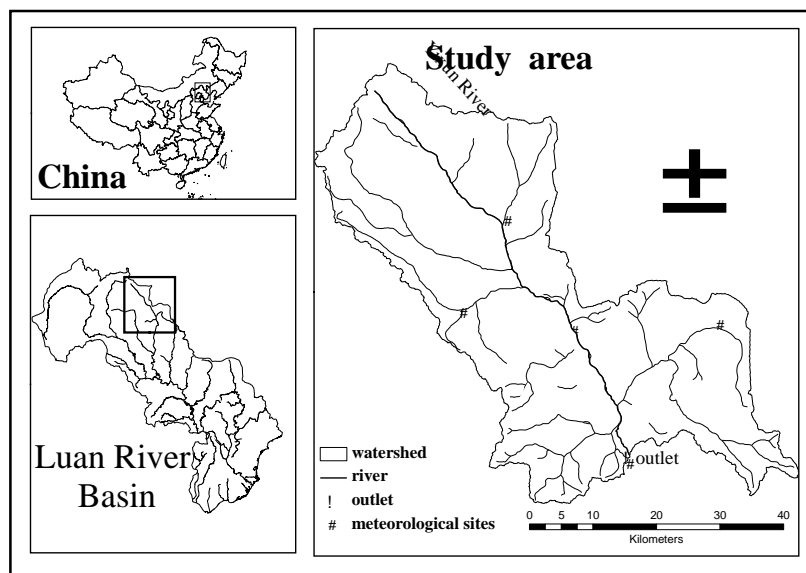


Figure 1. The upper Yixun River, HeibeI province, China

The DEM (1:24,000) for the watershed was downloaded from the International Scientific Data Service Platform, Chinese Academy of Science, and has a 30×30 m horizontal resolution. The land use data were

developed using Spot5 imagery of 20 m resolution for the year 2007 as acquired from the Data Sharing Infrastructure of Earth System Science. The land use data were classified into 18 groups according to the standards regulated by the State land management industry of China. Soil data (1:1,000,000) were downloaded from the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences. Hydrology and sediment data of watershed outlet were collected between 2007 and 2009 from the Chengde Branch of Hebei Provincial Survey Bureau of Hydrology and Water Resources (Table 1), whereas the meteorological data (precipitation, evaporation, temperature, wind speed, solar radiation, dew-point temperature and cloud cover etc.) were collected from the China Meteorological Data Sharing Service System.

Table 1. Measured data from the upper Yinxun watershed

	2007	2008	2009
Rainfall (mm)	435	580	519
Flow ($\times 10^8 \text{ m}^3$)	1.046	1.447	0.748
Sediment (kg/m^3)	1.04	4.46	1.91

3. Methodology

3.1. The HSPF model description

The HSPF model is a distributed, continuous time watershed scale model developed to simulate water quantity and quality (Bicknell *et al.*, 2001). In HSPF, a watershed is represented in terms of land segments and river reaches/reservoirs. Each land segment is referred to as a hydrologic response unit (HRU). Conceptually, runoff from the watershed moves laterally to a down slope segment or to a river reach/reservoir. HSPF uses simple storage-based (non-linear reservoir) equations for flow routing (Johnson *et al.*, 2003). The equations consist of the spatially uniform and temporarily variable continuity equation and a flow equation is expressed in terms of channel (or plane) roughness and geometry, such as Manning's equation (Equation 1 and 2):

$$\frac{ds}{dt} = I - O \quad (1)$$

$$Q = \frac{1}{n} A^{5/3} R_h^{2/3} \sqrt{S_0} \quad (2)$$

here, s is the storage volume of water (m^3), t is the time step used (s), I is the inflow rate ($\text{m}^3 \text{ s}^{-1}$), O is the outflow rate ($\text{m}^3 \text{ s}^{-1}$), Q is the flow per unit width ($\text{m}^3 \text{ s}^{-1} \text{ m}^{-1}$), n is the Manning's roughness coefficient, A is the flow cross-sectional area per unit width ($\text{m}^2 \text{ m}^{-1}$), R_h is the hydraulic radius (m), and S_0 is the energy gradient (m m^{-1}). Other processes include evapotranspiration (ET), interception, percolation, interflow, and groundwater movement. Channel routing is computed using a storage routing or a kinematic wave routing (Borah and Bera, 2003).

Within HSPF, the SEDMNT module simulates the production and removal of sediment from a previous land segment. The basic to simulation sediment is the soil detachment equation and the detached sediment wash off equation. In hill slope routing, rainfall splash detachment and wash off of the detached sediment are based on transport capacity as a function of water storage and outflow plus scour from flow using power relation with water storage and flow. In channel routing, non-cohesive (sand) sediment transport using user-defined relation with flow velocity or the Toffaleti or the Colby method, and cohesive (silt, clay) sediment transport based on critical shear stress and settling velocity (Borah and Bera, 2003).

3.2. Model identification

The HSPF model parameters that affect flow and sediment in the upper Yixun River were calibrated using measured monthly streamflow and sediment data for the period 2007-2009. The model was calibrated and evaluated using the observed data at the watershed outlet. The objective function used in model calibration was the Nash-Sutcliffe Efficiency (NSE), defined as:

$$NSE = 1 - \frac{\sum_{i=1}^n (y^{sim} - y^{obs})^2}{\sum_{i=1}^n (y^{sim} - y^{avg})^2} \quad (3)$$

where y^{sim} is the simulated output, y^{obs} is the observed output, y^{avg} is average value for the selected period, and i is month.

The high-resolution spatial data (i.e. 30 m resolution DEM and 20 m resolution land use) were used to simulate the baseline scenario. Flow and sediment were simulated using six additional DEM resolutions (60 × 60, 90 × 90, 120 × 120, 240 × 240, 480 × 480, 1000 × 1000 m) and five land use data resolutions (60 × 60, 120 × 120, 240 × 240, 480 × 480, 1000 × 1000 m). Spatial data at coarser resolutions were obtained by resampling the high-resolution data using the nearest method.

3.3. Model uncertainty due to DEM and land use resolution

Modelled uncertainty due to spatial resolution was described in terms of the relative change (RC) in the model performance given as:

$$RC = \frac{y^{sim} - y^{base}}{y^{base}} \quad (4)$$

Where " y^{base} " is the output from the baseline scenario (DEM at 30 × 30 m resolution and land use data at 20 × 20 m resolution), and " y^{sim} " is the simulated variable at different resolution.

In total five distributions (i.e. gamma, generalized extreme value (GEV), normal, Weibull (3P) and log-normal (3P)) were used to fit the distribution of the RC (Table 2). The "optimum" PDF was selected based on the Kolmogorov-Smirnov (KS) statistic, which serves as a goodness-of-fit test and has been widely used in hydrological studies (see among others, Haan and Skaggs, 2003). Depending on the distribution fit (aiming to minimize the KS value), the corresponding statistical parameters were estimated.

Table 2. Parameters of the gamma, generalized extreme value (GEV), normal, Weibull (3P) and log-normal (3P) distribution ⁽¹⁾.

Distribution	PDF	CDF
Normal	$f(x) = \frac{\exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]}{\sigma\sqrt{2\pi}}$	$F(x) = \Phi\left(\frac{x-\mu}{\sigma}\right)$
General extreme value ⁽²⁾	$f(x) = \frac{1}{\sigma} \exp\left[-(1+kz)^{\frac{1}{k}}\right] (1+kz)^{\frac{1}{k}}; k \neq 0$	$F(x) = \exp\left(- (1+kz)^{\frac{1}{k}}\right)$
Gamma (3P)	$f(x) = \frac{(x-\gamma)^{\alpha-1}}{\beta^\alpha \Gamma(\alpha)} \exp\left(-\frac{(x-\gamma)}{\beta}\right)$	$F(x) = \frac{\Gamma_{x-\gamma}(\alpha)}{\Gamma(\alpha)}$
Weibull (3P)	$f(x) = \frac{\alpha}{\beta} \left(\frac{x-\gamma}{\beta}\right)^{\alpha-1} \exp\left(-\left(\frac{x-\gamma}{\beta}\right)^\alpha\right)$	$F(x) = 1 - \exp\left(-\left(\frac{x-\gamma}{\beta}\right)^\alpha\right)$
Log-normal (3P)	$f(x) = \frac{\exp\left(-\frac{1}{2}\left(\frac{\ln(x-\gamma)-\mu}{\sigma}\right)^2\right)}{(x-\gamma)\sigma\sqrt{2\pi}}$	$F(x) = \Phi\left(\frac{\ln(x-\gamma)-\mu}{\sigma}\right)$

(1) μ , k , and α are the location parameters; σ and β are the scale parameters; and γ is the shape parameter

(2) where

$$z = \frac{x-\mu}{\sigma}$$

4. Results and discussion

4.1. Model performance

Model's potential to predict observed flow and sediment data is firstly assessed based on DEM 30 × 30 m and land use map 20 × 20 m. NSE values for flow and sediment were 0.83 and 0.79 respectively, showing that the model can adequately represent both variables. We further examined the overall water balance within each land segment. This effort involved analysis of the model results, including rainfall, runoff (including surface runoff, interflow, and base flow), and losses (including evapotranspiration, interception, upper zone, lower zone, base flow, and active groundwater), for individual land uses. The average annual values of these components were consistent with expected values (soft information) for the region.

The average simulated stream flow and sediment are showed in Table 3 and 4 as a function of the DEM and land use spatial resolution.

Table 3. Average annual modelled flow and sediment for different DEM resolutions

DEM resolution (m)	Flow		Sediment	
	Volume (m ³)	RC (%)	Mass loss (kg)	RC (%)
30 × 30 (<i>baseline</i>)	114 269 065	-	305082255	-
60 × 60	114 254 069	0.0	304 321 866	- 0.2
90 × 90	114 241 879	0.0	299 487 352	- 1.8
120 × 120	114 239 172	0.0	283 061 404	- 7.2
240 × 240	111 525 517	- 0.2	269 741 107	- 11.6
480 × 480	109 720 552	- 4.0	258 575 459	- 15.2
1000 × 1000	102 247 448	- 10.5	233 642 107	- 23.4

Table 4. Average annual modelled flow and sediment for different land use resolutions

Land use resolution (m)	Flow		Sediment	
	Volume (m ³)	RC (%)	Mass loss (kg)	RC (%)
20 × 20 (<i>baseline</i>)	114 269 065	-	305 082 255	-
60 × 60	113 964 135	- 0.3	302 624 552	- 0.8
120 × 120	113 673 341	- 0.5	302 001 435	- 1.0
240 × 240	113 480 152	- 0.7	303 028 668	- 0.7
480 × 480	112 027 540	- 2.0	295 405 858	- 3.2
960 × 960	109 864 770	- 3.9	287 246 666	- 5.8

4.2. Model uncertainties due to DEM resolution

Table 5 presents the effects of DEM resolution on the watershed delineation, stream network, average slope and channel slope drop. Results show that as the DEM resolution decreased, total computed watershed area, average watershed slope, total stream length and channel slope drop also decreased. However, when the DEM resolution was 90 m, watershed area is higher than the area from a 30 m DEM. Similarly the total stream length from a 90 m DEM is larger than the length from a 60 m DEM and close to the length from a 30 m DEM. The modelled stream network became consistently less accurate in comparison to the 30 × 30 m baseline scenario at coarser resolutions. This leads to loss of topographic detail and consequent error propagation to the streamflow and sediment prediction.

The relative change (RC) (i.e. flow and sediment) in model performance (NSE) using different DEM resolutions compared to the performance of the baseline scenario is illustrated in Figure 2. Average annual flow and sediment (2007-2009) of the model output decreased when the DEM resolution is reduced. When DEM resolution decreased from 30 m to 60, 90, 120, 240, 480 and 1000 m, the flow reduced by 0.01, 0.02, 0.03, 2.4, 3.9 and 10.5%, respectively, and the sediment reduced by 0.25, 1.83, 7.22, 11.6, 15.2, and 23.4%, respectively. This shows that predicted flow and sediment can be significantly

affected by the DEM resolution. Coarser resolutions reduced the average slope and channel slope drop of the modelled watershed, which is important for the calculation of the water balance in HSPF. The average slope of the watershed was reduced from 24% at the 30 m DEM to 9% at the 1000 m DEM, and further resulted in less flow. Watershed characteristics affect the flow generation induced from the Manning formula, as described in Equation (2). Sediment predictions followed the same trend; a coarser DEM resolution reduces the sediment predicted values, probably due to the decreased slope and stream length at coarser DEM resolutions. In addition, we note that the watershed characteristics affect the coefficient in the detached sediment wash-off equation during sediment simulation.

Table 5. DEM resolution effects on watershed characteristics.

DEM resolution (m)	Watershed area (km ²)	Total stream length (km)	Max stream length (km)	Average slope (-)	Channel slope drop (m)
30 × 30	2266.00	87.22	31.98	0.24	84.00
60 × 60	2262.70	85.50	31.61	0.24	84.40
90 × 90	2267.30	86.67	31.84	0.24	70.83
120 × 120	2261.50	85.55	31.58	0.23	70.00
240 × 240	2238.20	84.97	33.07	0.19	69.17
480 × 480	2194.20	81.79	32.05	0.14	71.83
1000 × 1000	2049.00	83.25	30.14	0.09	79.00

Moreover, results show that the DEM spatial resolution had a larger impact on the sediment than flow prediction. Similar conclusions were drawn by Cotter *et al.* (2003) and Chaplot (2005) using the SWAT model.

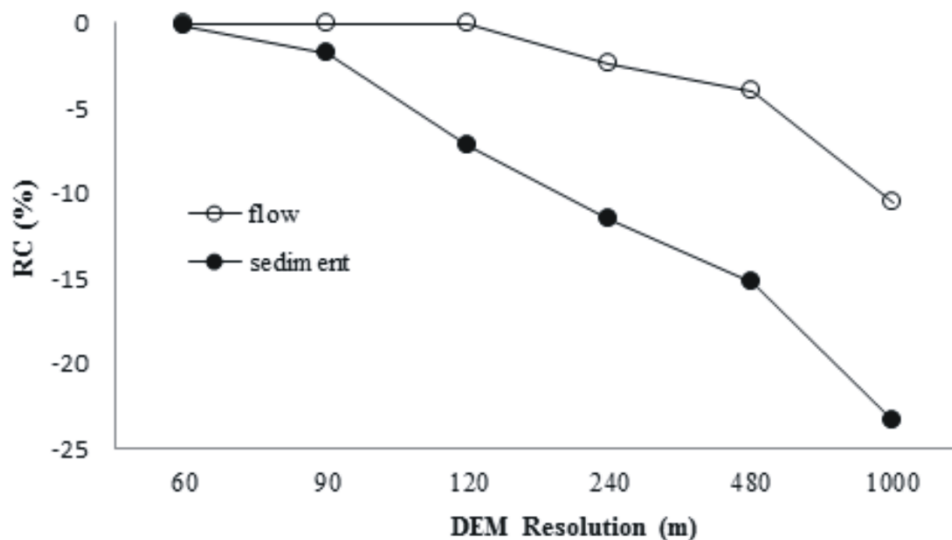


Figure 2. Relative error (RC) for flow and sediment using different DEMs for the period 2007-2009

PDF and CDF can be adequate to describe model uncertainty (Andronova and Schlesinger, 2001; Xiu and Karniadakis, 2003; Diaz-Ramirez *et al.*, 2007). DEM resolution induced uncertainty distributions and the distribution-fit analyses are presented in Table 6. The accumulation of RC values was found in low-frequency regions, which show less error. Although the best-fit distribution could not be clearly defined due to the constraint of relatively few data, it was found from the KS statistic that the log-normal achieved the best-fit with the lowest KS value of 0.336 for flow (see Table 6). The DEM resolution induced uncertainty (described by RC) in flow (f(Df)) simulation can be described with a log-normal distribution using the parameter estimates of Table 6. Consequently this gives the following distribution:

$$f(D_f) = \frac{\exp\left(-\frac{1}{2}\left(\frac{\ln(x+154.55)-5.025}{0.026}\right)^2\right)}{0.026(x+154.55)\sqrt{2\pi}} \quad (7)$$

For sediments, the lowest KS value was 0.155 for a general extreme value distribution (Table 6). The PDF of the sediment uncertainty (described by RC) due to the DEM resolution ($f(D_s)$) is defined in Equation (8) using the parameter estimates of Table 6 (a general extreme value distribution).

$$f(D_s) = \frac{1}{1.865} \exp\left(-\left(1-2.562\left(\frac{x+0.062}{1.865}\right)^{\frac{1}{2.562}}\right)\right)\left(1-2.562\left(\frac{x+0.062}{1.865}\right)^{\frac{1}{2.562}}\right) \quad (8)$$

Table 6. Distributions fits and parameters estimates for DEM resolution-induced uncertainty in flow and sediment. The optimum values (based on the KS statistic) are highlighted in bold.

RC due to DEM	KS statistic		Parameters	
	Flow	Sediment	Flow	Sediment
Normal	0.366	0.297	$\sigma=4.244$ $\mu=-2.468$	$\sigma=8.712$ $\mu=-9.924$
General extreme value	0.407	0.233	$k=-2.562$ $\sigma=1.865$ $\mu=-0.602$	$k=-0.599$ $\sigma=10.554$ $\mu=-11.8$
Gamma (3P)	0.375	0.319	$\alpha=217.34$ $\beta=0.279$ $\gamma=-63.203$	$\alpha=117.86$ $\beta=0.762$ $\gamma=-99.657$
Weibull (3P)	0.402	0.306	$\alpha=1.619E+8$ $\beta=-3.584E+8$ $\gamma=-3.584E+8$	$\alpha=34.702$ $\beta=-228.19$ $\gamma=-234.42$
Log-normal (3P)	0.336	0.307	$\sigma=0.026$ $\mu=5.025$ $\gamma=-154.55$	$\sigma=0.032$ $\mu=5.511$ $\gamma=-257.3$

4.3. Model uncertainties due to land use resolution

Table 7 shows an insignificant change in the total area up to 90 m resolution; however, the area of forest increased, the area of agricultural land decreased, whereas the area of other type varied erratically.

Table 7. Land use change with different resolution.

Land use resolution (m)	Agricultural areas (km ²)	Forest areas (km ²)	Grass areas (km ²)	Orchard areas (km ²)	Urban and built-up areas (km ²)	Water (km ²)	Total area (km ²)
20 × 20	313.75	1676.45	115.70	9.92	103.68	38.59	2258.09
60 × 60	311.18	1687.31	109.59	10.02	101.80	37.62	2257.51
120 × 120	305.85	1699.95	102.91	9.68	102.10	36.82	2257.31
240 × 240	290.25	1710.62	104.16	10.99	104.41	37.26	2257.69
480 × 480	283.30	1715.07	100.54	11.03	97.14	46.87	2253.94
960 × 960	269.96	1740.42	104.62	7.37	94.38	43.55	2260.28

The spatial resolution was resampled based on the nearest method in which the area is redistributed in accordance with a bigger cluster of class neighbouring pixels. The data were then used to simulate flow and sediment for different sets of land use maps. Figure 3 presents the RC variance in each annual model

output due to land use resolution for the calibration period. As the resolution decreased, especially when the resolution is less coarse than 240 m, the flow and sediment prediction gradually decreased.

Relative distribution of urban and built-up land, agricultural, and forest areas within a watershed can affect the prediction of flow and sediment response when land use characteristics are used to derive model parameters. When land use was redistributed from agricultural land to forest, the water losses (including interception, potential evaporation, upper and lower zone flow, base flow, and active groundwater) increased, resulting in less surface runoff. This further leads to decreased predicted flow and sediment transport.

RC induced by land use resolution was next analysed using PDF and CDF. In case of land use data resolution, when the spatial resolution decreased from 20 m to 60, 120, 240, 480 and 960 m, the flow reduced by 0.267, 0.512, 0.690, 1.962 and 3.854%, respectively, whilst the sediment reduced by 0.806, 1.010, 0.673, 3.172, and 5.846%, respectively (Figure 3).

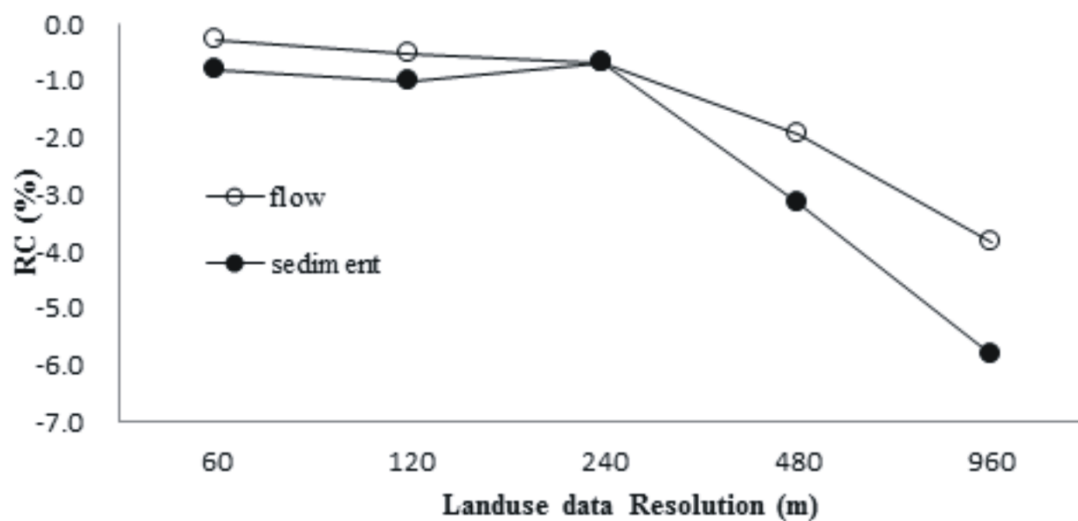


Figure 3. Relative error (RC) for flow and sediment using different land use for the period 2007-2009

The spatial resolution of land use seems to have greater impact on the sediment prediction than the flow prediction. This result is in accordance with the findings by Luzio *et al.* (2003) using the SWAT model; the study showed that although runoff estimates are not affected by the land use input, sediment yields are significantly biased.

Results from the distribution-fit of RC induced by land use resolution analysis are presented in Table 8. Based on the lowest KS value for flow and sediment (0.233 and 0.302 respectively), the PDF of land use data resolution induced uncertainty (described by RC) in flow ($f(D_f)$) and sediment ($f(D_s)$) simulation can be described by Equation (9) and (10) using the parameter estimates of Table 8; described by a general extreme value distribution.

$$f(D_f) = \frac{1}{1.489} \exp \left[- \left(1 - 0.17 \left(\frac{x + 1.115}{1.489} \right)^{\frac{1}{0.17}} \right) \right] \left(1 - 0.17 \left(\frac{x + 1.115}{1.489} \right)^{\frac{1}{0.17}} \right) \quad (9)$$

$$f(D_s) = \frac{1}{2.034} \exp \left[- \left(1 - 1.688 \left(\frac{x + 1.663}{2.034} \right)^{\frac{1}{1.688}} \right) \right] \left(1 - 1.688 \left(\frac{x + 1.663}{2.034} \right)^{\frac{1}{1.688}} \right) \quad (10)$$

Table 8. Distributions fits and parameters estimates for land use resolution-induced uncertainty in flow and sediment. The optimum values (based on the KS statistic) are highlighted in bold.

RC due to land use	KS statistic		Parameters	
	Flow	Sediment	Flow	Sediment
Normal	0.156	0.319	$\sigma=1.490$ $\mu=-1.459$	$\sigma=2.229$ $\mu=-2.301$
General extreme value	0.155	0.302	$k=-0.17$ $\sigma=1.489$ $\mu=-1.115$	$k=-1.688$ $\sigma=2.034$ $\mu=-1.663$
Gamma (3P)	0.169	0.335	$\alpha=167.68$ $\beta=0.106$ $\gamma=-19.225$	$\alpha=157.58$ $\beta=0.167$ $\gamma=-28.595$
Weibull (3P)	0.189	0.343	$\alpha=2451.2$ $\beta=2179.9$ $\gamma=-2180.8$	$\alpha=4.841E+5$ $\beta=6.415E+5$ $\gamma=-6.415E+5$
Log-normal (3P)	0.177	0.338	$\sigma=0.024$ $\mu=4.019$ $\gamma=-57.111$	$\sigma=0.027$ $\mu=4.335$ $\gamma=-78.66$

4.4. Discussion

Overall, the sediment prediction was affected more than flow prediction by the land use spatial resolution. Watershed characteristics, such as slope and stream length, and land use redistribution can affect the flow generation. Sediment generation was affected both by the watershed characteristics and runoff. In other words, uncertainty in simulated flow can be induced (or propagated) to simulated sediment.

In this study, the best-fit distribution may not be clearly defined given the relatively few available data; however parameter estimates could provide insights on the watershed model uncertainty. The distribution of DEM and land use resolution-induced uncertainty could provide useful information to the estimation of the total model uncertainties, i.e. using a Bayesian approach. Moreover, use of such methodology could reduce the risk of faulty assumptions in the error distribution. The uncertainty analysis in the watershed modelling could be more reliable with the method described here. It is important to note that the computation of RC for more data scenarios may refine the distribution fit depending on the DEM and land use resolution. Moreover, the distribution fits for DEM and land use resolution-induced uncertainty cannot be regionalised to other basins; similar investigations at other basins is required.

This study explored input data-induced uncertainty for the HSPF model only from spatial data resolution viewpoint. However, studies revealed that spatial-temporal distribution of precipitation could significantly affect model uncertainty (Segond *et al.*, 2007; Younger *et al.*, 2009; Pechlivanidis *et al.*, 2010). Our study is limited in neglecting the impact of spatial resolution of precipitation at fine temporal resolutions (i.e. hourly time steps). Although, we applied disaggregated hourly data in the HSPF, a loss of information due to the “real” temporal rainfall distribution is expected. Finally, from a water quality management perspective, given that DEM and land use resolution affect the flow and sediment generation, we believe that similar conclusions can be drawn regarding the HSPF simulated pollution load (e.g. NH₃-N, phosphate, total nitrogen and total phosphorus); further investigation is required.

5. Conclusions

This study highlighted the impact of DEM and land use resolution on stream flow and sediment of the HSPF model. Results show that the model performance can be significantly reduced when input data of coarse resolution are applied and demonstrated the discriminative power of the PDF in quantifying these uncertainties, which is very important for the estimation of the total uncertainties, i.e. using methods based on a Bayesian approach. In the upper Yixun River, high-resolution DEM and land use maps

generated higher flow volumes and sediment loads compared to their coarser counterparts. DEM resolution can affect the stream length, watershed area and average slope, which further induce uncertainty in simulated flow and sediment. Land use data resolution can affect infiltration and evaporation loss, which can further alter the flow dynamics and affect sediment detachment and wash off; and hence affect sediment generation. Results indicate that every effort must be made to collect spatial data at a fine resolution to reduce this source of uncertainty and its propagation to the model simulations.

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