Streamflow Routing in Perspective of Muskingum Scheme

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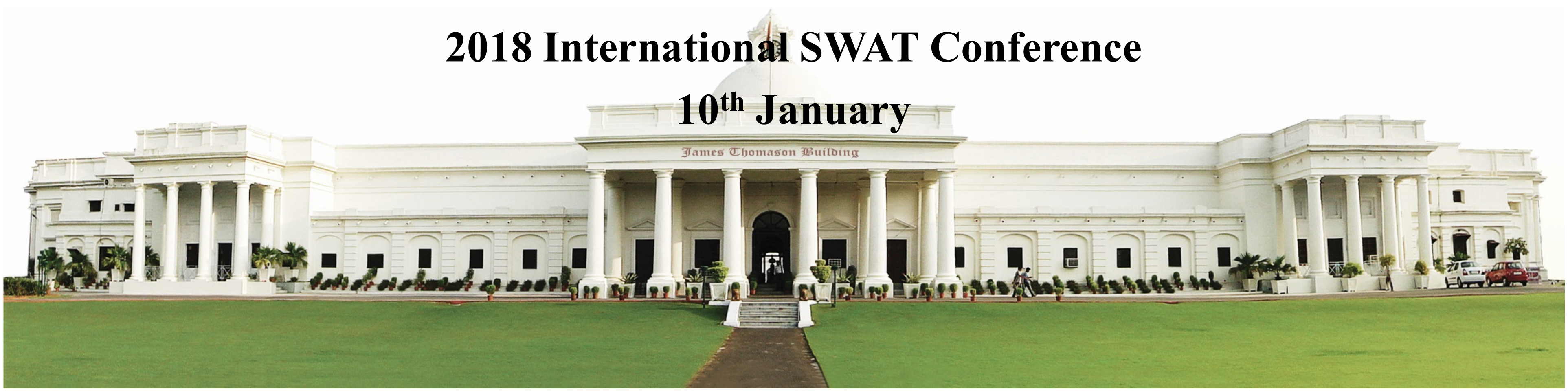


Motivation for the Study

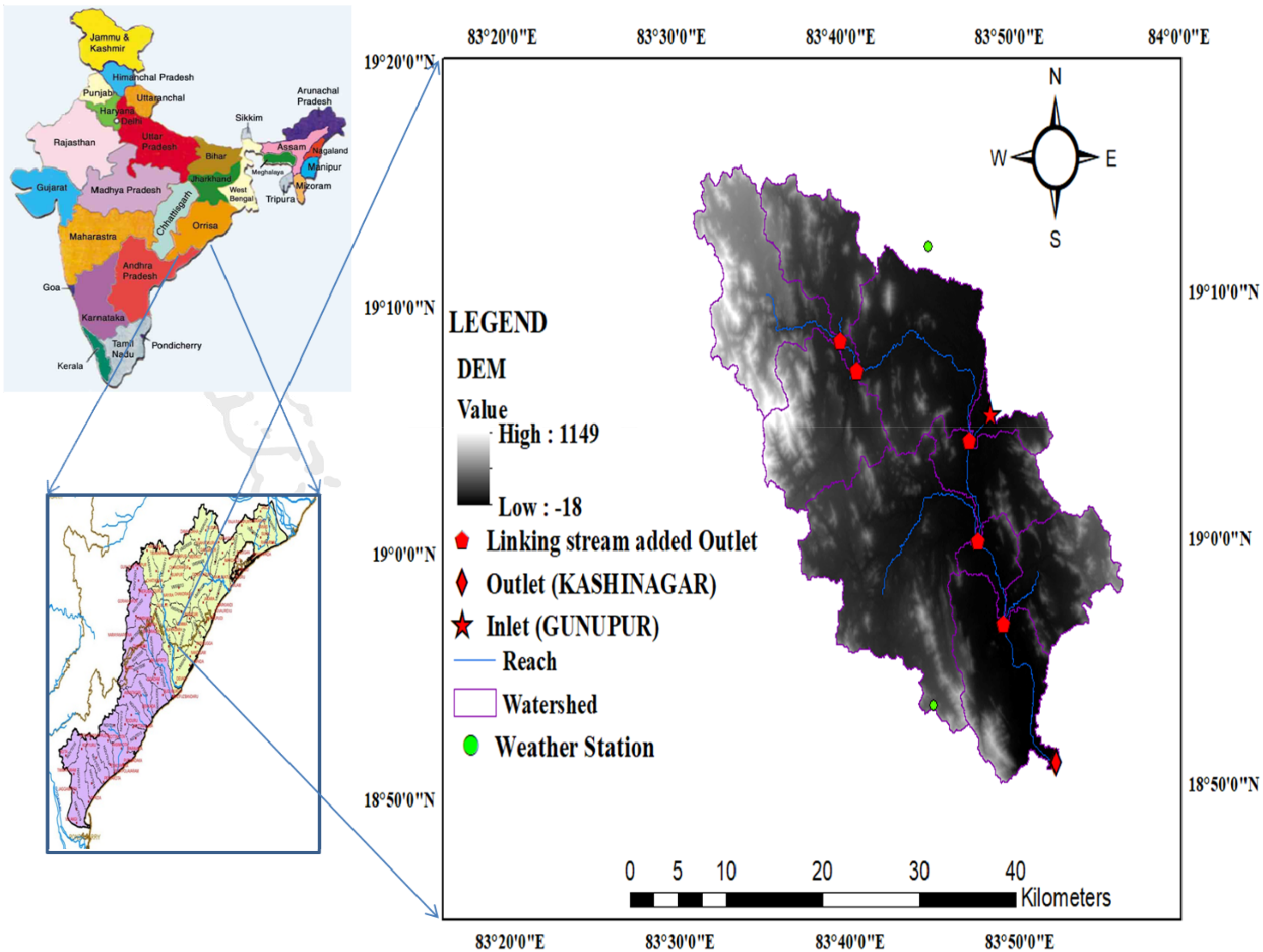
- ***Flood Routing*** *generally uses*

1.Hydrologic routing (consist of ***continuity equation + storage equation****)*

2.Hydraulic routing (consist of ***continuity equation + momentum equation****)*

- ***But****, SWAT Model applied in watershed modeling*
  - *uses the hydrologic routing models, namely; Muskingum Routing Method and Variable Storage Routing Method*
- ***So****,* ***the objective is to compare the Muskingum routing scheme results of SWAT and VPMM model in the Vansadhara basin between Gunupur and Kashinagar gauging stations of Odisha***

Study Area Location



Study Area Description

- *Upstream station (**Gunupur**):altitude 80.25m above MSL*
- *Downstream station (**Kashinagar**):altitude 51m above MSL*
- *Reach length between upstream and downstream is around 32km*
- *Slope of the reach is calculated to be approximately 0.0009*
- *Average annual rainfall in the basin is around 1200-1400mm*
- *Being subjected to tropical climate, the basin has annual maximum and minimum temperature of about 33.28º C and 23.33ºC, respectively*

✓ ***For detailed description :(East Flowing Rivers Between Mahanadi and Pennar Basin, Version 2, by Central Water Commission and National Remote Sensing Center, (March 2014))***

Features of Muskingum Routing Scheme in SWAT Model *(Neitsch et al., 2011)*

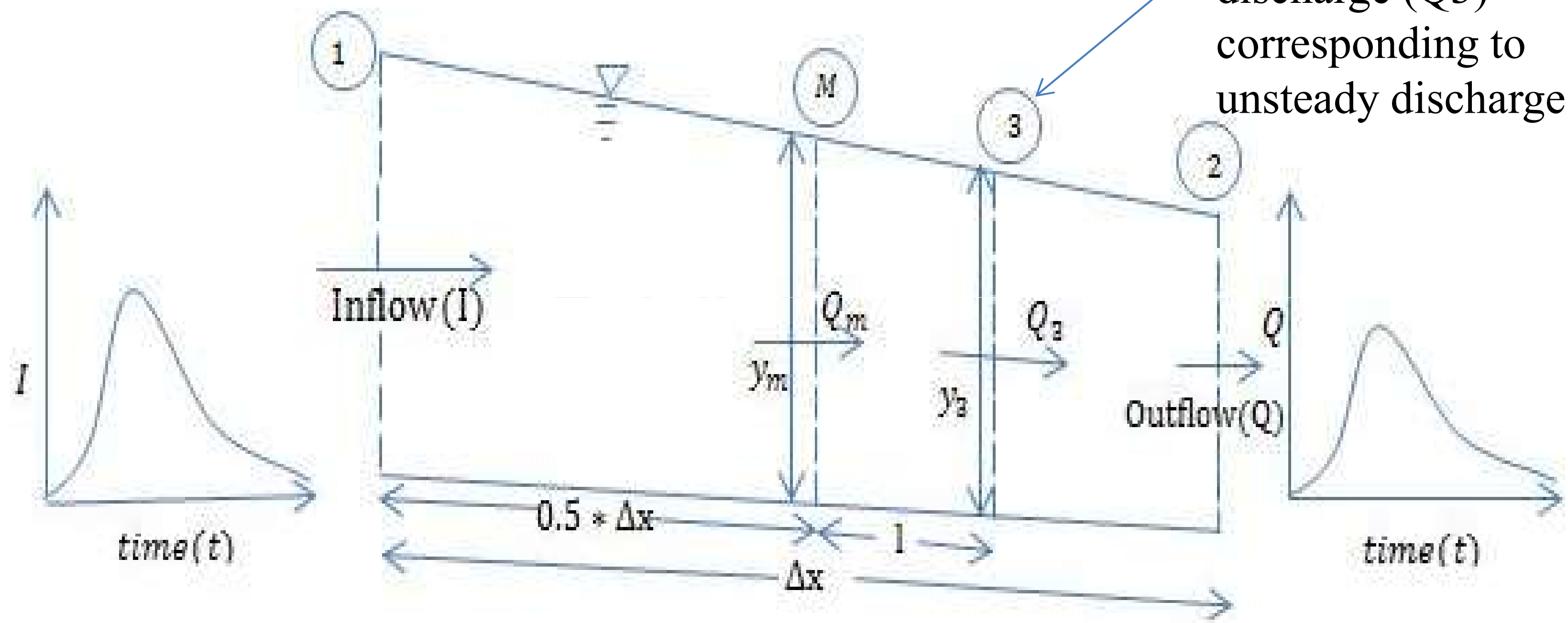
- $2K\theta < \Delta t < 2K(1-\theta)$ mandatory for numerical stability and to avoid negative initial flow
- Storage time constant (K) for the routing scheme obtained as $K = coef_1 K_{bnkfull} + coef_2 K_{0.1bnkfull}$, where *coef1* and *coef2* are user-defined parameter and K for bank-full and low flow condition are estimated by using Cunge (1969)'s expression
- θ is weighing factor (0-0.5), which is user-defined
- Cross-sectional area is assumed to be trapezoid
- Side slope of the main and flood plain is 1:2 and 1:4, respectively
- Bottom slope of flood plain is five times more than top width of bank-full width of main channel

Features of Muskingum Routing Scheme in VPMM Model *(Proposed by Perumal and Price, 2013)*

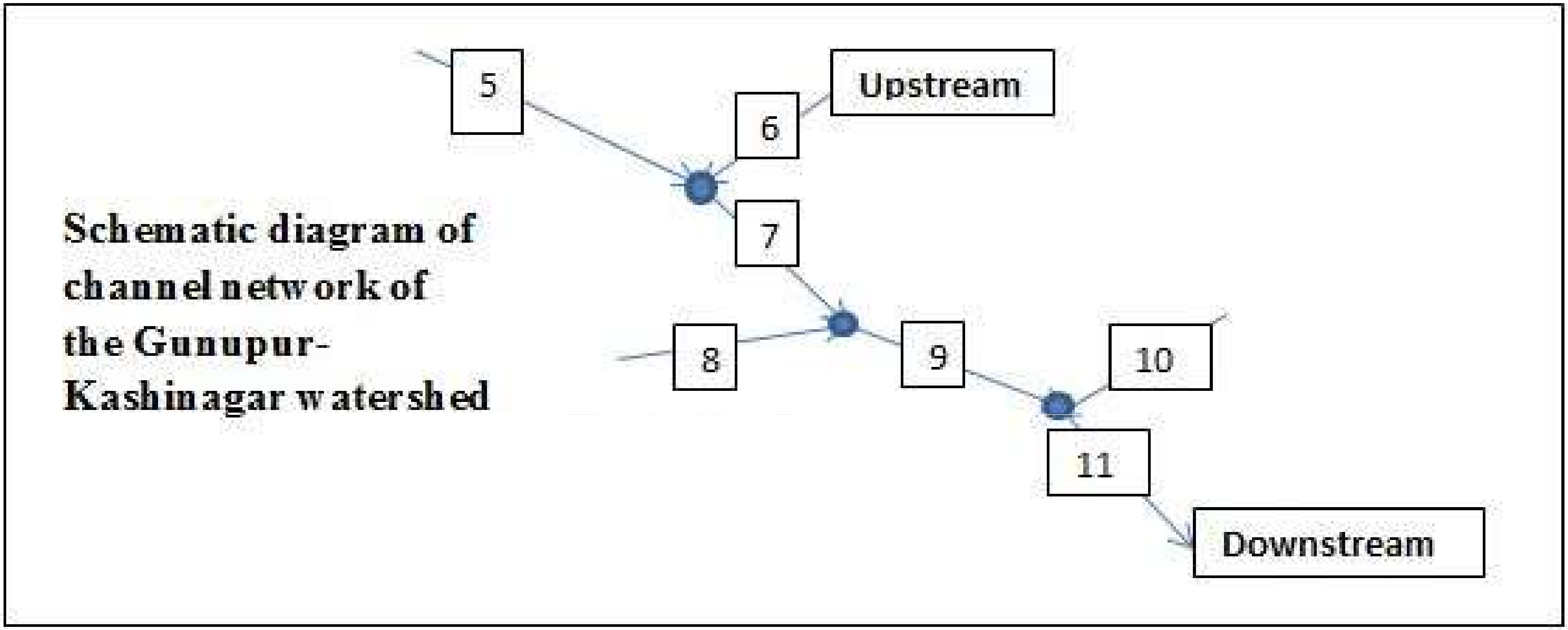
- *Discarded the Cunge (1969)'s postulate that "Diffusion in Muskingum scheme is due to numerical one, and has no physical basis."*
- *Derived from St. Venant's equation directly*
- *Takes into account the nonlinearity in the routing procedure*
- *No assumptions on type of prismatic channel cross-section for routing*
- *Weighing factor and storage coefficient obtained by physical basis*
- *Has following assumptions:*
  - *Prismatic channel cross-section is assumed*
  - *Point lateral flow is added to the Muskingum reach*
  - *The slope of the water surface* $\left(\frac{\partial y}{\partial x}\right)$, *the slope due to local acceleration* $\left(\frac{1}{g}\frac{\partial y}{\partial t}\right)$, *and the slope due to convective acceleration* $\left(\frac{v}{g}\frac{\partial v}{\partial x}\right)$ *are small in magnitude, but not negligible in comparison to bed slope (So).*

Definition Sketch of the Muskingum Reach

Section of normal discharge (Q3) corresponding to unsteady discharge (Qm)



Point Lateral Flow Determination for VPMM Model



SUB BASIN	LATERAL FLOW
6	Inflow6-(inflow to sub basin6)
7	Inflow7-(outflow5+outflow6)
9	Inflow9-(outflow7+outflow8)
11	Inflow11-(outflow10+outflow9)

Basic Governing Equation for VPMM Model

- $$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=0$$ **Continuity Equation**
- $$g\left(S_f-S_o+\frac{\partial y}{\partial x}\right)+v\frac{\partial v}{\partial x}+\frac{\partial v}{\partial t}=0$$ **Momentum Equation**
- **Final Governing Equation of VPMM model**

$$Q_{i+1}{}^{j+1}=\frac{\left(-2K^{j+1}\theta^{j+1}+\Delta t\right)}{2K^{j+1}\left(1-\theta^{j+1}\right)+\Delta t}Q_i{}^{j+1}+\frac{\left(2K^{j}\theta^{j}+\Delta t\right)}{2K^{j+1}\left(1-\theta^{j+1}\right)+\Delta t}Q_i{}^{j}+\frac{\left(2K^{j}\left(1-\theta^{j}\right)-\Delta t\right)}{2K^{j+1}\left(1-\theta^{j+1}\right)+\Delta t}Q_{i-1}{}^{j}$$

- **Where,**

$$k=\frac{\Delta x}{v_{0,M}} \quad \& \quad \theta=0.5-\frac{Q_{0,M}}{2*\Delta x*C_{0,M}*S_o*B_M}\left(1-\frac{4F_M{}^2}{9}\left(\frac{P\frac{\partial R}{\partial y}}{B}\right)_M^2\right)$$

Data Sources for the Study Area

Data Type	Scale	Source	Data Description
Topography	30 meter	Cartosat1,version3R1 (http://bhuvan.nrsc.gov.in/data/download/index.php)	Digital Elevation Model(DEM)
Land use land cover	30 meter	Landsat L7 ETM+ (http://earthexplorer.usgs.gov/)	Land Use and Land Cover map
Soil	1:50000	National Bureau of Soil Survey and Land use Planning (NBSS)	Soil map
Meteorology	daily	SWAT Global weather data (http://globalweather.tamu.edu)	Rainfall, Max-Min temperature, Relative humidity, wind data, solar radiation data
Hydrology data and Cross-section data	daily	WRIS data (http://www.india-wris.nrsc.gov.in/)	Daily discharge and cross-section data at gauging stations

SWAT And VPMM Model set-up for Calibration and Validation

- ✓ Calibration and validation done for 2004-2006 and 2008-2012, respectively on daily temporal resolution
- ✓ Sensitive parameters of the SWAT model are CH_N2, CH_K2, GWQMN and GW_DELAY in the decreasing order
- ✓ VPMM model set up and calibrated and validated for its single parameter manning's coefficient for the same period as SWAT model
- ✓ Both SWAT and VPMM model performances are optimized using maximization of NSE and R2
- ✓ Stage hydrograph of the corresponding discharge hydrograph obtained from VPMM is also compared to the observed stage hydrograph

Parameters Used in Model Calibration

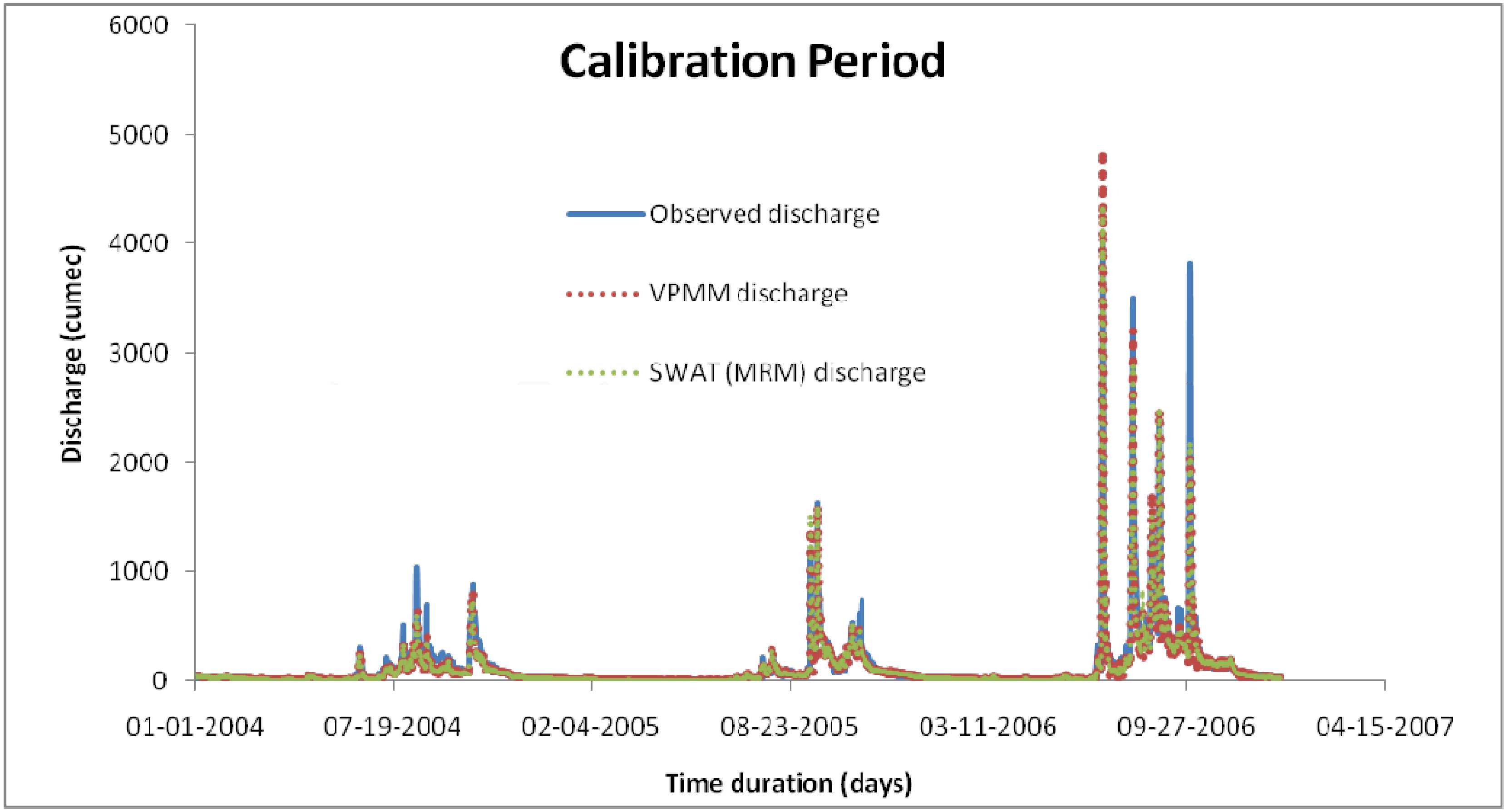
Parameter Name	Description	Min value	Max value	Calibrated value
SOL_BD ( )	Moist bulk density (g/cm3) (relative)	-0.5	0.6	0.197
CN2	Initial SCS runoff curve number for moisture condition II (n/a) (relative)	-0.2	0.2	-0.144
ALPHA_BF	Base flow recession constant (days) (replace)	0	1	0.697
GW_DELAY	Ground water delay time (days) (replace)	30	70	33.74
GWQMN	Threshold depth of water in shallow aquifer required for return flow to occur (mm) (replace)	0	1000	199.85
SOL_K ( )	Saturated hydraulic conductivity (mm/hr) (relative)	-0.8	0.8	-0.159
SOL_AWC( )	Available water capacity of soil layer (mm/mm) (relative)	-0.4	0.4	0.014
LAT_TTIME	Lateral flow travel time (days) (replace)	0	180	156.65
REVAPMN	Threshold depth of water in shallow aquifer for percolation to deep aquifer to occur (mm) (replace)	0	1000	889.99
SURLAG	Surface runoff lag coefficient (n/a) (replace)	1	24	13.420
CH_N2	Manning's coefficient for the main channel (n/a) (replace)	0.01	0.3	0.025
ESCO	Soil evaporation compensation factor (n/a) (replace)	0	1	0.618
EPCO	Plant uptake compensation factor (n/a) (replace)	0	1	0.467
CH_K2	Effective hydraulic conductivity in main channel (mm/hr) (replace)	0	130	0.347
GW_REVAP	Ground water "revap" coefficient (n/a) (replace)	0	0.2	0.144
CANMX	Maximum canopy storage (mm) (replace)	0	100	57.455

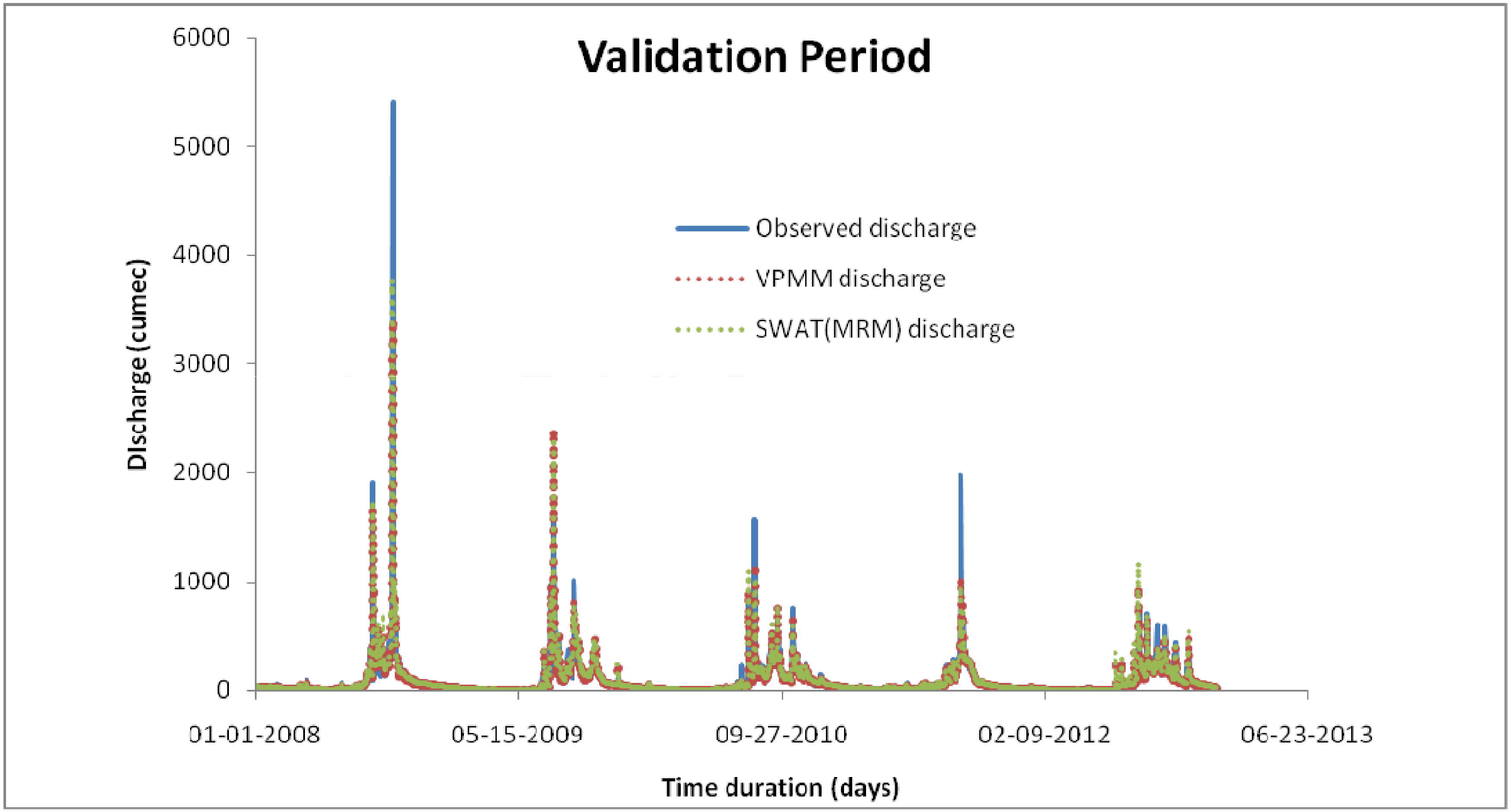
Test Statistics

Test Statistics for Calibration Period (2004-2006)		
	VPMM	SWAT (MRM)
NSE	0.89	0.92
R2	0.89	0.93

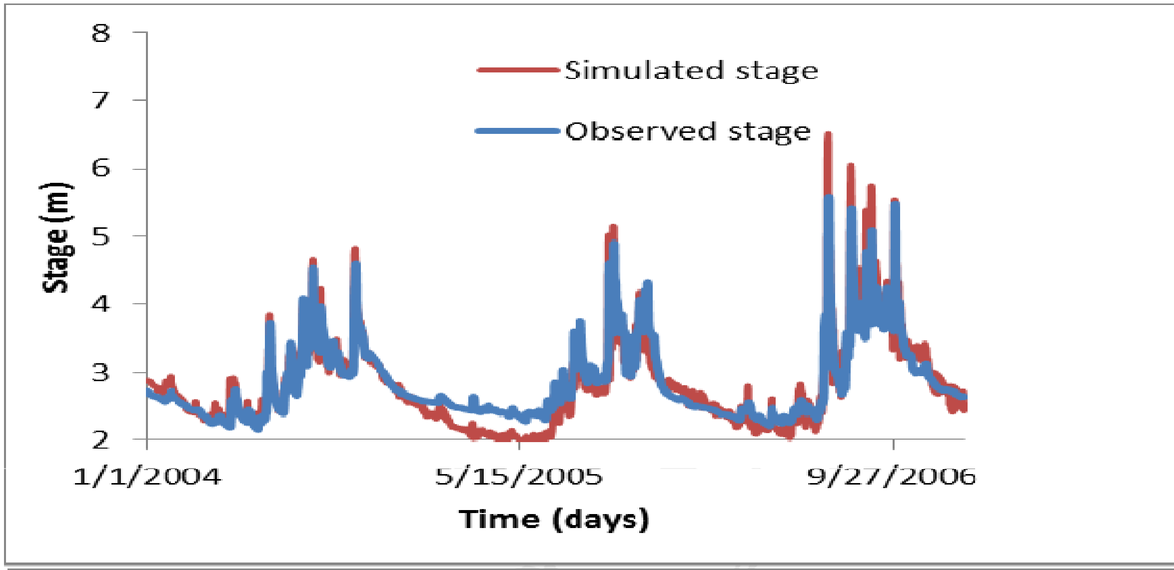
Test Statistics for Validation Period (2008-2012)		
	VPMM	SWAT (MRM)
NSE	0.72	0.71
R2	0.71	0.70

Test Statistics for VPMM stage simulation		
	Calibration	Validation
NSE	0.80	0.76
R2	0.90	0.83

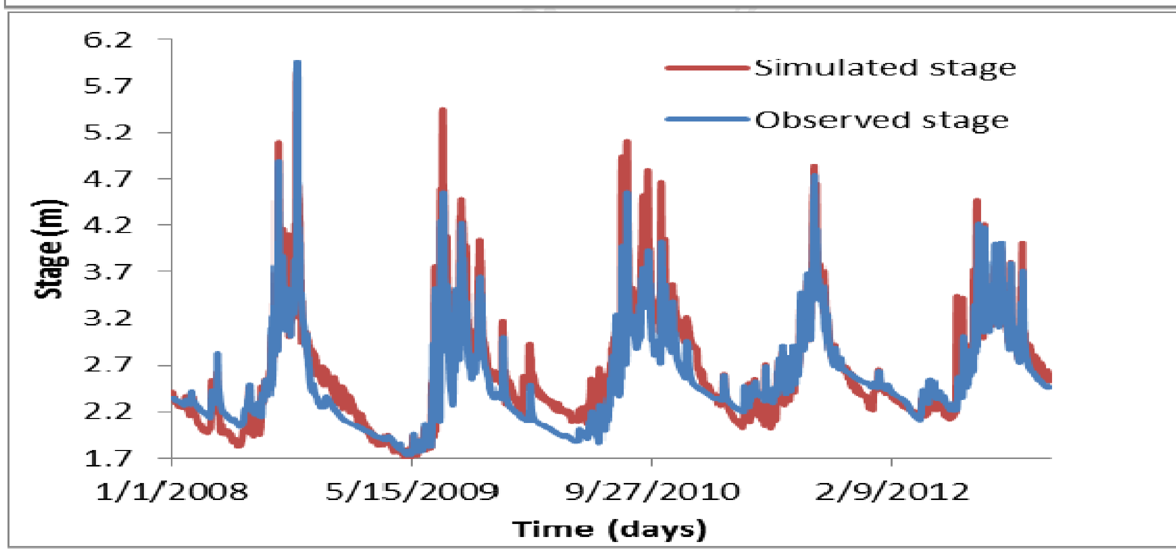

Calibration Period
Discharge (cumec)
6000
5000
4000
3000
2000
1000
0
Observed discharge
VPMM discharge
SWAT (MRM) discharge
01-01-2004
07-19-2004
02-04-2005
08-23-2005
03-11-2006
09-27-2006
04-15-2007
Time duration (days)


Validation Period
Observed discharge
VPMM discharge
SWAT(MRM) discharge
6000
5000
4000
3000
2000
1000
0
DIscharge (cumec)
01-01-2008
05-15-2009
09-27-2010
02-09-2012
06-23-2013
Time duration (days)

Stage Simulation Performance of VPMM Model



Calibration Period

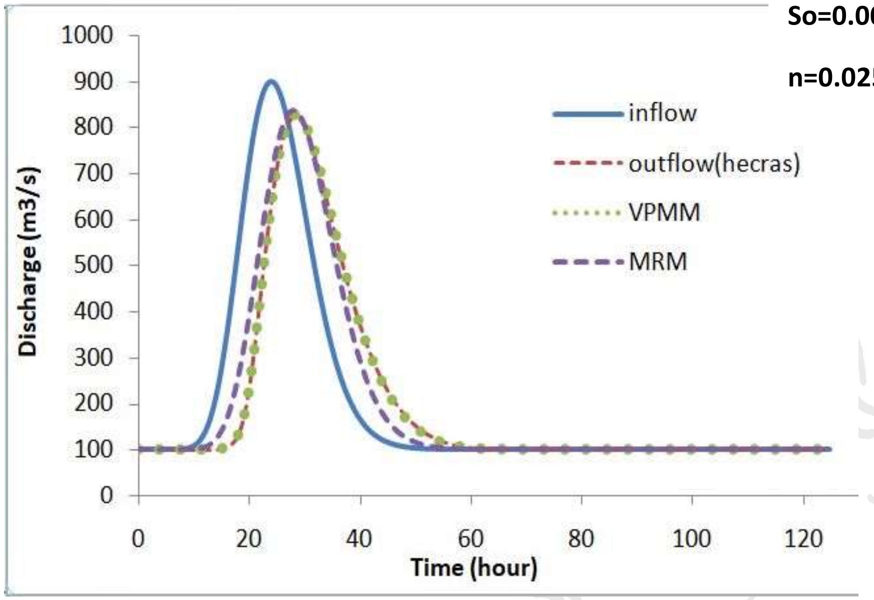


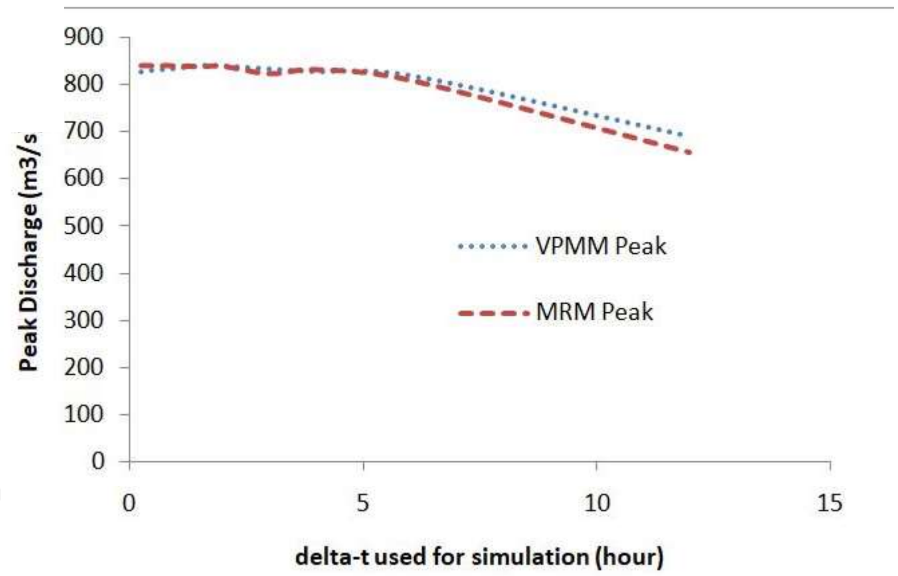
Validation Period

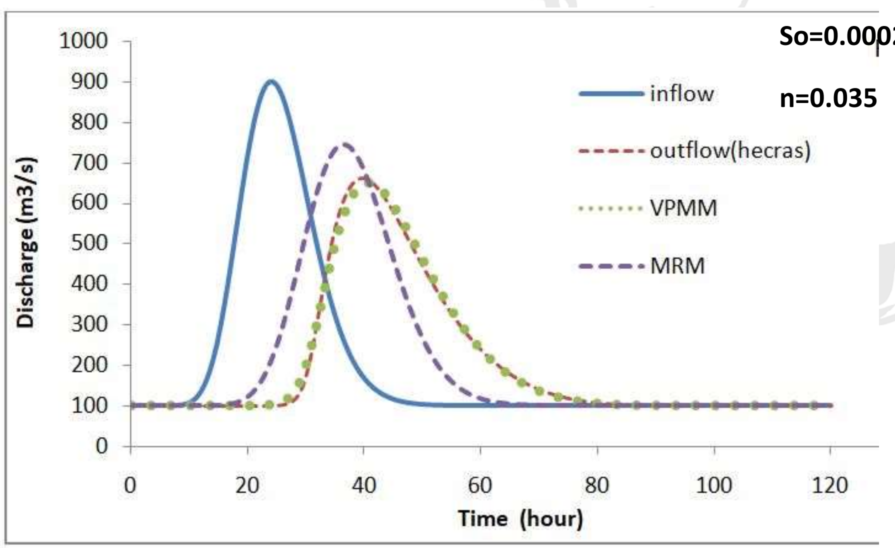
Performance Overview of Both SWAT and VPMM Model

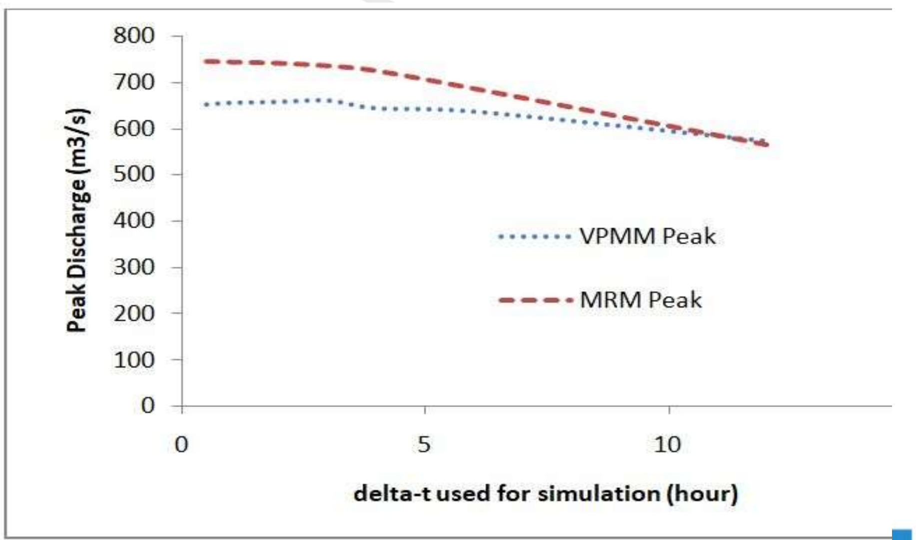
- Simulated peaks are not matching with the observed ones for both Muskingum routing methods.
- Reason of such underperformance could be attributed to the following reasons:
  - lack of well spread hydro-meteorological stations in the basin
  - numerical diffusion introduced by the routing schemes due to the use of $\Delta t >> K$ (the flood wave travel time in the reach) (Kim and Lee, 2010)
- VPMM model under-performance to that of SWAT model during calibration is due to
  - point lateral flow obtained from calibrated SWAT model output is added to the main channel for VPMM routing
    - ✓ Due to absence of gauging stations in the intermediate sub-basins
- But, VPMM performs slightly better in validation
  - Due to its physical basis for obtaining the storage coefficient and weighing constant

Performance Overview of Both SWAT and VPMM Model

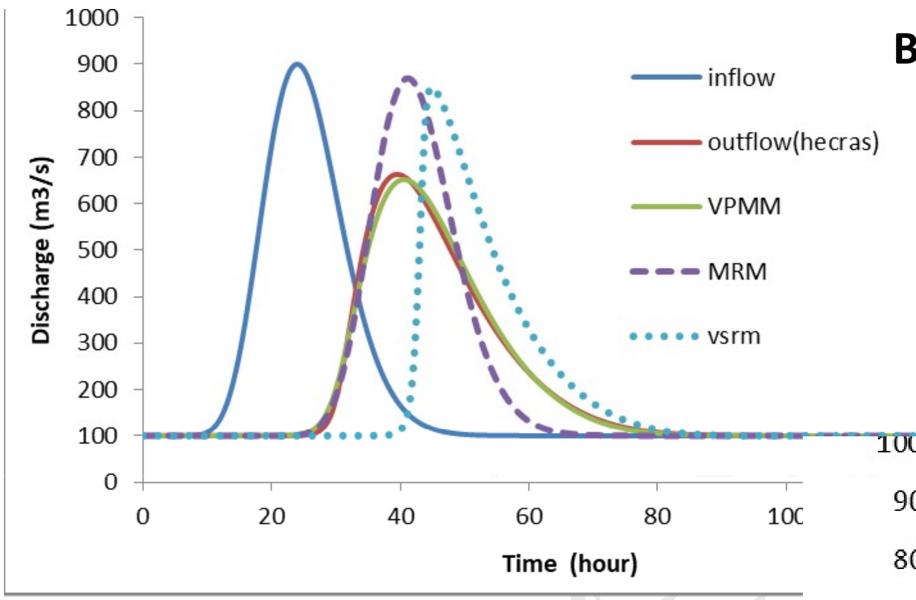


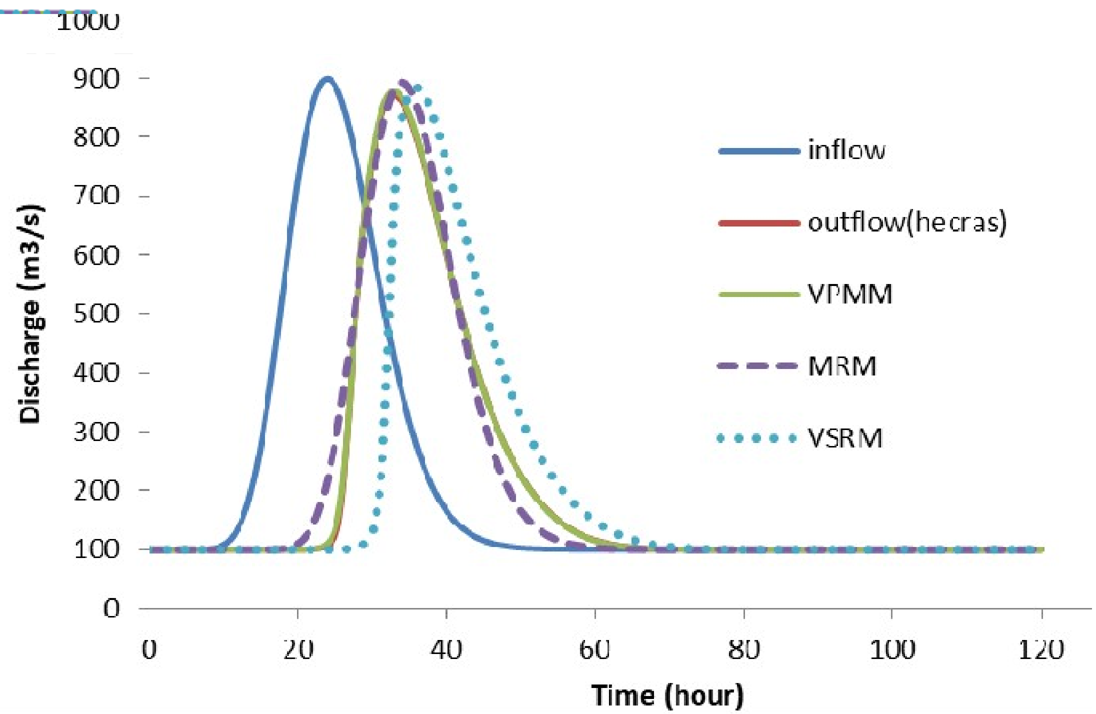






Benchmark solution for slope=0.00025





Benchmark solution for slope=0.001

Conclusions

- In the current study, VPMM model result is at par with SWAT model
- Under better data availability at the intermediate catchment, the result of VPMM could be improved
- VPMM has full physical basis with no theoretical limitation as that of MRM in terms of cross-section, amount of side slope etc.
- Stage hydrograph can be estimated corresponding to a discharge hydrograph at a section
- Utility of SWAT model can be improved by accurate estimation of stage value, which could be useful for
  - rating curve development and determining the possible inundated area under a probable flooding scenario
  - in-stream nutrient transformation studies
  - sediment routing

THANK YOU….