Open Source Parallel Computing Hydrological Model and its Application In Hydrological Analysis – A Review

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Abstract- *Hydrology is becoming integrated and interdisciplinary which increasingly relies on computer based models. In recent years, a growing number of open source hydrological models have been developed in parallel computing platform with the advent of high performance computer. Open source hydrological models provide a stimulating experience to the new users for hydrological analysis, where there is no in-house model. Increasing complexity of models and multitude of simulation requires more computational power. Therefore, parallel computational compatible hydrological models are key paradigm. This paper reviewed four hydrological models such as ParFlow (PARallel FLOW), PIHM (Penn State Integrated Hydrologic Model), Storm Water Management Model (SWMM) and Variable Infiltration Capacity model (VIC) with respect to their application in hydrological analysis, source code availability and compatibility in parallel computation.*

Keywords- hydrological model, open source, parallel computing

I. INTRODUCTION

Hydrological disasters are among the most destructive natural disasters, threatening lives as well as properties [e.g., 1; 2]. Due to climate change impact hydrological disasters are expected to occur more frequently at different times and locations on the Earth and become more catastrophic [3]. Hydrological analysis has significant importance for decision makers in taking anticipatory measures against extreme hydrological event. Hydrological analysis techniques include rainfall-runoff and hydrological and hydrodynamic flow routing models that aim to translate meteorological observations and forecasts into estimates of river flows [e.g., 4]. Advanced warning of impending hydrological events could save lives and help mitigate the impact. Computer based hydrological and hydro-meteorological models can generate hydrological simulations ahead of the actual event [e.g., 5]. Designing hydrological analysis system, the meteorological, spatial and non-spatial data are used into hydrological model to analysis the flood flow and corresponding water levels for different lead periods. Physically-based, spatially distributed hydrologic models have been widely used for larger watershed with course resolution for watershed management (e.g., flood forecasting) [e.g., 6]. High spatiotemporal resolution hydrological analysis and simulating of larger watersheds is a challenging because significant computational resources and data are required [e.g., 7; 8]. Restricted computing power has become one of the primary factors obstructing advancement in basin simulations for majority of hydrological models. Recent advancements in computational technology, the parallel computing is one of the most suitable approaches to resolve this problem. Rapid computation with high resolution modelling will require high performance parallel computer and suitable algorithms which utilise the computer power most efficiently. [e.g., 9].

In recent years, a growing number of open source hydrologic models (e.g., WRF-Hydro, Parflow, PIHM, Delft3D Suite, Anuga), commercial (e.g., MIKE Flood) and free (e.g., HEC-RAS) have been developed for hydrological analysis in parallel computing environments with the advent of high performance computing. With the development of the parallel computing techniques, computation capacity has been rapidly advanced [e.g., 9; 10; 11; 12]. Numerical models can be parallelized with the parallel algorithms, such as the Message Passing Interface (MPI) [20] that allows information to travel between different computers (nodes) and Open Multi-Processing (OpenMP) application program interface which allocate further breakup of operations to different cores (processors) [e.g., 21; 22]. Therefore, the availability of model source code, parallel programming tools and the high performance computer encourages the advance hydrological analysis. This study reviews the open source parallel computing models and its application in hydrological analysis

II. OPEN SOURCE HYDROLOGICAL MODEL

A. ParFlow

ParFlow (PARallel FLOW) was developed by Lawrence Livermore National Laboratory, USA [e.g., 13]. It is an open-source, object-oriented, parallel watershed flow model. ParFlow has been fully-integrated to coupled surface-subsurface flow to enable the simulation of hillslope runoff and channel routing [e.g., 14; 15]. The model solves flow in the subsurface using a 3-D form of Richards' [16] equation and includes surface runoff routing using the kinematic wave approximation for the shallow water equations as part of an overland flow boundary condition [15]. ParFlow has ability to simulate complex topography, geology and heterogeneity and coupled land-surface processes including the land-energy budget, biogeochemistry and snow (via land surface model – CLM) [e.g., 15]. It is also fully-coupled to a CLM and to a mesoscale atmospheric model (ARPS). ParFlow was designed for range of single and multi-processor parallel computing platforms and suitable for large scale and high resolution modelling [e.g., 14; 15]. ParFlow model have been used for overland flow simulation [15], surface and subsurface hillslope flow estimation [17], simulating urban watersheds using spatial data at the meter and sub-meter scale [18] and quantifing baseflow and overland runoff in heterogeneous hillslopes [19].

B. PIHM

PIHM (Penn State Integrated Hydrologic Model) is a physics-based, fully coupled, distributed, multiprocess and multiscale hydrologic model developed by the Pennsylvania State University (Penn State) [23; 24; 25]. This model simulates hydrological processes including overland flow, groundwater flow, channel routing, infiltration, evapo-transpiration, recharge and snowmelt as a fully coupled system [e.g., 26]. 1D Channel flow and 2D overland flow are based on Saint-Venant [27] equations. The model has been tested at both small-sized [e.g., 28; 29] and mid-sized watersheds [e.g., 24]. Triangular and rectangular elements are used in PIHM [e.g., 26]. Unsaturated flow and groundwater flow are described using the Richards equation [30], and the unsaturated hydraulic conductivities are calculated using the van Genuchten [31] equations. The model has been used various applications and project for example, watershed modelling for understanding hydrologic and hydraulic of the urban [32], predict streamflow volume in response to storms for a range of hydroclimatological conditions [33], simulate the long-term hydrological cycle for forest management practices and demonstrated the model capabilities in the OntoSoft project [34].

C. SWMM

Storm Water Management Model (SWMM) is a physically based hydrodynamic model that incorporates the Saint Venant differential equations. SWMM was first developed in 1969-71 by U.S. Environmental Protection Agency (EPA) [35]. It is a dynamic rainfall-runoff simulation model used for single event or continuous (long-term) simulation of runoff quantity and quality at various spatial and temporal scales [e.g., 35; 36]. The runoff component of SWMM generates a runoff based on the precipitation of the collection of sub catchment areas and the routing through a system of channels, pipes, pumps and storage units [e.g., 35]. SWMM measure the track the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps.

The hydrological response initiated by the subcatchments is simulated as nonlinear reservoirs while the hydraulic dynamics within the pipeline system are calculated via kinematics wave or dynamic wave approaches [35]. The SWMM tool is not capable of simulating a two-dimensional surface inundation effect (i.e. inundated depth and extent) and hence only provides descriptions of pipe and node flows (e.g. water depths in pipes, location and flood volume of overloaded nodes) as a reflection of the physical impacts of flooding due to system overloading.

D. VIC

VIC model (Variable Infiltration Capacity model) is a semi distributed grid based hydrology model which uses both energy and water balance equations. The model simulates results with the inputs of precipitation, temperature, wind speed and land cover types. VIC computes the infiltration, runoff, base flow etc based on various empirical relations. Surface runoff is generated by infiltration excess runoff (Hortonian flow) and saturation excess runoff (Dunne flow). VIC simulates saturation excess runoff by considering soil heterogeneity and precipitation. It consists of three layers, top layer allows quick soil evaporation, middle layer represent dynamic response of soil to rainfall events and lower layer is used to characterise behaviour of soil moisture. Kuchar,et al, [37], found that this model is flexible to integrate with various thematic domains, regions and data. The model is not explicitly written for parallel processing; however, VIC's design will support for parallelization.

III. DISCUSSION

Four open source parallel computation models have been studied and their utilizations are discussed here. ParFlow is suitable for simulating of surface and subsurface hillslope runoff, channel routing, overland flow and urban watershed [e.g., 14; 15; 18]. Ashby and Falgout, [14] and Kollet and Maxwell [15], found that ParFlow is appropriate for high resolution modelling on single to multi-processor parallel computers. PIHM is multiprocess and multiscale hydrologic model which used for computing and simulating of overland and groundwater flow, channel routing, infiltration, evapo-transpiration, recharge and snowmelt [e.g., 26]. SWMM is found to be suitable for simulating the runoff quantity and quality [e.g., 32; 38]. However, SWMM tool is not appropriate for simulating a two-dimensional surface inundation. VIC model is used for calculating infiltration, runoff, base flow etc. Present VIC model code support for parallelization but not explicitly written for parallel processing. Nijssen et al., [39] studied that this model performance is good in moist area. Singh et al., [40] found that VIC model can be efficiently used for agricultural water management.

IV. CONCLUSION

Open source parallel computing hydrological models were reviewed with the aim of assessing their suitability in hydrological analysis on parallel computers. Generally, hydrological models are the standard tools used for studying hydrological processes. A large number of models with different applications with different platform have has been developed. Each model has got its own unique platform dependent and particular applications. Models were assessed based on their availability of source code, flexibility and suitability with parallel computers. The selection criteria of the modes are naturally subjective, but important, where there is no in-house model. This technical review can provide as an initial step in the model selection for hydrological analysis. The identified candidate models need to be quantitatively tested over a unique parallel computer structure and number of basins to assess the hydrological performance before including any models into an operational framework.

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