# CHOOSING AN APPROPRIATE HYDROLOGIC MODEL

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**Abstract:** Hydrologic processes are very difficult to estimate due to their non-linearity and highly complex relationships among different parameters. The hydrologic processes depend on many parameters such as precipitation, temperature, relative humidity, wind speed, solar radiations, evapotranspiration, vegetation, soil characteristics, land use, land cover etc. which makes it much more complex and difficult to get a reliable relationship among all the parameters. This will further raise the question of getting compatible results with that of observed values. Choosing the right hydrologic model is very important for getting good results. Reliable results can be obtained if the right hydrologic model is chosen for a particular catchment having particular characteristics and the purpose of research. These results can be further used to find out the impact of climate change, change in land use, urbanization, forecast runoff and extreme events like flash floods etc.

This paper shows a brief review of the five hydrologic models viz. SHyFT (Statkraft Hydrologic Forecasting Toolbox), HBV (Hydrologiska Byråns Vattenbalansavdelning), MIKE SHE (Systeme Hydrologique European), HEC-HMS (hydrologic engineering center-hydrologic modelling system) and SWAT (Soil and Water Assessment Tool). The review is based on the model availability and accessibility, amount of input data required, routines available, size of catchment, available resolution of data, model calibration, required resolution of output, efficiency of the model in different climatic and topographic regions, and their limitations. This compilation of the five models will provide guidance to choose an appropriate model for a particular type of situation, problem, catchment size, region or condition for which these models are most appropriate. In this paper, a thorough summary of the compilation of these models is included in a tabular format by considering all the previously mentioned parameters and the directions for future research and scope is mentioned in the end.

**Keywords:** Hydrologic Modelling, Flood simulation, Distributed hydrological model, Hydrological Processes

**1. Introduction**: Hydrologic processes are the components of hydrologic cycle viz. precipitation, infiltration, runoff, evaporation, transpiration etc. Hydrological modelling is used to describe the relationship between the various hydrological processes and components in a hydrologic cycle. Rainfall-runoff modelling describes the process of generating streamflow hydrograph resulted from the excess rainfall onto the catchment, after considering various hydrological processes such as precipitation, evaporation, transpiration, groundwater, and interflow [31]. The different input data required by the models can be precipitation, air temperature, observed discharge, wind speed, relative humidity, solar radiation, evapotranspiration, land use, land cover, vegetation and soil characteristics, elevation data, snow cover etc. to obtain specific outputs, such as groundwater outflow, subsurface flow, overland flow or surface runoff to streams and the ocean, sediment yield etc. These results can be used to find out the impact of climate change, change in land use, urbanization etc. The other applications are to deal with various hydrological problems such as erosion, sediment control, planning and management of water resources, reservoir management, watershed and water resources management, drought and flood forecasting etc.

According to the Organization for Economic Cooperation and Development, the damage caused by worldwide floods is more than $40 billion and by 2050 the annual flood losses can be expected to increase five times and approximately 17 times by 2080 [33]. A flash flood event is categorized as flash floods if the flooding takes place within six hours of a causative event [19]. Hence, the flash floods more dangerous because of a very short timescale for runoff formation and propagation leading to unusually short warning times [26]. Flash flood is generally caused because of very intense rainfall in a very short time. It can also lead to landslides in the mountainous regions. Various basic review studies have been done in this area [9] [36]. A technical review of 24 hydrological models was provided by Kauffeldt et al. [25] for the implementation of large-scale hydrological models in operational flood forecasting schemes on a continental level. Sood et al. [37] reviewed 12 global hydrological models with a specific focus on strengths, weaknesses and structure of individual models and also discussed issues such as model uncertainty, data scarcity and integration of the models with remote sensing data. However, to our knowledge, no study has focused on which kind of model should be chosen before starting the actual simulations and how to choose the suitable model accordingly. Hence, this paper aims to provide a brief review of different hydrologic models on the basis of their suitability to different scenarios, climatic conditions, and the intended purpose of hydrologic modelling starting by providing an overview of the classification of hydrologic models.

**2. Hydrological Models:**

A hydrologic model represents the hydrologic processes in simplified form and mainly used for forecasting and understanding these processes. The best hydrologic model is the one, which is less complex but gives the result similar to the observed values by using the least input data [9]. The model determines the runoff based on the effects of several components of the hydrologic cycle i.e. evapotranspiration, surface storage, interception etc. All these components are a function of catchment parameters and give the output as runoff. Most of the hydrologic models have a function for defining the distribution of precipitation among these components. Depending upon the approach employed for defining the relationship between the input and output, the models can be classified into three main categories: black-box models, physical-based models and conceptual models [15].

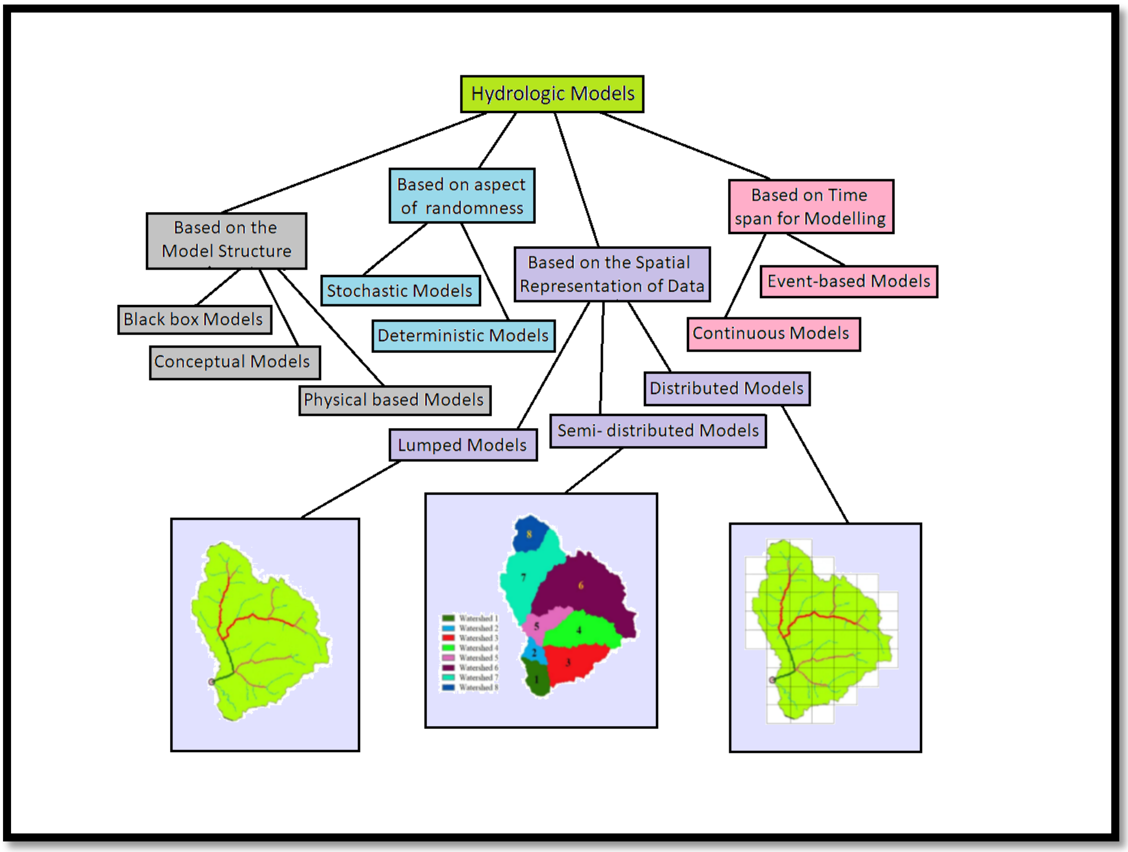


**Figure 1.**: Classification of hydrologic models

The black box models are also called empirical models or metric models. Results from these models are completely based on mathematical relation between the input and output [28]. In this kind of model, physical processes i.e. the catchment behaviour is generally not considered. Such models are usually good for modelling a particular area using available and analyzed data.

Physically-based models are deterministic models and also known as mechanistic models. These models are based on complex physical theories. These models need a huge amount of computational data and time. Physically-based models depend directly on the hydrological processes involved and use spatial discretization or other types of hydrological based units for the generation of streamflow. These models show the inside view of a procedure which helps to better understand the hydrological system. The conceptual models are also called parametric models or grey box. It can be said that these types of models are a substitution between black-box models and deterministic models [21]. Conceptual models are based on storage like reservoirs, lakes etc. which are filled through the various hydrological process. In such models, the different model parameters are calculated using the calibration approach based on time series of the rainfall and runoff. Such models generally consider the catchment as homogeneous.

Based on the aspects of randomness, the hydrologic models can be classified into two categories viz. Stochastic models and deterministic models. The output produced by a stochastic model has partial randomness whereas, a deterministic model, on the other hand, does not give randomness, which means these kinds of models work with a given input all the time and give the same output. So, it is possible to say that a stochastic model creates a prediction while a deterministic model makes a forecast [38].

Depending upon the distribution of input data in spatial and temporal scale, the hydrologic models are further divided as lumped, distributed, semi-distributed, continuous and event-based models. In lumped models, the whole catchment is considered as one and the average value of each parameter is used for the entire catchment. Hence the results are not that accurate for the large catchments. On the other hand, semi-distributed models divide the watershed into smaller sub-watershed units. Every sub-watershed has a separate set of model parameter values. Hence these types of models include spatial variability of the parameters and give better results than the lumped models. While in the fully distributed models, the watershed is discretized in a more detailed way into cells or a regular or irregular mesh. Further, the continuous models are used to estimate the discharge and other functions of the catchment over a long time period while the event-based models are used for the estimation of the runoff; only from a single storm event. These are normally used in designing purposes.

**3. Important aspects before selecting a hydrological model:** The efficiency of the results obtained by a hydrological model depends on many factors such as the method of distribution and resolution of input data, calibration method of the model, type of model, size and topography of study area etc. So, before choosing any model for flow simulation, one must find out wisely that which software or model would give better results for the particular application. Table 1 gives some basic guidelines aiding the selection of a suitable model.

| Que. 1 | Catchment Size? | | |
|---|---|---|---|
| | Small | Medium | Large |
| Model type | Lumped | Semi -Distributed | Distributed |
| Que. 2 | Catchment Relief ? | | |
| | Flat/Plain | Moderate/Hilly | Pronounced/Mountainous |
| Model type | Lumped | Semi -Distributed | Distributed |
| Que.3 | What is predominant flood causing rainfall? | | |
| | Seasonal | Frontal/ advective | Convective |
| Recommended data resolution | Daily | Daily/ hourly | Hourly/ sub-hourly |

**Table 1**: Some standards for model selection [43]

a) **Model availability:** A model should be easily available for use either open source or through agreements along with an active developer community and the possibilities of adaptation to specific purposes. Open-source models also allow users to perform modifications.

**b) Type of Model:** Type of model to be used can be decided based on the catchment size and relief as shown in table 1 and according to the additional required features.

**c) Input data requirement:** The model selection depends largely upon the available input data. If the distributed or gridded data is not available, the lumped model is the only option. Whereas some models have large data requirement which leads to difficulty in model calibration and validation.

d) **Spatial and temporal distribution:** The required resolution of the data depends on the predominant rainfall which is causing a flood in the area. If the flood is caused by seasonal rainfall than the daily data will be required, if it was because of frontal or advective rainfall then the daily or hourly rainfall data required. On the other hand, if it is the convective rainfall, then the hourly or sub-hourly rainfall is required. Require resolution of the data also depends on the purpose of modelling. For example, in case of flash flood simulations and forecasting, higher temporal resolution is required, so the model should be capable of simulating hourly or even sub-hourly time step. Whereas, the temporal resolution of daily time steps is good enough for long term simulations. Similarly, the model which is capable of working high spatial resolution should be chosen for small catchments.

**e)** **Model calibration process:** Model calibration can be done either manually or automatically. Manual calibration is usually time-consuming and requires experienced users. If the option for automatic calibration is provided in the model, one of the factors for model selection is that there are a limited number of calibration parameters. It is better if there is an option of combining the manual and the automatic calibration.

f) **Additional features:** Depending upon the purpose of modelling, the model should have options for choosing additional routines such as snow routine, soil routine, storage routine, response function and routing etc.

**g)** **User community/assistance available:** The user community should be large enough to provide sufficient assistance without having waited long in case one gets stuck in the process. There should be a good platform to share problems, where one can get the solutions quickly because the developers may not be always available to assist quickly.

**4. Models included in the review:**

The models reviewed in this study are commonly used and popular models which gave satisfactory results in previous research studies. Several researches have been done on these models either individually or in comparison to the other models. All the 5 models selected for this study are described briefly in the following section.

**HBV** (Hydrologiska Byråns Vattenbalansavdelning) was developed by SMHI (Swedish Meteorological and Hydrological Institute). It is a semi-distributed conceptual model which allows dividing a catchment into sub-catchments, these sub-catchments are then further divided into zones based on vegetation, lake area and altitude. It has many different versions such as Norwegian, Swedish, Finnish, Swiss etc., but today we can find many other versions of HBV model for different regions and different climatic conditions in the world. HBV is generally used at daily time steps, but it is possible to use shorter time steps also. This model can also be used partly in other models. HBV consists of many sub-routines too such as evapotranspiration estimation, meteorological interpolation, a soil moisture accounting procedure, snow accumulation and melt, routines for runoff generation and a simple routing procedure between sub-catchments and lakes. This model can be used for flood forecasting, to extend runoff data series or filling gaps, compute design floods for dam safety, simulating climate change effect spillway design floods simulation [3], for data quality control, water resources evaluation [24] [5], simulating discharge for ungauged catchments, nutrient load estimates [1] and investigating the effects of changes within the catchment.

**MIKE SHE** is a commercial model and not available in the public domain. It was developed by the Danish Hydraulic Institute (DHI). It is a distributed, physically based hydrological model and it gives quantitative results for the hydrologic water cycle if it is successfully calibrated for the parameters. This software can simulate various processes of the hydrologic cycle [32] [34]such as precipitation, infiltration, evaporation, evapotranspiration, interception, subsurface flow in saturated and unsaturated groundwater flow, surface flow etc. It can also simulate the pesticide, nutrient and sediment transport in an area, movement and the interaction of surface and groundwater and various water quality problems etc. This model couples the unsaturated zone flows with the overland flow processes by explicit simulations and generates high-resolution time series including the soil water content. it is a raster-based model and it has the capability to work in several temporal and spatial scales and account for different temporal and spatial variabilities of the watershed characteristics.

**SHyFT** (Statkraft Hydrologic Forecasting Toolbox) is an open-source integrated hydrological modelling toolbox, which was developed by Statkraft. It is the successor of the ENKI model, an early initiative for distributed hydrological simulation, which was developed at Sintef but funded by Statkraft [39]. This toolbox is constructed using open-source components in C++ and provides a high-level python-based interface which also allows the user to add their own codes to the orchestration [39]. It is based on the concept of lumped and distributed models. It can be used for hourly or daily meteorological inputs [6]. It provides an optimized platform for efficient modelling of hydrologic processes. SHyFT can be used for many different applications depending on the method of composition and parameters selected, such as forecasts for flood, snow, runoff, reservoir etc. It is a flexible framework in which model can be customized for the different processes of the hydrologic cycle, for example, Priestley Taylor for evapotranspiration, Kirchner routine for generating runoff response, Gamma snow, Skaugen snow or HBV snow routine for generating the snow response. Depending on the methods chosen, the framework contains 4 model stacks: PTGSK, PTHSK, PTSSK and HBVStack [13] [35]. This toolbox divides the whole catchment into grid cells.

**HEC-HMS** (Hydrologic Engineering Center- Hydrologic Modelling System) is developed by the US Army Corps of Engineers. This model was designed to simulate the hydrologic processes of watershed systems to deal with water balance equation for continuous as well as event-based hydrologic modelling [2] [23]. It is broadly used for precipitation-runoff simulation for a wide range of geographic areas by taking the important parameters into account such as various losses, base flow, direct runoff, river routing and the reservoir components [10]. It uses different models to represent different components of the rainfall-runoff scenario [28] such as meteorological component, precipitation loss component, direct runoff component, river routing component, reservoir component etc. The precipitation is distributed temporally and spatially over the whole catchment by the meteorological component as the first computation unit. The precipitation losses are modelled by the precipitation loss component [8] [11]. After computing the losses, the access rainfall is subject to either as direct runoff to the overland flow or subjected to the groundwater flow which is modelled by the base-flow component [11] [27]. The river routing component computes the attenuation and translation of the river flow after the base flow and overland flow has entered to the river channel [8]. The effects of the reservoir, ponds, lakes, wetlands, detention basins and natural depressions are computed in the end by the reservoir component [40].

**Assessment of the models:**

| S.No. | Models → <br> Criteria for comparison ↓ | HBV | SHyFT | SWAT | MIKE SHE | HEC-HMS |
|---|---|---|---|---|---|---|
| 1. | Model availability | Some simplified versions of the model are freely available | Freely available platform as open source | Open source | Commercial | Freely available |
| 2. | Type of model | Conceptual model | Conceptual distributed hydrological framework | Conceptual, Complex physically based model | Deterministic physically based model | Conceptual physically based model |
| 3. | Watershed representation | Semi-distributed | Fully-distributed: watershed divided into grid cells | Semi-distributed: Sub-catchments grouped based hydrologic response units and climatic conditions | Fully-distributed. rectangular/square overland grids | Semi-distributed |
| 4. | Input required | daily values of rainfall and air | precipitation, discharge, relative | hydrologic response units (HRU), DEM, land | Topography, Precipitation | hydro-meteorological data (rainfall and stream flow) |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | temperature, and daily or monthly estimates of potential evaporation, Air temperature can be omitted in snow free areas. | humidity, temperature, radiation, wind speed, catchment area, elevation, forest cover, lake percentage, Glacier fraction | use map, vegetation and soil characteristics, Daily rainfall data, maximum and minimum air temperature, solar radiation, relative air humidity and wind speed, and monitoring flow gauges | Evapotranspiration, additional data depending on the application; e.g. soil map, LULC radiation, temperature, etc. | and physiographic data (DEM, LULC and soil type) elevation, percent impervious area, and hydrograph information |
| 5. | Time scale | Usually daily, but possible to use shorter time steps | Both hourly and daily meteorological inputs | Efficient in long term simulations but possible to use for sub-daily and sub-hourly simulations. | Integration of various hydrological processes at different timescales is possible | Both daily and hourly simulations are possible |
| 5. | Model calibration | Option for automatic calibration is | Codes for model calibration are available. | built-in automatic calibration subroutine but combination of | Option for calibration is available. | Combination of manual calibration and automated |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | available. Calibration can also be done for each sub-catchment individually. | | automatic and manual calibrations is possible. | | calibration provided by the software. |
| 6. | Evapotranspiration | Penman formula (Penman, 1948). | Priestley–Taylor (PT) method (Priestley and Taylor, 1972) for estimating potential evaporation. | Penman Monteith, Priestly- Taylor and Hargreaves methods are used for the estimation of evapotranspiration. | Kristensen and Jensen (1975) method. | A gridded version of Penman Monteith and Priestly- Taylor methods are available. A user-specific method developed outside the program can also be used. |
| 7. | Additional routines | Snow-melt routine, soil routine, storage routine, response function and routing. | Snow response, soil routine, glacier melt | Subsurface flow, routing, channel sedimentation, chemical simulations, storage routine. | Subsurface flow, channel routing, sedimentation. | For snowmelt calculation, a temperature index method is available. |

**SWAT** (Soil and Water Assessment Tool) was developed by USDA's Agriculture Research Service. It was developed to forecast and evaluate the impacts of management practices on water, agricultural chemical yields and sediment circulation. It is a conceptual, physical-based and distributed catchment-scale model. In this model, the catchment is divided into sub-catchments and theses sub-catchments are further divided in hydrologic response units (HRU). HRU is the homogeneous units of soil type, land use and slope. This tool gives good results in long-term simulations, but it can also be run for sub-daily and sub-hourly time steps [4] [22] [44]. The applications of SWAT are in the fields of weather, hydrology, water and sediment circulation, soil temperature, vegetation growth, nutrients and pesticides circulation, agricultural management, water transfer, channel and reservoir routing.

**5. Assessment of the models:**

The HBV model was applied for a flash flood event in 645.7 km2 catchment [16]. Even though the observed data were not sufficient to evaluate the model because of damage of the rain gauge station, the model gave good results. There is a growing discussion of whether or not the conceptual rainfall-runoff models are able to simulate the water balance as the climatic conditions are changing [7] [12]. Under the changing climatic conditions, the calibrated parameter for a model might not be valid in a few years. Furthermore, the inadequate model calibration and validation strategies may contribute to bad temporal transferability of models. The HBV model has been broadly used and it has shown good results during evaluations, but the model requires additional enhancements on its conceptual model structure so that it can better quantify the effects of both changing climate and land use [20].

The performance of three distributed models (MIKE-SHE, SWAT, APEX) was evaluated in a study [14] for their capability to simulate the hydrologic processes for a catchment of 52.6 km2 area in Canada. All three models were tested using both quantitative and qualitative methods. The mean monthly/daily flow was simulated using the same discharge data and the results showed that MIKE SHE gave slightly more accurate results than the other two models. Another method was developed by Yu in [44] to perform event-oriented flood simulation using SWAT model on a sub-daily timescale and at the same time improved the unit hydrograph UH method which was originally used in the SWAT model for a large catchment. SWAT is an open-source code model, which makes it possible to perform such a modification. In another study by [30], runoff was simulated using MIKE-SHE model, and the results showed that the model is able to reproduce the runoff mechanisms for different periods which show different hydrological characteristics. But for high discharge periods, the model produced several underestimations as compared to the other periods with decreased runoff for which the model gave good results.

HEC-HMS is simple to operate, uses common methods and has the ability to simulate runoff in short events as well as in long events, therefore it has been implemented in many hydrological studies and became very popular. The accuracy of the simulated results was superior for the results from HEC-HMS, when it was compared with the traditional hydrological models [45]. Gumindoga in [17] found that the HEC-HMS model performance was good enough to be applied for ungauged runoff simulation. It successfully simulated total runoff volume but peak discharge with some peaks over-simulated. Nyaupane in [29] focused on the use of HEC-HMS for forecasting the highest flow condition in a small watershed (15.46 sq.km) and found that HEC-Geo HMS is a powerful tool to delineate natural watersheds and do automatic extraction of basin parameters for the preparation of HEC-HMS model. HEC-HMS was used in combination with GIS technology by Halwatura and Najim [18] and Gumindoga et al. [17] to simulate runoff in a data-scarce tropical watershed. The results showed that this model can also be used in flood forecasting research for simulating floods. Five models were selected for a comparative study of flood simulation in a hilly watershed by Wang et al. [41]. The study showed that HEC-HMS was the most suitable and effective hydrological model for rainfall-runoff simulation in case of heavy rainfall in short duration.

The publications using SHyFT is very limited but the available publication [13] [42] shows that the SHyFT framework has extraordinary features to allow a single model to have multiple differential parameters, using separate calibrations for the wet winter-spring season, and the dry summers. But the downside of the framework is the accessibility for users with limited knowledge of programming, and a bit high threshold to overcome. Also, certain elements in preparation, calibration and running the model has relied heavily on immediate access to developers and personal communication.

## 6. Conclusive remarks:

Based on all these research studies it can be concluded that the performances of hydrological models are very site-specific. And also, because no one model is perfect and better than the others under all conditions, the models should be applied to different watershed scales and hydrologic conditions for a complete understanding of overall comparative model performance. Other than this, every model has its own characteristics and respective applications. Also, every model has various drawbacks such as large data requirement, lack of user-friendliness, absence of clear statements of their limitations etc. Data scarcity and deficiency makes the calibration process difficult to fit the observed and simulated values. Therefore, the modelling process should always be provided with proper available data sources from the actual field-based measurements.

Also, all the models are associated with uncertainties; therefore, the comparison of models based on the evaluation criterion can help in identifying the uncertainties. The accurate estimation of model parameters plays a critical role by influencing the accuracy of the model prediction. The hydrological model selection for a specific application is mainly dependent on the primary processes which generate the runoff and their temporal and spatial extent, spatial coverage and resolution of data, and also on catchment features. This study is only the first step in the model selection process, these models should be further tested and compared quantitatively on various catchments to analyze the performance of each model and access the suitability based on the study for a particular kind of catchment.

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