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A Study on Estimation of Rainfall-Runoff Simulation Accuracy for Rihand Catchment with Remote Sensing Data Using Physically based Semi-Distributed HEC-HMS Model

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Abstract: ***Hydrologic modelling serves as a frequently employed tool for comprehending the processes of rainfall runoff in both monitored and unmonitored catchment areas, facilitating accurate quantitative assessment of water resource availability. In the present study, an attempt has been made to simulate surface runoff using physically based semi-distributed hydrological model for large scale catchment of Rihand River, called Rihand catchment, situated in Chhattisgarh state of India. The input physical parameters of the model were calculated and pre-processed based on Digital Elevation Model (DEM). The special focus in this study was utilization of Global Curve Number Grid data for computation of Curve Number of each subbasin of the catchment. This GCN250m grid data downloaded from Google Earth Engine, which saved the time consumption and data processing of Landuse and soil maps for computation of Curve Number for each subbasin. The loss method of Soil Conservation Service Curve Number (SCS-CN), and transform method of Soil Conservation Service Unit Hydrograph (SCS-UH), and Muskingum routing methods are adopted for simulation. Hydro-Meteorological data collected from 3 rain gauge stations from IMD-Pune. In and around Rihand catchment. The model performance was satisfactory with Nash Sutcliffe Efficiency (NSE) 0.512 to 0.706 and the coefficient of determination (R^2) 0.637 to 0.709, also PBIAS varies from 11.6 to 44.8 during calibration (2016-2017) and validation (2018). The established methodology is deemed applicable in unmonitored catchments, aiding water resources management and planning endeavors within projected future climate scenarios. This approach assists hydrologists in comprehending the effectiveness and utility of the HEC-HMS model for rainfall-runoff simulation modeling.***

Keywords: Hydrologic Engineering Center, Flow Hydrograph, Rainfall-Runoff, Curve Number, SCS-Unit Hydrograph

1. Introduction

Globally, the simulation and prediction of rainfall-runoff flows in gauged and ungauged catchments is considered vital for understanding the hydrological problems and practical applications. Accurate watershed hydrologic modeling is crucial for understanding the intricate relationship between rainfall and runoff. This understanding is vital for quantifying water resources and facilitating efficient system management, analysis and design. The rainfall-runoff modeling is a helpful tool for water resources managers and engineers to manage water resources projects and to mitigate floods and drought consequences. However, watershed modeling, not only needs adequate and large set of Spatio-temporal data (e.g., topography, land use/land cover. Soils, rainfall and flow monitoring, data), it also needs a sound understanding of Rainfall-Runoff processes of a particular watershed for accurate estimation of runoff quantity, flood and drought management and overall assessment of the watershed response as a part of strategic and master planning **[1]**. The choice of modeling approach typically hinges on its intended purpose, data availability, and user-friendliness. However, the dilemma lies in selecting a rainfall-runoff model that can precisely replicated hydrological processes across diverse climate conditions and with the given data **[2]**. Generally, stochastic and deterministic hydrological models are available based on output partial randomness and no randomness, respectively. The deterministic models further categorized into lumped and distributed models while the distributed models further classified into physically based semi-distributed and fully distributed models depends on distribution description. Distributed hydrological models have been found to be suitable for simulating a rainfall-runoff process in gauged watersheds successfully for the last four decades, but the representation of flow in ungauged watershed remains a challenge among the hydrologist **[3].** In the ungauged case, it is generally accepted that physically based hydrological models are a better choice **[4].** Physically based models are distributed and truly representative of the real hydrological processes with confident parameter quantification in catchment. In ungauged catchment, the model parameters are calculated from the existing climate and physiographic characteristics of the catchment. The parameters of physically based models are quantified using measurable physical properties, avoiding the necessity of calibration against observed data HEC-HMS model is a process based physical model with parameters to be estimated directly from field data and remote sensing data. The continuous and event based hydrological modeling of gauged and ungauged dendritic watershed systems has been performed using HEC-HMS model in different regions. Confidently validated the HEC-HMS model in Hoovinahole gauged watershed, India, and applied reliable calibrated parameters to neighbor ungauged Doddahalla agricultural watersheds for rainfall-runoff modeling and estimation of stream flow and peak flow **[5].** Simulated the flow regimes at ungauged sites in the southern California using HEC-HMS rainfall-runoff modeling where the HEC-HMS model was first calibrated and validated at different gauge locations and then HEC-HMS model associated with the most proximal gauge was assigned to each ungauged site **[6]**. Hydrological models mainly depends on the input data, hydrological parameter and structure of the model, particularly modeling in ungauged catchment using the climate and physiographic characteristics such as topography, land use, soil, vegetation and climate data **[7]. [8].** Similarly, for ungauged catchment flow simulations, the HEC-HMS underestimates high flows during the early wet season, and overestimates low flows in the late dry season **[9].** Ungauged river understanding and modeling for water resources management and planning such as the Keseke River catchment in South Ome River basin by using hydrological model (HEC-HMS) with GIS and Remote Sensing techniques can provide important information and analytical capability to hydrology and water resource assessment of the given river catchment **[10]**.

Hydrological Engineering Center-Hydrological Modeling System (HEC-HMS) is a semi-distributed physically based hydrological modeling software developed by the US Army Corps of Engineers. HEC-HMS is an integrated physically based simulation tool for all hydrologic processes of dendritic watershed systems and parameters can be directly measured from watershed. Importantly it provides reasonable results, beyond the measurement of the parameters, since the model maintain the physical laws of the process **[11]**. It has been adopted in many hydrological studies with a wide variety of watershed types to simulate the Rainfall-Runoff processes (rainfall loss, direct runoff, and routing) both in short and long time events due to simple operation, and the choice of various models for each segment of the hydrologic cycle **[12]**. The HEC-HMS model has been used in many studies to analyse urban flooding, flood damage reduction, flood warning system planning, floodplain regulation, flood frequency, reservoir and system operation, environmental flows and river restoration, water supply planning, etc **[13].** The runoff simulation by continuous Rainfall-Runoff models in ungauged catchments can also be used to estimate low flow **[14].** The continuous and event based hydrological modeling of gauged and ungauged dendritic watershed systems has been performed using HEC-HMS model in different regions. To name a few, Lake Tana Basin, Ethiopia [15], Simly dam watershed, Pakistan [16], Abnama Watershed, Iran [17], Qinhuai River basin, Chaina [18], Al-Zarqa Basin in Jordan [19], Oil Palm Catchment, Malaysia [20]. Most of these studies clearly indicated that the results of the model simulation were location specific, in that different combinations of a model set containing the loss methods, runoff transform methods, routing and baseflow separation techniques were found to respond variably. The objectives of the current study are (1) to develop the physically based semi distributed rainfall-runoff model (2) to calibrate and validate the model and fix the corresponding calibrated values for future hydrological investigations. This paper enhance the capacity and capability of physically based HEC-HMS model for synthesizing the hydrological processes at ungauged catchment during dry and wet seasons.

2. Study Area

Rihand River is an important right bank tributary of river Son originated from Matiranga hills in the region south west of the Mainpat plateau flows toward north through the states of Chhattisgarh, Madhya Pradesh Uttar Pradesh and joins to River Son near Sonbhadra district of Uttar Pradesh. The main tributaries of Rihand River are the Mahan, the Morana (Morni), the Geur, the Gagar, the Gobri, the Piparkachar, the Ramdia and the Galphulla. The study area comprise in upper part of Rihand river which is lies between geographic 22^0 30’ N to 24^0 00’ N latitude and 82^0 15’ E to 83^0 45’ E longitude and a total area of about 10,110 km^2. The maximum and minimum elevation encountered in the watershed about 200 m and 1180 m above mean sea level (MSL). Southern parts of the basin covered by dense forest while agricultural activity is dominate in the northern part. This river is mainly rain feed river and the maximum rainfall is received during the month of July to October. Geologically, the Rihand River watershed is part of Vindhyan Super Group, composed of low dipping formations of sand stone, shale and carbonate, with a few conglomerate and volcanic beds, separated by a major regional and several local unconformites **[21], [22].** The entire area occupied by 3 group of rock, i.e., (1) Mahakoshal group made of phyllite with quartzite, and alusite mica schist, limestone, acid intrusive, metabasic rocks, cherty quartzite, slate, marble and tuff, (2) Dudhi group overlie the Mahakoshal group and consist of medium-to-fine-grained diorite, gray granodiorite, epidotized pink tourmaline gneiss, leucocratic granite, and emclaves of metamorphites, amphibolites, granite gneiss, migmatite and metasedimentaries and (3) Damuda group consist of coarse ferruginous sandstone intercalcated with coal seams and green shale **[21].** Rihand Dam also known as Govind Ballabh Pant Sagar has been constructed over this river in the year of 1962 at Pipri in Sonbhadra Ditrict in Uttar Pradesh, the north most point of the study area. The study area of Rihand catchment outlet point demarcated at the tail part of the reservoir as shown in **Figure 1.**

3. Materials and Methodology

In this study, Remote sensing data of DEM, GCN20m grid data along with Meteorological data collected from different sources. The public domain software and physically based semi-distributed continuous hydrological model HEC-HMS was used for simulation, the simulated results were calibrated and validated on an hourly basis. Keeping in view, the following materials and methodology was adopted to simulate the rainfall-runoff flow in ‘Rihand’ catchment.

3.1 Data Acquisition

The datasets required for Rainfall-Runoff hydrological modeling include hydro-meteorological data like rainfall and stream flow, and physiographic database such as Digital Elevation Model (DEM), Land use/ Land cover and Soil data. A 30m x 30m digital elevation model of Cartosat-1 was collected from open source Bhuvan-ISRO web portal **[23]**. The DEM data **Figure 2** was used to extract physiographic characteristics of study area such as catchment, catchment slope, catchment analysis, HEC-HMS initial parameters such as basin area, river slope, and river length, terrain processing etc. The shape file data of land use/land cover and soil data were required for generation of Curve Number (CN) raster file to use in HEC-HMS model. Instead of generation of CN raster data for HEC-HMS model, in this study a CN raster data of entire globe collected from Google Earth Engine **[24], (Figure 3**) known as Global Curve Number Grid data of 250 m resolution (GCN250m).

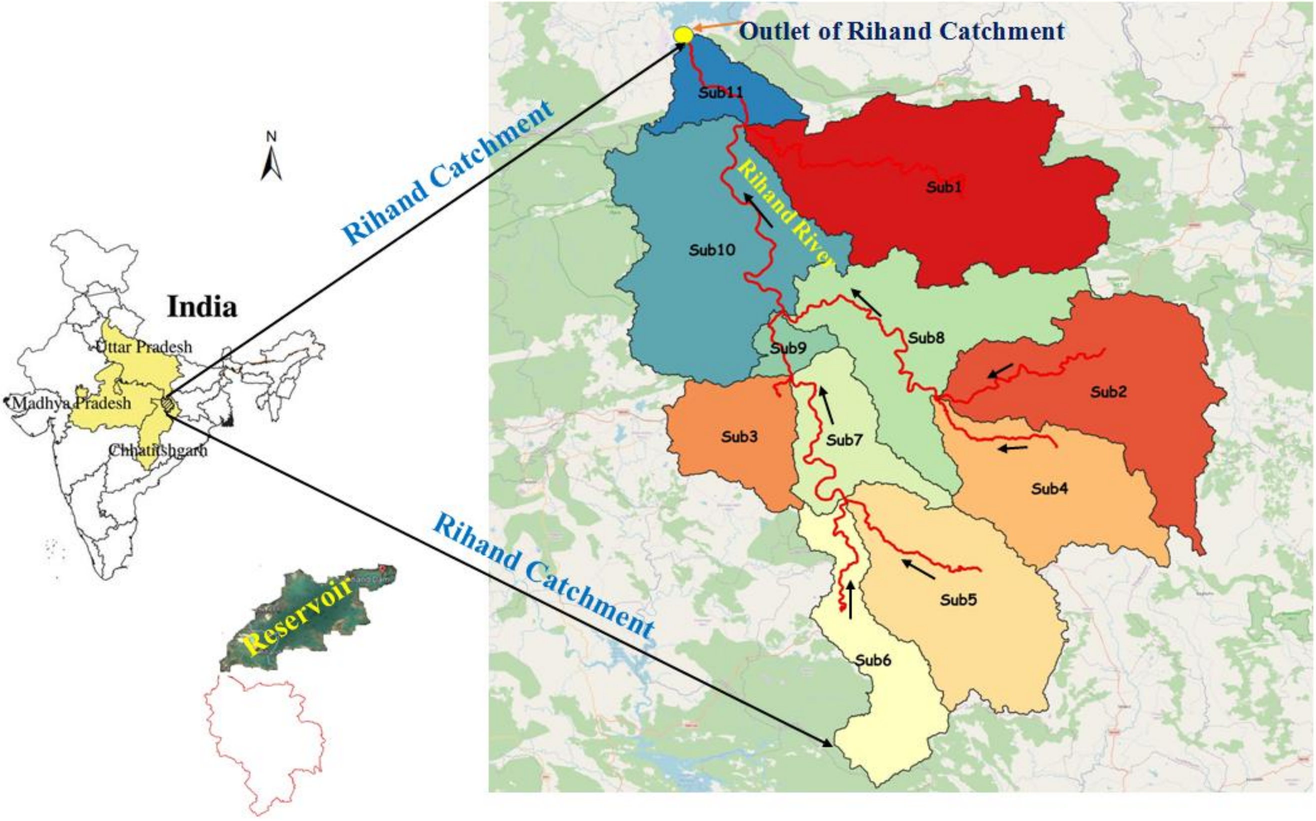

Figure 1: Location map of study area

The GCN250m grid data used for computation of CNs for each subbasin of the entire catchment, which was directly used in HEC-HMS model. The daily rainfall data at the gauge locations of Ambikapur, Bharatpur and Korba for the 21 years from 2001-2021 was obtained from IMD-Pune. The elevation of the study area varies from 1180 to 200 with steep slope in the northern mountains. Physical parameters based hydrologic modeling of catchment is suitable technique for simulating a rainfall-runoff process and flow conditions in wet and dry seasons. The characteristics and attributes of the catchments geographical features were identified through a spatial database and subsequently employed in the simulation of water flow. The central focus of this study lies in the integration of spatially distributed physical parameters into the HEC-HMS model to replicate surface flow within a watershed system. The systematic procedure adopted for this purpose is explained below.

3.2 Hydrological models setup

HEC-HMS ver.4.10 efficiently and easily created the input files with hydrologic parameters for model. The GIS module has geospatially analyse the DEM data by terrain pre-processing and delineate subbasins and stream network. The selected study area was delineated into multiple smaller subbasins with drainage network using the step-by-step procedure of pre-processing. The smaller threshold area is selected to delineate the stream and to get reasonable number of subbasins. In this way, the area is converted into semi-distribution condition for setting up the parameters. After terrain pre-processing, the basin processing step was used to combine and /or divide subbasins with merge and split option. The subbasin and stream physical characteristics such as basin slope, centroid, river length and slope longest flow path etc., were calculated using topographic features to estimate the subbasins hydrological parameters. For parameterizing the HEC-HMS model, initially estimate the hydrological parameters such as Curve Number (CN), percent impervious area, time of concentration (Tc), lag-time (T_{lag}) etc., based on soil and landuse database and terrain analysis. In this study, the subbasin loss method of SCS-CN, subbasins transform method of SCS-UH and river routing Muskingum routing used. The initial parameters of SCS-CN loss method such as basin CN is computed for each subbasin

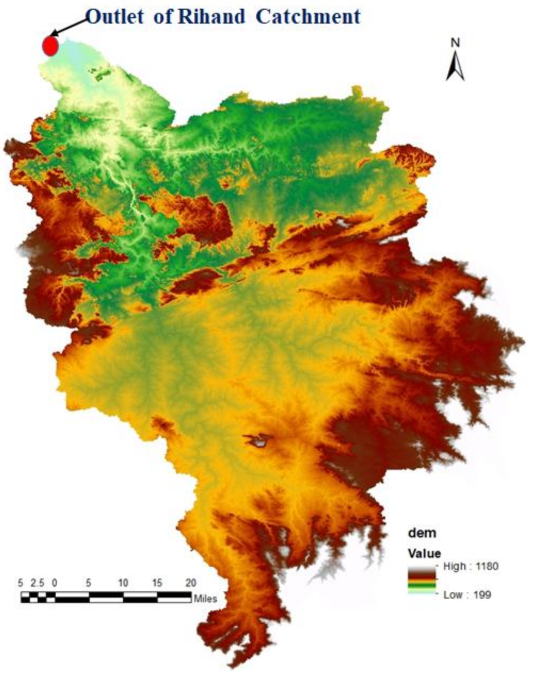

Figure 2: Digital Elevation Model (DEM)

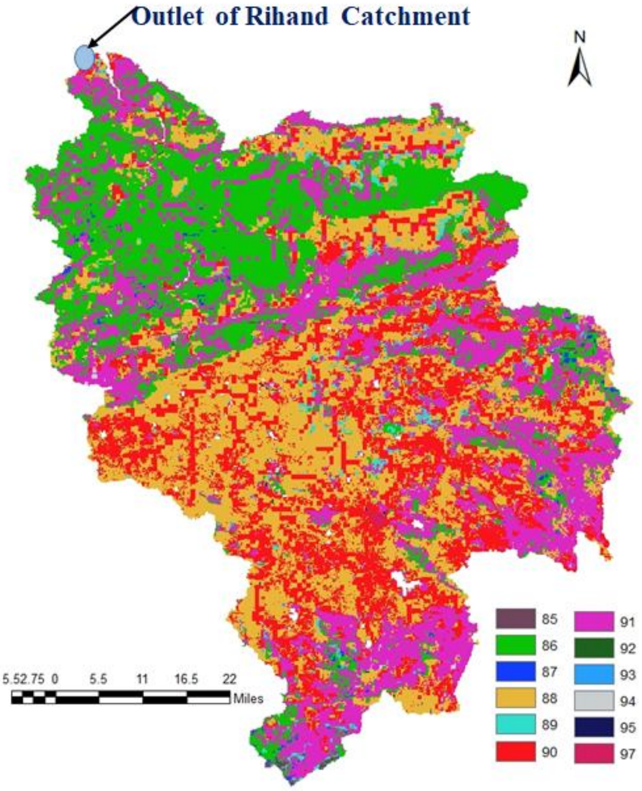

Figure 3: GCN250m Grid data (Google Earth Engine)

of Rihand catchment using CN raster data of CN-II (average condition) downloaded from Google-Earth-Engine. The SCS Unit Hydrograph transform method that needs only basin lag and its initial value was estimated using CN Lag method.

The input parameter of Curve Number (CN) is one of the basic data required for computation of runoff using different methods in HEC-HMS model.

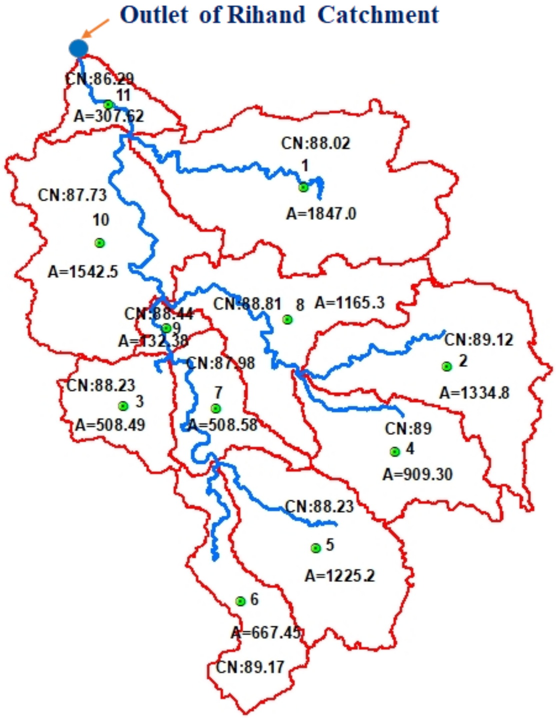

Figure 4: CN's of each sub-basin of Rihand catchment

The 'Rihand' catchment divided into 11 numbers of sub-basins and the CN of each basin was computed based on area weighted average and demarcated for each subbasin as shown in Figure 4. The sub-basin No 6 obtained highest CN value of 89.17, and the lowest CN value computed for the sub-basin No.11 which was situated before out let of catchment of 86.29.

4. HEC-HMS Model

It is a physically based hydrological model used to simulate rainfall runoff processes. Hydrologic Modeling System has been developed by the U.S Army Corps of Engineers **[11].** HEC-HMS models used for precipitation-runoff processes of dendritic watershed system. It has the capability of simulating the floods, runoff as well as meteorological phenomena such as evapotranspiration, snow melting and precipitation. The software is able to report a database, data entry tools, calculation engine and results. The modeling results are employed in evaluating current water budget and flow estimations. The primary model components area basin model, meteorological model and control specifications. A simulation calculates the precipitation-runoff response in the basin model given input from the meteorologic model. The control specifications define the time period and time step of the simulation run **[25].** All hydrological elements are connected to a network in order to model the relationship between precipitation and flow. Basin-subbasin, reaches and junctions are the main hydrological elements **[26].**

4.1 Basin Model

The system provides a variety of methods for calculating loss in a subbasin and transforming precipitation to flow. Green and Ampt, Deficit and Constant, Soil Conservation Services Curve Number (SCS-CN) are the main methods to estimate the amount of infiltration in the basin. The SCS-CN method is opted in this study to estimate loss in the form of infiltration. SCS-CN loss method was used to estimate direct runoff based on CN and initial abstraction values (Ia) in mm for each subbasin, and soil retention (S) in mm estimated using CN value. CN represents the combined effects of the primary characteristics of the catchment area, including soil type, land use, and the previous moisture condition. In the Curve Number method, the runoff is directly proportional to the precipitation with an assumption that the runoff is produced after the initial abstraction of 20% of the potential maximum storage (S).

4.2 SCS-CN Loss Method

In this study, the Soil Conservation Service –Curve Number (SCS-CN) loss model is utilized to calculate the precipitation excess as a function of cumulative precipitation, land use and soil type, given by the following equation **[27].**

$$Pe = (P-Ia)^2/(P-Ia)+S\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where
Pe = accumulated precipitation excess at time t
P = accumulated rainfall depth at time t
Ia = the initial abstraction
S = potential maximum retention, a measure of the ability of a watershed to abstract and retain storm precipitation

The SCS-CN method has expressed potential maximum retention in terms of a dimensionless parameter CN by the following equation.

$$S = (25400/CN) - 254 \qquad \text{eqn. (2)}$$

4.3 SCS-CN Lag Method

Soil Conservation Service Unit Hydrograph (SCS-UH) method is utilised in this study to convert the precipitation excess to surface runoff. This model is based on the parameters of the average Unit Hydrograph (UH) resulting from gauged rainfall and runoff data of a large number of small agricultural watersheds of the entire USA, which is included in the HEC-HMS program **[28].** In the transform method, the 'lag time' is the sole input parameter required in this method computed through the CN lag method equation. This equation is applied to calculate the lag time for the basin. It is the weighted time of concentration or time from the canter of mass of excess rainfall hyetograph to the peak of runoff hydrograph, represented by the following equation.

$$T_{lag} = (L^{0.8}x(S+1)^{0.7})/1900y^{0.5} \qquad \text{eqn. (3)}$$

Where,
t_{lag} = basin lag time (hr.),
L = hydraulic length of watershed in feet,
y = basin slope (%)
S = potential maximum retention estimated by equation (2)

4.4 Channel Routing

The Muskingum method, developed by McCarthy (1938), has been selected to model the flow regime of the streams in the Rihand river sub-basin. This is a simple approximate method that estimates the outflow hydrograph at the downstream of the channel reach based on the inflow hydrograph at the upstream end **[28].** The two most crucial parameters of this method are K and x. Theoretically, K symbolizes the time of passing of a wave in the reach length, and 'x' is a constant coefficient whose value ranges from 0 and 0.5. In this study, both the routing parameters, K and x, based on the assumption K>△t > 2Kx, where △t is the time interval which is 1 day for this study. The total storage in the channel reach can then be expressed as

$$S = K[x\, I^m + (1-x)\, Q^m] \qquad \text{eqn.(4)}$$

Where K and x are coefficients and 'm' is a constant whose value is 1.0 for natural channels.

4.5 Meteorologic Model

Meteorological model purposes are preparation of the meteorologic boundary conditions for sub-basins. A common meteorologic model can be used with many different basin models. The method of precipitation is selected as a Specified hyetograph for the meteorologic model of this study. The Specified Hyetograph method allows for definition of a specific time-series rainfall data at sub-basins **[24]**. In this study for preparation specified hyetograph 3 rain gauge stations data used. The rainfall data collected from from Indian Meteorological Department (IMD-Pune) rain-gauge stations situated at locations of Ambikapur, Bharatpur and Korba for about 21 years from 2001 to 2021.

The specified hyetograph computed for 100year return period from 21 years of rainfall data. The hyetograph belonging to the flood event for each rain gauge station computed and applied in the model. The elements of the hydrological model of HEC-HMS and the selected methods in this study are presented in the form of flow-chart as shown in **Figure 5.**

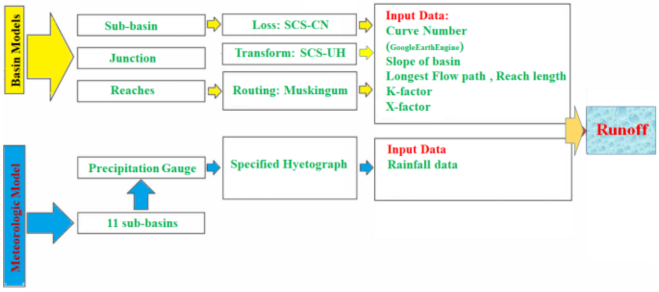

Figure 5: Methodology applied in HEC-HMS modeling

5. Application of HEC-HMS Model

Basins are divided into sub-basins in order to generate a more precise hydrological model. For this reason, sub-basins were formed by specifying the relevant exit points in the 'Rihand' catchment. The catchment area is divided into 11 sub-basins and area information is defined. Infiltration is taken into account with the SCS-CN method. In order to find the amount of loss, the values of the initial moisture content, surface retention and Curve Number parameters are defined.
These values vary according to the soil type, land use/land cover and AMC condition. The SCS-UH is used for

calculation of the hydrograph over the catchment. Within the scope of the method, lag time of sub-basins defined in the system. Junctions are added to each sub-basin outlet to route the surface runoff. The reaches representing the ‘Rihand’ river are defined in the model. As a routing method for each reach, the Muskingum method is used, which required travel time ‘K’ was assumed as Tc calculated by TR-55 method. The degree of storage (x) was assumed 0.2 for all reaches. Figure 6 represents the hydrological model of the ‘Rihand’ catchment generated in HEC-HMS. Here, blue squares represent the sub-basins, dark blue lines represent the reaches and blue rectangles represent junctions. After the basin model is formed, the meteorological model is selected as the Specified Hyetograph. The rainfall data provided by the IMD and is used in the watershed model to simulate the hydrological response of the region.

In this study, to estimate the runoff at the end point at Rihand reservoir, a basin model, a meteorological model, and control specifications were defined with the aid of HEC-HMS. The delineation of the watershed, merging sub-basins, extracting their characteristics, defining the input parameters, and preparing the meteorological model were accomplished using the HEC-HMS environment.

The Soil Conservation Service Curve Number (SCS-CN) method was applied to calculate infiltration loss. The SCS Unit Hydrograph (UH) method was employed to simulate the transformation of excess precipitation into direct surface runoff. The constant monthly method was used to consider the baseflow contributions. Finally, the Muskingum method was used for routing the flow through the river reaches. Both the observed precipitation and discharge data are essential for the meteorological model. About three rain-gauge stations exists in and around the Rihand Catchment area are used in meteorological model. Due to the unavailability of observed discharge data at the outlet point, it became necessary to simulate the discharge through this rainfall-runoff model. The control specifications govern the starting and ending date and time, followed by the time interval of 30 minutes time step for which the simulation has to process.

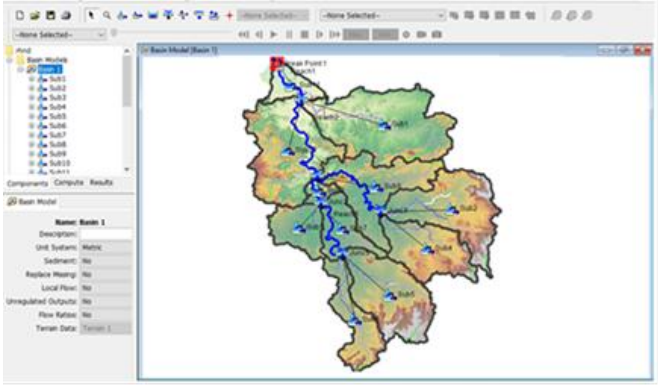

Figure 6: Schematic representation of HEC-HMS model

Some parameters in the HEC-HMS model are estimated through observation and measurements, whereas some need to be calibrated. The value of specific parameters is started with the initial assumption and fixed through trail and error until there exists a proper correlation among the simulated and observed hydrographs. This process is well known as optimization, which can be resolved both manually and automatically. In this study, two Muskingum parameters K and x, which are travel time of flood wave and weighting factor, respectively, are calibrated through the automatic optimization in HEC-HMS. For every individual reach in the basin, both K and x have been calibrated to obtain the optimized value. The calibration of these two parameters has been achieved through the Nelder-Mead method, which is a deterministic approach offered by HEC-HMS software. This method uses a downhill simplex algorithm to evaluate the parameters. The goal of the objective function in the calibration process is to minimize the statistics and percent error in peak discharge.

6. Results and Discussions

The Rihand catchment divided into 11 number of sub-basins. The basic input parameter of precipitation is used from 3 different rain gauge stations within and outside of the catchment. The losses from the catchment computed based on SCS-CN method, and the excess precipitation transformed into runoff hydrograph based on SCS-UH method. The Curve Number (CN) is the vital parameter to perform these two methods for calculation of loss and excess precipitation transformation. The CN for each sub-basin was computed using GCN250m grid data obtained from Google Earth Engine. The readymade availability of GCN250 grid data avoid the necessity of soil map and land cover data for estimation of CN for each sub-basin using some traditional methods for computation of CNs. The layout map derived from HEC-HMS model showing sub-basins, reaches and junctions with outlet of catchment as shown in Figure 7.

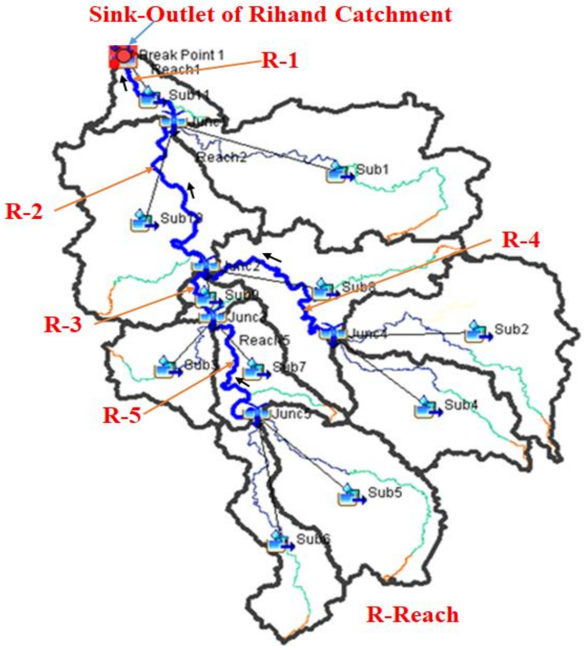

Figure 7: Catchment-Components derived from HEC-HMS model

The HEC-HMS model simulation was performed and the accumulated outflow at each junction derived from different subbasins and the flow routed through reaches and ultimately the outflow reached at outlet of Rihand catchment explained in the following paragraphs.

6.1 Junction-5

The flow computed from sub-basin 5 and 6, accumulated the total flow at junction 5 as shown in Figure 8. The peak flows of junction and each sub-basin occurred at different times.

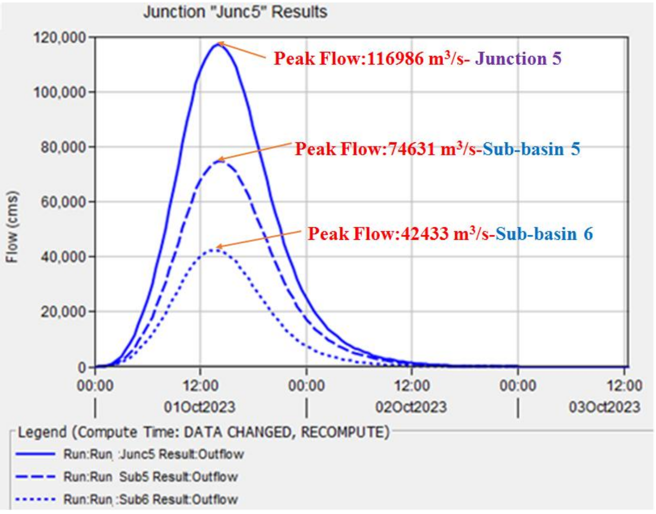

Figure 8: Model Flow–hydrograph at Junction 5 and sub-basins 5&6

It is caused due to variation of areas of each sub-basin and the Curve Number of sub-basins. The peak of subbasin 6 obtained at 13.30 hrs and peak of subbasin 5 delayed by 30 minutes (14.00 hrs) and the peak flow reached at junction 5 at 14.00 hrs. It was observed that the 3 hydrographs followed the same shape of traditional hydrograph shapes. The rising limbs has steep slope, indicates a possibility of flood occurred.

6.2 Junction-4

The model flow simulation carried from sub-basin 2 and 4 and accumulated the flow at junction 4 as shown in layout diagram. The flow hydrographs of sub-basins and junction 4 are shown in Figure 9.

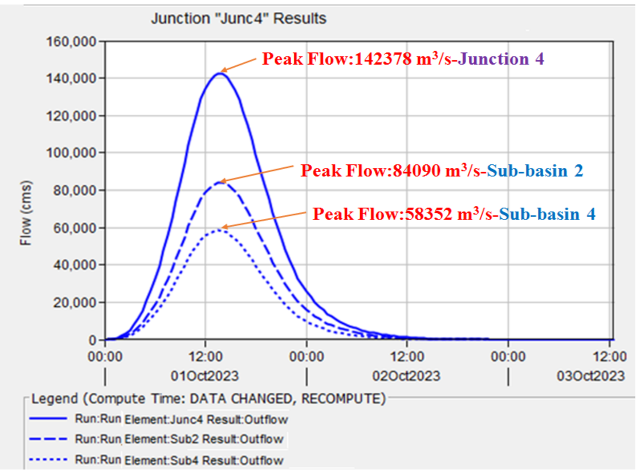

Figure 9: Model Flow–hydrograph at Junction 4 and sub basins 2&4

The shape of hydrograph and its peaks of flow hydrographs of all 3 elements follows similar trend. The rising limb and falling limb and crest of flow hydrographs have the same shape.

6.3 Junction-3

The accumulated flow at Junction-3 is the combination flow of Reach-5 and subbasin 3and 7 flow as shown in Figure10. The two subbasin has more or less same area, same precipitation volume, and similar loss volume, the subbasin 3 delivered higher flow than subbasin 7. The shape of subbasin 3 has fan type and reached peak flow at 13.30 hrs, and CN value has higher to subbasin 7. The subbasin 7 has fern or leaf shape, reached peak flow late by 2.0 hrs to subbasin-3 and it has low CN value to subbasin-3.

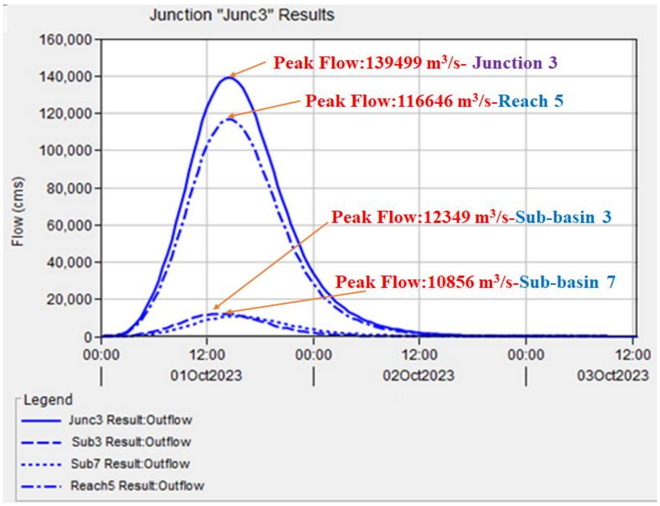

Figure 10: Model simulation flow –hydrographs at junction-3 and subbasins 3 & 7

6.4 Junction -2

The total flow from reach-3, Reach-4 and flow from subbasin 8 and subbasin 9 were accumulated at unction-2 as shown in Figure11. The figure reveals that the subbasin 8 has higher flow than subbasin 9. The subbasin 8 has higher area, CN value to subbasin 9. The peak flow value occurred at 9.30 hrs by subbasin 9 and for subbasin 8 by 15.00 hrs. The delay of peak flow reached by subbasin 8 caused due to its higher area, which will take time to reach peak of flow.

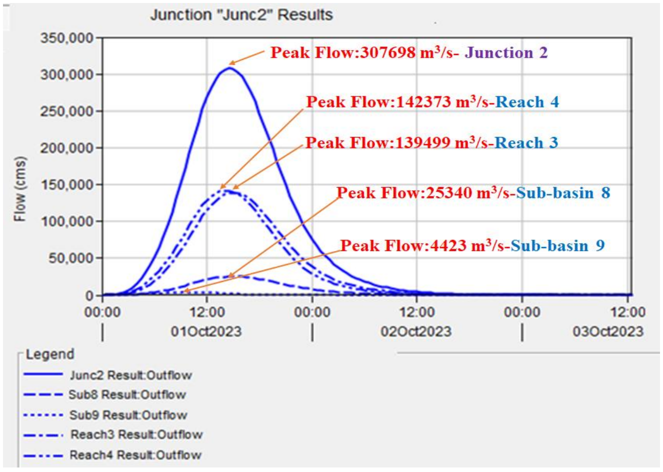

Figure 11: Model simulation flow at Junction-2 and subbasin 8&9

6.5 Junction-1

The flow at junction-1 accumulated flow from reach-2, subbasin 1and subbasin 10 as shown in Figure12. The subbasin 10 has lower area, low CN value, delivered a higher peak flow than subbasin 1. It is possible, because the shape of subbasin 10 is leaf type, in which the peak occurred at earlier time by 3.30 hrs to subbasin 1.

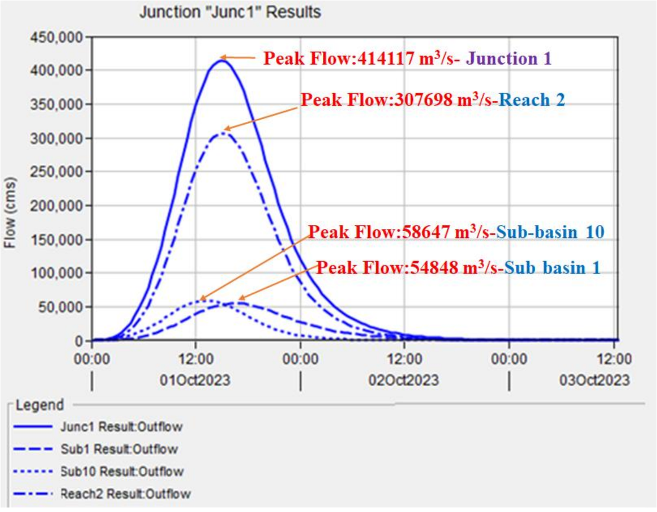

Figure 12: Model simulation flow at Junction-1 and subbasin 1&10

6.6 Sink-Outlet of Rihand Catchment

The accumulated flow at Sink obtained from Reach-2, which was carried from Jinction-2 flow and added from subbasin 11. The resultant flow hydrographs at outlet of catchment and corresponding flow hydrographs of Reach-2 and subbasin 11 are shown in Figure13. The entire flow at Junction-1 collected from subbasins 1 to 10 and through Reaches 1 to 5 and passed through Reach-1 and deposited at outlet point of Rihand catchment. The share of flow within the flow of Sink from subbasin 11 was a little and the peak flow at outlet of Rihand catchment was 414117 m^3/s.

7. Rainfall-Runoff Simulation Accuracy

The model performance was evaluated using three statistical evaluation techniques. The coefficient of determination (R^2) **[29],** which determines how well the modeled data is fit to observation data between the range $0 \leq R^2 \leq 1$. Nash-Sutcliffe Efficiency (NSE) **[30]** indicates how well the observed versus simulated data fits the 1:1 line. NSE ranges between -∞ and 1. The percentage bias (PBIAS) is the simplest goodness-fit criterion, which measures the average tendency of the simulated values to be larger or smaller than their observed ones [31]. The optimal value of PBIAS is 0.0, with low magnitude values indicating an accurate model simulation. Positive values indicate under-estimation bias, and negative values indicate over-estimation bias [32].

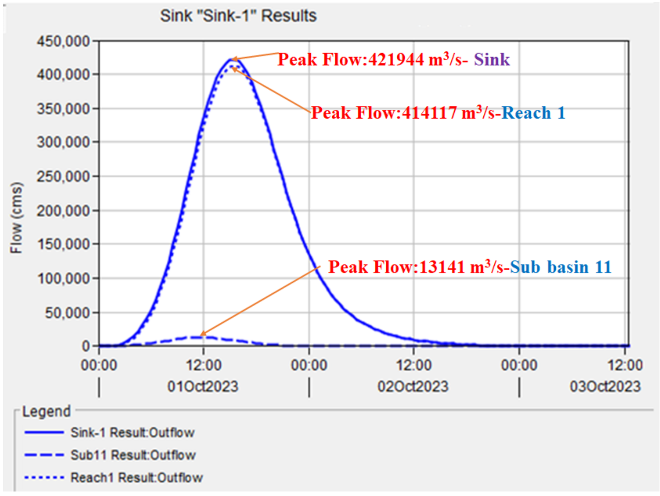

Figure13: Model simulation flow at Sink, Reach-1 and subbasin 11

The obvious correspondence of simulated and observed flows (R^2 0.623 and NSE 0.576) of this simulation before model calibration indicated that the performance of model is acceptable and satisfactory based on the criteria **Table 1**. This performance also indicated that the quantified physical parameters from DEM, soil and LandUse are reliable and can be used further for HEC-HMS model calibration and validation. Moreover, the selected loss (SCS-CN), transform (SCS-UH) and flow routing (Muskingum) methods in HEC-HMS are suitable for Rainfall–Runoff process of study area **[33]**, study also support the rainfall-runoff simulation results based on catchment physical characteristics such as topographic, soil and land use.

The simulated and observed peak flow reached at same time of 15.30 hrs. Subbasin 11 peak flow reached at 11.30 hrs. Among these three flow hydrographs, the low flow hydrograph of subbasin 11 reach its peak earlier to observed and simulated flow time. Both flow hydrographs followed the similar trend of shape of rising limb, recession limb and crest of hydrograph. The HEC-HMS model simulated peak flow obtained at outlet of catchment was 4,21,944m^3/s. The hypothetical peak observed flow was 1,60,338 m^3/s.

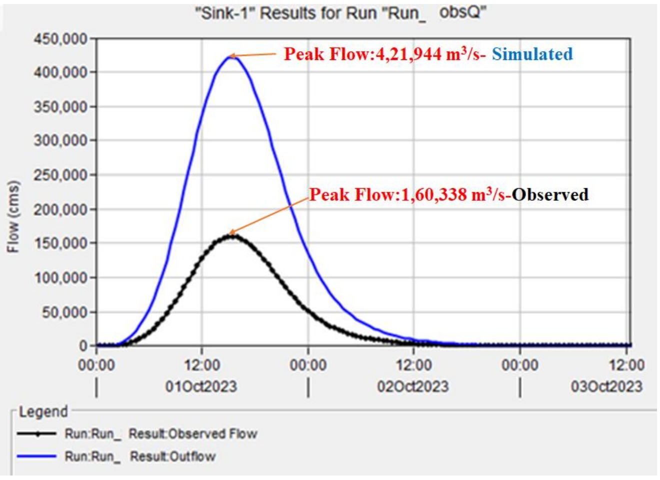

Figure 14: Model Simulation Vs Observed flow

The initial simulation with observed flow along with computed flow hydrology are shown in Figure 14. During initial simulation with observed flow, the accuracy assessment parameters of NSE was -2.928, RMSE Std. dev was 2.0, and percent Bias was 163.16%. These parameter values indicates very far away from permitted/limited values as mentioned in tabular form Table 1.

Table 1: Limited Values of Accuracy Parameters

Performance Classification	**Statistical Parameters**		
	R2	NSE	PBIAS
Very Good	0.85-1.00	0.75-1.00	PBIAS < ±10
Good	0.75-0.85	0.65-0.75	± 10 = to < ± 15
Satisfactory	0.60-0.70	0.5-0.65	± 15 = to < ± 20
Acceptable	0.4-0.6	0.4-0.5	± 20 = to < ± 25
Unsatisfactory	R2 = 0.40	NSE = 0.40	PBIAS = ± 25

7.1 Calibration and Validation of Hydrological Model

The direct runoff at the gauged location was calibrated on hourly time scale from 2016 to 2017 and results shown in Figure15. Only two parameters (CN and Ia) were used in optimization trails in HEC-HMS model, while other parameters were kept same and the most accurate optimized values were eventually generated and used. The simplex optimization method with peak weighted RMS objective function was used to evaluate the CN and Ia parameters, simultaneously. The auto-calibration using optimization method helped to calibrate the parameters. The optimization was performed by selecting the maximum and minimum value range for the parameters to be modified.

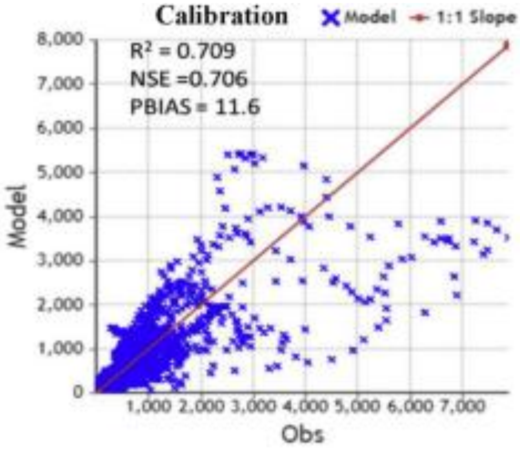

Figure 15: Model Calibration

The CN value was modified using scale factor between the range (0.5 to 1.25) and 0.716 optimum value was found. Similarly, the initial abstraction (I_a) was optimized using scale factor between the ranges 0.5-1.05 with optimum value 0.986. The optimum or calibrated CN and I_a values were achieved by changing the default values between ±0.75 and ±0.55, respectively.

The validation of the model performed on hourly basis and the values obtained are satisfactory except PBIAS results. After several modifications of the parameters values, PBIAS has no changes. The final model validation results shown in Figure.16.

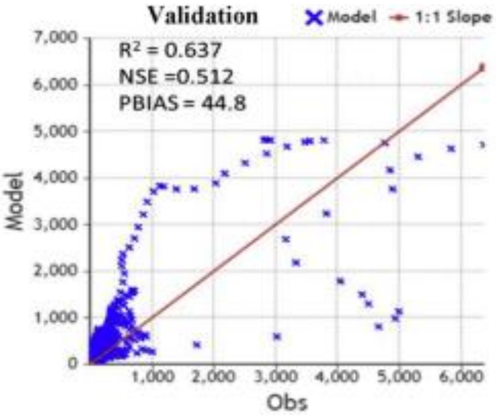

Figure 16: Model validation

8. Conclusions

This study demonstrated that the physically based semi-distributed hydrological (HEC-HMS) model is suitable and adaptable to simulate rainfall-runoff flows on event as well as continuous time scale with calibration and validation in Rihand area. The model is fully based on the hydrological characteristics, topography, and GCN250m grid data, which ultimately useful for computation of Curve Numbers of each subbasin of the catchment. Overall, the HEC-HMS model performance was satisfactory in terms of Nash Sutcliffe Efficiency (NSE) and coefficient of determination (R^2) based on the selected loss, transform and flow routing methods.

Understanding water availability from Rihand catchment will be useful to water resource managers, especially in irrigation, domestic and industry water user sectors. Therefore, it is concluded and suggested that the methodologies developed in this research can also be applied in other ungauged catchments and regions with similar characteristics for hydrology and water resources assessment. The developed model in the study catchment can be applied to generate more detailed information for modeling work, for water resource management and planning purposes under future climate scenarios. The outputs of this study will help hydrologists to understand the efficiency and application of physically based semi-distributed hydrologic model in river flow (rainfall-runoff) modeling. It is to be suggested that rainfall-runoff simulation accuracy could be enhanced through high quality rainfall data, employ high spatially distributed hydrological models, utilize accurate Digital Elevation Models (DEM), detailed Land use land cover information, incorporate accurate soil information into the model. In addition, calibrate model results using observed stream flow data and validate the model using independent data sets to ensure its performance outside the calibration period. The research could be continued with different conditions of GCN250m grid data, with different loss methods and transform methods available in HEC-HMS model.

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