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An investigation into the impact of reservoir management Kerala floods 2018: A case study of the Kakki reservoir

Ciarán Ryan[1]*, Mark A. Trigg[1], Adarsh S[2]
[1]School of Civil Engineering, University of Leeds, Leeds, UK
[2]TKM College of Engineering, Kollam, India

*Corresponding author: cn16clrr@leeds.ac.uk

Abstract. The coastal state of Kerala, India experienced unprecedented levels of rainfall and flooding in August 2018, resulting in huge life and property loss. Since then the impact reservoir management may have had on the severity of the 2018 Kerala floods has been in question. This study presents a novel approach to developing a reservoir model using HEC-HMS and HEC-ResSim models, combined with satellite remote sensing data. In order to establish a link between flood severity and reservoir management, a model of the Kakki reservoir in southern Kerala was created. Simulations were carried out for six long term, two short term, and two immediate run cases. It was found that all cases except the immediate simulation run resulted in a reduced peak flow. The long simulation run, which altered the guide curve after the heavy rainfall occurring on 14th August 2018, while constraining the outflow, was found to produce the greatest reduction in peak outflow. The significant peak outflow reduction achieved suggests that improved reservoir management could have reduced the severity of the 2018 floods.

Keywords: Kerala, Flood, Reservoir, Simulation, HEC-HMS, HEC-ResSim, GPM Precipitation

1. Introduction

Kerala, an Indian state located on the south west coast, normally receives about 70 % of the annual rainfall during the south west monsoon period (June-September). The State of Kerala experienced an abnormally high rainfall from 1 June 2018 to 19 August 2018. However, the flood severity was compounded by the fact that 20-25% of this rainfall fell on three days: 15-17th August. As per India Meteorological Department (IMD) data [1], Kerala received 2346.6 mm of rainfall from 1 June 2018 to 19 August 2018 in contrast to an expected 1649.5 mm of rainfall (about 42% above the normal). This combined with most major reservoirs being at 90% capacity or more resulted in an extreme peak discharge which caused widespread damage to over 175,000 buildings and resulted in an estimated 433 casualties [2]. The abnormal rainfall in 2018 resulted in an unprecedented and severe flooding in 13 out of 14 districts in the State. Subsequently, the role that reservoir management played in this disaster has been brought into question. Mishra et al. performed a study on the impact of rainfall and storage reservoirs on the Kerala floods of 2018 considering seven major reservoirs in the State, by developing the storage curves and depth-duration-frequency curves of rainfall [3]. Mishra et al. also reported that the study used the daily gridded rainfall for the analysis and that gauged station rainfall data and actual monitored releases could have given a better picture of the scenario. Sudheer et al. performed a detailed analysis on the Periyar basin located in central Kerala [4]. The study reported the results and analysis of a modelling exercise using HEC-HMS to simulate and analyse the role of reservoir operations in the flood of August 2018. The study concluded that the operation of dams had no major role in damages experienced after the 2018 floods. Recently Anandalekshmi et al. used Copulas as a modeling tool for investigating the joint dependencies of reservoir storage and extreme rainfall in four reservoirs in Kerala, namely: Idamalayar, Idukki, Kakki and Kallada reservoirs [5]. They reported that the planned management might have alleviated the flood damage and that Kakki and Idukki planned releases might have reduced the impact of flood damage. This study aims to quantitatively analyse reservoir management though a reservoir model to determine whether flood severity could have been reduced by improved reservoir management of the Kakki.

The specific objectives of the study are to:

- Develop a catchment and reservoir model for the Kakki reservoir using satellite remote sensing topography and rainfall data.
- Examine the impact of reservoir management on the flood magnitude downstream of Kakki through simulation runs of the developed reservoir model.

2. Methodology

This study uses HEC-HMS software to derive a reservoir inflow time series based on NASA Global Precipitation Measurement (GPM) data. Subsequently, the inflow was inputted intothe HEC-ResSim reservoir model which produced an outflow time series. A summary of this methodology is given in Figure 1.

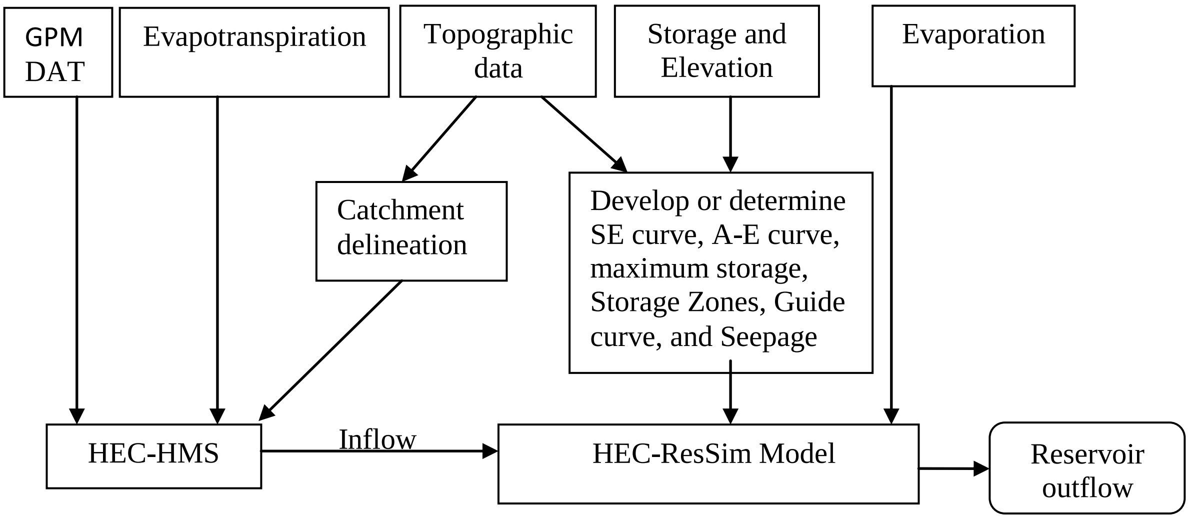

Figure 1. Flowchart showing data and methodology

2.1. Study Area

The Pamba river basin in southern Kerala is one of the major basins affected by the Kerala flood of 2018. The catchment has relatively few reservoirs, with the majority of the storage capacity contained within one reservoir, the Kakki reservoir. This allows a single reservoir model to be largely representative of the behavior of all storage in the basin. The Kakki Reservoir's sub-basin also experienced the uncharacteristic extreme rainfall from 15th-17th August [3]. It has been reported that the catchment experienced 700% higher rainfall compared to the long term mean in this three-day period [3]. The Kakki Reservoir, which began operations in 1966, is primarily a hydroelectric power generation reservoir. Accordingly, there is a minimum outflow from the reservoir to ensure it can generate electricity continuously. The location map of the Kakki reservoir is shown in Figure 2.

Figure 2. Location of the Kakki reservoir and its catchment (red outline) and its location within the southern tip of India

2.2. *Inflow generation using HEC-HMS*

The first step uses HEC-HMS to produce a reservoir inflow time series, using remotely sensed precipitation and catchment topography data. The rainfall data from a local gauge is normally one of the most reliable sources of data input to run a hydrologic model. However, due to the lack of a daily time series, NASA GPM data [6] was used to create a rainfall intensity time series. Precipitation data for the catchment was obtained for the area bound by the coordinates 9.35N, 77.23E and 9.23N,77.12E. However, the total precipitation was lower than that reported from gauge data. Therefore, a bias correction factor of 3.73 was applied to the data, considering the real gauge total estimate of 1762.7mm of rainfall between 1st June 2018 and 17th August 2018 reported by IMD. Thus, the GPM data is considered to be a proxy record that is bias corrected. It is not a direct gauged measurement record but is representative of the actual rainfall experienced in the study area. Analysis of the catchment topography was carried out using MERIT DEM [7] topography data. This enabled the catchment area and average slope to be determined directly, while providing the required parameters to determine the catchment lag time. The coordinates at the centre of the catchment are 9°17’30’’N, 77°10’20’’E, the catchment area of 219.8 km2 and the average slope of 68.95% were determined using QGIS. The catchment lag time (T_{lag}) was calculated using the Curve Number based equation stated by Costache [8]. To calculate T_{lag}, the longest drainage path length of 25.21 km and average catchment slope of 68.95%, were used. The average curve number was determined assuming a maximum water retention of 100mm Costache [8], as the heavily wooded nature of the catchment is clear from satellite imagery. This resulted in an average curve number of 71.75. The final estimate of T_{lag} was found to be 1.66 hours (99.9 minutes).

The daily Evapotranspiration data of Pathanamthitta District for 1901-2000 was collected from the India Water Portal [9] and converted to average monthly totals and inputted into the HEC-HMS model. In the absence of reliable flow gauge data, the SCS curve number technique was selected for runoff computation, as a calibration series is not required. The curve number was set as 77 [10] as the catchment is heavily wooded with negligible areas of open space around access roads. Assuming a canopy category of 1 (as the majority of the catchment’s canopy is undisturbed) a canopy storage capacity of 80 mm was estimated [11].

While it is likely that there are several inflows into the reservoir, for ease of computation the entire catchment has been modelled to produce a single inflow time series for input into the reservoir model. The precipitation series, the primary input for the hydrology model, and the inflow times series produced from HEC-HMS model are shown in Figure 3.

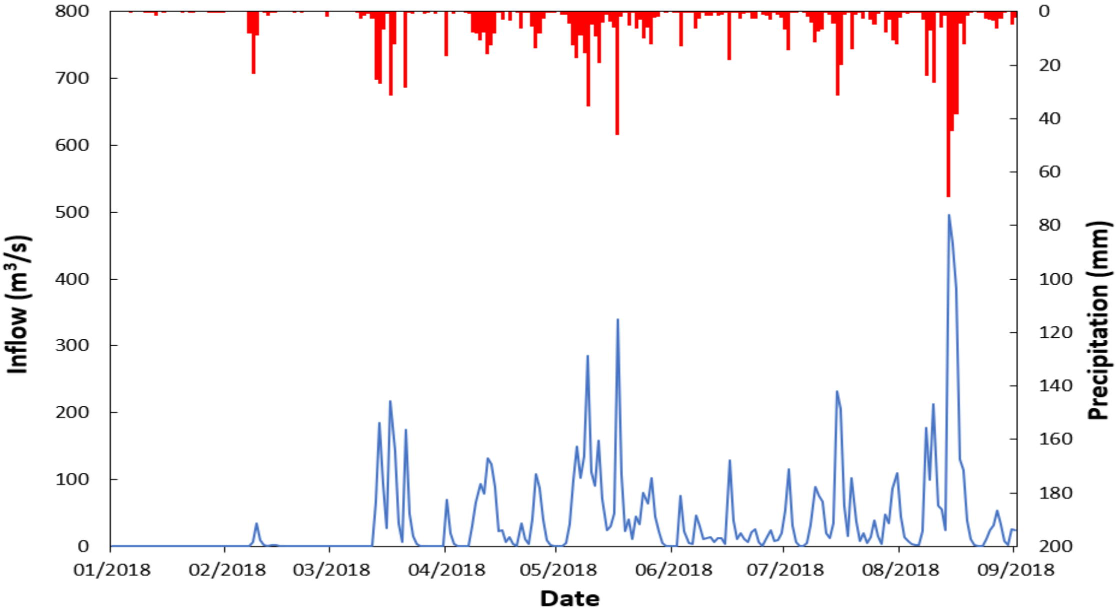

Figure 3. GPM bias adjusted precipitation and reservoir inflow from HEC-HMS model of reservoir catchment.

2.3. *Reservoir Characteristics*

In order to properly model the reservoir, several characteristics had to be determined and inputted into HEC-ResSim. Most of these characteristics were obtained from a time series of reservoir elevation and volume dating back to 1st January 2005 collected from the Water Resources Information System of India, 2012 [12]. First the storage-elevation (S-E) curve was prepared. It fits an exponential curve of S=(1*10-22)e0.0505E with an R2of 0.9769, where S is the storage in billion cubic metres (BCM), and E is the elevation from Mean Sea Level (MSL) in m. In order to determine the maximum capacity of the reservoir, the maximum water elevation is required. This was found to be 981.45m [12]. This coincides with the highest elevation recorded in the elevation and storage time series, suggesting that the information is reliable.

No area-elevation curves were readily available for the reservoir; therefore, these were derived from remotely sensed topography (MERIT DEM) at 90m resolution for observable elevations between 990-1040 m. This area-elevation (A-E) curve followed an exponential curve of A=e0.0404E with R2 of 0.872 (in which A is reservoir area in km^2 and E is elevation in m above MSL). This relationship was then extrapolated to derive areas below the normal water levels elevations i.e. elevations between 910-990 m.

In order to determine how the reservoir has been managed in the past, the elevation time series was used to determine a historic guide curve. First, a monthly elevation time series for 2018 was created from daily averages and plotted to produce a guide curve representative of the reservoir management in the year in question. Then an average guide curve was taken from the most recent five years of data available (2014-2018) to determine whether management varied from the average in 2018. Figure 4 illustrates that the 2018 guide curve has a higher elevation throughout the year when compared to the average curve, clearly suggesting a departure from typical operations in 2018. Figure 4 shows that the reservoir's minimum level for the year is reached earlier, in May rather than in June, and is over 10m higher than the average minimum. At this stage it was identified that the reservoir's poor performance in the flood event may be partially attributed to this deviation from normal operations.

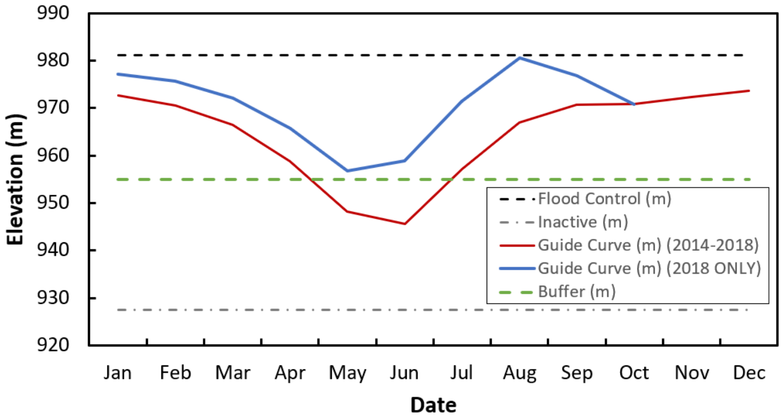

Figure 4. Average guide curve for 2014-18 for the Kakki Reservoir and guide curve for 2018. The 2018 curve ends at October due to the data availability at time of modelling.

As part of the decision-making process within HEC-ResSim, the software uses four elevation time series to control the reservoir, effectively dividing the reservoir capacity into four sections for which separate rules determining outflow can be applied. The highest and first level is the flood control zone (set to the maximum capacity of the reservoir), which is not used in everyday operation but is made available for flood control. The second storage zone is the guide curve (conservation curve). For the purposes of recreating actual reservoir performance, the 2018 behavior curve was used as the guide curve, then the averaged curve was used for alternative simulation runs. The third level is the buffer zone which is the capacity that is typically not utilised unless there is a drought, the level of this zone was set at an estimated typical value of 20% of capacity. The fourth and final level of storage is the inactive level at which it is unlikely that a reservoir would ever reach in its operational life. The elevation of this level was set at 5% of the reservoir's capacity.

In order to properly simulate the operations of the reservoir, the outflow requirements for functions such as irrigation, water supply and electricity generation must be known. This ensures that any changes to the reservoir regime made to improve flood control performance don't restrict the primary function of the reservoir. To estimate this required minimum outflow, the change in storage per day was calculated using the storage time series. This change in storage was then converted to m^3/s and subtracted from the inflow time series from the hydrology model. This then produced an approximate outflow time series for 2018 as shown in Figure 5.

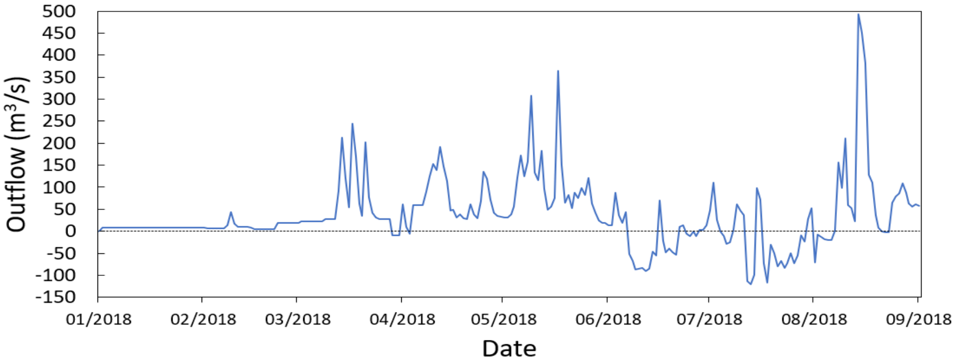

Figure 5. Reservoir outflow time series applying the estimated minimum release.

From observation we can see a period from 1st January 2018 to 1st February where there is no reservoir inflow but there is a constant outflow of 7.99 m3/s. Therefore, the minimum required outflow for the simulation has been estimated as equal to this constant outflow of 7.99 m3/s.

The maximum possible release capacity of this reservoir is 1785 m3/s [12], which may not be relevant here as the focal objective is to keep the peak outflow as low as possible. In order to estimate the seepage from the reservoir, it was determined that the local soil type, referred to as forest soil, is a mix of clay and loam [13]. For loam soil, the seepage ranges between 8 – 20 mm/day [14], the lower bound value of 8 mm/day was chosen as the catchment is dominated by loam. Seepage rates in m3/s were calculated at 10m elevation intervals from 910-990m MSL using the derived A-E curve.

2.4. Reservoir management using HEC-ResSim

HEC-ResSim is arranged into three modules; watershed setup, reservoir network, and simulation [15]. First the watershed (or catchment) was defined and the reservoir was placed into the catchment. As the hydrological model produced a single inflow time series, an arbitrary stream alignment was drawn, and the reservoir drawn onto the alignment. Two computation points, one upstream for the inflow and one downstream for the outflow time series were placed. In order to define the physical characteristics of the reservoir, the storage volume (in m^3) and the reservoir area (in hectares) at 10 m elevation intervals, average monthly evaporation, average monthly seepage from the reservoir in m^3/s, and maximum reservoir outflow were inputted into HEC-ResSim. Then the operational rules and storage zones for the model were also set and a minimum flow operational rule was applied to all zones to ensure that the reservoir always provides the minimum outflow required.

After inputting the require parameters, various simulation runs were carried out to determine the impact that changing the rules and guide curves of the reservoir had on the outflow time series produced. To investigate the impact of alternative management regimes on peak outflow, three simulation run durations (long, short and immediate) were tested. All the three durations aimed to limit this peak through either freeing up capacity prior to the event and/or artificially limiting the outflow capacity. In order to determine whether alternative management regimes were successful, a baseline must first be set using actual performance of the reservoir. In order to recreate the actual management of the reservoir, the 2018 guide curve was inputted into the model. To enable comparison between this baseline and all alternative regimes considered, the start date of the longest run time was used (1st July 2018). Running the simulation produced an out-flow time series with a peak of $492m^3/s$ on 14th August 2018.

Once the baseline performance was established, alternative regimes were considered which had the possibility of resulting in a lower peak outflow. This was done in three types of simulation, the first being a long-term simulation beginning on 1st July 2018 and running until the 31th August 2018. This represents the best-case option with over a month to correct the reservoir's operations prior the 14-17th August's heavy rainfall. A second simulation timescale was considered starting on the 7th August, giving a week to alter the reservoir's storage level to best mitigate the effects of the heavy rainfall. A third and final type of simulation was carried out which began on 13th August 2018 and represents the worst-case scenario where the reservoirs regime is unchanged up until that point and there is only one day to prepare the reservoir for the flood event. Each of these main types of simulation was iterated upon to produce the most efficient operational regime. The management strategies are to be chosen by prioritising the objectives keeping in mind that a regime designed to improve flood control performance must not restrict the reservoir's ability to carry out its other functions.

3. Results and discussion

3.1. Reservoir Simulation

Long run simulations (LRS) have been taken as the best-case scenario where the reservoir operators have over a month before the flood event occurs to alter its regime to best withstand the flood event. The optimal management strategy for this time period was developed over six simulation runs by altering the operational parameters to gradually reduce the peak outflow. The results of the six LRS along with the recreated baseline time series are given in Figure 6.

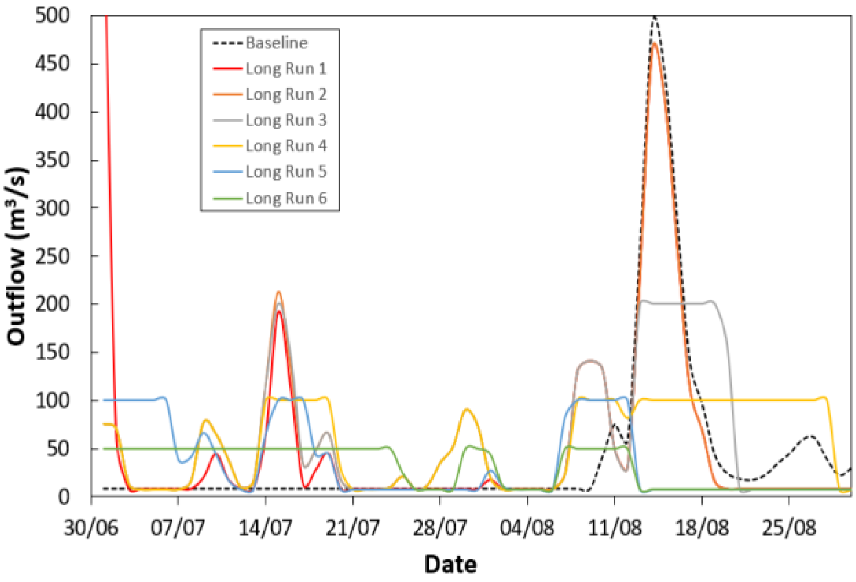

Figure 6. Outflow time series of Kakki reservoir model for long simulation runs, showing the reduced peak flows resulting from six alternative management strategies.

Table 1. Six Scenarios of LRS and their effect on reservoir peak outflow

Scenario	Description	*Flood Event Peak*	Features and Effect
LRS1	Substituted the averaged 2014-2018 guide curve for the baseline 2018 curve	465m^3/s (~5% reduction)	Note that there is an artificially large release at the start of this run as the model adjusts to the enforced reservoir guide curve.
LRS2	The guide curve was edited to coincide with the starting elevation of 964.78m for the simulation	465 m^3/s (~5 % reduction)	Avoids initial artificial release of storage volume seen in LRS1. Similar performance as LRS1.
LRS3	The same parameters as LSR2 were used but an upper limit of 200m^3/s outflow was enforced.	Continuous outflow of 200m^3/s during 13-19 August	Peak flow rather than total volume was the key factor in flood severity; therefore, this represents a significant improvement. However, several early pre-event releases of excess volume are required by the model to achieve this.
LRS4	The same parameters as LSR2 were used but an upper limit of 100m3/s outflow capacity was applied.	Continuous outflow of 100m^3/s during 13-28 August	Wouldn't result in flooding, therefore, represents a significant improvement. However, several early pre-event releases of excess volume are required by the model to achieve this.
LRS5	The guide curve was edited to fully utilise the flood control zone after 14th of August when the heavy rainfall occurs.	Shorter outflow peak before the extreme rainfall occurs after which the outflow drops down to its minimum value.	Represents a reduction in the volume of water released during the peak period and enables a staggering of peak flows. The peak outflow from the reservoir occurs prior to the event and the peak flow from runoff in other areas of the catchment would occur shortly after the peak rainfall. Therefore, this regime theoretically provides significant benefits for flood severity in the catchment.
LRS6	LRS5 parameters were maintained. The peak outflow was further limited to50m^3/s.	Continuous outflow of 50m3/s during 1-24 July	Shorter and earlier peak outflow obtained in LRS5 has been maintained while further reducing the peak.

Short run simulation (SRS) were carried out from 7th August 2018, one week prior to the extreme rainfall event. This allowed one week to optimize the reservoir's elevation for maximum flood mitigation. Figure 7 graphically compares the resultant outflows for the time period considered for both short simulation runs and the baseline performance. SRS1 was carried out using the modified 2014-2018 average guide curve (as used for LRS5) and resulted in the outflow reaching maximum capacity on the first day. Therefore, this run doesn't provide benefits over the baseline performance. For SRS2, the run followed the same operational rules as SRS1, but imposed an artificial outflow limit of 200m^3/s. This enables the large outflows resulting from transferring from the 2014-2018 curve to the 2018 curve to be eliminated. Further runs were attempted but 200m3/s was determined to be the lowest peak outflow obtainable within the timescale of the short run simulations.

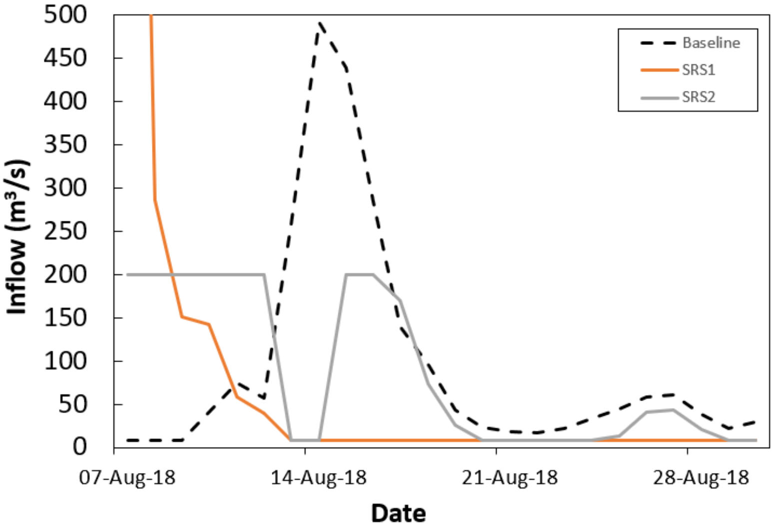

Figure 7. Outflow time series of Kakki reservoir model for the two short simulation runs.

The immediate run simulation (IRS) are intended to be the worst-case scenario and represents the last opportunity for positive intervention to reduce flood severity. The timescale considered in these scenarios starts on the 13th August, giving one day to make alterations to the reservoir's regime. IRS1 utilized the same modified average guide curve as LRS5, where the guide curve is moved to the flood control zone after the event to allow use of the reservoir's entire capacity. Using only this curve resulted in a relatively insignificant reduction in peak flow (475 m3/s). IRS2, was modified in order to improve on IRS1, and the same guide curve was used along with an artificial limit on outflow of 400 m3/s. This however resulted in the water level rising above the maximum of 981.45m, risking dam failure. As a peak of 400m3/s cannot be achieved during this timescale and any higher limits wouldn't represent a significant improvement in flood severity.

3.2. Implications for management of Kakki reservoir

The results of this study suggest that alternative management of Kakki reservoir could have resulted in drastically lower peak outflows, without inhibiting other functions of the reservoir. By following the average guide curve for 2014-2018 and utilising the flood control zone from the 14th August onwards, the peak outflow was reduced to 50m3/s in long run 6. Not only this, but the reduction was made without any impact on main reservoir function, meaning there is virtually no disadvantage to such management. The fact that with a month to alter the reservoir's elevation, such drastic improvements can be made may be indicative of poor or lack of flood mitigation awareness. However, implementing management options such as these would require a clear awareness of rainfall forecasts and perhaps procedures geared towards preparation for the monsoon conditions.

One key recommendation for future reservoir management is the reservation of flood storage to enable peak inflows to be absorbed by the reservoir. If many reservoirs weren't already at 90% or higher capacity, the flood severity may have been much less. Early release could have also helped in alleviating the flood damage, waiting until maximum capacity is reached to begin releasing resulted in little opportunity for flood mitigation and an exacerbation of the flood peak. Another finding of this study was that out of the three time periods considered, all were able to significantly reduce the peak outflow except the immediate runs starting one day prior to the event. Therefore, as might be expected, more than a day is required to change the flood performance of the reservoir in a meaningful way. On the other hand, the results suggest that even with just one week to alter the regime, a peak outflow reduction of over 50% would have been possible. Reliable seven-day rainfall forecasts are certainly viable and perhaps closer cooperation between reservoir managers and the Indian Meteorological Service would bring about improved risk reduction in future.

Most of the studies using HEC-ResSim software reported in the past [16], [17] used gauge data and reservoir surveys to create an accurate model. While some accuracy may be sacrificed, this study demonstrates that a representative reservoir model can be created with freely available remote sensing data. This further increases the possibilities with remote sensing and could enable valid models to be created of remote reservoirs quickly and readily in the future. This study attempted the recreation of a real past flood event. By showing that representative models can be created with remote sensing data, it is hoped that this study will encourage further modelling of past flood events to improve future management.

4. Conclusion

This study presents a novel framework for integrating HEC-HMS and HEC-ResSim for reservoir modeling using inflows and reservoir characteristics generated using satellite remote sensing data which it is hoped will be applied to future events to democratize reservoir management data, which can be difficult to obtain.

The long run simulation results showed that editing the guide curve to fully utilize the flood control zone after 14th of August (when the heavy rainfall occurs) was able to produce a peak outflow of 50 m3/sec. Through the methods described, the peak outflow was reduced from 493 m^3/sec to 50 m^3/sec. This is likely to represent a significant reduction in flood severity without negatively affecting any other aspect of the reservoir's operation. However, this will require operational changes to the reservoir management.

Therefore, we can conclude that flood severity could have been reduced through improved reservoir management in the 2018 floods in Kerala. Reserving sufficient storage to absorb extreme flows during flood events, minimising the peak outflow from the reservoir and early release of water to avoid high peak outflows are possible management strategies for minimizing flood severity in the future.

The novel methodology which makes use of remote sensing data is an efficient alternative to in situ data-based models when the lack of data would otherwise hinder the creation of the reservoir model. The proposed method is a generalized one which can be applied to any other region for flood management.

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References

[1] India Meteorological Department, 2018. Customised Rainfall Information System. [Online] Available at: http://hydro.imd.gov.in/hydrometweb/(S(y04urs45g5n1sa55nv3mklif))/landing.aspx [Accessed 3 April 2019].

[2] United Nations, 2018. Kerala Post Disaster Needs Assessment Floods and Landslides – August 2018, s.l.: UN.

[3] Mishra V, Aaadhar S, Shah H, Kumar R, Pattanaik DR, Tiwari AD (2018) The Kerala flood of 2018: combined impact of extreme rainfall and reservoir storage. Hydrol Earth Syst Sci Discuss, https://doi.org/10.5194/hess-2018-480

[4] Sudheer KP, Bhallamudi SM, Narasimhan B, Thomas J, Bindhu VM , Vema V, Kurian C (2019) Role of dams on the floods of August 2018 in Periyar River Basin, Kerala. Current Science 116 (5): 780-794

[5] Anandalekshmi A, Seenu T Panicker, Adarsh S,Muhammed Siddik A, Sajna Aloysius, Mehjabin M(2019) Modeling the concurrent impact of extreme rainfall and reservoir storage on Kerala Floods 2018: A Copula approach. Modeling Earth Systems and Environment (DOI: 10.1007/s40808-019-00635-6)

[6] NASA, 2019. GPM_3IMERGDL: GPM IMERG Late Precipitation L3 1 day 0.1 degree x 0.1 degree V05.[Online] Available at: https://disc.gsfc.nasa.gov/datasets/GPM_3IMERGDL_V05/summary?keywords=gpm [Accessed 30 March 2019].

[7] Yamazaki D, Ikeshima D, Tawatari R, Yamaguchi T, O'Loughlin F, Neal JC, Sampson CC, Kanae S, Bates PD 92017) A high accuracy map of global terrain elevations. Geophysical Research Letters 44: 5844-5853. http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_DEM/

[8] Costache, R., 2014. Using GIS Techniques for Assessing Lag Time and Concentration Time in Small River Basins. Case Study: Pecineaga River Basin, Romania. Geographia Technica, 09(1), pp. 31-38.

[9] India Water Portal, 2002. Met_Data. [Online] Available at: http://www.indiawaterportal.org/met_data/ [Accessed 25 March 2019].

[10] Purdue University, n.d. SCS Curve Number Method. [Online] Available at: https://engineering.purdue.edu/mapserve/LTHIA7/documentation/scs.htm [Accessed 20 March 2019].

[11] Chappell, N. A., Bidin, K. & Tych, W., 2001. Modelling rainfall and canopy controls on net-precipitation beneath. Plant Ecology, Volume 153, pp. 215-229.

[12] Water Resources Information System of India, 2012. Kakki(Eb) Dam D03369. [Online] Available at: http://india-wris.nrsc.gov.in/wrpinfo/index.php?title=Kakki(Eb)_Dam_D03369 [Accessed 5 January 2019].

[13] Department of Soil Survey and Soil Conservation, 2019. Soils of Kerala. [Online] Available at: http://www.keralasoils.gov.in/index.php/2016-04-27-09-26-39/soils-of-kerala#forest-soils [Accessed 25 March 2019].

[14] Green Clean Guide, 2012. How to calculate water losses through seepage?. [Online] Available at: https://greencleanguide.com/water-losses-through-seepage/ [Accessed 25 March 2019].

[15] Klipsch JD, Hurst MB (2013). HEC-ResSim Reservoir System Simulation User's Manual, Davis, CA: US Army Corps of Engineers Institute for Water Resources Hydrologic Engineering Centre.

[16] Osroosh M, Makenanizadeh H, Torfi S (2012) HEC – Res Sim Model for Simulating utilization from reservoir in the form of multiple-dam. International Journal of Structronics & Mechatronics.

[17] Babazadeh, H., Sedghi, H., Kaveh, F. & Jahromi, H. M., 2007. Performance Evaluation of Jiroft Storage Dam Operation Using HEC-ResSim 2.0. Eleventh International Water Technology Conference, pp. 449- 459.