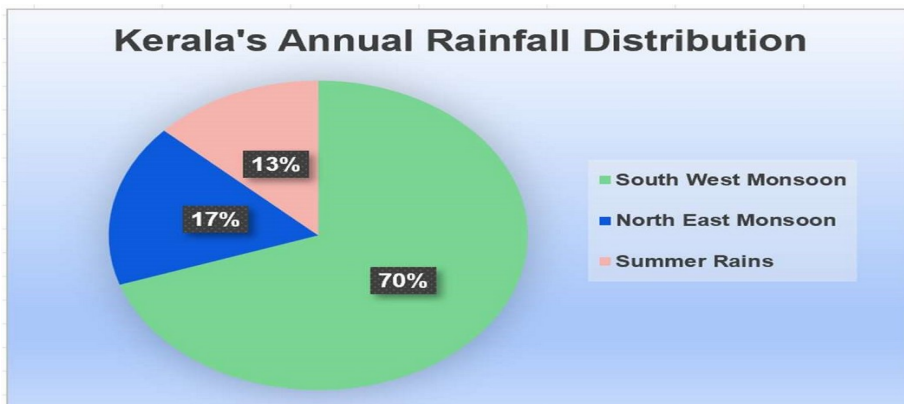


## RESERVOIR MONITORING OF KSEBL DAMS

From the point of view of water resources Kerala is having both abundance and scarcity. The spatial and temporal distribution pattern of the rainfall is mainly responsible for the frequent floods and droughts in Kerala. Indian Meteorological Department (IMD) recently revised 2890.8 mm as the average annual rainfall of the state based on long period average (LPA) of 1971-2020. As per IMD, the bulk of the



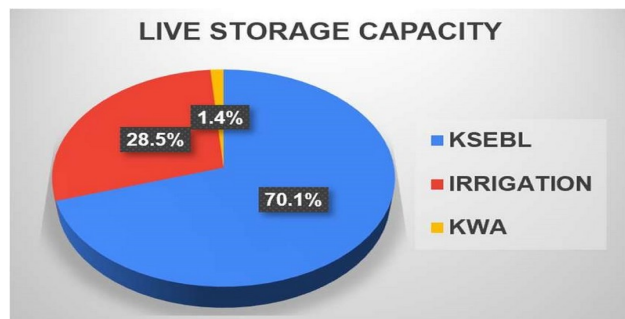
above rainfall around 70% is received during the South-West monsoon which sets in by June and extends up to September. The state also gets rains from the North-East monsoon during October to December, which amounts to 17% of annual rainfall. Rest 13% of the rainfall received during summer months of January to May.

Kerala has got 41 west-flowing rivers and 3 east-flowing rivers were originating from the Western Ghats. The total annual yield of all these rivers together is 78 billion Cubic Meters (BCM) as per the Water Resources of Kerala, 1974. The peculiarity of the rivers flowing across Kerala is short length of the river and the elevational difference between the high and the low land leading to quick flow of water collected from the river basin and quickly discharged into the Arabian sea. Therefore, the reservoirs play an important role in ensuring water availability during scarce summer months by storing the water during the monsoon period and absorbing medium intensity floods.

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## DAMS & RESERVOIRS

Kerala has 60 numbers of specified dams and 35 significant reservoirs. Some of the major reservoirs like Idukki, Kakki, Banasurasagar, Sholayar, etc are formed with



multiple dams. The combined live storage capacity of all these 35 reservoirs is 5058 MCM (5.8 BCM), out of which 3547.6 MCM (70.1%) falls under the 18 reservoirs owned by KSEBL. Meanwhile, 16 reservoirs of Irrigation Department store 1441.9 MCM (28.5%) and the lone reservoir maintained by Kerala Water

Authority stores 68.4 MCM (1.4%). Another important aspect to be noted here is that all the reservoirs owned by various agencies in the State together only store 7% of the total annual runoff of 78 BCM.

Further, Tamil Nadu Government owns 4 reservoirs inside Kerala's territory with a combined live storage of 618.4 MCM viz. Mullaperiyar, Parambikuam, Tunacadavu and Peruvareppallom.

### KSEBL RESERVOIRS

KSEBL owns 38 specified dams and 18 significant reservoirs. The biggest reservoir is Idukki (1459.5 MCM) and the smallest one is Sengulam with 0.39 MCM. Based on the volume of the reservoirs, they are categorized as major, medium and minor reservoirs.

Daily reservoir statistics along with all dam related information are being published at a dedicated website maintained by the Dam Safety Organisation ([www.dams.kseb.in](http://www.dams.kseb.in)) of KSEBL for public information.

### MAJOR RESERVOIRS

Five out of the eighteen reservoirs are categorised as major reservoirs, which consist of 92.3% of the combined storage capacity of KSEBL reservoirs. The details of the major reservoirs are given in the following table.

MAJOR RESERVOIRS		
#	RESERVOIR	LIVE STORAGE (MCM)
1	IDUKKI	1459.49
2	IDAMALAYAR	1017.80
3	KAKKI	446.51
4	BANASURASAGAR	201.00
5	SHOLAYAR	149.09
TOTAL		3273.89

## MEDIUM RESERVOIRS

There are six reservoirs falling into the category of medium reservoirs, whose storage capacity varies between 30.3 mcm to 54.77 mcm. These reservoirs combined storage capacity comes to 7% of the combined storage capacity of all KSEBL reservoirs. Due to the limited storage capacity, these reservoirs have no significant role in negotiating the floods and they spill during good monsoon years.

MEDIUM RESERVOIRS		
#	RESERVOIR	LIVE STORAGE (MCM)
1	MADUPETTY	54.77
2	ANAYIRANKAL	49.83
3	PONMUDI	47.40
4	KAKKAYAM	33.98
5	PAMBA	31.15
6	PORINGALKUTHU	30.30
TOTAL		247.43

## MINOR RESERVOIRS

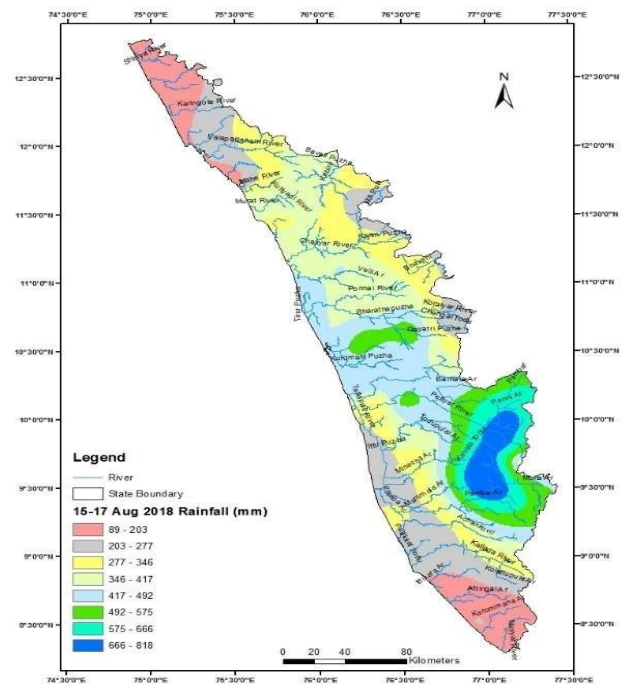
There are seven reservoirs falling into the category of minor reservoirs, whose storage capacity varies between 7.65 mcm to 0.39 mcm. The total storage capacity of these comes to just 0.7% of the combined storage capacity of all KSEBL reservoirs. Due to the insignificant storage capacity, these reservoirs used to spill, if there is good spell for a short period.

MINOR RESERVOIRS		
#	RESERVOIR	LIVE STORAGE (MCM)
1	KUNDALA	7.65
2	KALLARKUTTY	6.43
3	ERATTAYAR	5.29
4	LOWER PERIYAR	4.55
5	MOOZHIYAR	1.16
6	KALLAR	0.76
7	SENGULAM	0.39
TOTAL		26.23

## 2018 FLOODS

During the year 2018, Kerala had received above normal rainfall in the months of June and July, ie, 1607 mm against an LPA of 1357.9 mm (16.8% above normal). This above normal rainfall during the first half of South-West Monsoon, pushed many major reservoirs above 90% storage capacity at the beginning of August.

Further during 8-9 August, very heavy rainfall occurred at several places in the State. On 9 August, rainfall of 398 mm, 305 mm, 255 mm and 214mm was recorded at Nilambur in Mallapuram district, Mananthavadi in Wayanad district, Peermade in Idukki district, and Palakkad in Palakkad district, respectively, as per IMD data. This heavy storm resulted in severe flooding at several places in the Malabar areas, especially Nilambur in Malappuram district and Malampuzha in Palakkad district during 8-10 August. This heavy spell of rain was then followed by an extreme rainfall event which started on 14 August and continued up to 19 August. The peak of the rainfall was observed between 15-17 August, 2018.



The 3 day storm occurred between 15-17 August, 2018 was almost equal to the historical storm of 16-18 July, 1924 (known as the great deluge of 99). CWC had estimated that the three days storm of 2018 generated around 12.3 BCM runoff in the State, which is more than 15% of the average annual runoff of 78 BCM. It is worth to note that IMD had forecasted only a normal monsoon for 2018 in its both Long Range Forecasts (LRF).

The following table illustrates the rainfall received and consequent runoff generated from the catchment of the major reservoirs under KSEBL due to the 3 days storm in August, 2018.

RESERVOIR	RAINFALL	RUN OFF	RUN OFF AS % OF FULL STORAGE
IDUKKI	711 mm	431.72 MCM	29.6%
IDAMALAYAR	595 mm	240.23 MCM	23.6%
KAKKI	812 mm	154.37 MCM	34.6%
BANASURASAGAR	831 mm	46.80 MCM	25.3%

This extreme rainfall event had forced the authorities to open the spillways of the all reservoirs to release the excess spill water to safeguard those structures, thereby addressed the large public safety. After a detailed analysis of the extreme floods, CWC had concluded that:

*“From the analysis it has been found that the dams in Kerala neither added to the flood nor helped in reduction of flood, as most of the dams were already at FRL or very close to FRL on 14 August 2018, due to more than normal rainfall in the months of June to July 2018. It may be noted that, had the reservoir been a few feet below FRL, the flooding conditions would have not changed much, as the severe storm continued for 3 days and even for 4 days at majority of the places, and in any case, it would have been necessary to release from the reservoirs after 1st day of the extreme rainfall.”*

All reservoirs in Kerala are designed and operated as conservation reservoirs till 2018. As per IS 7323:1924, such reservoirs shall be operated to fill as early as possible to augment supplies during lean periods. However, considering the extreme floods and increased population density in the flood plains, CWC had recommended to implement rule curves for all major reservoirs, which are having more than 200 MCM capacity, in order to create some dynamic flood cushion for moderating the floods of lower return periods particularly in the early period of monsoon.

## UPPER RULE LEVELS

As recommended by the Central Water Commission (CWC), KSEBL had implemented upper rule levels (URL) from 2019 onwards in its four of its major reservoirs, which are having more than 200 MCM capacity. The URL are formulated based on a stochastic process considering long period data of reservoirs from their inception, as per the national norms. The URL helps to absorb medium floods and enable the dam managers to discharge such floods in a moderate manner taking long duration, thus ensuring safe reservoir operation. The URLs formulated by KSEBL were vetted and modified by the CWC and it was approved by the Government of Kerala.

Extreme care is taken to ensure that the spillway releases are moderate to the extent possible and does not create any flooding downstream. Thus, all dam operations by KSEBL since 2019 were done strictly adhering to the URL and ensured safe dam operations during 2019 floods as wells as intense monsoon spells of 2021 and 2022.

Moreover, a High Level Committee is constituted by the Government vide G.O. (Rt) No. 453/2021/DMD dated 3.06.2021 to strictly monitor the rule levels of all major dams continuously during the monsoon period and take appropriate decisions on the spillway releases. Additional Chief Secretary, Disaster Management heads this Committee, which includes the representatives from Water Resources, KSEBL, SDMA and all District Collectors.

The URL for the major reservoirs are provided in the following table.

UPPER RULE LEVELS OF RESERVOIRS WITH MORE THAN 200 MCM LIVE STORAGE				
TIME PERIOD	IDUKKI	IDAMALAYAR	KAKKI	BANASURASAGAR
1 JUN - 10 JUN	2373.00 ft	161.00 m	975.36 m	767.00 m
11 JUN - 20 JUN	2373.00 ft	161.00 m	975.36 m	767.00 m
21 JUN- 30 JUN	2373.00 ft	161.00 m	975.36 m	768.00 m
1 JUL-10 JUL	2375.33 ft	161.50 m	975.36 m	771.00 m
11 JUL-20 JUL	2377.95 ft	161.75 m	975.36 m	773.50 m
21 JUL-31 JUL	2380.58 ft	162.50 m	975.36 m	773.50 m
1 AUG - 10 AUG	2383.53 ft	163.00 m	975.75 m	774.00 m
11 AUG - 20 AUG	2386.81 ft	163.50 m	976.00 m	774.50 m
21 AUG - 31 AUG	2390.09 ft	164.00 m	976.20 m	774.50 m
1 SEP - 10 SEP	2392.55 ft	165.00 m	976.40 m	775.00 m
11 SEP - 20 SEP	2395.01 ft	166.00 m	976.60 m	775.00 m
21 SEP - 30 SEP	2396.94 ft	166.30 m	976.91 m	775.00 m
1 OCT - 10 OCT	2397.78 ft	166.60 m	977.95 m	775.00 m
11 OCT - 20 OCT	2398.86 ft	166.80 m	978.83 m	775.60 m
21 OCT - 31 OCT	2399.31 ft	167.00 m	979.84 m	775.60 m
1 NOV - 10 NOV	2399.79 ft	168.50 m	980.56 m	
11 NOV - 20 NOV	2400.03 ft	168.50 m	981.00 m	
21 NOV - 30 NOV	2403.00 ft	168.50 m	981.00 m	



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The fifth major reservoir, Sholayar is having less than 200 MCM capacity and is operated based on the levels specified in the Parambikulam Aliyar Project Agreement, which stipulates the reservoir shall be filled to its FRL on September 1<sup>st</sup> and February 1<sup>st</sup>. As annual entitlement of Kerala from Sholayar is 348.3 MCM (12.3 TMC), while the reservoir's live storage is limited to 149.09 mcm. The levels stipulated in the PAP Agreement ensures an optimum flow pattern considering the storage space in the upstream Tamil Nadu Sholayar. Safe reservoir operations are ensured at Sholayar too, with close co-ordination and monitoring with the Tamil Nadu Government authorities, who is having 4 major reservoirs in the Chalakudy basin.

### **ALERT LEVELS**

KSEBL issues three major alerts viz. BLUE, ORANGE AND RED when the reservoirs where URL is established is getting closer to URL or in case of other reservoirs, when there is a possibility of them reaching its full reservoir level (FRL). The spillways are being operated only after obtaining statutory permission from the concerned District Collectors and strictly adhering to the SOP under Operation and Maintenance Manual as well as the protocols insisted on the ORANGE BOOK by the Kerala State Disaster Management Authority (KSDMA).

- BLUE alert is issued as the first warning to indicate the reservoir is getting close to the URL or FRL, as the case may be
- ORANGE alert is issued when the possibility of opening of spillway is imminent and then mike announcements are made by KSEBL/Police/Fire Force/Local bodies
- The spillways shall open any time once the RED alert is declared, depends on the intensity of the inflow.

The sirens installed in the dams are ringed 3 times before opening of the spillways and the information is made available through the press and visual media along with web sites and social media platforms of KSEBL, KSDMA and DDMA.



## EMERGENCY ACTION PLANS



Emergency Action Plans (EAP) were prepared for all major dams based on the Dam Break Analysis (DBA) carried out using Digital Elevation Model (DEM).

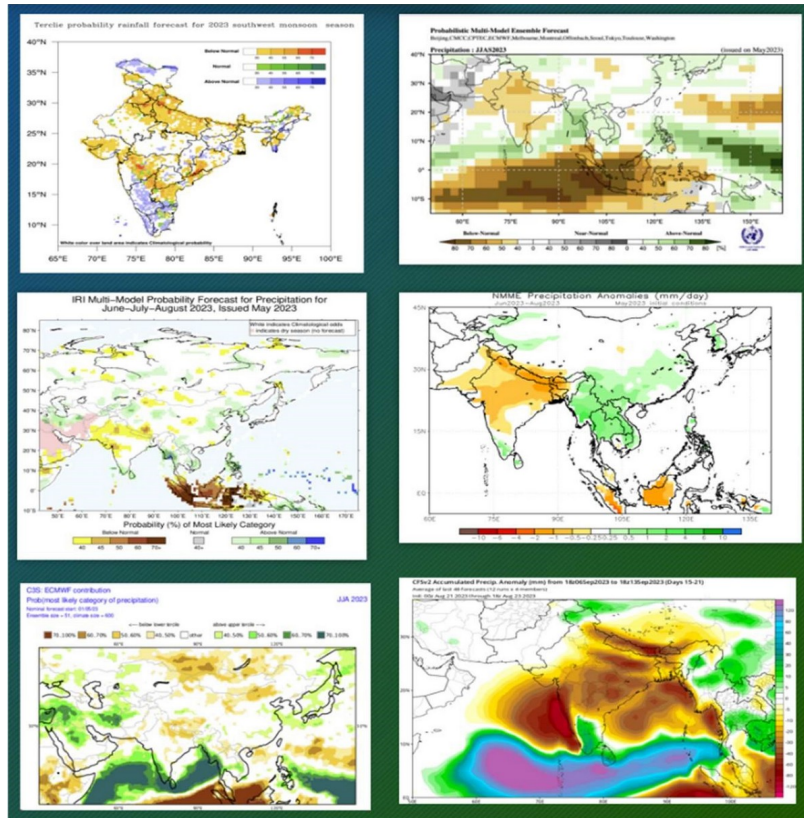
EAP was prepared considering various emergency possibilities and develop appropriate notification procedures for timely rescue and relief operations.

Inundation maps are prepared as part of the EAP and all the Panchayaths / Municipalities are identified on the path of the flood discharge. Also, KSEBL had conducted stakeholder meetings to disseminate EAP. The plans, which were vetted and approved by the CWC, are made available at State Disaster Management Authority (SDMA), District Disaster Management Authority (DDMA), KSEBL website, etc.

## MONSOON MANAGEMENT

Four months long operational planning for the South West Monsoon is being done based on the Long-Range Forecast (LRF) given by Indian Meteorological Department (IMD), as 70% of the inflow is received during the above period.

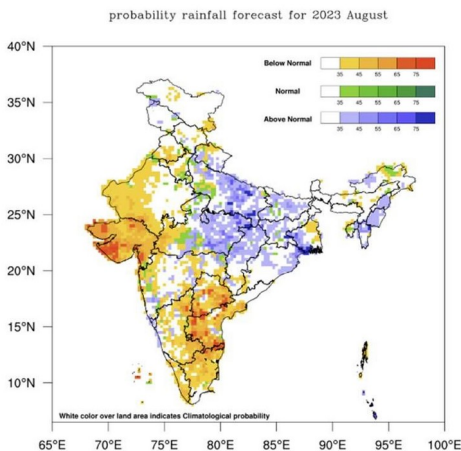




Further KSEBL also used to consider the seasonal forecasts provided by World Meteorological Organisation (WMO), International Research Institute (IRI), North American Mul Model Ensemble (NMME), European Union Medium Weather Forecast (ECMWF), Climate Forecasting System of NCEP (CFS).

## MONTHLY FORECASTS

The above South-West monsoon plan is tweaked and iterated every month based on the inflows received, storage position and monthly forecasts provided by IMD. KSEBL also consider the monthly forecasts from WMO, NMME, CFS & C3S to see whether those forecasts are in broad agreement with the IMD forecast.



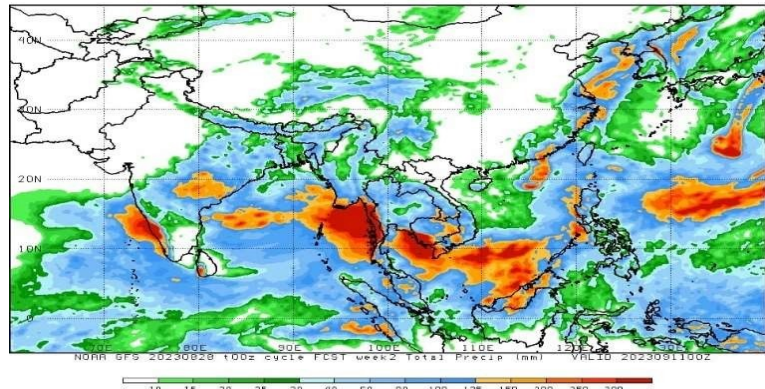
Different utilisation scenarios are drawn based on long term inflow series to keep the reservoirs under the upper rule levels. The operational strategy of the generating stations attached to the major reservoirs are being discussed and finalised with the engineers operating the Load Despatch Centre, so as to have optimum utilisation of the resources.

## EXTENDED RANGE FORECASTS

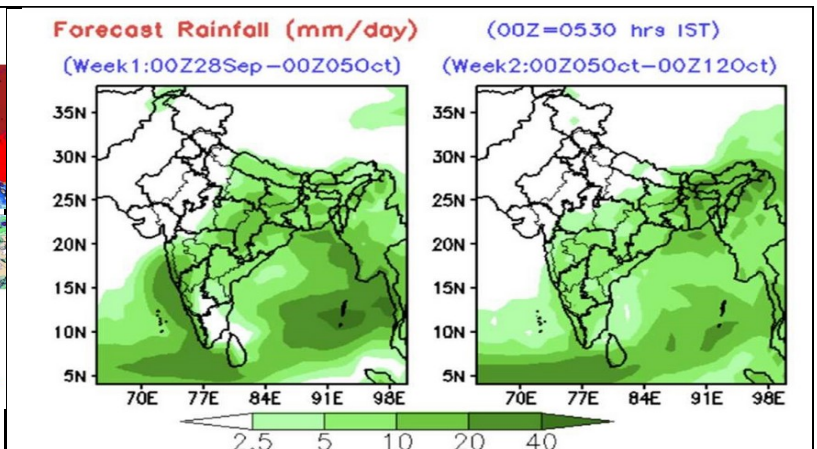
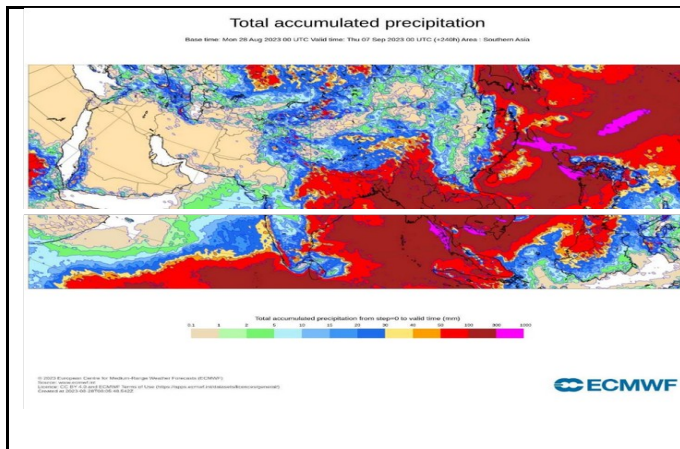
Further Extended Range Forecasts (ERF) by IMD, GFS & ECMWF are analysed to see the weather forecast for next me step in the (10 days) and the anticipated inflows are es mated for the operational advices.

Time Step Inflows based on long term series for each major reservoir is considering to arrive the worst-case scenario from the above forecasts.

The above scenarios drawn are further iterated based on the daily inflows received and storage position. The goal is to keep the reservoirs within the URL to avoid spill and same me ensure enough reserve for mee ng the lean period.



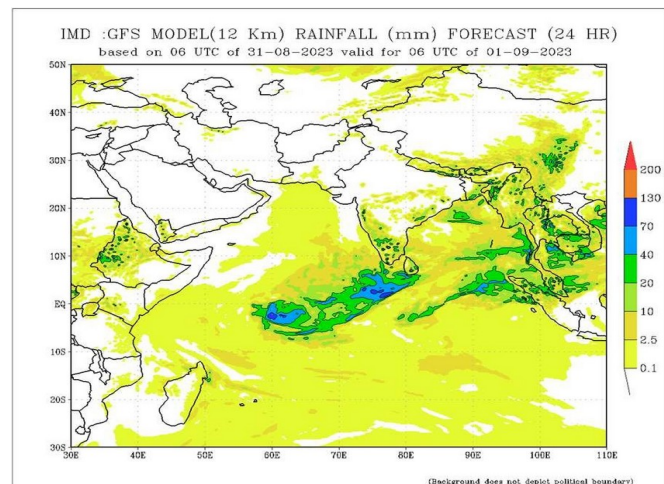
URL



## DAILY FORECASTS

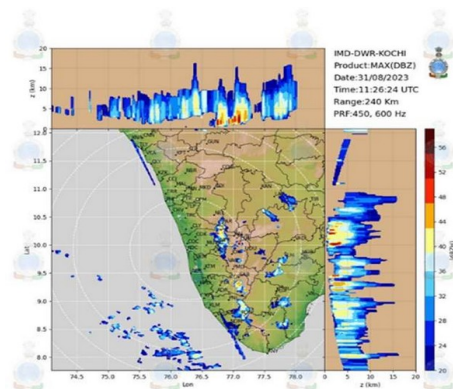
5 days District Rainfall Forecast (DRF) by IMD, daily forecasts issued based on GFS model of IMD, NOAA GFS, ECMWF along with ACCESS, ICON, UKMET etc also considered during peak monsoon periods.

Cyclones or western disturbances are closely monitored and get feedback from the meteorologists of IMD, SDMA, etc to take considered decision making.



ENSO, IOD & MJO etc which influence Indian Monsoon is also closely being monitored considering the inputs from Climate Prediction Centre, NOAA, USA and Bureau of Meteorology, Australia.

## REAL TIME MONITORING



As catchments of KSEBL reservoirs are comparatively small and steep, the travel time of runoff to the reservoirs is about 3-4 hours only. We collect and analyse hourly inflows from the dam sites, when very heavy rainfall occurs and when the reservoirs are at high storage position.

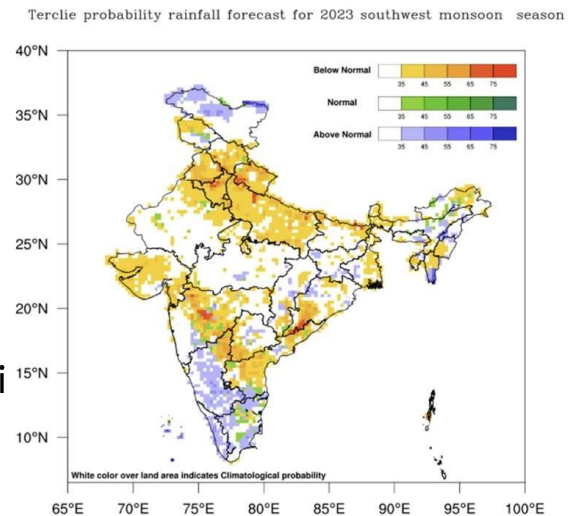
Also, we scrupulously monitor the radar data information from IMD, which is available at 30 min interval to get a broader picture of spatial rainfall events.

Communication facilities at the dam sites were revamped by providing satellite phones, so as to ensure a smooth information flow to aid the decision making process. Also, CCTV cameras were installed at various strategic locations at important dam sites for efficient surveillance and monitoring. Field Engineers share reservoir data at every 3 hour through WhatsApp Groups during the monsoon period, which is made available to the top management to have a live update at their disposal for decision making.

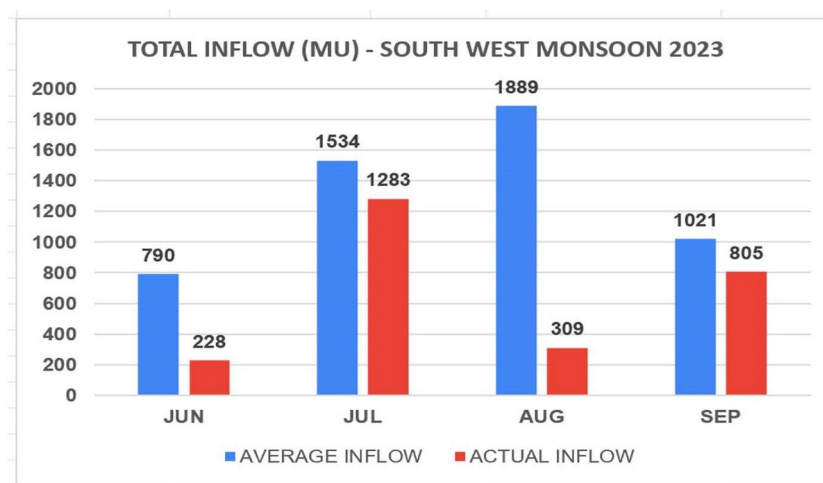


## SOUTH WEST MONSOON 2023

IMD's Long Range Forecast dated 26.05.2023 had forecasted 'above normal' rainfall during the South-West Monsoon for the Kerala region. However, as per IMD, the South-West Monsoon ended with 34% deficit rainfall for the State. The Idukki District, where majority of KSEBL reservoirs situated recorded a deficit of 54%.



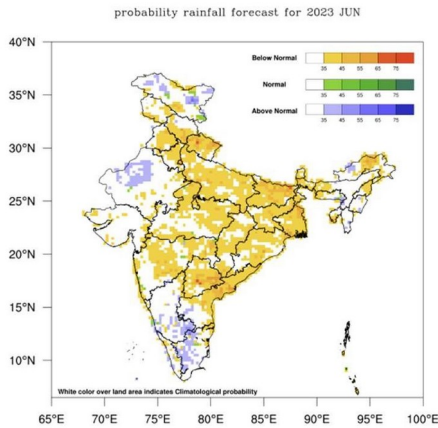
If we consider the inflow to all our reservoirs, we planned for normal inflow on a conservative side even though IMD forecasted 'above normal' rainfall for the Kerala State. However, we received only an inflow equivalent to 2626 MU against the last ten years moving average inflow of 5234 MU, ie, the actual inflow received was only 50.2% of the anticipated inflow.



The above graph shows how the total actual inflow received in KSEBL reservoirs is deviated from the last ten years' average inflow, which is taken for South-West Monsoon planning purpose, when the forecast is 'normal'.

To understand how the actual realisation is vastly deviated from the monthly forecast given by IMD and a comparison is made in the following paragraphs.

## JUNE 2023

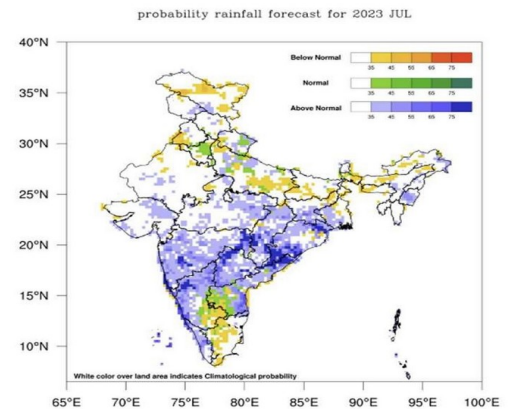


The monthly forecast by IMD for June 2023 was mostly fall in the 'uncertain' category, which means the rainfall can either be 'below normal' or 'normal' or 'above normal'. However, the total actual inflow received in all KSEBL reservoirs in June 2023 was 228 MU, ie, 28.9% of the last ten years average of 790 MU. Such a fatal failure of monsoon in June was not at all forecasted by IMD.

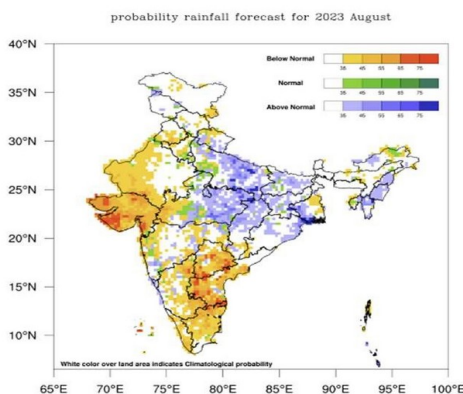
## JULY 2023

The monthly forecast by IMD for July 2023 was mostly fall in the 'above normal' category for Kerala region.

However, the total actual inflow received in all KSEBL reservoirs in July 2023 was 1283 MU, ie, 83.6% of the last ten years average of 1534 MU. Though this inflow was much better than June, it was also below normal, which also contradicted the forecast.



## AUGUST 2023



The monthly forecast by IMD for August 2023 was the 'below normal' category for Kerala region, with a climatological probability of 45%.

But, the month of August was devastating one and the total actual inflow received in all KSEBL reservoirs in August 2023 was an abysmal low of 309 MU, ie, a mere 16.4% of the last ten years average of 1889 MU. July & August months combined to bring almost 45% of the inflow to our reservoir systems. However, the extreme failure of August was not captured by the monthly



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## SEPTEMBER 2023

The monthly forecast by IMD for September 2003 was the 'below normal' category for Kerala region, though at patches it forecasted 'normal' rainfall.

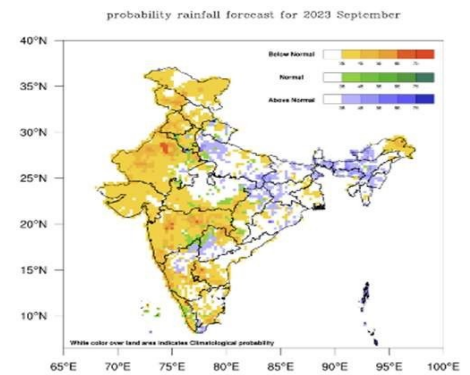
The total actual inflow received in all KSEBL reservoirs in September 2023 was 805 MU, ie, 78.9% of the last ten years average of 1021 MU. This is the only me, the actual inflow received in the reservoirs was as per the rainfall forecasted by IMD.

### UNCERTAINTIES ASSOCIATED WITH MONSOON FORECAST

Forecasting the Indian summer monsoon is one of the oldest challenges in climate science. Building and running a climate model is complex process of identifying and quantifying Earth system processes, representing them with mathematical equations, se ng variables to represent initial conditions and subsequent changes in climate forcing, and repeatedly solving the equations using powerful supercomputers. Forecasting the monsoon is quite complex, especially when we're talking about 4-month lead times at sub-national scales.

Many times, the actual rainfall deviates from the forecasts and all planning based on the forecast is thrown to the winds. The uncertain es associated with monsoon forecasts make reservoir management really challenging and complex. Whether to preserve water or to utilise it during the course of monsoon is a tough call to be taken by the dam managers, as both choices involve high stakes.

If we preserve by reducing the genera on and keep the reserve for the lean months, an extreme rainfall may force us to spill and waste the precious resources. Vice versa, if we generate and check the storages, any failure will severely jeopardise our lean period needs. Hence the experts in Dam Safety Organisation meticulously analyse all past outlier events, various probabilities of inflow recorded, inputs from multiple forecasts and taking decisions based on the limitations of each reservoir and possible maximum genera on capability of the associated power houses. A process of iteration is done monthly as well as me step wise by updating the actual inflow and utilisation, so as to have the op mum utilisation. Of course, there is no straight jacket formula is there, lots of the calls taken are based on their vast professional experience of managing the systems. Dam management is always done by placing public safety at the highest pedestal and same me balancing the responsibility to ensure quality power to their consumers at affordable cost. Each monsoon is an opportunity to learn new lessons to adapt and improving the dam management.



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While understanding these aspects, each one of us has a responsibility to use WATER judiciously. The demand side management at each household will go a long way. Similarly along the banks of reservoirs and rivers in catchment areas a proper watershed management, water harvesting, afforestations, tree plantations, avoiding erosion activity, avoiding changing topography, if controlled and all activities done scientifically in synch with nature, it will go a long way to do water management effectively as well as tackle climate change.

We, as a citizen of this world, have a role to play to preserve the environs. Kerala has done wonders in community led interventions. We take up the challenges due to climate change and strive to do our best.

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