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Hydrologic Safety Evaluation of Dams

Rule Curve including case study of Tehri Dam

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Rule Curve including case study of Tehri Dam

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Water release from Panchet Dam on 17.09.24



Vishnuparyag hydropower project

 circle of blue



CLASSIFICATION OF RESERVOIRS

Reservoirs can be classified from the point of view of reservoir operation and purposes they serve, i.e.

Single Purpose Reservoirs

Developed to serve only one purpose, which may be flood control or any of the conservation uses such as irrigation, power generation, navigation, industrial use, municipal water supply etc.

Multi-Purpose Reservoirs

Developed to serve more than one purpose which may be a combination of any of the conservation uses with or without flood control.

CLASSIFICATION OF RESERVOIRS

Pondage Reservoirs

Pondage reservoirs have larger storage than the diversion projects. The storage, however, would not be so large so as to confidently decide a season of increasing or decreasing storage.

Storage Reservoirs

- **Within the Year storage**

Within the year storage reservoirs are so designed that in normal circumstances they completely fill up and even spill during the flood season and are almost completely depleted in the low flow season. For such reservoirs, the storage accumulation and storage depletion period can be defined rather accurately.

CLASSIFICATION OF RESERVOIRS

- **Carryover (the Year) Storage Reservoirs**

They have an active storage element larger than the normal inflows and requirements specially in irrigation projects so that they do not reach up to MDDL every year. Small changes, in the distribution of flows within the year, would not normally affect their performance, which would be governed more by the sequence of annual flows.

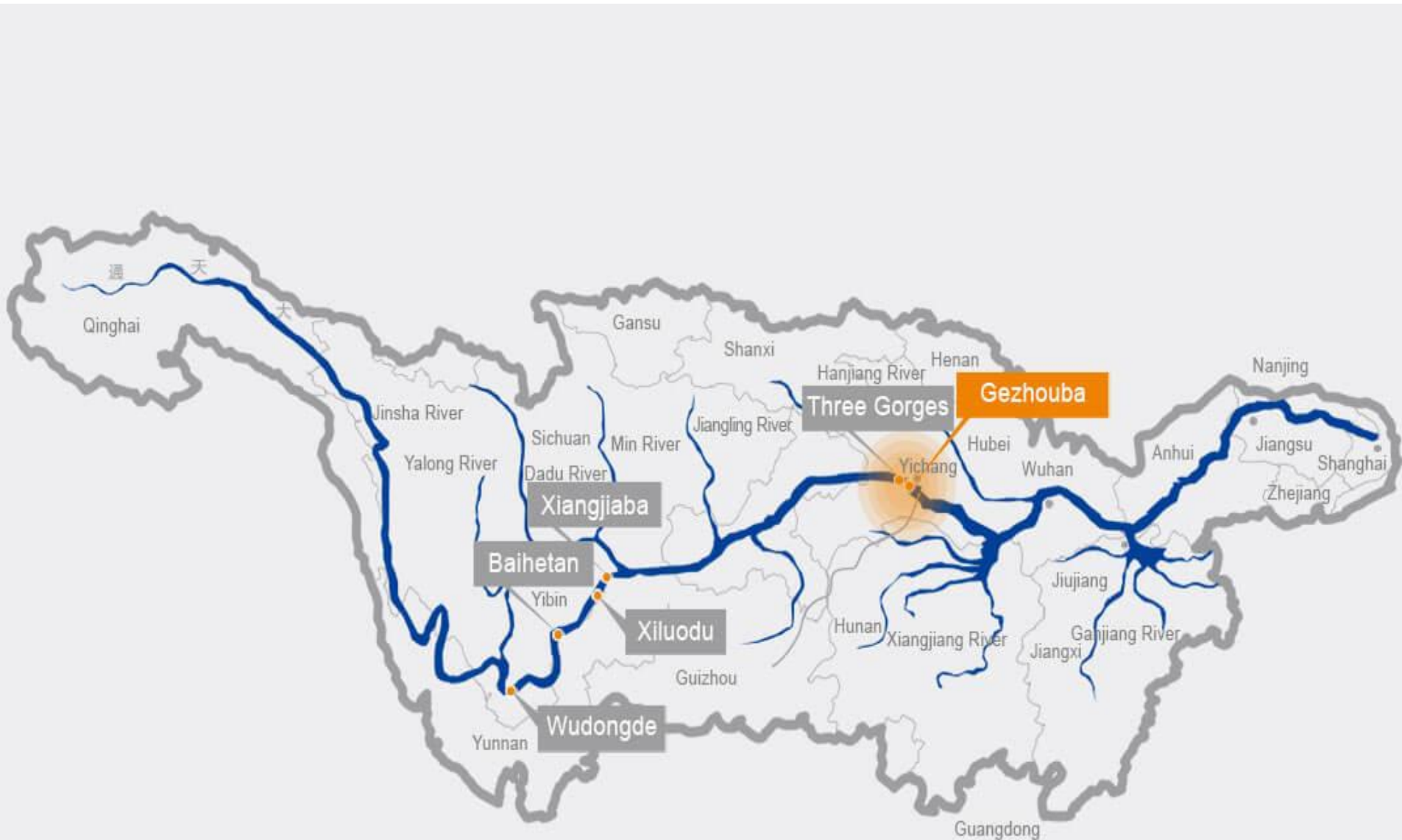
- **Cascade of Reservoirs**

These consist of a group of single / multiple purpose reservoirs, which may be operated in an integrated manner for optimum utilization of the water resources of the river system (e.g. Tehri hydro Power Complex).

Cascade of Reservoirs

- Cascade of reservoirs is more effective in terms of peak delay than the equivalent storage capacity combined in one reservoir, because cascading tends to generate a multi-peaked hydrograph.
- As there are number of Hydro Projects in a basin/vally, an Integrated Reservoir Operation System is required for moderation the floods.
- In addition, Upstream Power Plants can be operated to generate energy during peaking time while the Downstream Reservoir can act as Regulating Reservoir to regulate the releases to meet the Drinking and Irrigation water Requirement.
- In India, cascade of Dams has been constructed in many rivers such as Srisailam and Nagarjuna Sagar Dam, Bhakra and Nangal Dam, Tehri and Koteswar Dam etc.

Cascade Hydro Projects on Yangtze/Jinsha River China



Cascade Hydro Projects on Yangtze/Jinsha River China

Total Capacity-71743 MW

Hydro Project	Height	Type	Installed Capacity (MW)	River	Year of Commis.
<u>Baihetan Dam</u>	277 m (909 ft)	Concrete arch	16000 (16X1000)	<u>Jinsha River</u>	2 units commissioned in June 21
<u>Wudongde Dam</u>	240 m (790 ft)	Concrete gravity	10200 (12X850)	<u>Jinsha Rive</u>	2 units commissioned in July 20
<u>Xiluodu Dam</u>	285.5 m (937 ft)	Concrete arch	13860 (18X770)	<u>Jinsha River</u>	2013
<u>Xiangjiaba Dam</u>	161 m (528 ft)	Concrete gravity	6448 (4X812+ 4X 800*)	<u>Jinsha River</u>	2014
<u>Three Gorges Dam</u>	181 m (594 ft)	Concrete gravity	22500 (32X700+ 2X50)	<u>Yangtze River</u>	2008
<u>Gezhouba Dam</u>	53m	Concrete	2735	<u>Yangtze River</u>	1981

Principles of operation of Reservoirs

- Control of flood is better achieved if the reservoir level is kept low in the early stages of the monsoon season. However, at a later stage, if the anticipated inflows do not result, the reservoir may not get filled up adequately for meeting the various water demands. On the other hand, **if** the reservoir is filled up to FRL in the early stages of monsoon, to avoid the risk of reservoir remaining unfilled at later stage, there may be problem of accommodating high floods occurring at later stage.
- In some cases while planning reservoirs, social and other considerations occasionally result in adoption of a plan that may not be economically the best. Considering all these issues, Rule Curve is required for regulation of reservoirs, though it may not be possible to cover all types of cases.

Principles of operation of Reservoirs

1. Single Purpose Reservoirs

- Flood control - Operation of flood control reservoirs is primarily governed by the available flood storage capacity, discharge capacity of outlets, their location and nature of damage centres to be protected, flood characteristics, ability and accuracy of flood/storm forecast and size of the uncontrolled drainage area.
- **Conservation** - Reservoirs meant for augmentation of supplies during lean period should usually be operated to fill as early as possible during filling period, while meeting the requirements. All water in excess of the requirements of the filling period shall be impounded. No spilling of water over the spillway will normally be permitted until the FRL is reached.

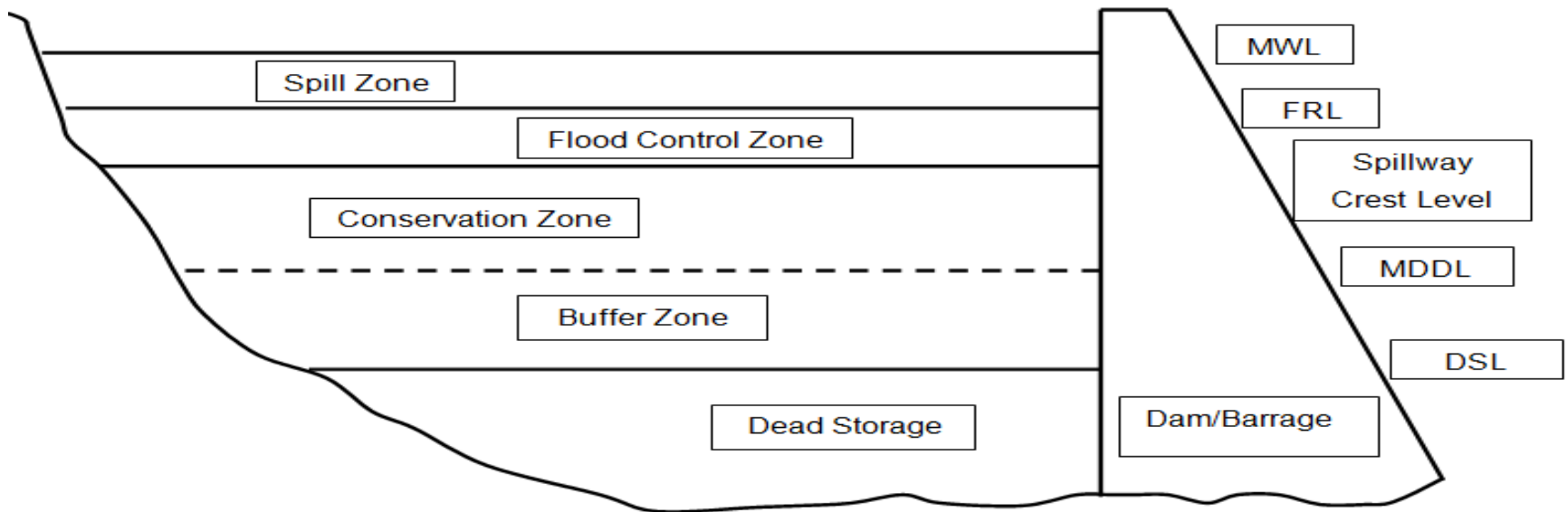
Principles of operation of Reservoirs

2. Multi Purpose Reservoirs

Operation of a multi-purpose reservoir should be governed by the manner in which various uses of the reservoir such as water for Drinking, Irrigation & Industrial use and Flood control have been combined. While operating the reservoirs to meet the demands of end users, the priorities for allocation may be used as a guideline. The various storage zones often identified are:

Zones of Reservoir

In general five basic zones of reservoir space may be used in operating a reservoir for various functions. Typical storage allocations for various uses are indicated in the figure below:



Zones of Reservoir

- **Dead storage zone (DSL)** - This is also called inactive zone. This is the lowest zone in which the storage is meant to absorb some of the sediments entering into the reservoir.
- **Buffer zone (MDDL)** -This is the storage space above dead storage level which is used to satisfy only very essential water needs in case of extreme situation.
- **Conservation zone** - This storage space is used for conservation of water for meeting various future demands. This zone is generally between FRL and dead storage level.

Zones of Reservoir

- **Flood control zone** - This is the storage space earmarked as temporary storage for absorbing high flows for alleviating downstream flood damages. This should be space emptied as soon as possible to negotiate next flood event.
- **Spill zone** - Storage space above the flood control zone between FRL and HWL, is generally referred to as spill zone. This space is occupied mostly during high floods and the releases from this zone are trade-off between structural safety and downstream flood damages.

Preventive Measures for mitigation of Floods

1. Integrated Operation of Reservoir-Rule Curve
2. Preparation of Emergency Action Plan
3. Inventory of Equipment, Material available with the Project, nearby Contractors/Projects, NDRF/SDRF, District Administration etc
4. Contact details of above Agencies
5. Identified Responsibilities in the Project
6. Proper Communication System
7. Inundation Plan
8. Inflow Forecasting System
9. Early Warning System

Operation of Reservoir-need of Rule curve

- Real time dam management during floods must rely on an operational, hydrological forecasting system in the catchment and downstream area. Operation under flood conditions can be performed through a rule curve within a real time information framework. The reservoir rule curve is essential requirement for reservoir operation during the monsoon period.
- A rule curve specifies the Target Reservoir levels indicating storage or empty space to be maintained in a reservoir during different times of the Monsoon Season.
- The performance of Reservoir/Reservoirs to be studied based on the ten-daily historical inflow series and incidents of peak flow at Dam site. After simulation for aforesaid period, outflows from reservoir worked out. The performance of Reservoir has also been studied.

Operation of Reservoir-need of Rule curve

- The rule curves are derived by operation studies keeping different criteria for filling the reservoir so as to have Minimum Probability of spillage or not filling upto full Reservoir level at the end of the Monsoon.
- Whenever Reservoir level rises above planned level, the water will be released through full operation of Machines or through spillway to create sufficient space for incoming floods.
- However special care has to be taken in case there is heavy rainfall or high water level in the river or in tributaries joining the river in D/S area
- Rule curves once prepared should be constantly reviewed and, if necessary, modified so as to have the best operation of the reservoirs.

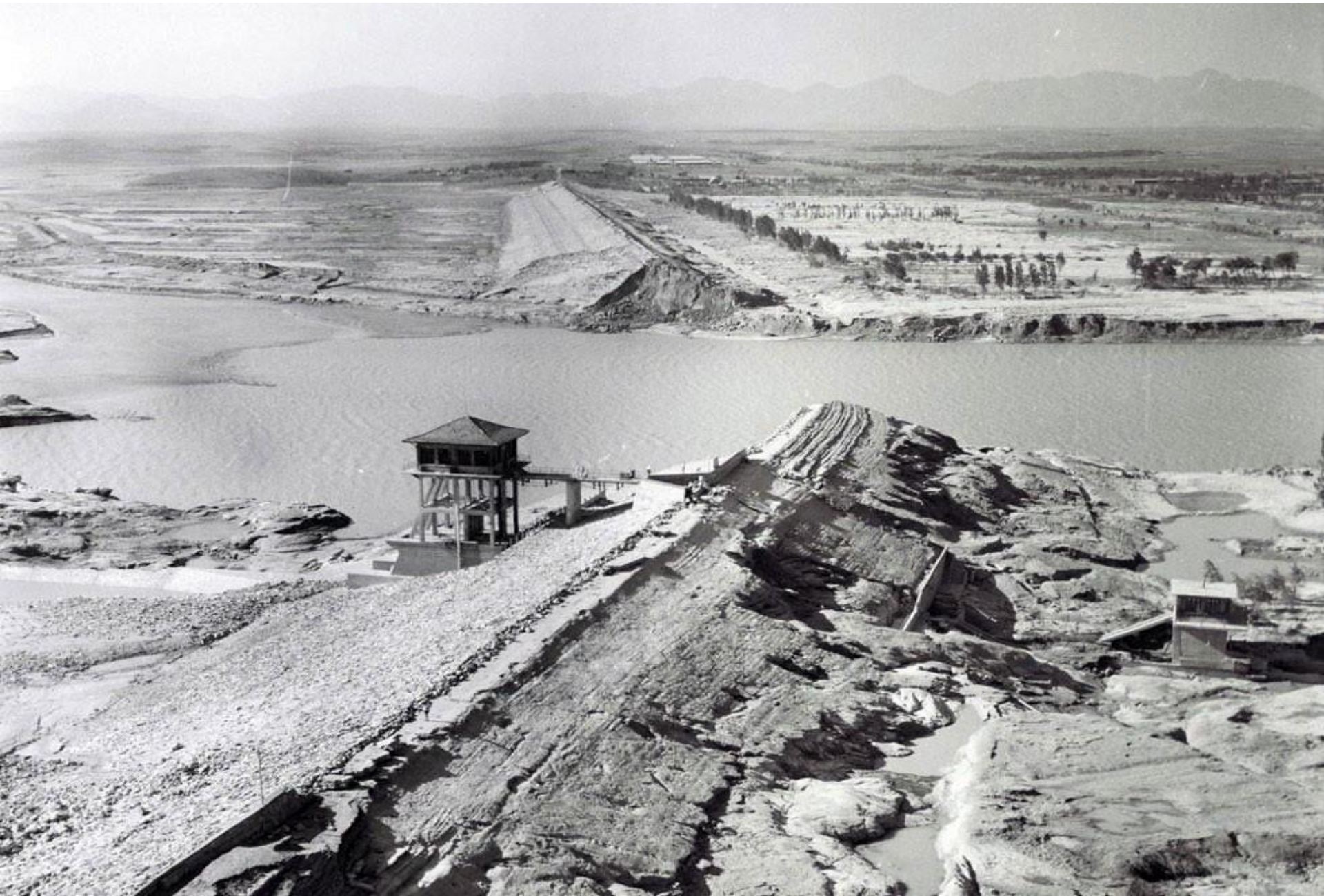
Failure of Banqiao Dam (Aug.75)

- Due to Typhoon Nina, heavy rain began to fall in the region, the gates of most dams were kept closed to retain as much water as possible. There had been a drought in the region for much of the summer . Over the next three days, over 150cm/60in of rain fell in many parts of Henan province . During the most intense parts of the storm, areas received seven inches in a single hour (Dam Failure).
- In the upper reaches of the Huai river system, on the Ru River, the Chinese built the Banqiao Dam in 1951. Built under Soviet supervision with a new design, “the iron dam,” and it was assumed to “be unbreakable,” even in the worst floods (Dam Failure). As rain fell throughout the region, many dams began to reach capacity and the reservoir management bureau tried to limit flood as much as possible. Typhoon Nina had disrupted the telephone connection to the Banqiao Dam, so downriver no messages were received it was assumed that the great dam had contained the floods (Si).

Failure of Banqiao Dam (Aug.75)

- On the evening of August 7th, 1975 , some smaller dams started to break below the Banqiao Dam. But dam workers furiously tried to shore up the other dams, trusting that the Banqiao dam would hold (Human Rights Watch). However, late that night on the seventh, floodwaters overtopped the Banqiao dam and the entire Banqiao reservoir began rushing down the Huai river valley (Dam Failure).
- The Chinese engineers had neglected to maintain or even removed flood mitigation measures to improve water retention and farmland access since the construction of the dams in the 1950s (HRW).
- This resulted the water to build and build as an increasing cascade down stream. In the torrent of water, there was a domino effect, water numerous smaller and mid-sized dams collapsed below the Banqiao dam added to the intensity of the flood. That night 62 total dams failed in the Huai river system (HRW).

Failure of Banqiao Dam



Preparation of Rule curves

- A rule curve is generally based on detailed sequential analysis of various critical combinations of hydrological conditions and water demands.
- These should be prepared in accordance with the Principles of operation of Reservoirs and should indicate reservoir levels and releases during different times of the year, including operational policies.
- Rule curves once prepared should be constantly reviewed and, if necessary, modified so as to have the best operation of the reservoirs.

Preparation of Rule curves

The following basic data is required for preparation of Rule Curves

- salient features & basic drawings
- Area – Capacity curves.
- Data of the historic floods.
- Latest design flood and flood routing study.
- Sequence of operation of spillway gates during monsoon.
- Discharge through spillway for different reservoir levels with different gate openings.
- sequence of operation of spillways, where more than one spillway exists

Preparation of Rule curves

The following aspects also need to be considered while preparing of rule curve.

- Instructions for operating control mechanisms, Gates etc.
- General instructions for the safe operation of the dam and appurtenances.
- Releases to be made for various purposes round the year including releases to be made as per Inter-State Agreements/MOU's with various States/Agencies/Projects, riparian releases etc.
- Inflow forecasting
- Flood release procedure
- Limitation on reservoir drawdown rate to prevent failure of u/s slope of the embankment/landslides along reservoir periphery

Integrated Reservoir Management

In case of system of reservoirs, it is necessary to adopt a strategy for integrated operation of reservoirs to achieve optimum utilisation of the water resources available and to benefit best out of the reservoir system.

- In the preparation of regulation plans for an integrated operation of system of reservoirs, principles applicable to separate individual reservoirs units are first applied. Modifications of schedules so developed should then be considered by working out several alternative plans for Integrated operation of combination of Reservoirs. In these studies optimisation and simulation techniques may be extensively used with the application of computers in water resources development.

Integrated Reservoir Operation - Introduction

- By adopting best Operation & Maintenance practices, we can ensure efficient operation and minimum downtime with high availability and reliability of power plant.
- Maintaining high Availability and Reliability for two cascading plants become more challenging when their operation and maintenance depends on each other as Outage of one Plant affects the availability of another, in such cases advancement in individual O&M practices are not sufficient to achieve operational and commercial targets of plants.

Integrated Reservoir Operation-Issues and Measures to be taken

As release from one upstream Project impacts the inflow and release from Downstream Projects, Integrated Reservoir operation is required to be done in close coordination with Upstream and Downstream Hydro Projects. For Integrated operation of all Hydroelectric Projects in a valley and to prevent Disaster/Flood situation following steps needs to be taken in close coordination detailed as below:

- i. Close coordination with the IMD & other weather forecasting Agencies, CWC and Upstream Power Projects to have advance information regarding inflow and release of water from their Project.
- ii. For all the projects in a basin, a combined seismological Monitoring System, Installation of Inflow Forecasting System & Early Warning System for intimation regarding water release from Spillways can be installed and cost can be shared between the Projects.

Integrated Reservoir Operation-Issues and Measures to be taken

- iii. In the case of heavy rains in the Catchment area, the water from the reservoir should be released in a regulated manner in advance so as to create a cushion in the reservoir to absorb the incoming floods.
- iv. Close watch should be kept in downstream areas on rainfall and inflow of various tributaries of the river. In the event of heavy rains in D/S area, water from Dam should be released in a regulated manner to offset the inflow peaks of different rivers / tributaries to prevent flooding in downstream areas
- v. Disaster Management and Emergency Action Plans should be prepared for all dams before initial filling of the reservoir and shared among all the Projects

Integrated Reservoir Operation-Issues and Measures to be taken

- vi. The Disaster Management and Emergency Action Plan should identify in advance the type of emergencies which may lead to release of water from the reservoir. This should also include Inundation Maps of the downstream areas for identification of likely affected areas, population, infrastructures due to various release scenarios during emergency / dam failure.
- vii. These plans should include mitigation measures to deal with the likely adverse situations specially to avoid loss of human life.

Operation under flood conditions can be performed through a rule curve within a real time information framework. Real time dam management during floods must rely on an operational, hydrological forecasting system in the catchment and downstream area.

Integrated Reservoir Management

- ***Balancing of reservoir*** – For balancing of reservoirs, the concept of ‘index levels’ may be employed, as an aid to making release decisions to keep the reservoir system in a balanced state. The reservoir storage allocation may be subdivided into flood control, conservation, and one or more buffer zones. The top of each of these zones has a corresponding reservoir level, which is assigned an integer or index level.
- When the index levels in all the reservoirs coincide, the system is in balance. In reservoirs operation, if the current index levels are unbalanced, the releases for the subsequent interval are adjusted as far as possible to restore equilibrium. The index levels are also useful in the regulation of parallel reservoirs with the equivalent reservoir concept.

Integrated Reservoir Management

The space rule - The release among parallel reservoirs be planned in such a way that the ratio of space available in each reservoir to that in all reservoirs equals, as far as possible, the ratio of predicted inflow into each reservoir in the remaining period of drawdown refill cycle to that in all reservoirs. Hence, the probability of some reservoirs being spilled while others being empty are minimised.

The pack rule - It is a flexible rule that specifies useful releases in excess of current demand, perhaps to create sufficient space instead of possible future spills.

The hedging rule - It accepts current shortage to avoid large shortages in future and is to be adopted when cost functions for shortages are nonlinear.

Integrated Reservoir Management

Flood control regulation - The basin-wise flood conditions are considered, rather than the condition of the individual subbasins. The occupancy of flood reserves in each of the reservoirs, distribution of releases among the reservoirs and bank-full stages at critical locations should be considered simultaneously.

- For instance, if a reduction in outflows is required, it should be made from the reservoir having the least capacity occupied or has the smaller flood run-off from its drainage area.
- If an increase in release is possible, it should be made from the reservoir where the percentage occupancy is the highest or relatively a higher of flood run-off is occurring. Higher releases from reservoirs receiving excessive flood run-off may be thus counter balanced, particularly in cases of isolated storms, by reducing releases from reservoirs receiving relatively less run-off.

Integrated Reservoir Management

- **Conservation regulation** - The current water demands for various purposes, the available conservation storage in individual reservoirs and the distribution of releases among the reservoirs, should be considered to develop a co-ordinated plan to produce the optimum benefits and minimize water losses due to evaporation and transmission.
- **Hydrologic forecast** - Hydrologic forecast plays a dominant role in reservoir operation. Forecast may be classified as short term (up to 2 days), medium term (2-10 days), long term (beyond 10 days) or seasonal (several months) according to WMO (World Meteorological Organization) guide to Hydrological Practices, Publication No. 108 (1983).

In India forecast issued by IMD, New Delhi is considered in reservoir operation.

Integrated Reservoir Management

Simulation Simulation is perhaps the most widely used method for evaluating alternatives due to its mathematical simplicity and versatility. Simulation is a surrogate for asking 'what if' and thereby providing a rapid means for evaluating the anticipated performance of the system.

- The advent of high speed computers has enabled development of detailed simulation programmes to describe the operation of a water resource system, Simulation methods do not identify the optimal design and operating policy but they are excellent means of evaluating the expected performance resulting from any design and operating policy.

Integrated Reservoir Management

Dynamic programming - Dynamic programming technique has been widely accepted for formulation of reservoir operation policies mainly because of its ability to accommodate non-linear functions. This technique is based on multi-stage decision process. For example, in a reservoir operation problem, the reservoir storage at any time is a typical choice of state variable, the release from the reservoir may be the decision variable and the time is a natural choice of control variable. Therefore, knowing the benefit or cost function the recursive equation may be established.

- Discrete differential dynamic programming (DDDP) has been found more suitable for reservoir operation problem because it is an iterative procedure in which the recursive equation of dynamic programming is solved within a restricted set of quantified values of the state variables.

Operation of Spillways

- Spillway operation practically is governed by the reservoir rule curves. If there is more than one spillway, sequence of operation is also to be decided beforehand.
- If the Reservoir level is more than rule curve or forecast of heavy rain, release from Power House is increased.
- If even after maximum release from Power House, reservoir level continues to rise or forecast of heavy rains, spillways can be operated before achieving FRL.
- Advance intimation for release of water from Spillways to be given to Distt. Administration and Disaster Management Authority.
- Inflow forecasting system in Reservoir Catchment area and Early Warning system in D/S area should also be functional.

Project features and Rule Curve of Major Reservoir Projects

Dams and Barrages in Damodar Valley

- Serious floods occurred in the Damodar valley in 1730, 1823, 1848, 1856, 1882, 1898, 1901, 1916, 1923, 1935 & 1943.
- The river spans over an area of 25,235 sq. km covering the states of [Bihar](#) (now [Jharkhand](#)) & West Bengal. The catastrophe caused by the 1943 flood, led to serious public indignation against the Government.
- As a result, the Government of Bengal appointed a board of Enquiry titled "Damodar Flood Enquiry Committee" with the Maharaja of Burdwan and the noted physicist Dr. Meghnad Saha as members for suggesting remedial measures and Construction of Dams.
- DVC has an Integrated Water Resources System on Damodar river & its tributaries, which consists of 4 (four) dams at Maithon, Panchet, Tilaiya & Konar and a barrage at Durgapur (handed over to West Bengal in 1964) along with a canal system network of length 2509 KM.

Dams and Barrages in Damodar Valley

DAMODAR RIVER VALLEY AREA

Koderma TPS

TILAIYA DAM

RIVER USRI

RIVER BARAKAR

KONAR DAM

RIVER KONAR

RIVER BOKARO

BOKARO BARRAGE

RIVER DAMODAR

TENUGHAT DAM

CTPS WEIR

MAITHON DAM

PANCHET DAM

Ajoy River

Silabati River

DURGAPUR BARRAGE

LEFT BANK CANAL

RIGHT BANK CANAL

Kasai River

Rupnarayan River

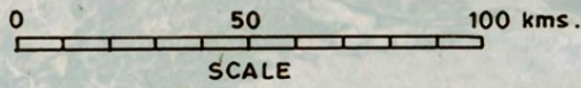
Hoogly River

Bhagirathi River

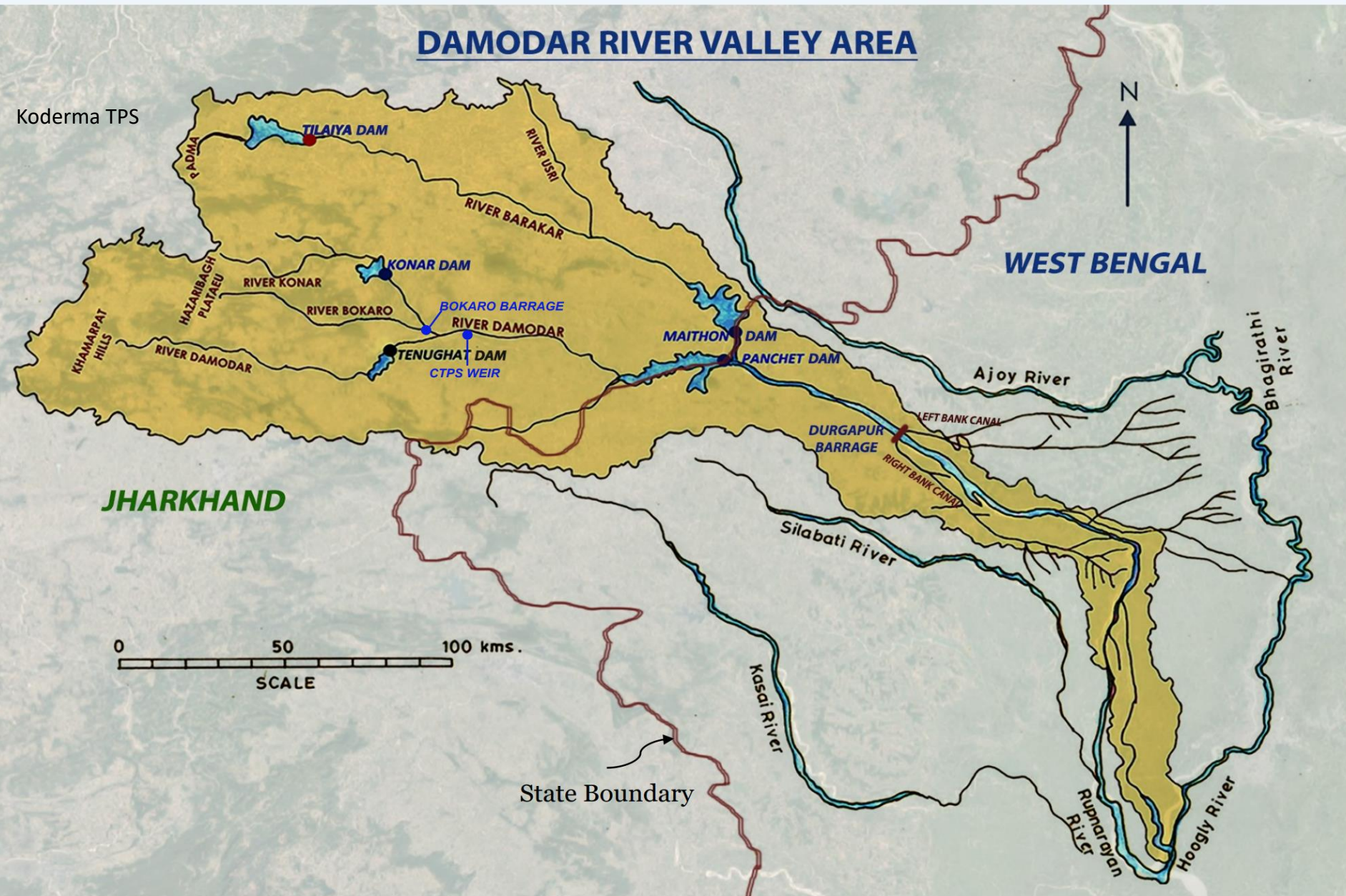
WEST BENGAL



JHARKHAND



State Boundary

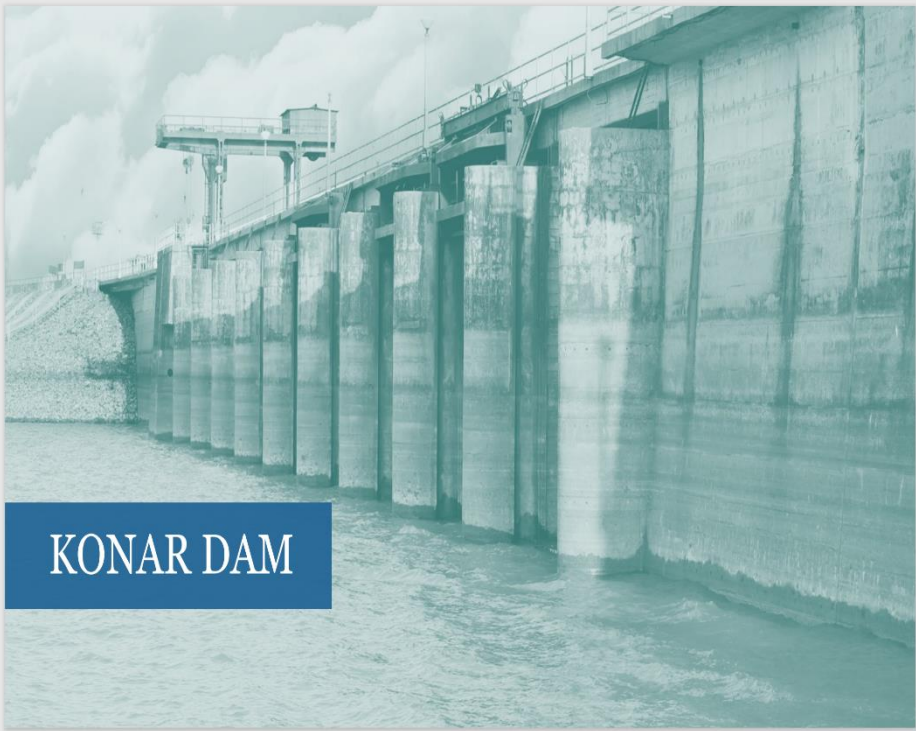
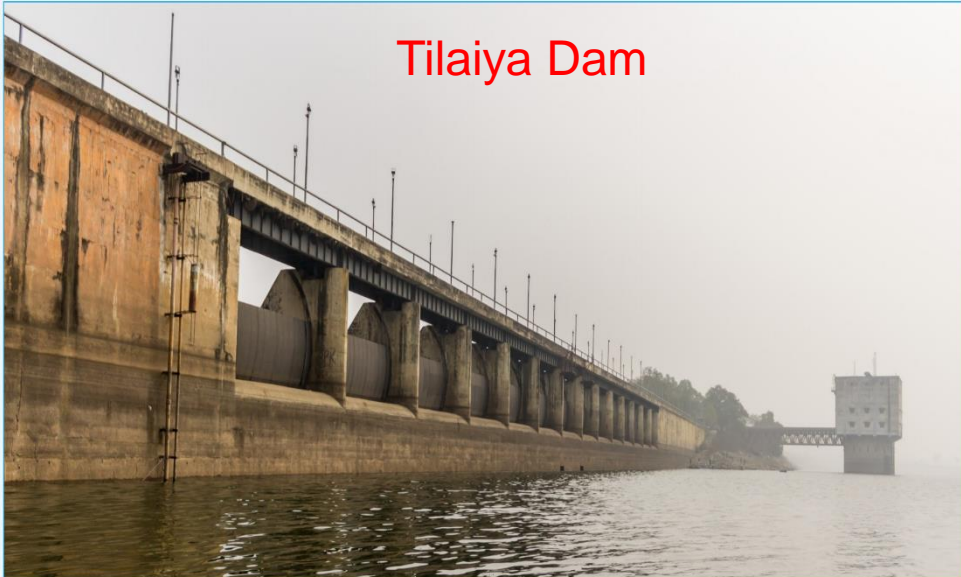


ZONES OF RESERVOIR- DVC Dams

	Tilaiya	Konar	Maithon	Panchet
Inauguration	21.02.1953	15.10.1955	27.09.1957	06.12.1959
River	Barakar	Konar	Barakar	Damodar
Dead Storage Level (m) above MSL	363.32	410.57	132.59	119.48
Dead Storage (MCM)	75	35	93	106
Conservation Level (m) above MSL	368.81	425.81	146.31	124.97
Conservation Storage (MCM)	141	175	441	169
Max. Utilizable Flood Management Level (m) above MSL	372.47	427.94	150.90	131.10
Flood Management Storage (MCM)	165	38	334	434
Installed Capacity	4 MW	Nil	63.5 MW	80 MW
Type of Turbine	Vertical shaft Francis	–	Horizontal Shaft Francis	Vertical shaft Kaplan
Maximum Head (m)	19.51	–	38.71	

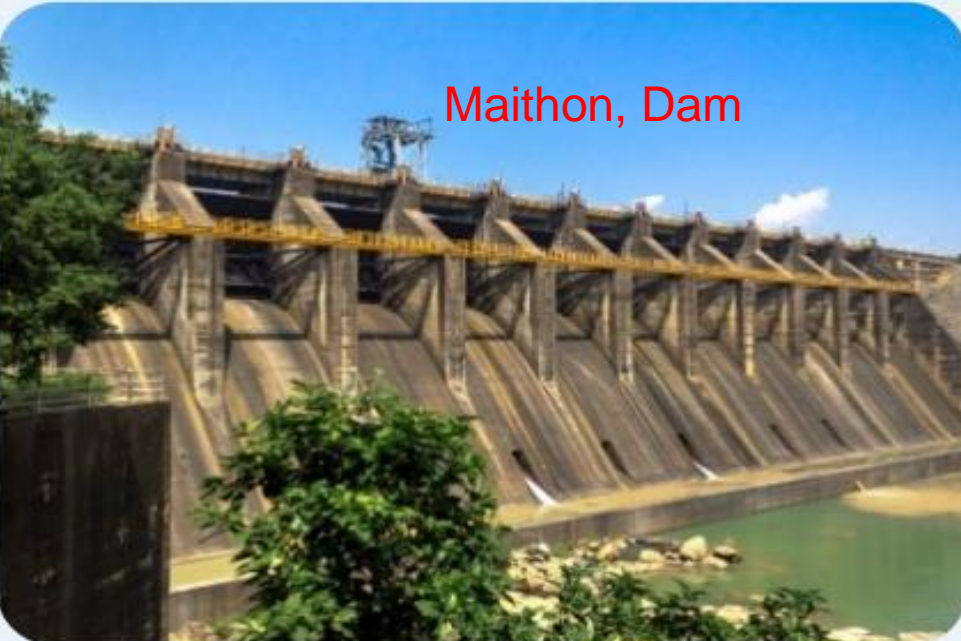
DAM – UPSTREAM VIEW

Tilaiya Dam



KONAR DAM

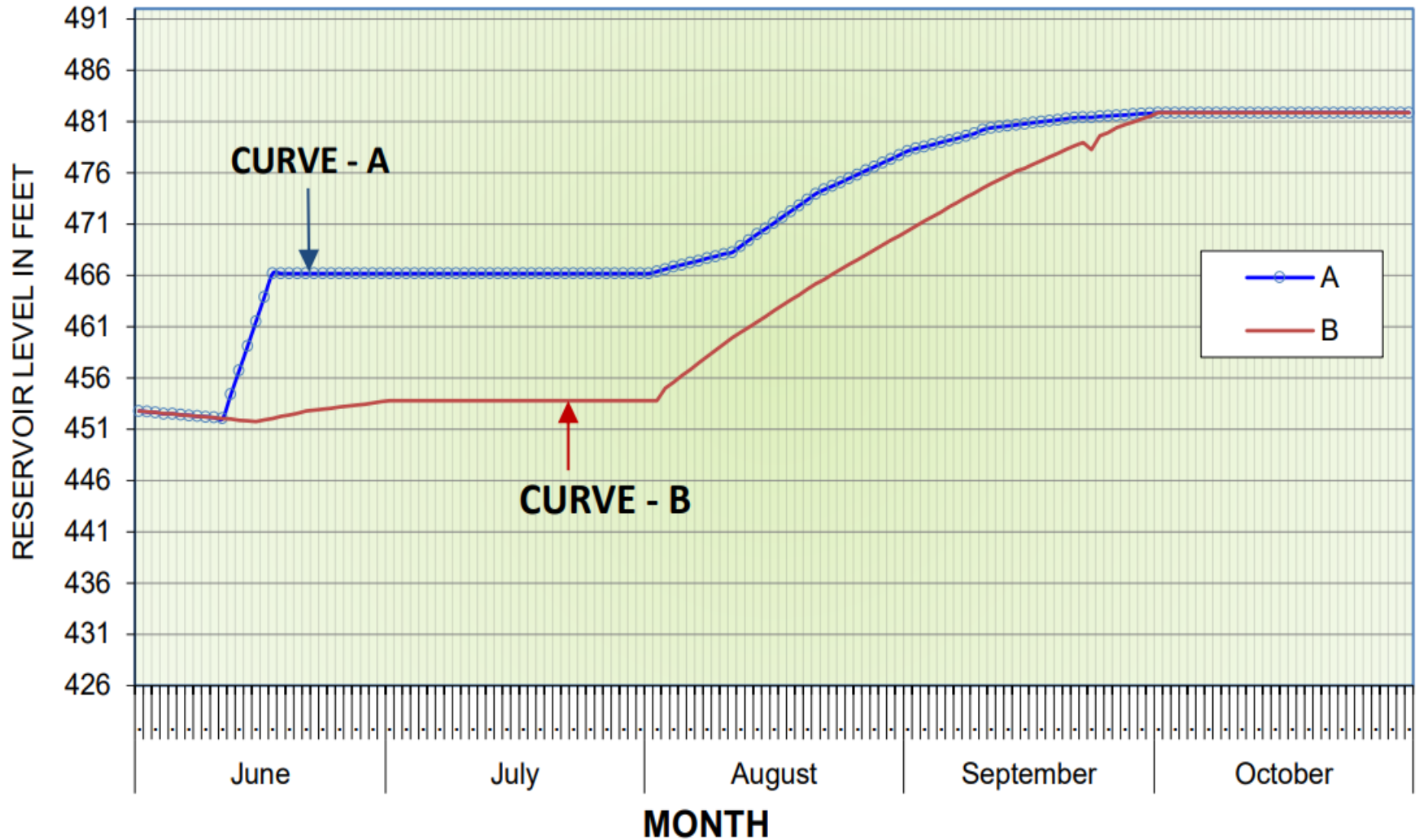
Maithon, Dam



Panchet Dam



GUIDE CURVE FOR MAITHON DAM



Where "Curve-A" denotes the Upper Operation **Rule** Curve and "Curve-B" denotes the Lower Operation **Rule** Curve

Fig. 3 Revised Guide Curve of Maithon Dam

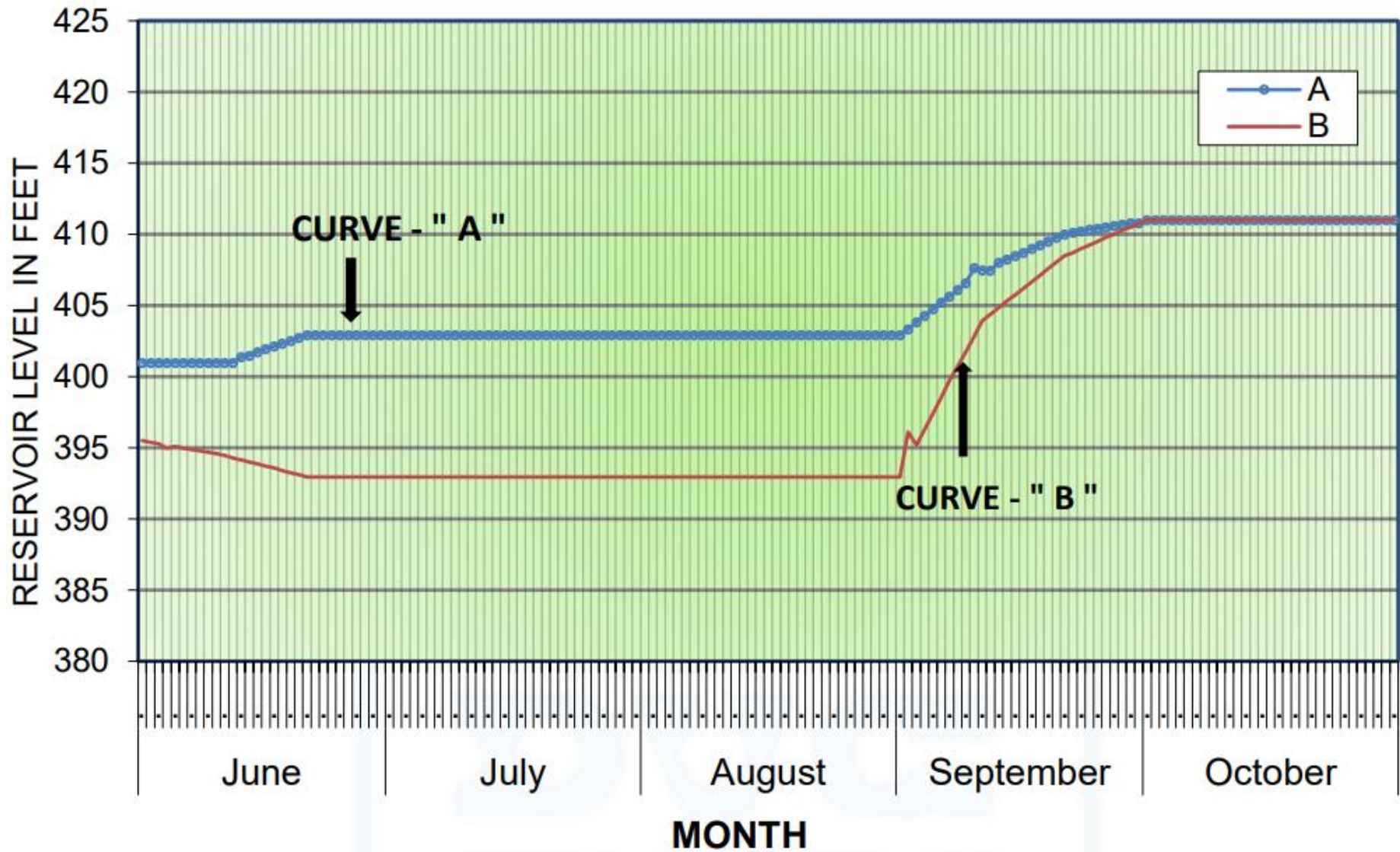
Rule curve for Maithon Dam

Flood Management Operations

- a) When the reservoir level rises or shows a tendency to rise above R.L. 481.857 ft (146.87 m) – as per the revised & approved guide curve (Fig .3), flood management operations shall commence and they may cease as soon as the reservoir level comes down to R.L. 481.857 ft (146.87 m).
- b) From the past experience of reservoir operation, it has been gathered that on several occasions, when the reservoir level was well below the R.L. 481.857 ft (146.87 m), floods of varied magnitude had impinged in the reservoir. With the stipulations originally contained in the existing Regulation Manual, the flood releases could not be commenced till the reservoir level neared to R.L. 481.857 ft (146.87 m), which at times led to higher flood releases as well as higher flood cushion occupation in the reservoirs.
- c) This is very critical due to the restricted carrying capacity of the lower Damodar channel and the congestion in the lower valley. To combat such situations the following decision was taken in the 48th meeting of Damodar Valley Reservoir Regulation Committee (DVRRC).

“When the reservoir level rises or shows a tendency to rise above the permissible level of the upper Guide curve relevant to that date, flood control operations may be commenced. This shall cease as soon as the reservoir level falls to the relevant Guide curve elevation.”

GUIDE CURVE FOR PANCHET DAM



Where "Curve-A" denotes the Upper Operation Rule Curve and "Curve-B" denotes the Lower Operation Rule Curve

Rule curve for Panchet Dam

Flood Management Operations

- a) When the reservoir level rises or shows a tendency to rise above R.L. 411.0 ft (125.273 m), flood management operations shall commence and they may cease as soon as the reservoir level comes down to R.L. 411 ft (125.273 m).
- b) From the past experience of reservoir operation, it has been gathered that on several occasions, when the reservoir level was well below the R.L. 411.0 ft (125.273 m), floods of varied magnitude had impinged on the reservoir. With the stipulations originally contained in the operation Manual, the flood releases could not be commenced till the reservoir level neared to R.L. 411 ft (125.273 m), which at times led to higher flood releases as well as higher flood cushion occupation in the reservoirs.
- c) This is very critical due to the restricted carrying capacity of the lower Damodar channel and the congestion in the lower valley. To combat such situations the following decision was taken in the 48th meeting of Damodar Valley Reservoir Regulation Committee (DVRRC).

“When the reservoir level rises or shows a tendency to rise above the permissible level of the upper Guide curve relevant to that date, flood control operations may be commenced. This shall cease as soon as the reservoir level falls to the relevant Guide curve elevation.”

Hydroelectric Projects in Beas-Satluj Valley

Bhakra and Nangal Dam on River Satluj

- Bhakra Dam was conceived before Independence for flood Moderation and irrigation of the then Punjab and Rajsthan. The dam holds excess waters during the monsoon and provides a regulated release during the year. It also prevents damage due to monsoon floods.
- The 225.55 m high Dam is of concrete straight gravity type having a gross storage capacity of 9621 million cum. Installed capacity of Bhakra Right Bank Power House is 785 MW (5x157 MW) and that of Bhakra Left Bank Power House is 594 MW (3x126 MW + 2x108MW). Total Installed Capacity 1379 MW.
- The 166 km² [Gobindsagar Reservoir](#), named after [Guru Gobind Singh](#), is created by this dam which is the third largest reservoir in India the first being [Indira Sagar Dam](#) and second [Nagarjunasagar Dam](#).^[5]
- Water flows from Bhakra Dam downstream Nangal dam where it is controlled and released into Nangal Hydrel Channel that later becomes Bhakra Main Line after Ganguwal and Kotla power plants
- The **Bhakra Canal** fed by this dam provides irrigation to 10 million acres of (40,000 km²) fields in [Punjab](#), [Haryana](#), and [Rajasthan](#).^[6]

Bhakra Dam



SALIENT FEATURES OF BHAKRA DAM

BASIC DATA

Name of Project	Bhakra Dam
Type of Project	Multipurpose Hydroelectric Project
Purpose	Irrigation and Hydro Power
River Basin	Indus

LOCATION DAM

Near Village Bhakra, Distt Bilaspur
Himachal Pradesh

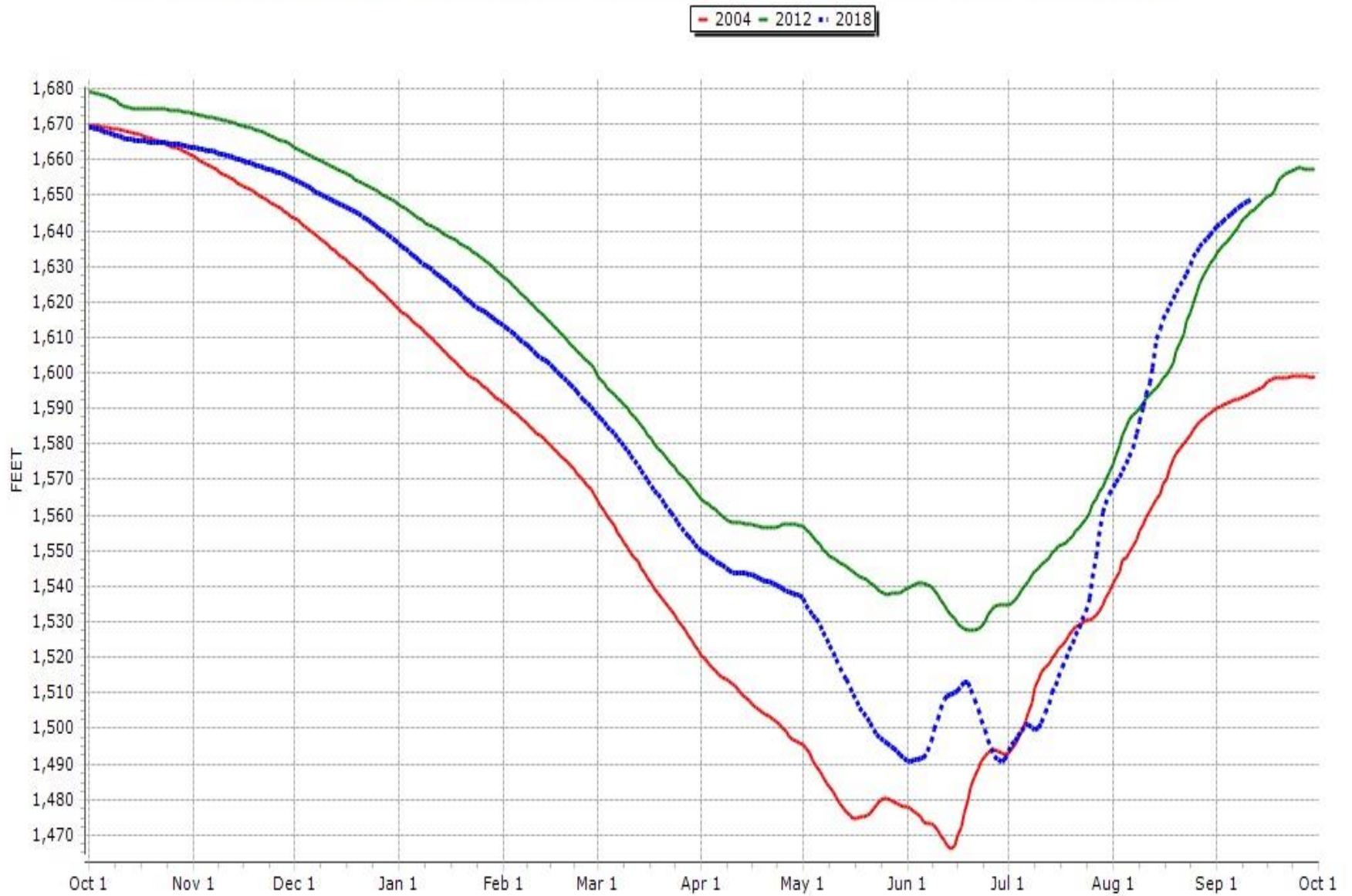
Type of Dam	Straight gravity concrete Dam
Elevation at the top of dam	El.518.16m (1700 ft)
Maximum, height of dam from deepest foundation level	225.55 m (740 ft)

Maximum height of Dam above river bed	167.64 m (550 ft)
Length at top	518.16 m (1700 ft)
Length at bottom	99.06 m (325 ft)
Width at top	9.14 m (30 ft)
Width at bottom	190.50 m(625 ft)

RESERVOIR

Maximum reservoir level	El.515.11 m(1690 ft) *
Normal reservoir level	El.513.58 m (1680 ft)*
Dead storage level	El.445.62 m(1462 ft)
Gross storage capacity at El.1685 ft	9621.14 million cum(7.80 MAF)
Live storage capacity at El.1685 ft	7189.33 million cum(5.83 MAF)

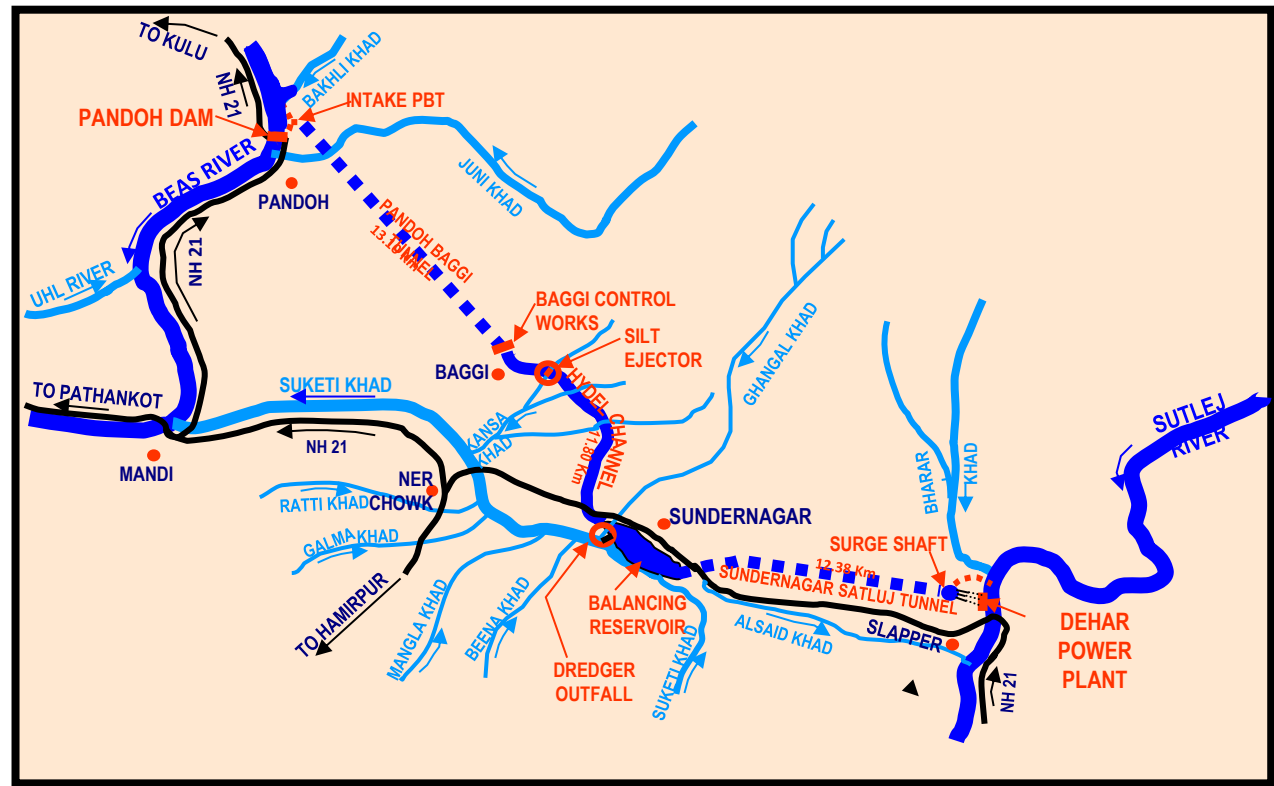
COMPARISON OF BHAKRA LEVEL IN FEET FOR YEAR 2004,2012 AND 2018 (WATER YEAR: OCTOBER TO SEPTEMBER)



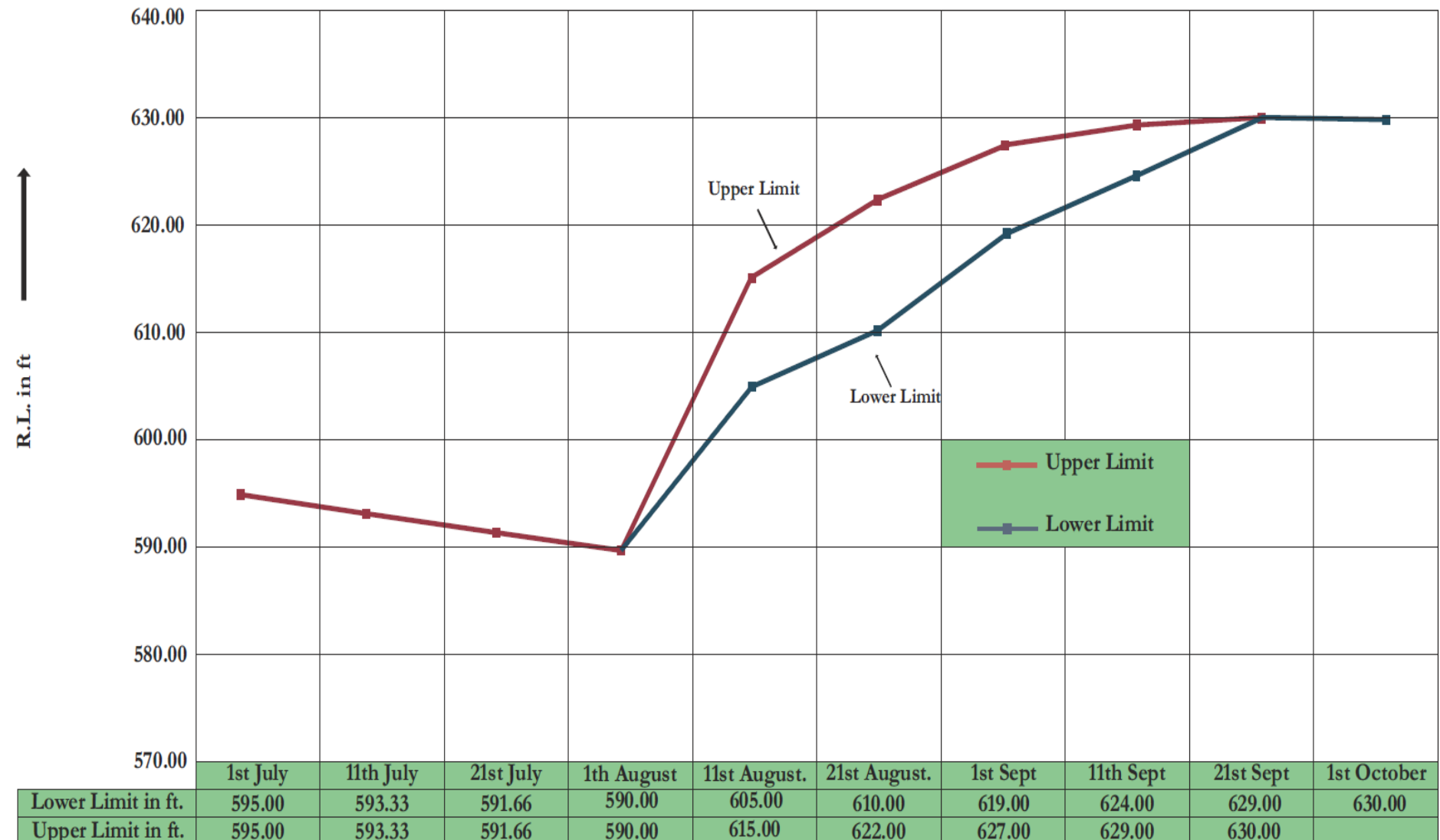
BEAS SUTLEJ LINK PROJECT

- The concept of Beas-Satluj link for diverting some water of river Beas into Satluj through two tunnels and an open channel to generate power and to increase the storage capacity of Bhakra reservoir (Gobindsagar)

The Beas Dam has been built on the [Beas River](#). It is an earth core gravel shell dam of 435 ft (132.6 m) height above the deepest foundation. The hydro-power plant located downstream, on the right side of the spillway structure, was initially planned for an installed capacity of 360 MW (6x60 MW) later upgraded to 396 MW (6x66 MW)

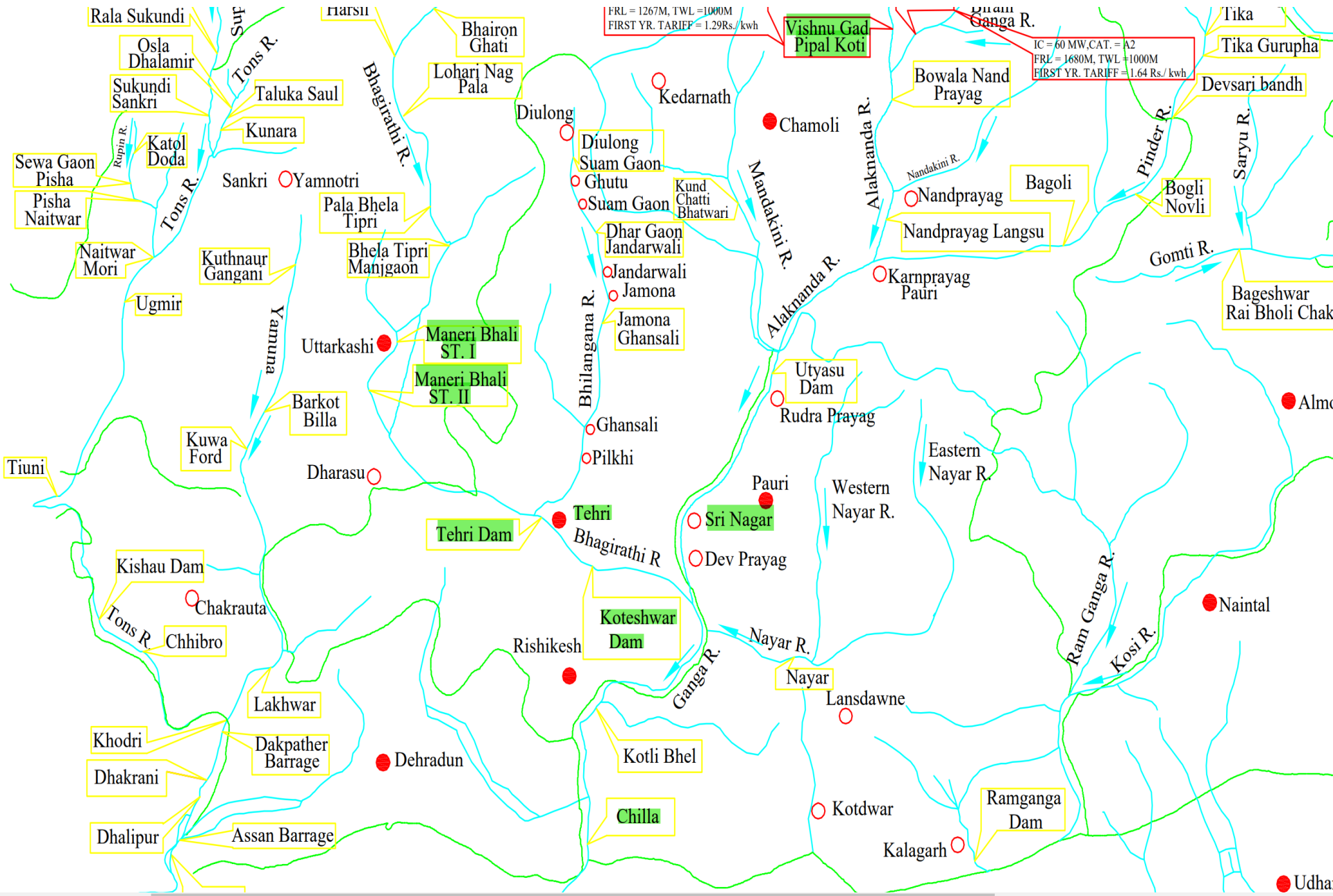


Rule Curve of Hirakud Dam (Odisha)



Operation of Reservoir and Rule curve of Tehri

HEP's and Dam/Barrages U/S and D/S of Tehri HPP



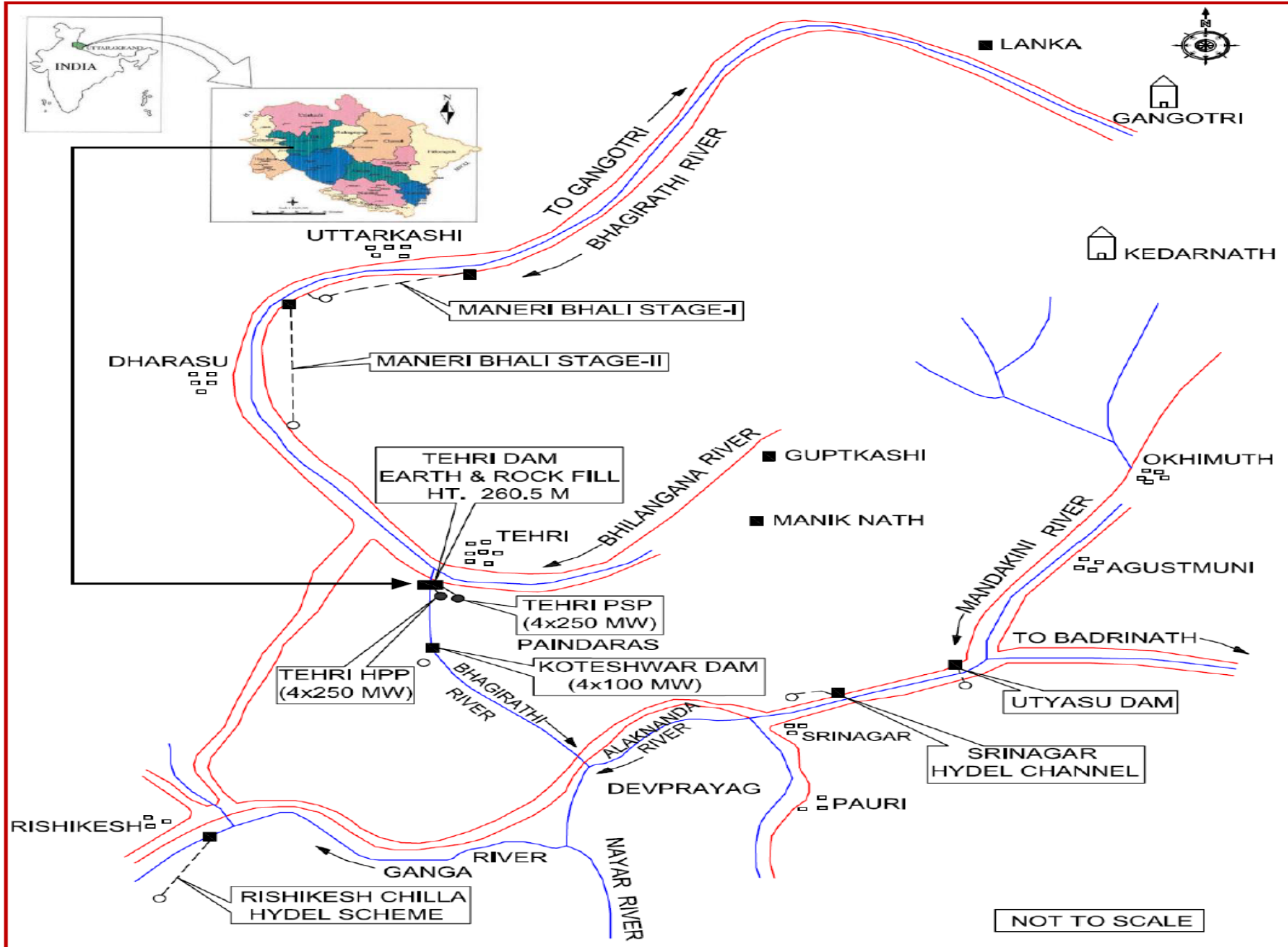


Figure 1: Schematic Location Diagram of Tehri Power Complex (2400MW)

HEP's and Dam/Barrages U/S and D/S of Tehri HPP

The major hydroelectric power plant and dams / barrages on river Bhagirathi & Ganges under operation / implementation/ construction in upstream and downstream of Tehri Dam are:

A. Upstream of Tehri Dam-

- Maneri Bhali Stage-2(Agency- UJVNL)- Under Operation
- Maneri Bhali Stage-1(Agency- UJVNL)- Under Operation

B. Downstream of Tehri Dam-

- Koteswar HEP(Agency- THDCIL)- Under Operation
- Pashulok Barrage at Rishikesh and Chilla Power House in Haridwar (Agency- UJVNL)- Under Operation
- Bhimgoda barrage in Haridwar (Agency-UPID) – Under operation

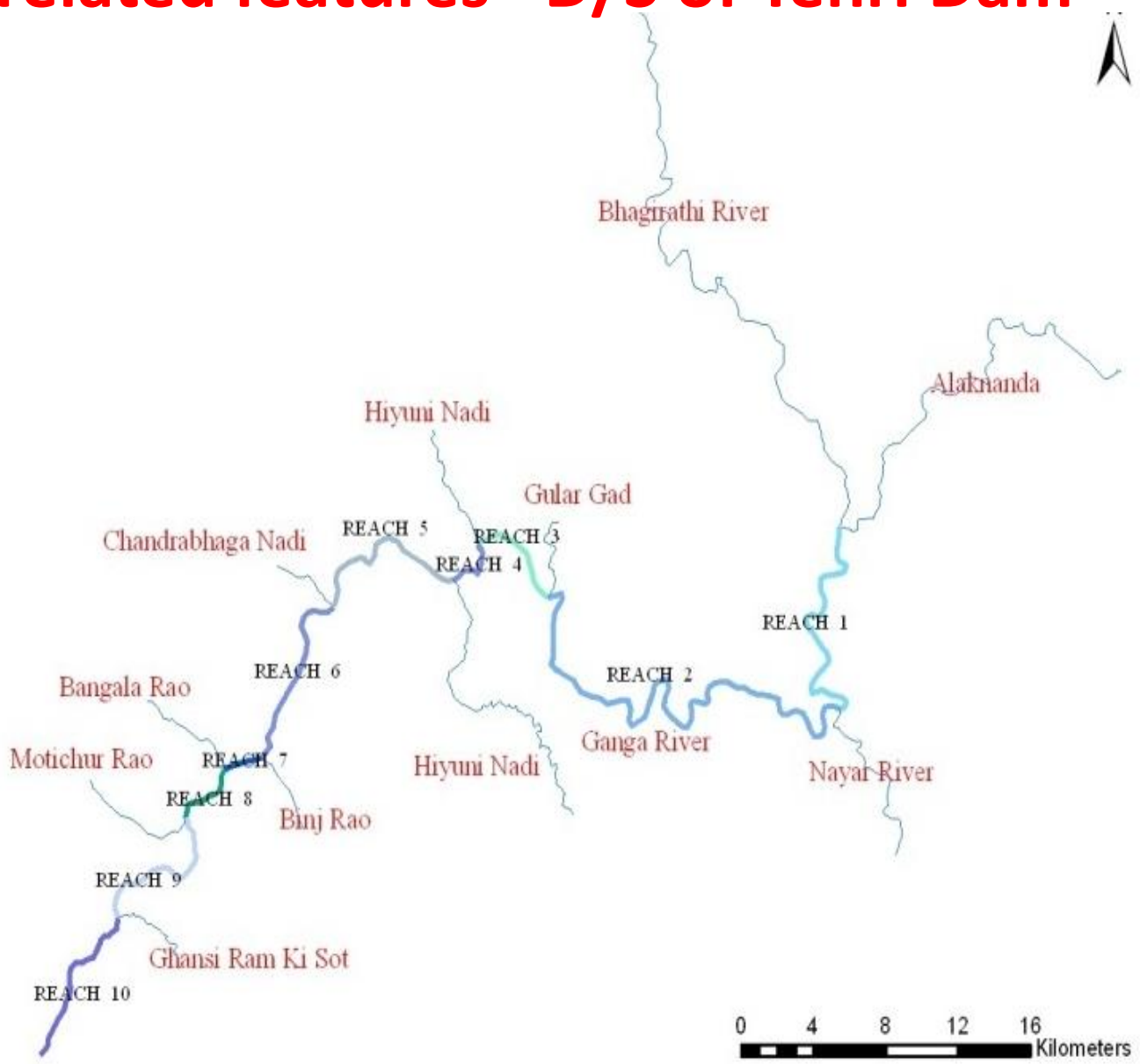
Apart from these water regulating structures, there are three major towns Devprayag at 40 kms, Rishikesh 105 kms and Haridwar 140 kms. Uncontrolled release from Tehri dam may be hazardous for these towns and some other small villages along the river Ganges and the hazard further increases due to threats to water regulating structures between Tehri and Haridwar.

Salient drainage related features –U/S of Tehri Dam

- Bhagirathi is the main river of the area and it flows NW-SE and has developed extensive terraces. Besides others, Bhilangana, Seansu and Jalkur are the main tributaries of Bhagirathi river.
- Jalkur river flows almost E-W to meet Bhagirathi near Bhaldiyana with a sudden southward bend. The course of the river is abnormally straight at places with deep gorges that show distinct tectonic control.
- Sensu Gad meets Bhagirathi near Seansu with a tectonically controlled WSW-ENE trending straight course.
- Bhilangana river also flows almost E-W and has its confluence with Bhagirathi at Tehri with a sharp southward bend. Tehri dam is located little downstream of the confluence where the river enters a deep gorge.
- Dhangmandar Gad meeting Bhilangana near Ghonti and Bal Ganga meeting Bhilangana near Ghansali show distinct tectonically controlled straight drainage patterns.

Salient drainage related features –D/S of Tehri Dam

- Downstream of the dam, Bhagirathi flows in a confined valley till it joins Alakananda at Deoprayag to form river Ganga.
- Downstream of Deoprayag the valley is still narrow till Rishikesh.
- The valley starts widening from Rishikesh.
- Downstream of Haridwar the flood plains become wide and extensive.



Rule Curve for Operation of Tehri Reservoir

- The performance of Tehri reservoir was studied based on the ten-daily historical inflow series at Tehri Dam site for the period 1964-65 to 2006-07 during the revision of Design energy by CEA.
- After simulation for aforesaid period, outflows from Tehri reservoir were worked out. The performance of Tehri Reservoir has also been studied keeping different criteria for filling the reservoir.
- Based on above considerations, the rule curve for operation of Tehri Reservoir has been prepared so as to have Minimum Probability of spillage or not filling upto full Reservoir level at the end of the Monsoon.
- Tehri dam reservoir is filled every year during monsoon season from EL 740m (MDDL) to EL 830m (FRL) and after monsoon season it is gradually depleted back to EL 740m before commencement of next monsoon. Reservoir filling period is considered from 21st June up to 31st October as requirement for release of water for irrigation and drinking purposes starts from 1st November and ends on 20th June.

Rule Curve for of Tehri Reservoir Operation

- One criterion has been to achieve maximum possible generation by filling the reservoir up to EL (\pm) 800.0m on 1st Aug every year. In this case, after simulating filling of the reservoir for inflows of the years 1964 to 2011, the probability of operation of Tehri spillways become slightly higher at about 15%.
- Similarly, as per various other criteria, simulations have been done for filling of the Tehri reservoir for inflow of the years 1964 to 2011 considering achievement of reservoir levels of EL (\pm) 790m, 795m, ----- 815m or 820m etc. on different dates. The most appropriate option of filling of Tehri reservoir appears to be arrival of EL (\pm) 785m on 1st Aug, EL (\pm) 800m on 11th Aug and EL(\pm) 828.5m on 1st Oct, which further reduces probability of operation of Tehri & Koteshwar spillways significantly (7%) as well as failure in achieving FRL.
- On this basis Reservoir Rule curve was prepared

Tehri Dam and Reservoir

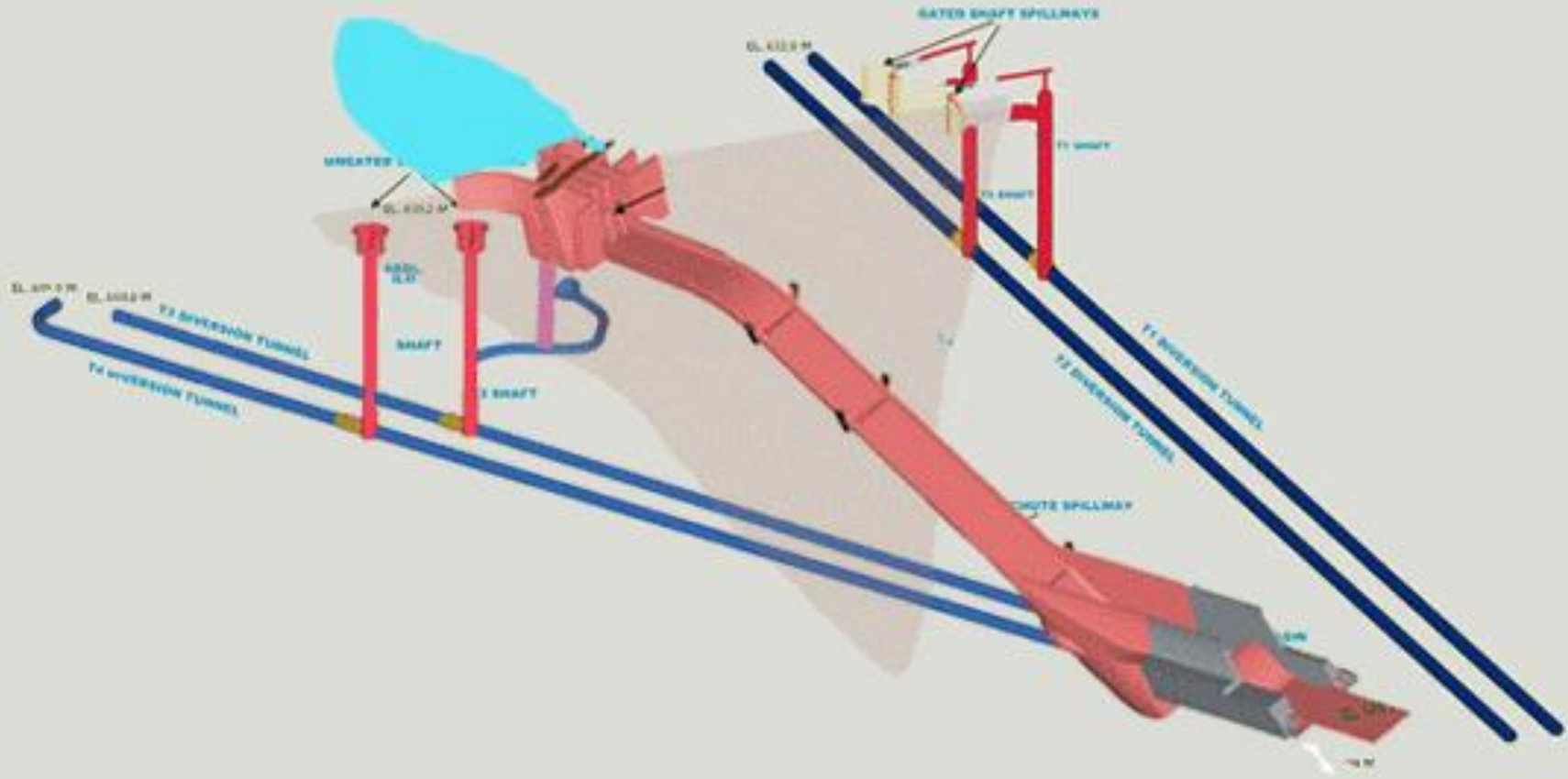


Water Spread	:	42 SQ KM
Gross Storage	:	3540 Million Cum
Live Storage	:	2615 Million Cum
Max. Flood Level	:	EL 835 m
Full Reservoir Level	:	EL 830 m
MDDL	:	EL 740 m

E.L. 815.70 16.10.07



SPILLWAYS SYSTEM



3D VIEW OF SPILLWAYS

LEFT BANK SHAFT SPILLWAYS

Head : 220 M
Type : Vertical Shafts
Nos : 2 (Gated)
Intakes : Tunnel type (80m long)
Crest level : 815 m
Discharge : 3800 cumecs
Vertical Shaft : 12m dia
Junction with tunnel : Tangential with 5.5m opening
De-aeration System : Through a Separation Chamber and de-aeration shaft opening In a De- aeration tunnel

Velocity at toe : 45 m/s

T-1

T-2

25.09.09

A CLOSE VIEW OF RIGHT BANK SHAFT SPILLWAYS



ILO Gate structure

T-3

T-4

Zones of reservoir and their capacities

Zone of reservoir	RL in m (from-to)	Gross/Live/Zone Storage in MCM (As per DPR)	Gross/Live/Zone Storage in MCM (2013 Survey)	Remark
Dead Storage Zone	Up to 700 (ILO Intake)	Gross-350 Live-Nil Zone-350	Gross-309 Live-Nil Zone-309	
Buffer Zone	700-740 (MDDL)	Gross-925 Up to Live- Nil 740 Zone-575	Gross-907 Up to Live- Nil 740 Zone-598	Water can be drawn from the reservoir in draught like situation through ILO
Conservation Zone	740-815 (Crest Level)	Gross-2965 Up to Live-2040 815 Zone-2040	Gross-2908 Up to Live-2001 815 Zone-2001	Regulation can be done through power house only
Flood Control Zone	815-830 (FRL)	Gross-3540 Up to Live-2615 830 Zone-575	Gross-3505 Up to Live-2598 830 Zone-597	Regulation can be done through spillways (gated) & power house only
Surcharge Zone	830 - 835 (MWL)	Gross-3770 Up to Live-2845 835 Zone-230	Gross-3720 Up to Live-2813 835 Zone-215	Regulation of PMF with all three (gated & un-gated) spillways

Tehri Reservoir Rule Curve

Date	Reservoir Rule / Lower Curve(RRC)	Spillage Rule / Upper Curve(SRC)	Remark
	Maximum Level beyond which discharge through power plant is to be increased to release excess inflow (m)	Maximum level beyond which Spillway is to be operated to release excess inflow (m)	
20-Jun	740.00 (MDDL)	-	76% of the live storage capacity between EL 740 & 815m is utilized to conserve water while regulating the discharge through power house 24% of the live storage capacity between EL 815 & 830m is kept for regulation of floods using power house and spillways Depleted to MDDL by releasing water as per requirement of UPID
30-Jun	755.00	-	
10-Jul	767.00	-	
20-Jul	780.00	815.00	
31-Jul	792.00	815.00	
10-Aug	803.00	815.00	
20-Aug	814.00	817.00	
31-Aug	823.00	825.00	
10-Sep	828.00	829.00	
20-Sep	830.00	830.00	
30-Sep	830.00	830.00	
10-Oct	830.00	830.00	
20-Oct	830.00	830.00	
31-Oct	830.00	830.00	
20-Jun	740.00	-	

Flood Peak and Return Period

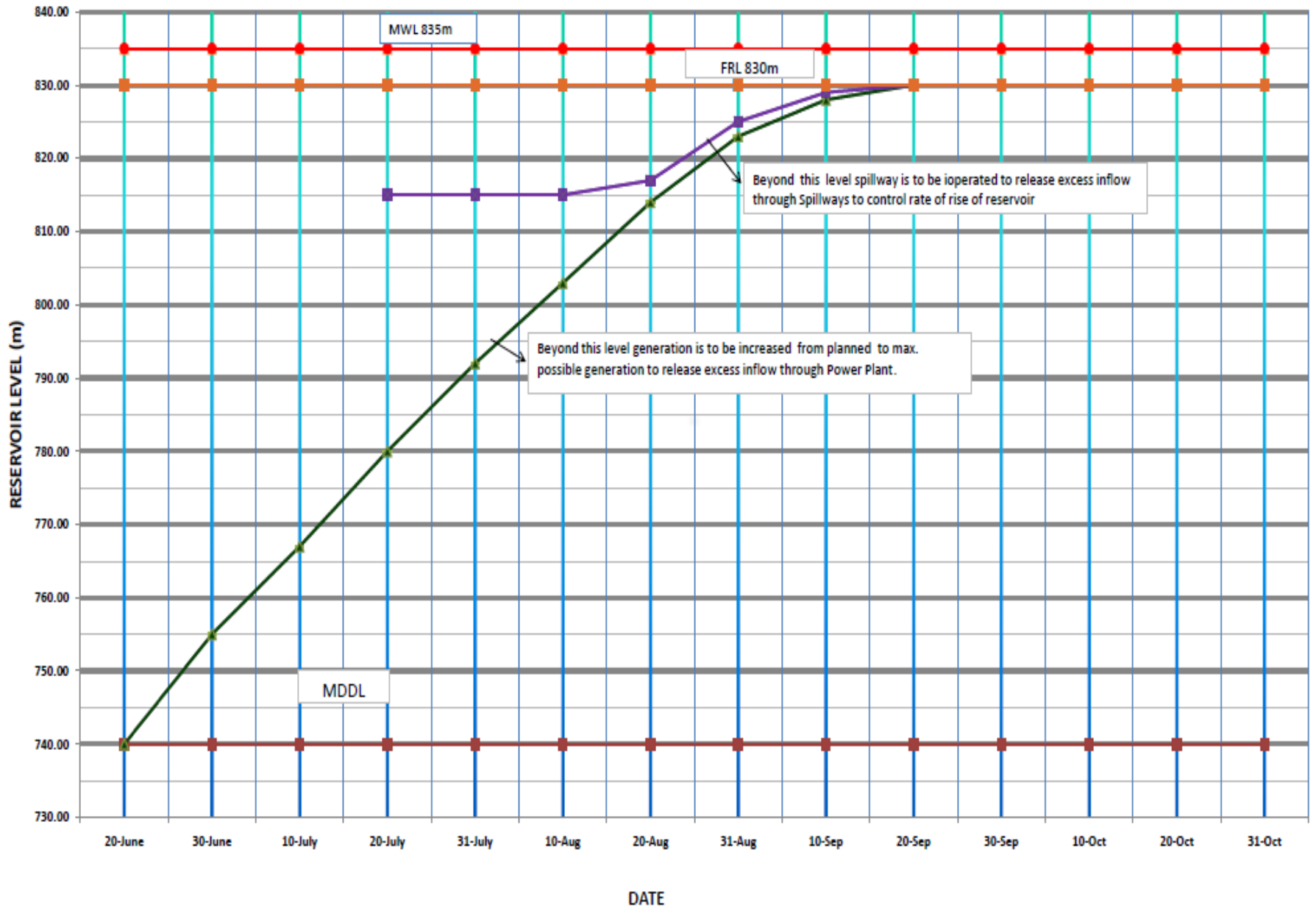
Return Period	Peak Flow Cumecs	Peak Flow Cusecs
10	3800	1,33,000
50	6881	2,40,835
100	9600	3,36,000
1,000	12848	4,49,680
10,000 (PMF)	15540	5,43,900

Peak discharges of observed floods since 2005

Year	Peak Flow Cumecs	Peak Flow Cusecs
2010	3510	1,22,850
2011	3492	1,22,220
2013	7542	2,63,970

RESERVOIR RULE CURVE OF TEHRI HPP-FILLING DURING MONSOON

Exhibit-2.1



Operation of Spillways

- According to conceptual approach, the Chute Spillway on the right bank goes into operation first by simultaneous lifting of all the three gates in case the water level tends to rise above the FRL i.e. EL 830m.
- If the reservoir level still tends to rise above FRL EL 830m, the left bank shaft spillway is operated by simultaneous lifting of both the gates
- If the reservoir level continues to rise and reaches EL 830.2m with full opening of all the gates of chute spillway & left bank shaft spillway, the RBSS start discharging the flood water automatically.
- Apart from conceptual approach, spillway operation practically is governed by the reservoir rule curve and spillways can be operated before achieving FRL, if the situation asks for.

***MITIGATION OF FLOOD
BY
TEHRI DAM***

Role of Tehri Dam in prevention of floods in 2010,2011 and 2013

Tehri dam played a crucial role in averting the flood of higher order in the river Ganga by storing flood water during 2010,2011 and 2013

• **Sept. 2010**

- In Sept. 2010, when all the major rivers were running at their highest on 19-20 Sep, the discharge of river Bhagirathi went above 3500Cumecs (122500Cusecs) at Tehri whereas only 800-900cumecs (28000-31500Cusecs) was released from the Tehri dam at the time of peak discharge.
- At this point of time, discharge from Alaknanda and other tributaries of Ganga was also heavy and flood situation at Rishikesh and Haridwar was grim and water was much above danger level.
- Tehri dam by storing the most of the flood water of river Bhagirathi in its reservoir, mitigated the flood discharge in the river Ganges which otherwise would have further increased the water level of at Rishikesh and Hardwar 1.5-2.0m

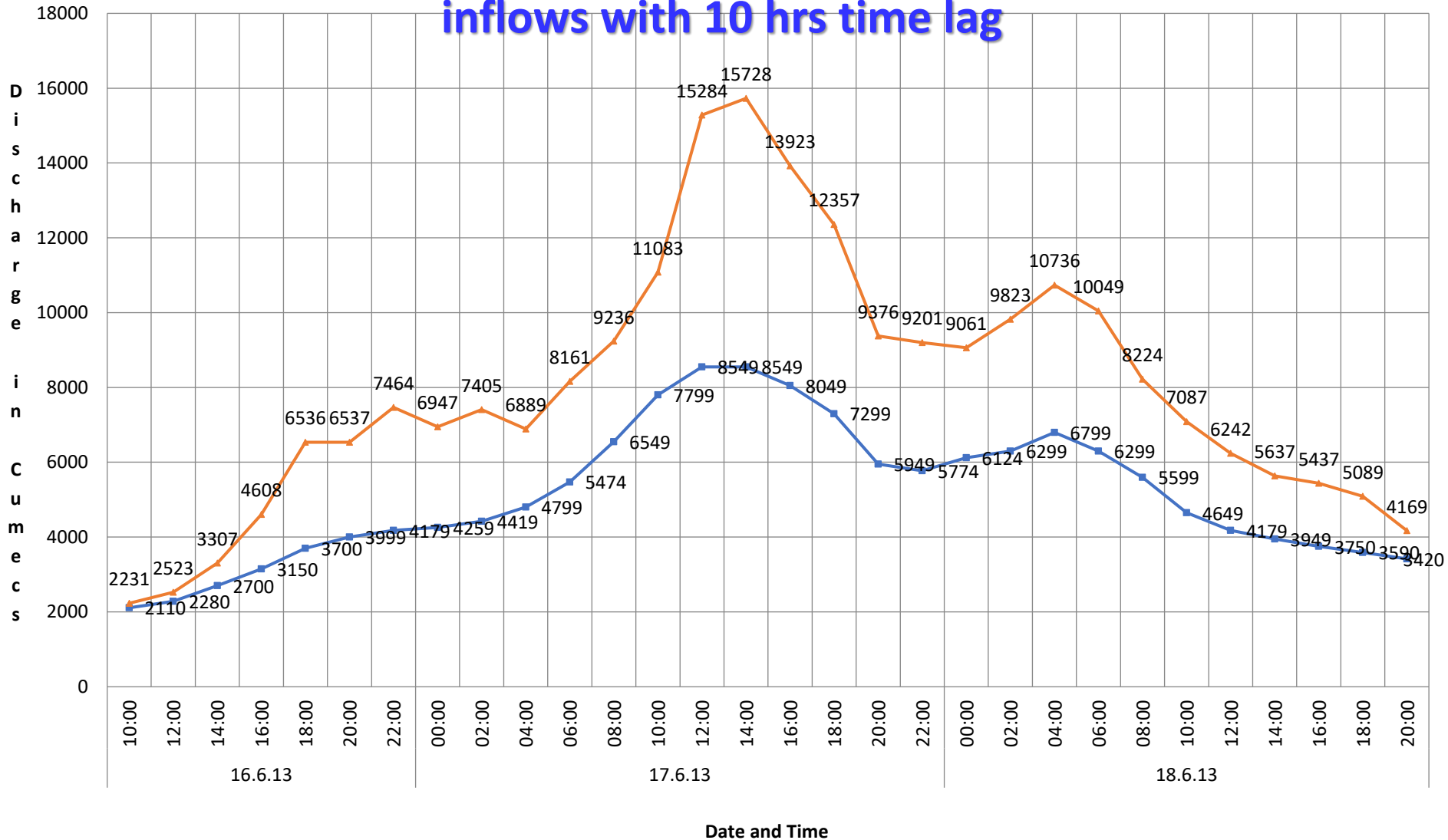
Role of Tehri Dam in prevention of floods in 2013

- In the Kedarnath flood of river Ganga during 16th & 17th June, 2013, discharge at Haridwar rose up to around 15000 cumecs and water level reached 295.90m in the evening of 17th (i.e. 1.90m above danger mark of 294.00m). In fact this flood was the contribution of river Alaknanda and tributaries of river Ganga in between Devprayag and Haridwar only.
- The flood of the order of about 7500Cumecs (262500Cusecs) peak discharge in river Bhagirathi had been stored in the Tehri reservoir by releasing only 500Cumecs (17500Cusecs).
- Had the Bhagirathi flood not been stored in Tehri dam, the peak discharge would have gone up to around 22000Cumecs (770000Cusecs) and devastation by this flood, not only at Haridwar but above and below Haridwar also, would have been beyond imagination with anticipated rise of 2.5 to 3.0m in water level above the observed highest level.
- It is gathered from the available records that recent flood in Ganges would have been of the order or even higher which had happened in the year 1924, had Bhagirathi flood not been hold by Tehri dam

FLOODS MITIGATION ON 16th & 17th JUNE 2013

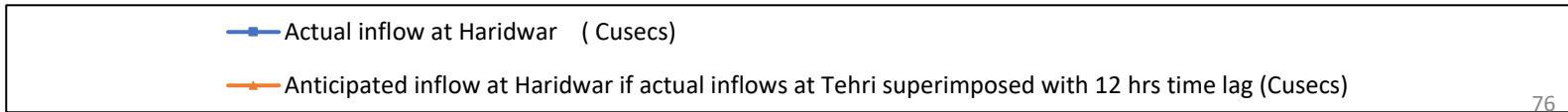
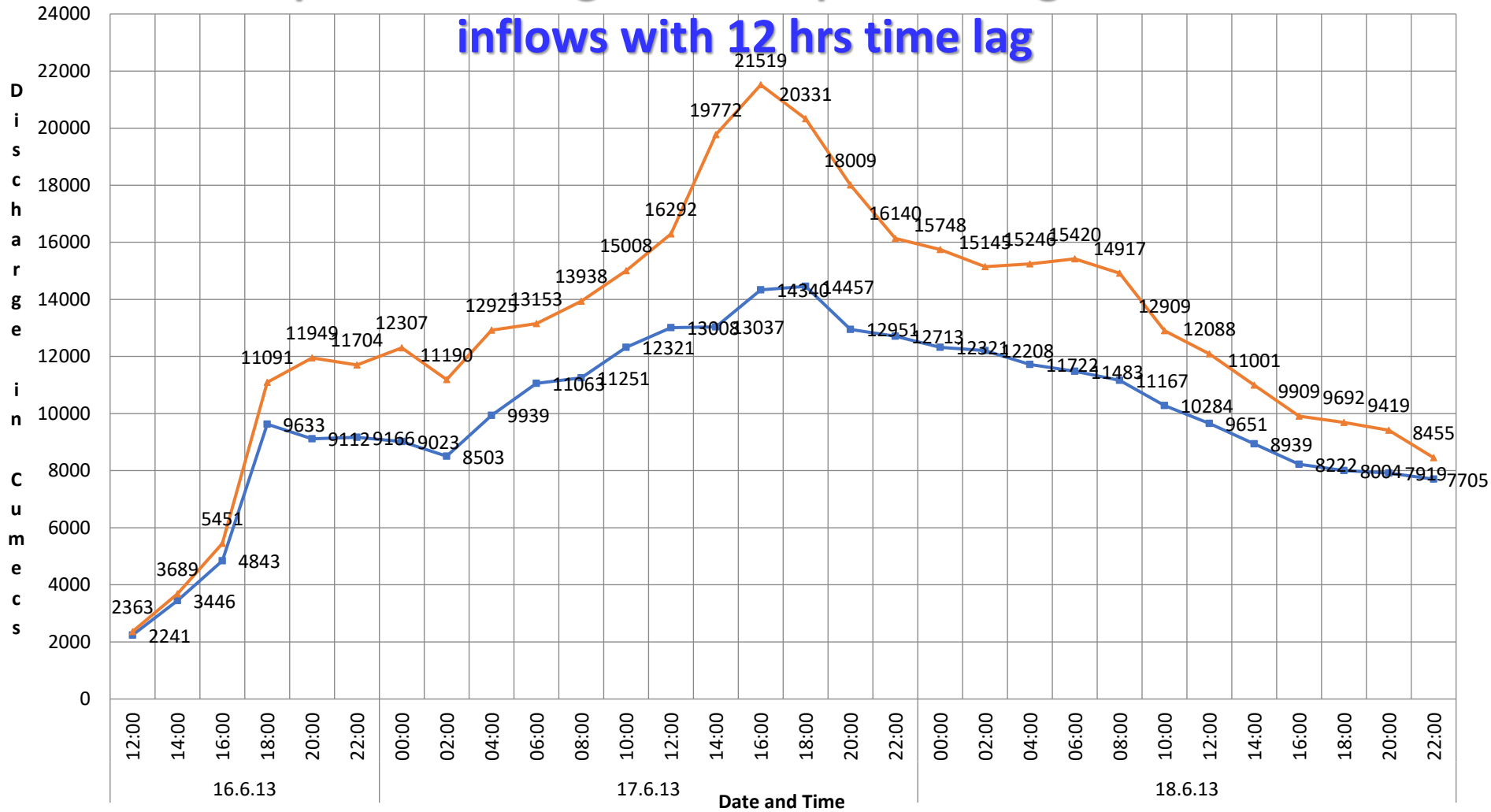
Peak Discharge at Haridwar due to River Alaknanda and other tributaries of Ganga	15000 Cumecs (525000 Cusecs)
Water level at Haridwar at 4pm	295.90 m (1.90 m above danger level)
Actual Peak Discharge of River Bhagirathi at Tehri at 6am	7500Cumecs(262500 Cusecs)
Releases from Tehri Dam	500 Cumecs (17500 Cusecs)
If the Bhagirathi flood not been stored in Tehri dam, the anticipated peak discharge	22000Cumecs (770000Cusecs)
Rise in Tehri reservoir level 25m	in 2 days
Prevented Flooding of Rishikesh & Haridwar	by about 2.5-3.0 m

Actual observed discharge of Ganga at Rishikesh and anticipated discharges after super imosing Tehri actual inflows with 10 hrs time lag

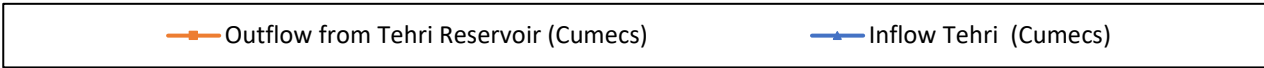
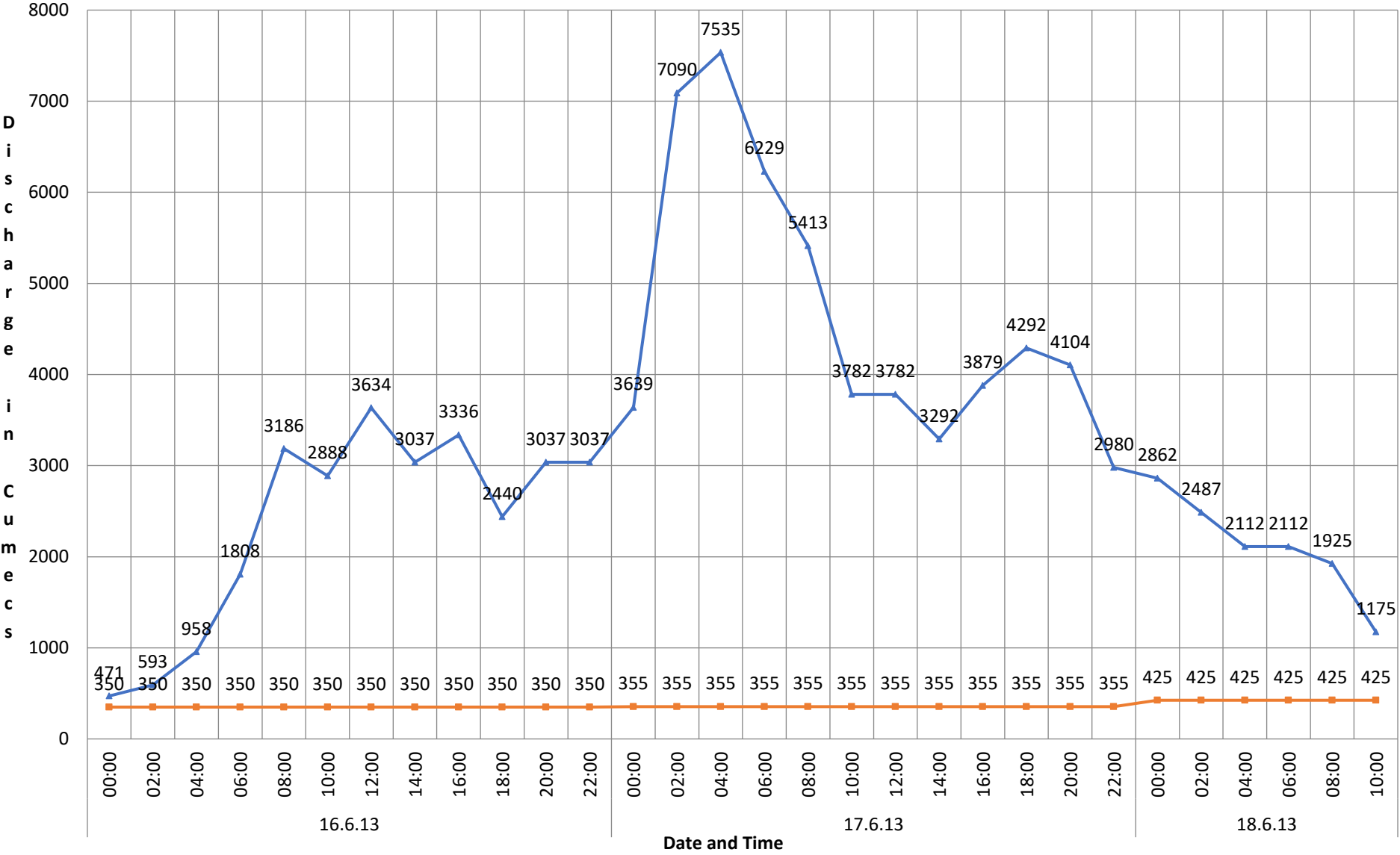


—■ Actual inflow at Rishikesh (Cumecs)
—■ Anticipated inflow at Rishikesh if actual inflows at Tehri superimposed with 10 hrs time lag (Cumecs)

Actual observed discharge of Ganga at Haridwar and anticipated discharges after super imosing Tehri actual inflows with 12 hrs time lag



Actual observed inflow and outflow at Tehri



Conclusion

For efficient operation of Reservoir and to meet the water requirement of D/S area, Reservoir Rule curve is essentially required. In addition, it also helps in flood Mitigation and safety of D/S Population

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THANKS