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# Revised Reservoir Gate Operation for Ukaidam

KEYWORDS: Peak Flood, Rule level, Reservoir operation, Flood forecasting, Simulation, Optimal solution.

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**ABSTRACT** *Out of the total rainfall of India, about 75% of it is received during the four moths (June to September) due to the South-West monsoon which is non-uniformly distributed in space as well. India is traversed by a large number of river systems. The rivers of North and Central India are prone to frequent floods during the South-West monsoon season, particularly in the month of July, August and September. Surat is one of the major important cities of Gujarat. In view of above scenario, it is observed that Surat is a highly developed, thickly populated cosmopolitan character city with full of various activities going on day and night. Any natural calamity which causes loss of lives to property & infrastructure along with effects on industrial processes going on has serious impact on economy of the state. So, it becomes highly necessary that past flood events must be studied and analyzed properly in order to propose adequate flood control & protection measures in time to come. In this research paper, effort towards revised reservoir operation for Ukai Dam listed and discussed. Based on results of analysis, few optimal solutions for minimization of the Tapi River flood impacts- Surat (Gujarat) recommended.*

## INRODUCTION

Floods are recurrent phenomena in India from time immemorial. Every year some or the other parts of the country are affected by floods of varying magnitude. Different regions of the country have different climates and rainfall patterns and as such it is also experienced that when part of the country is experiencing devastating floods, there is another part of the country at the same time which is in grips of severe drought. Out of the total rainfall of India, about 75% of it is received during the four moths (June to September) due to the South-West monsoon which is non-uniformly distributed in space as well. India is traversed by a large number of river systems. The rivers of North and Central India are prone to frequent floods during the South-West monsoon season, particularly in the month of July, August and September. In the Brahmaputra river basin, floods have often been experienced as early as in late May while in southern rivers floods continue till November. However, the heavy and intense rainfall is not the only factor contributing to floods. The other causes of flood are inadequate capacity within riverbanks to contain high flows and silting of riverbeds, landslides leading to obstruction of flow and change in the river course, retardation of flow due to tidal and backwater effects, poor natural drainage, cyclones, snowmelt and glacial outbursts, and dam break flow. With the flood plains which has resulted in more serious nature of damage over the year. The National Flood commission (1980) has reported that out of 40 million hectors (ha.) flood prone area, about 15.8 million ha. Areas have been provided with reasonable degree of protection so far. In India, about 40 million ha of land is flood prone, which is about 12% of the total geographical area (328 million ha) of the country the flooding occurs typically during the monsoon season (July-Sept.), caused by the formation of heavy tropical storms, ever decreasing channel capacity due to encroachments on river beds, and sometime due to tidal back water effects from the sea, The Indian sub-continent in general, and the western peninsula in particular, experienced heavy floods during 8th to 11th August 2006 that cause great damage to personal and property.

River Tapi is the 2nd largest west flowing river of Gujarat State, Central India. It originates from Mulati of Betul District of Madhya Pradesh; which is located 323 Km. from Maharashtra and 189 Km. from Gujarat. Tapi is known for occurrence of large floods due to influence of depressions originating from bay of Bengal traveling East to West causing rainfall, first in the upper catchment and then in lower catchment resulting of flood along its course.

Ukai Dam (Tapi River valley 2ndStage) is the largest multipurpose project, next to Narmada Project, undertaken by Government of Gujarat. It was completed in 1973. The Dam is located at village Ukai, Taluka Songadh of District Surat at distance of about 90 Km. from Surat city. It caters multiple purposes like Irrigation, Power generation, Water supply to industries and households, fisheries etc. It is major flood control point coming on Surat city.

Overtopping of TapiRiver embankments resulted in great damages in different areas like Fulpada, Chhapra-Bhata, Amroli-Uttran, Jahangirpura-Rander, Katargam, Ved-Dabholi, Rander-Adajan etc. covering major important areas of main city including outskirts. In addition to overtopping, back water effect of tide influenced the flood water level and added to the severity of the disaster. This flood caused damages on flood embankment and retaining wall at many places. It also resulted in losses of municipal properties like roads, equipments, material, street lights, infrastructures, furniture-assets, records in addition to buildings. The flood also resulted in total losses of Indian rupees 21000 Crores in the year 2006.

As mentioned earlier Surat has been blessed by the flow of Tapi however, it has also suffered a lot because of floods in Tapi since historic time. There have been several flood events shown in below Table.1, known to us since late 19th century; which has done great damage to this city. The most unforgettable and severe flood event was the flood of the year 2006.

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**Table.1 Details of Major Flood Received In River Tapi (After UkaiDam Construction)**

| Year | Date-Month | Maximum Water Level in Feet | Maximum Flood Released in Lacks Cusecs |
|---|---|---|---|
| 1975 | 28-Sept. | 345.10 | 2.99 |
| 1981 | 4-Oct. | 345.24 | 0.51 |
| 1989 | 8-Sept | 345.93 | 0.44 |
| 1994 | 23-Sept. | 345.24 | 5.08 |
| 1998 | 17-Sept. | 346.00 | 7.00 |
| 2006 | 9-Aug. | 346.07 | 9.10 |

**Note: Yellow Color Shows Maximum Value between Years (1972-2013).**

This flood event of 2006 signified concern on flood protection and control as such frequent event causes extensive damage to public property, infrastructure, agriculture, trade, industries, wages etc. along with loss to private properties and business establishments in general. Keeping in view, the serious concern of revised Ukai dam reservoir operation for flood protection & control. It feels the research in that direction for minimization of Tapi river flood impacts –Surat (Gujarat) is of vital importance.

In present study the "Optimal Solutions for minimization of Tapi River Flood Impacts- Surat (Gujarat)" has been carried out. Major flood control point Ukai dam in Gujarat State (India) has implemented on Tapi River in the year 1973. Out of this major dam Ukai, it is found that 10 another dams situated in upstream of Ukai dam. Only time lag 10 hours require to reach Tapi river flood from Radial gates of Ukai dam to Surat city (100 km.), ultimately meets Arabian Sea. Worst situations create when there is heavy rainfall, sudden release from 10 dams upstream of Ukai, release from Ukai dam, spring tidal wave effect from Arabian Sea and Surat also facing heavy rainfall at same time. Objective of this research paper is (i) to suggest a revised Ukai dam revised optimal reservoir gate operation policy/schedule after 1998 and 2006 flooding events. i.e. Policy which satisfy supply, demand, inflow and outflow(ii) Recommend optimal solutions minimize the Tapi River flood impacts-Surat (Gujarat).

## METHODOLOGY

Methodology adopted for this research study by Development of simulation model to simulate reservoir operation using monthly available historical inflow. Month end storage and canal releases obtained from simulation. Month end storage overlaid over a simulation period. Ultimately, calculation of rule level for revised Ukai reservoir operation done.

## DEVELOPMENT OF SIMULATION MODEL

In this research study, a water balance equation was derived and the performance of a project was analyzed. The water balance components were modeled without calibration, and compared with measured data, whenever possible. A reservoir simulation model was developing and the model storage capacities were compared with the observed storage capacities satisfactory. An optimization model was developed to solve the water resources of a large project in a computationally satisfactory manner. The optimal reservoir storage, optimal irrigation demand, and optimal reservoir release were computed. The optimal mean (1973-2008) model total water requirements for the dry and wet seasons were also computed and the optimal contribution by rainfall, reservoir, uncontrolled river flow, and recycled water were determined. The annual optimal flood water absorption volume from the reservoir systems was found to be 2217 MCM (Million cubic meters). The optimal mean model total water requirements were compared with other authors computed values for the same and a significant flood water absorption volume was achieved.

The planning and management of such a system often involves the establishment of optimal operating policies and the study of trade-off between objectives. Optimization model is to be developed in terms of determining values for a set of decision variables that will maximize or minimize an objective function subject to constraints. Constraints typically include storage capacities and other physical characteristics of the reservoir stream system, diversion or stream flow requirements for various purposes, and mass balance.

Thus, the step wise procedure of this paper are (i) to estimate the water balance components; (ii) to estimate the overall project efficiency; (iii) to calculate the total water requirements; (iv) to simulate the storage of reservoir systems, and (v) to optimize the water withdrawals from the reservoir systems.(vi) Calculation for revised rule level for reservoir operation month wise.

Reservoir simulation model is developed to simulate reservoir operation for 34 years using monthly available historical inflows and monthly generated inflows. Monthly reservoir storage and canal releases are obtained from the simulation.

Development of simulation model to simulate reservoir operation using monthly available historical inflow. Month end storage and canal releases obtained from simulation. Month end storage overlaid over a simulation period. Ultimately, calculation of rule level for revised Ukai reservoir operation.

## CONSTRAINTS FOR SIMULATION

The reservoir operation program is simulated based on the following constraints

**Storage Constraint:**

The reservoir storage in any month should not be more than the capacity of the reservoir and should not be less than the dead storage. The constraint is:

$$S_{min} \le S_t \le S_{max} \qquad t = 1, 2, 3 \ldots 12 \qquad (1)$$

Where,

| | | |
|---|---|---|
| St | = | Initial storage during the month 't' |
| Smin | = | Minimum storage capacity of the reservoir in MCM |
| Smax | = | Maximum capacity of the reservoir in MCM |

**Overflow Constraint:**

When the final storage exceeds the maximum capacity of the reservoir, the constraint is given by:

$$O_t = S_{t+1} - S_{max} \text{and} O_t \ge 0 \quad t = 1, 2, 3.1..12 \qquad (2)$$

Where,

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| | | |
|---|---|---|
| Ot | = | Surplus from the reservoir during time period t |
| St+1 | = | Final storage in the month t in MCM |

**Releases Constraint:**
The irrigation release during any month should not exceed the irrigation demand and the constraint is given by:

$R_t \leq D_t \quad t = 1, 2, 3 \ldots 12$ (3)

| | | |
|---|---|---|
| Rt | = | Releases for irrigation during time period t |
| Dt | = | Irrigation demand for the month t in MCM |

**Mass balance constraint:**
The relationship between the month to month storage is given by the continuity eq.stated by:

$S_{t+1} = S_t + I_t - D_t - R_t - E_t - O_t \quad t = 1,2,3,..12$ (4)

Where,

| | | |
|---|---|---|
| It | = | Monthly inflow during time period t in MCM |
| Et | = | Evaporation loss in the reservoir during time period t in MCM |
| Rt | = | Releases for the riparian rights in the river downstream during time period t in MCM |
| Ot | = | Surplus from the reservoir if any during time period t in MCM |
| St+1 | = | Final storage in the month t in MCM |
| St | = | Storage in the reservoir at the beginning of time period t. |
| Dt | = | Demand of water to be satisfied during time period t. |

## SAMPLE CALCULATION
Specimen basic calculation for June – 1975 shown below to understand all calculation for month and year listed in Table.2.

Initial Storage in starting of month

= 1142 $Mm^3$ + Inflow 406.8 $Mm^3$
= 1548.80 $Mm^3$ total storage.

Demand deduction
= ULBC Requirement 59.21 $Mm^3$ + D/S irrigation require ment 255.33 $Mm^3$ +Hydro power 353.53 $Mm^3$
= 668.07 $Mm^3$.

Final storage at month end
= Total storage – Demand
= 1548.80 $Mm^3$ – 668.07 $Mm^3$
= 880.73 $Mm^3$

**Specimen calculation for mean monthly inflow shown in Table.3.**
Here, the time period for simulation is considered as month. Month as a unit of time is most appropriate because level to be maintained at the end will be determined and the data regarding inflows, evaporation and water demand to be satisfied by project is given per month. The reservoir simulation is carried out for 34 years. Revised rule levels calculated from 34 years historical flood data used for Ukai dam reservoir operation. Existing data available for 34 years as Ukai dam II[nd]valley project implemented on Tapi River in the year 1973 i.e. 1974 to 2008. Hydrological cycle occur after every 100 years so, perfect prediction is not possible. Results of analysis for revised reservoir operation in terms of rule level shown in Fig.1 to 5. These calculated rule levels are plotted and compared with existing rule level policy for Ukai dam. This comparison clearly indicates that rule level kept very high for July month as per existing reservoir operation policy even though all demand satisfied, while in suggested rule level on monthly basis shows space for quantum of flood absorption in Mm. In this revised reservoir operation has minimize the deficiency of Irrigation and maximizing the hydro power generation without flooding downstream in existing condition. Moreover, this revised operation suggests each quantity of flood releases by indicating Ukai dam radial Gate opening height and numbers as shown in Table no.4 and 5 to save downstream people and property.

**Table.2 Basic Calculation**

| Month | Initial Storage in starting of month | Inflow | ULBC Require-ment | D/S irri. Require-ment | Through Hydro | Final Storage at month end | Spill | Final Storage after spill at month end | Average Storage | R.L. with respect to average storage | Surface area with respect to R.L. Of average storage | Monthly Evaporation Rate | Evapora-tion losses | Demand Deficit | Final Storage after Evaporation losses at month end | Storage | RL Low | Storage Low Row No | Storage High Row No | Storage High | RL High | RL Low | RL Low Row No | Area Low | RL HI Row No | RL High | Area High |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mm3 | Mm3 | Mm3 | Mm3 | Mm3 | Mm3 | Mm 3 | Mm3 | Mm3 | m | Mm2 | m | Mm3 | Mm3 | Mm3 | | | | | | | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| Jun-75 | 1142 | 406.8 | 59.21 | 255.33 | 353.53 | 880.73 | 0 | 1142 | 1142 | 86.15 | 491.48 | 0.2 | 99.87 | -40.66 | 1042.13 | 1140.42 | 86.14 | 476 | 477 | 1144.57 | 86.17 | 86.14 | 476 | 491.48 | 477 | 491.65 | 491.65 |
| Jul-75 | 1042.13 | 1380.03 | 19.74 | 103.61 | 357.17 | 1941.64 | 0 | 1941.64 | 1491.89 | 88.54 | 505.04 | 0.1 | 51.31 | 0 | 1890.33 | 1488.21 | 88.51 | 554 | 555 | 1493.39 | 88.54 | 88.51 | 554 | 505.04 | 555 | 505.22 | 505.22 |
| Aug-75 | 2438.41 | 4184.3 | 74.01 | 398.41 | 412.5 | 5737.78 | 0 | 5737.78 | 4088.1 | 98.5 | 561.91 | 0.1 | 57.09 | 0 | 5680.69 | 4080.37 | 98.48 | 880 | 881 | 4092.51 | 98.51 | 98.48 | 880 | 561.91 | 881 | 562.08 | 562.08 |
| Sep-75 | 5680.69 | 4093.8 | 61.67 | 310.83 | 1813.67 | 7588.32 | 0 | 7588.32 | 6634.5 | 103.82 | 592.35 | 0.15 | 90.27 | 0 | 7498.04 | 6630.85 | 103.82 | 1055 | 1056 | 6648.66 | 103.85 | 103.82 | 1055 | 592.35 | 1056 | 592.52 | 592.52 |
| Oct-75 | 7498.04 | 406.51 | 40.7 | 219.56 | 342.46 | 7301.84 | 0 | 7301.84 | 7399.94 | 105.13 | 599.83 | 0.2 | 121.89 | 0 | 7179.95 | 7396.48 | 105.13 | 1098 | 1099 | 7414.29 | 105.16 | 105.13 | 1098 | 599.83 | 1099 | 600 | 600 |
| Nov-75 | 7179.95 | 106.96 | 74.01 | 252.86 | 292.55 | 6667.49 | 0 | 6667.49 | 6923.72 | 104.32 | 595.13 | 0.15 | 90.7 | 0 | 6576.8 | 6915.74 | 104.3 | 1071 | 1072 | 6933.54 | 104.33 | 104.3 | 1071 | 595.13 | 1072 | 595.3 | 595.3 |
| Dec-75 | 6576.8 | 182.06 | 55.51 | 293.57 | 528.99 | 5880.78 | 0 | 5880.78 | 6228.79 | 103.08 | 588 | 0.13 | 74.68 | 0 | 5806.11 | 6216.54 | 103.05 | 1030 | 1031 | 6232.72 | 103.08 | 103.05 | 1030 | 588 | 1031 | 588.17 | 588.17 |
| Jan-76 | 5806.11 | 30.26 | 86.34 | 318.24 | 722.21 | 4709.58 | 0 | 4709.58 | 5257.84 | 101.16 | 577.05 | 0.13 | 73.28 | 0 | 4636.29 | 5244.16 | 101.13 | 967 | 968 | 5258.87 | 101.16 | 101.13 | 967 | 577.05 | 968 | 577.22 | 577.22 |
| Feb-76 | 4636.29 | 0 | 85.11 | 358.94 | 623.89 | 3568.35 | 0 | 3568.35 | 4102.32 | 98.54 | 562.08 | 0.13 | 71.38 | 0 | 3496.96 | 4092.51 | 98.51 | 881 | 882 | 4104.65 | 98.54 | 98.51 | 881 | 562.08 | 882 | 562.26 | 562.26 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mar-76 | 3496.96 | 0 | 90.04 | 323.17 | 713.11 | 2370.64 | 0 | 2370.64 | 2933.8 | 95.38 | 544.17 | 0.2 | 110.58 | 0 | 2260.06 | 2931.63 | 95.37 | 778 | 779 | 2942.02 | 95.4 | 95.37 | 778 | 544.17 | 779 | 544.35 | 544.35 |
| Apr-76 | 2260.06 | 0 | 88.81 | 347.84 | 720.36 | 1103.06 | 0 | 1142 | 1701.03 | 89.77 | 512.18 | 0.23 | 117.08 | -28.27 | 1024.92 | 1700.66 | 89.76 | 594 | 595 | 1705.84 | 89.79 | 89.76 | 594 | 512.18 | 595 | 512.35 | 512.35 |
| May-76 | 1024.92 | 0 | 90.04 | 379.91 | 779.86 | -224.9 | 0 | 1142 | 1083.46 | 85.72 | 489.04 | 0.25 | 124.22 | -34.18 | 1017.78 | 1082.34 | 85.71 | 462 | 463 | 1086.49 | 85.74 | 85.71 | 462 | 489.04 | 463 | 489.22 | 489.22 |
| Jun-76 | 1017.78 | 2013 | 59.21 | 255.33 | 829.9 | 1886.34 | 0 | 1886.34 | 1452.06 | 88.29 | 503.65 | 0.2 | 102.34 | 0 | 1784 | 1449.28 | 88.27 | 546 | 547 | 1453.83 | 88.3 | 88.27 | 546 | 503.65 | 547 | 503.83 | 503.83 |
| Jul-76 | 1784 | 3849.27 | 19.74 | 103.61 | 947.21 | 4562.7 | 0 | 4562.7 | 3173.35 | 96.08 | 548.17 | 0.1 | 55.69 | 0 | 4507.01 | 3172.06 | 96.07 | 801 | 802 | 3183.15 | 96.1 | 96.07 | 801 | 548.17 | 802 | 548.35 | 548.35 |
| Aug-76 | 4507.01 | 5321.86 | 74.01 | 398.41 | 801.58 | 8554.87 | 43.87 | 8511 | 6509.01 | 103.6 | 591.13 | 0.1 | 60.06 | 0 | 8450.94 | 6507.84 | 103.6 | 1048 | 1049 | 6524.02 | 103.63 | 103.6 | 1048 | 591.13 | 1049 | 591.3 | 591.3 |
| Sep-76 | 8450.94 | 5002.7 | 61.67 | 310.83 | 865.03 | 12216.11 | 3705.1 | 8511 | 8480.97 | 106.99 | 610.44 | 0.15 | 93.03 | 0 | 8417.97 | 8480.18 | 106.99 | 1159 | 1160 | 8498.73 | 107.02 | 106.99 | 1159 | 610.44 | 1160 | 610.52 | 610.52 |
| Oct-76 | 8417.97 | 194.89 | 40.7 | 219.56 | 817.43 | 7535.17 | 0 | 7535.17 | 7976.57 | 106.29 | 606.44 | 0.2 | 123.23 | 0 | 7411.95 | 7974.19 | 106.28 | 1136 | 1137 | 7991.19 | 106.31 | 106.28 | 1136 | 606.44 | 1137 | 606.61 | 606.61 |
| Nov-76 | 7411.95 | 510.56 | 74.01 | 252.86 | 566.41 | 7029.22 | 0 | 7029.22 | 7220.58 | 104.82 | 598.09 | 0.15 | 91.15 | 0 | 6938.07 | 7218.43 | 104.82 | 1088 | 1089 | 7236.24 | 104.85 | 104.82 | 1088 | 598.09 | 1089 | 598.26 | 598.26 |
| Dec-76 | 6938.07 | 33.37 | 55.51 | 293.57 | 645.3 | 5977.07 | 0 | 5977.07 | 6457.57 | 103.51 | 590.44 | 0.13 | 74.99 | 0 | 5902.08 | 6443.1 | 103.48 | 1044 | 1045 | 6459.29 | 103.51 | 103.48 | 1044 | 590.44 | 1045 | 590.61 | 590.61 |
| Jan-77 | 5902.08 | 0 | 86.34 | 318.24 | 718.28 | 4779.22 | 0 | 4779.22 | 5340.65 | 101.33 | 578.09 | 0.13 | 73.42 | 0 | 4705.81 | 5332.42 | 101.32 | 973 | 974 | 5347.13 | 101.35 | 101.32 | 973 | 578.09 | 974 | 578.26 | 578.26 |
| Feb-77 | 4705.81 | 0 | 85.11 | 358.94 | 701.23 | 3560.53 | 0 | 3560.53 | 4133.17 | 98.61 | 562.61 | 0.13 | 71.45 | 0 | 3489.08 | 4128.94 | 98.6 | 884 | 885 | 4141.08 | 98.63 | 98.6 | 884 | 562.61 | 885 | 562.78 | 562.78 |
| Mar-77 | 3489.08 | 0 | 90.04 | 323.17 | 995.35 | 2080.52 | 0 | 2080.52 | 2784.8 | 94.94 | 541.57 | 0.2 | 110.05 | 0 | 1970.47 | 2775.72 | 94.92 | 763 | 764 | 2786.12 | 94.95 | 94.92 | 763 | 541.57 | 764 | 541.74 | 541.74 |
| Apr-77 | 1970.47 | 0 | 88.81 | 347.84 | 1017.64 | 516.19 | 0 | 1142 | 1556.24 | 88.91 | 507.3 | 0.23 | 115.97 | -27.16 | 1026.03 | 1555.57 | 88.91 | 567 | 568 | 1560.75 | 88.94 | 88.91 | 567 | 507.3 | 568 | 507.48 | 507.48 |
| May-77 | 1026.03 | 0 | 90.04 | 379.91 | 855.9 | -299.82 | 0 | 1142 | 1084.02 | 85.72 | 489.04 | 0.25 | 124.22 | -34.18 | 1017.78 | 1082.34 | 85.71 | 462 | 463 | 1086.49 | 85.74 | 85.71 | 462 | 489.04 | 463 | 489.22 | 489.22 |
| Jun-77 | 1017.78 | 1659 | 59.21 | 255.33 | 897.97 | 1464.27 | 0 | 1464.27 | 1241.03 | 86.87 | 495.65 | 0.2 | 100.72 | 0 | 1363.56 | 1239.97 | 86.87 | 500 | 501 | 1244.52 | 86.9 | 86.87 | 500 | 495.65 | 501 | 495.82 | 495.82 |
| Jul-77 | 1363.56 | 1714.61 | 19.74 | 103.61 | 1033.21 | 1921.6 | 0 | 1921.6 | 1642.58 | 89.42 | 510.09 | 0.1 | 51.82 | 0 | 1869.78 | 1638.48 | 89.4 | 582 | 583 | 1643.66 | 89.43 | 89.4 | 582 | 510.09 | 583 | 510.26 | 510.26 |
| Aug-77 | 1869.78 | 2859.78 | 74.01 | 398.41 | 659.13 | 3598.01 | 0 | 3598.01 | 2733.9 | 94.79 | 540.69 | 0.1 | 54.93 | 0 | 3543.08 | 2723.75 | 94.76 | 758 | 759 | 2734.15 | 94.79 | 94.76 | 758 | 540.69 | 759 | 540.87 | 540.87 |
| Sep-77 | 3543.08 | 2975.71 | 61.67 | 310.83 | 436.41 | 5709.88 | 0 | 5709.88 | 4626.48 | 99.78 | 569.22 | 0.15 | 86.75 | 0 | 5623.13 | 4618.49 | 99.76 | 922 | 923 | 4631.85 | 99.79 | 99.76 | 922 | 569.22 | 923 | 569.39 | 569.39 |
| Oct-77 | 5623.13 | 411.18 | 40.7 | 219.56 | 931.86 | 4842.19 | 0 | 4842.19 | 5232.66 | 101.11 | 576.87 | 0.2 | 117.22 | 0 | 4724.97 | 5229.45 | 101.1 | 966 | 967 | 5244.16 | 101.13 | 101.1 | 966 | 576.87 | 967 | 577.05 | 577.05 |
| Nov-77 | 4724.97 | 216.21 | 74.01 | 252.86 | 733.35 | 3880.96 | 0 | 3880.96 | 4302.97 | 99.04 | 565.05 | 0.15 | 86.11 | 0 | 3794.85 | 4298.91 | 99.03 | 898 | 899 | 4311.05 | 99.06 | 99.03 | 898 | 565.05 | 899 | 565.22 | 565.22 |
| Dec-77 | 3794.85 | 158.04 | 55.51 | 293.57 | 798.83 | 2804.98 | 0 | 2804.98 | 3299.92 | 96.42 | 550.09 | 0.13 | 69.86 | 0 | 2735.12 | 3293.97 | 96.41 | 812 | 813 | 3305.05 | 96.44 | 96.41 | 812 | 550.09 | 813 | 550.26 | 550.26 |
| Jan-78 | 2735.12 | 0 | 86.34 | 318.24 | 698.77 | 1631.77 | 0 | 1631.77 | 2183.45 | 92.2 | 526.09 | 0.13 | 66.81 | 0 | 1564.96 | 2183.26 | 92.2 | 674 | 675 | 2189.86 | 92.23 | 92.2 | 674 | 526.09 | 675 | 526.26 | 526.26 |
| Feb-78 | 1564.96 | 0 | 85.11 | 358.94 | 697.73 | 423.18 | 0 | 1142 | 1353.48 | 87.63 | 499.83 | 0.13 | 63.48 | 21.63 | 1078.52 | 1349.17 | 87.6 | 524 | 525 | 1353.72 | 87.63 | 87.6 | 524 | 499.83 | 525 | 500 | 500 |
| Mar-78 | 1078.52 | 0 | 90.04 | 323.17 | 499.16 | 166.15 | 0 | 1142 | 1110.26 | 85.91 | 490.09 | 0.2 | 99.59 | -9.55 | 1042.41 | 1107.23 | 85.89 | 468 | 469 | 1111.38 | 85.92 | 85.89 | 468 | 490.09 | 469 | 490.26 | 490.26 |
| Apr-78 | 1042.41 | 0 | 88.81 | 347.84 | 553.25 | 52.51 | 0 | 1142 | 1092.21 | 85.78 | 489.39 | 0.23 | 111.88 | -23.07 | 1030.12 | 1090.64 | 85.77 | 464 | 465 | 1094.79 | 85.8 | 85.77 | 464 | 489.39 | 465 | 489.56 | 489.56 |
| May-78 | 1030.12 | 0 | 90.04 | 379.91 | 888.52 | -328.34 | 0 | 1142 | 1086.06 | 85.74 | 489.04 | 0.25 | 124.22 | -34.18 | 1017.78 | 1082.34 | 85.71 | 462 | 463 | 1086.49 | 85.74 | 85.71 | 462 | 489.04 | 463 | 489.22 | 489.22 |
| Jun-78 | 1017.78 | 803 | 59.21 | 255.33 | 573.99 | 932.25 | 0 | 1142 | 1079.89 | 85.69 | 488.87 | 0.2 | 99.34 | -40.13 | 1042.66 | 1078.2 | 85.68 | 461 | 462 | 1082.34 | 85.71 | 85.68 | 461 | 488.87 | 462 | 489.04 | 489.04 |

**Table.3 Mean Monthly Inflow**

| Month June | Initial storage Average | Final Storage | inflow | Through Hydro | Spill | Month July | Initial storage Average | Final Storage | Inflow | Through Hydro | Spill | Month August | Initial storage Average | Final Storage | Inflow | Through Hydro | Spill |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jun-75 | 1142.00 | 880.73 | 406.80 | 353.53 | 0 | Jul-75 | 1042.13 | 1941.64 | 1380. 030896 | 357.1719804 | 0 | Aug-75 | 2438.41 | 5737.78 | 4184. 29648 | 412.5035169 | 0 |
| Jun-76 | 1017.78 | 1886.34 | 2013.00 | 829.90 | 0 | Jul-76 | 1784.00 | 4562.70 | 3849.27 | 947.2123567 | 0 | Aug-76 | 4507.01 | 8554.87 | 5321.86 | 801.5837353 | 43.8665251 |
| Jun-77 | 1017.78 | 1464.27 | 1659.00 | 897.97 | 0 | Jul-77 | 1363.56 | 1921.60 | 1714.61 | 1033.213588 | 0 | Aug-77 | 1869.78 | 3598.01 | 2859.78 | 659.1258466 | 0 |
| Jun-78 | 1017.78 | 932.25 | 803.00 | 573.99 | 0 | Jul-78 | 1042.66 | 2705.18 | 2645.95 | 860.0832644 | 0 | Aug-78 | 2652.61 | 5965.98 | 5488.78 | 1702.99662 | 0 |
| Jun-79 | 1017.78 | 1574.12 | 1061.00 | 190.13 | 0 | Jul-79 | 1472.98 | 1284.51 | 1054.86 | 1119.970804 | 0 | Aug-79 | 1233.63 | 8329.17 | 8658.87 | 1090.910648 | 0 |
| Jun-80 | 1017.78 | 1700.68 | 1538.00 | 540.56 | 0 | Jul-80 | 1599.04 | 924.09 | 977.94 | 1529.547314 | 0 | Aug-80 | 1091.15 | 3862.63 | 4522.66 | 1278.754541 | 0 |
| Jun-81 | 1017.78 | 582.49 | 57.00 | 177.75 | 0 | Jul-81 | 1042.66 | 2373.00 | 1743.18 | 289.4932781 | 0 | Aug-81 | 2320.94 | 7044.24 | 6403.82 | 1208.107877 | 0 |
| Jun-82 | 1017.78 | 661.08 | 527.00 | 569.16 | 0 | Jul-82 | 1042.66 | 1499.58 | 1181.3 | 601.0299988 | 0 | Aug-82 | 1449.12 | 1396.75 | 1261.36 | 841.3108631 | 0 |
| Jun-83 | 1017.78 | 713.02 | 98.00 | 88.22 | 0 | Jul-83 | 1042.66 | 2208.83 | 1304.95 | 15.42796329 | 0 | Aug-83 | 2157.06 | 4685.76 | 4403.6 | 1402.486513 | 0 |
| Jun-84 | 2724.51 | 2386.85 | 83.00 | 106.13 | 0 | Jul-84 | 2277.79 | 2640.86 | 662.4 | 175.9820749 | 0 | Aug-84 | 2586.63 | 5861.69 | 3998.25 | 250.7667905 | 0 |

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| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jun-85 | 1017.78 | 825.65 | 330.00 | 207.59 | 0 | Jul-85 | 1042.66 | 1425.02 | 505.71 | 0 | 0 | Aug-85 | 1374.70 | 2622.43 | 1991.74 | 271.5894032 | 0 |
| Jun-86 | 1017.78 | 883.06 | 314.00 | 134.18 | 0 | Jul-86 | 1042.66 | 2933.49 | 2050.86 | 36.68361584 | 0 | Aug-86 | 2880.59 | 6291.75 | 4515.22 | 631.6388235 | 0 |
| Jun-87 | 1017.78 | 845.83 | 660.00 | 517.42 | 0 | Jul-87 | 1042.66 | 1498.64 | 988.78 | 409.4551119 | 0 | Aug-87 | 1448.17 | 2044.81 | 1137.95 | 68.89248623 | 0 |
| Jun-88 | 1017.78 | 1051.59 | 487.00 | 138.65 | 0 | Jul-88 | 1042.66 | 4704.73 | 3795.65 | 10.23393124 | 0 | Aug-88 | 4649.55 | 6490.62 | 3504.26 | 1190.769155 | 0 |
| Jun-89 | 3087.76 | 2338.62 | 181.00 | 615.60 | 0 | Jul-89 | 2228.82 | 3225.91 | 1568.92 | 448.4800789 | 0 | Aug-89 | 3170.98 | 5720.34 | 3847.06 | 825.2737081 | 0 |
| Jun-90 | 1017.78 | 889.67 | 1057.00 | 870.57 | 0 | Jul-90 | 1042.66 | 2796.74 | 2569.95 | 692.5237418 | 0 | Aug-90 | 2744.03 | 9642.86 | 8336.36 | 965.1113385 | 1131.85854 |
| Jun-91 | 1016.86 | 741.73 | 393.00 | 353.58 | 0 | Jul-91 | 1042.66 | 2194.68 | 1588.36 | 312.9924198 | 0 | Aug-91 | 2142.93 | 2592.91 | 1892.98 | 970.576938 | 0 |
| Jun-92 | 1017.78 | 1539.94 | 926.00 | 89.30 | 0 | Jul-92 | 1438.94 | 1298.44 | 170.48 | 187.6383832 | 0 | Aug-92 | 1247.58 | 4032.68 | 3308.44 | 50.92744747 | 0 |
| Jun-93 | 1017.78 | 291.18 | 40.11 | 452.17 | 0 | Jul-93 | 1042.66 | 3515.61 | 3200.46 | 604.1640332 | 0 | Aug-93 | 3461.91 | 3865.82 | 1800.48 | 924.1462549 | 0 |
| Jun-94 | 1017.69 | 460.72 | 520.88 | 763.31 | 0 | Jul-94 | 1042.66 | 3242.55 | 2937.46 | 614.2267058 | 0 | Aug-94 | 3189.22 | 6586.82 | 4383.8 | 513.7736857 | 0 |
| Jun-95 | 1092.59 | 451.59 | 40.19 | 366.65 | 0 | Jul-95 | 1042.34 | 2702.29 | 2003.02 | 219.7200328 | 0 | Aug-95 | 2649.74 | 2543.00 | 621.85 | 256.1736726 | 0 |
| Jun-96 | 1017.78 | 716.57 | 176.53 | 163.20 | 0 | Jul-96 | 1042.66 | 2347.42 | 1512.86 | 84.7534894 | 0 | Aug-96 | 2295.42 | 3662.83 | 2010.72 | 170.8892812 | 0 |
| Jun-97 | 1017.78 | 1023.08 | 519.64 | 199.80 | 0 | Jul-97 | 1042.66 | 756.90 | 106.03 | 268.4382429 | 0 | Aug-97 | 1092.28 | 4341.84 | 4038 | 316.0188058 | 0 |
| Jun-98 | 1017.78 | 471.17 | 75.40 | 307.47 | 0 | Jul-98 | 1042.66 | 1718.84 | 1013.17 | 213.6427951 | 0 | Aug-98 | 1667.95 | 1333.62 | 315.83 | 177.7396297 | 0 |
| Jun-99 | 1013.32 | 1402.68 | 1089.27 | 385.37 | 0 | Jul-99 | 1302.25 | 1947.01 | 1016.42 | 248.3080047 | 0 | Aug-99 | 1895.24 | 3558.14 | 2730.26 | 594.9356353 | 0 |
| Jun-00 | 1017.78 | 1050.92 | 684.82 | 337.14 | 0 | Jul-00 | 1042.66 | 2911.72 | 2248.05 | 255.6452172 | 0 | Aug-00 | 2858.85 | 2498.05 | 446.99 | 335.3734867 | 0 |
| Jun-01 | 1017.78 | 1592.32 | 889.08 | 0.00 | 0 | Jul-01 | 1491.11 | 1807.16 | 485.33 | 45.92913967 | 0 | Aug-01 | 1755.30 | 3842.65 | 2622.24 | 62.47028457 | 0 |
| Jun-02 | 1017.78 | 2025.04 | 1476.18 | 154.38 | 0 | Jul-02 | 1922.20 | 1685.03 | 141.45 | 255.2733411 | 0 | Aug-02 | 1632.67 | 3668.99 | 2599.72 | 90.98485991 | 0 |
| Jun-03 | 1739.21 | 2094.55 | 910.49 | 240.61 | 0 | Jul-03 | 1989.17 | 4047.55 | 2295.01 | 113.2754044 | 0 | Aug-03 | 3992.12 | 3430.65 | 264.54 | 353.5905204 | 0 |
| Jun-04 | 1017.78 | 458.83 | 64.47 | 308.88 | 0 | Jul-04 | 1042.66 | 872.01 | 236.72 | 284.0227856 | 0 | Aug-04 | 1092.28 | 4697.60 | 4089.75 | 12.01257528 | 0 |
| Jun-05 | 1017.78 | 1027.95 | 526.16 | 201.45 | 0 | Jul-05 | 1042.66 | 2520.40 | 1746.69 | 145.6017093 | 0 | Aug-05 | 2468.12 | 5029.97 | 3179.17 | 144.8971021 | 0 |
| Jun-06 | 1017.78 | 476.41 | 9.07 | 235.90 | 0 | Jul-06 | 1042.66 | 4346.42 | 3508.84 | 81.72954988 | 0 | Aug-06 | 4291.54 | 16384.07 | 13905.96 | 1341.007083 | 7873.07366 |
| Jun-07 | 3208.45 | 2975.22 | 81.31 | 0.00 | 0 | Jul-07 | 2864.11 | 10556.36 | 7815.6 | 0 | 2045.36405 | Aug-07 | 8451.84 | 11992.55 | 4013.13 | 0 | 3481.55232 |
| Jun-08 | 4629.83 | 4401.62 | 86.33 | 0.00 | 0 | Jul-08 | 4286.23 | 4403.06 | 240.18 | 0 | 0 | Aug-08 | 4345.60 | 5824.18 | 1951 | 0 | 0 |
| June Mean | 1326.44 | 1259.35 | 581.87 | 334.43 | 0.00 | July Mean | 1409.27 | 2691.76 | 1772.37 | 366.53 | 60.16 | Aug Mean | 2620.73 | 5227.53 | 3665.02 | 585.80 | 368.54 |

**Note: Reservoir cap = 7414.29 (Mm³) and Reservoir level for Spill to start = 105.16 (Mt)**

## ANALYSIS

**Results of analysis shown in below Fig. 1 to 5.**

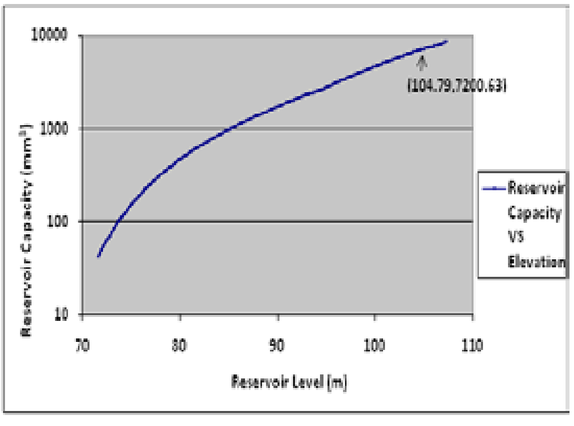


**Fig.1 Reservoir Capacity Vs Elevation Chart**

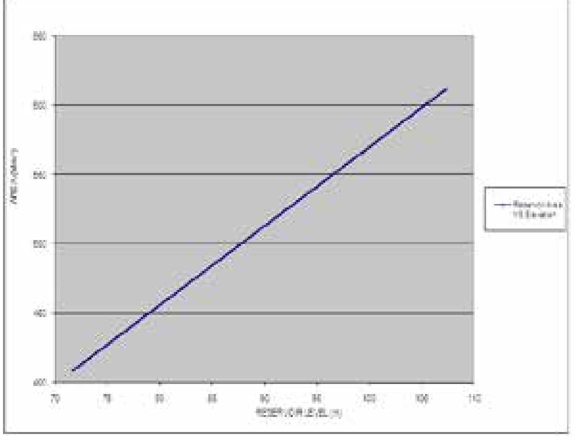

**Fig.2 Reservoir Area vs. Elevation Chart**

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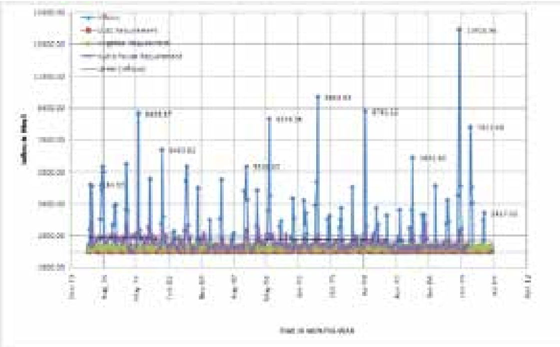

Fig.3 Inflow v/s Time.

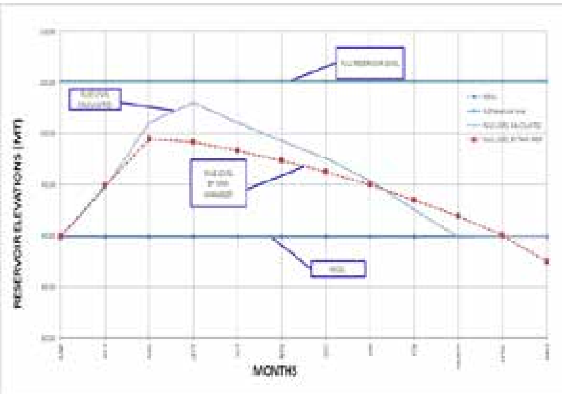


Fig.4 Revised Rule Levels for Ukai Dam Reservoir

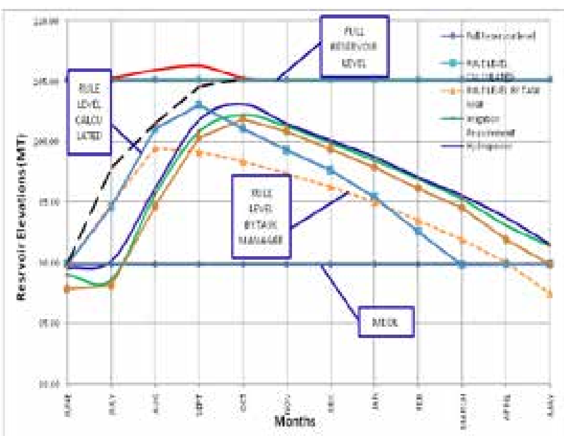


Fig.5 Suggested Rule Levels for Ukai Dam Reservoir Operation

Development of simulation model to simulate reservoir operation using monthly available historical inflow. Month end storage and canal releases obtained from simulation. Month end storage overlaid over a simulation period. Ultimately, calculation of rule level for revised Ukai reservoir operation.

## RESULTS

Results of analysis from revised reservoir operation listed in this chapter as shown below in Table no.4 and 5. Calculated revised rule level compared with existing rule level and flood absorption volume determined. Table 4 shows suggested rule level for flood absorption for monsoon month and Table.5shows revised gate operation schedule of Ukai dam.

**Table.4 Suggested Rule Level for Flood Absorption**

| Month | Suggested Rule Level In Mt | Rule Level in 2000 by Task Mgr Mt | Difference Mt Task (AC-AB) | Flood absorption Volume $Mm^3$ |
|---|---|---|---|---|
| JUNE | 89.92 | 90 | 0.08 | 484.73 |
| JULY | 94.67 | 97.86 | 3.19 | 1145.79 |
| AUGUST | 101.10 | 101.52 | 0.42 | 207.85 |
| SEPTEMBER | 103.07 | 104.55 | 1.48 | 834.24 |
| OCTOMBER | 101.06 | 105.18 | 4.12 | 2217.49 |

**Table.5 Revised Gate operation schedule ofUkai dam**

| Sr. No. | Overflow in Cusecs | Gate Nos. to be opened | Total Nos. of gates to be opened | Opening of gates when RWL is 345feet | Opening of gates when RWL is 339 feet. |
|---|---|---|---|---|---|
| 1 | 1.00 lac | 1 to 22 | 22 | 1.00 | 1.00 |
| 2 | 2.00 lac | 3 to 9,11 to 20 | 17 | 4.00 | 5.00 |
| | | 1,2,10,21,22 | 5 | 2.00 | 5.00 |
| 3 | 3.00 lac | 3 to 9,11 to 20 | 17 | 7.00 | 9.00 |
| | | 1,2,10,21,22 | 5 | 3.00 | 3.00 |
| 4 | 4.50 lac | 3 to 20 | 18 | 12.00 | 14.00 |
| | | 1,2,21,22 | 4 | 6.00 | 6.00 |
| 5 | 5.00 lac | 3 to 20 | 18 | 24.00 | 25.00 |
| | | 1,2 | 2 | 13.00 | 15.00 |
| | | 21,22 | 2 | 7.00 | 9.00 |

## CONCLUSIONS

It is a general policy to assume impingement of the design flood at the FRL, and the dam reservoir system is designed for this condition. The Ukai dam has also been designed for such a situation. The PMF with a peak value of 21.16 lac cusecs (46,270 cumec) from the dam spillway, and attainment of a maximum water level of 351.0 ft (106.99 m) in the reservoir. As the capacity of the Tapi River downstream of Ukai dam been adequate to pass this flood, without causing any serious inundation, the flood control operation of this dam would have been a simple affair.

Unfortunately, the safe carrying capacity of the river, particularly near the city of Surat is grossly inadequate to pass the floods of such high order. The effort is to restrict the downstream flow to around 7 lac cusecs (19,822 cumec), at least for the size of floods already experienced by the dam. Full advantage of the flood forecasting facility available for the Ukai reservoir is taken to permit possible predepletion of the reservoir. Temporary filling of the reservoir above the rule level is also allowed when the forecast indicates recession in the flood discharge. This creates room for storing more flood waters, and permits further moderation of the flood peak. As the safety of the dam is of paramount importance, the reservoir level under no circumstances shall be allowed to go above the MWL of 351.00 ft (106.99 m).Normal, high alert and emergency situations have been defined and detailed operational procedures under each of these situations described in this research study. Reasonably accurate forecasts of inflows into the Ukai reservoir, and the stipulated information about the rainfall in the Upper Tapi catchment are assumed to be available during the period of flood.

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