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ASSESSMENT OF FUTURE WATER DEMAND FOR RAJKOT CITY FROM BHADAR-1 RESERVOIR

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Abstract— In present study, a Linear Programming technique used to maximize water supply release from Bhadar-1 reservoir. The deterministic inflows were estimated from the monthly probability distribution of observed stochastic inflows. The linear programming model were formulated for different six dependability level for LINGO 18 version. Present and Future population as well as water demand forecasting were done by considering census 2011 for few wards of Rajkot city. The results obtained from different models were analyzed and recommended to release water supply from bhadar-1 reservoir at 50% dependability of level of inflow. The results obtained from model of 50% dependability level of were used for assessment of present as well as future water demand as on year 2018 and 2028 respectively for few wards of Rajkot city. From the calibration, it has been found present and future water demand will be deficit 0.02MCM and 1.94MCM respectively.

Keywords— LINGO 18, Bhadar-1 Reservoir, Future Water Demand, Maximize Water Supply Release and Population Forecasting

I. INTRODUCTION

Many regions are facing formidable freshwater demand challenges and Over the last decade, an integrated approach to water development has emerged which places water supply projects in the context of demand-side issues, as well as issues of water quality and ecosystem preservation. Ajudiya B.K. et al (2018) presented the models for Aji-1 were prepared and solved for nine different dependable inflow levels using optimizer LINGO 14 Version. The models provided an infeasible solution for three dependable inflow levels. The conclusions were derived from the study, the maximum revenue generated from water supply release was at 50% dependability inflow level, i.e., 20.63 million rupees and it gradually reduced owing to decreased optimal release of water at 75% dependability inflow level with LPMM, i.e., 5.99 million rupees. A straight correlation was also observed between maximum revenue generation and inflow dependability level. From an optimum release analysis, a decreasing tendency in release was observed, with increasing probability levels of inflow [1]. Stockholm Environment Institute (2013) used the WEAP model was chosen for integrated approach to simulating water system and WEAP is powerful in evaluating the current situation and future options in water supply system. The variation of the predicted value and actual value of water demand for the year 2012 and 2013 were 15.32MLD and 44.75MLD respectively [2] . Saxena S. And S. M. Yadav (2016) presented the WEAP model was chosen for integrated approach to simulating water system and WEAP is powerful in evaluating the current situation and future options in water supply system. The variation of the predicted value and actual value of water demand for the year 2012 and 2013 were 15.32MLD and 44.75MLD respectively. The formulated scenarios for year 2041 with possible future growth population and change in climate conditions results in increased water demand. Evaluation of WEAP is done for 2011 population census and the water distributed across various Water Distribution Systems is the data of 2011 [3].Narul N.M. et al(2015) the present water study analyses the effects of three different scenarios using water evaluation and planning (WEAP) model to evaluate the plausible future water scenarios of water availability in Selangor. The first scenario is business as usual which is later referred to as reference in this study. Second, higher population growth and third is the application of the demand side management onto the reference and higher population growth scenario. These scenarios were then used to calculate the impact on the supply demand gap by the year 2050. To use the WEAP model to evaluate the water supply and demand in Selangor [4].Muzzafar A.M. et al (2015) used to future scenario incorporated new irrigation and hydropower schemes on the main stem of the Nile and its principal tributaries. Data for all existing and planned schemes were obtained from the basin master plans as well as from scheme feasibility studies. Water use was simulated over a 32-year period of varying rainfall and flow. Preliminary results indicate that currently irrigation demand in Sudan is approximately 8.5 Bm3per year for 1.16 million hectares (mha). This compares to a total irrigation demand in Ethiopia of just 0.2 Bm3peryear. Although total flows are reduced, greater regulation results in higher dry season flows at both locations. The WEAP model has been configured to simulate the impacts of water resource development in the Blue Nile basin [6].Alazzy A.A. et al (2014) The study holds significance keeping in view the global climatic concerns, which began to cast their shadows on the climate of Jammu and Kashmir as well. In order to accomplish the present study, WEAP (water evaluation and planning model) of Stockholm Environment Institute was used. This model is a tool for integrated water resource management and planning like, forecasting water demand, supply, inflows, outflows, water use, reuse, water quality, priority areas and Hydropower generation, etc. The water demands for Srinagar i,e., irrigation demands for agriculture and water supply demands for

our domestic needs was analysed, industrial demands were not analysed as we have negligible demands in this sector[7].Zakari et al (2011) presented to syria is one of the Middle Eastern countries that suffer from scarcity in water resources availability, which affects the growth and development of economic activities. In this research, the Water Evaluation and Planning (WEAP) model is applied to evaluate future water demand in the Euphrates and Aleppo basin (EAB), Syria, by taking into account the climate change that may affect water demand in the domestic, industrial, and agricultural sectors until 2050 [8].

II. STUDY AREA AND DATA COLLECTION

Rajkot City is spread over 176km^2 and had a population of 1.4 million as per 2011 census and It lies between latitude 22^{o}18'0" N and longitude 70^{o}51'0" E. The study areas also include under RMC. Currently insufficient data and lack of the plan for the future are restricting the management of water supply system of Rajkot city and the decision making for future options for various urban issues. Bhadar river basin can be consider major water resources for water supply to Rajkot city which having catchment area 2406km^2.

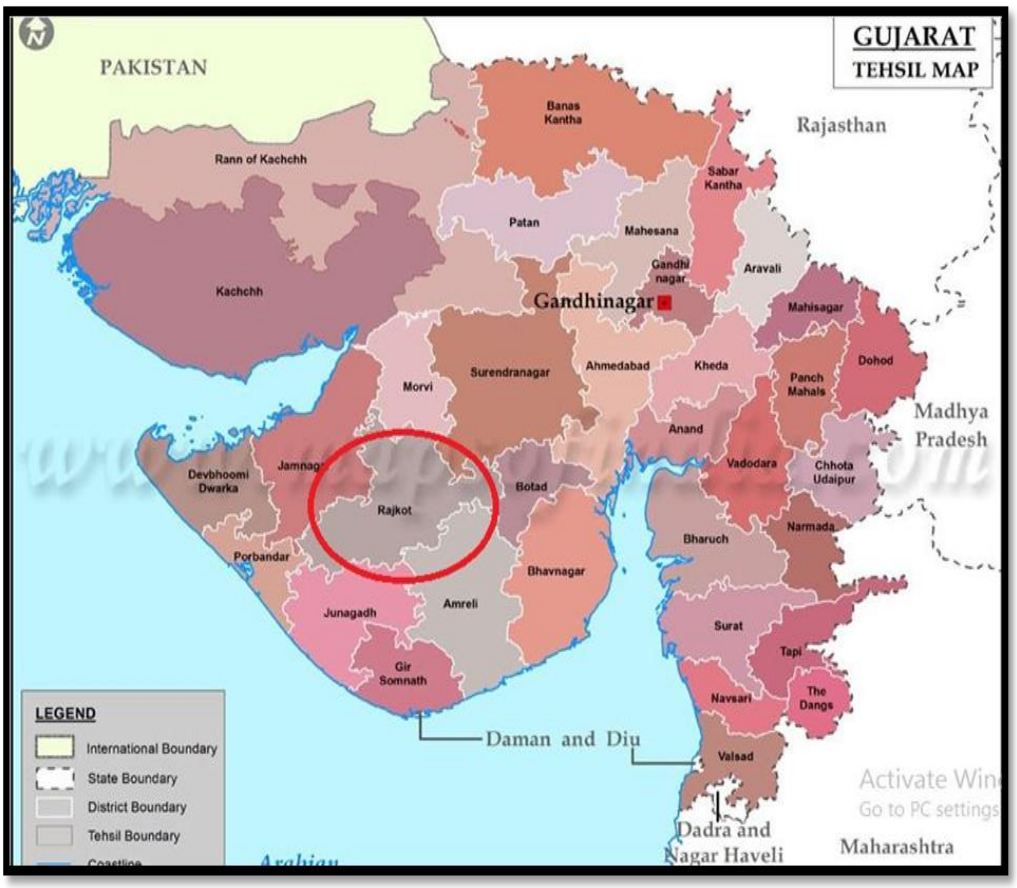


Fig.1 Location Map of Rajkot City

It flows south from its origin through Jasdan, then turns south-west and generally west until it empties into the Arabian Sea near Porbandar. Its length is 200 km. & 7094 sq.km. Catchment area. Gondali, Chhaparvadi, Phophal, Utavali, Moj, Venu are right bank tributaries & Vasavadi, Surva, Galoliya are left bank tributaries of Bhadar river. The city meets its Annual water demand from various surface reservoirs, i.e., from Aji-1 30 MLD, Nyari-1 32.4 MLD, Nyari-2 10.6 MLD, Bhadar-1 45 MLD and Lalpari-Randarda lake 2.9 MLD as on year 2015–16. Water is supplied to ward No.3, 7, 11,12,13,14, 15, 17, 18, 20,25,26,28 of Rajkot city from bhadar-1 reservoir. For this Research, Relevant data were collected water account sheet of Bhadar-1 Reservoir (2001-2016) and ward wise population data of Rajkot city as per census 2011 . To Predict population of 2028 year Arithmetic Increase method has been used. Monthly future water demand was calculated based on considering 135 lpcd. Bhadar-1 reservoir is located at latitude 22^{o}10'0"N and longitude 71^{o}20'0"E. It was mainly built to meet the water supply and irrigation needs of Rajkot city. The construction of the project was completed in 1964. Its live storage capacity is 221MCM and gross capacity 238MCM.

III. METHODOLOGY

To Assess of Future Water Demand as per Following Steps:

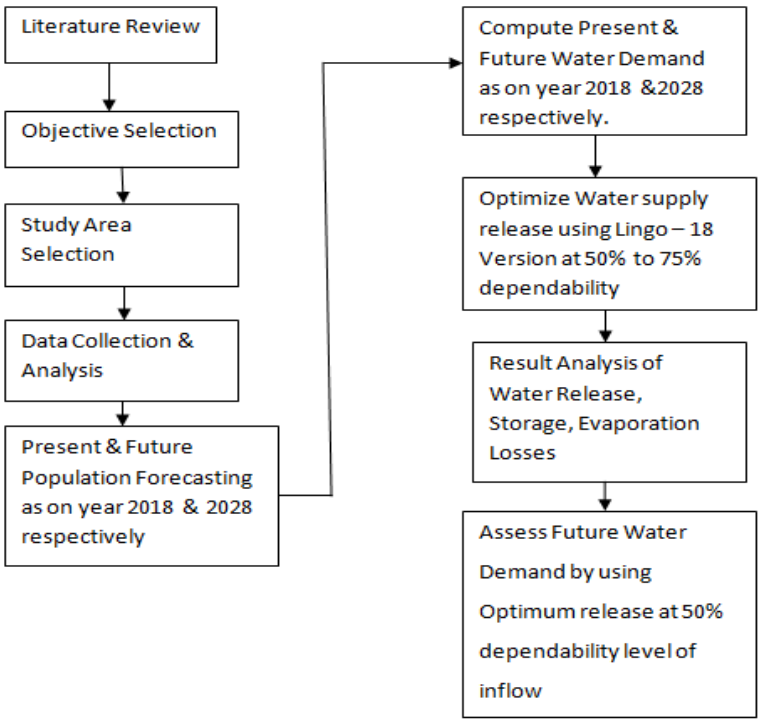


Fig. 2 Proposed Methodology

A. Model Formulation Methodology

The LP model formulation consists of objective function and sets of constraints to obtain maximization. In this section, various steps involved in the formulation of the model have been discussed in following section.

1) Objective Function: The objective function of the model is to maximize annual water supply release from Bhadar-1 reservoir over a year, which is mathematically represented as

$$\text{MaxR} = \sum \text{RWi} \quad (1)$$

Where, Max R = Maximize annual water supply release in MCM; I = index of the month, i = 1, 2, 3…….12; and RW = Release of water supply in MCM.

2) Capacity Constrained: At any time period, the capacity of the reservoir storage should not be more than the maximum storage capacity of the reservoir, and it also should not be less than the dead storage.

$$S_{min} <= S_t <= S_{max} \quad (2)$$

Where Smin = Dead storage capacity observed in MCM; Smax = Maximum storage capacity observed in MCM, and St =Storage at any time‘t’.

3) Evaporation Constraints: A linear relationship has to be established between the volume of evaporation loss in the reservoir and the average storage at time‘t’.

$$E_t = C_t + m_t * (S_t + S_{t+1}) * 0.5 \quad (3)$$

Where Et = Evaporation loss from the reservoir in MCM during the period‘t’; S_t = Initial storage at time‘t’;S_{t+1} = Final storage at time‘t’, and Ct & mt are regression coefficients at time period t.

Monthly linear regression models are developed using 15-year actual data of evaporation using Microsoft Excel; the summary of statistical parameters are presented in table I.

TABLE I

SUMMARY OF MONTHLY REGRESSION MODEL PARAMETER

MONTH	C	m	r
JAN	0.51	0.03	0.65
FEB	0.56	0.03	0.64
MARCH	0.72	0.05	0.65
APR	0.64	0.06	0.66
MAY	0.99	0.06	0.60
JUN	1.25	0.05	0.42
JUL	2.92	0.03	0.43
AUG	2.39	0.04	0.62
SEPT	1.67	0.04	0.66
OCT	1.11	0.03	0.60
NOV	0.80	0.03	0.61
DEC	0.59	0.03	0.63

4) Release Constraint: At any time period, the water supply should not be more than the maximum release limit, and also not be less than the minimum release.

$$R_{min} <= R_t <= R_{max} \quad (4)$$

Where Rmin = Minimum release observed at time's' in MCM; Rmax = Maximum release observed at time't' in MCM, and Rt = Release at any time't'.

5) Storage Continuity Constraints: The storage continuity constraint expresses the link of the month to month storage of reservoir and is mathematically written as:

$$S_{t+1} = S_t + I_t - RW_t\text{-}OVF_t\text{-}E_t \quad (5)$$

Where, It = Dependable inflow in MCM into the reservoir in month t, and OVF_t = Overflow from the reservoir in the month t in MCM.

6) Dependable Inflow: Monthly projected dependable inflow values were taken for the formulation of the model. Project dependable inflows were calculated using the Weibull method. Fifteen years of historical inflow data were used to project dependable inflows at 50, 55, 60, 65, 70 & 75% dependability levels.

7) Overflow constraint: The overflow constraint is provided in the linear programming model; otherwise the model will result in spill even when the reservoir storage is less than its capacity. The overflow constraint is mathematically express as:

$$OVFt = St+It-RWt-K \quad (6)$$

Where t = 1, 2, 3…..12; and K = Capacity of the reservoir in MCM.

B. Future Water Demand Calculation

As per Annual Water Demand calculate is 135 lpcd for Rajkot city. Total Monthly and Annually Water Requirement for 2028 is 2.58MCM and 30.96MCM respectively. Same as Total Monthly and Annually Water Requirement for current year 2018 is 2.42MCM and 29.04MCM respectively.

IV. RESULT AND DISCUSSION

The Linear Programming Model (LPM) has been formed to maximize annual water supply from Bhadar-1 Reservoir. Monthly linear programming models were formulated for six various dependable inflow levels, i.e., 50%, 55%, 60%, 65%, 70%, 75% and solved in LINGO 18. Resulted value from different models are analysed step by step in this section..

A. Analysis of Release Water Supply

The resulted maximum water releases from Linear Programming Model are shown in fig.3, From Fig. 3 it can be sheen that the release of water supply was increase from 50% to 75% dependability level of inflow. The peak water supply release during July-November is increase because of greater availability of water in reservoir and the least water supply is during February-June due to less availability of water in the reservoir. Besides, if the reservoir is full at a starting of monsoon season then there is no need to adjust the release of water for remaining months of the year. The maximum annual water supply release was resulted at 50% dependability level of inflow, therefore it is recommended to release water according LPM at 50% dependability level of inflow.

TABLE III
Resulted Water Supply Release from different LPM

Month	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Total**
Probability of exceedence													
50%	2.53	2.59	2.47	2.41	2.41	2.30	2.39	2.40	2.29	2.44	2.36	2.43	**29.02**
55%	2.53	2.59	2.47	2.41	2.41	2.30	2.39	2.40	2.29	2.44	2.36	2.43	**29.02**
60%	2.53	2.59	2.47	2.41	2.33	0.05	2.39	2.40	2.29	2.44	2.36	2.43	**26.69**
65%	0.47	0.16	0.13	0.30	0.25	0.05	2.39	2.40	2.29	2.44	2.36	2.43	**15.67**
70%	0.13	0.16	0.13	0.30	0.25	0.05	2.39	2.40	2.29	2.44	1.49	0.20	**12.23**
75%	0.13	0.16	0.13	0.30	0.25	0.05	2.39	2.40	2.29	2.44	1.27	0.20	**12.01**

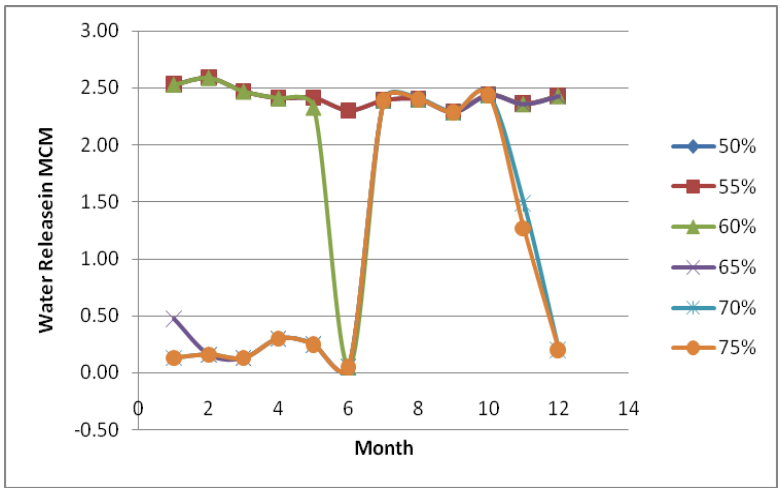


Fig. 3 Water Release from Model of Bhadar-1.

C. Evaporation Losses

For each dependable inflow level evaporation losses are shown in Fig.4. From Fig.4 it can be seen peak evaporation losses during September as the storage in reservoir is maximum during a month and least was observed during a summer season even increasing a depth of evaporation because of lower storage. The Evaporation Losses result is inversely proportional to dependability level of inflow.

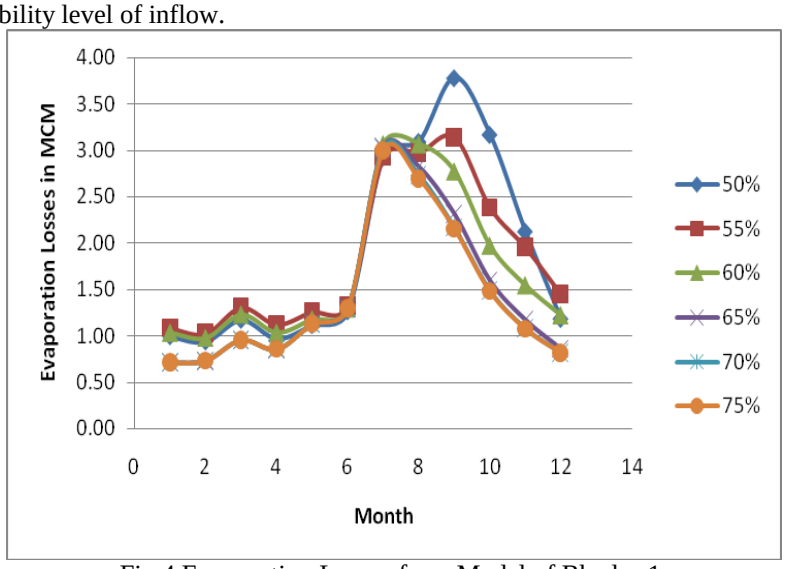


Fig.4 Evaporation Losses from Model of Bhadar-1.

D. Initial Storage

The initial storage from results is shown in Fig.5. From fig. 5, it can be show that a peak storage value was in October at all six different dependability inflow levels due to higher inflow value during that time. It was suggested to maintain initial storage as indicated in curve at various dependable inflows.

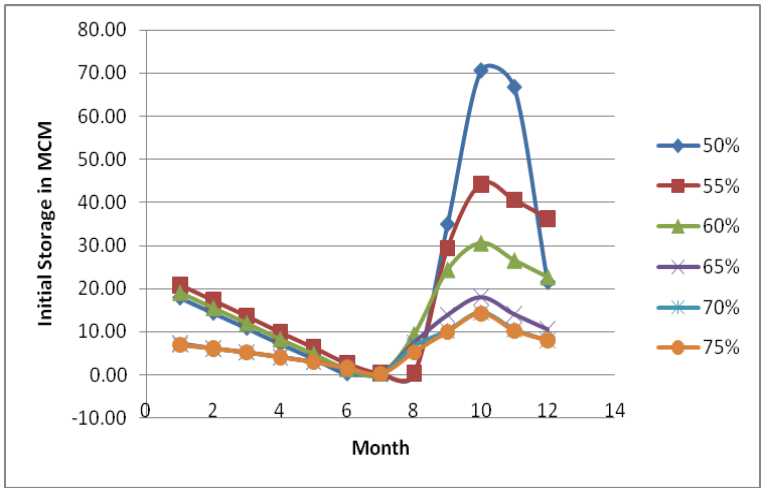


Fig. 5 Initial Storage from Model of Bhadar-1.

E. Comparison between Actual Water Supply Release and Suggested Water Supply Release

Fig. 6 is shown comparison between Actual Water Supply and Suggested Water Supply Release. It can be seen that Resulted water supply release from LPM at 50% dependability inflow is nearly same as the actual observed water release of four years stated as 2014-15, 2015-16, 2004-05 and 2010-11.

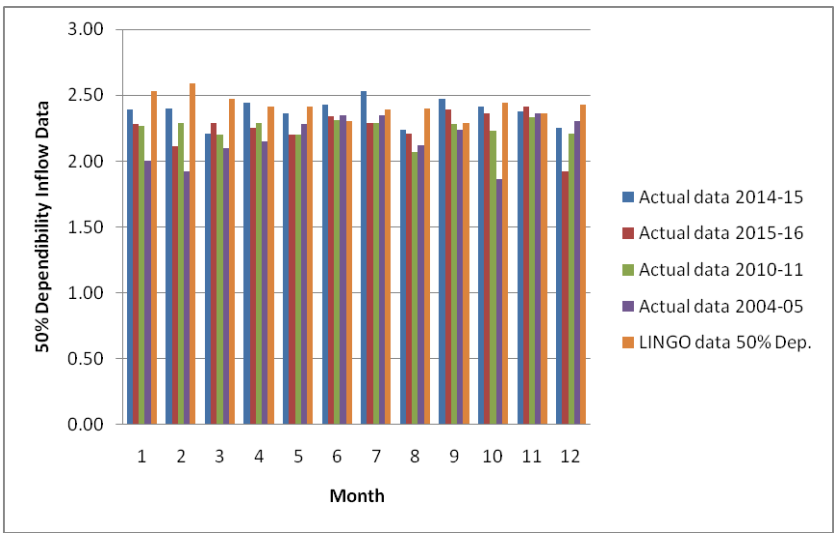


Fig. 6 Comparision between Actual & Model water supply release.

F. Assessment of future water demand

In Rajkot city , ward No. 3,7,11,12,13,14,15,17,18,20,25,26,28 are getting domestic water supply from Bhadar-1 reservoir. Population of current year 2018 and future year 2028 is forcasted based on population of census -201. From these forcasted population monthly water demand for current year 2018 and future year 2028 is calculated and presented in Table III. Deficit water demand is calculated based on resulted maximum water supply release from LPM at 50% depenndability level of inflow. From Table 3, it can be seen that deficit water demand as on 2028 year is computed 1.94 MCM and deficit water demand as on 2018 year is computed 0.02 MCM. It has been also found that deficit water demand is lowest calculoated at LPM at 50% dependability level.

TABLE IIIII

FUTURE WATER DEMAND ANALYSIS

LPM Dependability level of Inflow	Resulted Annual Water Supply Release(MCM)	Fixed Monthly Water Supply Demand of Year 2028 (MCM)	Deficit water Demand(2028)(MCM)	Monthly Frequency deficit as on year (2028) (%)	Fixed Monthly Water Supply Demand of Year 2018 (MCM)	Deficit water Demand(2018)(MCM)	Monthly Frequency deficit as on year (2018) (%)
50%	29.02	2.58	1.94	91.67	2.42	0.02	58.33
55%	29.02		1.94	91.67		0.02	58.33
60%	26.69		4.27	91.67		2.35	58.33
65%	15.67		15.29	100		13.37	83.33
70%	12.23		18.73	100		16.81	91.67
75%	12.01		18.95	100		17.03	91.67

G. CONCLUSIONS

The models results were analyzed for water supply release, losses due to evaporation and initial storage with respect to six different dependability inflow levels. The conclusions were derived from the study, the maximum water supply release was at 50% dependability inflow level, i.e., 29.02MCM and it gradually reduced owing to decreased optimal release of water at 75% dependability inflow level with LPM, i.e., 12.01MCM. From an optimum release analysis, a decreasing tendency in release was observed, with increasing probability levels of inflow. The resulted water supply releases from model at 50% dependability inflow were compared with actual observed water supply release of last 15 year. From comparative analysis, it is suggested to release water supply with LPM 50% dependability level of inflow to derive maximum annual release of water supply. Present and Future water assessment of water demand analysis were carried out, it has been seen that monthly frequency deficit of water supply calculated is 92% while annually deficit of

water supply is calculated 1.94 MCM as on year 2028. While 58% monthly frequency water supply deficit and 0.02 MCM annually water supply deficit is calculated as on year 2018.

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