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Methodology for planning water supply under drought conditions

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SUMMARY – The water supply scenarios under water supply shortage caused by droughts, so that the adverse effects are minimized is the subject of discussion in this paper. This paper outlines a methodology which enables the estimation of the probability of satisfaction of a scenario of water supply using the original storage and the probability of having the necessary inflow so that the total volume of the inflow plus the existing storage minus the evaporation and losses equal or exceed the water demand of the scenario in consideration. The probabilities of inflows being equal or exceeded are derived from the actual long-term inflows for certain period. Using the water supply scenarios for full or part satisfaction of the normal water demand and carrying out a mass water balance the required inflow is calculated. For each Scenario the required inflow is calculated and for this inflow the probability of occurrence of this inflow been equalled or exceeded is derived from the normal distribution function. For each scenario an array of probabilities as a function of starting time (starting early in the beginning of the Hydrological Year and ending next April), is derived, showing the probability of satisfaction of the demand. From these curves the water managers will be able to select the most probable scenario that may be adopted to minimize or eliminate the water cuts in the water supply scenarios. The derived water supply scenarios will span over a period of twelve months providing to the water consumers the reliability and security of water supply.

Key words: Drought, reliability of water supply, water supply scenarios, inflows, storage, water demand.

Introduction

Under drought conditions and within a Drought Management Plan one of the most important tools for drought mitigation is the Water Supply Scenario to be implemented during the duration of the drought. The Water Supply Scenario will most probably define the severity of water shortage and the severity of adverse impacts that the Drought Management Plan will have to deal with. The Water Supply Scenario will have to be chosen from a number of possible scenarios that will suit the conditions at the time of taking the decision such as the water availability, the probabilities of having additional quantities of available water, the water demand, the social and economic situation and generally the ability of certain groups to exercise pressure on the decision makers. The proposed methodology when applied diligently and by those who are aware of the water resources management of the project for which the analysis will be carried out, will provide to the water managers and the decision makers an array of probabilities of satisfaction of different water supply scenarios, at a forecast time to be chosen. Of course the longer the forecast time the greater the error will be in a similar manner that occurs in weather forecast models.

The methodology is applied on surface water supply projects whose inflow is the major source of water and inflow measurement records are available for long periods to allow proper statistical analysis. The methodology also requires good knowledge of the water demand on the project on a monthly basis both for domestic and irrigation. Water Demand Scenarios must be based on rational assumptions practicable and applicable. The methodology will provide the probabilities for satisfaction of Water Supply Scenarios extending over a period of twelve months, starting in May and ending within twelve months thereafter. The same method may be repeated for the next year taking as initial values of water in storage the results of the first year calculation and using similar Scenarios with updated water demand values.

The base case

The Methodology is applied on a three sources project (groundwater and recycled water which are considered highly reliable supplies and surface water which is considered highly unreliable), which supplies water for irrigation and domestic needs. The methodology shall derive the probability of satisfying the water demand by calculating the probability of the inflow been equal or more than the minimum required to satisfy the demand of a number of scenarios under different initial conditions of water in storage. The question usually asked by a water manager is the following: Given the water in storage at certain time and the water demand for a number of Scenarios, with the known probabilities of water inflow, been equal or exceeded (see Table 2), calculate the probabilities of satisfaction of each water demand Scenario. From the results the water manager will be able to choose the Scenario with the least adverse effects.

The methodology for calculating the water supply under drought conditions

For carrying out the analysis the following parameters and conditions should be defined:

(i) *Start of Planning period:* First of October of the starting year (zero year).

(ii) *End of Planning period:* End of March of the year two. The planning period lasts between October of year zero and the end of April of year two, i.e. 19 months.

(iii) *The Forecast dates array "Ti":* This array defines the starting time of each analysis. The first analysis may be carried out on the first of October, the second on the first of November and monthly or in bimonthly periods till the beginning of next March.

(iv) *The Inflow Periods Arrays "IPi":* These arrays defines the wet months periods for which the inflow probability functions of equal or exceedance values shall be derived. Each inflow periods start on the corresponding forecast date and extends till the end of next April. The Inflow periods may be the periods of Oct-Apr, Nov-Apr, Dec-Apr, Jan-Apr, Feb-Apr and Mar-Apr.

(v) *The Water Demand Periods arrays "WDPi":* These periods start on the forecast time and extends till the end of the planning period. For these periods the water managers will calculate the water demand scenarios.

For the execution of the process the following data must be available:

(i) The average monthly inflow distribution to the dam in MCM per month for the months October till April. From each inflow period calculate the average inflow and the standard deviation .

(ii) The monthly water demand of the project in MCM for the irrigation and the domestic consumers. The data shall be arranged in an array starting in the October of year zero and ending on March of year two.

To answer the question set in section 2 the present methodology has been developed. The process will be normally initiated in October to establish if the water resources available at the time and the expected inflows during the rest of the wet months (wet months October to April) will give a high probability for satisfaction of the water demand till the end of the planning period. If the water in storage at the beginning of the month is high obviously the results will be promising. If the amount in storage is not satisfactory then the process will be applied repeatedly during the next months using the next month's actual storage till the beginning of March. The process will give an array of probabilities to satisfy the water demand scenarios for each forecasting date. For the October forecasting date the water manager will be given the probabilities for each of the five scenarios been satisfied, taking into account the October actual amounts in storage; for the December forecasting date the results will take into account the December actual volumes in storage and so on. Since neither the October (too early) nor April (too late) are good periods for taking decision on the best water scenario the methodology will be repeated till February and at this time the water managers using the results, based on the actual conditions of February will propose the most promising Scenario which will satisfy at best the basic needs and will not cause irreparable damages to the economy.

The methodology is completed in five steps as follow.

Step 1: Calculation of probabilities of equal or exceedance of an inflow. Using the inflow data for each inflow period (Oct-Apr, Nov-Apr, Dec-Apr etc), calculate its average value and its standard deviation. Assuming the occurrence of inflow is normally distributed calculate the probability of the inflow been "equal or exceeded" and derive the mathematical functions by correlation. For this presentation the inflow data for the years 1987 to 2005 was used and Table 1 shows the inflow, the normal cumulative distribution and the probability of the inflow been equal or exceeded, for three inflow periods (Nov-Apr, Dec-Apr, Mar-Apr). For each inflow period the function of probability of inflow been equaled or exceeded is derived from the normal distribution function by using the correlation method.

Table 1. Calculation of normal cumulative distribution and the probability of equal or exceedance of an inflow

No.	Inflow Period Nov-Apr			Inflow Period Dec-Apr			Inflow Period Mar-Apr		
	Inflow MCM	Normal Cumulat. Distrib.	Probability of equal or exceeded	Inflow MCM	Normal Cumulat. Distrib.	Probability of equal or exceeded	Inflow MCM	Normal Cumulat. Distrib.	Probability of equal or exceeded
1	0.000		100.00%	0.000	0.00%	100.00%	0.000	0.00%	100.00%
2	0.548	14.86%	85.14%	0.548	14.66%	85.34%	0.224	26.73%	73.27%
3	2.332	18.23%	81.77%	2.134	17.68%	82.32%	0.554	28.19%	71.81%
4	3.457	20.57%	79.43%	3.208	19.93%	80.07%	1.061	30.49%	69.51%
5	5.158	24.45%	75.55%	5.158	24.43%	75.57%	1.091	30.63%	69.37%
6	5.300	24.79%	75.21%	5.300	24.78%	75.22%	1.257	31.40%	68.60%
7	5.636	25.60%	74.40%	5.425	25.09%	74.91%	1.567	32.87%	67.13%
8	6.070	26.68%	73.32%	6.070	26.72%	73.28%	1.979	34.86%	65.14%
9	6.600	28.02%	71.98%	6.554	27.97%	72.03%	2.095	35.43%	64.57%
10	6.613	28.05%	71.95%	6.568	28.01%	71.99%	2.135	35.63%	64.37%
11	7.079	29.25%	70.75%	6.745	28.47%	71.53%	2.269	36.29%	63.71%
12	11.707	42.30%	57.70%	9.630	36.53%	63.47%	2.628	38.08%	61.92%
13	15.586	54.01%	45.99%	15.426	54.26%	45.74%	3.076	40.36%	59.64%
14	18.671	63.13%	36.87%	18.423	63.31%	36.69%	3.790	44.05%	55.95%
15	20.533	68.32%	31.68%	20.362	68.83%	31.17%	3.888	44.56%	55.44%
16	20.821	69.10%	30.90%	20.821	70.09%	29.91%	4.270	46.56%	53.44%
17	23.025	74.73%	25.27%	23.025	75.75%	24.25%	7.742	64.51%	35.49%
18	27.690	84.63%	15.37%	27.523	85.28%	14.72%	8.705	69.13%	30.87%
19	30.222	88.75%	11.25%	30.222	89.59%	10.41%	10.322	76.21%	23.79%
20	53.918	99.87%	0.13%	53.858	99.90%	0.10%	34.906	100.00%	0.00%
Average	14.261	0.5		14.053			4.924		
St. Dev	13.155			12.846			7.570		

Step 2: Preparation of the water demand scenarios using the actual water demand. Select the water demand scenarios and for each calculate the annual water demand using the monthly water demand. Five water demand scenarios were selected as follow; (i) Pre-Alarm Scenario (100% satisfaction for DWS and for Irrigation); (ii) Alarm 1 Scenario (100% satisfaction for DWS and 90% satisfaction for Irrigation); (iii) Alarm 2 Scenario (100% satisfaction for DWS and 80% satisfaction for Irrigation); (iv) Emergency 1 Scenario (90% satisfaction for DWS and 70% satisfaction for Irrigation); and (v) Emergency 2 Scenario (80% satisfaction for DWS and 60% satisfaction for Irrigation). Table 2 shows the Scenarios, the irrigation and domestic demand, and the total demand. On the same Table the available water resources are also shown at each of the forecast date.

Step 3: Calculate the Required river inflow to the dam to satisfy the water demand scenarios, (see Table 3). For each Water Demand period and using the Scenarios prepared in step 2 calculate for each Scenario and Forecast date the water demand from dam as seen on columns 5-8 of Table 3. Then with the help of a simple simulation model and using the actual or assumed amounts of water in storage shown on columns 9-12, calculate the required inflow to satisfy the demand shown on columns 13-16.

Table 2. Water Demand Scenarios and water availability at the forecast date

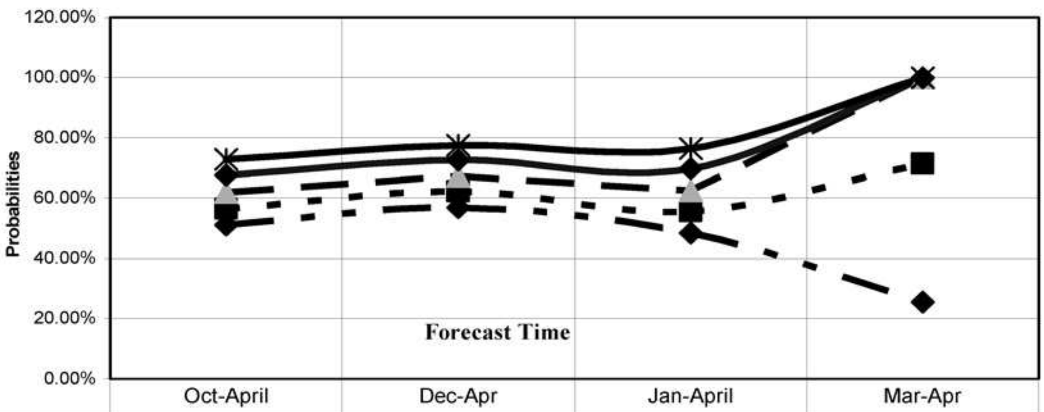
No	Description	Annual Demand in MCM			% Satisfaction		
1	Water Demand Scenarios	Irrigation	Domestic	Total	Irrigation	Domestic	Total
1.1	Normal Demand	16.000	4.000	20.000			
1.2	Scenario 1: Pre-Alarm	16.000	4.000	20.000	100%	100%	100%
1.3	Scenario 2: Alarm Scenario 1	14.400	4.000	18.400	90%	100%	92%
1.4	Scenario 3: Alarm Scenario 2	12.800	4.000	16.800	80%	100%	84%
1.5	Scenario 4: Emergency Scenario 1	11.200	3.600	14.800	70%	90%	74%
1.6	Scenario 5: Emergency Scenario 2	10.400	3.200	13.600	65%	80%	68%
2	Water Resources	Quantity	Remarks				
2.1	Groundwater	2.000	Probability of availability of this quantity is 100%				
2.2	Recycled domestic effluents	1.800	Probability of availability of this quantity is 100%				
2.3	Surface water available on forecast date						
a	1st October	6.000	This is the actual quantity on date shown				
b	1st December	7.000	This is the actual quantity on date shown				
c	1st Jan	9.000	This is the actual quantity on date shown				
d	1st Mar	13.000	This is the actual quantity on date shown				

Table 3. Water Demand Scenarios and water availability at the forecast date

Scenario No.	Total demand	GW supply	Yearly demand for dam	Water demand from dam starting at forecast date				Water Available at forecast date				Inflow required till end of inflow period				Probabilities %			
				Oct-April	Dec-Apr	Jan-April	Mar-Apr	Oct-April	Dec-Apr	Jan-April	Mar-Apr	Oct-April	Dec-Apr	Jan-April	Mar-Apr	Oct-April	Dec-Apr	Jan-April	Mar-Apr
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Full Demand	17.90	3.80	14.10	19.9	15.5	15.5	15.5												
1 Demand	17.90	3.80	14.10	19.9	18.8	17.7	15.5	6.00	7.00	9.00	13.0	13.9	11.8	8.71	2.51	51.1	56.9	48.4	25.5
2 Demand	16.30	3.80	12.50	18.1	17.0	15.9	13.7	6.00	7.00	9.00	13.0	12.1	10.0	6.95	0.75	56.5	62.2	55.5	71.4
3 Demand	14.70	3.80	10.90	16.4	15.3	14.2	12.0	6.00	7.00	9.00	13.0	10.4	8.29	5.19	0.00	61.9	67.3	62.5	100.0
4 Demand	12.91	3.80	9.11	14.4	13.3	12.2	10.0	6.00	7.00	9.00	13.0	8.42	6.32	3.22	0.00	67.6	72.6	69.9	100.0
5 Demand	11.12	3.80	7.32	12.52	11.4	10.252	8.052	6.00	7.00	9.00	13.00	6.45	4.35	1.25	0.00	72.9	77.5	76.5	100.
Demand for winter months MCM				4.0	3.0	2.0	0.0	Average inflow			12.8	14.26	14.05	8.31	1.563				
Coefficient for evaporation losses				1.1	1.1	1.1	1.1	Standard dev					12.85	9.78	1.44				

Step 4: Calculation of the Probabilities to satisfy each of the five Scenarios (see Table 3, columns 17-20). Using the required inflow quantities to satisfy the calculated water demand for each scenario and each Forecast Date the probability of the inflow been equal or more inflow to the dam is calculated using the probability function calculated in Step 1. The probability of satisfying the water demand scenario for each forecast date is shown on columns 17-20 of Table 3. The results of the probability to satisfy each of the five scenarios for each period are shown on Fig. 1.

Step 5: Selection of the most suitable Scenario. Figure 1 shows for each scenario of water demand and for each forecast date the probability of satisfaction, The probabilities of satisfaction of each scenario for each Forecasting Date are calculated at the time shown so any graph can contain one, two, three or four or more forecasting dates depending on the prevailing conditions at the forecast date. For example if the calculated probabilities of satisfying full demand by December are favorable then it will not be necessary to repeat the process and take a decision at any time thereafter. However if the calculated probabilities are low in December and January then the process must be repeated in February and possibly in March to get more reliable results. Depending on the precipitation pattern and the streamflow pattern, as well the water levels in storage, which must be known to the water manager the decision on which scenario to propose for adoption can be taken at any time during the period January-March. From Fig. 1 it can be stated that by March or two months before the implementation of the water supply scenario the probabilities for satisfaction for Scenarios 3, 4 and 5 are 100%, for Scenario 2 it is 71.38% and for Scenario 1 are 25.54%. Under the above conditions it would be advisable to start implementation of Scenario 3 and update by the end of April if necessary.



	Oct-April	Dec-Apr	Jan-April	Mar-Apr
Scen 1	51.09%	56.93%	48.36%	25.54%
Scen 2	56.55%	62.23%	55.53%	71.38%
Scen 3	61.88%	67.31%	62.51%	100.00%
Scen 4	67.59%	72.63%	69.86%	100.00%
Scen 5	72.91%	77.49%	76.47%	100.00%

Conclusion

The present paper provides a methodology to calculate the probabilities for satisfying different water demand scenarios, enabling the water managers and the water policy makers to choose the most promising scenario with the least water cuts. It is a probabilistic model and can be extended to give probabilities for next year thus giving to the water managers a long term planning.