European Water 41: 35-39, 2013.

A dimensionless solution for the storage-yield process of a reservoir comprising inter-basin transfer

S. Giakoumakis
Laboratory of Reclamation Works and Water Resources Management. School of Rural and Surveying Engineering
National Technical University of Athens
9, Iroon Polytechniou Str., 157 80, Athens–Greece
e-mail: sgiakou@central.ntua.gr

Abstract: For an effective water resources management in semiarid regions, the construction of surface storage systems (dam or off-stream storage reservoir) is often the unique option. The water yield of such systems is influenced by many factors (i.e. annual demand and its time distribution, inflows to the reservoir, evaporation losses etc) and so, some risk must be tolerated if the expected yield is to be sufficient to make demand scenarios viable. In the present work, reservoir simulation was performed for determining the storage-yield process of a reservoir in north-eastem Crete. Different scenarios of inflows, comprising interbasin transfer of diverted runoff from an adjacent watershed, were considered. A dimensionless solution is presented in the form of a storage-yield diagram.

Key words: reservoir simulation, storage-yield process, interbasin transfer, dimensionless solution

1. INTRODUCTION

In semiarid regions there is a considerable variation in precipitation within the year and from year to year. Thus, the runoff could be extremely variable and in a drought year can be negligible (Mitchell, 1982). The construction of surface storage reservoirs allows to collect and store runoff water during the "wet period" of the year in order to achieve an effective management for covering different needs (urban use, irrigation etc) during the "dry period".

Under such circumstances, estimating the safe yield of surface reservoirs as a function of the available volume of storage is a laborious task requiring long time series of reliable measured data, i.e. precipitation, evaporation, streamflow etc. (Fletcher and Ponnambalam, 1996; Giakoumakis and Kanaris, 2002). A general review of different techniques for determining the storage-yield relationship of a surface storage reservoir, i.e. for ascertaining the risk of failure to supply full demand, was given by McMahon et al. (2007). A recent work is based on a complex stochastic approach for determining the storage-yield relationship (Silva and Portela, 2012). On the contrary, the solution presented in this paper, is rather simple and easily applied.

2. DESCRIPTION OF THE RIVER BASINS

The region of application is the Aposselemis river basin having a total area of 122 km^2, average altitude of 464 m and outlet at the Cretan Sea (Tsakiris et al., 2006). In this basin there is a hydrometric station near Potamies village. The area of the river basin upstream the hydrometric station is of 68 km^2 and the measured mean annual runoff (MAR) for a thirty year period (1967-1997) was equal to $11 \cdot 10^6$ m^3. The proposed dam site is lying approximately one km upstream the hydrometric station (corresponding area upstream: 60 km^2). Measured runoff values at the station were adjusted to the dam site using the areas ratio coefficient (i.e. 60/68=0.88). For instance, the MAR at the dam site was so found equal to $9.7 \cdot 10^6$ m^3. The whole basin area is mainly consisting of limestones and the runoff coefficient is relatively low (i.e. 20%) Thus, in order to increase inflows to the reservoir of Aposselemis dam, interbasin transfer of diverted runoff was planned through a rather complicated diversion system from the adjacent Tzermiado river basin (total area of 128 km^2). This is a closed area, a rather complicated karstic system draining at Katavothres sinkhole in its north west side, through which important groundwater recharge is effected (Fig. 1).

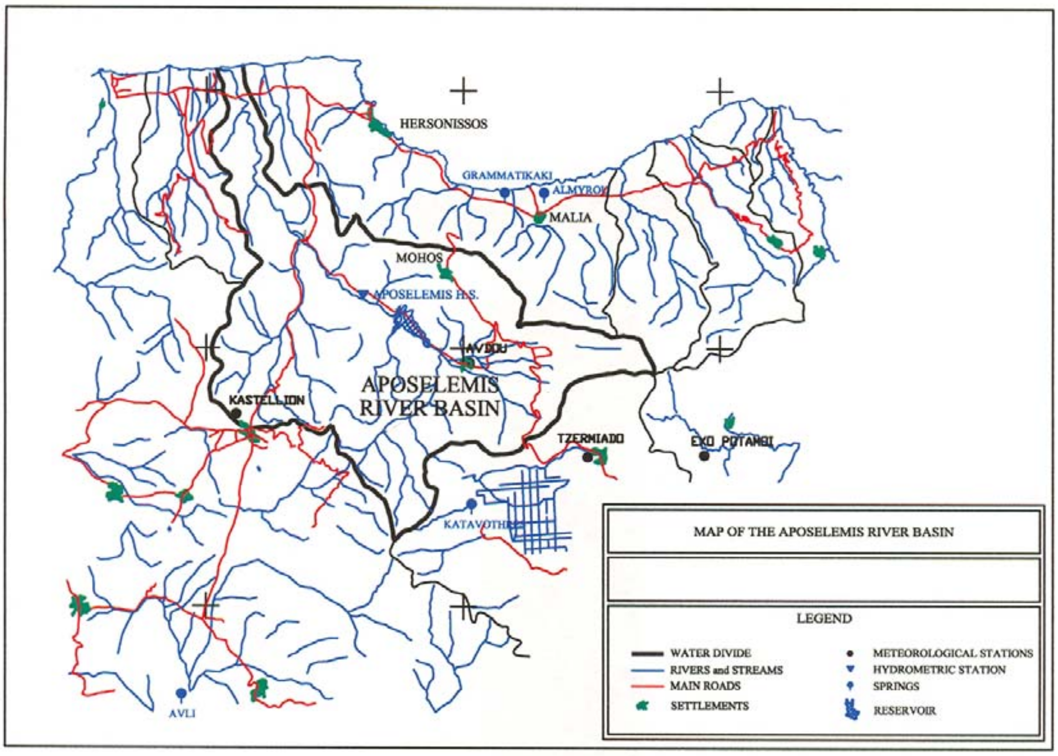

Figure 1. Aposselemis river basin and Tzermiado river basin's outlet (Katavothres).

The MAR of the period 1967-1997 from measurements at the above mentioned site was calculated as equal as 16.7 · 10^6 m^3. Moreover, the mean values of the measured monthly runoff (MMR) for the same time period, in both sites (i.e. Potamies and Katavothres hydrometric stations, respectively), are given in Table 1.

Table 1. Mean Monthly Runoff (MMR) and Standard Deviation (SD) in 10^6 m^3 at the sites of hydrometric stations.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Mar	Jun	Jul	Aug	Sep
MMR Potamies	0.0	0.6	1.3	3.5	2.4	2.3	0.5	0.3	0.1	0.0	0.0	0.0
SD Potamies	0.0	2.7	2.3	5.7	2.4	3.0	0.6	1.0	0.1	0.0	0.0	0.0
MMR Katavothres	0.0	0.9	2.4	4.6	4.1	3.4	0.7	0.4	0.0	0.0	0.0	0.0
SD Katavothres	0.3	2.4	2.6	4.6	2.7	2.5	0.7	1.1	0.1	0.0	0.0	0.0

3. SIMULATION RESULTS

The proposed active storage capacity S of the reservoir of Aposselemis dam was chosen as equal as 27.09 · 10^6 m^3 (spillway level). The dead storage capacity was equal to 1.05 · 10^6 m^3, (Tsakiris, 2002). With these design parameters the reservoir of the dam is expected to cover an important part of the water shortage of the year-target (2035) for the two over crowded cities of north-eastern Crete (Herakleion and Agios Nikolaos). This was estimated as equal as 18 · 10^6 m^3/year. Nevertheless, the percentage of the potential diversion of runoff from the adjacent Tzermiado river basin can not reach 100% in any case, for reasons of environmental protection (i.e. groundwater recharge). Percolation through Katavothres into the groundwater system ensures its sustainability, feeding many springs in the area. For this reason, in the present work for the two out of three scenarios of inflows examined, we assumed that 50% and 80% at most of the runoff reaching Katavothres might be diverted. We then studied the storage process of the reservoir of Aposselemis dam for examining two things: (i) if taking into account different percentages of diverted inflows, keeping however the dimensions of the dam as initially proposed, its capacity is enough or not to cover the water shortage for the year-target (ii) if a smaller reservoir is enough or not to cover the water shortage and decreasing so, the high cost of construction of the proposed dam. The range of capacities was chosen as follows: The minimum active storage capacity was set as equal as $4.09 \cdot 10^6$ m^3. The criterion for choosing this as minimum value was that, the flooding of a village upstream the dam site is so avoided. On the contrary, as maximum active storage capacity was chosen the proposed one (i.e. $27.09 \cdot 10^6$ m^3). According to the topography of the dam site, the value of $27.09 \cdot 10^6$ m^3 was considered as the maximum possible active storage capacity which is feasible to be obtained. Other storage capacity values in the interval between $4.09 \cdot 10^6$ m^3 and $27.09 \cdot 10^6$ m^3, used for performing simulations were: (25.09, 23.09, 21.09, 19.09 and 14.09) $\cdot 10^6$ m^3. It should be noticed that the initial storage condition was empty reservoir.

Leakage losses from the reservoir bottom were considered negligible due to the impermeable local soils, whereas evaporation was calculated on a monthly basis via Penman method using relevant meteorological data. Its mean annual value was found to be equal to 1200 mm. Monthly precipitation records were taken from the station Avdou inside the river basin of Aposselemis, upstream the dam site. According to these records, the mean annual precipitation was equal to 800 mm. For all simulations, both the monthly precipitation and the monthly evaporation were assumed constant from year to year, equal to their mean values.

In this study, because that the drawoff from the reservoir is uniquely for urban use, a 1 % risk level was tolerated (i.e. 1 failure in 100 years). Thus, 100-year synthetic streamflows were produced by the well-known Thomas and Fiering model, based on the historic data of each stream gauge (Thomas and Fiering, 1962). From a number of trial replicates, it was seen that: (i) there was not any significant difference in the basic statistics of synthetic inflows, (ii) these statistics were almost identical to those of the corresponding historic records (see Table 1).

The following water balance equation was used:

$$V_i=V_{i-1} +Q_i-E_i-A_i-Y_i \qquad (1)$$

with:

$A_i = \min \{B_i ,V_{i-1} + Q_i - E_i\}$

$Y_i =\max\{0, V_{i-1} + Q_i - E_i - A_i - S\}$

where:

V_i , V_{i-1} : active volume of water in storage for the months i and i-1 respectively, (10^6 m^3)

Q_i : volume of inflows for the month i (10^6 m^3)

E_i : volume of net evaporation loss for the month i (10^6 m^3)

A_i : volume of actual drawoff for the month i (10^6 m^3)

Y_i : volume of spill for the month i (10^6 m^3)

B_i: volume of demand for the month i, (10^6 m^3), (computed from eq. 2)

S: active storage capacity of the reservoir (10^6 m^3)

For each scenario of inflows adopted, reservoir water balance simulations were performed on a monthly basis and in each case, the monthly percentages β_i of distribution of the annual demand B (10^6 m^3) according to the local water needs, were assumed constant from year to year (eq. 2, Table 2):

$$B_i = \beta_i \cdot (B/100) \qquad (2)$$

Table 2. Monthly percentages (%) of distribution of annual demand.

Oct	Nov	Dec	Jan	Feb	Mar	Apr	Mar	Jun	Jul	Aug	Sep
8.4	4.9	5.0	5.0	4.5	6.1	8.2	11.7	11.4	11.7	11.7	11.4

The annual demand volume B in eq. 2 was variated through a trial and error procedure during successive simulations, till only one failure in 100 years was achieved.

In Figure 2 simulation results are presented in the form of a dimensionless diagram. In the horizontal axis of this figure, values of the ratio: storage capacity S to the MAR of the historic timeseries is illustrated. In the vertical axis, values of the ratio: safe annual yield D to the MAR are shown. Each curve in this figure corresponds to a different scenario of inflows, i.e. Scenario 1: no diversion at all, Scenario 2: with 50% diversion, Scenario 3: with 80% diversion.

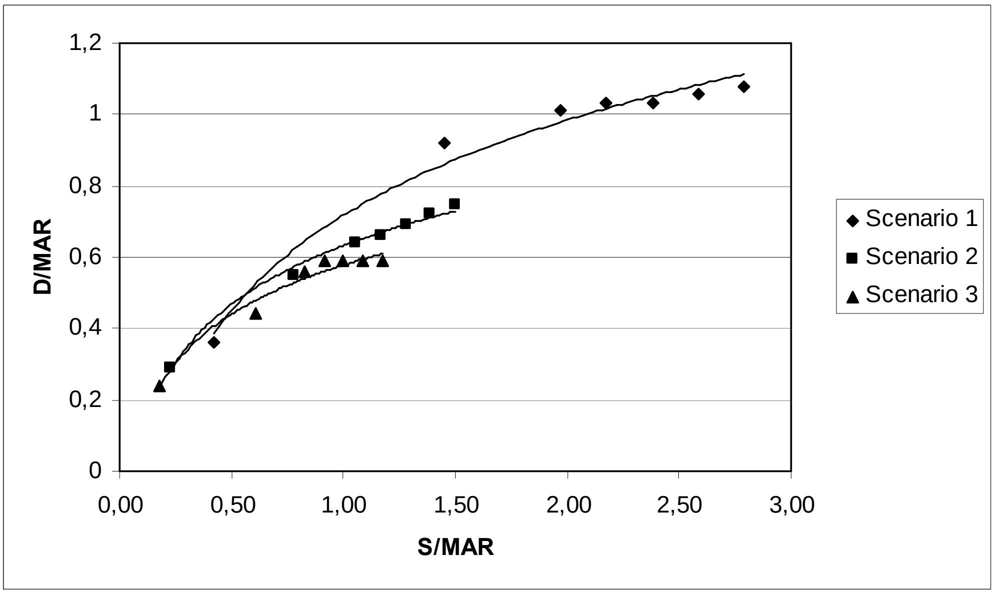

Figure 2. Aposselemis reservoir: Storage-Yield diagram.

From Figure 2, a number of remarks can be made:

- There are three distinct curves corresponding to the different scenarios of inflows considered. For each one of them, as the reservoir capacity increases, the corresponding increase of the reservoir yield is much less important.
- None of the storage capacities is quite enough to cover the total water shortage ($18 \cdot 10^6$ m^3) for the year-target 2035. For instance, for the maximum storage capacity of $27.09 \cdot 10^6$ m^3, even for the second and third scenarios (with diverted inflows of either 50% or 80%, respectively), the safe annual yield never exceeded $13.5 \cdot 10^6$ m^3/year (i.e. D/MAR= 0.74 and 0.58, corresponding to S/MAR=1.5 and 1.175 for the second and third scenarios of inflows respectively).
- For the no diversion case (Scenario 1), the maximum safe annual yield which can be achieved approaches $11.0 \cdot 10^6$ m^3 per year and this, for the maximum storage capacity of $27.09 \cdot 10^6$ m^3, i.e. D/MAR=1.13 corresponding to S/MAR= 2.79.

4. CONCLUDING REMARKS

In this study a series of simulations of the storage process of Aposselemis reservoir in north-eastern Crete were performed on a monthly basis. 100-year synthetic runoff records were produced based on the available 30-year historic runoff, as inflows to the reservoir according to three different scenarios, two among them comprising interbasin transfer. Results are presented in the form of a dimensionless diagram. This information could be useful for estimating the storage-yield process at ungauged watersheds in the area.

REFERENCES

Giakoumakis S. and Kanaris G., 2002. Estimating the Water Yie!d of Surface Storage Systems: Application to Aposselemis River Basin, Proceedings 5th International Conference of E.W.R.A.: "Water Resources Management in the Era of Transition", Athens, Greece.

Fletcher S.G., Ponnambalam K., 1996. Estimation of reservoir yield and storage distribution using moments analysis, Journal of Hydrology, Vol. 182, pp. 259-275.

Mitchell T.B., 1982. Potential water yield in semiarid regions, "Optimal Allocation of Water Resources", Proceedings of the Exeter Symposium, IAHS Publ. no. 135.

Mc Mahon T.A., Pegram G., Vogel R.M., Peel M.C., 2007. Revisiting reservoir storage-yield relationships using a global streamflow database, Advances in Water Resources, 30(8), 1858-1872.

Silva A.T. and Portela M.M., 2012. Stochastic Assessment of Reservoir Storage-Yield Relationships in Portugal: A Case Study. Journal of Hydrologic Engineering. doi:http://dx.doi.org/10.1061/(ASCE)HE.1943-5584.0000650

Thomas H.A. and Fiering M.B., 1962. Mathematical synthesis of streamflow sequences for the analysis of river basins by simulation. Chapter 12 in Design of Water Resources Systems, ed. Maass et al., Harvard Univ. Press, 620 pp.

Tsakiris G., 2002 (Scientific Coordinator). Research Project: "Integrated Assessment of Water Resources Development Scenarios of Aposselemis Watershed, Crete", NTUA, Athens.

Tsakiris G., D. Tigkas and M. Spiliotis, 2006. Assessment of interconnection between two adjacent watersheds using deterministic and fuzzy approaches, European Water 15/16: 15-22.