CVEN 4838/5838 Dam Engineering Fall 2008
Homework #1 Basin Yield
DUE: Thurs Sept 4

Problem 1.
Using the data from Example 3.5 in McMahon and Adeloye, compute the storage yield function (plot of storage vs firm yield) with 4 points. What is the maximum yield? (Note: this goes really fast and easy in Excel.)

Problem 2.
Next assume that each year has two distinct hydrologic seasons, one wet and the other dry, and that 80% of the annual inflow occurs in season $t = 1$ and 80% of the yield is desired in season $t = 2$. Pick one capacity/yield point calculated in Problem 1 and determine the reliability using each half year as a single time period. (Recall that in Problem 1 the firm yield represents a reliability of 100%).

Problem 3.
Determine the increase in storage capacity required for the same annual (firm) yield resulting from within-year redistribution requirements.

Problem 4.
The following yield curves were developed for the Borjad reservoir in Hungary (Nagy et al. 2002). Assume that the supply reliability (also called vulnerability) is the percentage of the total demand that is met in the worst case. What capacity and demand would provide 80% reliability with 95% supply reliability?

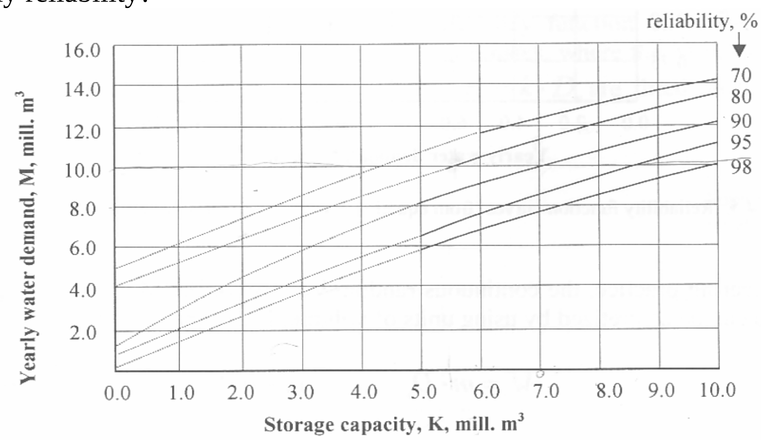

Figure 4.4. The efficiency function, K=f (M,P_t), for the Borjad reservoir in Hungary

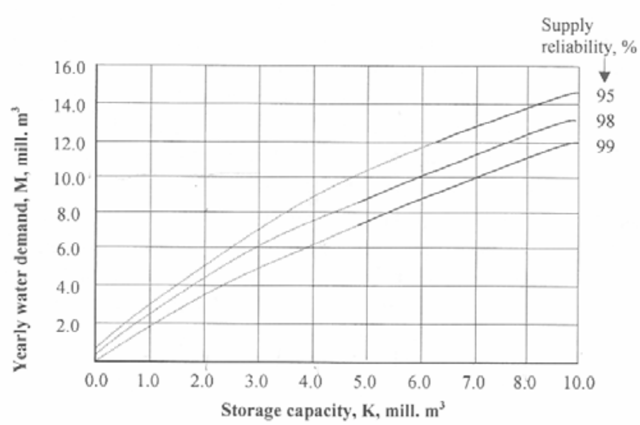

Figure 4.6. Efficiency function, [K=f (M,P_v)], characterized by the supply reliability, P_v for the Borjad reservoir in Hungary

For Information and Correspondence:

Water Resources Publications, LLC
P. O. Box 260026 • Highlands Ranch • Colorado 80163-0026 • USA

WATER RESOURCES YIELD

by

Thomas A. McMahon[1]

and

Adebayo J. Adeloye[2]

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[1] Centre for Environmental Applied Hydrology and the Cooperative Research Centre for Catchment Hydrology, Department of Civil & Environmental Engineering, The University of Melbourne, Victoria, 3010, Australia.
[2] School of the Built Environment, Heriot-Watt University, Edinburgh, EH14 4AS, United Kingdom.

The Gringorten equation is

$$T = \frac{N + 0.12}{r - 0.44} \tag{3.49}$$

where T is the average recurrence interval for a given deficit, N is the number of years in the record and r is the rank of the deficit.

The reduced Gumbel variate (y) is related to the average recurrence interval (years) as follows:

$$y = -\log_e(-\log_e(1 - \frac{1}{T})) \tag{3.50}$$

Values of y are calculated in Table 3.7 and are plotted against the deficit values in Figure 3.5 noting, however, that Pegram (pers. comm.) recommends excluding all deficits with recurrence intervals less than 10 years.

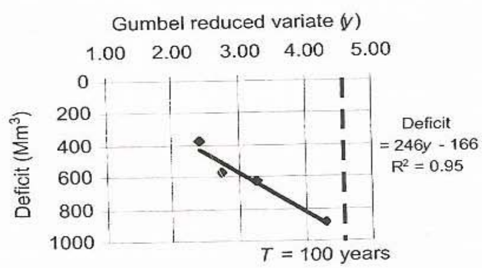

Figure 3.5: Relationship between reservoir deficit and Gumbel reduced variate for the Richmond River at Casino for a constant draft of 70% using annual data

To calculate the average recurrence interval of the maximum deficit we could use the equation associated with Figure 3.5, but this is not strictly correct given that the equation is based on least squares with the deficit as the dependent variable. The equivalent equation is

$$y = 0.0039\ Deficit + 0.79 \tag{3.51}$$

For a deficit of 881 Mm^3, from Equation (3.51) $y = 4.23$ and from Equation (3.50), $T = 69$ years.

End Example 3.4

3.5.4 Reservoir planning by simulation – the Sequent Peak Algorithm

Simulation models are based on the mass balance equation and they perform computations period by period under a given set of conditions. Mass balance formulation for the purpose of simulation can be based either on storage or deficits; the former is termed simulation (see Section 3.5.8) and the latter is nothing more than the Sequent Peak Algorithm (SPA). While the former is much more versatile and can readily accommodate storage dependent phenomena such as water surface flux and seepage and can design for any reliability, it requires an operating policy for its implementation even for the simple case of single reservoir systems. Except where a heuristic operating policy such as the standard operating policy (see Section 2.3.9) is used, this is generally unavailable during planning.

Furthermore, as will be seen in Section 3.5.8 the implementation of storage-based simulation (Behaviour analysis) even for a no-failure performance over the historical record is a trial and error process. Where the design is to include failures, the trial and error nature of the approach makes it very difficult to control the level of shortfall during the failure periods. In other words, it is problematic to design simultaneously for desired reliability and vulnerability using the storage-based simulation approach, because any attempt to restrict both the (volumetric) shortfall and duration of the deficits could easily become oscillatory thus preventing a unique solution from being obtained. One possible outcome of this inability to control simultaneously the duration and magnitude of deficits is the strange swinging in the behaviour of the mean and median of storage reported in Pretto *et al.* (1997). Such problems are not associated with the SPA (see Adeloye *et al.*, 2000), which therefore makes it procedurally much simpler. Nonetheless, because storage-based simulation is a widely used technique, particularly for complex multiple reservoir systems, the technique will be covered in greater detail in Section 3.5.8. The following sections consider the SPA in its basic form and subsequent modifications.

Basic Sequent Peak Algorithm for single reservoirs

The basic SPA developed by Thomas & Burden (1963) is often termed the automated version of the graphical Rippl (1883) technique because it can be implemented on a computer. However, the formulation presented here is due to Lele (1987) and is much simpler to implement on a computer than the original formulation of Thomas and Burden (see, for example, McMahon and Mein, 1986).

In its basic form, the SPA technique estimates the active storage capacity for a failure-free operation of an initially full reservoir over the historical record, i.e. for 100% reliability over the N-year period.

Let K_t be the cumulative sequential deficit at the beginning of period t in a record of N periods, K_{t+1} be the corresponding deficit at the end of t, i.e. at the beginning of $t+1$, D_t be the demand in period t and Q_t be the inflow during t.

Then the SPA is implemented in the following steps:

Step 1. Set $K_0 = 0.0$, i.e. assume that the initial deficit is zero, in other words that the reservoir is initially full. (Note: This assumption is common with all critical period techniques although it is not a problem with the SPA because if it is wrong, it will become apparent during the solution of the problem.)

Step 2. For $t = 1,2...,N$, calculate

$$K_{t+1} = \max\{0.0,\ (K_t + D_t - Q_t)\} \qquad (3.52)$$

Step 3. If $K_N = K_0$, then go to step 4; else if this is the first iteration, then set $K_0 = K_N$ and go to Step 2; else STOP: the SPA has failed because gross demand is higher than the average inflow.

Step 4. Active reservoir capacity $S = \max(K_{t+1})$ all over $t = 1,2,..,N$.

Example 3.5: Basic Sequent Peak Algorithm

We illustrate the basic SPA with a simple hypothetical example of a single reservoir whose inflows over a 15-period interval are: 5, 7, 8, 4, 3, 3, 2, 1, 3, 6, 8, 9, 3, 4, and 9. The demand per period is 4.5. Determine the required capacity to meet the given demand during the 15 periods.

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The solution can be carried out in tabular form as presented in Table 3.8.

Table 3.8: Basic Sequent Peak Algorithm

t	Q_t	D_t	$K_{t+1} = \max\{0.0, (K_t+D_t-Q_t)\}$
0			0
1	5	4.5	0.0
2	7	4.5	0.0
3	8	4.5	0.0
4	4	4.5	0.5
0	3	4.5	2.0
6	3	4.5	3.5
7	2	4.5	6.0
8	1	4.5	9.5
9	3	4.5	11.0 = Capacity S
10	6	4.5	9.5
11	8	4.5	6.0
12	9	4.5	1.5
12	3	4.5	3.0
14	4	4.5	3.5
15 = N	9	4.5	0.0 (K_{N+1} = 0.0); hence no need for repeating the data record

There are two important issues worthy of note in the above example. First is that at the end of the record, the sequential deficit is zero, which means that the reservoir has returned to its full state at the end of the record. Thus, although the SPA is normally formulated as a two-cycle procedure, repeating another cycle of the data record when the deficit at the end of the first cycle is zero is a waste of time because such an exercise will not produce a new sequence of deficits or reservoir capacity. The second issue is that while the SPA is a numerical alternative to the graphical mass curve (Rippl) diagram, it still suffers from some of the limitations of the mass curve technique, namely:

1. the estimate of capacity is only based on the worst historic drought and says nothing about the reliability of meeting the demand (although if future droughts are not as severe as the design drought, then the implied reliability is 100%); and

2. the method is unable to accommodate storage-dependent fluxes (e.g. evaporation losses) because the exposed reservoir surface area for estimating such fluxes depends on the storage whereas the SPA is normally formulated in terms of the deficit.

Consequently, the basic SPA requires modifications if it is to be used as a comprehensive technique for S-Y-P analysis. Furthermore, any such modification must also anticipate the use of the technique for the planning of multiple reservoir systems. Modifications of the basic SPA for single reservoir systems are discussed in Sections 3.5.5 and 3.5.7, while the extension of the methodology to the planning of multiple reservoir systems is presented in Chapter 4.

End Example 3.5

Example 3.6: Required storage capacity for a hypothetical reservoir on Hatchie River using basic SPA

For the Hatchie River at Bolivar, compute the required reservoir capacity based on annual streamflows to provide a yield equal to 75% of the mean annual flow using the basic SPA.

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Assume there are no net evaporation losses. The results of the application of the four steps in Section 3.5.4 are presented in Table 3.9 where K_{t+1} is the cumulative sequential deficit, initially zero. The draft is 75% of mean annual streamflow (Table 1.1) (i.e. 0.75* 2178 = 1634 Mm^3). From the analysis using annual flow data (Table A2.2) it is noted that the critical period begins in 1939 and ends in 1943 requiring a storage capacity of 1975 Mm^3 to provide 75% draft during the 55-year period without failure occurring.

Table 3.9: Basic SPA applied to annual streamflows for Hatchie River

Year	Annual inflow (Mm^3)	K_{t+1} (Mm^3)	Comment
1930	1667.42	0.00	
1931	1716.83	0.00	
1932	3713.57	0.00	
1933	2872.74	0.00	
1934	1327.16	306.64	
1935	2320.74	0.00	
1936	1561.86	71.94	
1937	1791.14	0.00	
1938	1689.53	0.00	
1939	2500.76	0.00	Start of critical period
1940	1280.66	353.14	
1941	865.87	1121.07	

1942	1248.46	1506.41	
1943	1164.85	1975.36	End of critical period
1944	2185.73	1423.43	
1945	2994.03	63.20	
1946	2902.91	0.00	
1947	1914.47	0.00	
1948	3241.88	0.00	
1949	2690.47	0.00	
1950	3584.27	0.00	
1951	3055.72	0.00	
1952	1801.15	0.00	
1953	2529.60	0.00	
1954	1179.53	454.27	
1955	1683.51	404.56	
1956	1669.20	369.16	
1957	3054.82	0.00	
1958	1750.60	0.00	
1959	1534.65	99.15	
1960	1488.07	244.88	
1961	2155.14	0.00	
1962	2111.56	0.00	
1963	1147.49	486.31	
1964	1792.11	328.00	
1965	1508.72	453.08	
1966	1077.88	1009.00	
1967	1790.76	852.04	
1968	1976.70	509.14	
1969	1878.53	264.41	
1970	2079.43	0.00	
1971	1658.51	0.00	
1972	2433.21	0.00	
1973	3933.23	0.00	
1974	3233.50	0.00	
1975	3145.89	0.00	
1976	1758.35	0.00	
1977	2429.92	0.00	
1978	2323.80	0.00	
1979	4136.38	0.00	
1980	2432.24	0.00	
1981	1280.30	353.50	
1982	2743.20	0.00	
1983	3384.18	0.00	
1984	2418.81	0.00	K_{N+1} is zero, i.e. full reservoir at end of N. Maximum K_{N+1} is capacity and is equal to 1975.36

End Example 3.6