Tr. J. of Engineering and Environmental Science
23 (1999) , 423 – ??.

Conjunctive Optimization of Hydroelectricity Benefits and Flood Damage Costs

Neşe AÇANAL, Tefaruk HAKTANIR
Erciyes University, Department of Civil Engineering,
38039, Kayseri-TURKEY
Recep YURTAL
Çukurova University, Department of Civil Engineering,
01330, Adana-TURKEY

Received 04.08.1999

Abstract

An Incremental Dynamic Programming program is developed to optimize both the firm and secondary energies of hydroelectric generation at monthly periods. First, the six-stage flood routing program developed in a previous study is applied sequentially to the Yedigöze, Çatalan, and Seyhan dams, all on the Seyhan River in Turkey, for 18 combinations resulting from different active storages, and optimum flood operation policies for all three dams are determined. Second, the Dynamic Programming program is applied to these three dams with 18 combinations, and optimum hydroelectricity generation policies for all three dams are computed. Finally, the optimum active and flood retention storages for the three dams are determined so as to maximize the net difference of the probability-weighted present worths of (hydroelectricity benefits) - (flood damage costs).

Key Words: Flood damage, hydroelectricity, optimization

Hidroelektrik Kazançlarının Taşkın Zararları ile Birlikte Optimizasyonu

Özet

Aylık zaman birimi bazında güvenilir ve sekonder hidroelektrik enerisini optimize eden bir Arttırımlı Dinamik Programlama programı geliştirilmiştir. Önce, üçü de Seyhan Nehri üzerinde bulunan Yedigöze, Çatalan, ve Seyhan Barajlarının farklı faydalı hacim değerlerinin alınmasıyla ortaya çıkan 18 farklı kombinasyonun her biri için, bu üç baraja, daha önceki bir çalışmada geliştirilmiş olan altı-safhalı taşkın işletme modeli uygulanarak, optimum taşkın işletme politikaları hesaplanmıştır. Sonra, yine bu 18 farklı kombinasyonun her biri için, yine bu üç baraja, geliştirilmiş olan Dinamik Programlama programı uygulanmış, ve optimum hidroelektrik üretimi politikaları hesaplanmıştır. Sonuçta, bu üç barajda, ihtimal-ağırlıklı (hidroelektrik kazançları)-(taşkın zararları) farkının ekonomik eşdeğerini en iyileyen faydalı hacim-taşkın kontrol hacmi miktarları belirlenmiştir.

Anahtar Sözcükler: Taşkın Zararı, Hidroelektrik, Optimizasyon

1. Flood Routing and Hydroelectricity Generation

Generation of electricity by hydropower turbines is a conventional practice, and many feasible projects are operational in developed countries. With a 120 Billion kWh/year potential, Turkey is among the fortunate countries in the region, and only about 30% of this was being produced by the existing hydropower plants as of 1998 (DSİ, 1998). rest of the plants are either under construction or at the project and bidding stages (DSİ, 1997, 1998).

Hydroelectric power production is directly proportional: a) to the difference between the elevation of the reservoir water surface and that of the downstream pond water surface at the exit of the turbines, and b) to the flow rate of water passing through the running turbines. Both factors necessitate a reservoir as full as possible. Effective flood routing, on the other hand, requires a reservoir as empty as possible prior to the arrival of the flood wave. Therefore, flood damage mitigation and hydroelectricity generation are two conflicting purposes. Reducing the volume of the active storage will result in more efficient flood attenuation but less hydroelectricity generation. Flood routings and the resultant outflow peaks with their induced damage costs will change with different active and flood retention storages. Therefore, optimization of total hydroelectricity production over a definite service life leaving flood mitigation as a simple empty storage constraint as in most former studies (e.g. Yeh, 1985; Yurtal, 1993) is not a comprehensive approach; furthermore, optimization of hydroelectricity benefits should be done in conjunction with optimization of flood damage costs.

Once the optimum flood operation rules are determined for a definite active storage volume, as in Açanal & Haktanır (1999), the damages caused by the peaks of the outflows can be weighed against the hydroelectricity income so as to choose the most beneficial combination of active storage and flood retention storage. This scheme can be applied to a single reservoir or to many reservoirs in a basin. Hence, the objective of this study was to optimize the net difference of (hydroelectricity benefits)-(flood damage costs) by accounting for these two quantities separately for the entire service life of the reservoir(s), rather than using the flood retention objective as a simple storage constraint of a classical dynamic programming optimization of hydroelectricity generation only.

2. Selection of Active and Flood Retention Storage Combinations and Application of the Six-Stage Flood Routing Model on Three Reservoirs in Seyhan Basin

The subbasins between the Yedigöze and Çatalan dams and between the Çatalan and Seyhan dams are rural areas with little agricultural activity and with almost no flood-damage-prone areas. Adana, the fourth largest city in Turkey, lies about 10 km downstream from Seyhan Dam. Because Adana is situated directly within the flood plains of the Seyhan River on both sides, it is vulnerable to flood damage. There are levees, built in the 1950's, on both banks of the Seyhan River from the toe of Seyhan Dam all the way down to the delta. The capacity of the levees is 1200 m3/s (DSİ, 1981), but many buildings, such as a huge mosque and a large supermarket, have been built close to the shoulders of the Seyhan River. And downstream from Adana, intensive agricultural activity is taking place at the farmers' own risk within the highly productive overbank areas between the levees. Therefore, considerable losses are bound to occur even for flow rates less than 1200 m3/s. It is calculated that a discharge of 400 m3/s is the upper bound of the flow rates to be confined within the main channel cross-section causing no flood damages (Japan International Corporation Agency, 1994).

In the area between the city of Adana and the Mediterranean shore lies a highly productive agricultural region known as Çukurova Plain, which is one of the most fertile cotton and citrus cultivation plains of Turkey. Therefore, Çukurova Plain is also an area susceptible to high flood damages. In short, the area downstream of Seyhan Dam is a region with a rather high risk of urban and agricultural flood damage. Some remarkable flooding has been recorded, with damage loss accounts and hydraulic characteristics (DSİ, 1969, 1975, 1981). The Yedigöze-Çatalan and Çatalan-Seyhan subbasins, however, will not suffer any appreciable flood damage. Therefore, in the system of Yedigöze, Çatalan and Seyhan dams, all three of which generate electricity, the high outflows from the Seyhan Dam will cause flood damage.

The tops of the active pool elevations in the original projects of the three dams are: 233.9 m, 118.6 m, and 63.5 m, respectively for Yedigöze, Çatalan, and Seyhan reservoirs (DSİ, 1988; Japan International Corporation Agency, 1994; Verbund-Plan, Romconsult, Temelsu, 1980a). Seyhan Dam has a gated ogee type service spillway with a maximum capacity of about 2500 m^3/s and a separate emergency spillway which is a free-fall ogee profile weir. The crest elevation of the emergency spillway is 67.50 m. Now that Çatalan Dam is in operation, there is a tendency for the Seyhan Dam officials to keep its top full all year round, which means the top of active storage would be 67.50 m. Therefore, two different reasonable values for active storage for the Seyhan Dam were chosen: 63.50 m and 67.50 m. Initial calculations led to the choice of values: 235.0 m, 233.9 m, 231.9 m; and, 119.3 m, 118.6 m, 117.6 m, for top elevations of the active storages for the Yedigöze and Çatalan reservoirs, respectively. Altogether, there were 3×3×2 = 18 different combinations of active storage of these three reservoirs in series, and the optimum solution was sought within this range.

The computer program executing the six-stage flood operation model was applied in due order in the downstream direction to all these three dams for all 18 storage combinations, and the optimum flood operation rules together with the resultant outflow hydrographs were calculated. The outcome of these computer runs was expressed in a concise manner in 18 different tables. One of these tables, the one summarizing the combination of the original project values of the active storages, is given in Açanal & Haktanır (1999). The rest of the tables are in Açanal (1998).

3. Determination of Flood Losses

A detailed study of the available data about past floods in the area led to the finding that only three major events caused noteworthy losses (DSİ, 1969, 1975, 1981, 1988). In Table 1, the concise data of these floods are given.

Table 1. Data of three intense floods at Adana and Çukurova

Flood year	Peak discharge from Seyhan Dam (m3/s)	Total flood loss updated to 1996 (urban + agricultural) (Million US $)
1969	1186	7.66
1975	1146	5.37
1980	2830	14.2

The equation below is a good fit to these three flood damage data points:

$$FD = 0.00475.Qp + 0.75 \tag{1}$$

where, FD is the summation of urban damage costs in the city of Adana and agricultural damage costs further downstream in the productive plain of Çukurova in millions of US dollars, and Qp is the peak of the outflow hydrograph released from the Seyhan Dam in m^3/s. FD=0 for any Qp≤400 m^3/s.

No one was killed in the 1980 flood. Hence, there is no component for the worth of human life in Eq.1. After 1980, a large shopping center, a huge mosque, and many other buildings have been constructed, perhaps unwisely, right in the overbank areas of Seyhan River at Adana. Moreover, cotton and citrus prices have increased since 1980. For all these reasons, during economic analyses of this study, for calculation of the instantaneous flood loss in the future, the flood damage cost given by Eq.1 was multiplied by 2.

The expected annual flood damage, EAFD, is as defined below (e.g.: HEC, 1990, Ch.8; Mays & Tung, 1992, Ch.13; Linsley et al., 1992, Ch.7):

$$EAFD = \int_0^1 FD.dP \tag{2}$$

where EAFD is the probability-weighted (expected) annual flood damage cost in US$, FD is the total flood damage due to any particular flood in US$, which is a random variable, and dP is the differential of the nonexceedence probability of that particular FD.

Because analytical integration of most probability distributions is either impossible or very cumbersome, EAFD is computed by numerical integration. The limit floods for the six-stage routing are determined beforehand in order to calculate the gate opening rules. Since these are only six different values, we may need a greater number of points to approximate this integral with reasonable precision. Therefore, the flood hydrographs of the 20-, 50-, 200-, 500-, 2,000-, 5,000-year return periods were also computed by multiplying the PMF by the corresponding ratios given in Açanal & Haktanır (1999).

After having determined the operation rules of the six-stage routing using the limit 10-, 100-, 1,000-, 10,000-, 100,000-year floods, and PMF, the other intermediate floods were next routed directly with the already determined rules, and the peaks of their outflow hydrographs were also computed. Altogether, peaks of the routed outflow hydrographs from the downmost Seyhan Dam of 12 different floods, which were 10-, 20-, 50-, 100-, 200-, 500-, 1,000-, 2,000-, 5,000-, 10,000-, and 100,000-year floods, and PMF, were obtained. Applying the trapezoidal rule to Eq.2 and doing all manipulations result in the following equation with these 12 different floods:

$$\begin{aligned} EAFD = {} & 0.025.FD_{10} + 0.04.FD_{20} + 0.02.FD_{50} + 0.0075.FD_{100} + 0.004.FD_{200} + \\ & 0.002.FD_{500} + 0.00075.FD_{1000} + 0.0004.FD_{2000} + 0.0002.FD_{5000} + \\ & 0.000095.FD_{10000} + 0.0000055.FD_{PMF} \end{aligned} \tag{3}$$

where, for example, FD_{200} is the total instantaneous flood damage in US$ due to the peak of the outflow of the 200-year flood hydrograph routed from Seyhan Dam.

To be weighed against the hydroelectric generation monetary benefits, the present worth of total flood damages was computed by the following classical formula:

$$TFD = EAFD.\{[(1+i)^n - 1]/[i.(1+i)^n]\} \tag{4}$$

where i is the discount rate, for which 5% is used in this study as done by the State Hydraulic Works of Turkey in economic analyses related to flood damage costs (DSİ, 1996); n is the economic life, for which 50 years is used herein; and TFD is the present worth of total flood damages in US$.

In the design of a hydraulic structure like a spillway or a culvert, it is quite reasonable to determine the T-year flood peak by statistical analysis of the available samples of instantaneous highest peak recorded in a year. Naturally, a culvert conveying the 1st highest peak in a year will more safely tolerate the 2nd highest peak. There occur many floods within a year, and the 2nd highest peak of a particular year may be even greater than the 1st highest peak, the so-called annual peak, of another year. In order to calculate the total flood damages in a whole year, all appreciable floods next to the 1st highest must be taken into account, simply because they will also cause some flooding with their resultant damages. Therefore, computation of the expected annual damage based on the frequency analysis of only the 1st highest peaks would be incorrect.

Because there are four different seasons, there are many different precipitation types, different storm patterns, and many different meteorological events. Therefore, as the 1st annual peak is treated like a random variable, the independent 2nd highest peak (peak of another flood hydrograph in the same year), and similarly the 3rd, 4th, etc., highest peaks can also each be treated like random variables. Similar frequency analyses can be applied to the 2nd, 3rd, ... peaks, and the recurrence of each such peak can be separately considered. In this study, it is suggested that the ranking of these smaller peaks should continue downwards all the way to the point where even the most extreme value of that rank would be under the threshold discharge to cause any monetary flood damage.

Through special correspondence with the General Directorate of Electrical Works Planning Administration of Turkey, the data containing the 1^{st}, $2^{nd}, \ldots,$ and 12^{th} highest independent peaks recorded at gauging stations 1805-Gökdere and 1818-Üçtepe were obtained (EİEİ, 1997). Because station 1805 has a record length of 54 years (the longest), it is taken to represent Seyhan River characteristics. Careful analyses revealed that 3-parameter log-Normal distribution with zero skewness estimators, LN3-CSx=0, represented the 1^{st}, $2^{nd}, \ldots,$ highest peaks series reasonably. In Figure 1, the frequency curves of the first six highest peaks by the LN3-CSx=0 model are shown. In Table 2, the ratios of 10-, 20-, ..., 1,000,000-year return-period values of the 2^{nd}, $3^{rd}, \ldots,$ 6^{th} highest peaks to those of the 1^{st} highest peak are given by the LN3-CSx=0 model at station 1805-Gökdere.

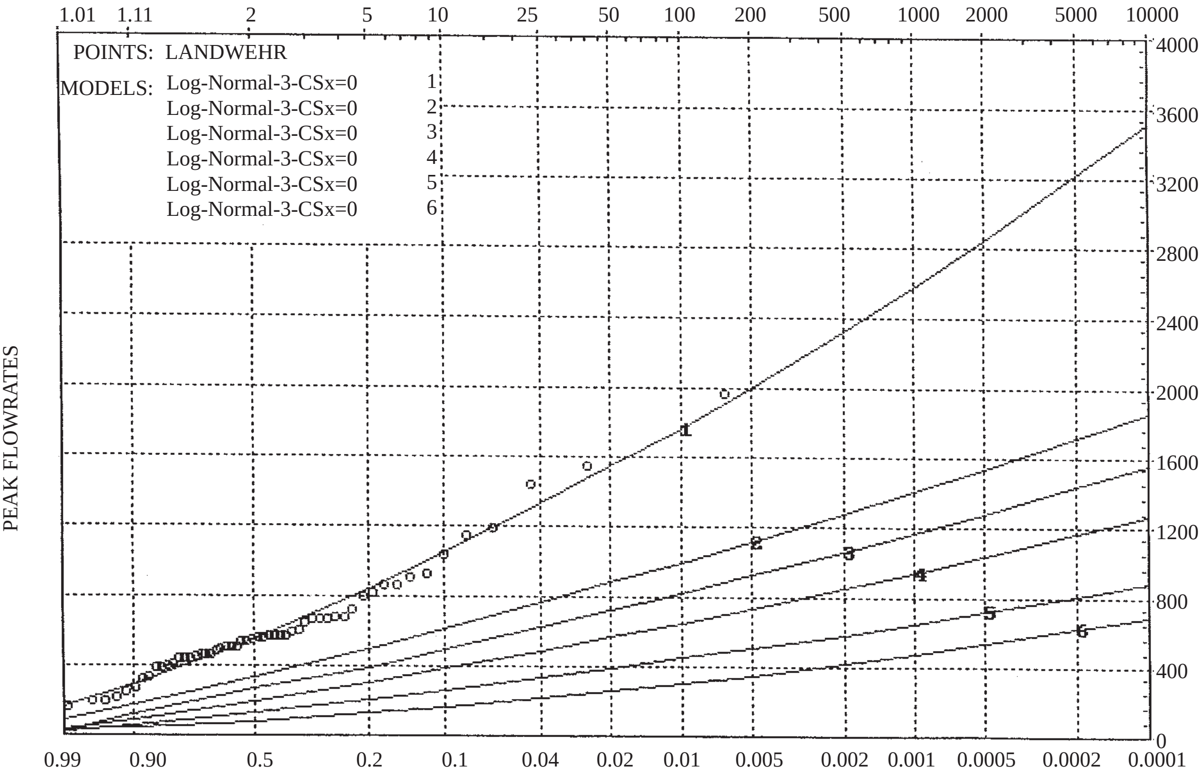

Figure 1. Frequency curves of the 1st, 2nd,..., 6th highest peaks at 1805-Gökdere

Table 2. Ratios of various return-period values of the 2nd,..., 6th highest peaks to those of the 1 st highest peak at 1805-Gökdere by LN3-CSx=0 model

Return period	2nd	3rd	4th	5th	6th
10	0.59	0.47	0.37	0.25	0.15
20	0.58	0.47	0.37	0.25	0.16
50	0.57	0.47	0.37	0.25	0.17
100	0.57	0.47	0.37	0.25	0.17
200	0.56	0.46	0.37	0.25	0.17
500	0.55	0.46	0.37	0.25	0.18
1,000	0.55	0.46	0.37	0.25	0.18
2,000	0.54	0.45	0.36	0.25	0.19
5,000	0.53	0.45	0.36	0.25	0.19
10,000	0.53	0.44	0.36	0.25	0.20
100,000	0.51	0.44	0.36	0.25	0.21
1,000,000	0.51	0.43	0.35	0.25	0.22

All hydrographs of the 1^{st} highest floods from 10-year up to 1,000,000-year return periods have already computed as summarized in Açanal & Haktanır (1999), and the rules of the six-stage routings were determined for all three dams based on those hydrographs. Using the 12 peaks of the routed outflows from Seyhan Dam in Eqs.1, 3, 4, TFD for the 1^{st} highest floods was computed. Next, the 1^{st} highest hydrographs were multiplied by the ratios given in Table 2, and 12 sets of hydrographs of the 2^{nd}, 3^{rd},... highest floods were thus computed. First, the 12 hydrographs of the 2^{nd} highest peaks were routed sequentially from Yedigöze, Çatalan, and Seyhan Dams with the already determined six-stage rules; and ultimately, the peaks released from Seyhan Dam were computed. Eqs.1, 3, and 4 were used with these 12 outflow peaks and the present worth of the total flood damages of the 2nd highest floods in a single year was computed. Proceeding downwards, the present worths of the 3^{rd}, 4rth, and 5^{th} highest floods were also computed similarly as a result of the involved routing cycles. Table 3 summarizes the present worths of the total flood damages of the 1^{st}, 2^{st},... floods computed in this manner, and their sums, which make up the net total flood damage losses, for all 18 active storages combinations.

4. Optimized Hydroelectricity Generation

An efficient Incremental Dynamic Programming with Successive Approximations (IDPSA) model for the purpose of determining optimum turbine operation rules in monthly periods to maximize both the firm and secondary energies applicable to a system of dams was developed by Yurtal (1993). A modified version of this IDPSA program was applied to the three dams of this study.

Computations begin at the most upstream dam. Optimization is achieved for one of the dams while the operations of the other dams are kept the same as the previous step. Then, the next dam in the downstream direction is optimized. This iterative optimization continues until the operation rules for all dams in the system do not change. The operation policy of all dams at the beginning is the release of 70% of the long-term monthly average flow from the turbines. First, the critical period of an n-year long monthly flow series is found and the firm energy is maximized over this drought span. Next, using the optimized firm energy as a constraint, the secondary energy is optimized for the entire n-year period (Yurtal, 1993).

Table 3. Present worths in US$ of the total flood damage costs of the 1^{st}, 2^{nd},..., and 5^{th} highest peaks

Beginning lake elevations (top of active storages) (m)			Present worths of flood damage costs of US$ of					
Yedigöze	Çatalan	Seyhan	1st peaks	2nd peaks	3rd peaks	4th peaks	5th peaks	Yearly Totals
231.9	117.6	63.5	1.61	0.03	0.01	0.00	0.00	1.65
231.9	117.6	67.5	19.32	13.26	12.01	10.93	3.63	59.15
231.9	118.6	63.5	12.98	0.55	0.19	0.00	0.00	13.72
231.9	118.6	67.5	22.83	13.64	12.08	10.94	3.63	63.12
231.9	119.3	63.5	13.77	1.20	0.24	0.00	0.00	15.21
231.9	119.3	67.5	24.78	13.88	12.13	10.96	3.63	65.38
233.9	117.6	63.5	1.62	0.03	0.01	0.00	0.00	1.66
233.9	117.6	67.5	19.32	13.26	12.01	10.93	3.63	59.15
233.9	118.6	63.5	12.99	0.55	0.20	0.00	0.00	13.74
233.9	118.6	67.5	24.81	13.89	12.13	10.96	3.63	65.42
233.9	119.3	63.5	13.84	1.20	0.25	0.00	0.00	15.29
233.9	119.3	67.5	27.38	14.16	12.18	10.97	3.63	68.32
235.0	117.6	63.5	1.66	0.03	0.01	0.00	0.00	1.70
235.0	117.6	67.5	22.54	13.43	12.04	10.93	3.63	62.57
235.0	118.6	63.5	13.00	0.55	0.20	0.00	0.00	13.75
235.0	118.6	67.5	27.32	14.17	12.18	10.97	3.63	68.27
235.0	119.3	63.5	13.88	1.20	0.25	0.00	0.00	15.33
235.0	119.3	67.5	30.27	14.48	12.25	10.98	3.63	71.61

4.1. Brief Information about The Package Program HEC-4 And Its Application

HEC-4, Monthly Streamflow Simulation, is one of the package programs developed by the Hydrologic Engineering Center of The U.S.Army Corps of Engineers (HEC, 1971). This program analyzes recorded monthly streamflows at a number of interrelated gauging stations, preferably in the same basin, and it computes generated synthetic data again in monthly values for any desired length. The program initially reconstitutes missing data of the short-record stations based on multiple regressions among stations using the recorded data of those longer-record stations. The multiple regression uses the current and preceding monthly flows of the other stations in the group and the preceding monthly flow of the station itself as independent variables. More information about HEC-4 can be obtained from its users' manual (HEC, 1971) and related HEC publications.

Taking the recorded monthly flow data at the gauging stations of 1801-Himmetli, 1805-Gökdere, 1806-Ergenuşağı, 1817-Emeğil, 1818-Üçtepe, 1820-Hacılı Köprüsü, and 1823-Arapali, all in Seyhan Basin, from the pertinent source (EİEİ, 1955-92) and using them as input to HEC-4, 1,000-year long synthetic monthly flow series were generated. Transferring the monthly flow data to the axes of each of the three dams with the help of the formulae suggested by Yurtal (1993), 20 nonoverlapping 50-year monthly flow segments were obtained for each subbasin of the three dams in question.

4.2. Economic Quantification of The Optimized Hydroelectricity Production

The IDPSA program was run with each of the 20 synthetic data segments, and optimized firm and secondary energies for each one was computed. The present worth of the total optimized hydroelectric energy was computed by:

$$TEI_k = \sum_{j=1}^{50} AEI_j.[1/(1+i)^j]\} \tag{5}$$

where AEI$_j$ is the summation of firm and secondary energy income in the j'th year in US\$, i is the discount rate, which is 9.5% here because the State Hydraulic Works uses 9.5% for economic analyses of hydroelectricity projects (DSİ, 1996), and TEI$_k$ is the present worth of the total energy income at the beginning of the 50-year economic life of the k'th segment. AEI$_j$ was computed by

$$AEI_j = (0.06).FE_j + (0.029).SE_j \tag{6}$$

where AEI$_j$ is the total firm energy in kWh in the j'th year, and SE$_j$ is the total secondary energy in kWh in the j'th year. The rates adopted by the State Hydraulic Works (DSİ, 1996) for unit income of the firm energy and secondary energy are 0.06 US\$/kWh and 0.029 US\$/kWh respectively.

The IDPSA program was applied to each of the 20 50-year monthly flow segments, and 20 TEIk values were computed. Since monthly flows are random variables, the present worth of the summation of optimized hydroelectiricity produced by these three dams is also a random variable, and the 20 TEIk values obtained are a sample series of this variable. It was assumed that TEI obeys an LN3 distribution, and its parameters were computed by the maximum-likelihood method using this 20-element sample. The expected (probability-weighted) present worth of total optimized electricity production by the three dams is defined by

$$ETEI = \int_0^1 TEI.dP \tag{7}$$

where, ETEI is the abbreviation for the expected present worth of total optimized hydroelectricity produced by these three dams in US\$, and dP is the differential of the nonexceedence probability of TEI. This definite integral can be computed by the trapezoidal rule. In order to do that, first the values of those TEI's having the nonexceedence probabilities of 0.0001, 0.001, 0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 0.99, 0.999, and 0.9999 were computed, after the three parameters of the adopted LN3-ML model were determined. The approximation of Eq.8 by the trapezoidal formula with these 17 points after all manipulations is

$$\begin{aligned} ETEI = {} & 0.00045.TEI_{0.0001} + 0.00495.TEI_{0.001} + 0.0245.TEI_{0.05} + \\ & 0.075.TEI_{0.1} + 0.1.TEI_{0.2} + 0.1.TEI_{0.3} + 0.1.TEI_{0.4} + 0.1.TEI_{0.5} + 0.1.TEI_{0.6} + \\ & 0.1.TEI_{0.7} + 0.1.TEI_{0.8} + 0.075.TEI_{0.9} + 0.045.TEI_{0.95} + 0.0245.TEI_{0.99} + \end{aligned}$$

$$0.00495.TEI_{0.999} + 0.00045.TEI_{0.9999} \quad (8)$$

where $\mathrm{TEI}_{0.0001}$, $\mathrm{TEI}_{0.001}$, etc are TEI's computed by the fitted LN3-ML distribution with those nonexceedence probabilities indicated by the subscripts.

5. Hydroelectricity Benefits Minus Flood Damage Costs

Application of Yurtal's IDPSA program to 20 50-year monthly flow segments followed by computations by Eqs.7, 6, and 9, in this order, lead to a single value in US dollars, which is the expected present worth of the optimized total hydroelectricity produced by the three dams for one of the 18 active storages combination. Therefore, at the end of all computations, 18 values of optimized hydroelectricity benefits and 18 values of optimized flood damage costs were obtained. These 18 numbers of benefits and costs and their differences are given in Table 4. The overall optimum solution is theoretically the combination in Table 4 with the greatest value in its last column.

Table 4. Present worths in US$ of 1) total optimized hydroelectricity benefitsof the three dams, 2) total flood damage costs, and 3) differences of 1) and 2)

Beginning lake elevations (top of active storages) (m)			Present Worths of total optimized hydroelectricity benefits (Million US$)	Present Worths of total flood damage costs (Million US$)	Net difference (Million US$)
Yedigöze	Çatalan	Seyhan			
231.9	117.6	63.5	694.62	1.65	692.97
231.9	117.6	67.5	714.64	59.15	655.49
231.9	118.6	63.5	700.40	13.72	686.68
231.9	118.6	67.5	719.89	63.12	656.77
231.9	119.3	63.5	701.88	15.21	686.67
231.9	119.3	67.5	722.34	65.38	656.96
233.9	117.6	63.5	702.50	1.66	700.84
233.9	117.6	67.5	725.13	59.15	665.98
233.9	118.6	63.5	708.28	13.74	694.54
233.9	118.6	67.5	730.86	65.42	665.44
233.9	119.3	63.5	710.90	15.29	695.61
233.9	119.3	67.5	733.48	68.32	665.16
235.0	117.6	63.5	730.08	1.70	728.38
235.0	117.6	67.5	735.55	62.57	672.98
235.0	118.6	63.5	735.62	13.75	721.87
235.0	118.6	67.5	738.73	68.27	670.46
235.0	119.3	63.5	736.21	15.33	720.88
235.0	119.3	67.5	741.11	71.61	669.50

6. Results and Discussion

A more comprehensive approach for conjunctive optimization of flood mitigation and hydroelectricity generation by one or a few reservoirs, rather than taking flood retention requirements as simple empty storage constraints of a program optimizing the hydroelectricity energy only, is suggested and demonstrated on a system of three reservoirs in the Seyhan Basin in Turkey.

Specific results of the study can be summarized as follows:

1) With the purpose of accounting for intangible losses due to flooding and hence giving slightly

more weight to flood damage costs over hydroelectricity benefits, the discount rates used in this study for flood costs and power benefits were 5% and 9.5%, respectively. This choice has been deliberate for being slightly biased towards flood damage costs, and at the same time for complying with the practice of DSI, the federal body which has designed and constructed these dams, and is presently operating them during floods. Despite the greater weight of flood costs adopted herein, the overall hydroelectricity benefits have surpassed the former, as can be seen by comparing the 4^{th} and 5^{th} columns of Table 4. If all these economic analyses were repeated with equal discount rates, it is obvious that, the superiority of net hydroelectricity benefits would be even more pronounced than in the present case.

For any other basin, the probability-weighted flood damage costs may turn out to be in the same order of magnitude as those of hydroelectricity benefits. As noted above, these results are "specific" to Seyhan Basin, and the presented methodology can be adapted to any other basin with results peculiar to its own.

2) It could be said that the effect of the economic analysis period is negligible beyond 50 years. Although the physical lives of the earthfill dams of the Seyhan Basin may be greater, 50 years was taken as the analysis period in this study. It is believed that repeating all analyses with 100 years, for instance, would not appreciably alter the results obtained with 50 years. However, sensitivity analyses with different discount rates and different economic lives could be performed in a real-life project in order to observe their effects.

3) As can be seen from Table 4, the case: 235.0 m, 117.6 m, 63.5 m for top of active storages for the Yedigöze, Çatalan, and Seyhan reservoirs, respectively, turned out to be the final result. Seyhan Dam must not be kept top full, since all combinations of 67.5 m had appreciably smaller net income than those of 63.5 m.

4) Yedigöze reservoir has a rather small capacity with no flood retention storage. Therefore it has a weak flood routing effect. Yet, because of its high and narrow valley, it has the greatest share in hydroelectricity production as compared with the other two dams.

References

Açanal, N., Hidroelektrik Üretimi ve Taşkın Zararlarının Birlikte Değerlendirilmesiyle Aşağı Seyhan Havzasındaki Seyhan, Çatalan, Yedigöze Barajlarının Taşkınlarda Optimum İşletilmesi için Safhalı İşletim Modeli. Doktora Tezi, Çukurova Üniversitesi, Fen Bilimleri Enstitüsü, Adana, 1998.

Açanal, N. and Haktanır, T., "Six-Stage Flood Routing for Dams Having Gated Spillways", TÜBİTAK, Journal of Engineering and Environmental Sciences, Series B (this issue), 1999.

DSİ, 1969 Su Yılı Taşkın Yıllığı, Devlet Su İşleri Genel Müdürlüğü, Ankara, 1969.

DSİ, 1975 Su Yılı Taşkın Yıllığı, Devlet Su İşleri Genel Müdürlüğü, Ankara, 1975.

DSİ, Seyhan Taşkın Raporu (27 Mart 1980 - 6 Nisan 1980), Devlet Su İşleri Genel Müdürlüğü, Ankara, 1981.

DSİ, Seyhan - Çatalan Barajı ve Hidroelektrik Santralı, Devlet Su İşleri VI. Bölge Müdürlüğü, Adana, 1988.

DSİ, Ajanda, Özet Bilgiler, 1996, Devlet Su İşleri Genel Müdürlüğü, Ankara, 1996.

DSİ, Türkiye'deki Barajlar ve Hidroelektrik Santrallar, Devlet Su İşleri Genel Müdürlüğü, Ankara, 1997.

DSİ, DSİ'nin Tanıtımı, Devlet Su İşleri Genel Müdürlüğü, Dış İlişkiler Başmüşavirliği, Ankara, 1998.

EİEİ, 19** Su Yılı Akım Rasat Yıllığı, Elektrik İşleri Etüt İdaresi Genel Müdürlüğü, Hidrolik Etütler Dairesi Başkanlığı, Ankara, 1955 - 1992.

EİEİ, Erciyes Üniv., Müh.Fak., İnşaat Müh.Bölüm Başkanlığına hitaben yazılmış 18.07.1997 tarih - 709 sayılı yazının eki, Elektrik İşleri Etüt İdaresi Genel Müdürlüğü, Hidrolik Etütler Dairesi Başkanlığı, Ankara, 1997.

HEC, HEC-4, Monthly Streamflow Simulation, Generalized Computer Program, Hydrologic Engineering Center, US Army Corps of Engineers, 1971.

HEC, HEC-1, Flood Hydrograph Package, User's Manual, Hydrologic Engineering Center, US Army Corps of Engineers, 1990.

Japan International Corporation Agency, Feasibility Study on Flood Control, Forecasting and Warning System for Seyhan River Basin. Final Report, Volume I, Summary, The Republic of Turkey, General Directorate of State Hydraulic Works and Nippon Koei, 1994.

Linsley, R.K., Franzini, J.B., Freyberg, D.L., Tchobanoglus, G., Water Resources Engineering, Fourth edition, McGraw-Hill, 1992.

Mays, W.L. and Tung, Y.K., Hydrosystems Engineering and Management International Edition, McGraw-Hill, 1992.

Verbund-Plan, Romconsult, Temelsu, Aşağı Seyhan Havzası Master Planı, Cilt I, Genel Mühendislik Raporu, Verbund-Plan, Viyana; Romconsult, Bükreş; Temelsu, Ankara, 1980.

Yeh, W.W-G., "Reservoir Management and Operations Models: A State- of-the-Art Review, Water Resources Research, 21(12), 1797-1818, 1985.

Yurtal, R., Çoklu Baraj Sistemlerinin Enerji Optimizasyonu için Geliştirilmiş Etkin Bir Artırımlı Dinamik Programlama Modeli ve Aşağı Seyhan Havzası'na Uygulanması, Doktora Tezi. Çukurova Üniversitesi, Fen Bilimleri Enstitüsü, İnşaat Mühendisliği Anabilim Dalı, Adana, 1993.