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Pre-Event Dam Failure Analyses for Emergency Management

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Abstract

Simultaneous dam-break analyses of two dams, namely the Nilüfer and Doğancı dams, due to a breach in their bodies, were performed under various hydraulic conditions. Both of the dams are located in the same river branch of the Nilüfer Basin in the province of Bursa in Turkey. The main purpose of the study was to see the negative effects of such failure on the city of Bursa, which is located downstream of the dams, as well as to make available the results of the study to the relevant public officials for their use in a real-time emergency management. The numerical model used in the study is called DAMBRK. This model is very comprehensive and was developed at the National Weather Service (NWS) in the United States and is used widely in other countries. The results of the multiple-dam failure analyses performed in different scenarios indicate that some parts of downstream region near Bursa may be affected adversely. It appears that it would be appropriate for the public officials who are in charge of public safety to prepare emergency action plans (EAP) in advance to manage effectively such an undesirable event, in case it occurs.

Key Words: Dam-Break, Breach, Numerical Model, DAMBRK, Emergency Management

Afet Yönetimi için Baraj Yıkılma Öncesi Analizleri

Özet

Çeşitli hidrolik koşullar altında iki barajın, (Nilüfer ve Doğancı barajları) gövdelerinde açılan bir gedik sonucu, eşzamanlı yıkılmaları durumu için baraj yıkılma analizleri yapıldı. Her iki baraj Türkiye'nin Bursa ilinde Nilüfer havzasında aynı nehir kolu üzerinde yer almaktadırlar. Çalışmanın ana amacı, böyle bir afetin Bursa şehri üzerindeki olumsuz etkilerini görmek ve çalışma sonucu elde edilen bulguları ilgili yetkililere afet yönetiminde kullanmaları için sunmaktır. Çalışmada kullanılan nümerik modelin adı DAMBRK'tir. Çok geniş kapsamlı olan bu model Amerika Birleşik Devletlerinde Milli Hava Servisi tarafından geliştirilmiş olup, başka ülkelerde de yaygın olarak kullanılmaktadır. Değişik senaryolar altında gerçekleştirilen çoklu baraj yıkılma analizleri sonuçları, mansapta Bursa yakınlarındaki bazı bölgelerin olumsuz olarak etkilenebileceğine işaret etmektedir. Toplum güvenliğinden sorumlu kamu yetkililerinin, arzu edilmeyen böyle bir olayın olması durumunda onunla etkin bir şekilde baş edebilmeleri için Acil Eylem Planları (AEP) denilen planları önceden hazırlamaları uygun olacaktır.

Anahtar Sözcükler: Baraj Yıkılmaları, Gedik, Nümerik Model, DAMBRK, Afet Yönetimi

Introduction

Dams provide essential benefits for society, some of which are water supply, flood control, recreation, hydropower and irrigation. Because of different reasons, a dam may fail and cause significant problems. When a dam fails, a large amount of water stored in its reservoir may trigger a catastrophic flood as the impounded water escapes through the breach into the downstream valley. In general, the magnitude of the peak flows created by dam breaching may greatly exceed all initially calculated floods caused by heavy precipitation. More importantly, the response time in dam failures to warn people living downstream is much shorter than the response time in any hydrologic event.

Although it is impossible to prevent all of the potential dam failures, it is possible to mitigate the adverse affects of such events by conducting a contingency plan based on available data obtained from numerical and physical models as well as from observed events. Dam break flood analysis is considered to be a part of dam design. The determination of the inundated areas due to a dam failure incident will also guide us in disaster management. In fact, a proper emergency evacuation plan resulting from forecasting the downstream flooding (inundation information and warning times) is the only way to avoid a large number of victims. The validity of this observation was positively tested at Baldwin Hill and San Fernando dam failures; in both cases it was possible to evacuate thousands of people. More recently, the collapse of Quail Creek dam with no injuries illustrates the value of evacuation plans and other safety requirements (Danielson and Mc Intyre, 1989).

In Turkey, a number of publications have appeared recently, by Sezer (1992), and Bozkuş (1994a, 1994b), Merzi at al. (1997), Bozkuş and Kasap (1998), indicating that there is a growing interest both for predicting the potential hazards of the dam break problem and for informing public officials on the subject.

Consequently, the major goal of the present study by Güner (1998) is to contribute further to the subject. Specifically, it is aimed to provide flood hydrographs at the critical cross-sections downstream of Nilüfer and Doğancı dams, which are expected to help the public officials of Bursa in making a proper emergency plan for the city, in case of the simultaneous failure of these dams. This type of planning provides information that is vital during an emergency to alert people on time and evacuate them safely before the predicted flood waves arrive. There is no doubt that an uncontrolled dam failure can lead to a great number of lives being lost. Needless to say, dam break analysis of the Nilüfer and Doğancı dams is important for the city of Bursa, whose population is about 1.5 million.

The Numerical Model (DAMBRK)

The dam break-forecasting model called DAMBRK was used in the present study to perform the numerical analyses. It was developed by Fread (1977), at the National Weather Service (NWS) in the U.S. This model was selected based on the study performed by Wurbs (1986), in which he concluded that DAMBRK was an optimal model for adoption by the Military Hydrology Program in the U.S., especially in cases where dam break forecasting studies are to be performed in advance for preparing flooding maps for regions under consideration. In his extensive study, Wurbs compared several leading dam break numerical models in use worldwide to reach his conclusion.

DAMBRK is a very sophisticated computer program as it employs an elaborate numerical scheme to simulate a flood wave moving downstream in a valley. The governing equations used in the model are the complete one-dimensional Saint–Venant equations of unsteady flow, which are coupled with internal boundary equations representing the rapidly varied (broad-crested weir) flow through structures. Moreover, appropriate external boundary equations at the upstream and downstream sections of the routing reach are employed. The system of equations is solved by a non-linear weighted four-point implicit finite-difference method. The model consists mainly of three functional steps: (1) a description of the dam failure mode, i.e. the temporal and geometrical description of the breach; and (2) a hydraulic computational algorithm for determining the time history of the outflow through the breach as affected by the breach description, reservoir inflow, reservoir storage characteristics, spillway outflows, and downstream tailwater elevations; and (3) routing the outflow hydrograph through the downstream valley in order to account for changes in the hydrograph due to valley storage, frictional resistance, downstream bridges or dams, and to determine the resulting water surface elevations (stages) and flood wave travel times. A complete description of the model can be found in the user documentation of the model (Fread 1991).

It should be stated that the DAMBRK model is best suited for pre-emergency dam-break analyses since it requires detailed input data for an accurate analysis, as well as technical expertise to use it. It can be used reliably to prepare inundation maps of the regions which may be subject to potential dam-break floods.

Physical Data for Dam-Break Model

The Nilüfer River starts from Uludağ Mountain, and flows through the city of Bursa which is located near the southeast of the Marmara Sea, in the northwestern part of Turkey. The Doğancı dam, which is a rock-earth fill dam, is located upstream of Bursa, and it supplies drinking water for the city. Because of the ever increasing population growth of Bursa, the Doğancı dam water supply capacity will not meet the demand in the year 2005. Thus, the State Water Works of Turkey (DSİ) has decided to build the Nilüfer dam upstream of the Doğancı dam. The Nilüfer dam, a rock-fill dam, is currently under construction and will be completed in the year 2002. Table 1 shows the hydrological and physical characteristics of both dams. The variation of the surface area and the water volume of the dam reservoirs with respect to elevation are shown in Tables 2 and 3. Figure 1a is a sketch showing the location of the dams with respect to one another and also the location of seven cross-sections of the river valley selected and used in the computer simulations, downstream of each dam. Figure 1b shows a general layout plan of the Nilüfer River Basin.

Moreover, Figures 2a and 2b show the catastrophic hydrographs for the Nilüfer dam and Doğancı dam, respectively. Those hydrographs were used as inflow hydrographs that triggered the dam breaks in various failure scenarios outlined in the next section. Figure 3 shows a typical cross-section of the river valley in which the Nilüfer river flows.

Failure Scenarios

As forecasting dam break failures involves some uncertainties, it is important that reasonable failure scenarios be employed to prepare a sound emergency warning system for a given region. Consequently, some theoretically possible failure situations were utilized in the present study by assuming various hydraulic and structural features. The scenario status matrix is provided in Table 4. This table shows the state of the spillway gates to indicate whether or not they work properly or fail during an assumed event; that is, whether or not they can be lifted while the maximum catastrophic inflow hydrograph is entering the reservoir of one of the dams or both. The same table also specifies the inflow hydrograph for each dam. For instance, in Scenario 1, the table indicates that the spillway gates of both dams are working properly and the inflow hydrographs entering the reservoirs of both dams are maximum catastrophic hydrographs. In this scenario, it was shown that the dams did not fail. On the other hand, in Scenario 2, the spillway gates of both dams could not be lifted. Consequently, the dams failed due to breaching. In that scenario, the maximum catastrophic hydrograph was used as the inflow hydrograph for the upstream dam (the Nilüfer dam). On the other hand, the flood wave resulting from Nilüfer dam failure was employed as the inflow hydrograph

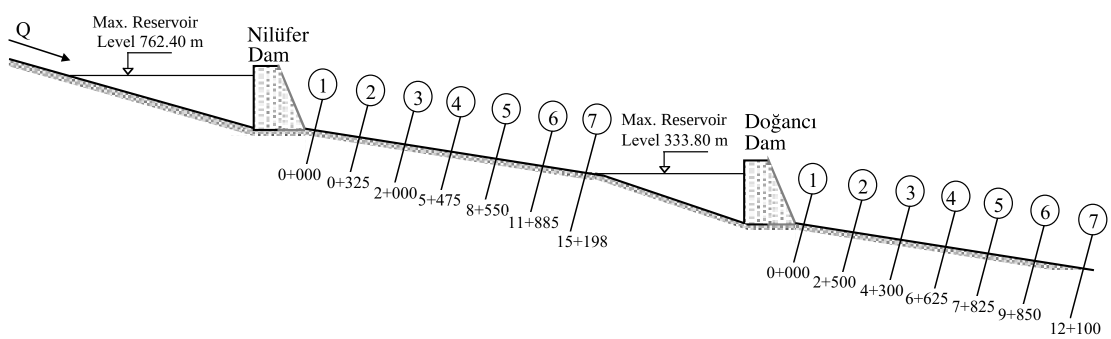

Figure 1a. Locations of Cross-sections with Respect to the Dams

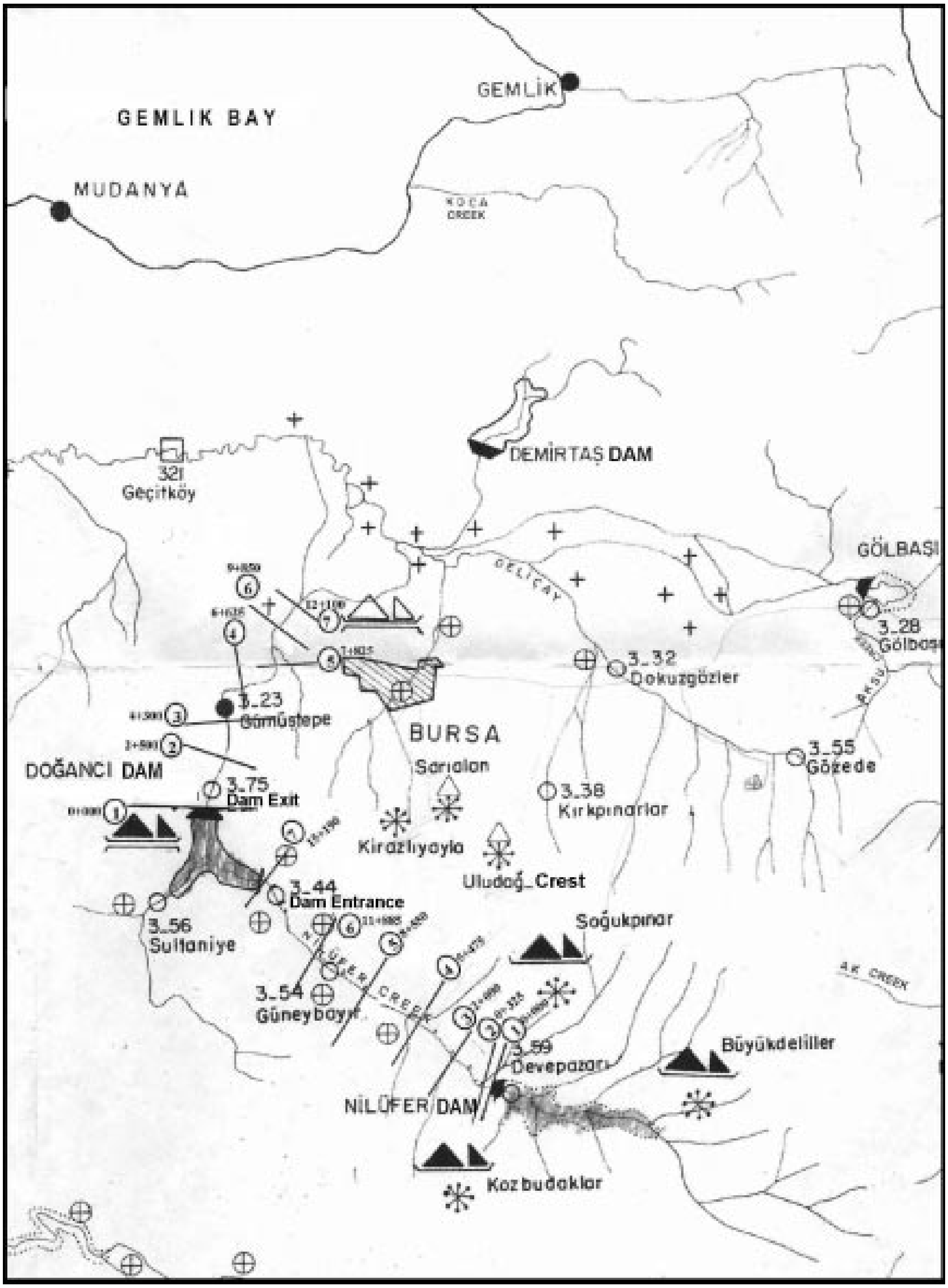

Figure 1b. Nilüfer River Basin and the Nilüfer and Doğancı Dams' Locations

Table 1. Hydrological and Physical Characteristics of the Nilüfer and Doğancı Dams

	Nilüfer dam	Doğancı dam	Unit
Catchment area	193.30	450.00	km^2
Annual mean inflow	93.30	164.75	hm^3/year
Average yield	50.00	70.00	hm^3/year
Type of dam	Rockfill	Rock-earth fill	-
Crest length	400.00	285.85	m
Height above ground level	84.50		m
Height above thalweg level	74.50	65.00	m
Total embankment volume	3,485,000	2,514,000	m^3
Crest elevation	764.50	334.00	m
Thalweg elevation	690.00	270.00	m
Maximum reservoir water level	762.40	333.80	m
Normal reservoir water level	760.00	330.00	m
Minimum reservoir water level	720.00	312.00	m
Reservoir capacity at normal res. water level	39.50	37.44	hm^3
Reservoir surface area at normal res. water level	147.20	162.30	hm^2
Dead storage	4.40	19.71	hm^3
Spillway type	Gated, 4 span	Gated, 3 span	
Number of gates and dimensions	4 and 5.50x8.50	3 and 8.00 x 11.50	m x m
Spillway crest elevation	752.00	322.00	m
Peak design flood	958.60	1970.00	m^3/sec

Table 2. Elevation vs. Area and Volume for the Nilüfer Dam

Elevation (m)	Area (hm^2)	Volume (hm^3)
690	0.00	0.00
695	2.21	0.06
700	6.64	0.28
705	12.78	0.76
710	20.72	1.60
715	28.67	2.83
720	33.88	4.40
725	49.81	6.49
730	61.64	9.28
735	73.55	12.66
740	87.46	16.68
745	100.03	21.37
750	111.78	26.66
755	127.75	32.66
760	147.21	39.50
765	168.66	47.43

for the Doğancı dam. In all of the scenarios, it was assumed that the initial water surface elevation in the reservoirs of both of the dams was at the maximum level permitted in the design. This assumption naturally accelerated the failure process.

Table 3. Elevation vs. Area and Volume for the Doğancı Dam

Elevation (m)	Area (hm^2)	Volume (hm^3)
270	0.000	0.000
275	0.002	0.001
280	3.100	0.080
285	14.000	0.510
290	27.700	1.550
295	41.500	3.280
300	55.600	5.710
305	71.000	8.870
310	86.800	12.820
315	102.100	17.540
320	120.500	23.100
325	145.300	29.750
330	162.300	37.440
335	184.300	46.100

In the DAMBRK computer model, the user is given a choice in assuming how the breaching of the dam develops. In the numerical simulations, the user can impose several breaching parameters such as the shape of the breach: trapezoidal, rectangular or triangular. This can be accomplished by varying the side slopes and base widths of the breaches suitably. Figure 4 defines the geometrical breach parameters. In addition, the user may decide how long it would take the breaching to complete its formation. For Scenarios 2 to 4, the same nine different groups of breach parameters shown in Table 5 were used. The time of failure as used in DAMBRK is the duration of time between the first breaching of the upstream face of the dam until the breach is fully formed.

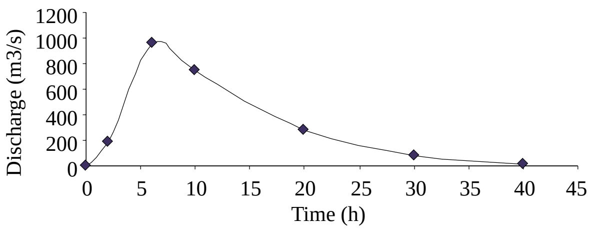

Figure 2a. Nilüfer Dam Inflow Hydrograph (Catastrophic)

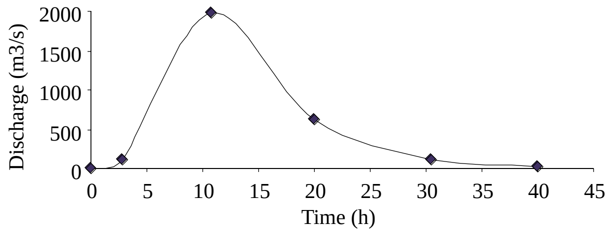

Figure 2b. Doğancı Dam Inflow Hydrograph (Catastrophic)

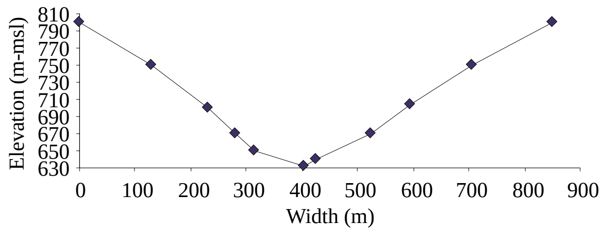

Figure 3. A Typical Cross-section in the River Valley

Table 4. Scenario Status Matrix

	STATUS OF SPILLWAY GATES, @		INFLOW HYDROGRAPH STATUS, @	
	Nilüfer dam	Doğancı dam	Nilüfer dam	Doğancı dam
Scenario 1	Working	Working	Maximum Catastrophic	Maximum Catastrophic
Scenario 2	Failed (Dam fails)	Failed (Dam fails)	Maximum Catastrophic	Flood wave from Nilüfer
Scenario 3	Failed (Dam fails)	Working (Dam fails)	Maximum Catastrophic	Flood wave from Nilüfer
Scenario 4	Working	Failed (Dam fails)		Maximum Catastrophic

Discussion of the Results

There are several residential areas, roads and agricultural areas in the downstream valley of each dam. For instance, the Çaybaşı village is located 5.5 km downstream of the Nilüfer reservoir and is 60 m above the riverbed. Cross-section 4 downstream of the Nilüfer dam passes through this village.

Doğancı village is 2.5 km downstream of the Doğancı reservoir. Cross-section 2 used in the Doğancı dam-break flood routing passes through that village, which is 30 m above the riverbed. The cross-section near Gümüştepe village, located 7.8 km downstream of the Doğancı dam, corresponds to cross-section 5 in this dam's analysis. This village is only 15 m above the riverbed. Residential areas of the city of Bursa start 12.1 km downstream of the Doğancı dam, which is cross-section 7 in the Doğancı dam analysis. Hydrograph routing through the Nilüfer River within the city of Bursa could not be performed due to the presence of bridges and retardation basins along the course of the river.

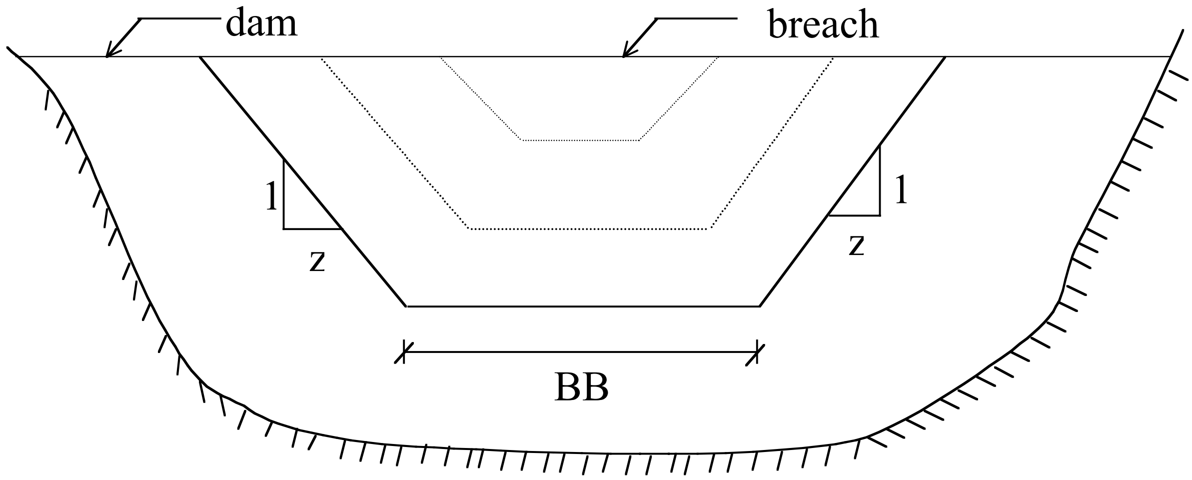

Figure 4. Definition Sketch for the Geometrical Breach Parameters

Table 5. Breach Parameter Groups for Scenarios 2, 3 and 4.

Breach Parameter Group Number	Failure Time of Breach, h	Breach Base Width, m (BB)		Breach Shape	Side Slope of Breach (z)	Bottom Breach Elevation, m (YBMIN)	
		Nilüfer Dam	Doğancı Dam			Nilüfer Dam	Doğancı Dam
1	1.0	0	0	Triangular	1	690	270
2	1.0	120	60	Trapezoidal	1	700	285
3	1.0	0	0	Triangular	2	690	270
4	2.0	0	0	Triangular	1	690	270
5	2.0	120	60	Trapezoidal	1	700	285
6	2.0	0	0	Triangular	2	690	270
7	3.0	0	0	Triangular	1	690	270
8	3.0	120	60	Trapezoidal	1	700	285
9	3.0	0	0	Triangular	2	690	270

The DAMBRK computer model was used to predict the flood wave motion downstream of the riverbed, caused by the conditions in the scenarios explained in the previous section. In the numerical simulations, the storage routing (i.e. level-pool routing) option was used to route the inflow hydrographs across each dam reservoir, instead of dynamic routing, since that method requires reservoir basin cross-section data, which were not available. As a feature of the DAMBRK computer program, the mixed flow option was used when the outflow hydrograph of a dam was routed to a downstream reach. This means that supercritical or subcritical flow is permitted to occur in the reach. The 1991 version of the DAMBRK model used in the present study contains an alternative solution method for treating the mixed flow problem. It consists of an algorithmic procedure that automatically subdivides the total routing reach into sub-reaches in which only subcritical or supercritical flow occurs. The transition locations where the flow changes from subcritical to supercritical or vice versa are treated as boundary conditions, and thus avoid the application of the Saint-Venant equations to the transition flow.

In Scenario 1, it was assumed that the maximum catastrophic inflow hydrograph entered the reservoirs of both dams in which the initial water surface elevations were at the maximum level. It was also assumed that the spillway gates at both dams were lifted properly. Table 6 shows the numerical results, namely, the maximum water depth and the maximum flow and their occurrence times at the pre-specified cross-sections for the Nilüfer dam. As seen in the table, the peak flood wave travels in the riverbed very fast, and arrives at cross-section 7 in 0.45 h (i.e. 27 min). Table 7 shows similar information for the Doğancı dam. Likewise, the peak flood wave travels very quickly in the riverbed, and arrives in about 0.30 h (i.e. 18 min). In short, the numerical simulation results based on this scenario indicate that the catastrophic inflow was discharged adequately through the dam spillways whose capacities were sufficient to prevent overtopping of the dam. Consequently, both dams stood strong. Since the maximum water depth elevations are below the level of villages nearby, there seems to be no major threat to the well-being of the people living in those villages, in this scenario.

Table 6. Maximum Water Depths and Flows Downstream of the Nilüfer Dam for Scenario 1

	Max. Water Depth (m) at Time (h)	Max. Flow (m3/s) at Time (h)
Cross-section 1 Km: 0+000	4.34 m 7.60 h	866 m^3/s 7.90 h
Cross-section 3 Km: 2+000	6.03 m 7.60 h	866 m^3/s 7.90 h
Cross-section 4 Km: 5+475	4.88 m 7.90 h	866 m^3/s 7.95 h
Cross-section 5 Km: 8+550	6.77 m 8.10 h	866 m^3/s 8.10 h
Cross-section 7 Km: 15+190	6.74 m 8.25 h	866 m^3/s 8.35 h

Table 7. Maximum Water Depths and Flows Downstream of the Doğancı Dam for Scenario 1

	Max. Water Depth (m) at Time (h)	Max. Flow (m^3/s) at Time (h)
Cross-section 1 Km: 0+000	10.21 m 0.00 h	1900 m^3/s 0.00 h
Cross-section 2 Km: 2+500	8.35 m 0.01 h	1900 m^3/s 0.01 h
Cross-section 4 Km: 6+625	11.57 m 0.20 h	1897 m^3/s 0.15 h
Cross-section 5 Km: 7+825	12.55 m 0.20 h	1896 m^3/s 0.20 h
Cross-section 6 Km: 9+850	8.94 m 0.25 h	1890 m^3/s 0.25 h
Cross-section 7 Km: 12+100	6.68 m 0.35 h	1885 m^3/s 0.30 h

In Scenarios 2 and 3, the DAMBRK program was run on the upstream dam, the Nilüfer dam, first. Then the last hydrograph, computed at the farthest cross-section from the Nilüfer dam, was treated as the input hydrograph for the downstream dam, the Doğancı dam. The only difference between Scenarios 2 and 3 is that in Scenario 3 it was assumed that the spillway gates of the Doğancı dam work properly. Tables 8 and 9 show the numerical results obtained for all of the nine simulations in Scenario 2 for both dams. In those tables one can easily see the maximum water depth, maximum flow and their occurrence time at some pre-specified cross-sections downstream of the Nilüfer and Doğancı dams, respectively. Figure 5 shows how the peak flow varies along the downstream of both dams in Scenario 2 at the same cross-sections.

It is clearly seen in the figure and tables that the worst conditions are generally created by Simulations 2.2 and 2.3, due to the largest breach opening and the shortest failure time selected in the assumptions. In Simulation 2.2, a trapezoidal breach with a side slope of z=1 was used for both dams. On the other hand, in Simulation 2.3, a triangular breach shape with a side slope of z=2 was used for both dams. The failure time in both simulations was taken to be 1 hour. Based on the results of the numerical simulations, an investigation was carried out to see whether or not residential areas were flooded. The following observations were made. The most critical locations seem to be cross-section 2 near Doğancı village and cross-section 5 near Gümüştepe village. Although, the peak water elevation does not reach the Doğancı village elevation, some agricultural lands are flooded. The maximum water depth in Simulation 2.2 was computed to be 26 m, occurring at hour 5.5 at cross-section 2 (i.e. Doğancı village). The peak flow passing this location was 43154 m^3/s, occurring at the same time.

As stated earlier, the other critical location was cross-section 5 near Gümüştepe village, located 15 m above the riverbed. Simulation 2.7 caused the largest water depth, 51.36 m, at that location. This means that the village is most likely to be flooded, including most of the houses, and the mosque, school and cultivated lands. One should also note that there is a large increase in water depth between cross-sections 2 and 5 in all simulations. This is attributed to the fact that cross-section 5 is much narrower than the preceding cross-sections 2, 3, and 4. Thus, the flood wave cannot pass through this location easily due to choking, resulting in an increase in water depth just upstream of that cross-section. For all simulations considered in the computations, the maximum water depths will occur between 4.81 and 7.79 h. Similarly, the maximum peak flows will occur between 5.50 and 7.94 h.

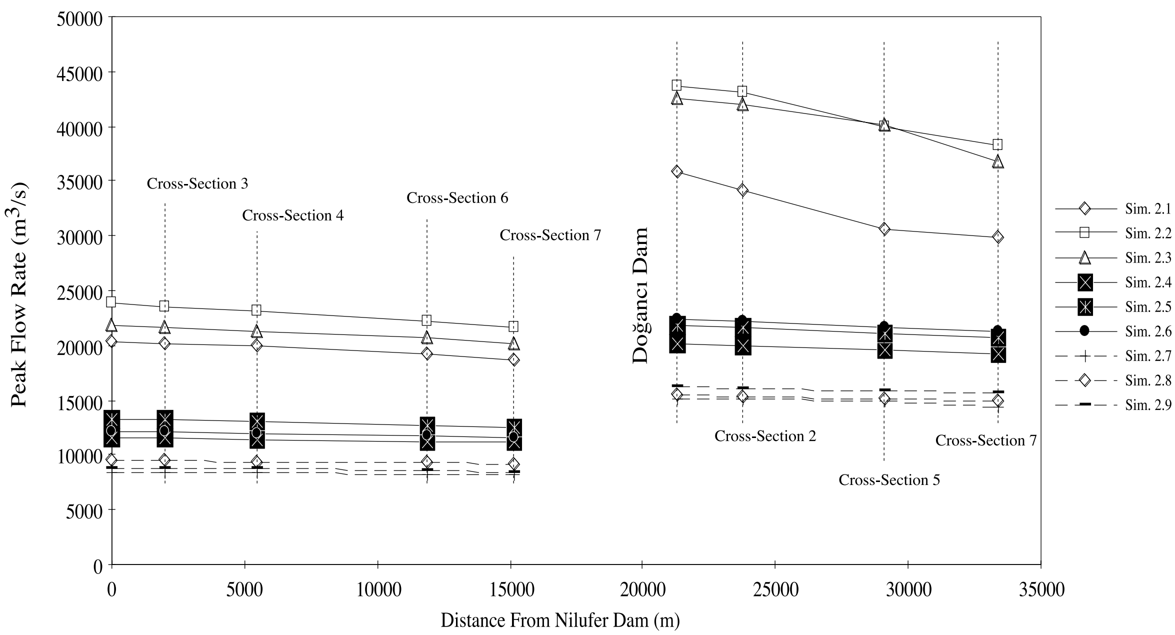

Figure 5. Peak Flow Rate Versus Distance from the Nilüfer Dam for Scenario 2

Table 8. Maximum Water Depths and Flows Downstream of the Nilufer Dam for Scenario 2

Simulation Number	Failure Time of Breach (h)	Breach Base Width (m)	Breach Shape	Side Slope of Breach (z)	Bottom Breach Elevation (m)		Max Water Depth (m) At time (h) Max. Flow (m3/sec) At time (h)				
		Nilüfer Dam			Nilüfer Dam	Doğancı Dam	Cross-section 1 0+000 km	Cross-section 3 2+000 km	Cross-section 4 5+475 km	Cross-section 6 11+885 km	Cross-section 7 15+190 km
2.1	1	0	Triangular	1	690	270	14.39 m 5.22 h 20407 m3/sec 5.22 h	18.33 m 5.270 h 20215 m3/sec 5.27 h	15.13 m 5.27 h 19974 m3/sec 5.27 h	22.62 m 5.37 h 19153 m3/sec 5.37 h	21.98 m 5.42 h 18684 m3/sec 5.42 h
2.2	1	120	Trapezoidal	1	700	285	15.41 m 5.00 h 23950 m3/sec 5.00 h	19.54 m 5.05 h 23592 m3/sec 5.05 h	15.99 m 5.10 h 23173 m3/sec 5.10 h	24.07 m 5.20 h 22247 m3/sec 5.20 h	23.32 m 5.25 h 21686 m3/sec 5.25 h
2.3	1	0	Triangular	2	690	270	14.81 m 5.09 h 21857 m3/sec 5.04 h	18.84 m 5.09 h 21626 m3/sec 5.09 h	15.51 m 5.14 h 21339 m3/sec 5.14 h	23.36 m 5.24 h 20653 m3/sec 5.24 h	22.67 m 5.29 h 20210 m3/sec 5.29 h
2.4	2	0	Triangular	1	690	270	11.27 m 5.82 h 11556 m3/sec 5.82 h	14.73 m 5.82 h 11507 m3/sec 5.82 h	12.29 m 5.92 h 11414 m3/sec 5.92 h	18.27 m 6.02 h 11229 m3/sec 6.02 h	17.78 m 6.12 h 11117 m3/sec 6.12 h
2.5	2	120	Trapezoidal	1	700	285	11.88 m 5.42 h 13334 m3/sec 5.42 h	15.51 m 5.42 h 13183 m3/sec 5.42 h	12.93 m 5.52 h 13077 m3/sec 5.52 h	18.18 m 5.62 h 12676 m3/sec 5.62 h	18.61 m 5.72 h 12498 m3/sec 7.72 h
2.6	2	0	Triangular	2	690	270	11.48 m 5.50 h 12181 m3/sec 5.50 h	15.00 m 5.50 h 12078 m3/sec 5.50 h	12.52 m 5.60 h 12003 m3/sec 5.60 h	18.62 m 5.7 h 11710 m3/sec 5.70 h	18.05 m 5.8 h 11590 m3/sec 5.80 h
2.7	3	0	Triangular	1	690	270	9.98 m 6.28 h 8420 m3/sec 6.28 h	13.06 m 6.28 h 8379 m3/sec 6.28 h	10.92 m 6.43 h 8332 m3/sec 6.43 h	15.89 m 6.58 h 8218 m3/sec 6.58 h	15.86 m 6.58 h 8154 m3/sec 6.58 h
2.8	3	120	Trapezoidal	1	700	285	10.44 m 5.8 h 9565 m3/sec 5.8 h	13.69 m 5.8 h 9496 m3/sec 5.8 h	11.42 m 5.95 h 9389 m3/sec 5.95 h	17.70 m 5.8 h 9260 m3/sec 5.95 h	16.54 m 6.10 h 9150 m3/sec 6.10 h
2.9	3	0	Triangular	2	690	270	10.14 m 5.92 h 8811 m3/sec 5.92 h	13.28 m 5.92 h 8770 m3/sec 5.92 h	11.09 m 6.07 h 8687 m3/sec 6.07 h	16.17 m 6.22 h 8543 m3/sec 6.22 h	16.09 m 6.22 h 8474 m3/sec 6.22 h

Table 9. Maximum Water Depths and Flows Downstream of the Doğancı Dam for Scenario 2

Simulation Number	Failure Time of Breach (h)	Breach Base Width (m)	Breach Shape	Side Slope of Breach (z)	Bottom Breach Elevation (m)		Max Water Depth (m) At time (h) Max. Flow (m3/sec) At time (h)			
		Doğancı Dam			Nilufer Dam	Doğancı Dam	Cross-section 1 0+000 km	Cross-section 2 2+500 km	Cross-section 5 7+825 km	Cross-section 7 12+100 km
2.1	1	0	Triangular	1	690	270	30.07 m 5.63 h 35852 m3/sec 5.63 h	23.36 m 5.64 h 34211 m3/sec 5.64 h	37.10 m 5.64 h 30621 m3/sec 5.74 h	25.89 m 5.84 h 29778 m3/sec 5.84 h
2.2	1	60	Trapezoidal	1	700	285	32.25 m 5.50 h 43689 m3/sec 5.50 h	26.14 m 5.50 h 43154 m3/sec 5.50 h	37.82 m 5.35 h 39979 m3/sec 5.50 h	37.31 m 4.806 h 38287 m3/sec 5.65 h
2.3	1	0	Triangular	2	690	270	31.96 m 5.43 h 42623 m3/sec 5.43 h	25.69 m 5.48 h 41939 m3/sec 5.48 h	36.74 m 5.48 h 40134 m3/sec 5.53 h	28.73 m 5.58 h 36812 m3/sec 5.63 h
2.4	2	0	Triangular	1	690	270	23.04 m 6.82 h 20089 m3/sec 6.82 h	18.44 m 6.92 h 19912 m3/sec 6.92 h	27.62 m 7.12 h 19559 m3/sec 7.02 h	21.24 m 7.12 h 19306 m3/sec 7.12 h
2.5	2	60	Trapezoidal	1	700	285	23.95 m 6.56 h 21849 m3/sec 6.56 h	19.12 m 6.56 h 21646 m3/sec 6.56 h	22.46 m 6.66 h 21168 m3/sec 6.76 h	22.02 m 6.76 h 20790 m3/sec 6.86 h
2.6	2	0	Triangular	2	690	270	24.25 m 6.47 h 22451 m3/sec 6.47 h	19.34 m 6.47 h 22221 m3/sec 6.47 h	27.80 m 6.67 h 21665 m3/sec 6.67 h	22.98 m 6.77 h 21181 m3/sec 6.77 h
2.7	3	0	Triangular	1	690	270	20.27 m 7.64 h 15137 m3/sec 7.64 h	16.33 m 7.64 h 15057 m3/sec 7.64 h	51.36 m 7.04 h 14835 m3/sec 7.79 h	18.56 m 7.79 h 14445 m3/sec 7.94 h
2.8	3	60	Trapezoidal	1	700	285	20.47 m 7.00 h 15479 m3/sec 7.00 h	16.46 m 7.08 h 15348 m3/sec 7.08 h	25.46 m 7.38 h 15101 m3/sec 7.23 h	18.87 m 7.38 h 14969 m3/sec 7.38 h
2.9	3	0	Triangular	2	690	270	20.91 m 6.99 h 16211 m3/sec 6.99 h	16.78 m 7.00 h 16053 m3/sec 7.00 h	25.97 m 7.30 h 15768 m3/sec 7.15 h	19.25 m 7.30 h 15628 m3/sec 7.30 h

Table 10. Maximum Water Depths and Flows Downstream of the Doğancı Dam for Scenario 3

Simulation Number	Failure Time of Breach (h)	Breach Base Width (m)	Breach Shape	Side Slope of Breach (z)	Bottom Breach Elevation (m)		Max Water Depth (m) At time (h) Max. Flow (m3/sec) At time (h)				
		Doğancı Dam			Nilufer Dam	Doğancı Dam	Cross-section 1 0+000 km	Cross-section 2 2+500 km	Cross-section 3 4+300 km	Cross-section 5 7+825 km	Cross-section 7 12+100 km
3.1	1	0	Triangular	1	690	270	26.48 m 6.44 h 27145 m3/sec 6.44 h	21.08 m 6.45 h 26998 m3/sec 6.45 h	18.78 m 6.45 h 26696 m3/sec 6.45 h	33.07 m 6.45 h 25864 m3/sec 6.5 h	24.07 m 6.55 h 25280 m3/sec 6.55 h
3.2	1	60	Trapezoidal	1	700	285	29.92 m 5.84 h 35357 m3/sec 5.84 h	23.75 m 5.95 h 34887 m3/sec 5.89 h	24.06 m 5.95 h 34770 m3/sec 5.95 h	38.04 m 5.8 h 33631 m3/sec 5.99 h	26.99 m 6.09 h 32666 m3/sec 6.09 h
3.3	1	0	Triangular	2	690	270	30.08 m 5.80 h 35902 m3/sec 5.78 h	23.86 m 5.83 h 35658 m3/sec 5.83 h	26.55 m 5.88 h 35130 m3/sec 5.88 h	37.33 m 5.81 h 34238 m3/sec 5.98 h	27.16 m 6.03 h 33134 m3/sec 6.03 h
3.4	2	0	Triangular	1	690	270	19.82 m 7.23 h 14415 m3/sec 7.23 h	16.00 m 7.33 h 14355 m3/sec 7.33 h	14.61 m 7.43 h 14303 m3/sec 7.43 h	24.77 m 7.53 h 14222 m3/sec 7.53 h	18.38 m 7.63 h 14144 m3/sec 7.63 h
3.5	2	60	Trapezoidal	1	700	285	20.83 m 6.89 h 16085 m3/sec 6.89 h	16.69 m 6.99 h 15827 m3/sec 6.99 h	15.19 m 7.00 h 15731 m3/sec 7.00 h	25.72 m 7.19 h 15463 m3/sec 7.09 h	19.04 m 7.19 h 15256 m3/sec 7.19 h
3.6	2	0	Triangular	2	690	270	21.23 m 6.85 h 16800 m3/sec 6.85 h	17.00 m 6.95 h 16531 m3/sec 6.95 h	15.46 m 6.95 h 16437 m3/sec 6.95 h	26.19 m 7.15 h 16136 m3/sec 7.05 h	19.41 m 7.15 h 15898 m3/sec 7.15 h
3.7	3	0	Triangular	1	690	270	17.07 m 8.21 h 10281 m3/sec 8.21 h	13.81 m 8.36 h 10158 m3/sec 8.21 h	12.69 m 8.36 h 10135 m3/sec 8.36 h	20.81 m 8.51 h 10021 m3/sec 8.51 h	15.59 m 8.51 h 9951 m3/sec 8.51 h
3.8	3	60	Trapezoidal	1	700	285	17.62 m 7.69 h 11051 m3/sec 7.69 h	14.23 m 7.70 h 10921 m3/sec 7.70 h	13.04 m 7.85 h 10832 m3/sec 7.85 h	21.47 m 7.85 h 10697 m3/sec 7.85 h	14.09 m 7.99 h 10535 m3/sec 7.99 h
3.9	3	0	Triangular	2	690	270	18.34 m 7.62 h 12106 m3/sec 7.62 h	14.78 m 7.63 h 11935 m3/sec 7.63 h	13.52 m 7.78 h 11839 m3/sec 7.78 h	22.40 m 7.93 h 11651 m3/sec 7.78 h	16.70 m 7.93 h 11526 m3/sec 7.93 h

As stated previously, the same initial hydrologic conditions were used in Scenario 3 as in Scenario 2. The only difference being that in Scenario 3 it was assumed that the spillway gates of the Doğancı dam worked properly during the event. Table 10 shows the maximum water depths and flows downstream of the Doğancı dam for Scenario 3. Moreover, Figure 6 shows the variation of peak flow rate along the downstream river reach of both dams in Scenario 3. Simulations 3.2 and 3.3 resulted in the worst conditions, as was the case in corresponding Simulations 2.2 and 2.3 in Scenario 2 previously. Naturally, similar conclusions were reached in this scenario, with the most critical locations being cross-sections 2 (Doğancı village) and 5 (Gümüştepe village). The maximum water depth at cross-section 2 computed in simulation 3.2 was 23.75 m, occurring at hour 5.95. Similarly, the peak flow passing this location was 34887 m^3/s, occurring at hour 5.89. However, the largest water depth in Simulation 3.2 was computed at cross-section 5 (38.04 m). For all simulations performed in this scenario, the maximum water depths will occur between 5.8 and 8.51 h. Similarly, the maximum peak flows will occur between 5.78 and 8.51 h. The fact that the spillway gates of the Doğancı dam worked properly in Scenario 3 helped reduce the maximum water depths compared to those of Scenario 2. Nevertheless, the computed depths and flows were still dangerous for Doğancı and Gümüştepe villages, as significant parts of them were observed to be flooded in this scenario.

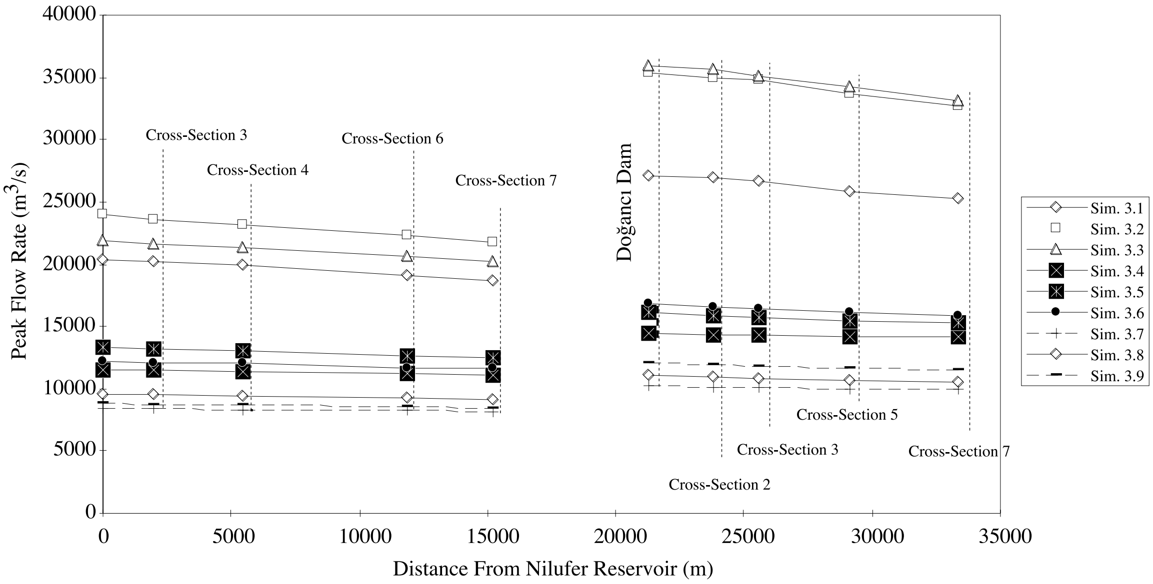

Figure 6. Peak Flow Rate Versus Distance from the Nilüfer Dam for Scenario 3

In Scenario 4, it was assumed that everything was normal in the reservoir of the Nilüfer dam, and that its spillway gates worked properly. However, things were not so favourable downstream for the Doğancı dam, since it was assumed that the inflow hydrograph was the maximum catastrophic hydrograph, and that its spillway gates failed to open. In this scenario, the worst hydraulic conditions were computed in Simulation 4.3, in which a triangular breach shape was employed with a side slope of z=2, and the failure time of breach was taken to be 1 hour. Although the flooding was not as serious as it was in Scenarios 2 and 3, this scenario was still observed to be harmful at Doğancı and Gümüştepe villages. However, the most negatively affected region was Gümüştepe village. This village was still completely flooded.

Scenario 2 was found to be the worst among all the scenarios employed in the present study. This is the scenario in which the spillway gates of both dams did not function properly, and both dams failed. This is apparent in Figure 7, which shows the relationship between the peak flow and the distance downstream for all scenarios in which dams failed.

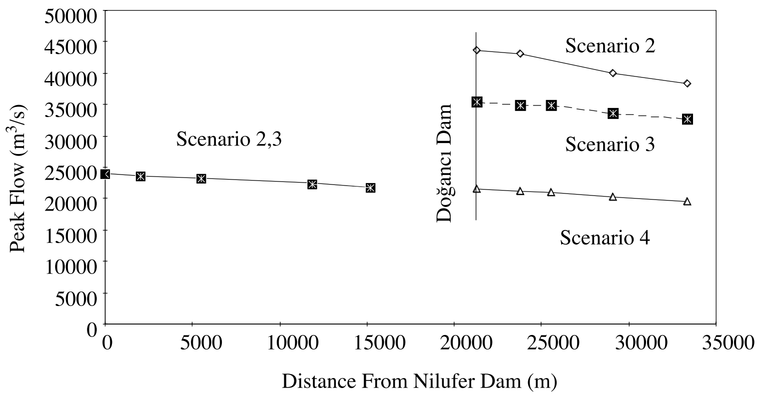

Figure 7. Comparison of Maximum Peak Flow Rates for Scenarios 2,3 and 4

As Petrascheck and Sydler (1984) demonstrated, it was observed that the peak flow, inundation levels and flood arrival time are sensitive to changes in breach width and breach formation time. For locations well downstream of a dam, the timing of the flood wave peak can change significantly with changes in breach formation time, but peak discharge and inundation levels are insensitive to changes in breach parameters. Warning and evacuation time can dramatically influence the loss of life from dam failure. When establishing hazard classifications, preparing emergency action plans (EAP), or designing early warning systems, good estimates of warning time are crucial. Warning time is the sum of the breach initiation time, breach formation time, and flood wave travel time from the dam to a population centre. Case history-based procedures developed by the Bureau of Reclamation (Brown and Graham, 1988) indicate that loss of life can vary from 0.02% of the population at risk with a warning time of more than 90 minutes to 50% of the population at risk when the warning time is less than 15 minutes.

Summary and Conclusions

In the present study, simultaneous dam-break analyses of two dams (i.e. Nilüfer and Doğancı dams) located in the same branch of the Nilüfer river in the province of Bursa were performed, using a computer program called DAMBRK, under four different scenarios. For each scenario, nine different breach parameter combinations were employed.

One of the major goals was to determine the potential areas that would be subject to flooding caused by dam-break failures. It is known that there are several residential areas, roads and agricultural areas in the downstream valley of each dam. After extensive simulations were performed for all of the scenarios, it was concluded that the worst conditions were created by Scenario 2 in which both dams failed simultaneously. One should keep in mind that the computations were carried out under some theoretically possible scenarios that may never be the case during the economic lifetime of the dams. Nevertheless, the results indicated that some precautions should be taken by the officials in the region to avoid or at least to minimize the hazards of potential dam-break failures. It is recommended that the city officials in charge of public safety establish emergency action plans (EAP), which were developed by the Bureau of Reclamation of the U.S. (1995). Some steps that should be taken in the pre-event case are listed below.

Area/Regional offices should

a) ensure that EAPs are developed and implemented at all significant and high hazard dams.

b) ensure that EAPs are reviewed annually and revised or updated in a timely manner. Reviews will include both the specific procedures contained in the EAPs as well as the names, telephone numbers, radio frequencies, and organizations contained in the Communications Directory.

c) ensure that EAPs contain complete descriptions of available communication capabilities and related notification procedures. Appropriate communication directories should also be included.

d) ensure that EAP's contain initiating conditions (including hydrologic and non-hydrological events), emergency response levels, expected actions for each response level (operating personnel and pertinent government agency offices), and hazard specific appendices with procedures to follow.

e) ensure that EAPs contain descriptions of potentially affected areas in the flood plain with inundation maps wherever appropriate, and tables showing flood wave travel times and other pertinent information that may be needed by local emergency management officials.

References

Bozkuş, Z., "Baraj Yıkılması Analizleri İçin Geliştirilmiş Matematiksel Bir Model", DSİ Teknik Araştırma ve Kalite Kontrol Dairesi Başkanlığı Yayını, YN:Hİ-879, 1994a.

Bozkuş, Z., "Baraj Yıkılma Analizlerinde Kullanılan Matematiksel Modellerin Kıyaslanması ve Uygulamalı Örnekler", DSİ Su ve Toprak Kaynaklarının Geliştirilmesi Konferansı Bildirileri, Ankara, 2, 731-747, 1994b.

Bozkuş, Z., and Kasap, A., "Comparison of Physical and Numerical Dam-Break Simulations", Tr. J. of Engineering and Environmental Science, 22, 429-443, 1998.

Brown, C.A., and Wayne J.G., "Assessing the Threat to Life from Dam Failure", Water Resources Bulletin, 24(6), Dec., 1988.

Danielson, J.A. and Mc Intyre, W.C., "A Status Report on Dam Safety in the U.S.", Hydro Review, 8(2), April, 1989.

Fread, D.L., "The Development and Testing of a Dam-Break Flood Forecasting Model.", Proc. of Dam-Break Flood Modeling Workshop, US Water Resources Council, Washington D.C., 1-34, 1977.

Fread, D.L., "The NWS DAMBRK Model: Theoretical Background/User Documentation", Hydrologic Research Laboratory, National Weather Service, Silver Spring, Maryland 20910, August 1991.

Güner, A.İ., "Pre-Event Dam Failure Analyses for Emergency Management", MSc. Thesis in Civil Engineering at Middle East Technical University, Ankara-Turkey, Dec., 1998.

Merzi, N., Usul, N., and Molu M., "Dam-Break Flood in a Natural Channel: A Case Study", Tr. J. of Engineering and Environmental Science, 21, 19-27, 1997.

Petrascheck, A.W. and Sydler P.A., "Routing of Dam Break Floods", International Water Power and Dam Construction, 36, 1984.

Sezer, C., "Barajların Yıkılması ve Tehlike Analizlerinin Önemi", DSİ Teknik Bülteni, 77, 79-92, 1992.

U.S. Bureau of Reclamation "Emergency Planning and Exercise Guidelines", March, 1995.

Wurbs, R.A., "Military Hydrology; Report 13: Comparative Evaluation of Dam-Breach Flood Forecasting Methods", Miscellaneous Paper EL-79-6, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1986.