Chapter 3. Water and Wastewater System Performance in the August 17, 1999 Izmit (Kocaeli), Turkey Earthquake

John Eidinger[1], Teresa Elliott[2], Le Val Lund[3],

## Abstract

This chapter describes damage to several water and wastewater systems that were affected by the $M_w$ 7.4 earthquake of August 17, 1999, with epicenter near Izmit, Turkey. Figure 1 shows the main locations covered in this chapter.


Figure 1. Map showing main locations, fault location

[1] M. ASCE, Principal, G&E Engineering Systems, 6315 Swainland Road, Oakland, CA 94611
[2] M. ASCE, Portland Water Bureau, Portland, OR xxxxx
[3] M. ASCE, Los Angeles, California, xxxxx

## Seismologic Aspects

The Izmit earthquake occurred at 3:02 am local time, on August 17, 1999. The earthquake occurred on the northern segment of the Anatolian fault system. It has been estimated to be a moment magnitude Mw 7.4 event.

As of mid-September 1999, the exact length of surface faulting for this earthquake is not known precisely. At a minimum, there was surface faulting for about 60 km of length; however, there may also have been surface faulting in underwater sections, and the total length of fault rupture may reach almost 200 km.

As of mid-September, 1999, data from 35 strong motion accelerometers have been reduced (minimum level of ground motion 0.005g or larger). The highest horizontal peak ground acceleration recorded was 407 cm/sec^2 (0.41g), for an instrument located near Adipazari. The second highest recording was 0.38g, for an instrument near Duzce (Duzce is located about 40 km east of Adapazari, off the map in Figure 1). Key aspects of recorded motions are as follows:

- The trend of the highest ground shaking follows a east-west line, which agrees with the location of the northern segment of the Anatolian fault.
- No very high acceleration ground motions (0.6g to 0.8g or higher) were recorded. The lack of recordings for such high ground motions does not mean that such motions did not occur.

From 1939 to 1992, there had been 10 separate earthquake events on the Anatolian fault system, with moment magnitude of 6.5 or larger. These events occurred in 1939, 1942, 1943, 1944, 1949, 1951, 1957, 1966, 1967, 1971 and 1992, with the 1939 event being the first and largest (Mw 7.9) of this sequence. Figure 2 shows the sequence of earthquakes. Generally, these events have progressed along the fault system from east to west, progressively increasing the stress on the unbroken fault to the west. Current theory [Stein et al] suggested that the Izmit section of the fault was becoming highly stressed, and most likely to. It did.

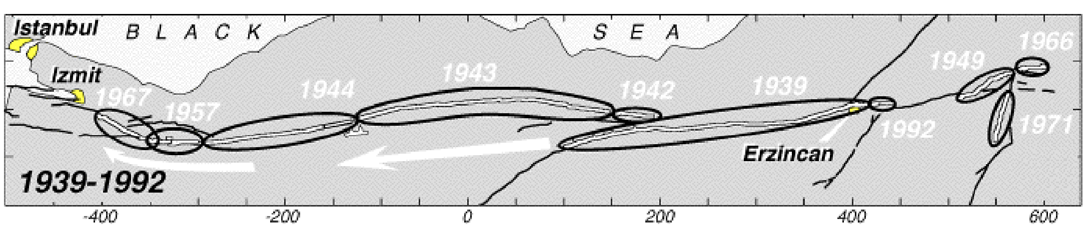


*Figure 2. Sequence of Earthquakes Along the Anatolian Fault (Horizontal Scale in km)*

## Soil Conditions

Adapazari City is located in a region covered by alluvial deposits. Many parts of Adapazari City suffered extensive liquefaction. Some buildings sank, settled and tilted due to liquefaction while some of them collapsed. Cracks were observed on pavement in the city and local highways, limited sand volcanoes and ground cracks have been observed. The following describes the soil subsurface conditions in the downtown area of Adapazari, based on recent boreholes.

- Boring 1. The location this boring is Cark Street, where there was great damage to buildings. The top meter is composed of artificial fills and silty clay. There is a non plastic silt layer with sand seams lying below the artificial fill and silty clay layers. SPT blow counts are less than 10 for the soil layers down to about 4 m below the surface. There is a dense gravelly sand layer underlying the silty layer.
- Boring 2. The location this boring is close to the Municipality Building; that building which was moderately damaged. The top soil layers are artificial fill and silt. There is a loose sand layer down to 5 m. At this point dense gravelly sand layer dominates again below the loose sand.
- Boring 3. The location of this boring is close to the Industrial Center Project. There are loose silt and sand layers down to 14 m. A similar soil condition is dominated in much of the heavy damaged area in the city.
- The ground water table varies from approximately 1 to 3 m in depth due to the presence of two rivers surrounding the city and nearby Sapanca Lake.

Izmit City is located on Izmit Bay. The effect of local soil condition on structures where they are close to Izmit Bay has been observed strongly. Some buildings settled and slightly tilted. The general soil condition of the area of Izmit Bay shore is characterized as soft organic clay down to approximately 30 m. Silty sand layers are dominated below the soft clay layer. The ground water table is approximately 1 m in depth.

Heavy damaged has been observed at the Ciftlikkoy vicinity near Yalova. A boring was drilled in Ciftlikkoy site for a telecommunication project. The boring shows a 5 m thick sand layer underlying a clay layer. Silt and clay layers lie below the sand layer. Heavy damage has been developed the part of Ciflikkoy where is close to the Marmara Sea.

### General Damage to the Building Stock

The damage to the general building stock was widespread and extensive. While other reports concentrate for the reasons for the damage, the following general observations are made.

The general building stock is constructed as reinforced concrete frame buildings with hollow clay tile infill walls. Most residential buildings are from 5 to 6 stories in height. The high damage rates described below can be attributed to a designs with insufficient lateral force withstand capability; strong ground shaking (0.3g or higher in many areas); numerous instances of soft story construction / irregularities in plan; inadequate detailing of reinforced concrete confinement steel; use of smooth rather than deformed steel bars in reinforced concrete; non ductile reinforced concrete frames; and poor quality of concrete mix.

In Adapazari, about 15% of all buildings collapsed, another 15% were in the complete damage state (but not collapsed), another 20% in the extensive damage state, and the remaining 50% in the none, slight or moderate damage states. Damage was especially high due to widespread liquefaction in this area, with settlements common of a few inches to over 1 foot. The common design practice in this area was to construct the buildings on mat foundations, with no piles or piers to counter the potential for differential settlement from liquefaction.

In Golcuk, a about 45% of all buildings either collapsed or will have to be torn down. The high failure rate is attributed to surface faulting, soil failures near the sea shore, and strong ground shaking (likely over 0.4g in many areas).

In Yalova and Izmit, the percentage of buildings in the complete or collapse modes was lower than in Adapazari or Golcuk, but still substantial (in the range of 10% to 25%). Highest instrument-recorded ground shaking was 0.26g in Yalova and 0.22g in Izmit..

**Water and Wastewater Systems in the Adapazari Area**

Figure 3 is a schematic diagram of the water systems serving the Adapazari area. The key features are as follows.

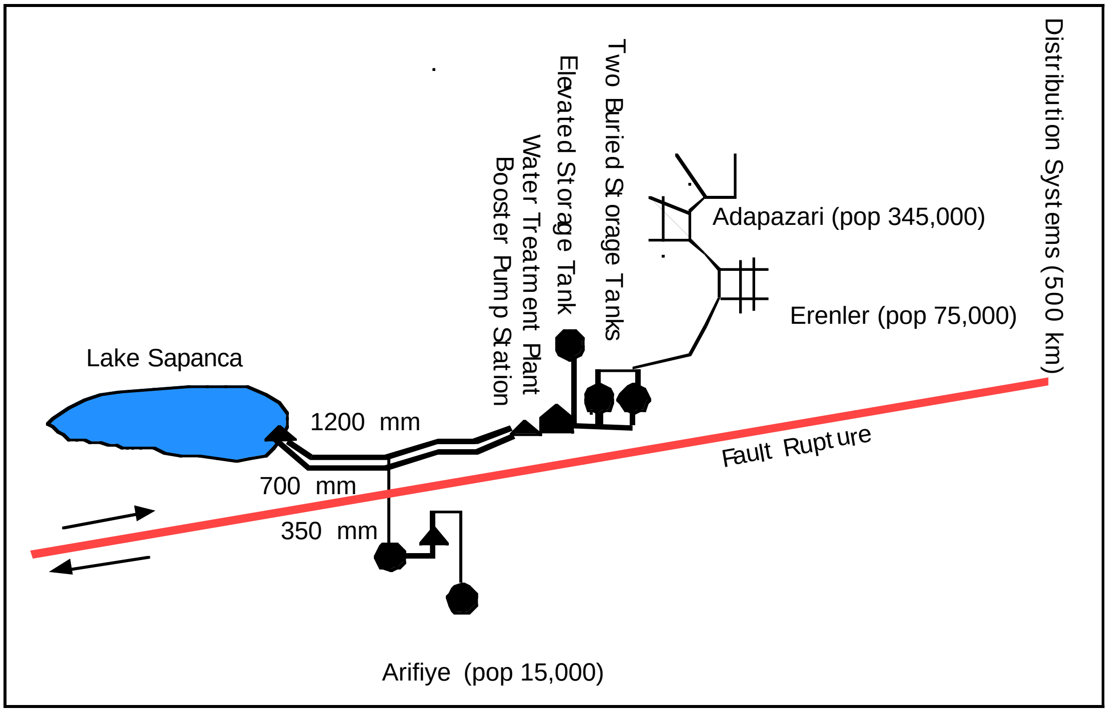


*Figure 3. Water System Schematic Diagram for the Adapazari – Arifiye – Erenler Area*

Raw water is taken from Lake Sapanca, located about 15 km west of Adapazari. The water is drawn from the lake via an intake structure, and then pumped to a hillside location in Adapazari, called Maltepe. In 1998, a new water treatment plant was opened at Maltepe, with a booster pump station. The Maltepe Water treatment plant provides potable water to the City of Adapazari, Erenler, and 5 other local communities.

The raw water is delivered to the Maltepe WTP via two parallel transmission pipelines of 700 and 1200 mm (28 and 47 inch) diameter. The Maltepe WTP treats the water using rapid sand filters. The finished water is stored in two buried reinforced concrete tanks adjacent to the WTP, as well as in a smaller elevated concrete tank. The buried tanks provide gravity flow storage for most of Adapazari and surrounding communities. The elevated tank provides gravity flow storage for the smaller community on Maltepe hill.

The earthquake produced the following damage to water and wastewater systems in the Adapazari region.

**Arifiye Water System**. Arifiye draws its water supply directly from the two transmission pipelines from Lake Sapanca. The raw water supply to Arifiye is chlorinated, but is otherwise not treated. The earthquake knocked out power to the pump station at Lake Sapanca, caused damage to the intake structure's trash screens, and broke the transmission pipelines. Given these issues, it took about 3 days to restore water supply to the Arifiye water system.

The Arifiye water system is in two pressure zones (see Figure 3). The two local storage tanks are buried concrete reservoirs, and were not damaged. Both pressure zones lost water quickly after the earthquake, once water from the two local storage tanks was lost through broken pipes.

Once water supply was restored from Lake Sapanca, it was discovered that there were many pipeline breaks in the Arifiye area. Of largest concern was the damage to the 350 mm (14 inch) diameter welded steel pipeline (wall thickness 4 mm) where it crossed the fault trace. Once this pipeline was repaired, water supply could be restored to all regions of the lower zone, and the backbone pipes of the upper zone.


*Figure 4. Ovalized Steel Pipeline, Removed From Fault Offset Location, Arifiye*

The 350 mm steel pipeline (Figure 4) was damaged due to right lateral fault offset of about 3.6 m (12 feet). The pipeline crossed the fault at about a 70 degree orientation, placing the pipeline in tension due to the offset (90 degrees = the pipe is perpendicular to the fault). Contributing factors to the pipeline damage could be the large amount of offset; a possible concrete encasement of the pipeline where it crossed beneath the motorway; and a mitred joint in the pipeline where it changed direction to go under the motorway. Note the significant amount of ovalization in the piece of steel pipeline that was removed (Figure 4); according to the City Manager in charge of pipeline repairs, the ovalization shown in Figure 4 was exactly how the pipe looked before it was taken out of the ground.

By September 6 (21 days after the earthquake), water supply had been restored to most customers in the lower zone, as well as to the two storage tanks. However, damage to distribution pipelines in the upper zone and elsewhere had not yet been repaired. In total, about 60% of the town's water customers had water restored by September 6. A detailed map of the water system for this community of 15,000 people was not available; however, it is estimated that there are about 20 km of distribution pipelines serving this community. The repair force dedicated to repairing water, sanitary and storm sewers averaged about 11 people, working about 12 hour days. Allowing that this repair crew could fix, on average, two damage locations per day, about 40 locations were already repaired, with possibly 20 more locations needed to complete the job for the water system. This suggests a forecasted total number of 50 water repair locations, with a similar number of sanitary and storm pipes to be repaired.

It was apparent that the City had not designed its water system to withstand the effects of earthquake; the fault trace was not known to bisect the major backbone transmission pipeline for the city.

Similar damage was sustained to the sanitary and storm sewer systems in Arifiye. Figure 5 shows about 10 feet of right lateral offset of a storm sewer, where it crossed the trace of the fault.


*Figure 5. Fault Offset Through Storm Drain, Arifiye*

**Maltepe Water Treatment Plant**. The Maltepe WTP was recently built, opening for operation in 1998. It serves five municipalities, including Adapazari, Erenler and three others. The WTP performed as follows.

The steel enclosure (Figure 6) building suffered no visible damage.


*Figure 6. Maltepe Water Treatment Plant (Steel Building and Elevated Concrete Tank)*

The thirty six rapid sand filters are located in 3 m diameter elevated steel storage tanks. These tanks are supported on four steel columns, each column bolted to a concrete foundation with four bolts. With the exception of some bolts which were stretched, there was no damage to the tanks.

The tanks are arranged in groups of four. For each group, there is a vertical pump (no damage) and various attached small bore pipes. Some attached steel pipes were loosened by the earthquake, which required minor repair.

The chemicals used for treatment (chlorine, alum) were housed in plastic tanks. These tanks were not anchored, and likely slid sideways small amounts during the earthquake. However, the attached chemical line pipes (PVC) were apparently sufficiently flexible (few / no anchor points observed) and had no reported damage.


*Figure 7, Unanchored Plastic Tanks – Maltepe WTP*

The booster pump station is enclosed in a buried concrete vault. There was no damage to the ten horizontal pumps (all well anchored), or attached water and power lines (all well installed). There was minor damage to one small section of the pump station building where it used infill block walls. The circuit breakers for the pumps are housed in a small building located at grade; these circuit breakers were in an unanchored electrical cabinet, and the cabinet fell over sideways in the earthquake. An adjacent electrical cabinet housed batteries; the batteries also fell over during the earthquake (Figure 8). For both the circuit breakers and batteries, the plant operator informed us that they were repositioned after the earthquake, and they functioned properly.


*Figure 8. Unanchored Batteries at Maltepe WTP. They Tipped Over in the Earthquake*

- The power transformer used for the booster pump station and the WTP was installed on roller wheels. One bushing of the transformer had been damaged and replaced (Figure 9).


*Figure 9. Unanchored Transformer Serving Maltepe WTP. A Bushing was Damaged.*

The two clearwells (one 5,000 and one 15,000 cubic meter storage, or 5.3 million U.S. gallons total) were undamaged by the earthquake. However, all water from both clearwells was lost almost immediately (within 1 hour) after the earthquake, due to downstream distribution system pipeline damage.

The water treatment plant lost raw water supply immediately after the earthquake. This was caused by a series of problems: lost power supply at Lake Sapanca intake structure; damage to the trash rack at the intake structure; and pipeline damage to the 1200 and 700 mm transmission pipelines. The power supply was restored in two days; the other damage was repaired shortly thereafter. It took 3 days to restore partial flow of the water supply to the Maltepe WTP. (By one account, it took 10 days to restore raw water flow to the WTP). During this time frame, there was no water available via the distribution system in the Adapazari area.

**Adapazari Water Distribution System.** For the City of Adapazari, there are 500 km of buried distribution pipelines. About 75% of these pipelines are made from Asbestos Cement pipe (AC pipe), 25% from PVC pipe and a small amount of butt welded steel pipeline (3 to 4 km). Typical AC pipe joinery was with rubber gasketed joints. Typical steel pipes use butt welded joints.


*Figure 10. Typical Rubber Gasket Joint Fitting for AC Pipe, Common to All Water Systems in the Area*

As of September 6 (day 21 after the earthquake), only 20% of the City had water service restored. The total number of people performing pipeline repairs was estimated by one city official at between 400 to 600 people, with mutual aid forces accounting for more than one-half the effort. However, further interviews with other officials suggested that perhaps at most 200 people were devoted to distribution pipeline repairs, and possibly as few as 40 to 60 people. The repair strategy was hampered by the following: lack of up to date distribution pipeline maps; congestion in streets due to collapsed buildings and debris removal; lack of suitable pipeline hardware for replacements.


*Figure 11. Damage to 14" Diameter AC Pipe – Liquefaction Area*

The distribution pipeline repair strategy was to repair the largest distribution pipelines leading away from the Maltepe water treatment plant. Once a pipeline was repaired, the valves were opened and the location of additional leaks was observed by visual inspection of water coming up to the street level (the water utility staff called this "hunt and seek").


*Figure 12. Common Damage Pattern to AC Pipe In Areas with Settlement*

For the main distribution pipeline serving the downtown area (18" diameter), the entire length of AC pipe was being dug up and replaced with butt welded steel pipe. Our investigation team noted that the effort was going along at about a 200 feet of pipe replacement per day, using a single crew. Figure 13 shows the replacement steel pipe outside the trench, ready for installation. Note the following: the replacement steel pipe uses bevelled joints; there is no interior lining for the steel pipe; the exterior coating appears to be a coal tar finish; there are no special safety precautions used to construct and maintain the trench; there appears to be special soil bedding or compaction being used for the new steel pipe; there is evidence that liquefaction occurred adjacent to the alignment. It appeared from our limited observations that the repairs to the distribution system did not include flushing the pipeline with super-chlorinated water prior to returning the line to service.


*Figure 13. New 16" Diameter Butt Welded Pipe for Replacement of AC Pipe*

The typical service lateral in the area is made from polybutylene pipe. Breaks to these service lines are not currently being addressed by the water utility, except where valves on the service lines are located beyond the break. Many service lines were ruptured, especially due to the differential settlements of buildings due to liquefaction.


*Figure 14. Installation of New Butt Welded Steel Pipe – Adapazari*

Based on the level of effort devoted to pipeline repairs, and the progress made through September 6, it is estimated that an average of 50 people were actually in the field making pipeline repairs. The city reported to us that they had 10 repair crews, operating 3 shifts per day. Included as part of this effort were repair crews and equipment from other cities, including Ankara, Istanbul and the Turkish DSI. As of September 6, 20% of Adapazari had water supply restored. An average repair crew included a heavy truck driver, a backhoe operator, and three laborers. Assuming a 5-person crew could effect about two repairs per shift, then about 300 repairs could have already been made by September 6. The forecasted number of repairs for the entire Adapazari region could reach 1,000 or more, before 100% of the area will have restored water supply.

**Adapazari Wastewater Collection System.** At the time of the earthquake, the City of Adapazari operated a sanitary sewer collection system and a separate storm water system. There is no wastewater treatment plant for Adapazari, although plans were underway to construct one.

The earthquake caused heavy damage to the collection system. In some areas, temporary bypasses had been made to allow the broken sanitary sewers to discharge into the storm water collection system. Figure xx shows such a location, with solids floating down the storm channel.


*Figure 15. Broken Sanitary Sewer in Adapazari.*


*Figure 16. Solids in Storm Canal Due to Combined Flow from Broken Sanitary Sewers*

**Erenler Water Distribution System.** The city of Erenler (population 75,000) is located adjacent and just east of Adapazari. Erenler's water distribution system receives its water from the Maltepe WTP. Through September 6, 1999, about 50% of the water distribution system was operational.

Labor and parts shortages were the major issues in limiting how fast the City could restore water service. For example, only about 25% of the City's municipal work force was available, due to the large number of casualties in the earthquake, coupled with the need for non-injured staff to take care of other family responsibilities. About 15 to 20 people were working on repairing the water system pipeline damage, as of September 6. All pipeline repairs were being made with AC pipe.

Almost immediately after the earthquake, many potable water vendors started to show up in Erenler, to distribute potable water. The City Staff were concerned that not all the vendors might be delivering truly potable water, and within two days after the earthquake they instituted control points for all water vendors; at these control points, the water was inspected and manually chlorinated.

No fires started in Erenler after the earthquake.

Sanitary sewer pipes in Erenler were heavily damaged by the earthquake. The sewer pipe is about 90% concrete and 10% reinforced concrete. The system was not working as of September 6. Soon after the earthquake, there were lots of blockages in the sewer collection system (a gravity collection system); the system was smelling so badly that they dedicated resources to find those locations and unblock them.

Over the three weeks after the earthquake, there were no reports of disease that could be traced back to this emergency potable water supply, or the poor performance of the sanitary sewer system.

**Goodyear Tire**. The Goodyear Tire manufacturing facility is located on the northeast shoreline of Lake Sapanca. This facility was built in 1965, originally as a Uniroyal facility, and then bought by Goodyear in 1986. The facility includes its own water and wastewater systems. The facility has 800 employees; 5 of whom were killed by the earthquake, and many of which were displaced by damage to their homes. The facility had installed a large tent shelter facility on its site to house its employees and families.

The facility was in mostly full operation by September 7, although some damage from the earthquake had yet to be repaired. Based on the location of the facility, it appears the site is located on a flat alluvial site, with firm soils. There was no observation of liquefaction settlement at the site.


*Figure 17. Well at Goodyear Tire Facility – No Damage*

There are four water systems for the Goodyear Tire facility. The primary system for showers and sanitary purposes is from a well. The well is 50m deep. It suffered no damage from the earthquake with the exception of loss of power (there was no on-site backup power for operating the well). A secondary system for water supply for showers and sanitary purposes is a connection to the Adapazari city-wide distribution system; as of September 7, this connection was still not repaired, with no schedule yet made as to when that connection would be re-established; however, this was not considered vital, as the local well was sized large enough to provide all water needed. The plant manager estimated it might take up to 6 months for the City water to be restored to the plant facility; this estimate may be too long.

A fiberglass 1,500 liter tank atop a small building was used to store potable water. This tank broke its connections and was a total loss.

The on-site water buried distribution pipeline system is composed of PVC and screwed steel pipelines. The plant manager informed us that there were a few leaks to be repaired, but not many; and only for the screwed steel pipes.

For drinking water, all water at the Goodyear Tire facility is provided from bottled water sources (this was true before and after the earthquake).

For process water, there is a raw water intake from Lake Sapanca.

The facility also operates two small wastewater treatment plants. The first plant treats the shower and sanitary water, with effluent going to a creek; the creek eventually flow to the Black Sea. This plant includes a grit removal system, a settling basin, two trickle biologic media basins, and a chlorine contact tanks. Damage to the facility included sloshing-induced damage to baffles in the settling basin; this damage had not been repaired by September 6.

The second wastewater plant is an oil separation facility. The influent is the process water used in the tire manufacturing process. The water first enters an aeration pond (no damage), with removal of the largest solids. The water is then pumped into a settling basin. A track—guided oil skimmer sits atop this reinforced concrete basin; there was no damage to the skimmer, even though the tank is kept full of the oil-water mixture. The skimmed oil is stored in another open reinforced concrete tank (about 3m x 3m x 3m), which was about one-third full at the time of the earthquake. Oil sloshed out of the oil storage basin, and had yet to be cleaned up by September 6. Adjacent to these tanks was an older settling pong with baffles; while this older pond was no longer in use, it had water in it, and some of the baffles were damaged; likely due to sloshing forces.

### Water Systems in Yalova Area

**Yalova Water Treatment Plant**. The water source for the Yalova area is a water treatment plant located about 6 km southwest of Yalova (Yalova WTP). The estimated level of ground shaking at this site is about 0.10 to 0.20g. The Yalova WTP has a capacity of 1,600 liters per second (37 million gallons per day).

The Yalova WTP was constructed and made operational in 1986. This WTP serves 13 municipalities. The plant manager did not know if the plant had been specifically designed for earthquakes.

The raw water source for the Yalova WTP is an impoundment reservoir (earthen dam) located adjacent to the water treatment plant. The dam was not inspected by our team, but was reported to have no damage.

Raw water from the dam is pumped up a hill to the Yalova WTP. Power was lost to the pumps immediately after the earthquake. Offsite power was restored to these pumps in two days. There were no permanent backup power supplies at the WTP to restore raw water supply any sooner.

The earthquake caused significant damage to the downstream transmission pipeline and distribution systems served by the Yalova WTP. The 5,000 cubic meter clearwell (1.3 million gallons) emptied within 30 minutes after the earthquake, due to the downstream pipeline damage.

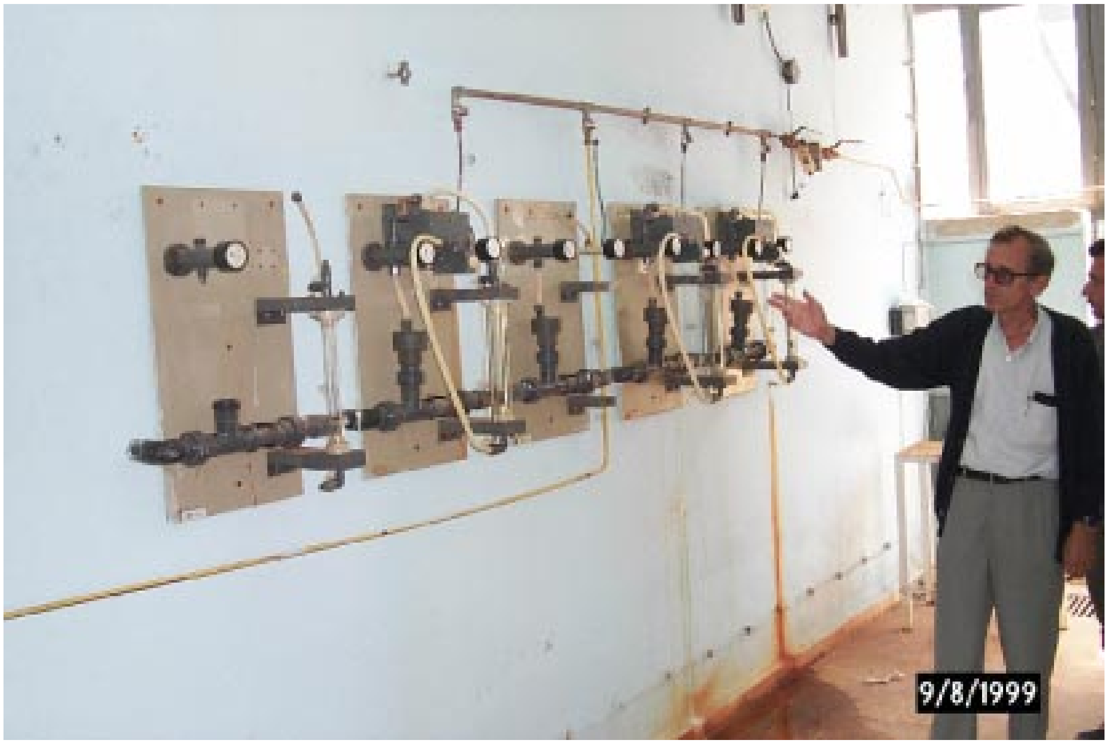


*Figure 18. Damage to Five Chlorine Mixing Units – Yalova WTP*

During the two days when the WTP could produce no water, fire water supplies were provided by water tanker truck, with the tanker trucks drawing supply from the raw water reservoir. Fortunately, there were few fires in the Yalova area, and these did not spread. The lack of many ignitions and lack of spread was attributed to: little to no wind at the time of the earthquake; almost complete lack of timber construction materials; no natural gas system in the area; few if any cooking fires (propane systems) were in use at the time of the earthquake (3 am).

The Yalova WTP serves communities from Yalova in the west, to just past Golcuk in the east. The total population served in this area varies according to the time of year; during the summer months, there are a lot of vacationers from nearby Istanbul, and the population swells to over 800,000.

Damage to the WTP was limited to the loss of all five chlorine mixing units. Sodium hypochlorite was manually added to the finished water while repairs to the mixing units were made. As of September 8, only 3 of the 5 mixing units had been repaired.

The apparent lack of other types of damage to the facility can be attributed to the following factors. The level of ground shaking at the site was moderate (0.10g to 0.20g range estimated); all clarifiers were reinforced concrete, with all internal baffles and water troughs and intermediate basin walls also made from reinforced concrete. The main filter beds also used  reinforced concrete water troughs. The site is on a hillside, characterized as a rock foundation. While the plant did well overall, we noted that the one ton chlorine tanks were unanchored (not strapped); lab equipment (glassware and countertop equipment) had not toppled; nearby housing structrures of average structural quality were not damaged.


*Figure 19. Clarifiers at Yalova WTP. No Damage to RC Water Troughs or Baffles*

The 80-km long transmission pipeline carrying treated water from the Yalova WTP to the coast was damaged in many areas. Repairs to this steel pipeline were made beginning at the location nearest the WTP, towards Golcuk. It took 2 days to restore water service via the transmission pipeline to Yalova (limited by the power outage), 6 to 8 days to restore water service to Golcuk. Between 7 and 20 days, the steel transmission pipeline suffered additional damage, causing ongoing water outages. This additional damage was attributed to aftershocks in the Golcuk area, or continuing ground movements.

After the earthquake, the level of disinfection (chlorine) for the effluent from the WTP was increased four fold over normal levels. In addition, there was a boil water alert. This was done to preclude water borne disease, over concern that breaks from sanitary sewers would contaminate the potable water supply.

By September 8, the Yalova WTP was producing between 1,200 l/s (28 MGD) and 700 l/s (16 MGD) during peak daytime and lower nighttime hours. This represents about 30% reduction from normal production levels.

**Yalova Water Distribution System**. The city of Yalova (population 78,000) is located adjacent to the Sea of Marmara. It receives its treated water from the Yalova WTP, by gravity feed.

As of September 8, 1999, there were still ongoing repairs being made to the distribution pipelines near the coast.

Within the city, there are several elevated water towers. These towers hold treated water. The towers are typically made from reinforced concrete, with a reinforced concrete support structure (Figure xx). While none of the towers were known to have collapsed, there was damage to the towers. This included spalling of concrete (Figure xx), and leaking inlet / outlet pipes (Figure xx). This damage had not been repaired 22 days after the earthquake, indicating that scarce repair crews were being used elsewhere to make pipeline repairs.

**Golcuk Water Distribution System**. The City of Golcuk (population 290,000) is located about 40 km east of the Yalova WTP.

The buildings in Golcuk suffered widespread damage. Of a total of 26,000 buildings, about 12,000 collapsed.

The building housing the water department collapsed. The building was located in the zone affected by fault offset. Temporary offices were set up in the maintenance yard. The workforce for the water and wastewater departments totaled 480 people; 27 employees died in the earthquake.

At the time of the earthquake, the only source of water to Golcuk was via a 1 m diameter transmission pipeline from the Yalova WTP. A new WTP had been constructed nearby (Thames River Kullar WTP), but the connection (1.4 m diameter transmission pipeline) to that WTP had not been put into service before the earthquake (apparently for economic reasons). After the earthquake, the connection to the Kullar WTP was made operational, although it was unclear as to whether this would be on a permanent basis. After the earthquake, it took 8 days to repair the transmission pipeline from Yalova, and 7 days to repair the transmission pipeline from Izmit.

The main highway (the Ataurkbulrari highway) through Golcuk runs in a east to west direction. It divides Golcuk into areas of higher elevation (south of the highway) and lower elevation (north of the highway, down to the sea).

South of the main highway, the water system was still in the process of being repaired, as of September 9 (day 23). About 10% of the water system in this area was damaged. Water service had been restored to most of the structures that were still in use. About 2/3 of the total water system is located south of the main highway.

North of the main highway, the remaining 1/3 of the water system was essentially 100% out of service, as of September 9 (day 23). This was due to several reasons. First, water was being first restored nearest the transmission pipelines (higher elevations south of the highway). Second, there was extensive damage to the distribution system north of the highway, up to the shoreline. This damage was due to extensive fault offset, coupled with ground subsidence towards the Sea of Marmara. Third, there was still many heavily damaged structures north of the highway which were a continued threat to collapse, and the water department did not want to work in the area with this continuing threat.

The City of Golcuk has three main potable water tanks in its distribution system. The size of two of the tanks are 5,000 cubic meters (1.3 million gallon) and the third is 700 cubic meters (185,000 gallons). All three were buried reinforced concrete tanks. There was no damage reported to these tanks. The City's water distribution system operated in three pressure zones. The two upper zones are served by a total of three pumping plants. The lower zone is a gravity zone.

There are 1,010 km of distribution pipelines in the water distribution system. The primary backbone pipelines within the system are 600 mm  (24 inch) diameter butt welded steel pipe. The next smaller group of backbone pipes are 350 to 400 mm (14 to 16 inch) diameter AC pipe, using AC couplings with rubber gaskets. The smaller distribution pipes are 100 to 250 mm (4 to 10 inch) diameter PVC pipe.

After the earthquake, Golcuk received emergency potable water via boat from Istanbul; each shipment was 300,000 cubic meters (79 million gallons). Water was distributed within Golcuk using 400 temporary storage tanks, ranging in capacity from 500 to 3,000 liters.

**Golcuk Wastewater System**. The Golcuk sanitary sewer collection system was heavily damaged. Most of the damage (known as of September 9) was concentrated in the fault offset area. The gravity flow system brought wastewater down to the lowest elevation, where a large diameter interceptor was located near the sea. This interceptor took the wastewater counterclockwise around the Izmit Bay, to a wastewater plant in Izmit. However, the interceptor pipeline was destroyed in many locations, with parts of it falling into the sea due liquefaction, lateral spreading and/or fault offset. Currently, the collection system simply empties into the sea.

### Water Systems in Izmit Area

**Kular Water Treatment Plant**. The Kular WTP is located about 3 km south of the town of Kular. This modern plant is a privately funded operation, owned by a consortium which includes the Thames River Water Company and two Japanese companies. The consortium is called Izmitsu (Izmit Water). The Kular WTP and pipeline transmission system was built and put into first operation in January, 1999. The WTP has a nominal operating capacity of 490,000 cubic meters per day (129 MGD). The WTP serves a population of 1,200,000 people in 19 municipalities.

According to plant staff, the plant was designed to the latest seismic code, for a ground motion of 0.4g.

The WTP is staffed by 70 employees on site. The facility includes reinforced concrete shear wall buildings used as residences for some of their employees. None of these buildings were significantly damaged by the earthquake, although they did suffer some minor non structural damage (fallen over items, etc.)

Raw water supply for the WTP is via a 2.2 m (86 inch) diameter pipeline from a nearby impoundment reservoir. There was no reported damage to the impoundment reservoir dam.

The WTP includes a permanent 13 MW backup diesel engine power supply. The batteries for the diesel were anchored. The facility also uses UPS systems for battery backup power to computer systems.

The WTP uses chloride gas for disinfection. The plant also monitors water quality at the plant and at the turnouts to the various municipalities.

There is a 80,000 cubic meter (21 million gallon) clearwell at the WTP site.

The Izmitsu system includes a main transmission pipeline that takes treated water from the WTP and sends it to the various cities served by the Kular WTP. This transmission line is 140 km long. It begins as a 2.2 meter (86 inch) diameter welded steel pipeline when it leaves the WTP, continuing north around Izmit Bay, then west to Gebze. At

Karfez, the pipeline is 1.6 m (63 inch) diameter. At Gebze, it is 1.2 mm (47 inch) diameter. The pipeline is rated at 150 psi. The pipeline is epoxy coated. The branch line to Golcuk is 1.6 m diameter (63 inch) butt welded steel pipe. The transmission pipeline is fully cathodic protected with impressed current per AWWA and British standards.

The transmission system includes five pump stations, of which three are on the main line, and two are on branch lines. The transmission system also includes 25 potable water reservoirs that provide balancing storage for some of the municipalities served from this WTP. Branch lines to various municipalities are ductile iron with restrained joints.

After the earthquake, they shut down the WTP for two days to check for damage at the WTP and breaks along the transmission pipelines. The WTP lost offsite commercial power for 3.5 days.

No structures at the WTP were damaged. There are four rectangular clarifier tanks; each tank was subdivided into numerous bays with a total of 350 bays. Water enters and discharges from each bay via two underwater PVC pipes, called tridents (called tridents due to their three-pronged collection headers). 170 of the 700 tridents were damaged by the earthquake. Most likely, these failures were due to sloshing forces from the water, and possibly the pipes had not been designed for these loads. Sloshing of water that caused water to spill out of the basins was noted. This damage caused a modest reduction in plant capacity. Since the earthquake, the plant has been operating at a much lower than normal capacity, owing to the great amount of destruction in the local distribution pipeline systems, and the large number of displaced people.

The transmission pipeline was reported to have suffered no complete breaks, although it did suffer a number of leaks via attached small diameter blow-offs (wash outs). Also, it was reported that a transmission pipeline was leaking where it crossed the fault offset near Golcuk. Also, leaks were reported at gasket locations at blind flanges.

Prior to the earthquake, the WTP had an emergency response plan, but did not have mutual aid agreements with other water agencies. Since the earthquake, they plan to implement mutual aid agreements.

They have tents on site to house employees displaced from their damaged homes; they have plans to bring in pre-fabricated structures to provide more permanent housing for their employees.

Near Izmit, the Tofuz refinery suffered a large fire which burned for several days. It was reported that the refinery had elected not to purchase water from the Kular WTP, and turned down offers to obtain water from the Kular system during the fire.

**Izmit Water Distribution System**. The City of Izmit (population 220,000 in the central district) currently gets its water supply from the new Kular WTP. The Izmit water system also serves two outlying districts. Prior to the recent connection to the Kular system, the water supply was from springs in the local mountains.

The Izmit water distribution system includes larger diameter backbone transmission pipelines (700 to 2200 mm in diameter). There are seven pump stations and 19 buried concrete storage reservoirs. The distribution system includes steel, ductile iron, AC and PVC pipe.

Immediately after the earthquake, the Izmit water system relied upon its original (old) source for water, due to loss of water supply from the newer Kular WTP.

There was damage to the connection to the Izmitsu (Kular) transmission pipeline.

At one fault crossing of a 900 mm (36 inch) diameter transmission pipeline to Kular, there was a 20 cm slip (pull apart and telescoping) over a 150 m long length of pipe, with some permanent deformation to the pipe. This pipe was reported to have been layed in 80 m lengths, and was 25 years old.

As damage to the distribution is being repaired, they are replacing the damaged pipe with in-kind pipe. As of September 10, the water district believed that the damage to the distribution system was slight, but this could not be confirmed until debris from collapsed buildings would be removed.

There was no damage at the seven electric pump stations, except for the loss of commercial power supply for two days. The pump stations had no backup power supplies.

There was no reported damage to the buried concrete reservoirs.

Of the repairs made to the buried pipelines to date, most were at the joints to the pipelines. For thee first 10 days after the earthquake, the water system was providing minimal service to the area. As of September 24 (day 24), most of the area was restored to service, but they are continuing to find more leaks every day.

They are currently doing water quality checks, independent of the water quality testing at the Kular WTP.

The water utility had 200 people working on water and wastewater pipeline repairs. 3 of their staff died in the earthquake.

**Izmit Wastewater System**. The Izmit wastewater treatment plant (WWTP) has a normal capacity of 10,500 liters per second (242 MGD). The plant suffered some damage. The main collector pipeline (9 km long) was damaged and remained out of service as of day 24. As of September 24, the extend of damage to the main collector pipeline was not yet known. The damage to the WWTP included failures to a clarifier, scraper systems, and one motor was displaced.

The wastewater system included two lift stations, which were undamaged.

Immediately after the earthquake, they bypassed the WWTP, due to loss of commercial power, and they had no on-site backup power.

As of September 24, the WWTP was operating, but at very low levels (30,000 liters per day = 8,000 gallons per day); the low flow rates reflect that there is damage to the water distribution and wastewater collection systems, and the displacement of people from their houses has resulted in very little use of the wastewater collection system.

## Emergency Response for Water and Wastewater Systems

It is fair to say that in essentially all areas affected by strong ground shaking, most (70% is lesser affected areas to 100% in the worst affected areas) of the normal water supply was lost immediately after the earthquake. The dominant reason for long duration water outages was breakage to underground pipelines. The loss of power to water treatment plants caused a total loss of water production for the first two days after the earthquake, thereby hampering the pipeline restoration process. The three water treatment plants for the area each suffered minor damage to equipment.


*Figure 20. Water Trucks Bringing Potable Water to Urban Areas*

The use of modern water treatment plants in the earthquake zone is relatively new. The three plants were put on line in 1986, 1998 and 1999. Prior to that time, water supply to the area had only minimal treatment (chlorination), and therefore the normal attitude of the population was to use bottled water for drinking purposes. Even before the earthquake, this was the case, as old traditional thought as to the quality of the local water supply was only slowly changing.


*Figure 21. Small Potable Water Containers Being Delivered*

In some ways, this might be fortunate, in that there has been a robust system to produce, distribute and sell potable water in bottles and in small to medium size storage tanks. After the earthquake, almost 2,000 different water distribution points were set up, using 500 liter to 2,000 liter water storage tanks. Figures 19 to 21 show a few examples of water being distributed using these tanks.


*Figure 22. Potable Water Tank (2,000 liters) in Downtown Adapazari*

## Conclusions and Recommendations

This earthquake caused extensive damage to water and wastewater systems in the zones within 20 km either side of the rupture. The water and wastewater systems in the area were similar in many regards to systems in other parts of the world that had been recently subjected to strong earthquakes, including Kobe Japan (1995 Kobe earthquake), Los Angeles California (1994 Northridge earthquake), and San Francisco California (1989 Loma Prieta earthquake). The basic conclusions are as follows:

- The water and wastewater treatment plants in the Izmit earthquake suffered modest damage to equipment (baffles, underwater pipelines, some electrical equipment). The dominant reason for this damage was lack of attention to fluid sloshing forces. This type of damage reduces plant capacity for a short duration, but can often be repaired quickly.
- The water and wastewater treatment plants in the Izmit earthquake suffered little to no structural damage. This was because the plants were modern, and for the most part had been designed for large earthquake forces.

- Only one of the four major water and wastewater treatment plants in the Izmit earthquake had permanent standby power supplies. If permanent standby power supplies had been available at the two remaining water facilities, water service to customers would have only been marginally better, but downstream transmission pipelines would still have caused widespread water outages. Still, the availability of water from the WTPs immediately after the earthquake would have shortened the time needed to start making repairs to distribution pipelines, and would also have been essential if water had been needed for fighting fires following earthquakes.

- There was heavy pipeline damage to buried transmission and distribution pipelines. As of the time of writing this report, an accurate inventory of pipelines and damage locations is not available. However, it is estimated that there will ultimately be over 3,000 repairs made to the approximate 3,000 km of pipelines in the area of the strong ground shaking. The dominant reasons for pipeline damage were: ground settlements due to liquefaction (widespread in the Adapazari region); surface fault offset in the Golcuk region; strong ground shaking (regional); prevalent use of relatively weak pipeline materials (AC pipe).
- Damage to butt welded steel pipeline occurred at fault crossing and possibly other locations. This style of steel pipeline construction is not prevalent in the United States, where the common field girth joints are made using single lap welds. Some of these steel pipelines apparently did survive fault offsets of up to 10 feet, with no damage or only with leaks. Further investigations about the specific designs for these steel pipelines could shed important light on the future design and performance of pipelines for fault offset.
- The lack of a high number of fire ignitions and no fire spread could be attributed to several factors. There were calm wind conditions at the time of the earthquake. A fire resistant masonry-type style of construction was most common. There were adequate fire breaks in most areas. There were no natural gas underground pipeline systems in most areas. The earthquake occurred at 3 am, when there was little cooking. There was a regional power outage almost immediately after the earthquake, lasting for two days (or longer) in most areas.(Note: the influence of a lack of water at a major fire at a refinery is discussed in another chapter of this report).

## Abbreviations Used in This Chapter

| | |
|---|---|
| AC | Asbestos Cement |
| cm/sec | centimeter per second |
| g | acceleration (percent of gravity) |
| km | kilometer |
| l/s | liters per second |
| m | Meter |
| mm | Millimeter |
| Mw | Moment magnitude |
| MGD | Million Gallons per Day (U.S. measure) |
| PVC | PolyVinyl Chloride |
| WTP | Water Treatment Plant |
| WWTP | Wastewater Treatment Plant |

## Chapter Authors and Reviewers

This chapter was written by John Eidinger and reviewed by Teresa Elliott, Le Val Lund, Nesrin Bosaz. [TE, LVL, NB: change this is you end up originating some material!!!].


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Photo and Drawing Credits. Figure 1 was jointly prepared by Alex Tang and John Eidinger. Figure 2 is adapted from Stein, et al (Reference 1). Figures 3 through 19 and 21 to 22 (photos and drawings) were prepared by John Eidinger. Figure 20 was taken by Alex Tang. Note that in some photos, the correct date of 9/6/99 is shown incorrectly as 1/1/99 due to a Y2K bug.

## References

[1] Stein, Ross S., Barka, Ayjut A., and Dieterich, James H., Progressive failure on the North Anatolian fault since 1939 by earthquake stress triggering, Geophysical Journal International, 1997, Vol. 128, pp 594-604.