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AN ANALYSIS OF BATHYMETRIC CHANGES IN ALTINAPA RESERVOIR

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Abstract: The aim of this study was to determine changes in surface area and volume of the Altinapa Reservoir, in Turkey, according to the water levels. To adopt measures for collecting more water in dam reservoirs, lakes and ponds, to prevent water pollution, protect water sources and extend the service life of these facilities, it is important for users (Municipalities, SHW, Irrigation Unions etc.) to know the current topographic conditions and any changes in the storage capacities of these facilities. Sedimentation is one of the most serious factors that threaten aquatic environments such as dams, lakes and ponds. Sedimentation causes some lakes, ponds and dams to be filled and polluted in a short time. It also causes loss of capacity and reduces the lifespan of the facilities.

Changes in surface area and volume of the Altinapa Reservoir were identified by comparison of topographic and bathymetric data used for the management of the facility. Two ArcGIS digital elevation models, from 2009 and 1981, were used to determine changes in storage capacity of the reservoir. The calculations indicated that, within this 28-year period, the storage capacity of the reservoir decreased by 12.4% due to sedimentation. Furthermore, compared to volume data from 1967, when the dam was constructed, the water storage capacity was found to have decreased by 33.4%.

Keywords: Bathymetric surveying, Dam, Sediment, RTK-GPS.

1. INTRODUCTION

With three seas surrounding it, hundreds of lakes of various sizes, ponds and dams, Turkey has strategic and geopolitical importance in the world. Including the sea area within the continental shelf, Turkey has approximately 26 million ha of usable waters, 95% of which consists of seas, 1.3% of which consists of reservoirs, 3.5% of which consists of natural lakes and approximately 0.1% of which consists of ponds (Kalkan & Alkan, 2005). Reduced precipitation due to global warming, population growth and increasing life standards lead to increased consumption of potable water, which requires more effective and cautious use of water resources. Therefore, water sources should be protected, water pollution should be prevented, water sources should be managed and water that is not used should be stored in environments such as a dam/pond.

Accumulation of sediment is one of the most serious factors that threaten aquatic environments such as dams, lakes and ponds. Sedimentation causes some lakes, ponds and dams to be filled and polluted within a short time. It also causes loss of area and volume, and reduces the lifespan of facilities (Kalkan & Alkan, 2005).

It is known that Turkey's rivers transport a large amount of soil into dams, lakes and seas – 4 times the global average and 17 times the European average (Celiker & Anac, 2003). Significant losses have occurred in nearly twenty reservoirs and ponds in Turkey due to excessive accumulation of sediment; some others no longer function correctly or are very close to losing function (Celiker & Anac, 2003).

In order to store more water in reservoirs, lakes and ponds, or prevent water pollution, protect water sources and extend the service life of these facilities etc., it is important to know the current topographic conditions and any changes in the capacities of these facilities. For this reason, bathymetric maps of these facilities should be renewed at every five years. According to data from the State Hydraulic Works, bathymetric maps have not been produced for the majority of reservoirs, lakes and ponds in Turkey, and the majority of the existing maps were outdated or small-scaled (Sapcilar & Fakioglu, 2003; Fakioglu, 2005).

Studies have been carried out to determine volume changes caused by sediment deposit in various reservoirs and lakes (Childs et al., 2003; Kress et al., 2005; Boddy & Ganske, 2005; Jordan et al., 2005). Previous studies compared earlier bathymetric data, which was obtained through classical measuring techniques, with more recent bathymetric data, obtained from updated measuring equipment and GIS techniques. They analyzed volume changes caused by sediment deposition in lakes and dam reservoirs. It was reported that the capacity of the McConaughy Dam Reservoir (USA) decreased by 0.03%/year; Overholser reservoir (USA) decreased by 0.29%/year, Seyhan Reservoir (Turkey) decreased by 0.71%/year, and Sille Reservoir (Turkey) decreased by 0.48%/year. Based on these values, it can be suggested that sedimentation is a serious threat to the continued operation of Turkey's reservoirs. In addition, there are some studies that investigated of the changes of bed elevations and related to the sediment supply deficit or surplus of the rivers (Mureşan, 2009; Radoane et al., 2010).

The characteristic of sediment wasn't investigated in this study. There are two aim of this study. One is to produce updated (2009) topographic and bathymetric data for Altinapa Reservoir and, by comparison with existing data from 1981, to identify any changes in lake surface area and volumetric changes caused by sedimentation and erosion. Other is to obtain more detailed and more accurate information about Altinapa Reservoir using modern surveying technologies (Global Navigation Satellite System, Echo Sounder-sonar) and geographic Information System (GIS).

2. MATERIAL AND METHOD

2.1. Topographic and Bathymetric Measurements

Although the application of hydrographic measurements is limited with the coastline, to establish a connection between hydrographic maps and the coast, some details should be measured in the coastline and coastal belt. These details vary according to the aim and scale of the maps. For example, in small-scale sea maps, instead of the topography of the coastal belt, the preliminary aim is to show features that help geodetic or electromagnetic navigation. Apart from exceptional cases, the details of the coast line and the coastal belt make use of previously drawn land maps of the area, if these exist. If no land map of the area is available then, for small area classical methods (tachyometric, RTK-GPS etc.) and for large areas, photogrammetric and distance sensor methods are generally used.

In bathymetric measurements, to detect the locations of points in the vertical and horizontal planes, location and depth measurements are conducted simultaneously. Location measurements always apply classical (known) methods, based on geodesic points on the land. However, due to the characteristics of water surface studies, there are some variations in the application of the methods and the devices (Erkaya & Hosbas, 1998; Ozgen & Algul, 1977). Global Navigation Satellite Systems (GNSS) is the current method used for location measurements in lakes, reservoirs etc areas. This is a radio navigation system that can instantly detect permanent position, speed and time on a global coordinate system under any weather conditions, via electromagnetic waves sent from satellites in a specific orbit. Today, GPS and GLONASS are widely used satellite based positioning systems (Kahveci & Yildiz, 2005)

To determine the topography of sea floor, vertical depth measurements are performed from the surface of the water. Since depth measurement procedures determine the vertical location of the points of sea floor, the term bathometer is synonymous with the term leveling in classical mapping. However, the methods and devices used in leveling are totally different. Since the sea floor is not directly visible, the measurements are conducted according to a previously determined direction, and at certain time intervals, and the resulting data is related to the water level at the time of measurement.

Before depth values are processed to produce a map, corrections are made depending on the method, device and water environments, and then the water level is reduced to a common level. Depth measurement is either performed directly, by an operator, or performed automatically, according to the devices used. Depending on the device used in bathometer depth values are obtained directly or indirectly (Erkaya & Hosbas, 1998; Ozgen & Algul, 1977). Depth measurements currently use acoustic and bathometer methods.

2.2. Study Area

Altınapa Reservoir is located on the Dolay River, 20 km west of Konya province. It is a rock-fill dam, constructed by the State Hydraulic Works in 1967. The dam is currently operated by Konya Metropolitan Municipality Water and Sewage Administration. The dam is used for irrigation, flood control, potable water and industrial water supply, fishing, picnic and recreation. The some proporties of Altinapa Reservoir are given in table 1 (Orhan et al., 1991).

Table 1. The some proporties of Altinapa Reservoir

Type	Rockfill
Dam volume	975 000m^3
Crest elevation	1256.5 m
Crest length	252.0 m
Height from foundation	31.5 m
Height from river bed	30.5
Geological formation of foundation	Limestone
Maximum water surface elevation	1254.8 m
Normal water surface elevation	1246.5 m
Reservoir area at normal water surface elevation	2.20 km^2
Reservoir volume at normal water surface elevation	15.00 hm^3

2.3. Topographic Studies

Topographic measurements of Altınapa Reservoir were performed at the end of 2008, when the water level was at its minimum. Topcon Precision GPS Hiperpro GPS receivers and Topcon GPT 3007 electronic tachometers were used for measurements. Topographic measurements were conducted at a total of 2650 points which define characteristic of terrain (Fig. 1).

2.4. Bathymetric Measurements

A Matrix GPS 97 Humminbird Echo Sounder (sonar) device, fitted to a depth measurement hydrography boat, was used in bathymetric measurements of Altınapa Reservoir. The horizontal positions of the measured points were obtained from a RTK-GPS, using Topcon Precision GPS Hiperpro receivers, which were fitted on rage pole in the same vertical direction as the Echo Sounder device. One of the GPS receivers was permanently installed at a reference point, while the other was mobile and was used on the hydrography boat. The Echo Sounder device uses two different sound waves at frequencies of 200 Khz and 83 Khz. The Echo Sounder devices had a transducer (sender-receiver unit) that converts electrical energy into simultaneous sound waves and an Echograph (control-record unit). In these systems, sound waves sent from the transducer spread within a conical volumetric surface towards the sea floor and the sound waves reflected from the sea floor are detected by the receiver unit. As a result of the comparison within the control unit, the return time (t) of the sound waves is determined electronically. Since the control unit is adjusted to a certain sound speed (V), depth is calculated based on the following formula:

$$D = \frac{1}{2} V.t \qquad (1)$$

The calculated depth values were transferred into a light indicator and were recorded.

The elevation of the water surface on the day of measurement was determined with RTK-GPS using 3 different points. These data were checked with mareograph station data collected from D.S.I. the 4. Regional Directorate. Bathymetric measurements were completed in approximately 5 hours. Sea floor elevations were calculated by reducing the corrected depths according to average water surface elevation. Bathymetric measurements were performed during spring 2009, when the lake water level was at its maximum. Bathymetric measurements were conducted at 2610 surface points using a hydrography boat (Fig.1).

3. RESULTS

In order to compare current topographic and bathymetric data for Altinapa Reservoir with data from 1981, two 1:5000 scale bathymetric maps were produced from 1981 data. These were scanned at 300 dpi resolution to obtain raster images in TIFF (Tagged Image File Format) format. Map coordinates refer to Europa Datumunda (ED50) and orthometric elevations. Using the coordinates of grid points on the raster image and CAD software (NetCAD), they were Affine transformed.

The quadratic average of the conversion is ±0.59m.

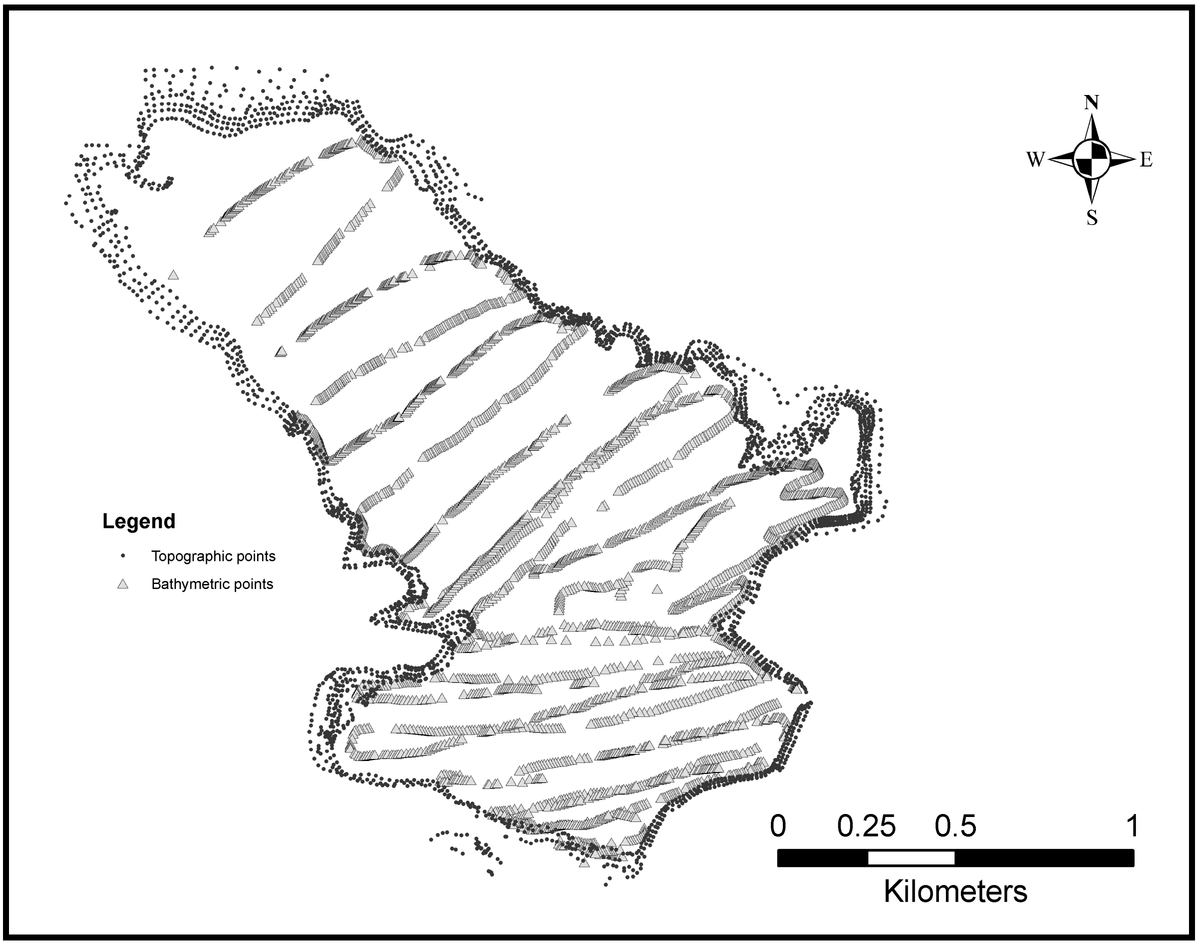


Figure 1. Locations of topographic and bathymetric survey points

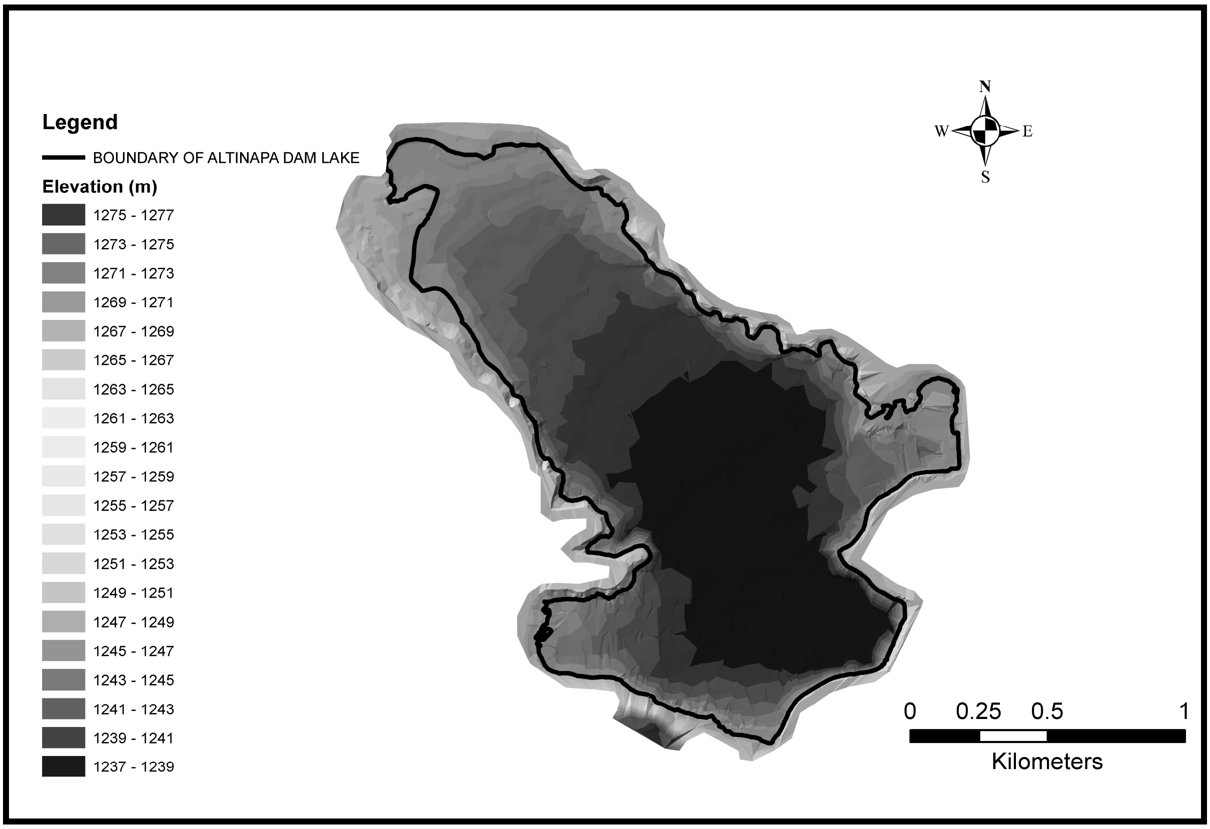


Figure 2. Digital elevation model of Altınapa Reservoir (2009)

Contour curves were digitized over the raster image in TIFF format and were converted into map vector and then exported in DXF format. The data in DXF format were transferred to ArcGIS software and a digital elevation model of the lake, based on 1981 data, was obtained. Updated topographic and bathymetric data of Altinapa Reservoir were combined using Cad software and were exported in DXF format. The data in DXF format was transferred to ArcGIS software and a digital elevation model of the lake, based on 2009 data was obtained (Fig. 2).

To analyze the changes in storage capacity of Altinapa Reservoir, surface areas and volumes of the lake at different water levels were calculated in ArcGIS, using digital elevation models obtained from the 1981 and 2009 topographic and bathymetric data.

The 1981 digital elevation model indicated that, at normal water elevation of the lake (1246.50 m), the lake surface area was 2,010,264 m^2 and the volume of the reservoir was 11.373.540 m^3. At maximum water elevation (1254.80 m), the lake surface area was found to be 3.592.840 m^2 and the volume of the reservoir was found to be 33.835.040 m^3.

The 2009 digital elevation model indicated that, at normal water elevation of the lake, the lake surface area was 1780384 m^2 and the volume of the reservoir was 9986590 m^3.

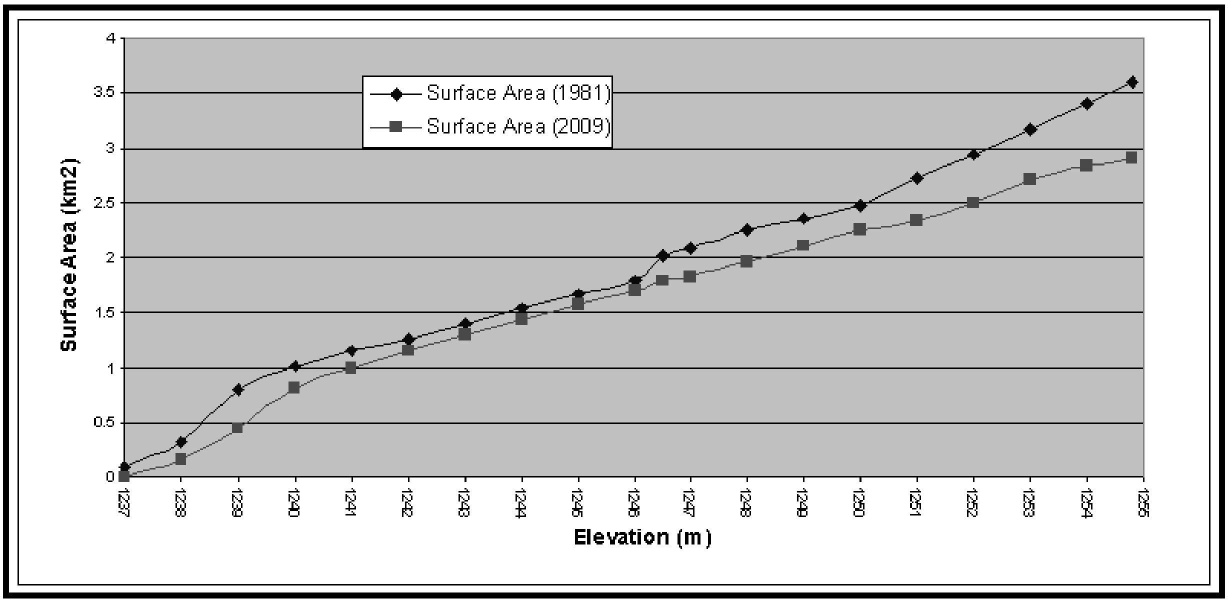


Figure 3. Surface Areas of Altinapa Reservoir

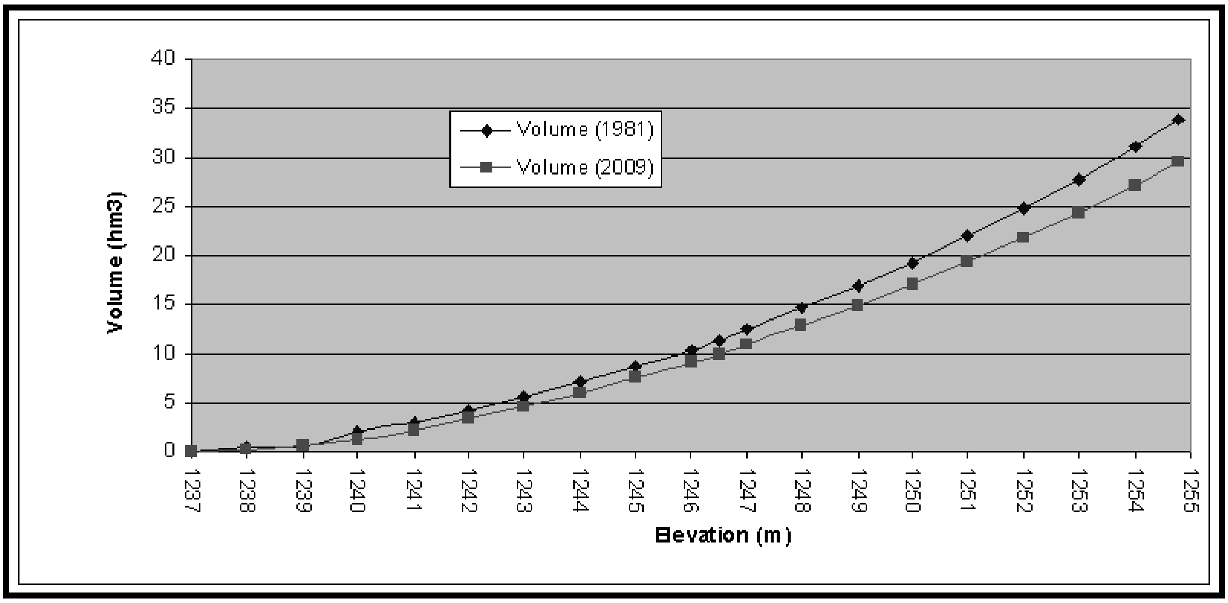


Figure 4. Volumes of Altinapa Reservoir

At maximum water level, the lake surface area was found to be 2,899,727 m^2 and the volume of the reservoir was found to be 29.423.994 m^3. The changes in lake surface area and volume according to lake water levels are indicated in figure 3 and 4.

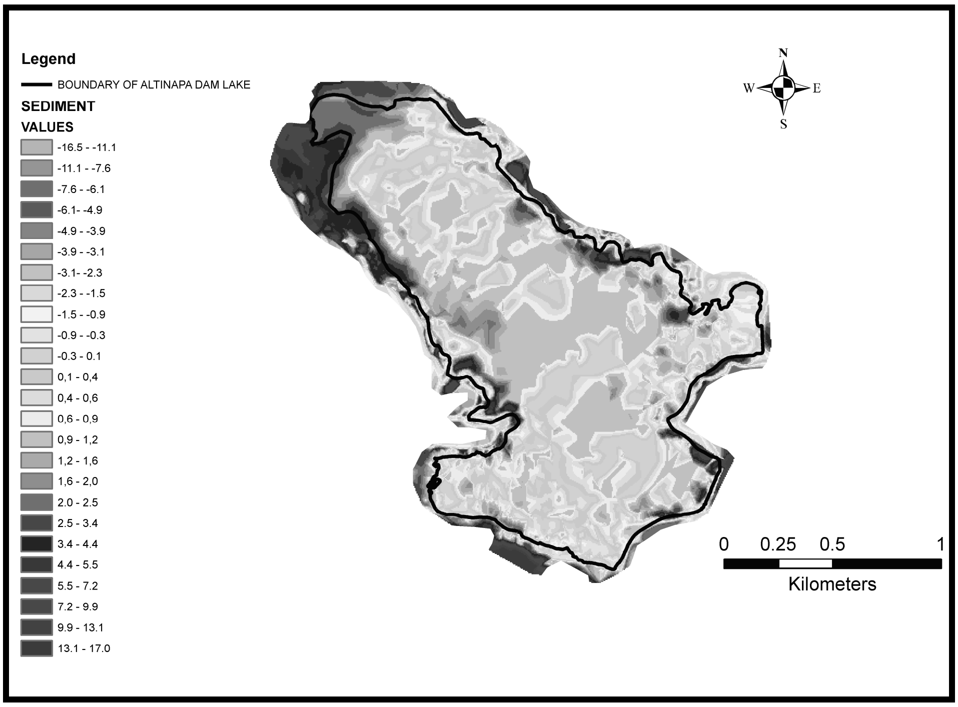


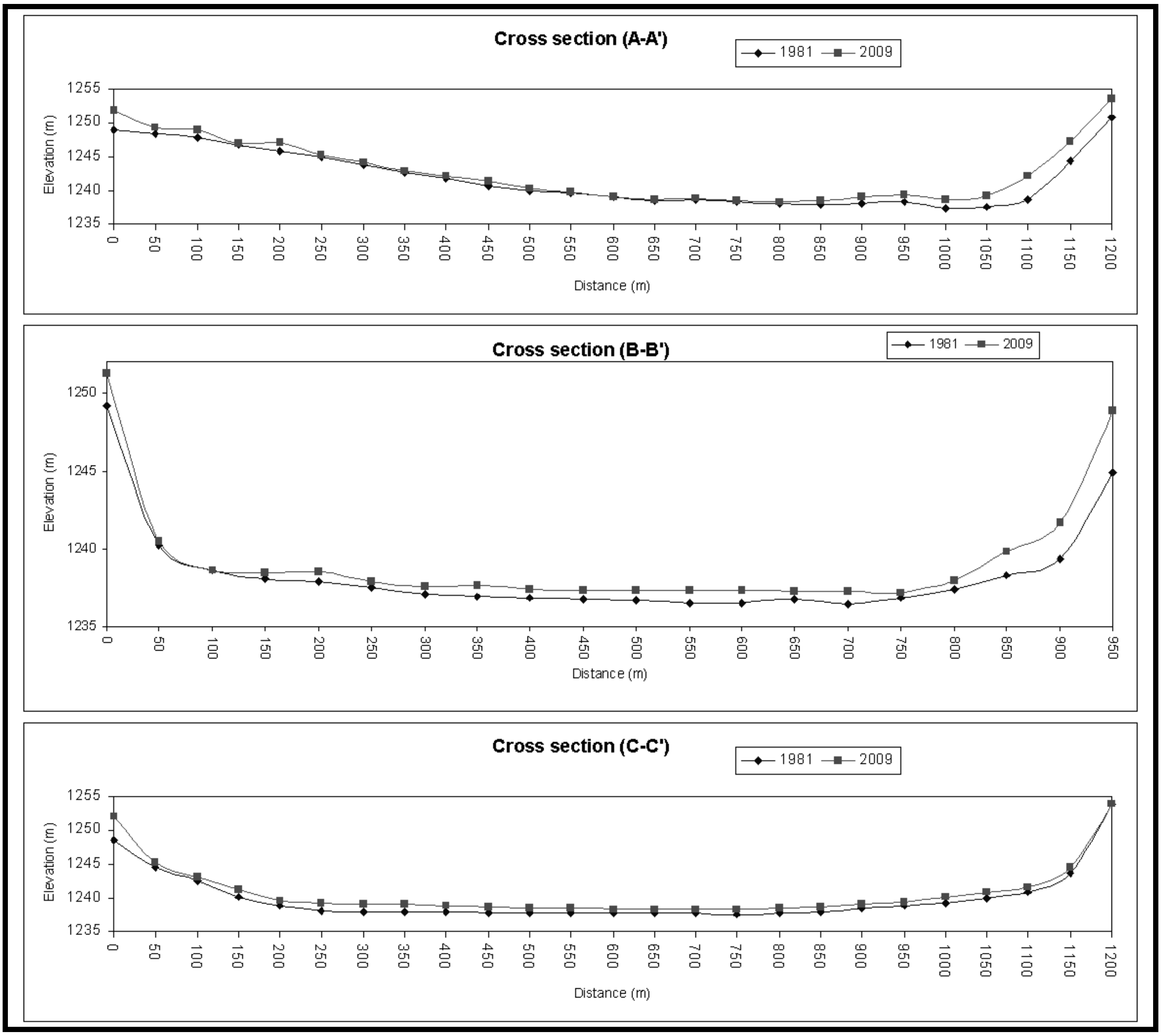
Figure 5. Sediment map of Altinapa Reservoir

Figure 6. Location of selected cross section lines of Altinapa Reservoir

This study indicated that, in this 28-year period, the storage capacity of Altınapa Reservoir decreased by 12.4% based on the normal water level and by 11.4% based on the maximum water level. Based on the first project data, when the Altınapa Dam was constructed, the storage capacity of the lake in 2009 had decreased by 33.4%.

A map showing the sediment deposition on the floor of Altınapa Reservoir was produced using ArcGIS software, based on 1981 and 2009 digital elevation models. First, the bathymetric and topographic points were combined and used to generate a Triangulated Irregular Network (TIN) of the study area in the ArcGIS software. Second, the data collected by TIN were transformed to GRID data being a raster data for both 1981 and 2009 year.

Last, sediment maps were obtained by comparing GRID data. Sediment maps are to show the spatial variation of sediment accumulation because they are obtained by comparing the digital surfaces. Sediment accumulation in the reservoir area is determined as the pixel values in the sediment maps (Fig. 5).To determine changes in the lake floor due to sedimentation; cross-sections were taken from the lake area at every 300 m (Fig. 6). Analysis of the cross-sections produced the following results (Fig. 7). Sediment thickness and standard deviation of cross sections are shown in table 2.



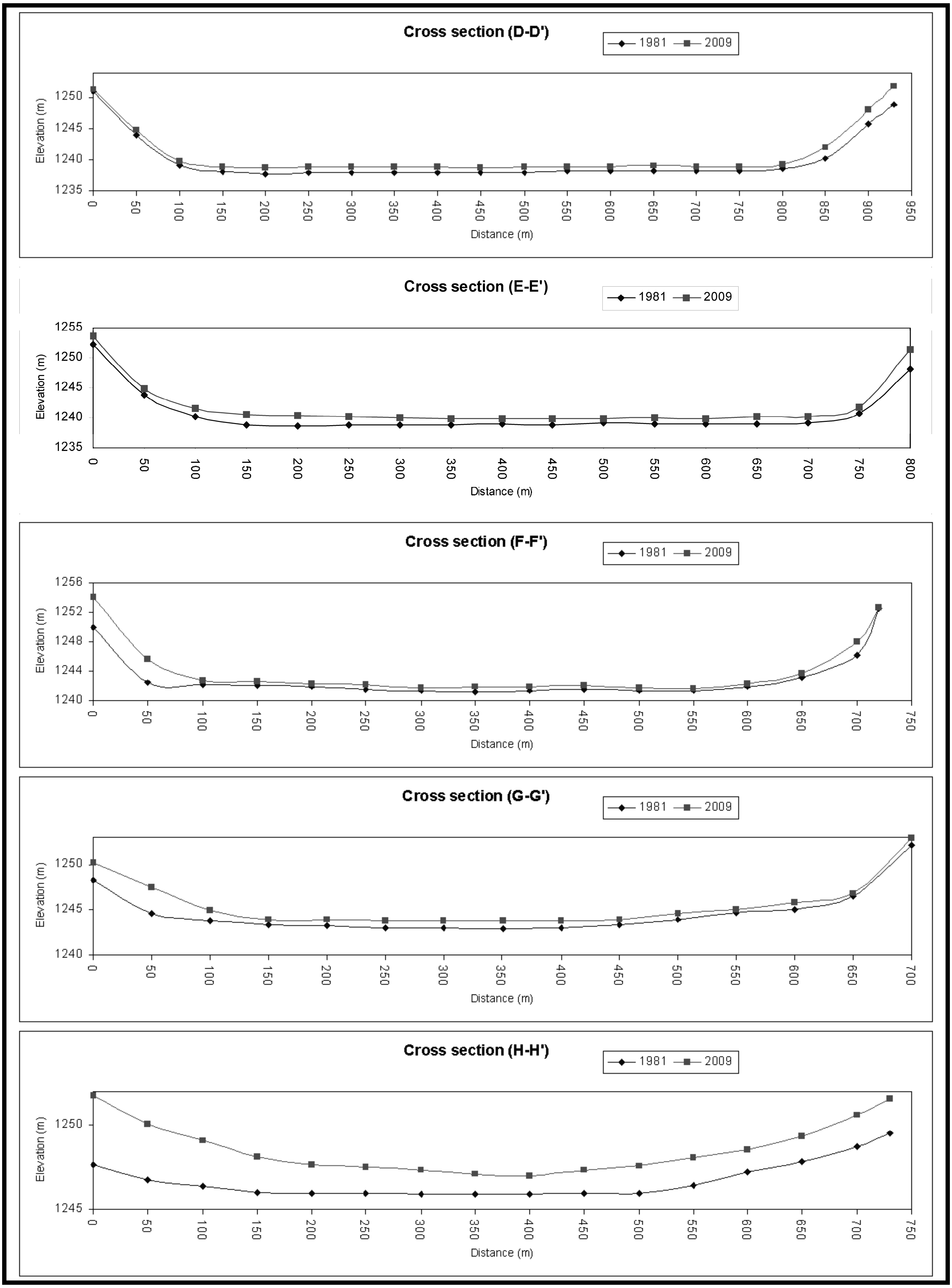


Figure 7. Selected cross sectional profile of Altinapa Reservoir

Table 2. Sediment thickness and standard deviation of cross sections

Cross sections	Max. sediment thickness (m)	Average sediment thickness (m)	Standard deviation (m)
A-A	2.70	0.96	±0.98
B-B	3.90	0.93	±0.90
C-C	3.4	0.86	±0.56
D-D	2.97	1.02	±0.59
E-E	3.32	1.29	±0.58
F-F	4.08	0.95	±1.07
G-G	2.88	0.92	±0.63
H-H	4.12	1.93	±0.80

4. CONCLUSIONS

For effective management of water sources, first, water that is not used should be stored in environments such as dams or ponds, wherever possible. In addition, prevention of water pollution, up-to-date topographic information on water reservoirs, changes in reservoir storage capacities due to erosion and sedimentation are given priority. In this context, this study was carried out to determine the current topographic and bathymetric situation, and the changes in the surface areas and volume due to sedimentation and erosion, in Altınapa Reservoir.

Calculations were made on ArcGIS software using digital elevation models of the lake based on date from the years 1981 and 2009. The data indicated that, over the 28-year period between the two datasets, the storage capacity of the lake decreased to 9,986,590 m^3, a reduction of 12.4%. The capacity of the lake therefore decreased by 157,540m^3/year (or 0.44%) on average. In addition, considering project data from 1967, when the dam was constructed (Orhan et al. 1991) it was found that the reservoir capacity had fallen by 33.4%. This value is consistent with the results of previous studies and is much greater than global and European averages.

A series of 8 cross sections were taken from the reservoir, to analyze bathymetric changes in the lake floor. The data indicated that, in coastal sections of the lake, the depth was reduced by between 1.86 and 4.12m inner sections of the lake, where the lake floor is lower, there were changes of between 0.63 and 1.73m.

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