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Full Length Article

Alternative model for electricity and water supply after disaster

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Abstract

Disasters can have adverse effect on human lives. The importance of access to electricity and safe water cannot be over-emphasized in the aftermath of a disaster. The primary objective of this paper is to examine an alternative to electricity and water supplies for human use during and after a disaster. According to this model, a volcanic lake can be used as a dam reservoir, serving as a proactive measure before a disaster, while a micro-hydropower system can be set up for electricity production, and its water can serve the population in emergency situations.

This paper demonstrates that the proposed method represents a better solution compared to the conventional dams and energy generating plants, which are usually destroyed during a disaster. In addition to the maximization of water and electrical service coverage, the objective of this model includes the minimization of expected and worst-case losses. The proposed model (Natural Storage Based) can be applied to the Gölcük Crater Lake in Isparta, Turkey and other similar areas with the same geomorphology worldwide. The region was stricken by one of the most destructive earthquakes registered in ancient time.

Keywords: disaster; electricity supply; water supply; hydropower; natural storage based model

1. Introduction

A disaster is a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community's or society's ability to cope using its own resources. In the last decade of the 20th century, almost two billion people – one-third of humanity – were affected by natural disasters, 86% of them by floods and droughts [1]. Natural disasters, such as floods, volcanic eruptions, earthquakes and tsunamis, have a strong impact on engineering structures, communication systems, supply of electricity and the availability of other utilities. In such crisis situations, it is difficult to supply emergency services [2]. Disasters can cause destruction to local water supplies affecting millions of people. In the 1994 Northridge, CA earthquake, for example, approximately 450 000 people lost water service. The city issued the first city-wide water purification notice, and took 5 days to restore water to 99% of customers [3]. The 1995 Hyogoken-Nanbu (Kobe) earthquake in Japan disrupted water service to more than one million customers and outages lasted up to 60 days in some regions [4]. Loss of water service

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and water purification notices in such events can significantly disrupt drinking supply, sanitation, hospital operation, industrial processes, and many other aspects of daily life [5,6]. The 2011 Eastern Japan earthquake was one of the world's largest but occurred offshore a relatively sparsely populated part of Japan – if there had been no tsunami, the event would have been relatively inconsequential. Nevertheless, several major industrial fires occurred, which generally could not be combated due to the general overwhelming of the fire service, as well as loss of water supply [7]. In a situation such as this, electric power is essential for virtually every urban and economic function. Failures of electric power networks, whether from or due to the disaster, can cause severe and widespread societal and economic disruption. In response to this, studies and research in energy security and natural disasters have been conducted around the world. For instance, Eiselt and Marianov [2] studied mobile phone tower location for survival after natural disasters which they applied to a region in Chile. Additionally, some researchers suggested methodology for emergency water treatment selection based on compensatory multi-criteria analysis [8]. Turkey is located on a highly active Anatolian plate, the source of numerous large scale earthquakes throughout the country's history. Turkey is exposed to various natural disasters resulting in substantial loss of lives and property. Therefore, it is necessary to find a proactive solution to water and electricity supply prior to a disaster.

Earthquakes are among the most destructive natural hazards and can cause secondary events including tsunamis, soil liquefaction and landslides [9]. Historical and recent seismic reports show a dense earthquake-clustering in the Fethiye – Burdur Fault Zone (FBFZ). Isparta, a region situated south of the FBFZ, has well-documented tectonic activities (Fig. 1). Both historical and instrumental records reveal that the study area and surroundings have been affected by destructive earthquakes for almost 2000 years [10–12]. The instrumental period shows that the Burdur and surrounding areas have been affected by two events greater than 6.0 in Mw since 1914 [13,14]. The 3 October 1914 (Mw 7.0) and 12 May 1971 (Mw 6.2) earthquakes that occurred on the NE-SW trending Fethiye-Burdur Fault system caused damages in Burdur and surrounding areas [13–17].

After an earthquake, many dams may collapse, interrupting the supply of electricity and may cease the water supply for a long time. This destruction is severe, but the most distressing effect is the incapacitation of communication lines and services. The disruption in the electric system caused by earthquake make it impossible to set up contingency plans for a disaster of such magnitude. This event has ripple effects, such as interrupted electricity supply, misaligned base stations and the rest of the system, and broken fibre optics lines. Furthermore, there is congestion due to the huge number of call attempts made in the first several hours after the earthquake. In this study, potential electricity and water supply in case of emergency cases is discussed and recommended.

2. Methods

The occurrence of disasters and their impacts on functional power systems has been of interest to countries worldwide, particularly in relation to earthquakes. Several countries, such as Chile, China, Haiti, Indonesia, Italy, Japan, Mexico, the Philippines, Turkey, and the United States, have experienced severe earthquakes that resulted in serious damage to their electric infrastructure and at times to their economic development, in addition to the loss of lives and property. However, it is not only earthquakes and related tsunamis that menace our electric infrastructure, havoc can also be caused by severe weather conditions, such as typhoons, hurricanes, tornados, floods and landslides, ice storms, volcanic eruptions, and even wildfires [18].

A new electricity supply system for the creation of disaster-resilient communities can be based on the traditional power distribution system, accommodate input from renewable energy supply sources, and be capable of mitigating risk from accidents and natural disasters. What is important when discussing energy as a societal piece of infrastructure is to understand its quality and quantity. Although efficient use of renewable energy is a direction that should be intensely pursued, renewable energy has the drawback of being highly difficult to collect from a quantitative point of view (e.g., in the case of solar and wind power, there are issues such as where to install the power generators, how large the size of the site has to be, and environmental pollution specific to such facilities) [19].

2.1. Proposed model (Natural Storage Based) for electricity and water supply

Each hydropower plant is precisely designed and constructed to respond to its surrounding topography, existing hydrological regime, prevailing environmental and social constraints, and existing infrastructure, among other boundary conditions.

In this model, water is diverted by a weir through an opening in the lake side (the 'intake') into a channel. A settling basin is built into the channel to remove sand and silt from the water. The channel follows the contour of

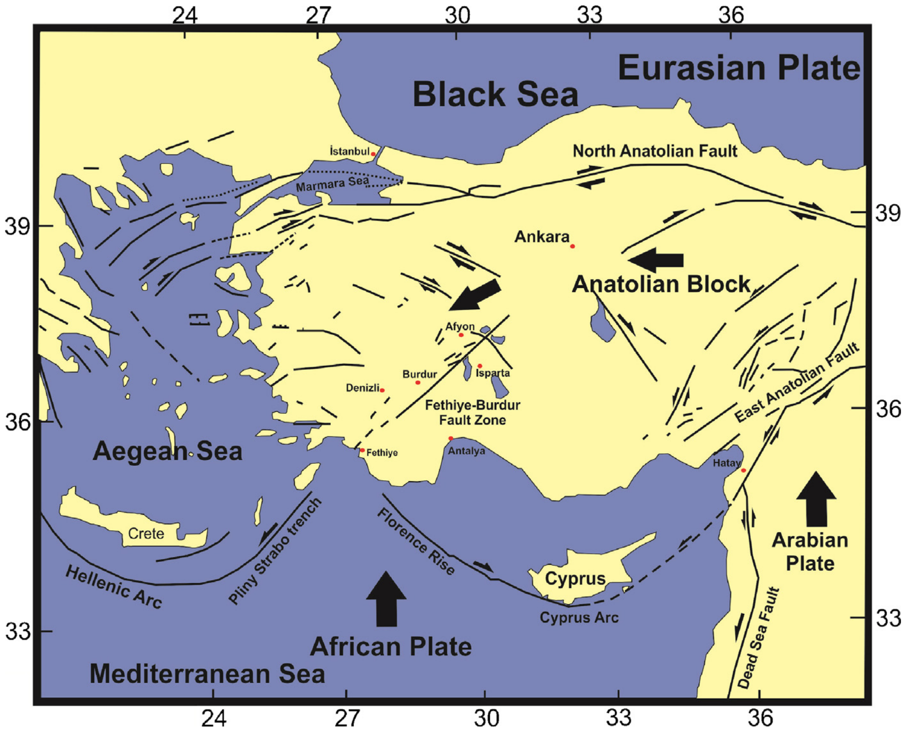

Fig. 1. Tectonic map of Turkey and the surrounding areas.

the area to preserve the elevation of the diverted water. The channel directs the water into a small reservoir/tank known as the 'forebay', from where it is directed on to the turbines through a closed pipe known as the 'penstock'. The penstock essentially directs the water in a uniform stream to the turbine at a lower level. The turning shaft of the turbine can be used to rotate a mechanical device (such as a grinding mill) or to operate an electric generator. When electricity is generated, the 'power house' where the generator is located transfers the electricity to a step-up 'transformer', which is later transmitted to the grid sub-station or to the urban area in the event of an emergency. Once electricity is produced, the water flow is transferred by pipe to Isparta.

2.2. Site description

The province of Isparta is located in the southwestern part (the Mediterranean region) of Turkey. The province is situated in the Lakes Area of Turkey's Mediterranean region and has many freshwater lakes. It has an area of 8,993 km^2 and a population of 547,525. It has a Mediterranean climate with dry and hot summers and cold and rainy winters. The mean annual precipitation is 546.2 mm and the mean annual temperature is 12 °C. The province is well known for its apples, sour cherries, grapes, roses and rose products. Its adjacent provinces are Afyon to the northwest, Burdur to the southwest, Antalya to the south, and Konya to the east. The study region covers the present day residential and agricultural areas situated between 37.7272°N and 37.8557°N latitude and 30.4811°E and 30.6532°E longitude, and has 256 km^2 of surface area. The city's population is 222,556 according to census of 2010 and elevation from sea level is 980 metres.

The proposed model (Natural Storage Based) can be applied to the Gölcük Crater Lake, in Isparta, Turkey and other similar areas with the same geomorphology worldwide. According to this model, a micro-hydropower system can be installed at the Gölcük Crater Lake (Fig. 2).

2.3. Data for alternative electricity supply

Hydropower remains the most important renewable resource for electrical power generation both worldwide and in Turkey. The first step in the proposed hydropower model requires collection of basic information concerning the site conditions as may be necessary, such as latitude and longitude, available head, or drop in elevation. This data are necessary to understand the topography and environmental conditions of the area.

Fig. 2. Location map of Gölcük Crater Lake and Isparta city.

Table 1
Equipment data analysis: summary of results.

Parameter	Value
Flow	100 l/s
The elevation that the water drops from the collection point to generator (Head)	152.4 m
Length of pipe from the collection point to the generator (Penstock Length)	45.72 m
Inner diameters of pipe (Inner Diameter)	167 cm
Static PSI	216.5
PSI loss due to pipe friction	15.31
PSI loss percentage	7.1%
Number and type of joints (If pipe has minimal straight joints, only one or two 45 degree joints, and one or two 90 degree joints)	1.2
Total estimated percentage loss	8.5%

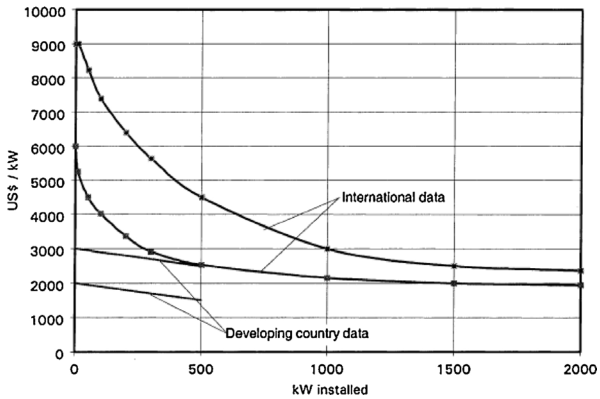

Fig. 3. Range of costs for small hydro projects [20].

The collected data are presented in Table 1. Data on micro-hydro turbine efficiency can be entered manually or can be calculated by a Free Micro Hydro Calculator.

2.4. Cost analysis for electricity production

Hydropower installations are extremely site specific. Prices vary widely depending on the type and size of the system. The analysis takes into account previous work in this field. Fig. 3 illustrates that installed costs of small hydro electrification projects tend to be in the range of $2500 to 3000/kW for the larger schemes. At the smaller end of the spectrum (500 kW), the costs can vary widely depending on the site and the country involved, and can exceed $10,000/kW. However, costs can be minimized by using indigenous expertise and technology, if available, such that costs below $1000/kW can be achieved [20].

Cost analysis is performed, considering daily and annual costs involved in the proposed model (Table 2). Our model "Natural Storage Based" cannot exceed $10,000/kW according to Fig. 3 and Table 2.

Table 2
Optimal energy calculation from Gölcük Crater Lake water source (www.rockyhydro.com) [21].

Parameter	Value
Watts available	72527
KWH produced in one day	1740.64
KWH produced in one year	635334.03
Cost of KWH	$0.25
Saved per month	$13.236.126
Saved per year	$158.833.51

2.5. *Water supply system in emergency cases*

The human body is comprised of approximately 80% of water. Hence, in order to survive one must drink at least 3 to 5 litres of water daily to maintain the required water balance in the body [22]. In the event of an emergency such as a natural disaster (e.g., flood, earthquake, and hurricane) or a man-made disaster (e.g., political unrest, and wars), one may not have access to clean and safe drinking water due to the destruction and disruption of the necessary infrastructure and facilities [23–25]. Therefore, the need for providing drinking water is often beyond the capability of relief agencies or local governments to respond effectively. Water is essential for human life as well as for various other activities, and normal consumption of water must not be allowed to pose a health risk [26]. Water quality standards and the World Health Organization [27,28] drinking water quality guidelines are, however, established from the viewpoint of avoiding long term chronic toxicity. Therefore, they are not intended to provide instructive guidance on short term acceptable limits of impurities in water for an emergency situation.

Disasters such as flooding can considerably increase microbial contamination of surface water [29]. Other water quality problems following a disaster include salinization and water contamination by hazardous material release [30,31]. Hazardous materials such as radionuclides were detected in water bodies following the 2011 Japanese earthquake. Debris contamination and water turbidity up to 10,000 NTU were also observed [32]. These show the complexity of water composition in the aftermath of a disaster. Overloading of microbial and chemical pollutants in water increases the potential failure of conventional water treatment systems [33]. These hazardous materials need to be removed if the water is to be drinkable.

Chemical properties of the Gölcük Crater Lake for the year 2013 are shown in Table 3. According to the water classification of the Turkish Water Pollution Control Regulation (TWPCR) [34], the water is “first class water quality” (Table 4).

Despite being in a closed basin, its water is drinkable according to TWPCR [34] (2004). According to this model, 1,585 gpm of water may be taken from the Gölcük Crater Lake. Discharge water is potable after power generation to Isparta is considered, and 8640 m^3 of water per day will be available. This will meet the needs of 1,728 people, as individuals are expected to consume approximately 5 litres of water per a day [27,28]. This amount can be obtained from reservoir pond lake water for 6 years (Table 5).

3. Results

The most feasible system to solve these problems is the natural storage based model. This system allows water in the lake to be used to generate electricity and is more advantageous than other systems from the viewpoint of efficiency and quality of energy. For this purpose, a Micro-hydropower system can be installed at the Gölcük Crater Lake at an elevation of 1,380 metres for water supply and electrical generation. Water from the lake will be taken by a water intake structure to the power unit via a penstock, while the water output from the power turbines will be transported by pipeline to Isparta (at an elevation of 980 metres) for consumption. For this purpose, a Free Micro Hydro Calculator was used and its results are displayed in Table 6.

Micro-hydropower installations typically service small communities with limited resources where the initial capital cost becomes the overriding issue, so it is more important to maximize power per unit cost than to maximize power alone. Since the penstock cost is typically 1/3 of the overall installation costs, it is one of the most expensive items and has to be carefully chosen [35]. There are two components to achieving the best power per unit cost; the first is finding the maximum power per unit length of penstock, and second is making a realistic choice of penstock slope [35]. The micro-hydropower installation is 3D modeled in Fig. 4. Additionally, the same water can be used for different purposes (e.g domestic, drinking and fire-fighting).

4. Discussion

In this paper, a new electrical supply system based on a natural storage model was proposed. According to this model, we can use a volcanic lake reservoir for energy production and water supply. The volcanic history of Gölcük ceased approximately 24 ka ± 2 ka [36]. Gölcük Crater Lake is 5 km from the Isparta city centre and

Table 3
Chemical properties for Gölcük Crater Lake water in March, June, August and October 2013.

Parameter	Unit	Surface water quality measurement periods				
		March		June	August	October
Temperature	°C	2.43		–	–	3.86
pH	–	8.1		8.2	8.4	8
Electrical İletkenlik EC	Mic/cm	40		0	0	0
Dissolved Oxygen Demand (DO)	mgL^{-1}	9.4		10.2	7.7	7.6
Dissolved Oxygen (O_2)	%	91		108	106	104
Chlorure (Cl^-)	mgL^{-1}	13.47		6.92	6.96	7.13
Sulfate ($SO_4{}^{2-}$)	mgL^{-1}	14.9		19.4	18.8	26.3
TSS (Total Suspended Solids)	mgL^{-1}	12		7	2	9
Ammonium Nitrogen ($NH_{4\text{-}}N$)	mgL^{-1}	0.003		0.013	0	0
Nitrate Nitrogen ($NO_{3\text{-}} - N$)	mgL^{-1}	0		1.2	0	0
Nitrite Nitrogen ($NO_{2\text{-}} - N$)	mgL^{-1}	0.002		0	0	0
Total Phosphorus (TP)	mgL^{-1}	0		0.02	0.03	0.03
o-PO4		2.84		0	0	0
TDS (Total Dissolved Solids)	mgL^{-1}	166		140	140	164
Color	mgL^{-1} Pt/Co scale		1	3	2	1
Sodium (Na)	mgL^{-1}		11.67	6.59	12.66	13.41
Ca++	mgL^{-1}		34.87	16.72	29.09	30.96
COD	mgL^{-1}		9.1	0.2	0	25
BOD	mgL^{-1}		4	0	6	3.9
TOC (Total Organic Carbon)	mgL^{-1}		2.43	–	–	3.86
Total Kjeldahl Nitrogen (N_{org})	mgL^{-1}		1	2	1.1	1.1
Methyl −Al	mgL^{-1}		123.8	142.1	40.9	124.4
Phenols	mgL^{-1}		–	–	–	–
Phenol Ftalain Alcalinite (P-Al)	mgL^{-1}		0	0	30	0
Permenganat Value (pV)	mg$O_2{}^{-1}$		3.58	2.88	2.92	2.59
Pesticides	mgL^{-1}		0	0.02	0.03	0.03

Parameter	Unit	Surface water quality measurement periods			
		March	June	August	October
Mercury(Hg)	mgL^{-1}	0	0	0	0.03
Cadmium (Cd)	mgL^{-1}	–	–	–	–
Lead (Pb)	mgL^{-1}		–	–	–
Arsenic (As)	mgL^{-1}	3.8	2.49	–	2.68
Copper (Cu)	mgL^{-1}	–	–	6.23	–
Chromium (Cr)	mgL-^{1}	4.3	2.49	–	6.41
Nickel (Ni)	mgL^{-1}	–	–	–	0.7
Zinc (Zn)	mgL^{-1}	–	6	–	4.9
Total cyanide (CN-)	mgL^{-1}	0	0	0	0
Florure (F-)	mgL^{-1}	0.55	2.24	2.16	2.26
Sulphur (S2-)	mgL^{-1}	< 1.0	< 1.0	< 1.0	< 1.0
Iron (Fe)	mgL^{-1}	26	7	15	0
Manganese (Mn)	mgL-1	36	0	0	8
Magnesium (Mg)	mgL^{-1}	3.2	1.3	2.7	2.8
Boron (B)	mgL^{-1}	0.01	0.02	0.05	0.08
Potassium (K)	mgL^{-1}	13.47	3.96	7.75	8.27
Selenium (Se)	mgL^{-1}	–	–	–	–
Barium (Ba)	mgL^{-1}	333.2	211.6	–	220.1
Aluminium (Al)	mgL^{-1}	12.39	–	–	25.41
Fecal Coliform Bacteria	kob/ 100 mL	0	18	0	2
Total Coliform Bacteria	kob/ 100 mL	0	18	6	2
Radioactivity (Alfaactivity)	Bq/L	0.186	–	–	–
Beta Activity	Bq/L	0.3	–	–	–
Toplam Sertlik (TH)	mgL^{-1} $CaCO_3$	100	47.5	86	89
Toplam Azot (TN)	mgL^{-1}	1.03	2.3	1.14	1.06
Turbidity	NTU	5	5	2	3

Table 4
Turkish Water Pollution Control Regulation (TWPCR 2004) by using the water quality measurements.

Water quality parameters	Water quality classes I[a]	II[b]	III[c]	IV
A) Physical and inorganic- chemical parameters				
Temperature (°C)	25	25	30	> 30
pH	6.5-8.5	6.5-8.5	6.0-9.0	< 6.0 or >9.0
Dissolved oxygen (mgL^{-1})	8	6	3	< 3
Chloride (mgL^{-1})	25	200	400	> 400
Sulphate (mgL^{-1})	200	200	400	> 400
Ammonium (mgL^{-1})	0.2	1	2	> 2
Nitrite (mgL^{-1})	0.002	0.01	0.05	> 0.05
Nitrate (mgL^{-1})	5	10	20	> 20
Total solids (mgL^{-1})	500	1500	5000	> 5000
Color (Pt-Co)	5	50	300	> 300
Sodium (mgL^{-1})	125	125	250	> 250
B) Organic Parameters				
Chemical Oxygen Demand (COD) (mgL^{-1})	25	50	70	> 70
Biochemical Oxygen Demand (BOD) (mgL^{-1})	4	8	20	> 20
C) Inorganic Pollution Parameters				
Iron (μg/L)	300	1000	5000	> 5000
Manganese (μg/L)	100	500	3000	> 3000
Boron (μg/L)	1000	1000	1000	> 1000
Aluminum (mgL^{-1})	0.3	0.3	1	> 1
D) Bacteriological Parameters				
Total coliform (numbers/100 mL)	100	20000	100000	> 100000

[a] I: Water that can be used for driking purposes following simple physical treatment and disinfection.
[b] II. Water that can be used as a potable water resource following apropriate treatment.
[c] III. Water that can be used by industries that do not require high quality water.

Table 5
Calculating water demand.

Parameter	Value
Circular shape	1500 m
Depth	32 m
Total water volume	18840000 m^3
Water take for energy	100 liters per minute
Water take for drinking purposes	8640 m^3 per a day
Health centre (patient usage)	5 liters
Total daily water needs for patient	1728 patients
Water demand duration	2180.55 day
Water demand duration	6 year

25 km from the Burdur city centre, and sits at an elevation of 1380 m. The full region of 6684 hectares was reinstated as a natural park. This special area is known for its volcanic cones, flora and fauna. There are no protected, endemic species in Gölcük Crater Lake [37]. Gölcük Crater Lake is rising to 150–300 m and is surrounded by hills covered with volcanic ash. The lake is circular in shape with a diameter of approximately 1.5 km, and a depth of 32 m in the middle of the lake. The lake is usually fed and recharged by rainwater and spring water. The objectives of the proposed model can be summarized as follows:

Table 6
Optimal energy calculation from Gölcük Crater Lake water source (www.rockyhydro.com) [21].

Parameter	Value
Flow	100 l/s
Feet at the elevation that the water drops from the collection point to generator (Head)	152.4 m
Length of pipe in feet from the collection point to the generator (Penstock Length)	45.72 m
Inner diameters of pipe (Inner Diameter)	167 cm
Static PSI	216.5
PSI loss due to pipe friction	15.31
PSI loss percentage	7.1%
Number and type of joints (If pipe has minimal straight joints, only one or two 45 degree joints, and one or two 90 degree joints)	1.2
Total estimated percentage loss	8.5%
Watts available	72527
KWH produced in one day	1740.65
KWH produced in one year	635334.03
Cost of KWH	$0.25
Saved per month	13236.126
Saved per year	158833.51

To generate electricity on a regional scale, which is to be accomplished by "Power unit". The Power unit plays a comprehensive part in absorption, storage, and

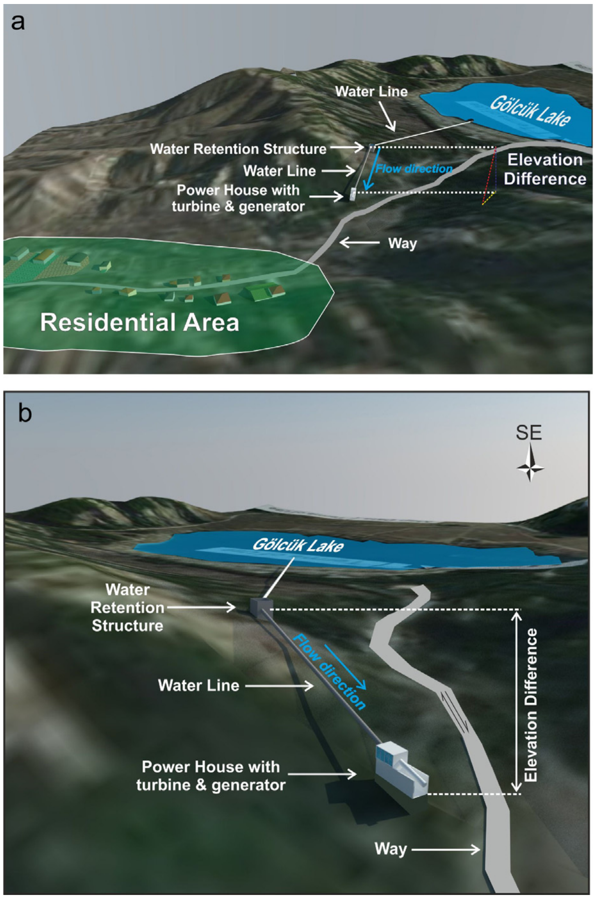

Fig. 4. a,b 3D model of proposed micro-hydropower.

preservation of electric power generated by renewable energy, and in responding to system power outages in the time of a disaster. Gölcük Crater Lake is a natural freshwater lake in Turkey containing water of sufficient quality to be used as drinking water.

5. Conclusions

With increasing frequency and intensity of disasters, one of the main priorities after a disaster is the supply of clean, safe drinking water and electricity. An alternative model for water and electric supplies are investigated in the event of an emergency. In this paper, a new electrical supply system based on natural storage model was proposed. According to this model, we can use the Gölcük Crater Lake water reservoir for energy production and water supply during and after disasters. All conditions (geomorphological, hydrological, structural and water quality) are met in applying this model. The Gölcük water is classified as "first class" water quality. The result of this study can be used as basic information to establish policies for the effective operation and management of disasters. This study serves as a suggestion for authorities and emergency services during emergency situations.

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