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The Effect of River Type Hydroelectric Power Plants on Aquatic Ecosystems: the Case Study of Göksu River-Eastern Mediterranean

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Abstract

The contribution of the hydropower energy potential to the reconstruction of the energy structure is very important in Turkey. In spite of numerous social and economic benefits experienced in the area in social and economic spheres due to the project, there is also a plurality of adverse impacts observed in the environment. In social and economic spheres, the land acquiring and resettlement of people are important issues. Large-scale irrigation causes salinization and leads to soil erosion; huge water reservoirs affect local climate and are a source of considerable amounts of pollution. The construction and operation of hydroelectric power plants is directly related to the flow of the river. Therefore, environmental flow is described as the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems. Environmental flow estimation is considered as a safe guard for an aquatic ecosystem in the water basins with regulated flow regime. Environmental flow not only the self purification flow to fulfill the water quality demand, but also the flow demand for the existing aquatic lives. Natural flow regime is critically important in sustaining the natural biodiversity and ecosystem integrity in river basins.

Construction of dams and hydroelectric power plants development projects will likely continue. As a result, legal and policy frame works for protecting and restoring them also continue to develop, and various governmental agencies, community-based organizations, private-sector actors, and individuals are becoming involved with implementing and monitoring these flows.

This research estimates the environmental flow requirements in the Göksu River in Eastern Mediterranean and to understand the impact of hydroelectric power plant in maintaining the natural flow regime. The current operation policy can cause severe hydrological alteration in the natural flow regime so current status and calculated amount of flow are compared.

Key words

Dams, ecosystems, environmental flow, hydroelectric power

1. INTRODUCTION

The environmental damage caused by hydropower schemes has become increasingly apparent over the last decade or so. Changes to river flows are one of the key consequences of the construction of dams and/or hydroelectric power plants. Maximizing the electricity output of a hydropower plant according to demand can have serious consequences both for ecosystems and other users, as flow conditions downstream of the plants are altered. However, in many cases it is possible to adjust the operational regime of a dam to better meet a variety of needs. So called ‘environmental flows’ provide critical contributions to river health, economic development and poverty alleviation [1].

Total economic hydroelectric power potential of Turkey is 129.5 TWh/yr by the end of February 2007. 35.5% of this potential is in operation while 11.1% and 53.4% of this potential are under construction and in various design level, respectively [2].

Turkey is an energy-importing country. In order to be less dependent on other countries, Turkey needs to use its sustainable sources. From this point of view, hydropower is a very attractive choice, since it is economical, sustainable, and environmentally friendly and it is a publically familiar source of energy in Turkey [3].

Environmental flow is regulated in order to contribute to river basin planning. Environmental flows can include some restrictive and active management such as dams planning, reducing irrigation and water supply. This management can be applied in various situations such as low and high flow regime, particularly during dry periods. The EFA finds the optimal balance between ecosystem and the various utilizations such as water use and regulation of flow within a river, wetland or coastal zone. There are adverse effects of a time-varying flow regime over the ecosystem [4]. The influence of climate change, decreasing river flows, degradation of the river bed, flow regulations, agricultural and industrials activities and human use cause the change of deterioration of the natural conditions of the rivers. Aquatic organisms that are using river as habitat are affected by these negative effects. The EFA approach was developed to establish balance between ecological concerns in the context of the river ecosystems and sustainability and requirements of modern world. If the river flow has been greatly influenced by the human activity and natural, such as reservoirs, channels and urban diversion, erosion, these will limit the application of the hydrological methods. Because of the erosion, the shapes of the cross sections are changing continuously, especially in the lower reaches. The natural flow regime consists of flow magnitude, frequency, timing, duration and rate of change of flows. In order to protect the ecological functions it is important to maintain a semblance of the natural state of each component of the flow regime as each of these components contributes towards maintaining critical instream ecological functions [5]. The major problem in the management of rivers has not been protection and use balance over the water resources Management problems normally exacerbate during low-flow periods and with on-going water resources development resulting in gradual reduction of flow available for instream uses[6].

Instream flows are usually referred as environmental, minimum or maintenance flows that guarantee a sufficient level of protection for the aquatic environment in regulated rivers. Various types of environmental flow methodologies have been proposed in different region of the world to secure particular environmental needs. Flows that led to a enough level of protection for the aquatic environment in rivers are usually name as environmental, minimum or sustainable flows. During the last few decades numerous methodologies have been developed to establish environmental flows in regulated rivers. These methodologies can be grouped in four categories (Tharme 2003) described which could be differentiated into hydrological (Hydrological or historic flow methods [5]. They are based on the study of historical flow regime records, for instance, the Tennant (1976) method determines the environmental flow as a percentage of the mean annual flow.), hydraulic rating(These methods are based on the study of the hydraulic geometry of stream channels (cross-sections), habitat simulation and holistic methodologies. These methods have been used by many researchers and they highlighted that the one of the most common method is the Tennant method and modified Tenant method [7], 7Q10, Q95 [8, 9], wetted perimeter method which can use both hydrological and ecological data [10]. A comparison of the approaches for instream flow methods were explained in some detail [11]. Application of the hydrologic and hydraulically derived geometric parameters was evaluated to determine the minimum water requirements of ecological habitats [12]. All these methodologies, independently of the advantages and disadvantages they may have and their theoretical foundation, have a common characteristic that usually make them difficult to apply, which is the need of a large amount of data. Due to the small data requirement, hydraulic rating methods are widely applied. But the relationships are also concluded from natural rivers. It may fail to assess ecological base flow in regulated river using hydraulic rating methods. Long-term high-quality information on hydrological or hydraulic parameters, or habitat preference data, is rarely available. Hydraulic and habitat simulation methods demand intensive field work and sometimes long periods of time for their correct implementation [5, 13].

The objective of this study is to compare four commonly used hydrologically based instream flow assessment methods. Environmental flows is calculated in the hydroelectric power plant on the Göksu river to using five hydrologically based methods. The recorded average daily flow data at the downstream point, Göksu river for 18 years (1995-2013) was analyzed in two periods from 1995 to 2010 as pre-hydropower plant construction and 2010-2013 as post-hydropower construction to obtain the flow alteration at the measuring station due to hydropower development in the river.

2. STUDY AREA

The Göksu river is located in Eastern Mediterranean basin (Turkey). The basin covers the provinces of Antalya, Konya, Karaman and Mersin.

The river is 260 km long and discharges into the Mediterranean Sea 16 km south east of Silifke (in Mersin province). Akgöl Lake and Paradeniz Lagoon are within the delta of the Göksu. The location of the study area in the basin are shown in Figure 1.

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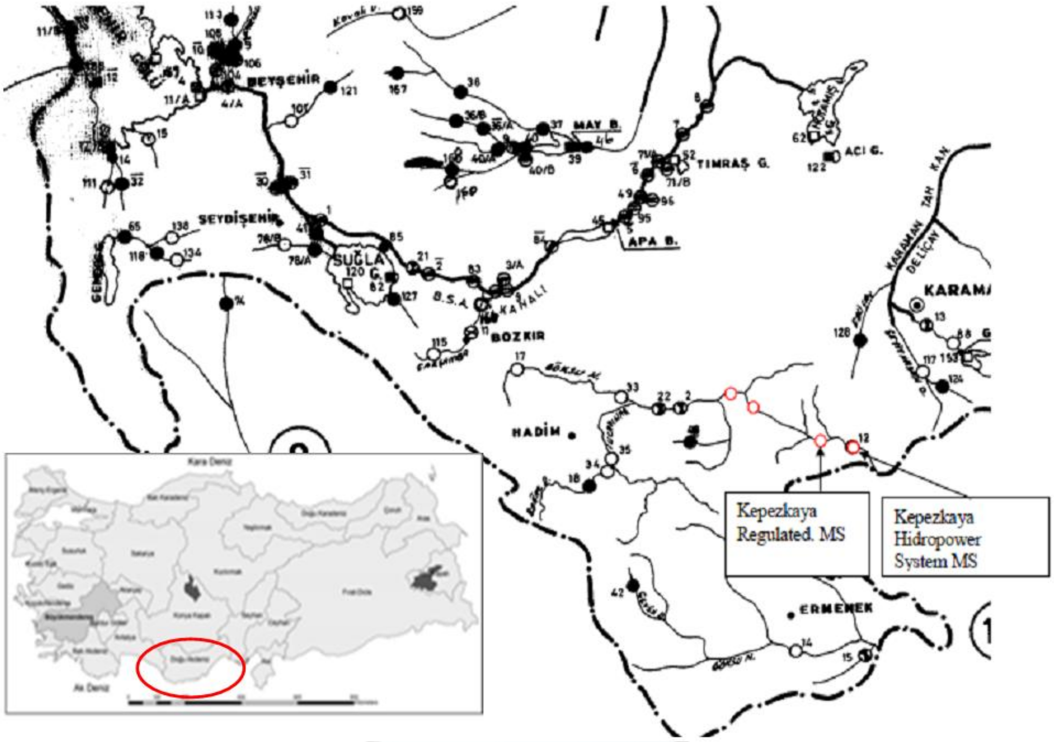

Figure 1. The location of study area

3. METHODS

Some methods, which are considered as hydrological and hydraulic methods, were examined to generate the environmental flow as explained above. These methods are 7Q10, Q95, the original Tennant method, modified Tennant method. These methods are summarized as the following.

3.1. 7Q10 Method

Daily river flows in the 7Q10 range are general indicators of prevalent drought conditions which normally cover large areas. The river flows that occurs over 7 consecutive days and has a 10-year recurrence interval period, or a 1 in 10 chance of occurring in any one year. 7Q10 values are also used by the U.S. for regulating water withdrawals and discharges into streams [9, 10, 14]. According to U.S. Fish and Wildlife Service the 7Q10 flow is a flow statistic used in identifying the volume for dilution to set permit limits for wastewater discharge so it does not cover the habitat alterations in rivers [14].

3.2. Q95 Method

The exceedance percentile Q95 can be interpreted as the flow discharge which can be expected to be exceeded 95% of the time. The index is sometimes described as one from Look-up table method that is using the flow duration curve of a river. Q95 index of natural low flow has been employed to define the environmental flow and the flow that is equaled or exceeded for 95% of the time. The Q95 index was determined solely by the hydrological data. However, the implementation of this method often requires the use of ecological information. Q95 index may be used to determine the dry periods such as the mean annual minimum flow [5, 11].

3.3. Original Tennant Method

It was developed by using historical data of 11 rivers in the states of Montana, Wyoming, and Nebraska in the USA to determine minimum flows to protect the aquatic life in rivers. Percentages of the mean annual flow are identified that provide different quality habitat for fish e.g. 10% for poor quality (survival), 30% for moderate habitat (satisfactory) and 60% for excellent habitat over two certain periods of the year for instance, October to March (6 mounts) as wet period and April to September (6 mounts) as dry period. This method can be used elsewhere, but there are some important issues about using this method in other areas. The method directly can be used for other areas if there are morphological similarities with other rivers. Otherwise application of this method directly is not recommended whereas the modification of this method is possible to simulate the aquatic life in other rivers [7,11].

3.4. Modified Tennant Methods

Modified Tennant method is different from original Tennant method that the selection of the periods may be different. The average flow of the river was determined by the means of 18-year data and 15% of the daily mean flow has been applied for wet period whereas 20% was for dry period [15].

4. RESULTS and DISCUSSION

For the station some statistics such as minimum, maximum and standard deviation of the daily mean flows is given in Table 1.

Table 1. Some statistics for the station

Month	Min	Max	STD	Mean
O	2.55	29.5	1.78	8.14
N	1.14	145	12.04	13.45
D	1.14	247	29.60	27.72
J	6.16	124	16.70	23.44
F	9.02	163	19.50	32.50
M	10.5	340	31.15	52.74
A	9.56	226	38.20	62.30
M	7.78	124	17.35	29.80
J	2.75	33.8	3.40	11.90
J	2.13	22.7	1.57	8.40
A	1.2	14.8	1.14	7.44
S	1.08	13.4	1.19	7.25

Daily average flow of the river is well illustrated in Figure 2. According to daily average flows data, 30 percent of 20-year daily flow data has exceeded the average flow and 50 percent of 20-year daily flow data has exceeded the median flow.

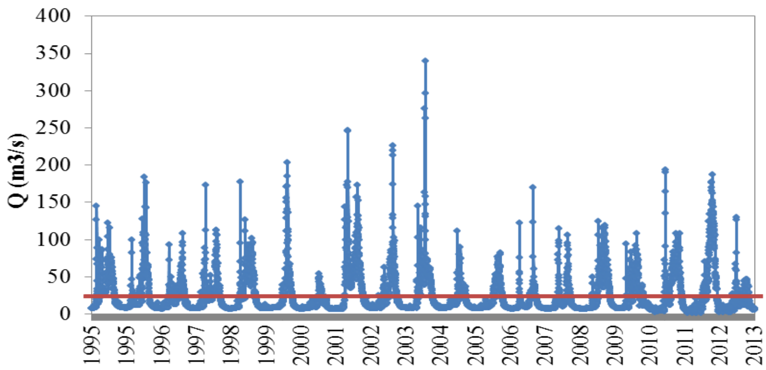

Figure 2. Flow time series

Figure 3 shows the flow duration curve of the river. The result of the Q95 method is derived from Figure 3 and calculated as to 7.22 m^3/s as the flow rate which is exceeded 95% of the time.

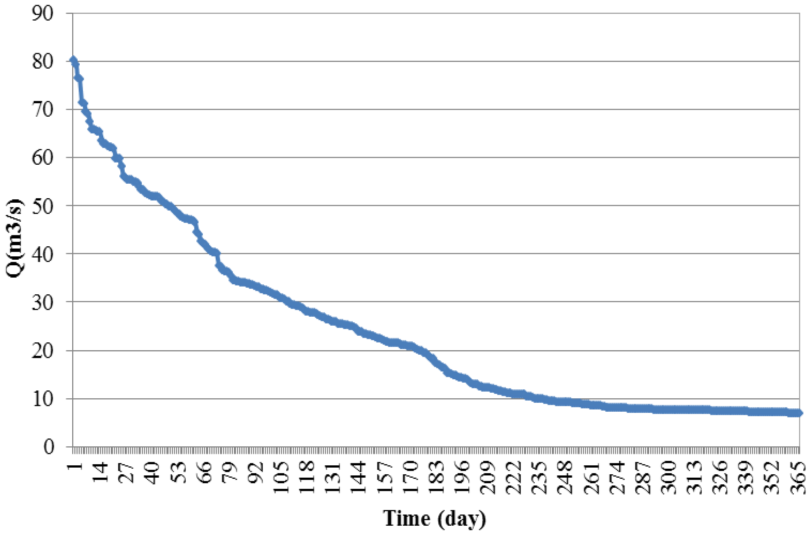

Figure 3. Flow Duration Curve

The monthly average flows are shown in Figure 4 Due to average and median flows are calculated for the estimating the environmental flow. In Figure 4 flow rate that plot above the average flow is accepted as wet period and below the average flow is dry period from which is indicated in the part of the modified Tennant method. Wet and dry periods, which set for each station, are provided in the Table 2.

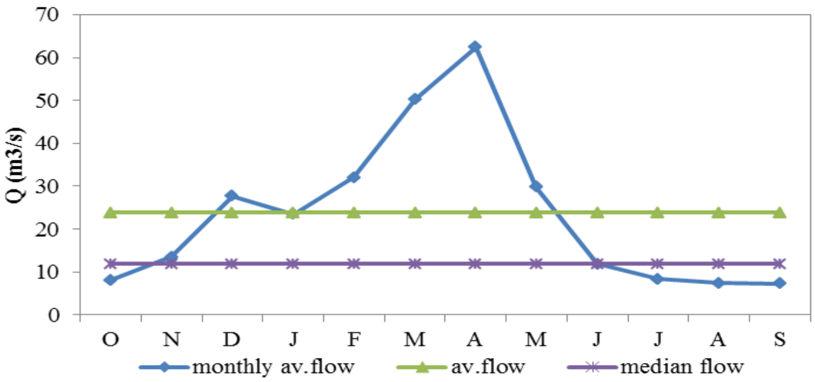

Figure 4. Monthly average flows

Table 2. Modified Tennant Method periods

Qaverage	From December to May (%15)	From June to November (%20)
Qmedian	From November to May (%15)	From June to October (%20)

The results of environmental flow with various methods are given in Table 3 where as the relationship between monthly incoming flows and release flows are given in Table 4 for the year of 2010-2013 periods. In order to compare them that must be in the same time period. For this, monthly incoming flows and release flows shown in Table 4 are the flows that exist in the river for the year of 2010-2013. Difference row of Table 4 shows the amount of water used for hydroelectric generation purposes.

Table 3. The results of environmental flow with various methods

	Flow rates by months (m^3/s)											
	O	N	D	J	F	M	A	M	J	J	A	S
Monthly Qav	8.14	13.45	27.72	23.44	32.5	52.74	62.32	29.8	11.9	8.4	7.44	7.25
Qav	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8
Qmed	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9
7Q10	4.23 (+)	4.23 (+)	4.23 (+)	4.23 (+)	4.23 (+)	4.23 (+)	4.23 (+)	4.23 (+)	4.23 (+)	4.23 (+)	4.23 (+)	4.23 (+)
Q_{95}	7.22 (+)	7.22 (+)	7.22 (+)	7.22 (+)	7.22 (+)	7.22 (+)	7.22 (+)	7.22 (+)	7.22 (+)	7.22 (+)	7.22 (+)	7.22 (+)
Original Tennant Method	3.9 (+)	3.9 (+)	3.9 (+)	3.9 (+)	3.9 (+)	3.9 (+)	4.23 (+)	4.23 (+)	4.23 (+)	4.23 (+)	4.23 (+)	4.23 (+)
Modified Tennant Method (by Qav)	1.88 (+)	1.88 (+)	5.64 (+)	5.64 (+)	5.64 (+)	5.64 (+)	5.64 (+)	5.64 (+)	1.88 (+)	1.88 (+)	1.88 (+)	1.88 (+)
Modified Tennant Method(byQmed)	1.72 (+)	5.12 (+)	5.12 (+)	5.12 (+)	5.12 (+)	5.12 (+)	5.12 (+)	5.12 (+)	1.72 (+)	1.72 (+)	1.72 (+)	1.72 (+)

(+) This amount of water is below baseflow, so, can be supplied by Monthly Qaverage

As it can be seen in Table 3, (+) indicates sufficient amount of water can be provided as environmental flow. When this situation is taken into consideration, all methods shows that environmental water flow exist in all months of the year. However for dry period, Modified Tennant methods have low values which cannot be assumed as environmental flow. Moreover the values which were calculated by Tennant methods were observed to be lower than the baseflow (7.25 m^3/s). In this case the flow amounts which remain lower than the base flow (which used to be evaluated as life water) are not suggested as environmental flow.

In the method which was suggested by Tennant in 1976 [7], water year was divided into two, as wet and dry periods. In modified Tennant method, if many factors such as hydrological and climatic properties of basin and river are taken into consideration it will not be meaningful to apply the original Tennant method directly to all rivers. When the flows that are supposed to exist in river system and the average flows in original Tennant method are checked, water deficiency is not observed in whichever months. In modified Tennant method according to average and median flow water deficiency is not observed. Environmental flow is calculated as 7.22 m^3/s using Q95 method. This value almost equals to baseflow. So, water deficiency can be observed especially in 2 months (Aug, Sep). Water should not be taken from river system in months that of water deficiency.

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Table 4. Relationship between incoming flow and release flow (2010-2013)

	Flow rates by months (m^3/s)											
	O	N	D	J	F	M	A	M	J	J	A	S
Monthly Qav	6.73	7.16	31.6	21.56	28.32	57.66	79.41	47.33	12.52	7.47	6.2	5.83
Release flow	2.5	2.63	17.61	3.25	4.05	21.93	43.76	15.87	2.61	2.43	2.85	2.43
Difference (Monthly Qav-Release flow)	4.23	4.53	13.99	18.31	24.27	35.73	35.65	31.46	9.91	5.04	3.35	3.4

When current status and calculated amount of flows are compared to one and other, the Tennant Methods are not suitable for the river because of calculated values much lower than those of average and median flow value. In current conditions, released flow values are low for some months. Although, the released flows are seemed to be appropriate comparing to some methods used in this investigation, it might be suggested to increase release flow up to some value towards the average monthly flows of the river.

5. CONCLUSION

Hydropower potential is an attractive solution for energy need because of being a clean way of energy generation. Hydropower plants are the large-scale water management program aiming to increase the domestic electricity production and develop vast irrigation schemes for agriculture. There are 25 hydrological basins in Turkey, Turkey has great advantages from the view point of hydropower potential without storage and hydroelectric energy which is a clean and renewable energy source rise in importance day by day due to its domestic energy resource feature to meet Turkey's electricity energy need.

Many reasons such as limited water sources throughout the world or the decrease in usable water amount requires more attention for the management of the water sources. The necessity to maintain the sustainability of water in long term against increasing water demand placed integrated water source management to forefront.

In this case environmental flow evaluation studies constitute the base of integrated water sources management. The environmental flow evaluation studies aim to minimize the pressure and effects on a river while maintaining the balance between using and preserving thus ensuring the effective usage of water. Environmental flow evaluation may vary from country to country and even in different basins within the country. Therefore environmental flow evaluation should be made specific to each river in the basin.

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