

# Regional Flow Duration Curves for Seyhan and Ceyhan Basins

Halil Ibrahim Burgan<sup>1</sup>, Hafzullah Aksoy<sup>2</sup>PhD Student, Department of Civil Engineering, Istanbul Technical University, Maslak, Istanbul, Turkey<sup>1</sup>Professor, Department of Civil Engineering, Istanbul Technical University, Maslak, Istanbul, Turkey<sup>2</sup>

**ABSTRACT:** The Flow duration curve (FDC) is one of the most fundamental pieces of information that feeds into the design of a low-flow, hydropower, water supply and pollution studies. Because of the scarcity of available streamflow data, acquisition of FDC at the basins is important. By the help of FDC, flow at any time exceeded by a certain probability can be estimated. A proposed method in the literature was used in this study to estimate regional flow duration curve for Seyhan and Ceyhan Basins. For this reason, all gauging stations in the two basins were considered. The flow data were nondimensionalized by dividing to their annual values calculated using an empirical equation based on drainage area of the basin. Observed and computed mean flows are compared to test the performance of the model based on results of the case study from Seyhan and Ceyhan basins.

**KEYWORDS:** Flow duration curve (FDC), Empirical flow estimation, Nondimensional flow, Seyhan basin, Ceyhan basin.

## I. INTRODUCTION

Widely used in water science the flow duration curve (FDC) indicates frequency distribution of flows graphically. FDC is used in hydrologic studies for hydropower design, flood control, water quality, sedimentation and watershed management. FDC can be acquired from flow data of gauging stations at daily, 10-daily, monthly and yearly time scales [1]. Historically long term observed data are necessary to be able to use FDC. In this way, the discharge which is in excess of a percentage of time can be found.

FDC has been used since the beginning of 20<sup>th</sup> century [3]. There are a lot of applications of FDC models in the literature. For example; FDC model in Illinois, USA was studied for streamflow data between 1950-1964 from 120 flow gauging stations [7]. Regression equations using basin area and mean basin elevation were developed to obtain FDC in New Hampshire [2]. Hydropower potential and water availability at ungauged sites in Philippines were studied. FDC and basin characteristics were used to make regionalization procedure. For FDC, the types of equations were as follows,

$$Q = Q_A \cdot e^{(-c \cdot D)} \quad (1)$$

$$Q = a \cdot D^{(-b)} \quad (2)$$

where  $Q$ : the discharge per unit area of the basin;  $D$ : the percentage of time that  $Q$  has been exceeded during the period of record; and  $Q_A$ ,  $a$ ,  $b$ , and  $c$ : positive constants [8].

The characteristics of monthly FDC were defined as the mean annual areal precipitation  $P$  (mm), the drainage area  $A$  (km<sup>2</sup>), the hypsometric fall  $H$  (m) and the length  $L$  (km) of the main river course from the divide of the basin to the gauging station using multiple regression [5]. The selection of confidence intervals in estimation of FDC was studied using yearly FDC [9]. An algorithm was described that was initially developed as a simple method for patching and extending observed time series of daily streamflow. The algorithm has been incorporated into a model that allows flows at a target site to be estimated from flows occurring at several source sites in South Africa [4].

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 12, May 2016

In this study, a regional FDC model developed for ungauged Himalayan catchments, India [6], was used and applied in Seyhan and Ceyhan basins, Turkey.

## II. MODEL STRUCTURE

The model has six steps to estimate regional FDC as follows,

- a) Nondimensionalization of flow
- b) Normalization of flow
- c) Normal quantile calculation
- d) Nondimensional quantile
- e) Empirical mean flow
- f) Dimensional quantile

### 2.1 Nondimensional flow

Flows are made nondimensional using mean value of flow gauging stations as

$$q = \frac{Q}{Q_{mean}} \quad (3)$$

where  $Q$ : observed flow series,  $q$ : nondimensional flow series and  $Q_{mean}$ : mean flow of the flow gauging station.

### 2.2 Normalized flow

The nondimensional flow time series is transformed to have the normal distribution using power transformation as

$$W = \frac{(q^\lambda - 1)}{\lambda}, \text{ if } \lambda \neq 0 \quad (4a)$$

$$W = \ln(q), \text{ if } \lambda = 0 \quad (4b)$$

where  $\lambda$  is a parameter determined by trial-and-error.

### 2.3 Normal quantile

Mean and standard deviation of normalized flow series are calculated. For the variable  $W$  which is compiled normal distribution,

$$W_D = \mu_w + Z_D \cdot \sigma_w \quad (5)$$

where  $Z_D$ : taken from normal distribution table,  $D$ : probability of exceedance. In this case,  $W_D$  gives transformed flows corresponding the probability of exceedance,  $D$ .

### 2.4 Nondimensional quantile

For known  $W_D$  and  $\lambda$ , the  $q$ -quantile of probability of exceedance  $D$ ,  $q_D$ , can be derived from (4a) and (4b) using the inverse transformation as

$$q_D = (W_D \cdot \lambda + 1)^{1/\lambda}, \text{ if } \lambda \neq 0 \quad (6a)$$

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 12, May 2016

$$q_D = e^{W_D}, \text{ if } \lambda = 0 \tag{6b}$$

## 2.5 Empirical mean flow

To estimate the  $Q$ -quantile of probability of exceedance  $D$ ,  $Q_D$ , using  $Q_{mean}$  for an ungauged watershed is derived assuming the empirical regional power relation of

$$Q_{mean} = C.A^m \tag{7}$$

where  $A$ : drainage area,  $C$ : coefficient and  $m$ : exponent determined by using regression.

## 2.6 Dimensional quantile

$Q_D$  for an ungauged watershed of area  $A$  can be determined by

$$Q_D = Q_{mean} \cdot q_D \tag{8}$$

### III. STUDY AREA

Seyhan and Ceyhan basins are selected as study area. The location and boundaries of the basins are given in Figure 1.



Fig. 1. Location of Seyhan and Ceyhan basins.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 12, May 2016

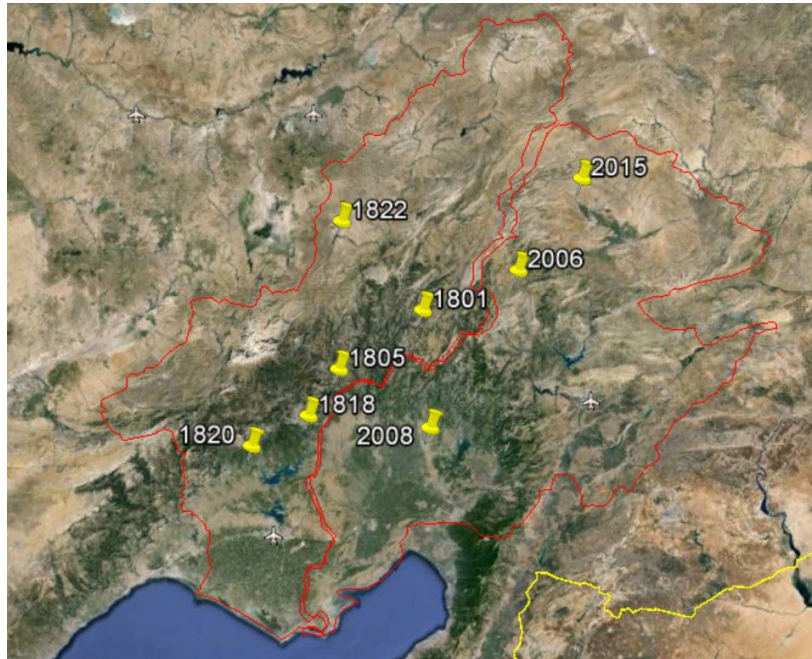


Fig. 2. Flow gauging stations in Seyhan and Ceyhan basins.

### 3.1 Data

Flow data were taken from Electrical Power Resources Survey and Development Administration (EIEI) of Turkey. Annual mean flow data of streamflow gauging stations 1801, 1805, 1818, 1820 and 1822 from Seyhan basin and 2006, 2008 and 2015 from Ceyhan basin were used (Figure 2). The longest flow series has been recorded between 1936-2000 while most have much shorter records. There are 345 annual mean flow data in the two basins, all together.

Model is developed based on these data set with the exception that gauging station 1805 was left for consideration of model validation.

## IV. APPLICATION

### 4.1 Calculation of nondimensional flows

Annual mean flows were calculated from the records for all stations and given in Table 1. Flow data records in hand are divided by mean flow of each station to obtain nondimensional flow values.

Table 1. Annual mean flows

Station no	Flow (m <sup>3</sup> /s)
1801	30.328
1805	59.949
1818	149.449
1820	14.486
1822	20.049
2006	9.108
2008	8.342
2015	8.280

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 12, May 2016

## 4.2 Normalization

Nondimensional flows were normalized by the Box-Cox transformation  $q' = q^{0.3}$ . The skewness coefficient of the time series was reduced 0 after transformation from 0.52 before transformation. The histogram of the normalized nondimensional flows is given Figure 3.

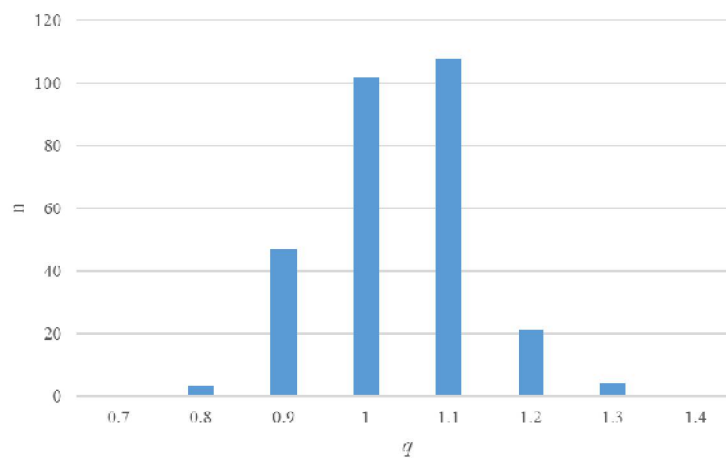


Fig. 3. Histogram of normalized nondimensional flows.

## 4.3 Calculation of nondimensional quantiles

The nondimensional flows corresponding probability of exceedance  $D$  were calculated. As presented in Table 2, any nondimensional flow can be calculated corresponding any probability of exceedance. Nondimensional FDC based on Table 2 is given in Figure 4.

Table 2. Nondimensional flows corresponding probability of exceedance  $D$

$D$ (%)	$Z_D$	$W_D = \mu_w + Z_D \cdot \sigma_w$	$q_D = W_D(1/0.3)$
5	1.64	1.14	1.54
10	1.28	1.11	1.40
15	1.04	1.08	1.31
20	0.84	1.07	1.24
25	0.67	1.05	1.18
30	0.52	1.04	1.13
35	0.39	1.03	1.09
40	0.25	1.01	1.04
45	0.13	1.00	1.01
50	0.00	0.99	0.97
55	-0.13	0.98	0.93
60	-0.25	0.97	0.90
65	-0.39	0.96	0.86
70	-0.52	0.94	0.82
75	-0.67	0.93	0.78
80	-0.84	0.91	0.74
85	-1.04	0.90	0.69
90	-1.28	0.87	0.64
95	-1.64	0.84	0.56



## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 12, May 2016

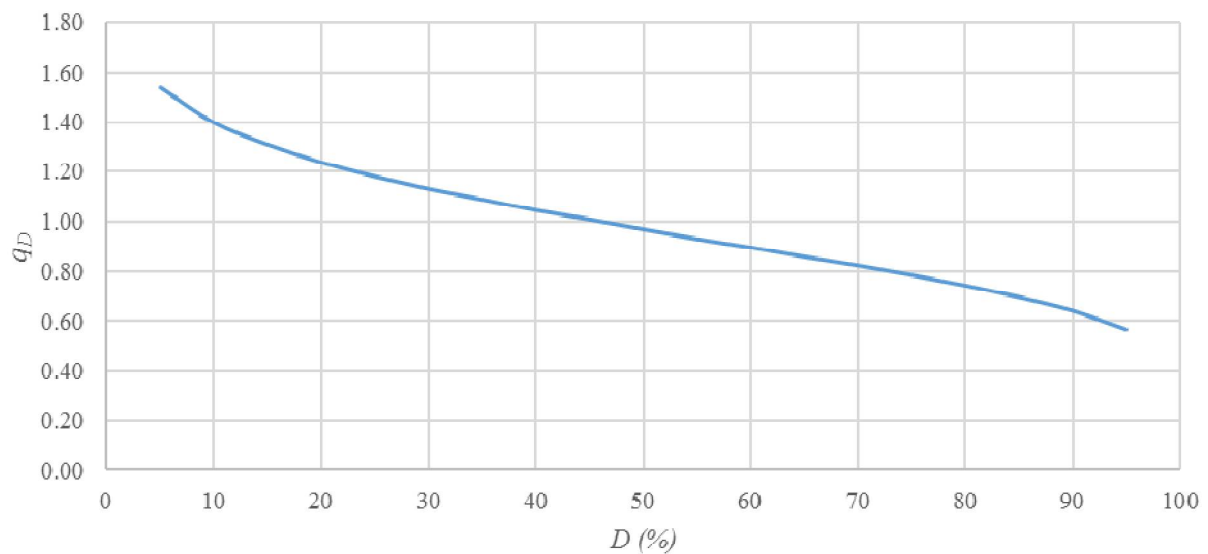


Fig. 4. Nondimensional FDC of observed flows.

#### 4.4 Empirical mean flow

In addition to Table 1, drainage areas for all basins are given in Table 3. Using the multiplicative regression analysis,

$$Q_{mean} = 0.0616A^{0.7564} \quad (9)$$

was derived as an empirical equation to be used for Seyhan and Ceyhan basins.

Table 3. Annual mean flows and drainage areas of gauging stations

Station no	Flow (m <sup>3</sup> /s)	Area (km <sup>2</sup> )
1801	30.328	2596.8
1805	59.949	4243.8
1818	149.449	1440.8
1820	14.486	6334.8
1822	20.049	739.2
2006	9.108	444.0
2008	8.342	915.2
2015	8.280	2596.8

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 12, May 2016

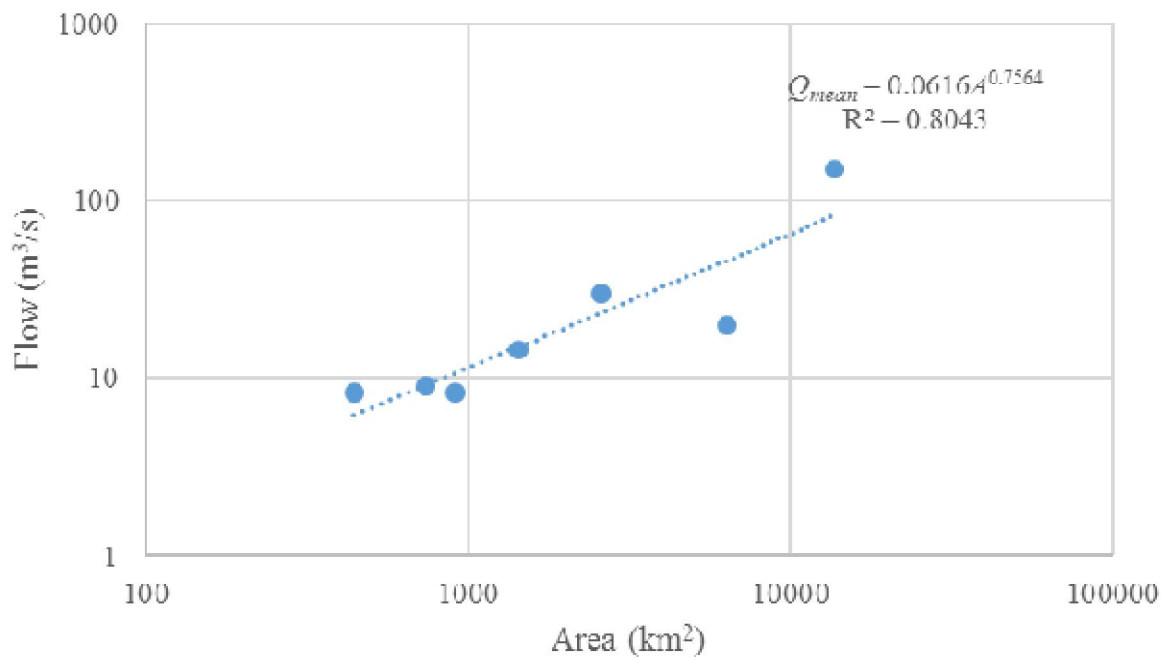


Fig. 5. Empirical relation between mean flow and drainage area.

### 4.5 Results

Observed and estimated mean flows are given in Figure for case study in gauging station 1805. The model underestimated the flow for all exceedance probabilities. The model has no success in this sense that can be linked to the low number of gauging stations and data with no proper length. Further datasets are required to make progress in the model development. Also revisions can be considered in the model for better hydrological studies for determination of FDC.

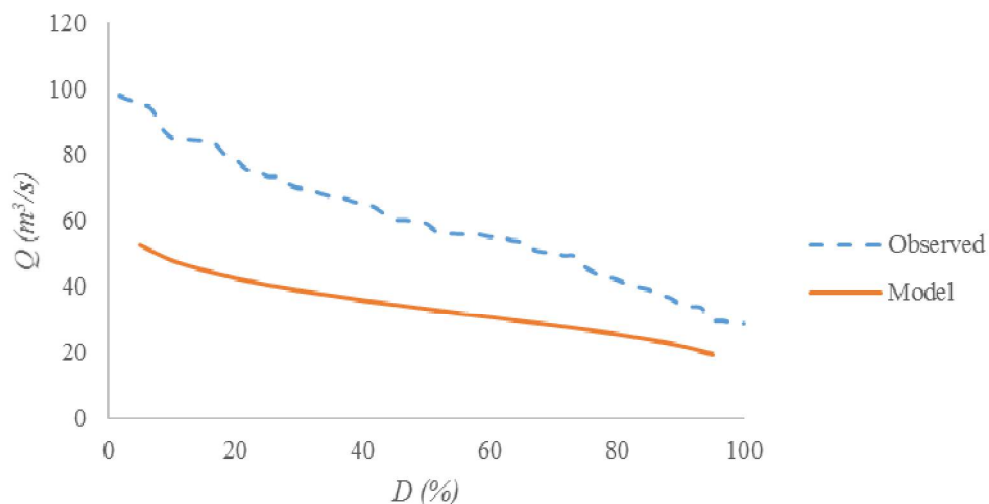


Fig. 6. FDC for gauging station 1805.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 12, May 2016

## V. CONCLUSION

A regional FDC model is developed considering nondimensionalization of observed streamflow data together with an empirical model using drainage area as independent variable. Results are promising although the model underestimates annual FDC for a streamgauge in Seyhan basin. The low performance of the model can be connected to the short data length and number of gauging stations for which further studies are in progress.

## ACKNOWLEDGEMENT

This study was supported by Research Fund of Istanbul Technical University through the PhD thesis “Flow Duration Curve (FDC) model for ungauged catchments” of the first author.

## REFERENCES

- [1] Cigizoglu, H. K. (1997). Mathematical models of flow duration curves. Istanbul Technical University PhD Thesis. 96 pages.
- [2] Dingman, S. L. (1978). Synthesis of flow duration curves for unregulated streams in New Hampshire. Water Resources Bulletin-American Water Resources Association, vol. 14(6), p. 1481-1502.
- [3] Foster, H. A. (1924). Theoretical frequency curves and their application to engineering problem. Am. Soc. Civil Engineers Trans., vol. 87, p. 142-203.
- [4] Hughes, D. A., Smakhtin, V. (1996). Daily flow time series patching or extension: a spatial interpolation approach based on flow duration curves. Hydrological Sciences Journal, vol. 41(6), p. 851-871.
- [5] Mimikou, M., Kaemaki, S. (1985). Regionalization of flow duration characteristics. Journal of Hydrology, vol. 82, p. 77-91.
- [6] Singh, R. D., Mishra, S. K., Chowdhary, H. (2001). Regional flow-duration models for large number ungauged Himalayan catchments for planning microhydro projects. Journal of Hydrologic Engineering, vol. 6, p. 310-316.
- [7] Singh, K. P. (1971). Model flow duration and streamflow variability. Water Resources Research, vol. 7(4), p. 1031-1036.
- [8] Quimpo, R. G., Alejandrino, A. A., McNally, T. A. (1983). Regionalized flow duration for Philippines. Journal of Water Resources Planning and Management, vol. 109(4), p. 320-330.
- [9] Vogel, R. M., Fennessey, N. M. (1994). Flow-duration curves I: New interpretation and confidence intervals. Journal of Water Resources Planning and Management, vol. 120(4), p. 485-504.