ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

INVESTIGATING HYDRAULIC GEOMETRY OF UNREGULATED RIVERS IN WESTERN TURKEY FOR SUSTAINABLE RIVER MANAGEMENT

M.Sc. THESIS

Gökçe DUMAN

Department of Environmental Engineering

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Thesis Advisor: Prof. Dr. Erdem GÖRGÜN
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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

SÜRDÜRÜLEBİLİR AKARSU YÖNETİMİ İÇİN REGÜLE EDİLMEMİŞ BATI TÜRKİYE AKARSULARININ HİDROLİK GEOMETRİSİNİN İNCELENMESİ

YÜKSEK LİSANS TEZİ

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OCAK 2015

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Date of Submission : 12 December 2014
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To my Sumbolon and family,

FOREWORD

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December 2014 Gökçe DUMAN

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ABBREVIATIONS and SYMBOLS

EFA : Environmental Flow Assessment
WR : Weakly Regulated
SHW : State Hydraulic Works
BMW : Büyük Menderes Watershed
KMW : Küçük Menderes Watershed
GW : Gediz Watershed
KEW : Kuzey Ege Watershed
SW : Susurluk Watershed
MEW : Meriç-Ergene Watershed
BAW : Batı Akdeniz Watershed
FWEE : Foundation for Water and Energy Education
FISRWG : Federal Interagency Stream Restoration Working Group
Q : Water discharge in cubic meter per second
w : Bankfull channel width
d : Bankfull channel depth
v : Velocity
n : Manning rougness factor
S : Slope
a : Coefficient representing width at unit discharge
c : Coefficient representing depth at unit discharge
k : Coefficient representing velocity at unit discharge
N : Coefficient representing roughness at unit discharge
s : Coefficient representing slope at unit discharge
b : Exponent in width-discharge relation
f : Exponent in depth-discharge relation
m : Exponent in velocity-discharge relation
p : Exponent in roughness-discharge relation
y : Exponent in slope-discharge relation

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INVESTIGATING HYDRAULIC GEOMETRY OF RIVERS IN WESTERN TURKEY FOR A SUSTAINABLE RIVER MANAGEMENT

SUMMARY

Playing a major role in the geographic cycle, rivers are both the routes over which the erosion products are carried to the sea and the mechanism for effecting the transportation. Through decades, it is observed that, a complete cycle of healthy river life consists of successive stages of youth, adolescence, maturity and old age. At the stage of maturity, a river is very well able to attain the condition of grade that connotes the existence of equilibrium in the river system. Stream characteristics tend to adjust themselves to the discharge and sediment load. Therefore, if necessary, a healthy river restoration ought to aim to mimic the most natural condition as much as it could. For a sustainable river restoration, selection of river cross-section is vital since it has a great influence on determining the magnitude of flood for a given section; defining sediment characteristics and transport process mechanism; thoroughly understanding the riverine ecosystem and determining the velocity, which can affect fish community.

The present work describes in quantitative terms the manner in which hydraulic geometry parameters change with discharge at a given unregulated/natural river cross-section and how environmental friendly river restorations and impact assessments can be figured out according to the river geometry. It has seen that some measured hydraulic characteristics of stream channels (width, depth, velocity, slope) vary with discharge as simple power functions at a given river cross section. The discharge related hydraulic geometry functions derived for a given cross section among various cross sections along the river differ only in numerical values of coefficients and exponents. An empiric quantitative relation among average measurements of width, depth, velocity and slope is derived from data on natural, unregulated rivers. Afterwards, characteristics of channel shape in the unregulated river cross sections are examined. At a given cross section with a gauging station, the bankfull width and depth and therefore, the velocity change with the amount of water flowing in the cross section. The changes in these geometric parameters seem to have certain characteristics which are applicable to many natural river cross sections. The data used in this study collected at regular river measurement stations for purposes of determining river discharge by State Hydraulic Works.

This study uses hydraulic data surveyed in 14 unregulated reaches within six different river basins (Büyük Menderes, Küçük Menderes, Kuzey Ege, Susurluk, Meriç-Ergene, Gediz) in the Western Turkey. These river basins have similar meteorological characteristics in common, representing the western mediterranean region. Combining Google Earth features with the gauging station data which was provided by State Hydraulic Works, first of all, unregulated reaches and weakly regulated reaches were determined by excluding dams and weirs along the reach for the six different river basins. Secondly, among the determined total unregulated reaches on those river basins, usable reaches were selected according to the applicable gauging station data corresponding to them. After deciding the reaches and stations, SHW data were gathered together to calculate the cross sectional area for each of the river basin reach. For that cross section data, rating curves and flow duration curves were computed then. Coming to the formative discharge, two statistical analysis were done to decide the best correlated discharge with the channel geometry. Subsequently, empirical equations, coefficients and exponents were generated according to the relationship between discharge values and cross-sectional geometry. The generated empirical hydraulic geometry and flow expressions were tested within the unregulated Batı Akdeniz river basin for the validation purpose of the empirical results.

Rivers tend to adjust and reconstruct themselves with their self healing capacity and if necessary, a healthy river restoration must mimic the most natural condition as much as possible. Overdesigning or enlarging the channel cross section (typically widening) can create a conflict in the large woody debris balance and may give rise to the thrash accumulation and eventually a slow death of a functioning river. For a sustainable river restoration, selection of river cross-section is vital since it has a great influence on determining the magnitude of flood for a given discharge; defining sediment characteristics and transport process mechanism and thoroughly understanding the riverine ecosystem. And with the help of flow patterns through history, a link can be established between the main river channel capacity and it’s flow interaction so that a natural flow regime and it’s relationship with cross-sections can be understood. Since formative discharges are main triggers of a typical cross-section of a river, this study is conducted to give a better understanding of hydraulic geometry parameters changing with discharge at a given unregulated river cross-sections located in Western Turkey and the results might be a transitional stage to the urban runoff planning and future works can be done to imitate unregulated river cross-sections where modified land use require different development strategies.

BATI TÜRKİYE AKARSULARININ HİDROLİK GEOMETRİSİNİN SÜRDÜRÜLEBİLİR NEHİR YÖNETİMİ AÇISINDAN İNCELENMESİ

ÖZET

Sağlıklı bir akarsuda ekolojik denge kendiliğinden kurulmakta, dış ortamdan herhangi bir etki olmadığı sürece doğal olaylar vasıtası ile varlığını sürdürmektedir. Ancak dünya nüfusunun kontrolsüz büyümesi ve buna paralel olarak şehirleşmenin de etkisiyle kaynak arayışlarının artışı sonucu, insan müdahalesi ile daraltılan, kanal içerisine alınan sular, akarsu akımları üzerinde neredeyse geri dönüşü olmayan sonuçlara sebep olmaktadır. İnsan müdahalesi sonucu akış kesitinin konut ve diğer kullanım amaçları için bozulması veya üstünün kapanması da daha fazla taşkına yol açmaktadır. Şehirleşme arttıkça, insan çıkarları doğrultusunda yapılan beton, asfalt gibi su geçirmeyen zeminlerin artması, şehir içindeki en önemli hidrolojik sorunlardan birisidir ve bilinçsiz yaptırımlar sonucu yağmur sularının yeraltına sızması azalarak bitme aşamasına gelmiştir. Geçirimsiz tabakalar arttıkça, yeraltına yağmur sularının süzülme oranının azalmasıyla yeraltı su seviyesi de düşmektedir. Yeraltı su seviyesinin düşmesiyle birlikte akarsuların rejimleri de değişmektedir. Yüzeyde biriken yağmur suları aniden akışa geçerek kendi ekolojik döngüsüne katılamayan taşkınları doğurmaktadır. Esas olan, yapılaşma hesabının doğru ve doğaya saygılı ölçütlerle hesap edilmesi ve hatta mümkün olduğu kadar betonlaşma ve asfaltlaşmanın önüne geçilmesidir. Mühendisler tarafından önerilen de şehirleşme çalışmalarında doğanın doğru ölçülmesi ve doğru değerlendirilmesinin yapılmasıdır. İklimin olumlu yönlerini olumsuz koşullara karşı kullanabilmek amacıyla, yapılaşma planları gün ışığından maksimum yararlanan ve iyi bir yalıtım ile daha az enerji tüketen konutlar üretme amacına göre hazırlanmalıdır. Yağışın yeraltı su kaynaklarını beslemesine imkan sağlayacak şekilde mevcut yeşil alanların genişletilmesi ve korunması esas alınmalıdır.

Tüm bunlarla birlikte akarsu yataklarında yapılaşma yasaklarına uyulmalı, felaketler oluşmadan önlemler alınmalı, gerekli görülen restorasyon çalışmaları ise doğanın ekolojik yenileme döngüsünü taklit edecek en yakın şekilde yapılmalıdır. Taşkınların en büyük nedenlerinden biri de şehir içindeki ve çevresindeki derelerin yanlış ıslahı, ıslah edilmemesi ya da ıslah adı altında kanal içerisine alınması ve kesitinin doğal akışı bozacak şekilde daraltılmasıdır. Esas amacı su taşıyıcılık olan dereler, çarpık, bilinçsiz kentleşme sonucu kanalizasyon atıkları ve çöplerle dolmakta, ve zaten şehirleşme sonucu akımı azalan akarsu, bunların sonucunda iyice kendini taşıyamaz hale gelmektedir. Şehir gelişmeleri planları hazırlanırken doğal ortam ilişkilerini iyi araştırarak ortaya koymak ve sürdürülebilir planlar yapmak gerekmektedir.

Doğal dengenin bozulmamasına önem gösterilmeli ve mümkün olduğunca beton alanların tekrar doğal haline çevrilmeye çalışılmasına yardımcı olunmalıdır. Sürdürülebilir akarsu restorasyon çalışmaları için nehir en kesiti seçimi, belirli bir debideki taşkın şiddetini belirlemede, sediment karakteristikleri ve taşınım mekanizmalarının belirlenmesinde, nehir ekosisteminin tam anlamıyla kavranmasında ve balık ekosistemini etkileyebilecek hızların ölçütlendirilmesinde

etkin rol oynadığından son derece önemli bir konudur. Şekillendirici debiler de tipik bir en kesitin oluşumunda ana tetikleyici faktör olduğu için, bu çalışma regüle edilmemiş Batı Türkiye nehir havzaları akarsularının belirli en kesitlerinin, debiyle değişen hidrolik geometri parametrelerinin anlaşılmasını kolaylaştırmak ve yapılacak ıslah çalışmalarına doğayı, nehir ekosistemi döngüsünü önemseyen akademik bir bakış açısıyla yaklaşılmasını, doğa dostu en kesit şekli tasarımları yapılmasını teşvik etmek amacıyla yürütülmüştür. Çalışma için Türkiye'nin batı bölgesine bir bakış açışı sağlama açısından Büyük Menderes, Küçük Menderes, Kuzey Ege, Susurluk, Meriç-Ergene, Gediz havzaları ve metot validasyonu amacıyla da Batı Akdeniz Havzası seçilmiştir. Bu havzaların seçilme sebebi ağırlıklı olarak, Batı Türkiye bölgesini yansıtan benzer meteorolojik karakteristiklere, karşılaştırılabilir benzer yağış karakteristiklerine, ve doğu bölgelerine kıyasla düşük eğimli akarsulara sahip olmalarından ileri gelmektedir.

Metot çalışmasına geçmeden önce insanın, akarsu kollarını nasıl şekillendirdiği ve tahmin edilemez sonuçlara yol açtığı daha genişletilmiş şekilde açıklanmış ve sonrasında kentleşmeyle birlikte hidroelektrik projeleri gibi doğal olmayan yapıların ve insan faktörünün akarsular ve taşkın yatağı bitkileri üzerindeki ekosistem etkilerinden kısaca bahsedilmiştir. Üçüncü bölümde doğal akarsuların jeomorfik karakterizasyonu ve önemli sınıflandırma parametreleri hakkında bilgi verilmiş ve akabinde kesit şekillerini ampirik ifadelerle anlamamızı sağlayan hidrolik geometri prensibine geçilmiştir. Çevresel akış çeşitleri ve doğa dostu, başarılı akarsu ıslah çalışmaları ve "yeniden doğallaştırma" kavramından bahsedildikten sonra metodolojik kısım anlatılmıştır.

Bu çalışmada kullanılan 14 regüle edilmemiş akarsu kolunun 23 regüle edilmemiş akım gözlem istasyonuna ait enkesit ölçümleri ve anahtar eğrisi ve debi süreklilik çizgisi hesapları için gerekli olan günlük ortalama debi verileri Devlet Su İşleri tarafından basılan akım yıllıklarından sağlanmış olup, regüle edilmemiş altı havza akarsularının tam dolu genişlik, derinlik, hız ve eğimlerinin kesit biçimlerici debiyle ilişkisini gösteren ampirik formülleri hidrolik geometri prensibine göre oluşturulmuştur. Google Earth üzerinden regüle edilmemiş akarsu kolları, kol boyunca akımı kontrol eden bent ve barajların elenmesiyle seçildikten sonra bu kollardaki akım gözlem istasyonları belirlenmiştir. Daha sonrasında bu akım gözlem istasyonlarına denk gelen kesitlerin şekilleri bilgisayar ortamında görselleştirilmiş ve tam dolu kesit geometrisi çıkarıldıktan sonra bu geometriye denk gelen tam dolu debiler, yine DSİ'den sağlanan debi ve derinlik ölçümü verilerine dayanarak hesaplanan anahtar eğrilerinden okunmuştur. Ardından enkesit biçimlendirici debiyi seçmek amacıyla "maksimum yıllık ortalama debi" tabanlı ve "debi süreklilik çizgisi" tabanlı iki istatistiksel metot izlenmiştir. Bu iki metodun debilerinin kesit geometrisiyle de ilişkilerine bakıldıktan sonra en iyi korelasyonu sağlayanın, debi süreklilik çizgisinden elde edilen "binde iki"lik debi olduğu görülmüştür ki bu da anlamlı bir taşkın dönüş aralığı olan 1,5 seneye tekabül etmektedir.

Daha sonra, şekillendirici en iyi korelasyonu sağlayan debi ve ölçülen kesit geometrisi yardımıyla elde edilen ampirik hidrolik geometri katsayıları ve üslerinin, genişliği ve derinliği bilinmeyen bir başka regüle edilmemiş akarsu havzası kolundaki geçerliliğini kontrol etme amacıyla, kesit şekli bilinmeyen Batı Akdeniz havzasının regüle edilmemiş istasyonlarının enkesit verileri tahmin edilmeye çalışılmış ve tutarlı sonuçlar açığa çıkmıştır.

Bu çalışma sonucunda maksimum yıllık ortalama debilerin ve günlük ortalama debilerin, regüle edilmemiş akarsuların kesitlerini biçimlerici özelliğini en iyi karakterize eden debiyi bulmada önemli rol oynadığı görülmüş ve validasyon sonuçları da çalışmada elde edilen ampirik hidrolik geometri katsayı ve üslerinin batı bölgelerindeki regüle edilmemiş diğer akarsu enkesit şekillerini belirlemede kullanılabileceğini göstermiştir. Akarsu havzası yönetiminde peyzaj yapılandırmaları ve taşkın kontrolü çalışmaları kadar akarsu restorasyonu da büyük önem taşımaktadır ve ana yatağın kapasitesi ile akışlar arasındaki ilişkisinin iyice anlaşılabilmesi için regüle edilmemiş kollarındaki enkesitlerin, debiyle olan davranışlarının incelenmesi büyük önem taşımaktadır. Bu çalışmanın en önemli özelliği, Türkiye'de henüz üzerinde durulmayan, restorasyon konusunda doğayı taklit etme amacımızda en önemli özelliğe sahip olan regüle edilmemiş akarsu havzası kollarına odaklanması ve buradaki akım gözlem istasyonlarına ait enkesit ve şekillerindirici debi verilerini ortaya çıkarmasıdır.

1. INTRODUCTION

1.1 Aim of the Thesis

Almost more than half of the world's accessible surface water is fragmented by humans, which is predicted to be increased by 2025 to an unprecedented level, %70 (Tharme, 2003). Supposedly water resource development works and alternations to the natural hydrological regime, most of which consist of weir diversions, interbasin water transfers, aquifer exploitations for agriculture, hydropower stations and impoundments, are the main reason for that subversive worldwide impacts to the riverine ecosystems. Though rivers tend to adjust and reconstruct themselves with their remarkable recovery capacity, when necessary, a healthy river restoration should mimic the most natural condition as much as possible. And once overdesigning or widening the channel cross section become involved, they can create a conflict in the large woody debris balance and may give rise to the thrash accumulation and eventually a death of a functioning river. Considering these devastating impacts, our study aims to suggest an environmentally friendly solution to the cross-section design by understanding the relationship between main river channel and it's flow patterns to mimic the natural flow and natural cross-section reconstruction. For a sustainable river restoration, selection of river cross-section is vital since it has a great influence on determining the magnitude of flood for a given section; defining sediment characteristics and transport process mechanism; thoroughly understanding the riverine ecosystem and determining the velocity, which can affect flora and fauna. The primary aim of this study is to give a better understanding to the hydraulic geometry of the unregulated rivers located in Western Turkey to provide a reliable background for the sustainable river restoration projects. Consequently, the results will provide contribution for sustainable river basin management strategy.

1.2 Scope of the Thesis

Based on all these arguments presented above, in this thesis it is particularly intended for understanding the relationship between formative discharge characteristics and channel geometry features of the natural rivers in Western Turkey. So as to attain this goal, unregulated stream gauging stations located in the six climatically alike river basins (Büyük Menderes, Küçük Menderes, Meriç-Ergene, Susurluk, Kuzey Ege and Gediz) were taken into consideration by analyzing their flow pattern data and the corresponding cross-section geometry characteristics. To tackle the effectiveness of the results, and ideal approach would aim at examining the generated data from selected natural rivers, on another unregulated river basin with cross-section data unknown. Therefore since the approach should be cost and time effective, generated empirical hydraulic geometry and flow expressions were tested within the unregulated Batı Akdeniz basin for the validation purpose.

In this context, the first section of the literature review of this thesis consists of how manmade effects can shape river channels throughout the history and how these effects can cause to unpredictable, devastating and hardly recoverable consequences and immediately afterwards urbanization, how hydropower projects can have an influence on the river channels and flood plain vegetation. Secondly, the geomorphologic characterization of the natural rivers is investigated through demonstration of the major stream types and their geometric characteristics and following that, in the light of the recognized geomorphologist and hydrologist Luna Leopold, “hydraulic geometry” principles which help us to understand the cross-section profiles with empirical equations are described. Right after mentioning environmental flows and the scope of ecologically healthy river restoration projects, methodologic set up used for the study, it’s hydrologic and statistical procedures are presented. Afterwards, the results of the empirical work that was conducted are evaluated and checked for validation and discussed.

2. LITERATURE REVIEW

In the beginning of the 90's, it's observed that 77% of the 139 largest river systems in Europe, North America and the republics of the former Soviet Union are entirely deprived of unregulated large rivers. Later on, Revenga et al. (2000) figured out that 60% of the world's rivers are already exposed to hydrological alteration, with %46 of the 106 primary watersheds diversified by at least one large dam. In addition, it is found out that 37% of rivers in the 225 basins throughout the world are highly fragmented. In the United States alone, there are more than 6575 large dams and 85% of all inland surface waters are artificially controlled (Tharme, 2003).

Supporting a natural flow paradigm, tremendous rate of scientific research has escalated worldwide where the magnitude, frequency, duration, variability and timing of a river flow regime are regarded as the key components. Detailed discussions of undeniable hydrological alteration effects on riverine systems at a global scale, with ecological impacts ranging from genetic isolation to biodiversity declines are presented in the corresponding articles later on.

The question "for the water resource development and management, to what extents the flow regime of a river can be altered from its natural form without destructing its integrity?" has led to the development of environmental flow assessment (EFA), which produces one or more explanations of possible modified hydrological regimes for the river, in parallel with the future ecosystem conditions, where attention has recently been directed at the flow-related aspects of river restoration (Arthington et al, 2006). The EFA scale has a wide range of study areas from a large river basin with regulated and unregulated tributaries to a single river flow restoration project.

The effect of human impact have to be thoroughly understood in order to comprehend and predict the styles and consequences of natural change within the rivers. Over the last 5000 years, the interference of the human activities has affected the river channels through various phases including engineering processes such as dam construction and river diversions.

These course of events led to direct and indirect modification pathways so as to rehabilitate and redress the overly modified river channels with the help of dam removal and stream and river restoration (Gregory, 2006).

According to Downs and Gregory, during investigations of which focused on the river channel changes, it has been seen that at least five main impact challenges persist: Dams, 45,000 large dams with an area of more than 400,000 km^2 worldwide; Channelization, 0,03 km/km^2 channelized density of 26,550 km major works in the USA; Channel modification, Little amount of semi-natural river conditions remain (average of <%20 of length of Alpine rivers); River diversions, Canal building to transfer water from river basins; Water extraction, Withdrawal of freshwater for human use.

Benefiting from the foundations pointing out the impacts of these various categories of engineering interferenced activities, urbanization and network consequences of channel change; the awareness and importance of human influence is established by means of essential key contributions covering:

i. The understanding of the channel type using the relationship between the involving bed material load, particle diameter, water discharge and slope.
ii. Channel extension complemented by aggradation downstream
iii. Erosion cycle of urban channels from forest through agricultural lands and urbanization
iv. River metamorphosis, thresholds and complex response
v. Rate law: changing from one equilibrium to another through a response and reaction time

However, it has not always been possible to predict what will happen in a particular location because of:

Complex response, meaning variety of changes which may occur after crossing a geomorphic threshold; Historical contingency, which is the state of systems or environment is at least partially dependent on one or more previous states or events in the past; Hypersensitivity: large amount of change due to a small hydrological change. Therefore some “What”, “How”, “When”, “Where” and “Why” questions need to be asked concerning human role in changing river channels to focus on the emphases in research, which is required to build a conceptual river metamorphosis model and to look through a holistic approach.

The prediction of the future's landscape and the morphological properties at a particular location is the first challenge in terms of developing cost-effective and sustainable river managemnet strategies. Such that, in semiarid areas due to occasional large events, channel eroding may occur which will lead increased channel capacities eventually, whereas, in humid areas, large events are the reason of flow inducement over the flood plain, exceeding the channel capacity. Different environments will have different and wide range of responses and it is needed to reduce uncertainty in the context of location of channel change.

Secondly, feedback effects should be taken into consideration, since identification of the connectivity of course sediments (buffers, barriers and blankets) may account for delays in the adjustment process and have to be seen as key elements for creating critical threshold conditions.

Thirdly, global climate change is another imperative key element considering the sensitivity and behavior of channels to the threshold conditions. As basin changes affect land cover in a river basin, it is crucial to know whether it will amplify or reduce the climate signal recorded in fluvial sediment or not.

Last but not the least, greater awareness is needed for a cultural dimension since cultural climatology is strongly related with cultural geomorphology. Public attitudes to rivers in the past and present must be understood thoroughly to assess the nature of river management concepts in different cultures, Gregory (2006) explained the individual perceptions might affect all forms of local decision making.

Although it has been more than 4000 years of exercise of human role in changing river channels, this topic has been addressed only since 1956 in scientific investigations. It is now possible to reduce the uncertainties and paradigm problems suggesting provisional knowledge.

2.1 Stream Health and Urbanization

Urbanization does much of is damage to urban streams via watershed paving, replacing the pervious forest land with the impervious ones such as roads.

Impervious surfaces not only creates frequent and larger floods but also prevents groundwater recharge by blocking the infiltration.

Activities of urbanization can affect a stream sediment regime in two early phases: first of which is the forming of the fine sediment from the construction activities in the watershed. Secondly, stream enlargement, in other words bed and bank erosion occurs because of the peak flows (bankfull discharges) on the impervious surfaces. In a pristine stream, bankfull discharge occurs every one to two years, however in an urbanized stream, it is three to five times per year. Both phases lead to sediment overload, where streambed is covered with fine material and it can take 15-50 years for the streambed to recover the initial sediment overload (Finkenbine et al, 2000). In the following sub-chapters, firstly hydroelectric projects and their effects on rivers are discussed. Supersaturation, sedimentation and eventually ecosystem changes which are discussed are just few of the inevitable distruption events. Secondly, natural and manmade disturbances on floodplain vegetation are explained briefly.

2.1.1 Hydroelectric Projects and Their Effects on River

Even though hydropower can be regarded as a renewable and clean energy source, there is also an environmental impact side that should be considered in the framework of a river's ecosystem. Flow rate, size, climatic conditions, and habitat of a river; the type and operation of the project are the major factors hydroelectric projects depend on. The most common hydroelectric facilities are storage projects and run-of-the-river projects. The first one is like a water reservoir waiting for to be released when the electricity demand increases, where the latter allows water to pass about the same rate the river is flowing.

2.1.1.1 Ecosystem changes, supersaturation and sedimentation

Reservoirs are included within the storage projects and they significantly slow the rate at which the water is moving downstream where water surface temperature tends to be warmer as the heat is absorbed from the sun by the slack water. On the other hand, colder water, containing low oxygen levels sink to the bottom, which forms *stratification*. When water is released from the bottom, it alters downstream habitat due to oxygen depletion. In many regulated river systems, modified flow regimes are followed by shifts in the thermal regime, especially where there are hypolimnetic water releases from dams, causing cold oxygen-deficient release of water downstream. (FWEE, 1998)

On the other hand, as water hits the pool below, creating air trap in water over a dam, a turbulence occurs in which dissolved nitrogen level of water increase significantly. This is called *supersaturation* and it can can enter fish tissues and even may result in fatal injuries. In addition, sediment build-up behind a dam may occur in the man-made or natural erosion of lands located near to a reservoir, leading to a situation called *nutrient loading*. The more nutrients are there available to be consumed, the more organisms gather together in the area. In the end, since much more oxygen is used, depletion of oxygen occurs in the reservoir.

2.1.1.2 The influence of run-of-the-river projects on riverine ecosystem

Run-of-the-river projects (Figure 2.1) are the type of hydroelectric generation projects whereby little or no water storage is provided and schemes can only operate when there is sufficient flow in the water and the amount of water available for power generation is also related to abstraction regime of individual schemes. Requiring an impounding structure and being mostly the re-developments of existing sites such as old mills or claiming construcion of small weirs, run-of-the-river project impacts on the aquatic life considering fish communities are still poorly understood. Weirs and barriers used in run-of-the-river schemes can pave the way for fragmentation and disturb longitudinal movement. Migratory behaviours can be distruped by impoundment structures and population decrease might occur eventually. Longitudinal and lateral connectivity maintenance is therefore vital to the viability of fish communities. (Sniffer, 2011)

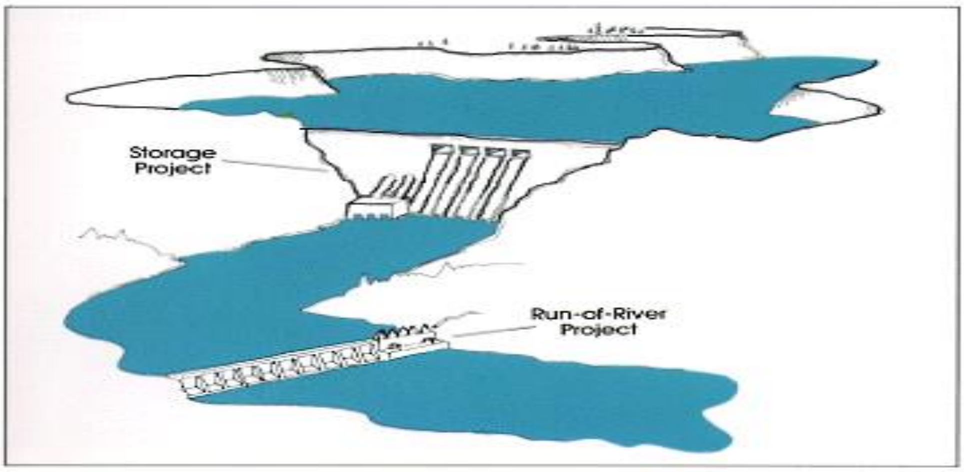


Figure 2.1 : Storage and run-of-the-river projects. (http://www.fwee.org)

2.1.2 Natural and Manmade Effects on Floodplain Vegetation

The nature, somehow, is capable of supporting the dynamic ecosystem of riparian landscapes and its disturbances. However, as a result of engineering activities, this high biodiversity becomes affected and plants which are already accustomed to their surroundings are faced with extinction.

In ecology, disturbance is defined as "any relatively discrete event in time that removes organisms and opens space which can be colonized by individuals of the same or different species". Today, human disturbances are becoming increasingly the dominant altering factors, controlling flooding and inhibiting bedload transportation.

2.1.2.1 Natural disturbances on floodplain vegetation

Erosion and accumulation of bedloads, together forming morphodynamics, are the strongest physical disturbance for floodplain vegetation (Figure 2.2), in which gravel and sand is transported by water, whereas new plant habitats are created by the accumulation of bedloads. Whilst morphodynamics strongly affect the main river course, hydrodynamics are responsible of the whole floodplain area.

2.1.2.2 Human disturbances on floodplain vegetation

Dams, water regulations, hydroelectric power plants and such civil engineering measures have great influence on watershed dynamics, and settlers cause deforestation in the catchment areas. When morphodynamics disappear and hydrodynamics get reduced, leading vegetation (Figure 2.3) becomes extinct and fossil flood plain forests occur due to river bed erosion.

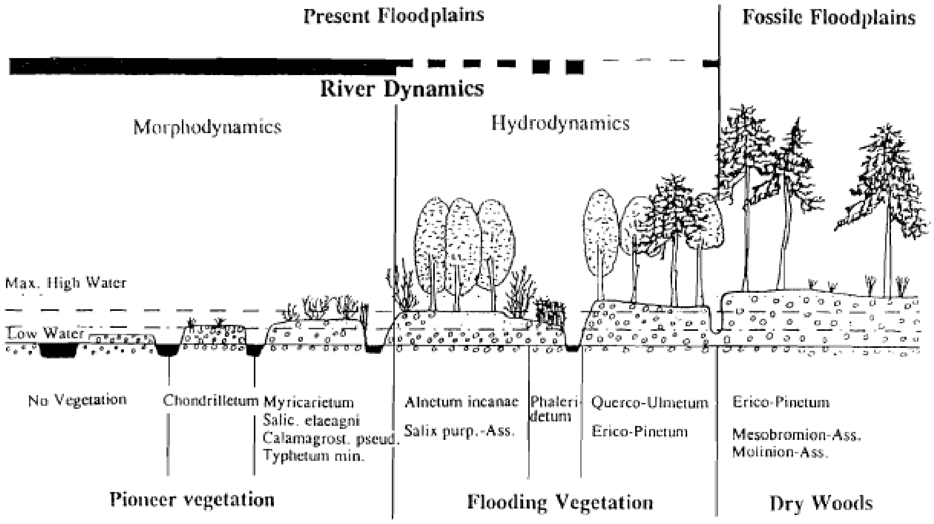


Figure 2.2 : Typical zonation of the floodplain vegetation under natural disturbances (Müller, 1998).

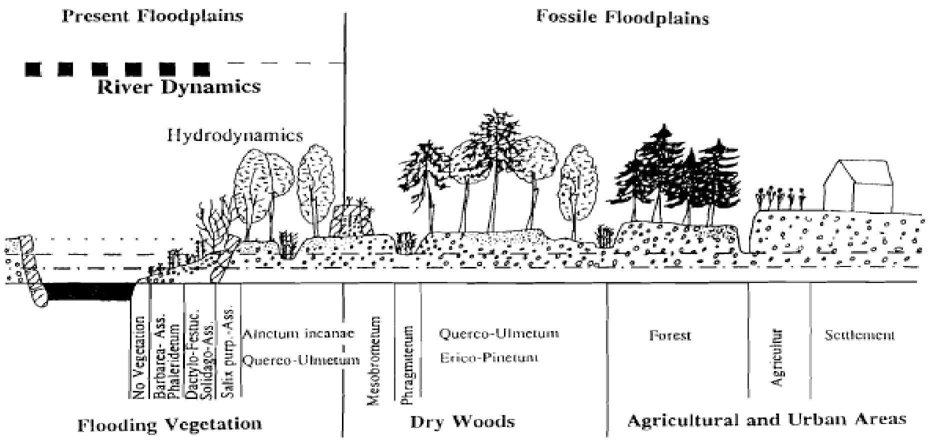


Figure 2.3 : Typical zonation of the floodplain vegetation under human disturbances (Müller, 1998)

2.2 A Classification of Natural Rivers

Real challenge in the river systems is that further investigations always lead to deeper ones as what initially appears complex gets even so more. Thereby for the sake of simplicity law, channel categorization which is suggested by Rosgen (1994) helps us

i. To estimate a river's behavior by reading it's appearance;

ii. To develop hydraulic and sediment relations for a given morphological channel type and state;

iii. To provide a reference data to those of similar character.

Platts (1980) defines classification as "the strictest means ordering or arranging objects into groups or sets on the basis of their similarities or relationships". Some beneficial usage of this stream classification includes: engineering applications such as hydraulic geometry relations, flow resistance, critical shear stress estimates, stream bank erodibility potential, fish habitat structure evaluation, water resource management and restoration.

2.2.1 Geomorphic Characterization

Geomorphic characterization deals with valley and channel morphology by combining the effects of life zones (desert shrub, alpine etc.), climate and depositional history within the landform and fluvial feature integration.

Stream style categorization can be described using some essential terms like longitudinal profiles, channel-sections and plan views (Fig.2.4 and 2.5). It was found that pool, riffle, cascade and rapid bed features are continually related to channel slope. In addition to this, sinuosity which can be calculated from aerial photographs is also a good initial indicator of major stream types. Another significant parameter is meander width ratio (belt width/bankfull surface width) (Fig.2.6), which is not only beneficial for classification but also for predicting the most probable channel pattern (Fig.2.7) when it comes to the stream restoration work. Relation between channel morphology and stream flow holds the required information for the successful restoration of the stream channels to a more stable condition.

River channels can be found in various kind of size and magnitude, where overall drainage network can be defined through stream relative magnitude that can be calculated via tributary addition to the downstream relative magnitude of the trunk channel. The number of channels define the drainage density, which equals the total stream channel length divided by the drainage area. According to Hack's law, the river length is directly proportional to the drainage area. Yet since the stream length control is greatly in the hands of tectonics, the drainage basin size might be limited according to the tectonic slope nature. On the other hand, at bankfull flow the magnitude of a channel depends on its width and depth. As the channel gets bigger, it can carry highher volume of water through itself, therefore the mean annual discharge magnitude is also an important channel classification parameter. High width/depth ratios refers to the channels with low-sinuosity characteristic.

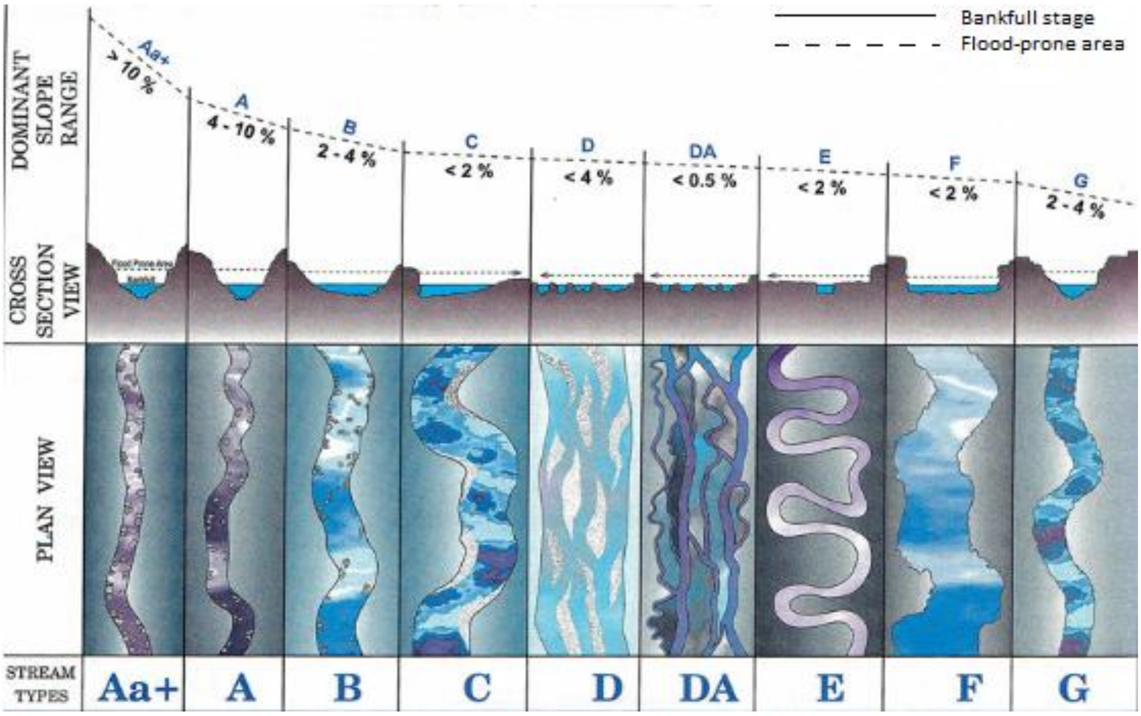


Figure 2.4 : Longitudinal, cross-sectional and plan views of major stream types. (Rosgen, 1994)

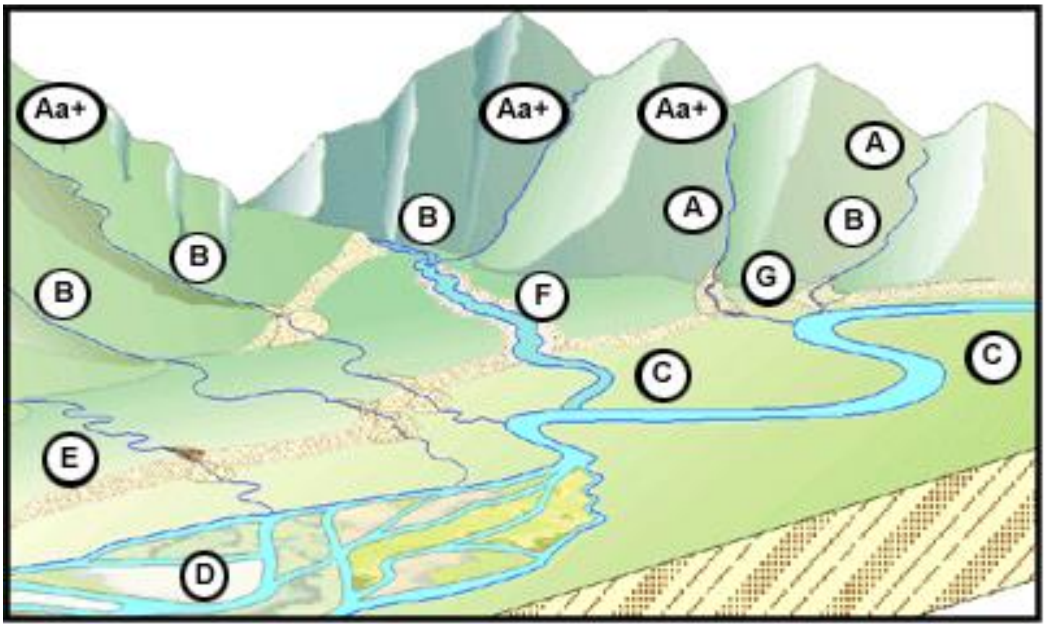


Figure 2.5 : Schematic distribution of longitudinal, cross-sectional and plan views of major stream types. (EPA, 2005)

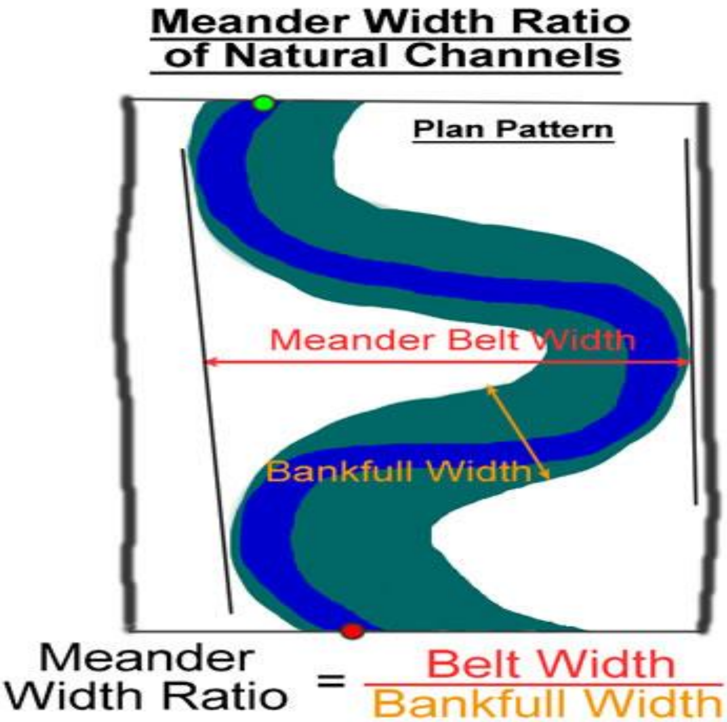


Figure 2.6 : Representative demonstration of meander belt and bankfull width. (http://www.fgmorph.com)

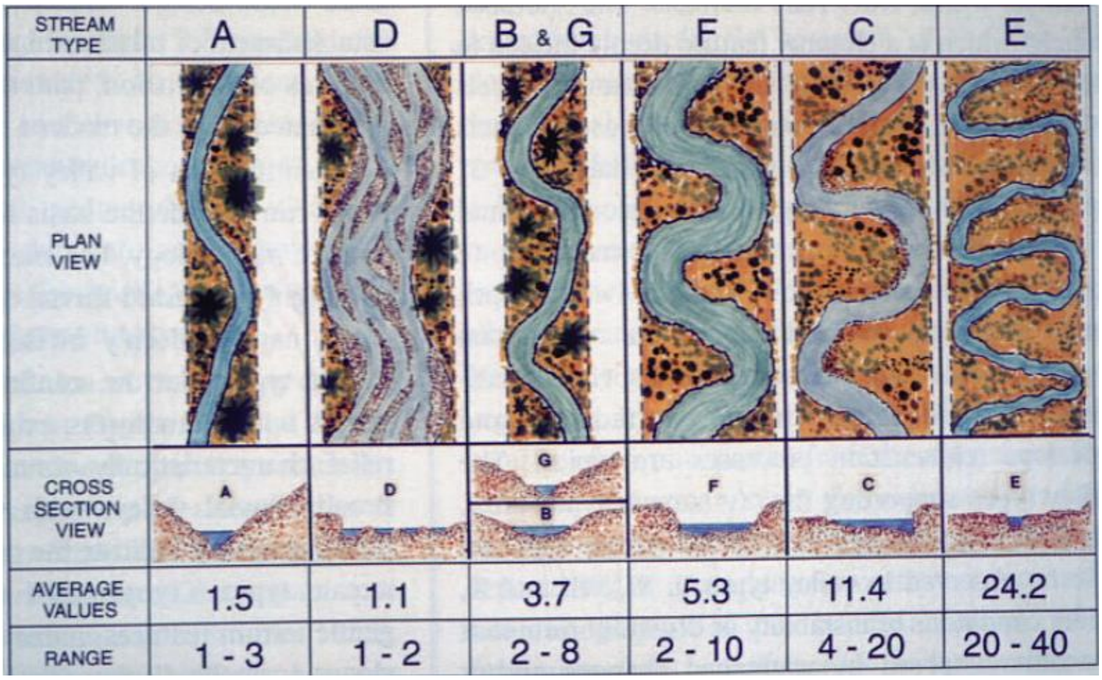


Figure 2.7 : Meander width ratio (belt width/bankfull width) by stream type categories. (Rosgen, 1994)

Meander geometry is directly related to sinuosity, which is the ratio of "stream length" to "valley length" (Fig. 2.8). When the sinuosity is mapped from the aerial photos, it is also possible to make interpretations of channel materials, entrenchment and slope. It can be said that 1,0 is a ratio for a downright straight river, 1,5 is a typical meandering river and 3,0+ is for a twisting course.

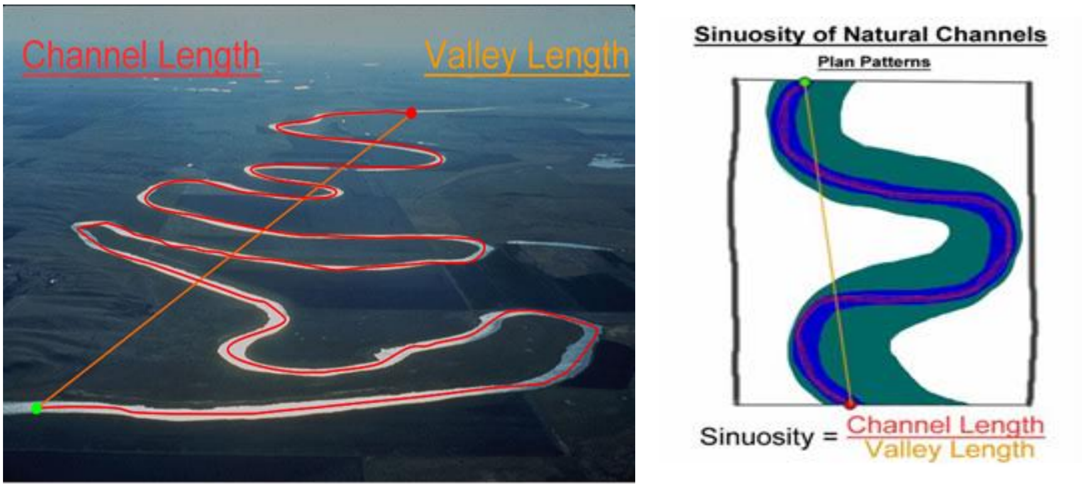


Figure 2.8 : Representative demonstration of channel and valley length. (http://www.fgmorph.com)

The relationship between the river and its landform is a key element when it comes to the classification. Entrenchment (Fig.2.9), an essential element of delineation defined as the vertical containment of river **(2.1)** and the degree to which it is carved in the valley floor (Rosgen, 1994), showing whether the flat contiguous to the channel is outside of a flood-prone **(2.2)** area or not.

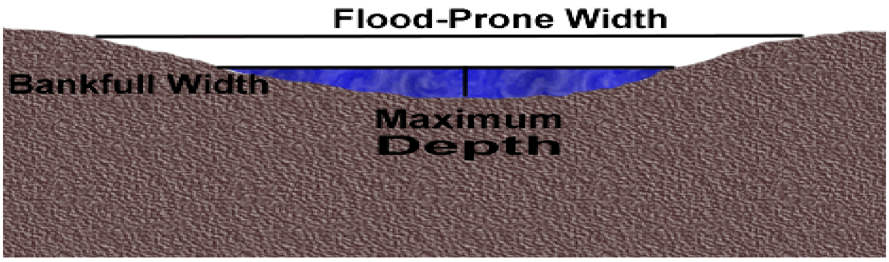


Figure 2.9 : Representative demonstration and calculation of entrenchment. (http://www.fgmorph.com)

$$Entrenchment\ Ratio = \frac{Flood\text{−}Prone\ Width}{Bankfull\ Width} \qquad \textbf{(2.1)}$$

$$Flood - Prone\ Width = 2\ \times Maximum\ Depth \qquad \textbf{(2.2)}$$

Another criteria, the "width/depth ratio" **(2.3)** can be regarded as the shape factor that equals to the ratio of the bankfull channel width to bankfull mean depth (Fig.2.10). Hydraulic geometry and sediment transportations depend on the magnitude and frequency of bankfull discharge, a term described as the momentary maximum peak flow, occurring a few days in a year.

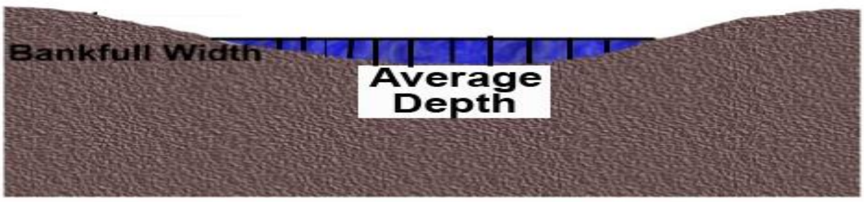


Figure 2.10 : Representative demonstration and calculation of width/depth ratio. (http://www.fgmorph.com)

$$Width\ to\ Depth\ Ratio = \frac{Bankfull\ Width}{Average\ Depth} \qquad \textbf{(2.3)}$$

Hydrological and biological channel function morphology is also related to water surface *slope* (Fig.2.11), a parameter obtained by the measurement of the difference in water surface elevation per unit stream length (Rosgen, 1994). The most frequently monitored slope categories and the other essential criterion ranges for 42 major stream types are shown in (Fig.2.12 and 2.13), which are based on Rosgen's huge data set of streams throughout the United States, Canada and New Zealand.

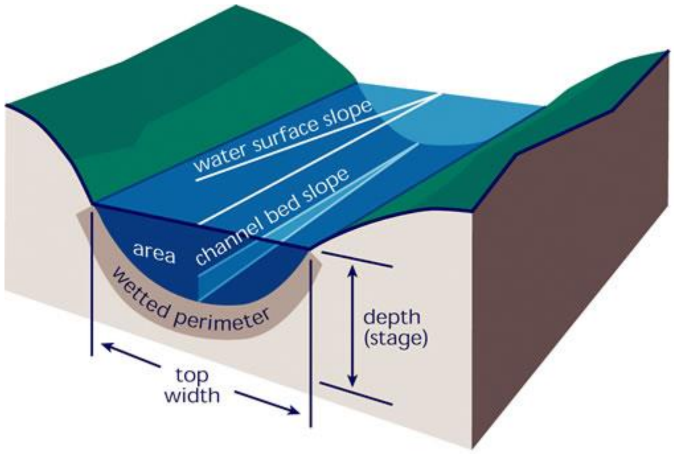
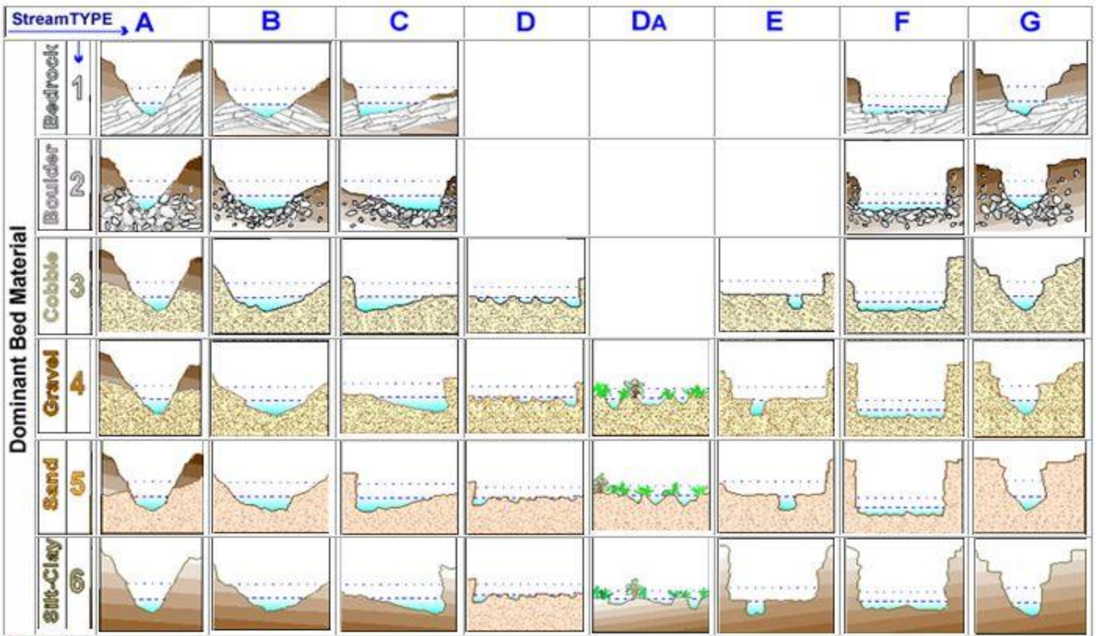


Figure 2.11 : Slope demonstrations. (FISRWG, 1998)



StreamTYPE	A	B	C	D	DA	E	F	G
Entrnch-ment.	<1.4	1.4 - 2.2	<2.2	n/a	<4.0	<2.2	>1.4	>1.4
W/D Ratio	<12	>12	>12	>40	<40	<12	>12	<12
Sinuos-ity	1-1.2	>1.2	>1.2	n/a	variable	>1.5	>1.2	>1.2
H_2O Slope	.04-.099	.02-.039	<.02	<.04	<.005	<.02	<.02	.02-.039

Figure 2.12 : Delineative criteria of major stream types. (Rosgen, 1994)

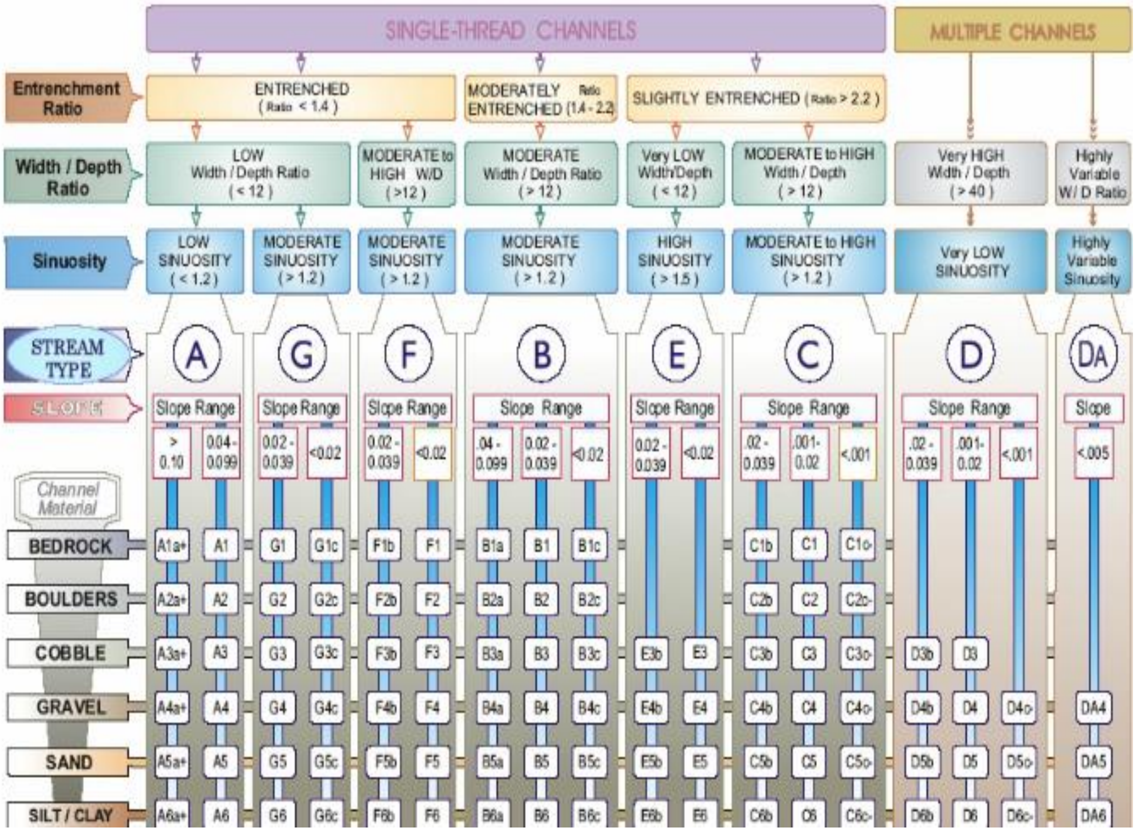


Figure 2.13 : Key chart to classification of natural rivers. (Rosgen, 1994)

For well-rounded characterizations, stream slope can be calculated via sinuosity measurement from aerial photos and valley slope measurement from topographic maps since the channel slope equals valley slope divided by sinuosity.

As can be seen, rivers are complex systems of nature. If a stream’s classification parameters and their changes over time is observed in the long term and useful enough, then it can be said that similar stream types with the same signs can also respond in the same way and risk assessments can be evaluated with the help of the previous works. Therefore it’s a fundamental and integral task to continue the river systems research works combining the interdisciplinary data collected. The stream classification (Fig.2.13) helps us hereby via its organized observations of river data, putting many pieces together into a logical and useable work pattern.

2.3 Hydraulic Geometry of Stream Reaches

Being a fundamental element in design criteria, planning and management of river engineering and management works, pioneering hydraulic geometry theory was provided by Leopold and Maddock (1953). Assuming the river flow is steady and uniform, all theories since then accept that river tends to keep itself in an equilibrium state and provide the basic hydraulic mechanism differences to explain the attainment of that steady state of the river.

Hydraulic geometry forms a relationship between the channel form (width, depth, cross-section, meander length); hydraulic variables (mean slope, mean friction, mean velocity for a given influx of water and sediment) and discharge both at-a-station and downstream along a stream network in a homogeneous basin hydrology.

As Leopold and Maddock (1953) expressed:

$$w = aQ^b \ , \ d = cQ^f \ , \ v = kQ^m \qquad \textbf{(2.4a)}$$

where Q being the flow discharge, equals the channel width (w), flow depth (d) and velocity (v) respectively, multiplied by the a, b, c, f, k and m parameters. To those equations, also added are

$$n = NQ^p \ , \ S = sQ^y \qquad \textbf{(2.4b)}$$

where n is Manning's roughness factor; S is slope; and N, p, s and y are parameters. The rate of change of the hydraulic variables w, d, v, n and S are represented by the exponents b, f, m, p and y respectively as Q changes. When Q = 1, coefficients a, c, k, n and S are scale factors that define the values w, d, v, and S.

Satisfying for rectangular channels the continuity equation:

$$Q = wdv \qquad \textbf{(2.5)}$$

Therefore,

$$a.c.k = 1 \ , b + f + m = 1 \qquad \textbf{(2.6)}$$

should be satisfied.

Leopold and Maddock (1953) invented the term “at-a-station hydraulic geometry” which describes empirical relations between width (w), mean depth (d) and mean velocity (v) of a stream channel cross-section and discharge (Q). At-a-station hydraulic geometry relations can be useful for flood routing, riverine habitat analysis, water quality management and sedimentation studies. Therefore it is essential to physical and biological stream studies in principle. Management efficiency of catchment-scale floodplains, sediment and nutrient transport and river habitats involves the evaluation of hydraulic geometry variations through river networks.

At a constant frequency of flow, the hydraulic geometry concept involving spatial variation in channel form is said to include two types of analyses, first of which is a typified expression of Leopold and Maddock (1953) that conducts a relation between downstream changes in flow properties (width, mean velocity and slope, friction) to mean discharge, describing flow adjustments of channel forms according to the discharge increase (Singh, 2003).

The second type of analysis is hydraulic geometry concept modification for a reference discharge downstream with a given frequency. The main goal of this analysis lies underneath the assumption of an appropriate discharge, being the dominant flow controlling channel dimensions. With the help of previous works explaining the relationship between hydraulic geometry equation exponents and different types of river sections, it had been found out that these relations can be used for preparing impact assessments since the cult work of Leopold and Maddock (1953) hydraulic geometry studies focused on the following major issues.

2.3.1 Basis of Hydraulic Geometry Relations

The mean values of the functions **(2.4a, 2.4b)** should correspond to the equilibrium state of channel, which is the one related to the maximum sediment transporting capacity. An average river system is inclined to progress in a way in order to afford a balance between channel, water and sediment that is being transported.

2.3.2 Limitations of the Equilibrium Assumption

Singh (2003) suggested that 1) climate, 2) bedload and 3) environmental history are the three major factors considering the geometric adjustments of the downstream discharge. However due to long term human disturbance and evolving geology, they have often been applied to small basins where each cross-sections of the channel has its unique equilibrium state within its own surface and subsurface environment.

2.3.3 Variation of Channel Width with Discharge

For small basins in lower flows and very big basins in very high flows, the low “b” values generally occur. According to Singh (2003), investigating the channel width variation with the downstream discharge, it is found out that b = 0.5 was a suitable average as also Leopold suggests, where the value of “b” ranged from 0.2 to 0.89. Watershed geometry and channel evolution networks are the essential work of areas that needs greater attention.

2.4 Environmental Flow

Quantity and quality of a water flow which is required to sustain freshwater and its ecosystem is called environmental flow and regime of this flow influencing its quality, biotic interactions and river habitats can be described in five states that vary seasonally:

i. **Extreme low flows:** Occur during drought and associated with limited species migration and reduced connectivity. Within a natural drought period, exotic species are outcompeted by the natural ones and thus maintaining extreme low flows at their natural level can improve habitat and vegetation.

ii. **Low (base) flows:** Dominating state of flow during a year, providing sufficient temperature, dissolved oxygen and habitat for micro and macro organisms, supporting feeding and spawning activities as well.

iii. **High flows:** Generally occur after precipitation periods and they are gathered in the natural banks of the river, decreasing temperature and increasing dissolved oxygen. Furthermore, they assist in preventing vegetation invasion over the river channels. On the other hand, high flows moving and scattering the gravels help the native fish population spread.

iv. **Small floods:** Occurring every two to ten years, small floods are responsible for migration to the breeding lands and decreasing the non-native plant species density.

v. **Large floods:** Can be seen few and far between. They reshape the path of the rivers, form new habitats and move the large amount of sediments. Last but not the least, they provide safe, nutrient-rich areas for juvenile fish in the connected floodplains.

Flooding is a natural process which builds up and maintains floodplains and coastal zones. Depending on different spatial and temporal scales of the interrelated mechanisms, natural flow regime of a river influences biodiversity principally via large events considering channel form and shape. Low-flow events and droughts as well have the ability to limit and change the habitat, in other respects though (Arthington, 2006).

2.4.1 Environmental Flow Assessment

Protection and restoration of ecosystems which govern environmental flows has become a major aspect of river basin management in more than 50 countries worldwide with the help of the growing awareness of the essential role of the hydrology. Every river system has an individual flow regime according to seasonal pattern of flows, the timing, frequency, predictability and duration of extreme events and other aspects of flow variability. Each of these hydrological characteristics has both individual and interactive regulatory influences on the biophysical structure of river and floodplain ecosystem functionings. Hydrological alteration of rivers on a global scale and the environmental degradation has led to recognition of the scientific research term “environmental flow assessment (EFA)” that basicly explains which specific temporal characteristics of the original flow regime of a river should continue in order to maintain characteristics of the riverine ecosystem (Arthington et al. 2005)

Potential and extant impacts of altered flow regimes has two main types of environmental flow assessment responses: One is the proactive approach, aiming to maintain undeveleped river regimes as close as possible to the unregulated condition. The latter is the reactive response approach, to restore certain characteristics of the pre-regulation flow regime in regulated rivers.

2.4.2 Environmental Flow Methodologies

Four discrete types of environmental flow methodologies are described by Tharme (2003): 1) Hydrological, 2) Hydraulic rating, 3) Habitat simulation and 4) Holistic.

- Hydrological methodologies represent the techniques where adequate amount of daily, monthly and annual hydrological data are analysed to achieve standard flow arrays which then will be recommended environmental flows in the future.
- Hydraulic, biological, geomorphological parameters and catchment variables are also regarded as secondary criteria data where necessary. On the other hand, hydraulic rating methodologies deal with hydraulic variables such as wetted parameter and maximum depth of a river cross section as a habitat factor surrogate known or assumed to be limiting to target biota.
- Habitat simulation methodologies also make use of hydraulic habitat-discharge relationships, but provide more detailed analyses where environmental flow recommendations are based on the integration of hydrological, hydraulic and biological response data. In addition to this, holistic methodologies have broader approach to sustain environmental flows and conserve river ecosystems and the entire panoply of species, including assessments of hydraulic habitat, water quality, riparian and aquatic vegetation, macroinvertebrates and fish mitigation.
- According to Tharme (2003), holistic methodologies are immensely important for use in developing countries, on the account of the fact that there's a requirement for resource protection at an ecosystem scale and the direct dependence of local people on the goods and services provided by aquatic ecosystems.

2.4.3 Ecologically Successful River Restoration

An ecologically dynamic state is the one where biota composition and abundance vary spatially and gradually as the channel configuration also change according to the natural flow. River managing have been evolving into ecologically based, environmental friendly solutions rather than the harsh and blind engineering works. Increasing number of projects start to look after ecosystem benefits.

On the other hand, whilst large amount of money was spent on the stream and river restoration, there are no green standards yet. It is critical and crucial for the engineers, practitioners and even funders that they adopt ecologically successful criteria including biological, hydrological and geomorphic aspects in restoration, so that nature's outcome can be beneficial and sustainable. For instance, though the projects which aim to achieve riverfront revival may result in economic and social success, they may not be considered ecologically successful if they are to do any harm to the river and floodplain as also Aldo Leopold (1948) stated that "the first rule of restoration is to do no harm". Likewise, it is also suggested that, transformation of a braided channel into a single-thread morphology might satisfy sense of aesthetics, it can cause inappropriate geomorphic conditions (Palmer et al, 2005)

The first step of river restoration ought to be finding a guiding image (aerial and ground photographs, maps, surveys etc.) which explains the prior conditions showing the biota or channel alteration over time. The guiding image should consider both average, ideal condition of the interdisciplinary variables and their evolution since they will not be static when especially human induced changes are taken into account. Then, empirical models, hydraulic relationships can be used to guide channel design and to come to a conclusion whether specific restoration actions are suitable to a site or not. In addition, the system should have the capacity to recover from natural and man-made disturbances and monitoring of the pre and post conditions of the situation ought to prove that restoration intervention has nothing to do with any kind of irreversible damage to the ecosystem.

However, the priority must be the conservation of rivers to their initial, natural condition before their degradation. Restoration might come into question where conservation has failed.

2.4.4 Renaturalization

There had been a long-term tendency to build concrete channels and other hard infrastructure since the second half of the 20th century among river managers and engineers. However, after considering and compheresing the negative environmental effects (such as high costs, deconstructive abnormous intervention to nature) of these unnatural structures, there is now high impetus to have wider stream corridors surrounded with riparian vegetation, streamside trails, and complex in-channel forms. The thought of converting the existing concrete infrastructure seems tough and hard to apply, unless a long-term perspective is taken.

Conventional flood control treatments insist on so-called efficient concrete-lined channels just to convey storm runoff as soon as possible; upstream reservoirs to minize peak discharge through urban areas or embarkments to prevent rivers from inundating their floodplains. Through early 1980s, these huge engineering projects were often founded by federal agencies in USA yet such approaches are now unlikely to be implemented due to the fact that environmental impact assessments are a must to do within the framework of environmental laws. In addition to these, there is great public awareness of the restoration benefits of the renaturalization of urban streams for ecological purposes. Natural channels require increased right of passage width and higher maintenance but very low replacement costs. In the long run, these channels will be less costly than multiple life cycles for concrete channels. For instance, the 50-year plan of Conta Costa Flood Control (California) study calls for strategies to replace concrete channels with natural channels via flood bypass, permitting the main channel to have vegetated banks, which is a very environmental friendly, beneficial and economic plan over a 50-year period.

3. METHODOLOGY

Turkey is divided into 25 hydrologically classified river basins (Fig. 3.1) which has a total mean annual discharge of 186 billion cubic meters (Table 3.1). Among these, the gauging stations (Fig. 3.2 and Table 3.2) in this study are chosen from Büyük Menderes, Küçük Menderes, Kuzey Ege, Susurluk, Meriç-Ergene and Gediz River Basin, which are climatically similar and and have comparable rainfall characteristics in common. Besides, those western mediterranean region basins consist of low gradient streams in comparison with the East.

Figure 3.1 : Basins of Turkey. (Ministry of Forestry and Water Affairs, 2012)

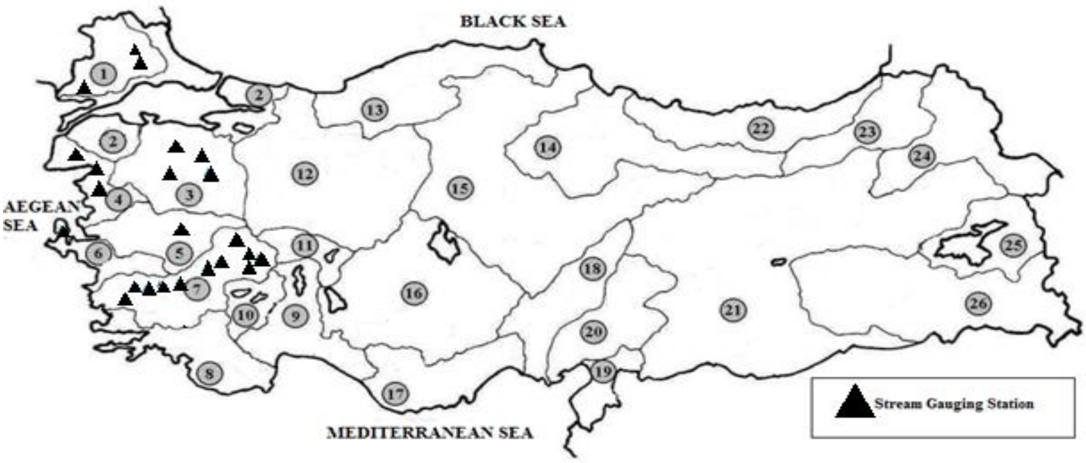


Figure 3.2 : Chosen stream gauging stations.

Table 3.1 : Basic Aspects of the River Basins of Turkey. (Ministry of Forestry and Water Affairs, 2012)

River Watershed Name	Catchment Area		Mean annual discharge		Mean annual efficiency
	(km²)	%	(km³)	(%)	(l/s/km²)
(01) Meriç-Ergene	14560	1.9	1.33	0.7	2.9
(02) Marmara	24100	3.1	8.33	4.5	11.0
(03) Susurluk	22399	2.9	5.43	2.9	7.2
(04) Kuzey Ege	10003	1.3	2.09	1.1	7.4
(05) Gediz	18000	2.3	1.95	1.1	3.6
(06) Küçük Menderes	6907	0.9	1.19	0.6	5.3
(07) Büyük Menderes	24976	3.2	3.03	1.6	3.9
(08) Batı Akdeniz	20953	2.7	8.93	4.8	12.4
(09) Antalya	19577	2.5	11.06	5.9	24.2
(10) Burdur Gölü	6374	0.8	0.50	0.3	1.8
(11) Akarçay	7605	1.0	0.49	0.3	1.9
(12) Sakarya	58160	7.5	6.40	3.4	3.6
(13) Batı Karadeniz	29598	3.8	9.93	5.3	10.6
(14) Yeşilırmak	36114	4.6	5.80	3.1	5.1
(15) Kızılırmak	78180	10.0	6.48	3.5	2.6
(16) Konya Kapalı	53850	6.9	4.52	2.4	2.5
(17) Doğu Akdeniz	22048	2.8	11.07	6.0	15.6
(18) Seyhan	20450	2.6	8.01	4.3	12.3
(19) Asi	7796	1.0	1.17	0.6	3.4
(20) Ceyhan	21982	2.8	7.18	3.9	10.7
(21) Fırat-Dicle	184918	23.7	52.94	28.5	8.3
(22) Doğu Karadeniz	24077	3.1	14.90	8.0	19.5
(23) Çoruh	19872	2.6	6.30	3.4	10.1
(24) Aras	27548	3.5	4.63	2.5	5.3
(25) Van Gölü	19405	2.5	2.39	1.3	5.0
TOTAL	**779452**	**100.0**	**186.05**	**100.0**	

Table 3.2 : Basic Information of the Studided Gauging Station.

Basin Name	SGS No	River Name	Station Name	Catchment Area (km^2)	Gauging starting date	Usable Gauging No
Büyük Menderes	12007120	Çapalı Gölü	Çıkış	368,9	2005	5
	12007108	Kargın Deresi	Köprüalan	30	1996	9
	12007103	Sarıçay	Bağarası	212	1993	8
	12007010	Dinar Suyu	Irgıllı Regülatör Çıkışı	293	1960	27
	12007026	Dinar Suyu	Irgıllı Sulama Kanalı	293	1980	18
	12007003	Kufi Çayı	Işıklı Köprüsü	2015	1959	26
	12007062	Büyük Menderes Nehri	Koçarlı Köprüsü	22653	1969	11
	12007032	Büyük Menderes Nehri	Nazilli Köprüsü	14193	1962	17
	12007081	Büyük Menderes Nehri	Sarayköy Köprüsü	11852	1996	5
	12007015	Tabakhane Deresi	Aydın Tersip Bendi	54	1960	18
	12007059	Çürüksu	Yukarı Samlı	1726	1976	16
Küçük Menderes	12006047	Sudeğirmeni Deresi	Yaylaköy	44,84	2011	3
Kuzey Ege	12004036	Zeytinli Çayı	Zeytinli	123,4	1994	15
	12004017	Karınca Deresi	Reşitköy	110,7	1965	34
	12004058	Karadere	Kocaömerli	126,7	2007	4
Meriç- Ergene	12001008	Ergene Nehri	Lüleburgaz	2794	1956	48
	12001020	Ergene Nehri	İnanlı	1415	1995	15
	12001057	Meriç Nehri	Ferek Köprüsü	50140	1987	18
Susurluk	12003008	Madra Çayı	Kahve	784,5	1962	31
	12003081	Mürvetler Deresi	Mürvetler	272,5	1985	28
	12003129	Dursunbey Çayı	Aşağıyağcılar	975,2	2001	10
	12003128	Simav Çayı	Kadıköy Köprüsü	2271,5	1999	7
Gediz	12005021	Tabak Dere	Çaltılı	81,1	1970	26

3.1 Study Area and Selection of Unregulated Stream Reaches

This study uses hydraulic data surveyed in 14 unregulated reaches and 5 weakly regulated reaches (Table3.2) in six different river basins (Büyük Menderes, Küçük Menderes, Kuzey Ege, Susurluk, Meriç-Ergene, Gediz) in the Western Turkey. The surveys provide cross-sectional profiles, rating curves and flow duration curves of each stream gauging station of each selected river basin reaches, 8 of which are in Büyük Menderes, 1 in Küçük Menderes, 3 in Kuzey Ege, 2 in Meriç-Ergene, 4 in Susurluk and 1 in Gediz (Table 3.3).

Table 3.3 : Unregulated Reaches and Their Usable Gauging Stations.

	BÜYÜK MENDERES	KÜÇÜK MENDERES	KUZEY EGE	MERİÇ-ERGENE	SUSURLUK	GEDİZ
Unregulated reaches	15	20	21	28	42	38
Usable unregulated reaches	5	1	3	2	3	1
Weakly regulated reaches	7	1	2		2	
Usable weakly regulated reaches	4				1	
Total usable reaches	19					
Total Unregulated SGS	15	20	25	39	47	43
Usable Unregulated SGS	6	1	3	3	3	1
Usable weakly regulated SGS	5				1	
Total usable SGS	23					

Combining Google Earth features (Figure 3.3-8) with the gauging station data which was provided by State Hydraulic Works (SHW), first of all, unregulated reaches and weakly regulated reaches were determined by excluding impoundment structures such as dams (Figure 3.9) and weirs along the reach for the six different river basins. Secondly, among the total unregulated reaches on those river basins, usable reaches were selected according to the applicable gauging station data corresponding to them. It is seen that for the total unregulated reaches , 15 of which are in Büyük Menderes, 20 in Küçük Menderes, 21 in Kuzey Ege, 28 in Meriç-Ergene, 42 in Susurluk and 38 in Gediz; there only exist 19 usable reaches, since there are no available gauging station data due to SHW or no cross sectional profile data at all.

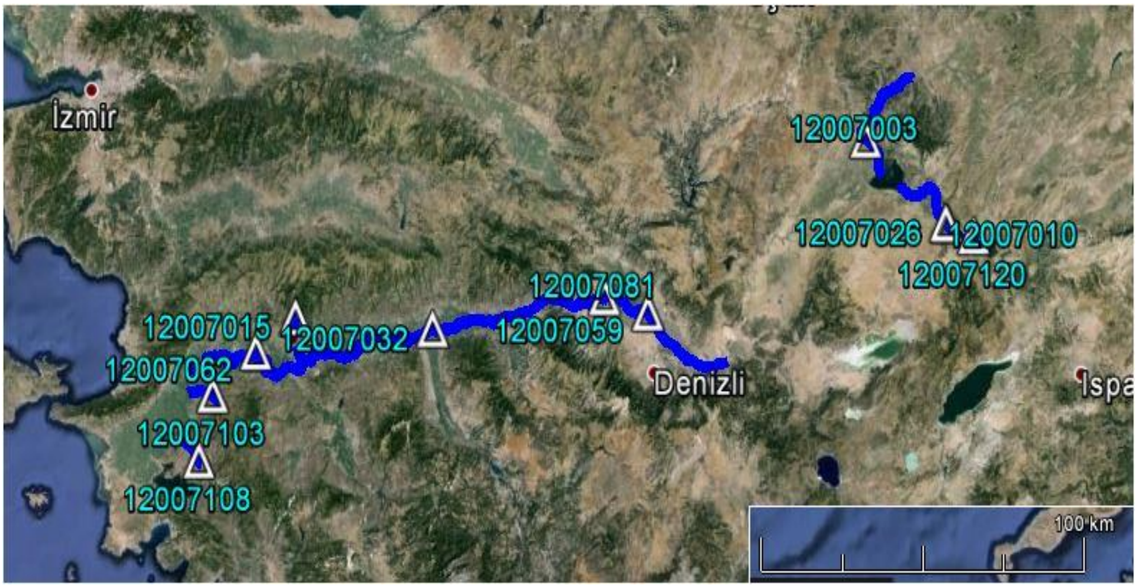
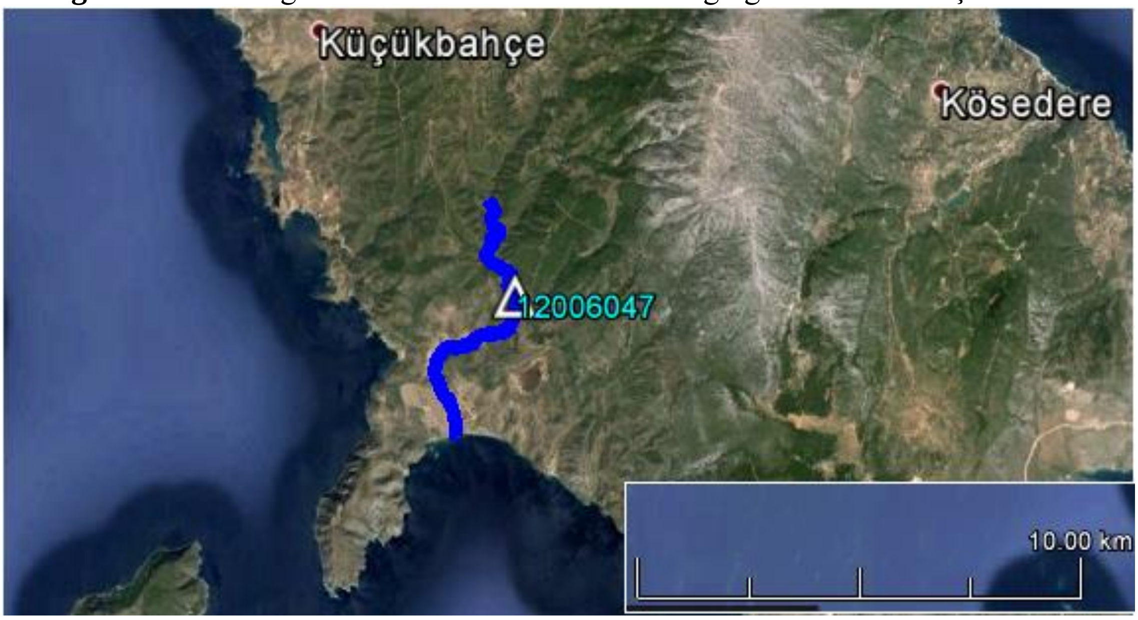


Figure 3.3 : Unregulated Reaches and Stream Gauging Stations of Büyük Menderes Watershed. (Google Earth, 2014)

Figure 3.4 : Unregulated Reaches and Stream Gauging Stations of Küçük Menderes



Watershed. (Google Earth, 2014)

Figure 3.5 : Unregulated Reaches and Stream Gauging Stations of Kuzey Ege Watershed. (Google Earth, 2014)

Figure 3.6 : Unregulated Reaches and Stream Gauging Stations of Meriç-Ergene Watershed. (Google Earth, 2014)

Figure 3.7 : Unregulated Reaches and Stream Gauging Stations of Susurluk Watershed. (Google Earth, 2014)

Figure 3.8 : Unregulated Reaches and Stream Gauging Stations of Gediz Watershed. (Google Earth, 2014)

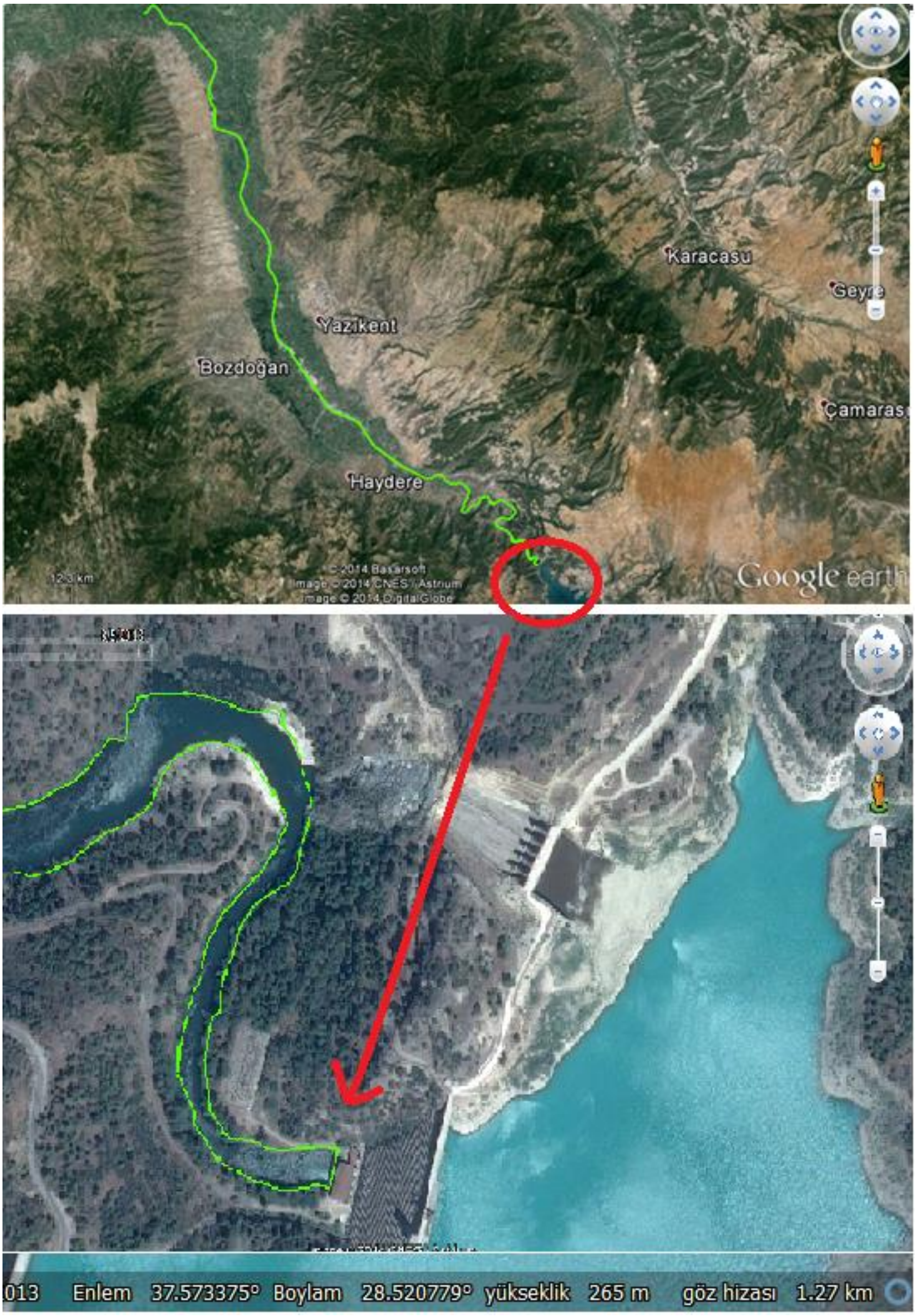


Figure 3.9 : Example selection step of the unregulated reach in BMW via zooming-in and excluding a dam. (Google Earth, 2014)

3.2 Quantifying the Relationship Between Formative Discharge on Main Channel Cross-section Geometry and River Basin Geometry Characteristics

The hydrologic analyses for this study emphasizes the conditions which responds to changes in river basin urbanization and that have a strong impact on biological and physical health. These conditions consist of the stream flow pattern over the stream gauing station observation years as expressed by four alternative new hydrologic metrics:

- Maximum mean annual discharge of the observation years ($Q1_{max}$)
- Average of the maximum three mean annual discharge of the observation years ($Q3_{max}$)
- Average of the maximum five mean annual discharge of the observation years ($Q5_{max}$)
- Average of the maximum ten mean annual discharge of the observation years ($Q10_{max}$)

and the probability and extent of streambed disturbance during a relatively common flood event, an extreme flow, expressed by seven hydrologic metrics from the flow duration curves:

- Discharge value equaled to one in a thousand (q1b)
- Discharge value equaled to two thousandths (q2b)
- Discharge value equaled to five thousandths (q5b)
- Discharge value equaled to one percent (q1%)
- Discharge value equaled to two percent (q2%)
- Discharge value equaled to three percent (q3%)
- Discharge value equaled to five percent (q5%)

These two hydrologic measures that are evaluated capture the mean annual and daily discharges over long time scales of gage records and help us to determine the cross-section formative discharge of stream flow in relation with channel geometry and drainage area. After that, empirical equations are generated and tested within the unregulated Batı Akdeniz river basin for the validation purpose of the results.

4. RESULTS

4.1 Rating Curves of the Selected Cross-Sectional Profiles

After deciding about the unregulated reaches and stations, SHW data (Table 4.1) were gathered together to calculate the cross sectional area for each of the river basin reach. For that cross sectional data, rating curves and flow duration curves were plotted then. The theoretical relationship between water-surface stage (water level) and flow discharge is called the rating curve of the station, an example of which is presented in Figure 4.1 in logarithmic form where Q and H are discharge and water level. It is also known as stage-discharge relation which is an essential tool in hydrology since the discharge data value reliabilities are dependent on this relationship at the gauging station. A rating curve can provide economical benefits and great saving on time by reducing the heavy physical workload of the river discharge measurement. Continuous measurement of flow past a river section is both expensive and impractical. Yet, stage holds the opportunity to be observed continuously or at regular time intervals with comparative ease and economy. With the help of this stage-discharge relationship, extreme discharge values and cross-sectional adjustment in response to those discharges can be predicted via a satisfactory logarithmic relationship graph, which transforms the observed stages into the corresponding discharges, where bankfull cross-section depths can be read as well.

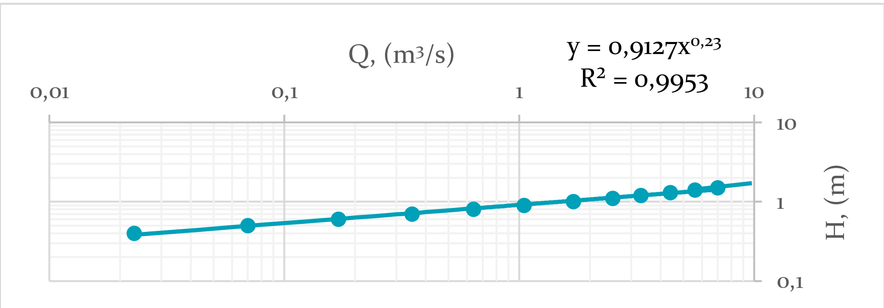


Figure 4.1 : Rating curve of BMW gauging station no: 12007120

Table 4.1 : Example State Hydraulic Works data of Susurluk Watershed Gauging Station no: 12003008 (DSİ Flow Yearbook, 2008).

03. Susurluk Havzasi

D03A008 MADRA ÇAYI Kalve

YERİ : BALIKESIR-EDREMIT KARAYOLUNUN 30 KM.SINDE.BALYA YOL AYIRIMI UZERINDEKI KOPRUNUN 50 M MANSABINDADIR.
27°32'44" Doğu - 39°36'53" Kuzey

YAĞIŞ ALANI : 784,45 km2 YAKLAŞIK KOT : 181 m

GÖZLEM SÜRESİ : 01.12.1962 - 30.09.2008

ORTALAMA AKIMLAR : Gözlem süresinde 5.339 m3/sn. (16 Yıllık) 2008 Su yılında 5.098 m3/sn.

ANLIK EN ÇOK VE EN AZ AKIMLAR:

2008 Su yılında anlık ençok akım	:	375.	m3/sn	05.12.2007
2008 Su yılında anlık enaz akım	:	0.000	m3/sn	01.10.2007
Gözlem süresinde anlık ençok akım	:	1400	m3/sn	11.01.1968
Gözlem süresinde anlık enaz akım	:	0.000	m3/sn	04.08.1977

17. Anahtar Eğrisi (Seviyeler cm olarak)

Seviye	Akım	Seviye	Akım	Seviye	Akım	Seviye	Akım
1	0.030	30	6.0	200	147.	430	460.
4	0.094	60	21.7	250	206.	500	565.
7	0.185	90	42.0	320	300.	560	680.
12	0.520	120	66.0	380	382.	580	720.
20	2.2	150	94.0	400	410.	630	824.

Akımlar 01 Ekim 2007 'den 30 Eylül 2008' a kadar m3/sn olarak

Gün	Ekim	Kasım	Aralık	Ocak	Şubat	Mart	Nisan	Mayıs	Haziran	Temmuz	Ağustos	Eylül
01	KURU	0.520	16.3	0.980	2.55	8.87	6.30	3.49	0.795	0.070	KURU	0.070
02	KURU	0.425	9.52	0.980	2.86	12.0	5.75	3.17	0.795	0.048	KURU	0.070
03	KURU	0.425	6.44	0.795	3.49	9.60	5.20	3.17	0.610	0.048	KURU	0.070
04	KURU	0.425	5.60	0.795	5.20	7.40	5.75	2.86	0.610	0.028	KURU	0.048
05	KURU	0.680	200.	0.610	4.27	6.85	5.75	2.86	0.610	0.048	KURU	0.048
06	KURU	0.840	76.3	0.610	3.49	6.30	12.0	2.86	0.610	0.048	KURU	0.070
07	KURU	1.00	30.5	0.610	3.17	5.75	39.5	2.86	1.29	KURU	KURU	0.094
08	KURU	0.840	19.0	0.610	2.86	5.20	19.0	2.86	0.980	KURU	KURU	0.120
09	KURU	0.840	18.1	0.610	2.55	4.73	13.5	2.55	0.980	KURU	KURU	0.120
10	KURU	4.00	21.3	0.610	5.75	4.73	12.0	2.55	0.795	KURU	KURU	0.150
11	KURU	13.2	34.3	0.470	7.40	4.73	9.60	2.55	0.795	KURU	KURU	0.150
12	KURU	4.40	33.0	0.470	6.30	4.27	8.13	2.55	0.610	KURU	KURU	0.150
13	KURU	35.0	152.	0.470	5.75	4.27	6.85	2.23	0.610	KURU	KURU	0.120
14	1.23	8.20	36.8	1.29	5.20	4.27	6.30	2.23	0.470	KURU	KURU	0.120
15	0.220	5.60	23.5	3.80	4.73	3.80	5.75	2.86	0.355	KURU	KURU	0.120
16	0.220	3.60	18.1	4.73	5.20	3.80	5.20	2.55	0.220	KURU	KURU	0.150
17	0.220	2.52	6.85	3.80	5.75	3.80	5.20	2.23	0.288	KURU	KURU	0.185
18	0.220	6.44	5.75	3.49	5.75	3.80	4.73	1.92	0.220	KURU	KURU	0.150
19	0.220	13.6	4.73	3.17	5.75	3.80	4.73	1.92	0.288	KURU	KURU	0.094
20	0.520	8.20	3.80	3.17	5.75	4.73	4.27	1.61	0.220	KURU	KURU	0.094
21	0.425	2.18	3.17	3.17	16.3	17.2	3.80	1.61	0.185	KURU	KURU	0.150
22	1.23	4.00	2.86	2.55	39.5	21.3	3.80	1.29	0.185	KURU	KURU	0.150
23	1.00	3.20	2.55	2.55	35.5	11.2	3.49	1.29	0.185	KURU	KURU	0.185
24	5.60	2.52	2.23	2.86	28.0	8.87	3.49	1.29	0.185	KURU	KURU	0.150
25	4.00	2.18	1.92	2.55	19.0	15.4	3.49	1.29	0.185	KURU	KURU	0.120
26	1.23	1.94	1.92	2.55	13.5	21.3	3.49	1.29	0.150	KURU	KURU	0.120
27	0.840	39.9	1.61	2.23	11.2	12.7	3.49	0.980	0.150	KURU	KURU	0.094
28	0.520	17.7	1.29	2.55	10.4	10.4	4.73	0.980	0.120	KURU	KURU	0.094
29	0.520	7.76	1.29	2.86	9.60	8.87	3.80	0.795	0.120	KURU	KURU	0.120

In this study, discharge and the corresponding stage data of the selected stream gauging stations are handpicked so that date of the measurement of cross sectional data matches with the date of the rating curve data (Table 4.2) as best as it can. In addition to that, there are some date gaps which are slightly longer than the generally overlapping data due to lack of SHW measurement data and graphical extrapolation is used in order to predict the bankfull flows outside the range of obversations. The plotted rating curves of each station used in this study can be seen in Appendix B.

Table 4.2 Data of Rating Curve Date of the Stream Gauging Stations.

	Reach No	Gauge Station No	Cross Section Date	Rating Curve Date	Δ Date (month)	Extrapolation	Qbankfull (m3/s)
Büyük Menderes	BM10	12007120	18.12.12	16.01.12	1	•	10
	BM62	12007108	12.07.11	07.08.12	13	•	120
	BM59	12007103	11.07.11	20.01.12	6	•	110
	BM11	12007010	06.07.11	18.02.10	7	•	10
		12007026	06.07.11	18.02.10	7	○	10
	BM8	12007003	05.10.12	31.07.12	3	○	120
Regulated	BM42	12007062	11.07.11	20.01.12	6	•	140
	BM31	12007032	08.07.11	01.08.11	1	•	130
		12007081	11.07.11	20.01.12	6	○	50
	BM44	12007015	06.07.11	20.01.12	6	•	10000
	BM26	12007059	04.10.12	20.01.12	9	○	20
Küçük Menderes	KM26	12006047	10.01.12	15.05.13	16	•	45
Kuzey Ege	KEN10	12004036	27.11.08	24.11.09	12	•	600
	KEN16	12004017	27.11.08	11.09.07	14	•	300
	KEN26	12004058	20.02.13	15.12.11	14	•	130
M-Ergene	ME50	12001008	24.11.08	10.02.12	57	•	125
		12001020	24.11.08	07.01.10	16	○	125
	ME52	12001057	24.11.08	03.10.13	59	•	1500
Susurluk	SU28	12003008	27.11.08	25.11.09	12	○	400
	SU35	12003081	27.11.08	23.02.06	33	•	70
	SU86	12003129	27.11.08	25.05.06	27	•	200
Regulated	SU5	12003128	27.11.08	25.02.14	63	•	6000
Gediz	GE39	12005021	1.6.2011	17.1.2012	7	•	1000

4.2 Determining the Best Characterizing Channel Formative Discharges and Cross-Section Geometry

Before describing the channel characteristics at a given cross section, it appears requirable to discuss frequency of discharge or in other words “flow duration curves”. Average of all rates for a day can be described as the daily mean discharge and it is expressed in cubic meters per second. Since the data of the mean discharge for each day of the year at measuring stations on rivers is published by SHW, the frequency of a daily mean discharge at a given river gauging station is determined by counting the number of occurences of this rate throughout a period of record. In hydraulic practice, this number of occurences is usually presented in the term of a cumulative frequency or flow duration curve, an example of which is presented in

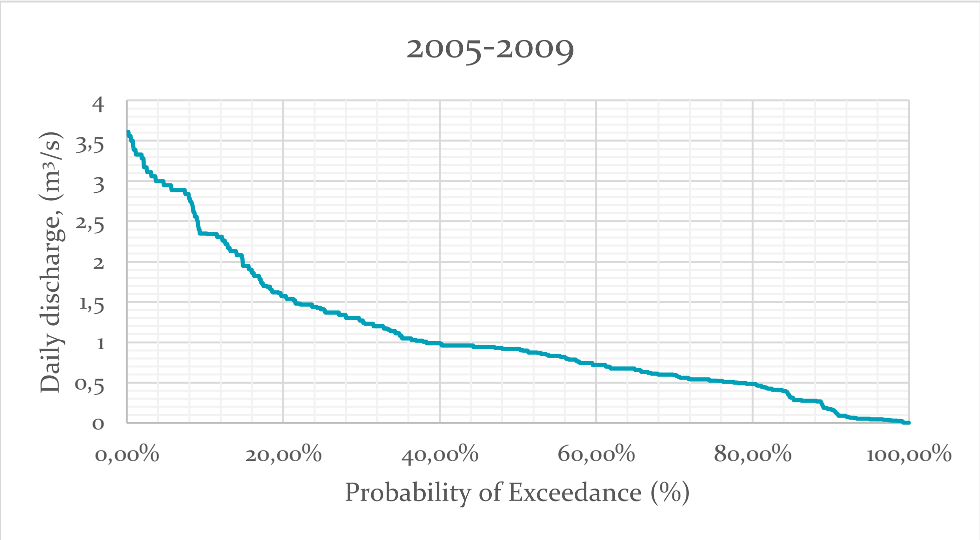


Figure 4.2 : Flow duration curve of BMW gauging station no: 12007120

In order to plot such a curve, a number of categories of rates of discharge are chosen according to SHW cross section data range. The numbers in each category are then ordered from the largest discharge category to the smallest and each cumulative data is divided by the total number of days of record. The quotients resulted demonstrate the percent of time given discharges are equalled or exceeded at the station. The data representing percent of time are then plotted against discharge to provide the flow duration curve. As can be seen from the Figure 4.2, a discharge of 2,3 m^3/s or more occurs about 10 percent of the time, meaning that through a long period, 10 percent of the days, or on the average 10 days in every 100, experienced a discharge of 2,3 m^3/s or more.

4.2.1 "Maximum mean annual discharges" based analysis

For each stream gauging station, first of all, after obtaining SHW record period database, top ten maximum mean annual discharges (Table 4.3) were filtered throughout the discharge data for all existing observation years. The plotted top ten maximum mean annual discharges of each station used in this study can be seen in Appendix D. To decide the best channel formative discharge among these maximum mean annual datum,

- Maximum mean annual discharge of the observation years ($Q1_{max}$)
- Average of the maximum three mean annual discharge of the observation years ($Q3_{max}$)
- Average of the maximum five mean annual discharge of the observation years ($Q5_{max}$)
- Average of the maximum ten mean annual discharge of the observation years ($Q10_{max}$)

were computed (Table 4.4). Afterwards, the best correlated discharge was estimated considering its relationship with the cross-section values of the gauging stations.

Table 4.3 Top Ten Maximum Mean Annual Discharges (m^3/s) of the Record Period of BMW 12007108

1996	1997	1998	1999	2000	2001	2002	2003	2004
15,2	23,6	7,11	13,6	11	22,5	10,8	8,98	28,1
13,2	13,8	5,48	12	7,79	18,5	8,47	7,11	12,2
7,45	8,47	3,85	10,2	7,62	11	5,08	5,2	9,15
6,18	6,04	3,63	7,96	5,76	10	5,08	3,46	9,15
3,85	4,93	3,52	6,46	4,8	8,81	4,12	3,32	8,98
3,63	3,19	3,41	5,76	3,3	8,47	4	1,83	5,34
2,86	2,97	3,41	5,76	2,66	8,47	3,91	1,67	4,36
2,66	2,86	2,97	4,53	2,37	8,3	3,55	0,874	3,73
2,53	2,75	2,37	4,26	2	6,77	3,37	0,648	3,19
2,37	2,75	1,36	3,99	1,42	6,32	2,82	0,544	3,01

Table 4.4 Average Maximum Mean Annual Discharges (m^3/s) of the Gauging Stations Throughout Their Available Record Periods.

	Reach No	Gauge Station No	Q1max	Q3max	Q5max	Q10max
Büyük Menderes	BM10	12007120	1,78	1,76	1,74	1,7
	BM62	12007108	15,65	11,39	9,19	6,36
	BM59	12007103	36,88	27	21,82	15,94
	BM11	12007010	4,80	4,57	4,49	4,35
		12007026	2,65	2,53	2,46	2,36
	BM8	12007003	52,86	42,54	37,44	30,19
Weakly Regulated	BM42	12007062	407,55	377,66	351,47	310,41
	BM31	12007032	155,29	153,14	148,18	137,93
		12007081	39,50	37,03	35,94	34,46
	BM44	12007015	7,71	6,26	5,6	4,48
	BM26	12007059	32,33	27,81	25,53	22,46
Küçük Menderes	KM26	12006047	2,28	1,13	1,58	1,23
Kuzey Ege	KEN10	12004036	26,48	20,51	16,51	10,52
	KEN16	12004017	19,80	14,66	11,8	8,67
	KEN26	12004058	30,45	24,17	21,26	16,21
M-Ergene	ME50	12001008	194,63	136,58	110,16	81,02
		12001020	125,30	103,33	86,22	63,22
	ME52	12001057	753,61	725,61	689,21	616,61
Susurluk	SU28	12003008	190,17	140,5	114,15	81,73
	SU35	12003081	46,80	38,87	33,47	26,17
	SU86	12003129	50,87	44,68	39,16	31,65
Weakly Regulated	SU5	12003128	53,41	44,24	40,15	34,3
Gediz	GE39	12005021	13,62	11,1	9,78	7,98

4.2.2 "Flow duration curve" based analysis

The mean gauged daily flow archive datasheet was provided by SHW for all the studied river basins and after computing the cumulative frequency of the data, flow duration curves of the gauging stations were plotted against discharge. The entire period of record for each gauging station is available; however since the channel forming discharge determination is the point in question, only seven vital permillage and percentile discharges were chosen to debate:

- Discharge value equaled to one in a thousand (q1b)
- Discharge value equaled to two thousandths (q2b)
- Discharge value equaled to five thousandths (q5b)
- Discharge value equaled to one percent (q1%)
- Discharge value equaled to two percent (q2%)
- Discharge value equaled to three percent (q3%)
- Discharge value equaled to five percent (q5%)

Hereby, permillage and percentile are the percentage of time that flows at a given site exceed a specific size threshold. For instance, in Figure 4.3, the q1b permillage has a flow value of 22,5 m^3/s, meaning that, for one in a thousand of the time, flows in the Kargın Deresi at this site are larger than 22,5 m^3/s. The plotted flow duration curves of each station used in this study can be seen in Appendix C and calculated permillage and percentile discharges of the gauging stations can be seen at Table 4.5.

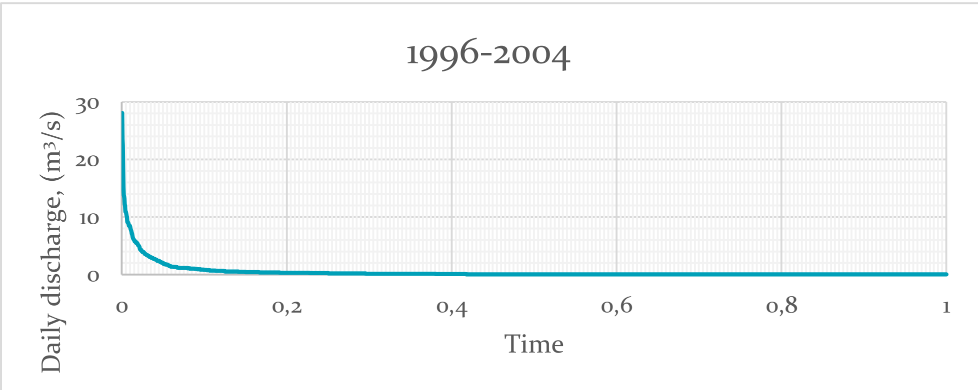


Figure 4.3 : Flow duration curve of BMW gauging station no: 12007108

Table 4.5 Permillage and Percentile Discharges (m^3/s) of the Gauging Stations Throughout Their Available Record Periods.

	Reach No	Gauge Station No	Record Period	q1b	q2b	q5b	q1%	q2%	q3%	q5%
Büyük Menderes	BM10	12007120	2005-2009	3,61	3,61	3,5	3,29	3,28	3,11	2,95
	BM62	12007108	1996-2004	22,5	15,2	10,8	8,3	5,08	3,41	1,99
	BM59	12007103	1993-2001	55,2	38,5	23,8	16,4	10,5	7,29	3,63
	BM11	12007010	1960-2007	7,5	7,4	7	6,5	6,2	6	5,6
		12007026	1980-2009	4	3,9	3,7	3,38	3,2	2,9	2,7
	BM8	12007003	1959-2008	82	72	51	36,5	27	21	15,5
Weakly Regulat	BM42	12007062	1969-2003	590	580	530	490	390	350	290
	BM31	12007032	1962-1998	230	230	220	195	170	155	130
		12007081	1996-2006	53,7	47,5	44,7	41,1	39,6	35	31,7
	BM44	12007015	1960-2009	10,1	9,28	8,6	7,34	5,3	4,19	3,3
	BM26	12007059	1976-1995	46	35	28	26	23	21	19,5
Küçük Menderes	KM26	12006047	2011-2013	3,76	3,24	2,3	1,88	1,28	0,9	0,56
Kuzey Ege	KEN10	12004036	1994-2009	82,5	31,2	16,2	10,3	5,16	3,85	2,42
	KEN16	12004017	2010-2013	42	29	23	15,5	9,9	7,6	5,6
	KEN26	12004058	1965-2000	51,7	36	32,8	19,8	14,2	9,53	6,1
M-Ergene	ME50	12001008	1956-2011	298	211	130	89	58,4	44,8	29
		12001020	1995-2011	170	132	90	61	38	28	19,5
	ME52	12001057	1987-2004	1312	1238	1077	948	740	678	570
Susurluk	SU28	12003008	1962-2012	260	200	140	89	57	42	29,7
	SU35	12003081	1985-2012	57,7	48,9	36,8	24	15,2	11,8	8
	SU86	12003129	2001-2010	81,4	63	46,7	32,9	25,6	20,8	15
Weakly Regulated	SU5	12003128	1995-2005	91,9	82,9	57,7	48	34,8	30,8	23,9
Gediz	GE39	12005021	1970-1995	22	19	13,5	8,9	6,2	5,3	3,9

4.3 Relationship Between the Best Correlated Channel Forming Discharge and the Channel Cross-Section

Mean of "maximum mean annual discharges" based analysis and "flow duration curve" based analysis comparison shows that the best correlated channel forming discharges are the "$Q1_{max}$" (Figure 4.4) and "q2b" (Figure 4.5) respectively, where q2b has a slightly higher coefficient of determination in the plot against channel width/depth. The plotted w/d versus discharge relationship of each channel forming discharge used in this study can be seen in Appendix D.

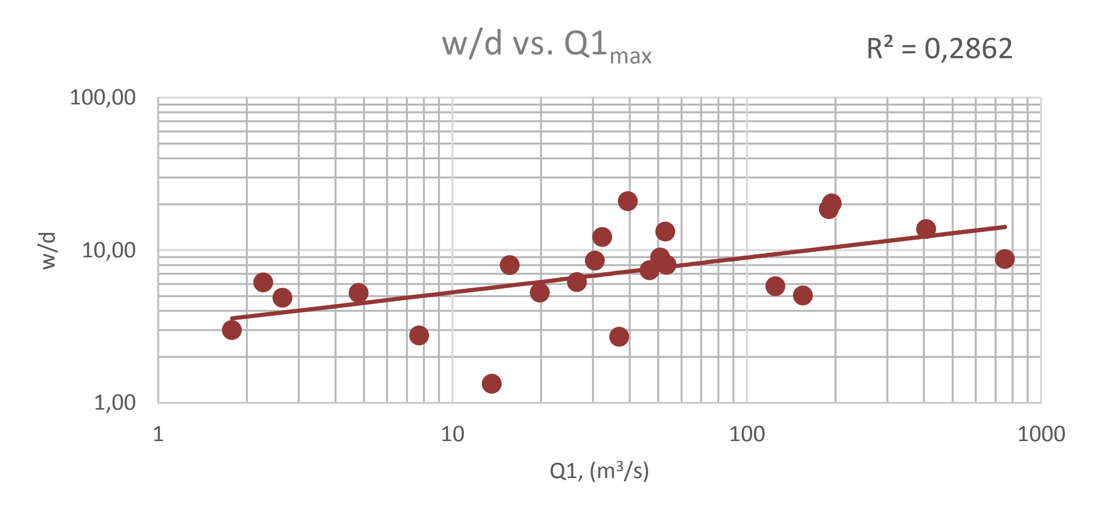


Figure 4.4 : The best relationship from the mean of maximum mean annual discharges analysis between width/depth and $Q1_{max}$.

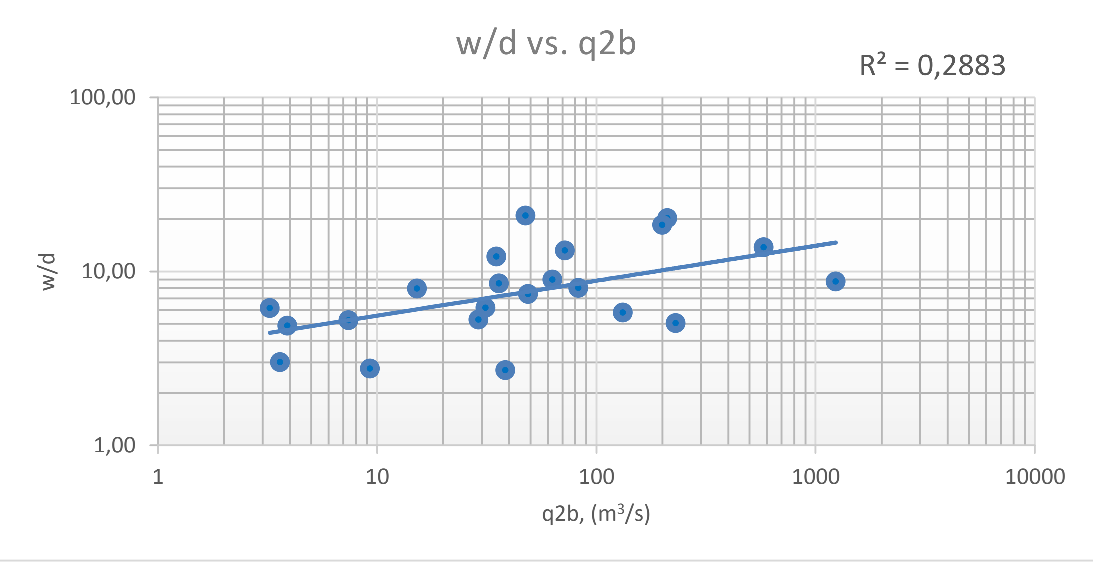


Figure 4.5 : The best relationship from the flow duration curve analysis between width/depth and q2b.

Since the "q2b" shows a higher coefficient of determination in the plot against channel width/depth, its relationship between channel geometry parameters (Figure 4.6-9) were examined individually later on, which are in good correlation.

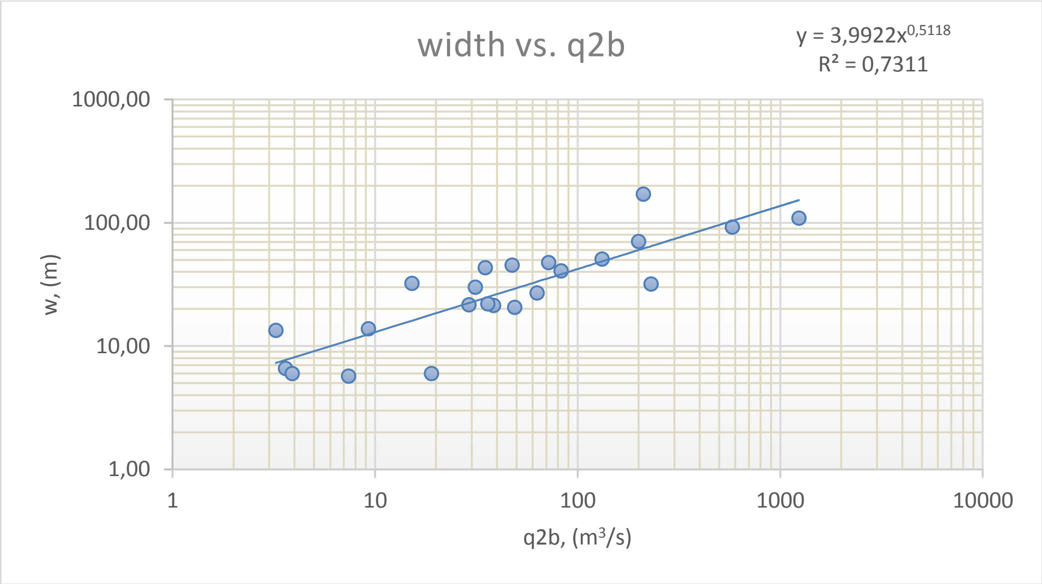


Figure 4.6 : Relationship between the best channel forming discharge "q2b" and the bankfull channel width.

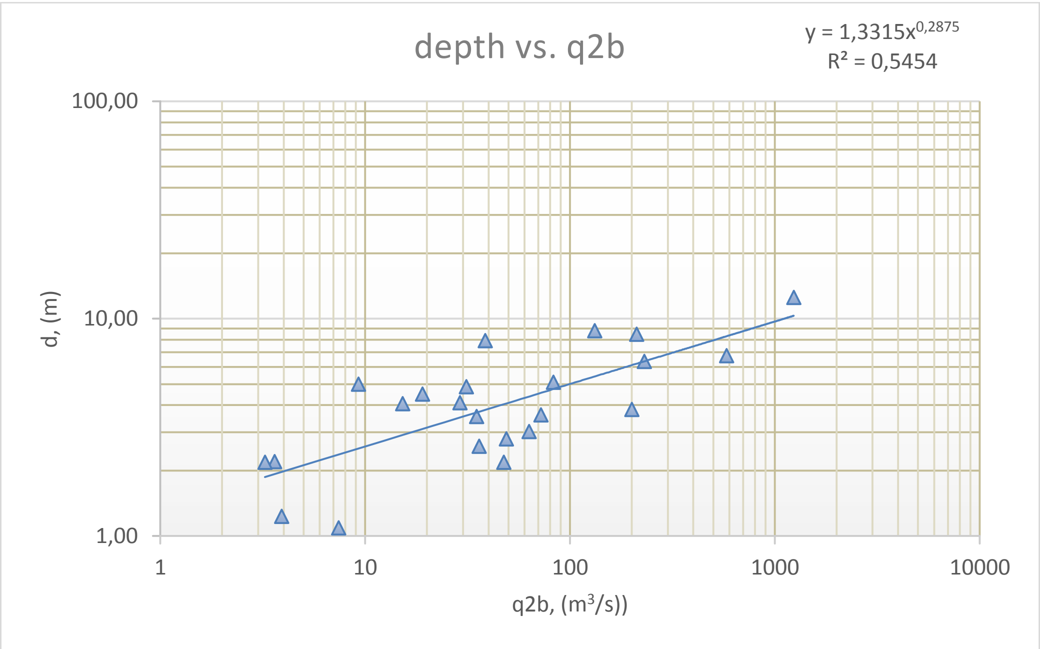


Figure 4.7 : Relationship between the best channel forming discharge "q2b" and the bankfull channel depth.

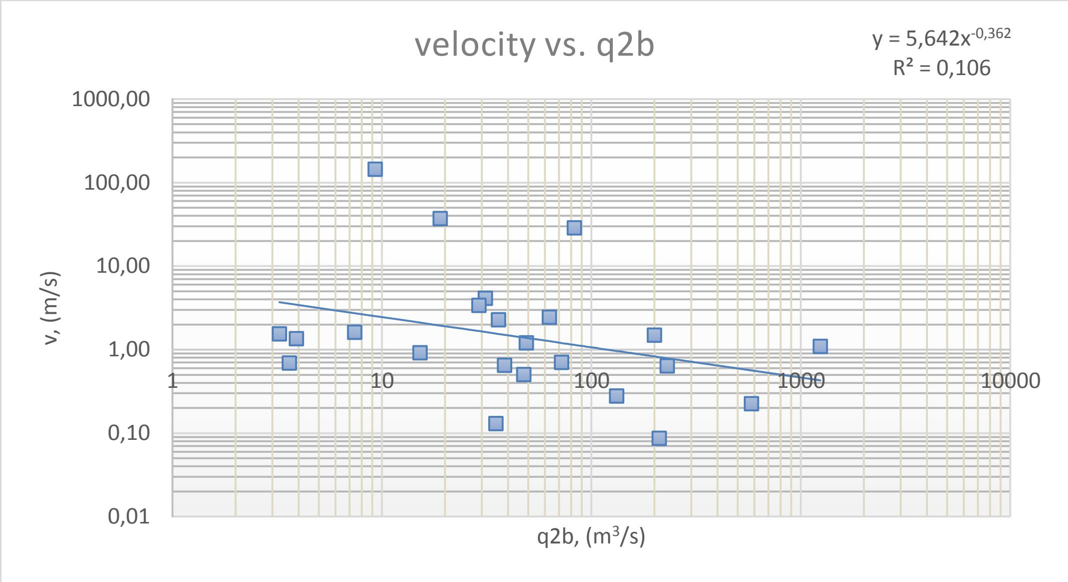


Figure 4.8 : Relationship between the best channel forming discharge "q2b" and the velocity.

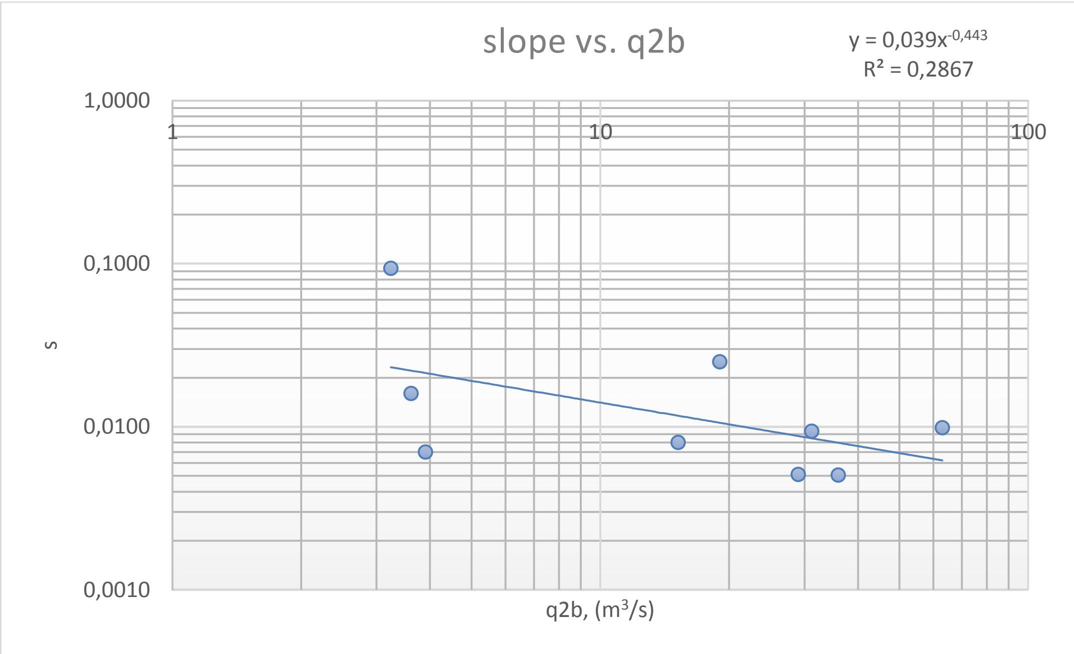


Figure 4.9 : Relationship between the best channel forming discharge "q2b" and the channel slope.

4.4 The Relationship Between River Basin Characteristics and Discharge and Cross-Section Geometry

When hydraulic geometry parameters, width, depth are plotted against discharge on logarithmic scale, it can be seen in Figure 4.10 that their relations to discharge are expressed by almost straight lines. Hereby, the best correlated discharge is chosen as the two thousandths of discharge, considering flow duration curves of all the gauging stations in accordance with their w/d versus q graphics, which means a 1.5-year return period in conformity with the literature criteria for extreme flows.

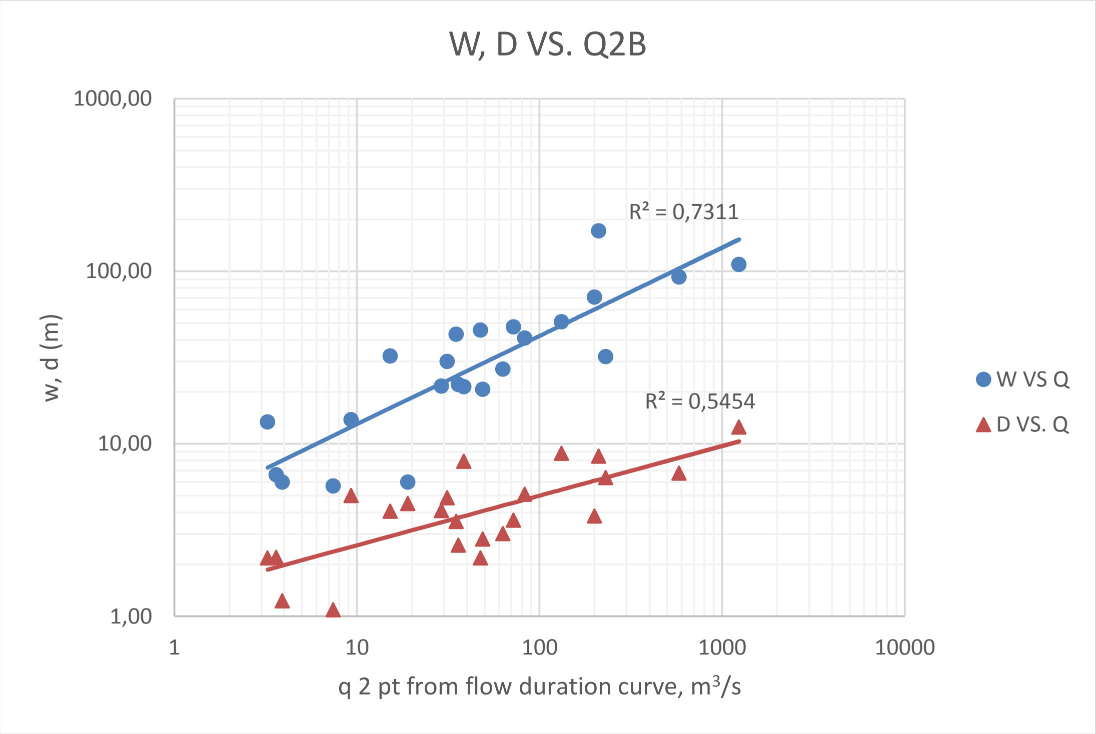


Figure 4.10 : Width and depth versus the best corelated discharge from the flow duration curves.

There is considerable scatter of the points on these graphs, some part of which are probably resultant of temporary scour and fill of the stream bed (Leopold et al. 1953). Another reason of the scattering might have arisen from human error. Inevitable poor measuring techniques, wading rather than measurement from a bridge or cable might be attributed to the fact that successive measurements are not made at exactly the same cross sections. The data analyzed indicate that through ranges of discharge up to the bankfull stage, the relations of width, depth and velocity to discharge in an unregulated stream section are in the form of simple power functions and plot as straight lines on logarithmic scale.

Average values of the exponents b, f, y and m have been computed for 23 unregulated (6 weakly regulated, represented with green dots below in Figure 4.11) river cross sections with gauging stations, representing a large variety of rivers in the Western Turkey, throughout 6 river basins totally. These values calculated for width, depth, slope and velocity are b = 0,5118, f = 0,2875, y = 0,0103 and m = 0,362 respectively.

The discharge tends to increase as well, proceeding downstream of a given river, since the drainage area increases progressively, too, where arid areas are an exception of this generalization. As a rough induction, it can be stated that width, depth relative to discharge are of the same order of magnitude for rivers of different sized drainage basins (Figure 4.11). However, in comparison with width/catchment area, the reason behind the lower correlation of depth and catchment area is that, alluvial grounds tend to enlarge to a certain extent, therefore the important parameter becomes the width not the depth hereby.

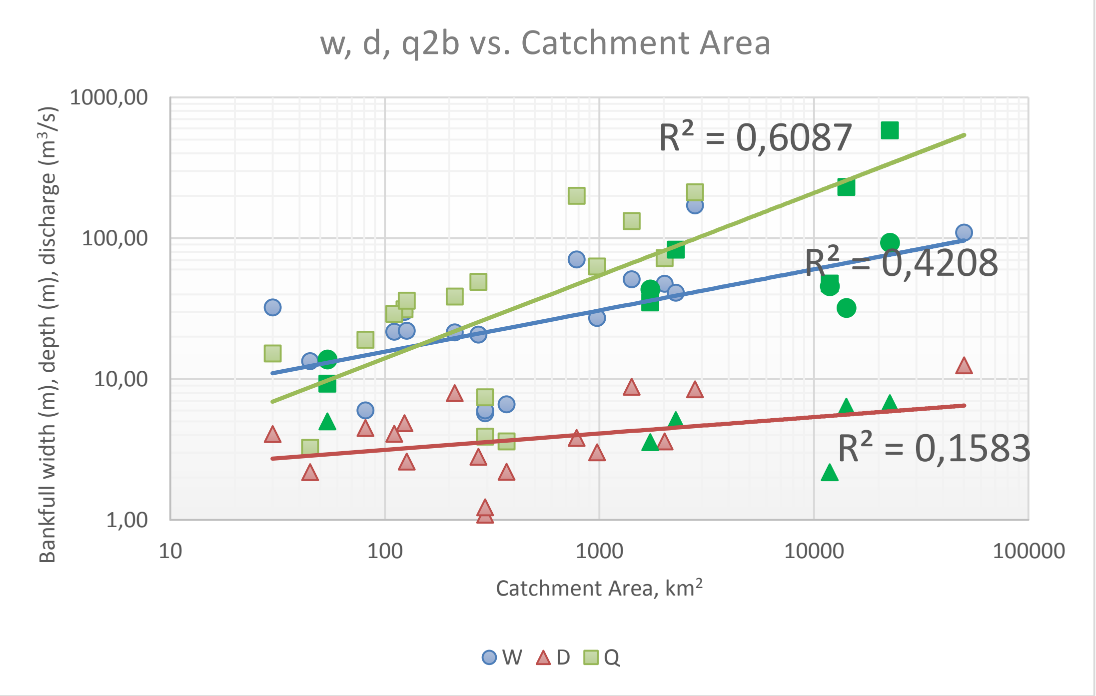


Figure 4.11 : Width, depth and discharge along the catchment area. Both at a given river section and in the downstream direction at mean annual discharge, width and depth increase with discharge. The functions demonstrating these relations are similar but contain different exponents and numerical constants (Table 4.6). The data for the calculation of hydraulic geometry parameters can be seen in Table 4.7.

Table 4.6 Averaged hydraulic geometry parameters for 6 Western River Basins.

		q2b (fdc)	$Q1_{max}$	
exponent	b	0,5118	0,511	*width*
	f	0,2875	0,283	*depth*
	y	0,443	0,849	*slope*
	m	0,362	0,368	*velocity*
coefficient	*a*	*3,9922*	*4,5579*	*width*
	c	*1,33115*	*1,4551*	*depth*
	s	*0,039*	*0,0573*	*slope*
	k	*5,642*	*5,2602*	*velocity*

Table 4.7 Hydraulic geometry values for exponent and coefficient calculations.

Q1max	q2b	w (m)	d (m)	v (m/s)	s
1,78	3,61	6,60	2,20	0,69	0,0160
15,65	15,2	32,29	4,06	0,92	0,0080
36,88	38,5	21,40	7,92	0,65	0,0000
4,80	7,4	5,70	1,09	1,61	0,0040
2,65	3,9	6,00	1,23	1,36	0,0070
52,86	72	47,50	3,60	0,70	0,0020
407,55	580	92,60	6,75	0,22	0,0000
155,29	230	32,00	6,36	0,64	0,0000
39,50	47,5	45,50	2,18	0,50	0,0010
7,71	9,28	13,80	5,00	144,93	-
32,33	35	43,20	3,55	0,13	0,0029
2,28	3,24	13,40	2,18	1,54	0,0936
26,48	31,2	30,00	4,86	4,12	0,0094
19,80	29	21,60	4,10	3,39	0,0051
30,45	36	22,03	2,59	2,28	0,0051
194,63	211	171,00	8,46	0,09	0,0001
125,30	132	51,00	8,80	0,28	0,0000
753,61	1238	109,50	12,51	1,10	0,0000
190,17	200	70,61	3,81	1,49	-
46,80	48,9	20,70	2,80	1,21	0,0031
50,87	63	27,05	3,02	2,45	0,0099
53,41	82,9	40,90	5,10	28,76	0,0000
13,62	19	6,00	4,50	37,04	0,0250

4.5 Relationship Between W/D and Channel Slope

In order to investigate the best correlated relationship between channel geometry and channel slope, slope measurements were done according to ± 500m, 1000m, 1500m, 2500m and 5000m for the gauging stations (Figure 4.12-16), regarded as the base points. It was found out that 1km (± 500m) slope values hold the best coefficient of determination in the plot showing its relation (Table 4.8) between bankfull channel width/depth.

Table 4.8 Measured slope values for ± 500m, 1000m, 1500m, 2500m and 5000m.

	Reach No	Gauge Station No	W/D	1km, R^2: 0,501	2km, R^2:0,038	3km, R^2:0,216	5km, R^2:0,189	10km, R^2:0,294
Büyük Menderes	BM10	12007120	3	0,01600	0,00400	0,01067		
	BM62	12007108	7,953202	0,00800	0,00300	0,00733		
	BM59	12007103	2,70202	0,00000	0,00000	0,00187	0,00457	
	BM11	12007010	5,229358	0,00400	0,00250	0,00300	0,00200	0,00200
		12007026	4,878049	0,00700	0,00500	0,00333	0,00220	0,00180
	BM8	12007003	13,19444	0,00200	0,00200	0,00267	0,00380	0,00500
Weakly Regulat	BM42	12007062	13,71852	0,00000	0,00000	0,00000	0,00030	0,00031
	BM31	12007032	5,031447	0,00000	0,00050	0,00033	0,00040	0,00090
		12007081	20,87156	0,00100	0,00000	0,00000	0,00080	
	BM44	12007015	2,76					
	BM26	12007059	12,16901	0,00288	0,00232	0,00182	0,00250	0,00249
Küçük Menderes	KM26	12006047	6,146789	0,09360				
Kuzey Ege	KEN10	12004036	6,17284	0,00939	0,00583			
	KEN16	12004017	5,27215	0,00510	0,00759	0,00767		
	KEN26	12004058	8,505792	0,00505	0,01430	0,01967	0,01050	0,01110
M-Ergene	ME50	12001008	20,21038	0,00008	0,00084	0,00100	0,00103	
		12001020	5,795455	0,00000				
	ME52	12001057	8,752998	0,00000	0,00000	0,00000	0,00000	0,00030
Susurluk	SU28	12003008	18,51337					
	SU35	12003081	7,392857	0,00311	0,00500	0,00433	0,00588	0,00537
	SU86	12003129	8,956954	0,00987	0,00498			
Weakly Regulated	SU5	12003128	8,019608	0,00000	0,00217	0,00146	0,00002	0,00150
Gediz	GE39	12005021	1,333333	0,02500	0,02500	0,04333	0,03660	0,03770

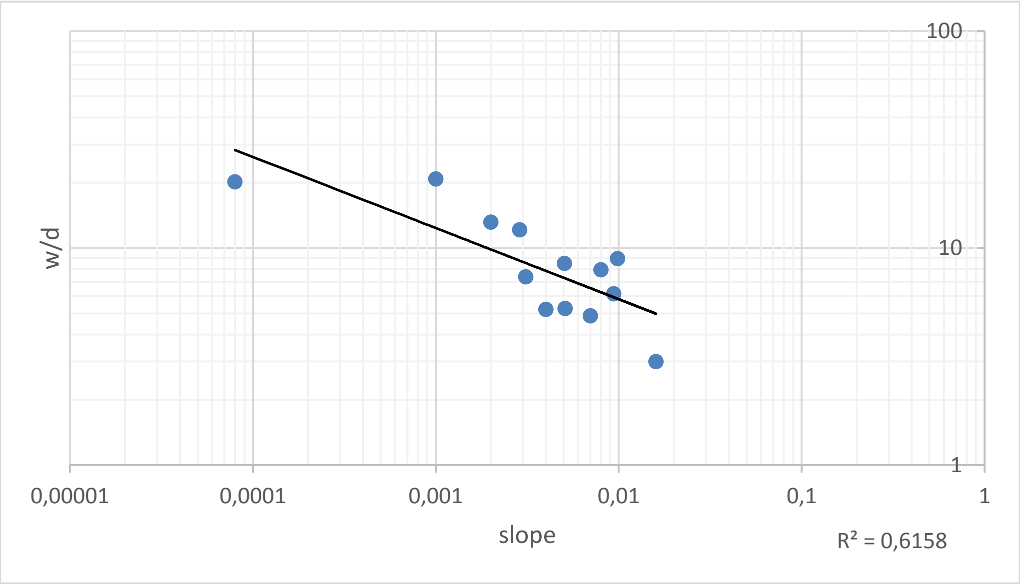


Figure 4.12 : Relationship between w/d and measured slope for ± 500m.

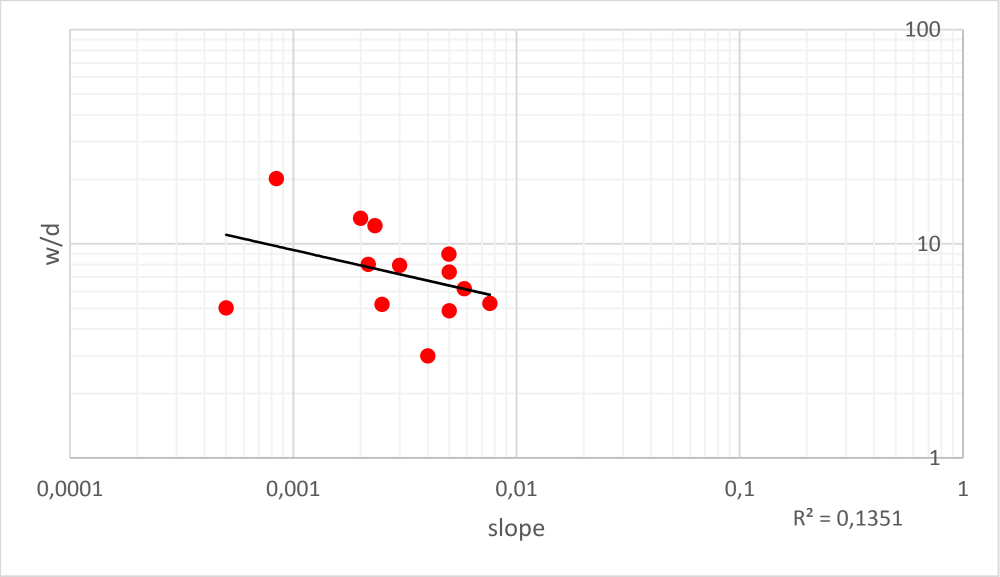


Figure 4.13 : Relationship between w/d and measured slope for ± 1000m.

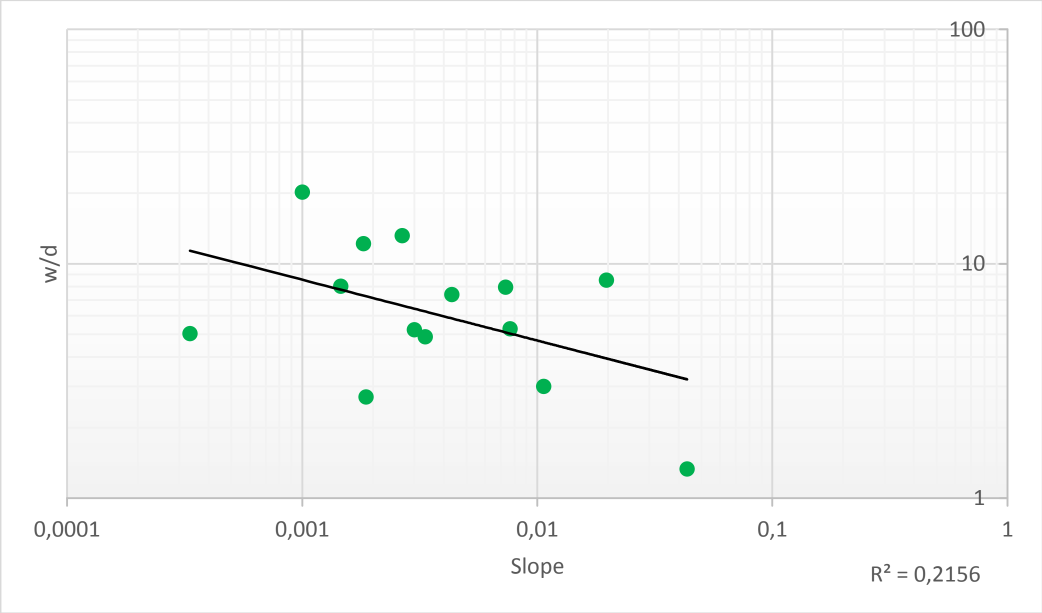


Figure 4.14 : Relationship between w/d and measured slope for ± 1500m.

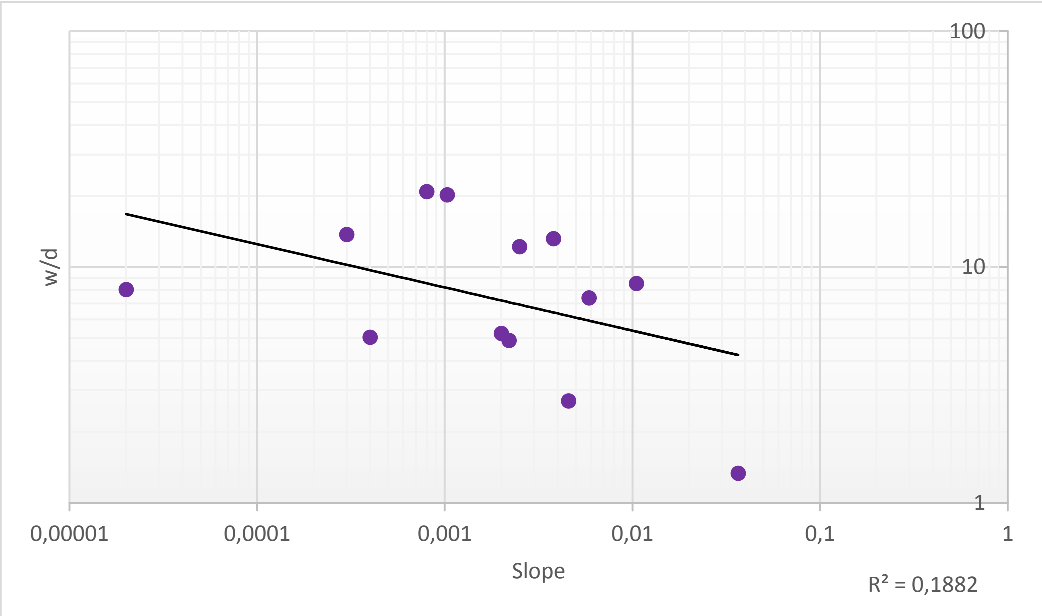


Figure 4.15: Relationship between w/d and measured slope for ± 2500m.

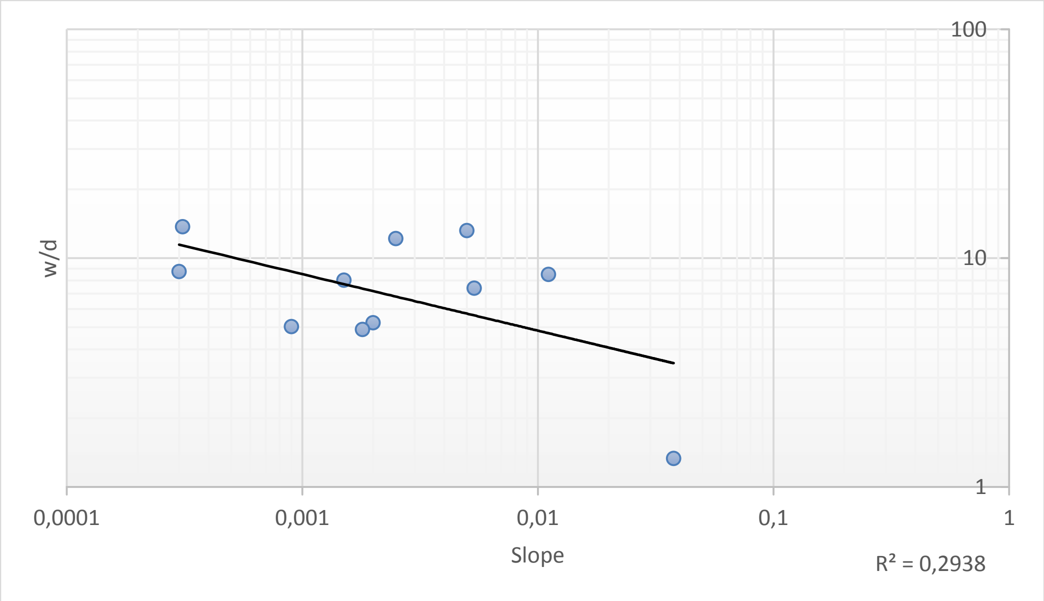


Figure 4.16: Relationship between w/d and measured slope for ± 5000m.

As can be seen in the graphs above, the correlation between the channel geometry and the slope is the best for ± 500m with a R^2 of 0,501 (Figure 4.12). With the help of that result, the channel geometry could have been estimated roughly without the need of in-situ measurement, which is both an expensive and hard work that takes time and effort. Using the existing terrain data to predict w/d ratio is an alternative and effortless solution.

4.6 Validation of the Empirical Expressions

In order to verify the calculated empirical exponents and coefficients of the hydraulic geometry parameters (width and depth) of the six studied Western river basins, Batı Akdeniz River Basin is chosen as a concurrent validation base region, which has ten usable unregulated reaches (Table 4.9) out of twenty nine. Daily mean discharge data is provided by SHW mean annual discharge handbook.

Table 4.9 Usable unregulated reaches of Batı Akdeniz River Basin.

Reach No	SGS No	Station name	Reach name
BA19	12008061	Mümür	Mümür Deresi
BA22	32008008	Çatallar	Başgöz Çayı
BA31	32008018	Kayadibi	Karaçay
BA32	32008015	Kınık	Eşen Çayı
BA34	12008089	Yanıklar	Kargı Çayı
BA36	12008140	Köyceğiz	Kargıcak Deresi
BA42	12008143	Ören Milas	Kocaçay
BA44	12008121	Karaova	Batış Deresi
BA50	12008097	Derince	Derince Deresi
BA52	12008087	Karadam	Değirmen Deresi

Since from the compared channel forming discharge analysis results, "flow duration curve" based analysis shows the best correlated relation between channel geometry, "q2b" values are selected from the flow duration curves of unregulated reaches of Batı Akdeniz River Basin. After that, measured discharge values are multiplied with the pre-calculated coefficient and exponents according to hydraulic geometry equations so as to obtain channel cross-section width and depth (Table 4.10), both are resulted in good validation.

Table 4.10 Calculated width and depth values of the unregulated reaches for Batı Akdeniz River Basin.

			w= a.Q^b			d= c.Q^f		
Reach No	SGS No	Q (q2b)	a	b	w	c	f	d
BA19	12008061	13,5	3,9922	0,5118	15,13	1,3315	0,2875	2,81
BA22	32008008	23,7	3,9922	0,5118	20,17	1,3315	0,2875	3,31
BA31	32008018	149	3,9922	0,5118	51,70	1,3315	0,2875	5,61
BA32	32008015	296	3,9922	0,5118	73,45	1,3315	0,2875	6,84
BA34	12008089	30	3,9922	0,5118	22,76	1,3315	0,2875	3,54
BA36	12008140	9,2	3,9922	0,5118	12,43	1,3315	0,2875	2,52
BA42	12008143	21,5	3,9922	0,5118	19,19	1,3315	0,2875	3,22
BA44	12008121	7,16	3,9922	0,5118	10,93	1,3315	0,2875	2,34
BA50	12008097	11,2	3,9922	0,5118	13,75	1,3315	0,2875	2,67
BA52	12008087	16,2	3,9922	0,5118	16,61	1,3315	0,2875	2,97

For the comparison, between the calculated hydraulic geometry width and the measured width from cross-section geometry, there is no enough available SHW cross-section data covering all unregulated Batı Akdeniz River Basin gauging stations. SHW stage data can only provide cross-section measurements (Figure 4.17) for the station 12008061. Therefore the result validity mostly relies on Google Earth based width measurement, which is quite consistent.

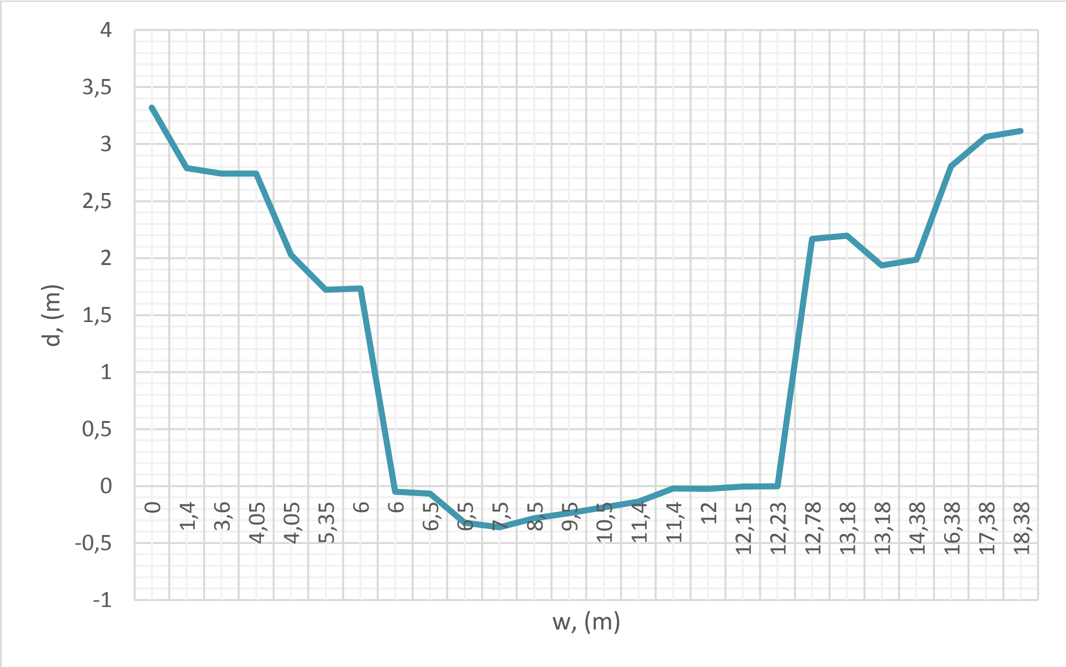


Figure 4.17 : Cross-section of BAW gauging station no: 12008061

From Figure 4.19 it can be seen that bankfull width and depth of the gauging station 12008061 on Mümür Deresi are approximately 12 m and 2,8 m respectively. On the other hand, as can be seen in Table 4.10, hydraulic geometry validation results show that estimated width and depth for this cross-section are 15,3 m and 2,81 m. This demonstrates that pre-calculated hydraulic geometry coefficients and exponents in this study are useful enough to predict any other unregulated western river basin cross-section geometry, with ±3-4 m margin of error. For the rest of the stations, validation is done by chosing three gauging stations randomly and measuring their width in Google Earth (Figure 4.18 and Figure 4.19) by its ruler. Whereas gauging station 12008140 has a predicted width of 12,43 m, in Google Earth it’s width can be measured as 15,6 m with 3,17 m error margin.

Figure 4.18 : Cross-section width measurement of BAW gauging statin no: 32008015 (Google Earth, 2014)

Figure 4.19 : Cross-section width measurement of BAW gauging statin no: 32008018 (Google Earth, 2014)

BAW gauging station 32008015 on Eşen Çayı with its best corelated channel forming discharge, q2b, 296 m^3/s, has a predicted width of 73.45 m as can be seen in Table 4.10. In Google Earth, cross-sectional width of that station is measured as approximately 71,8 m with 1,65 m margin of error. And BAW gauging station 32008018 on Karaçay with its q2b, 149 m^3/s, has a has a predicted width of 51,70 m. In Google Earth, cross-sectional width of that station is measured as approximately 51,40 m with 0,3 m margin of error This demonstrates that our hydraulic geometry coefficients are also useful enough to predict wide cross-sectional data as well.

To demonstrate the goodness of fit (Figure 4.20), absolute error and relative error calculations are done. Absolute error can be considered as the amount of physical error in a measurement. Let it be Δx, where x is any variable. On the other hand, relative error **(4.1)** is the indication of how good a measurement is relative to the size of the thing being measured.

$$\text{Relative error} = \frac{absolute\ error}{measured\ value} = \frac{\Delta x}{x} \qquad \textbf{(4.1)}$$

In the validation of the empirical expression part of our study, relative error for the bankfull width and depth for the station 12008061 respectively:

Relative error = $\frac{\Delta x}{x} = \frac{15{,}3-12}{12}$ = 0,275 where percent of error is 0,275*100= 27,5%

Relative error = $\frac{\Delta x}{x} = \frac{2{,}81-2{,}8}{2{,}8}$ = 0,00357 where percent of error is 0,00357*100= 0,36%

For the station 32008015, relative error for the bankfull width is:

Relative error = $\frac{\Delta x}{x} = \frac{73{,}45-71{,}8}{71{,}8}$ = 0,023 where percent of error is 0,023*100= 2,3%

For the station 32008018, relative error for the bankfull width is:

Relative error = $\frac{\Delta x}{x} = \frac{51{,}70-51{,}4}{51{,}4}$ = 0,006 where percent of error is 0,006*100= 0,58%

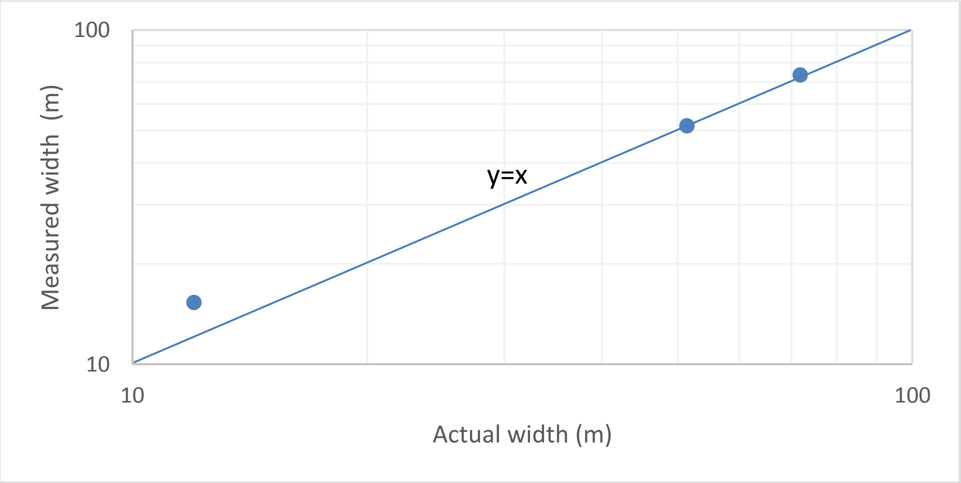


Figure 4.20 : Coefficient of determination from the plot of actual width vs. measured width of Batı Akdeniz River Basin cross-sections

5. CONCLUSION

Flood controlling channelization actions on rivers have been going on for decades yet it is no more than ten years that there has been a great awareness on re-naturalization of the stream channels which are affected by devastating channelization programs. On the other hand, stream characteristics tend to adjust themselves to the discharge and sediment load. Therefore, when necessary, a healthy river restoration ought to aim to mimic the most natural condition as much as it could. For a sustainable river restoration, selection of river cross-section is vital since it has a great influence on determining the magnitude of flood for a given discharge; defining sediment characteristics and transport process mechanism and thoroughly understanding the riverine ecosystem and determining the velocity, which can affect fish community.

Since formative discharges are main triggers of a typical cross-section of a river, this study is conducted to give a better understanding of hydraulic geometry parameters changing with discharge at a given unregulated river cross-sections located in Western Turkey. Based on two statistical analysis, after determining the best correlated channel formative discharge with its channel geometry, empirical equations were generated according to the relationship between discharge values and cross-sectional geometry, following a validation of the computed data with a different unregulated river basin (Batı Akdeniz) to verify the empirical exponents and coefficients.

The highlights show that a set of empirical equations that explain the formative discharges and the hydraulic geometry belonging to unregulated river reaches located in Western Turkey were generated, which makes this study quite unique. In order to determine the best characterizing formative discharge, two statistical analysis was carried out.

It has been seen that maximum mean annual discharges and mean daily discharges play a significant role in determining the best characterizing channel formative discharges of unregulated cross-section geometry. Among these two, results show that the best discharge correlation between channel geometry belongs to the discharge value equaled to two thousandths (q2b) which is generated from flow duration curves, that also fits into the flood return period of 1,5 -2 years.

In a healthy river restration framework, floods should be allowed to happen. First of all, looking at the bright side, it can be said that floods are fundamentally good for rivers, even though the initial results might look a little disappointing and harsh. The scouring actions of floods lead to deep pools that every angler knows are essential as cold-water shelters for fish. Floods rearrange cobbles into riffles needed for aeration of water, create habitat for invertebrates that become fish-feed, and accumulate gravel essential for spawning fish - salmon, for instance. Floods recharge groundwater that we depend upon later in the year, and they nourish riverfront forests - best habitat of all for wildlife. In our study, the relationship between the main river channel discharge and the geometry was conducted to predict an environmentally friendly future restoration and the validation results show that empirical hydraulic geometry coefficients and exponents generated in this study are useful enough to predict any other unregulated Western river basin cross-section geometry in Turkey.

Future works can be done within the framework covering the regulated reaches of the studied river basins and then formative discharges are expected to change in paralel with flow controlling obstacles like dams and weirs. In addition, imitation of the unregulated river cross-section plannings can be investigated in urban areas where modified land use require different development strategies. In order to protect and sustain urban development expanded in the river flood plain, graded flow controlling units can be placed starting from the upper reach and also egg-shape type cross section designs (where the height is by definition 3/2 times the width) can be considered to maintain the discharge level under low flow conditions and to prevent sediment accumulation.

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APPENDICES

APPENDIX A: Rating Curves

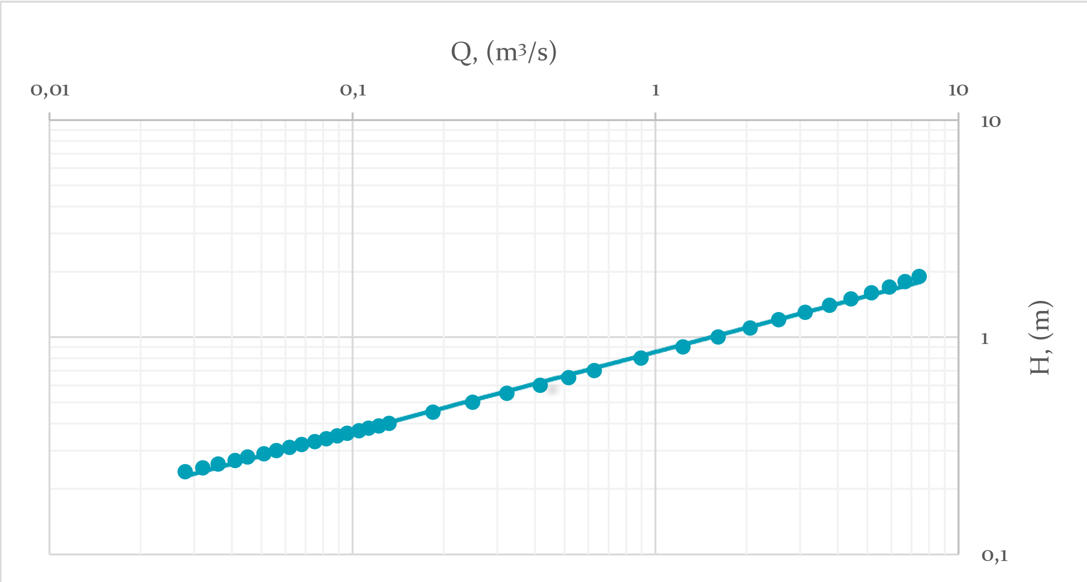

Figure A.1 : Rating curve of BMW gauging station no: 12007120, Çıkış, Çapalı Gölü, Afyon.

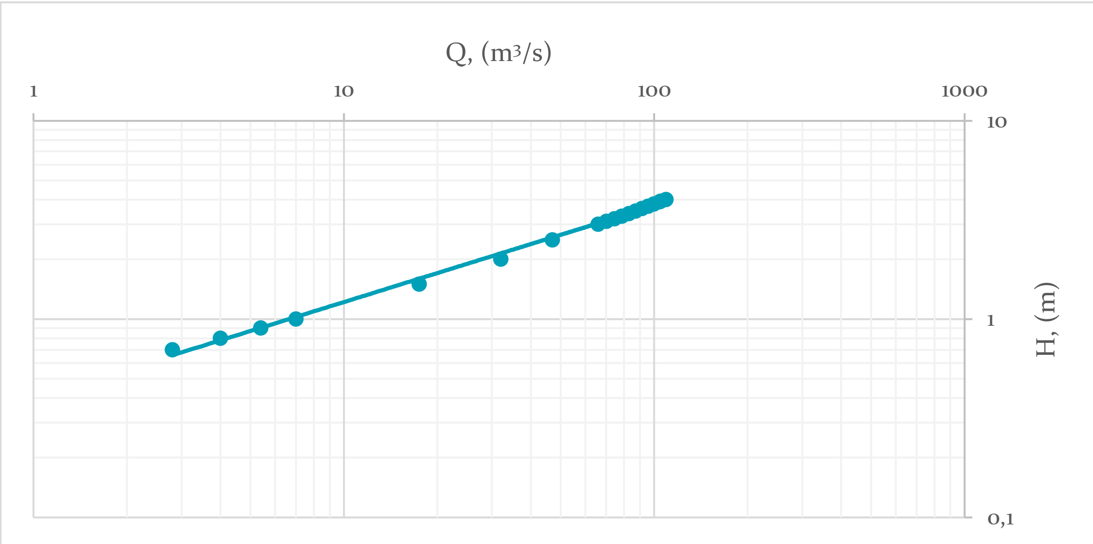

Figure A.2 : Rating curve of BMW gauging station no: 12007108, Köprüalan, Kargın Deresi, Aydın.

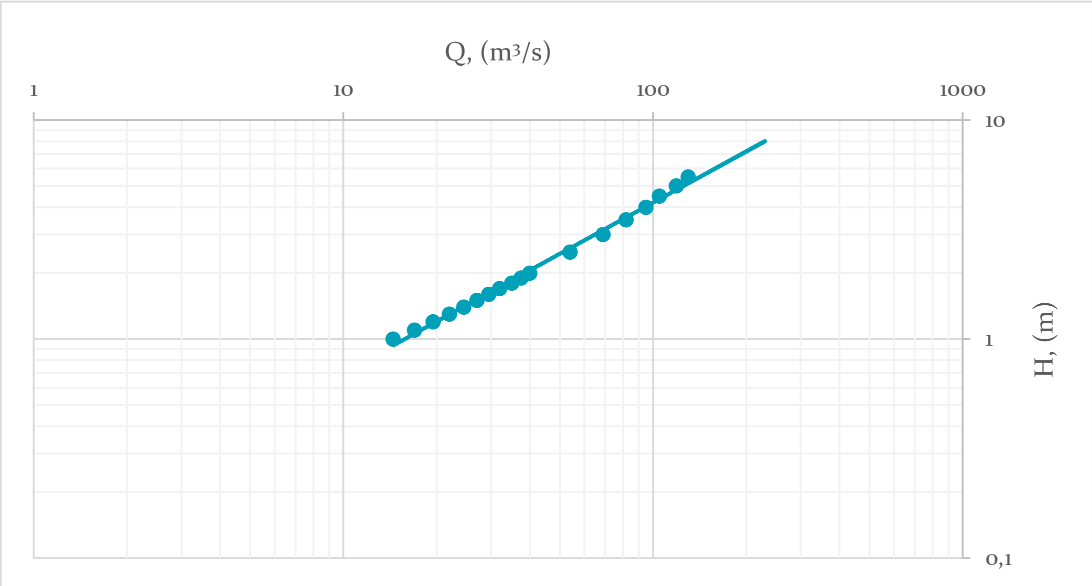

Figure A.3 : Rating curve of BMW gauging station no: 12007103, Bağarası, Sarıçay, Aydın.

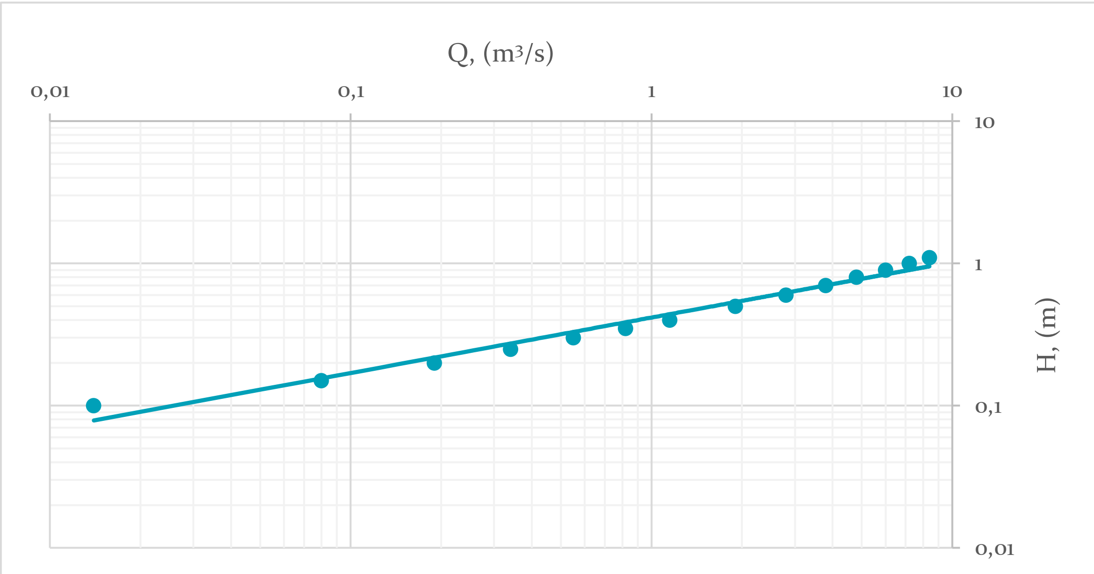

Figure A.4 : Rating curve of BMW gauging station no: 12007010, Irgıllı Regülatör Çıkışı, Dinar Suyu, Afyon.

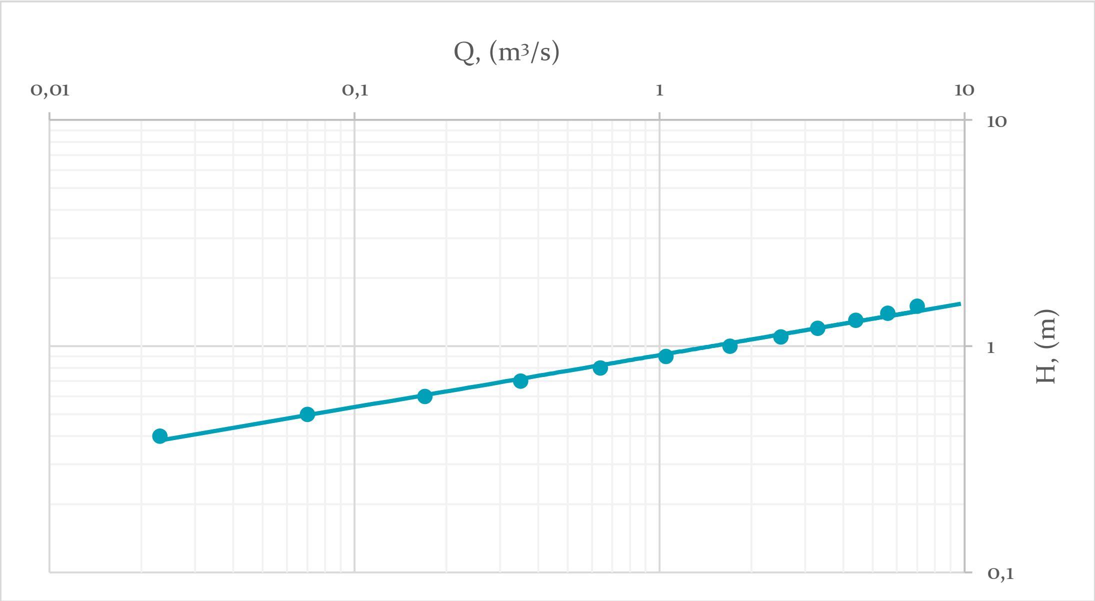

Figure A.5 : Rating curve of BMW gauging station no: 12007026, Irgıllı Sulama Kanalı, Dinar Suyu, Afyon.

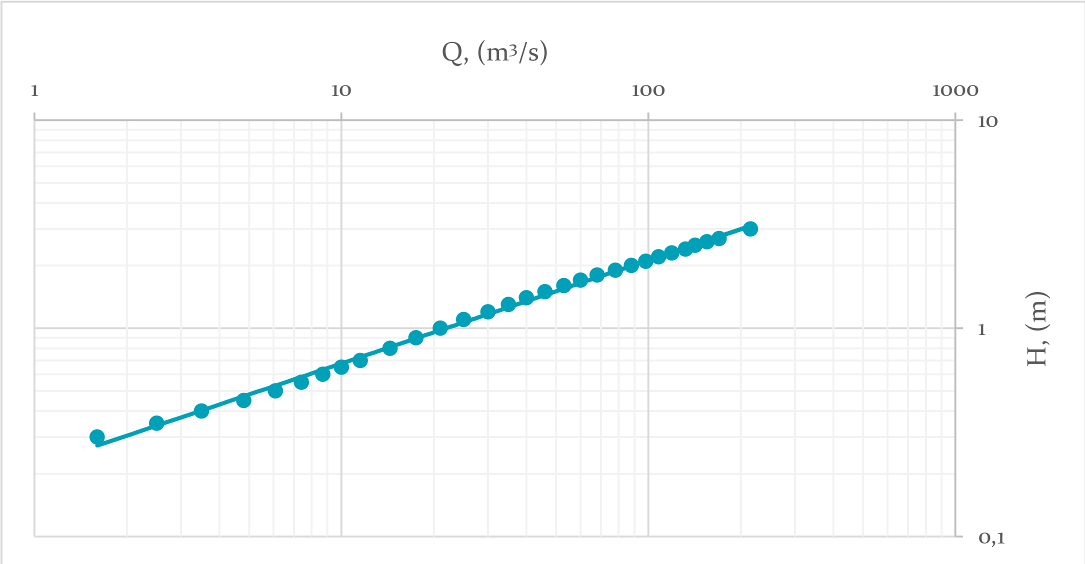

Figure A.6 : Rating curve of BMW gauging station no: 12007003, Işıklı Köprüsü, Kufi Çayı, Denizli.

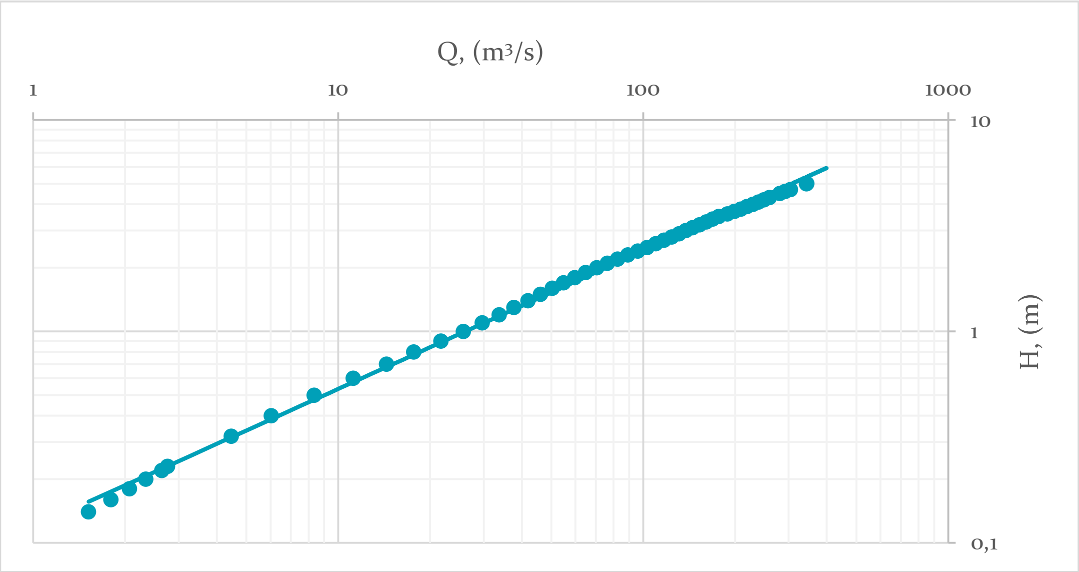

Figure A.7 : Rating curve of BMW gauging station no: 12007062, (weakly regulated), Koçarlı Köprüsü, Büyük Menderes Nehri, Aydın.

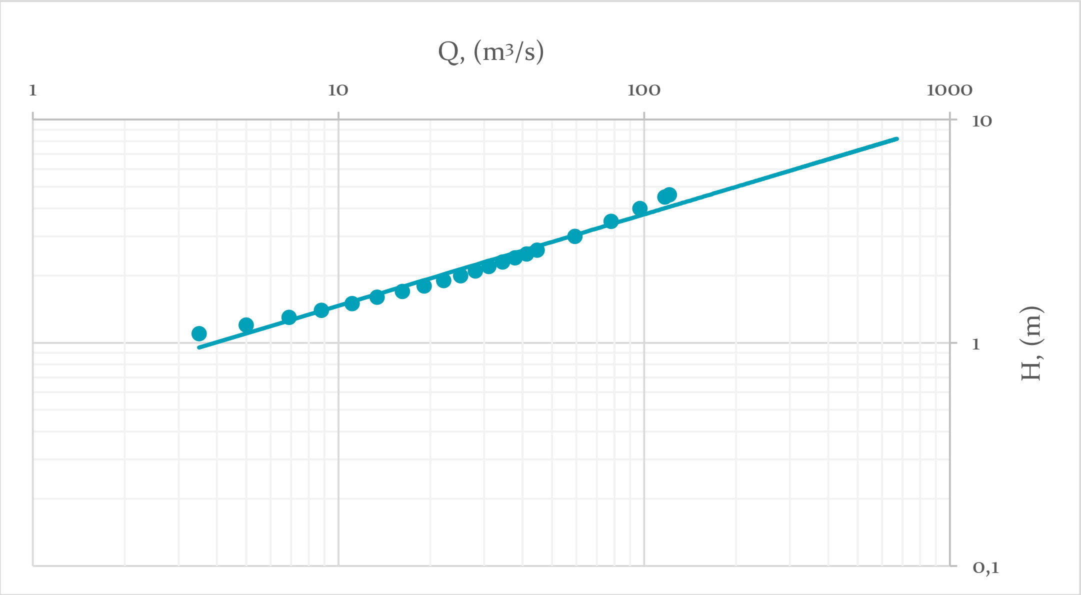

Figure A.8 : Rating curve of BMW gauging station no: 12007032, (weakly regulated), Nazilli Köprüsü, Büyük Menderes Nehri, Aydın.

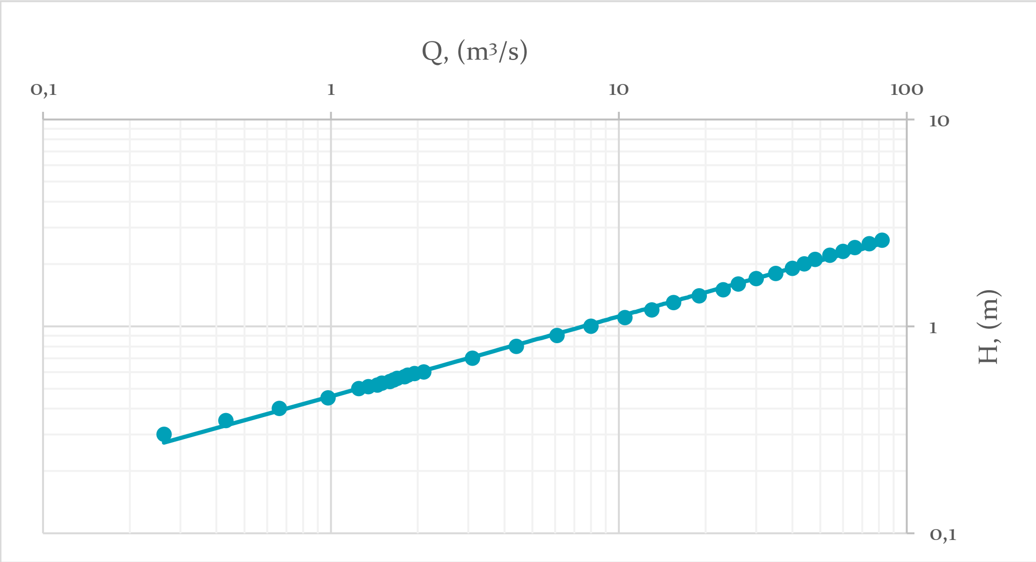

Figure A.9 : Rating curve of BMW gauging station no: 12007081, (weakly regulated), Sarayköy Köprüsü, Büyük Menderes Nehri, Denizli.

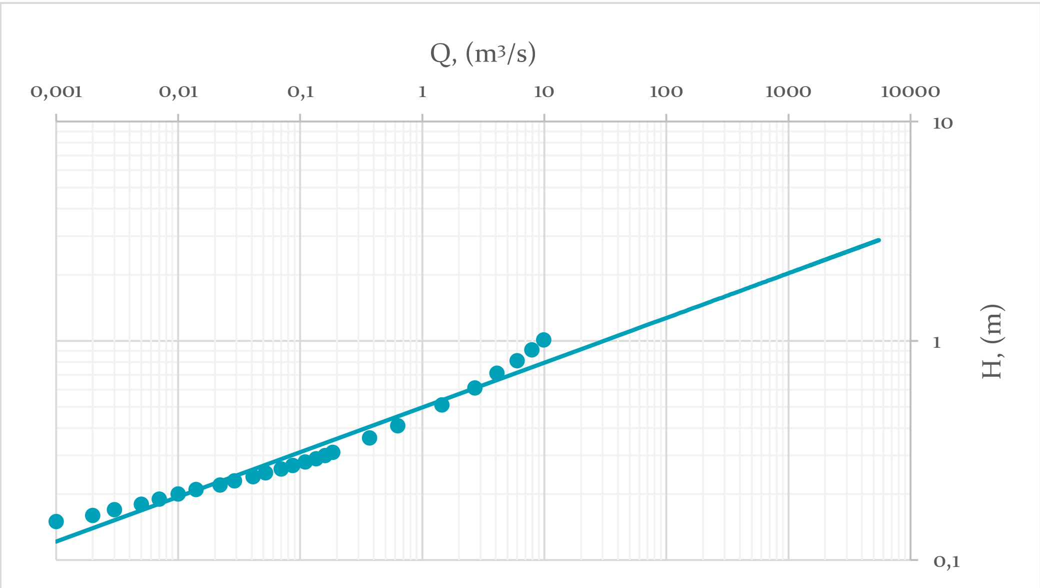

Figure A.10 : Rating curve of BMW gauging station no: 12007015, (weakly regulated), Aydın Tersip Bendi, Tabakhane Deresi, Aydın.

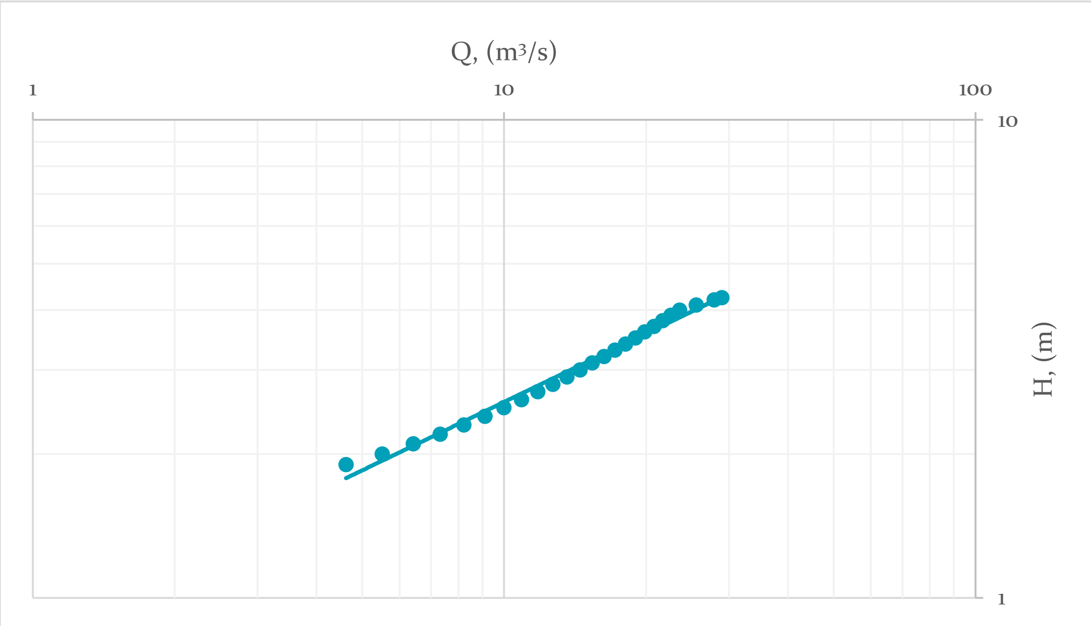

Figure A.11 : Rating curve of BMW gauging station no: 12007059, (weakly regulated), Yukarı Samlı, Küçüksu, Denizli.

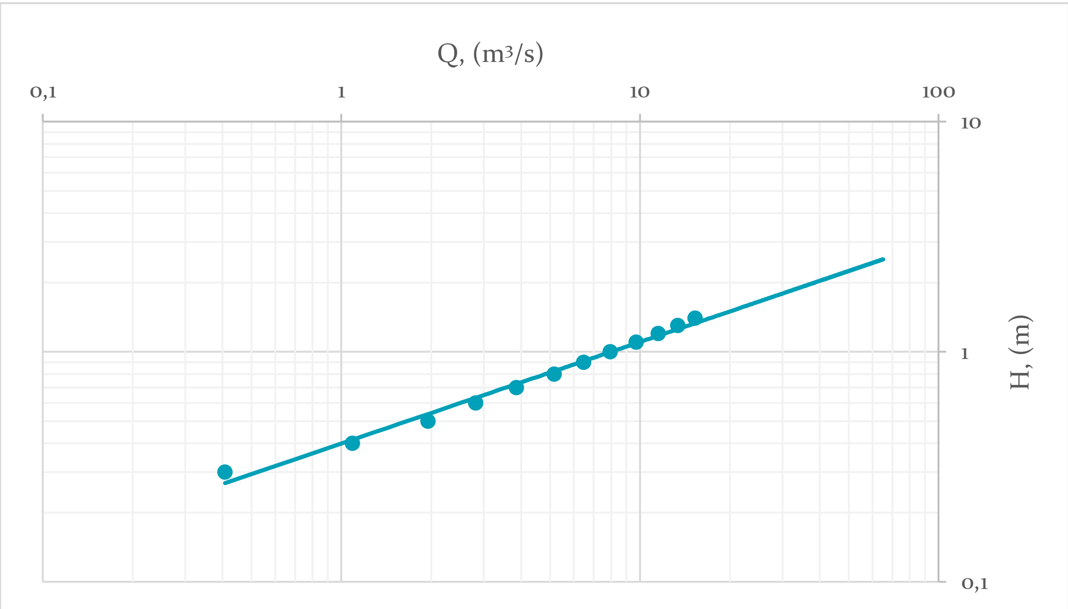

Figure A.12 : Rating curve of KMW gauging station no: 12006047, Yaylaköy, Sudeğirmeni Deresi, İzmir.

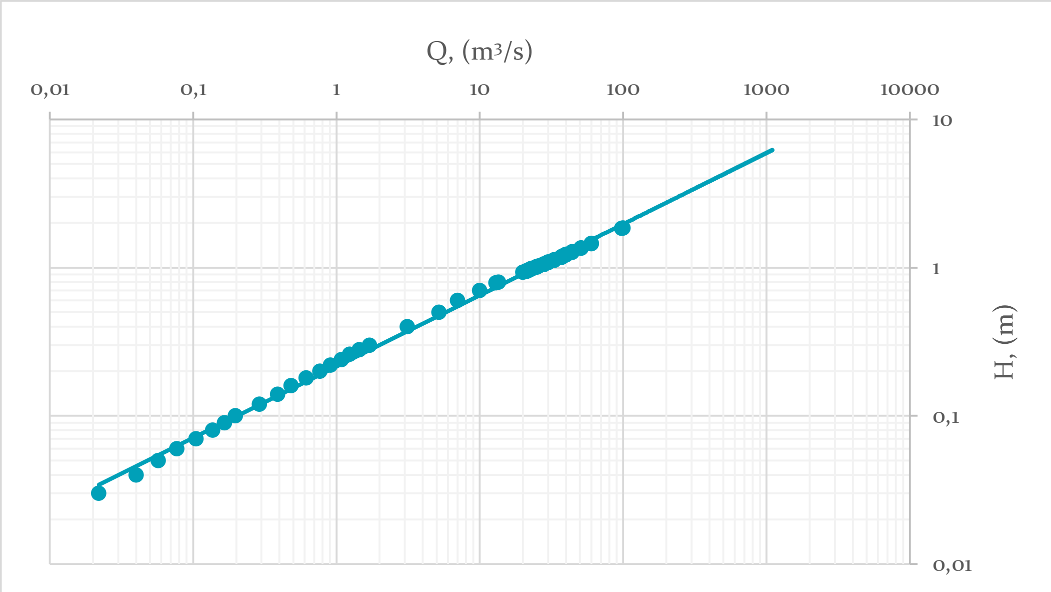

Figure A.13 : Rating curve of KEW gauging station no: 12004036, Zeytinli, Zeytinli Çayı, Balıkesir.

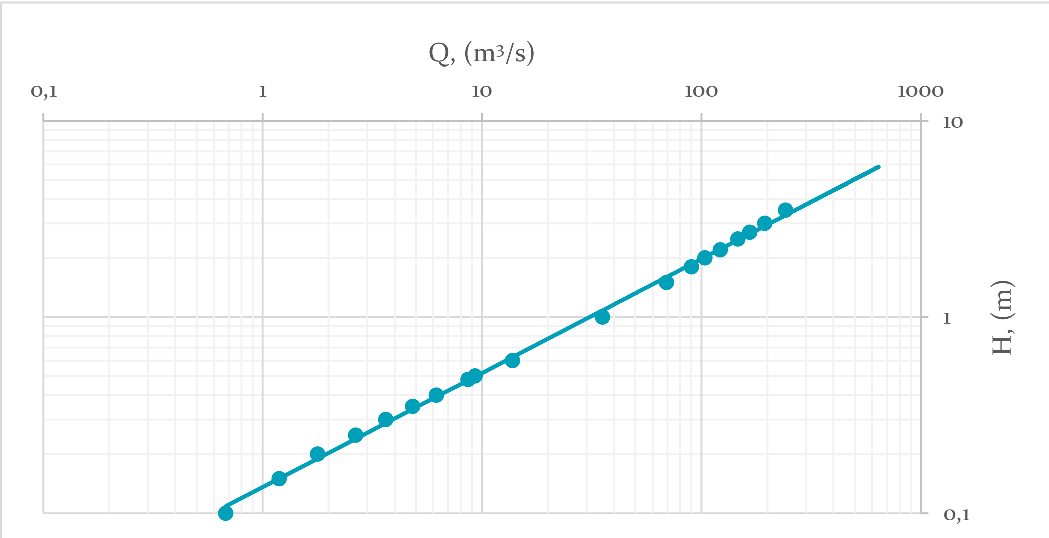

Figure A.14 : Rating curve of KEW gauging station no: 12004017, Reşitköy, Karınca Dere, Balıkesir.

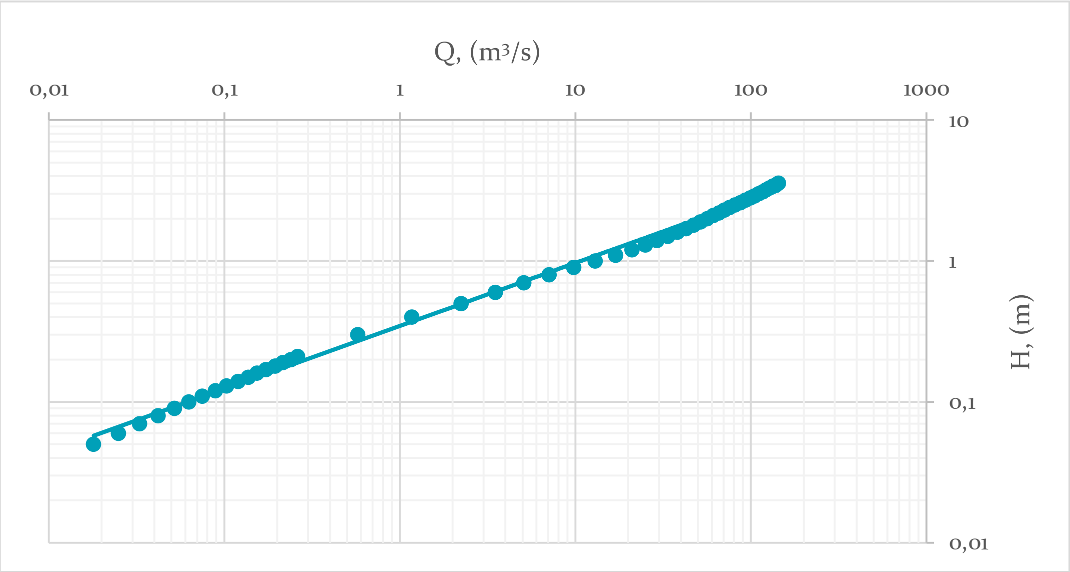

Figure A.15 : Rating curve of KEW gauging station no: 12004058, Kocaömerli, Karadere, İzmir.

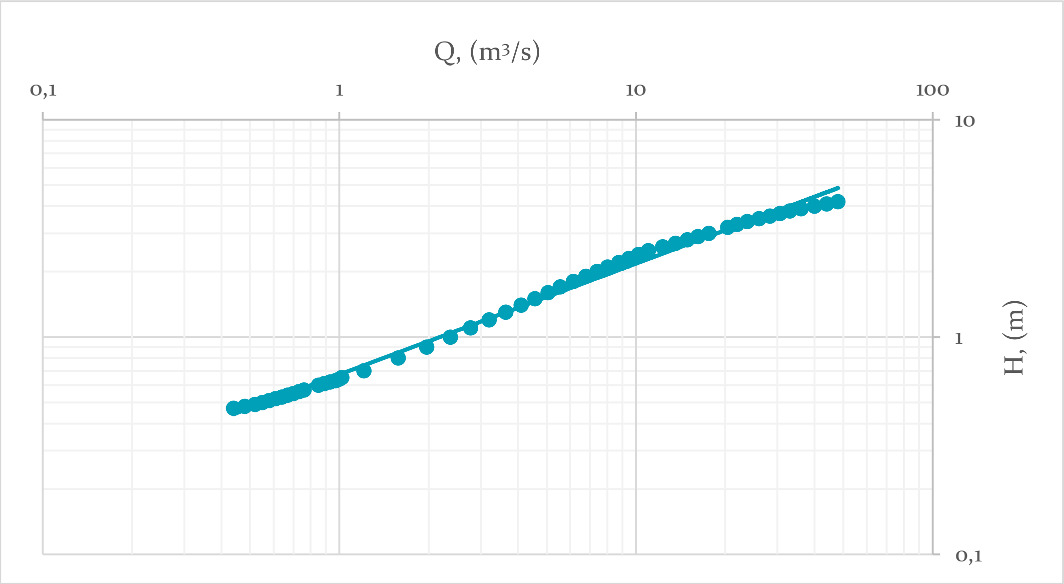

Figure A.16 : Rating curve of MEW gauging station no: 12001008, Lüleburgaz, Ergene Nehri, Kırklareli.

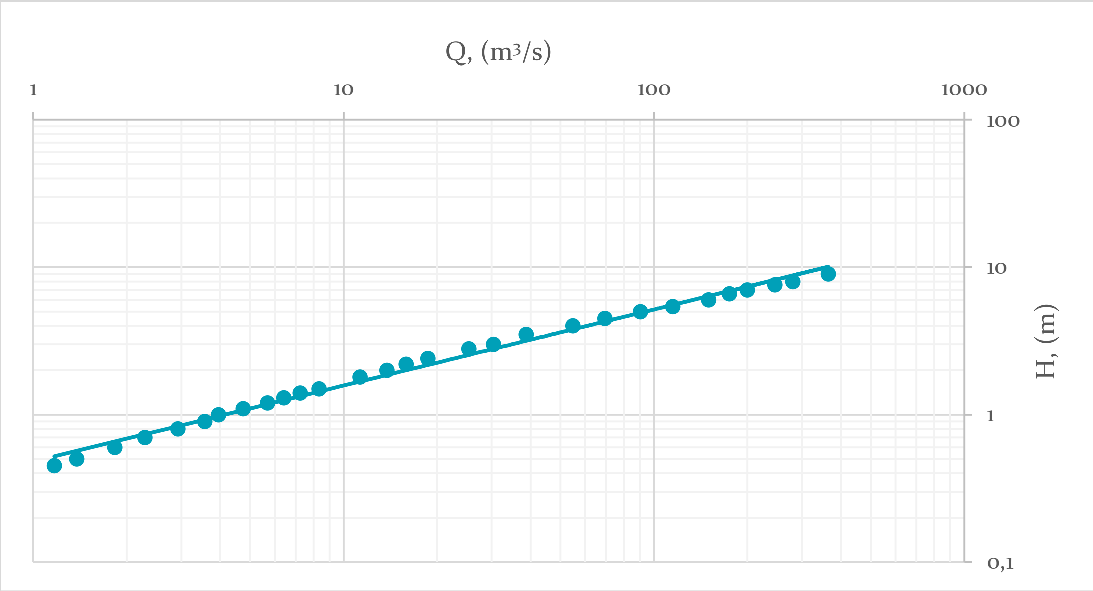

Figure A.17 : Rating curve of MEW gauging station no: 12001020, İnanlı, Ergene Nehri, Tekirdağ.

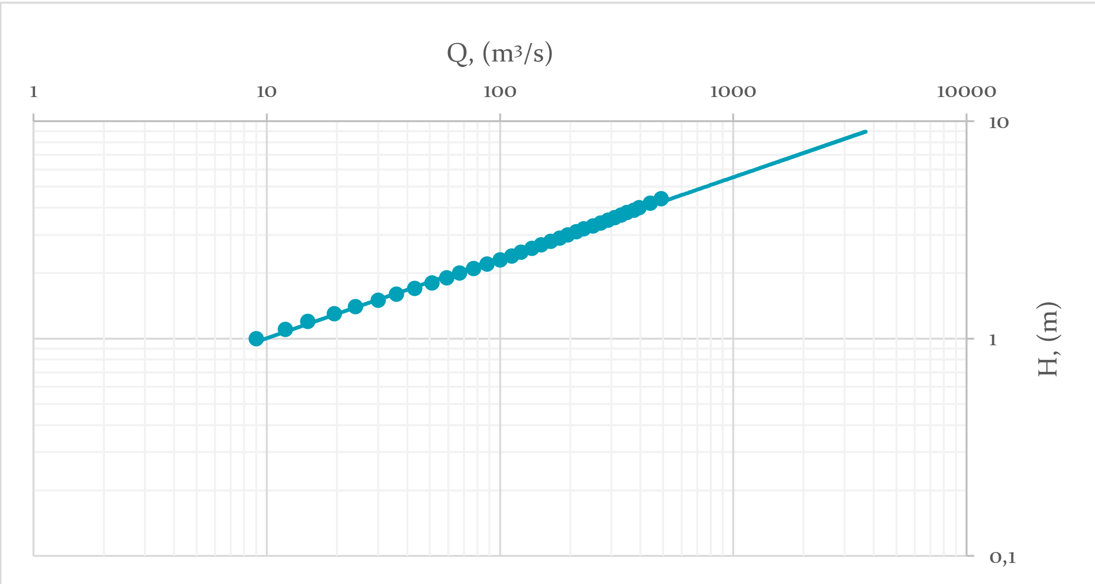

Figure A.18 : Rating curve of MEW gauging station no: 12001057, Ferek Köprüsü, Meriç Nehri, Edirne.

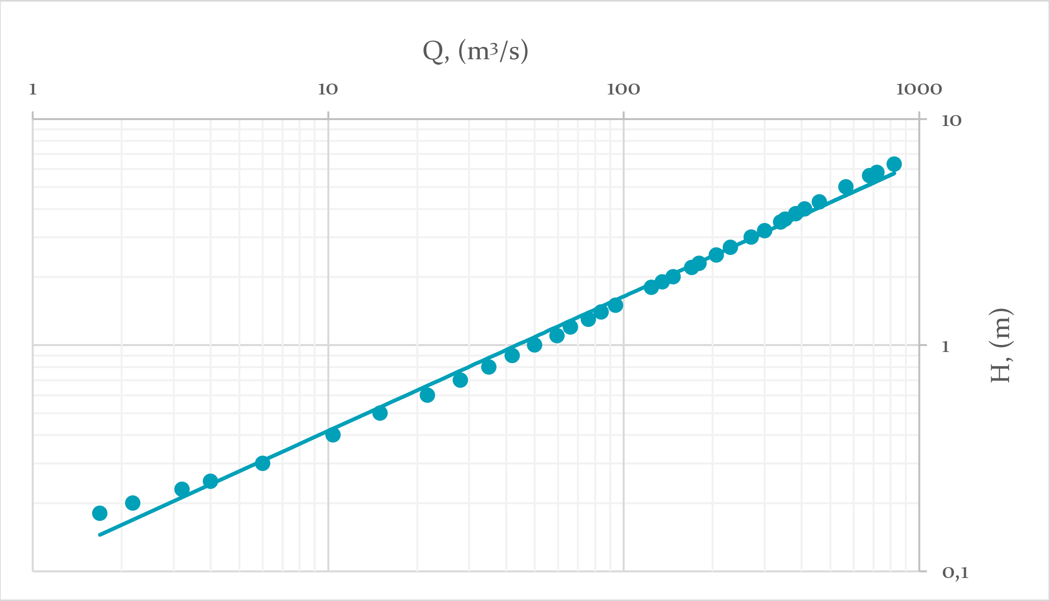

Figure A.19 : Rating curve of SW gauging station no: 12003008, Kahve, Madra Çayı, Balıkesir.

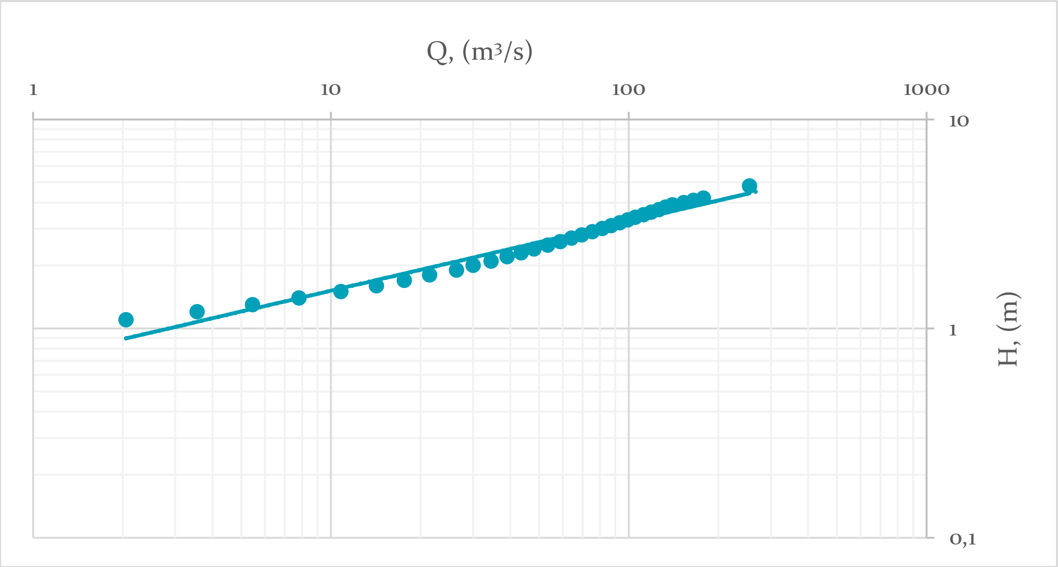

Figure A.20 : Rating curve of SW gauging station no: 12003081, Mürvetler, Mürvetler Deresi, Balıkesir.

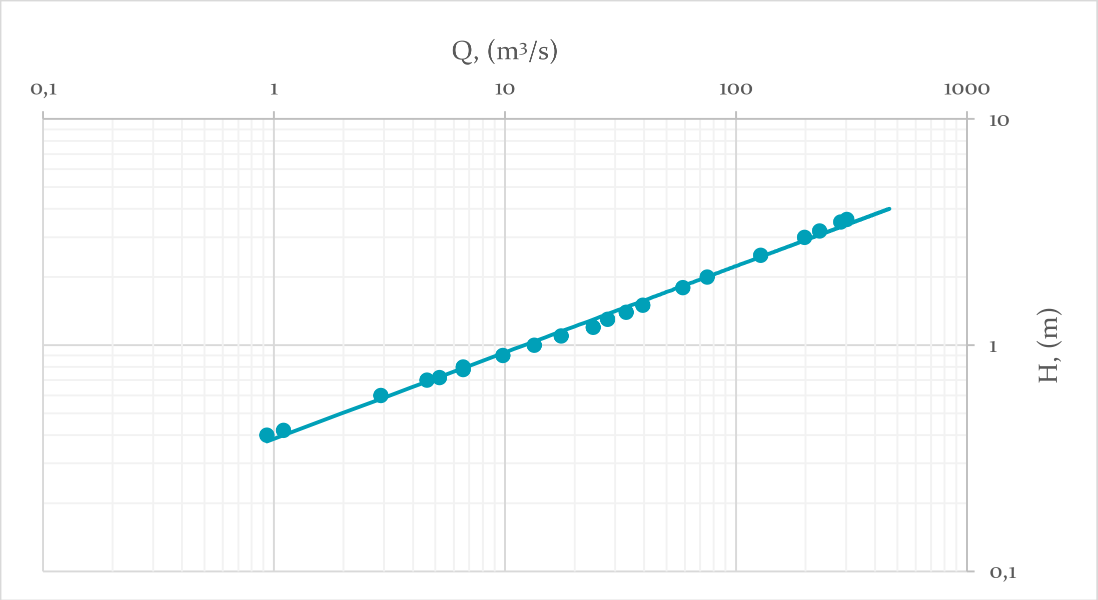

Figure A.21 : Rating curve of SW gauging station no: 12003129, Aşağıyağcılar, Dursunbey Çayı, Balıkesir.

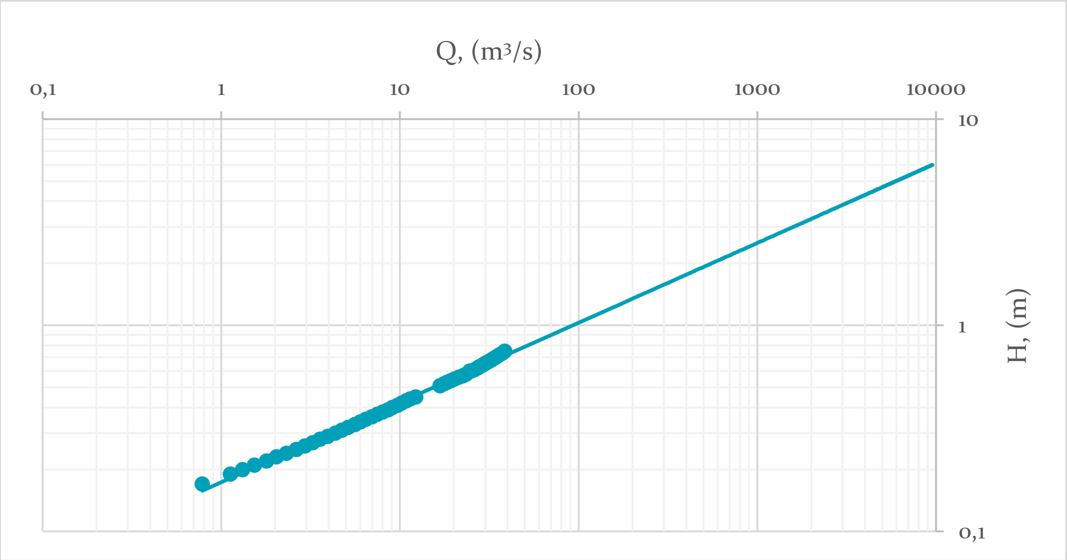

Figure A.22 : Rating curve of SW gauging station no: 12003128, (weakly regulated), Kadıköy Köprüsü, Simav Çayı, Balıkesir.

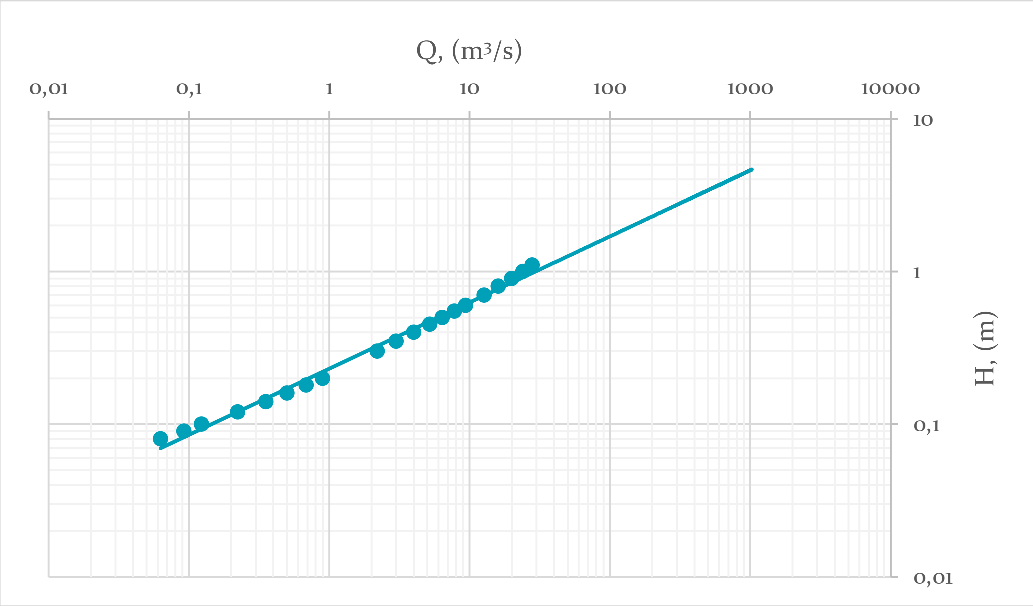

Figure A.23: Rating curve of GW gauging station no: 12005021, Çaltılı, Tabak Dere, Manisa.

APPENDIX B: Flow Duration Curves

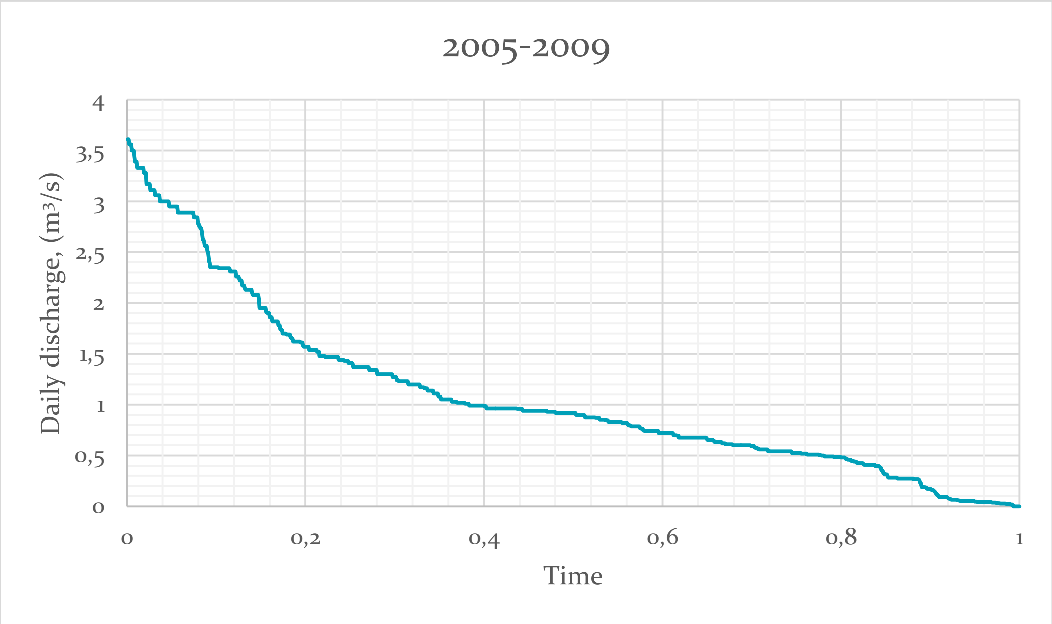

Figure B.1 : Flow duration curve of BMW gauging station no: 12007120, Çıkış, Çapalı Gölü, Afyon.

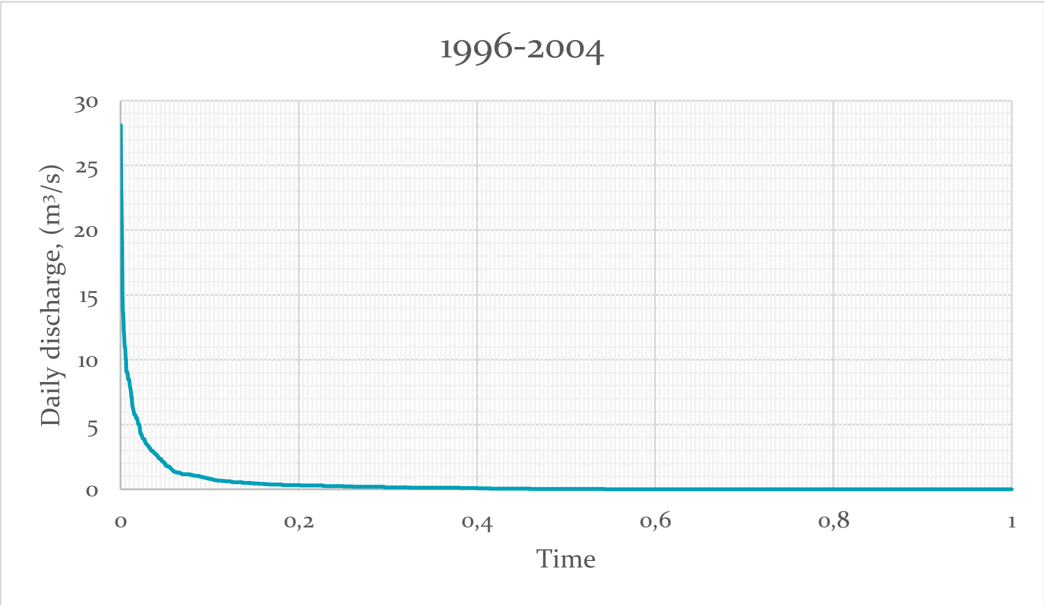

Figure B.2 : Flow duration curve of BMW gauging station no: 12007108, Köprüalan, Kargın Deresi, Aydın.

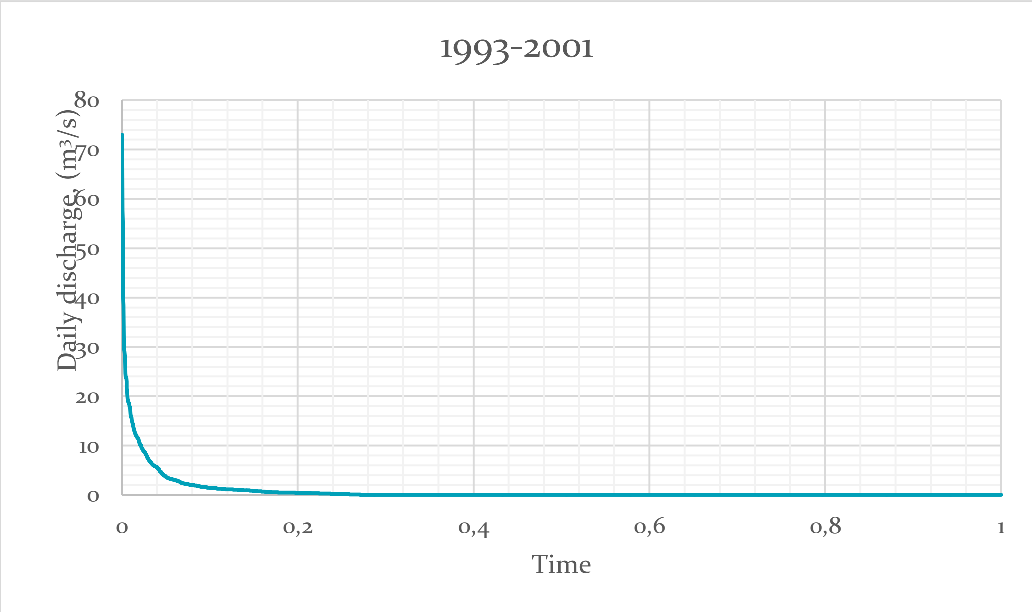

Figure B.3 : Flow duration curve of BMW gauging station no: 12007103, Bağarası, Sarıçay, Aydın.

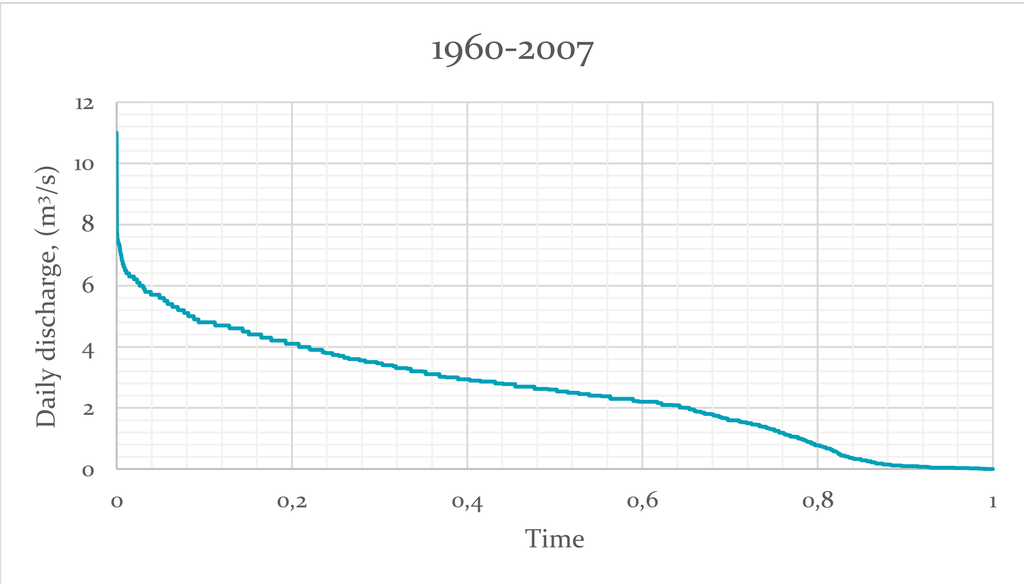

Figure B.4 : Flow duration curve of BMW gauging station no: 12007010, Irgıllı Regülatör Çıkışı, Dinar Suyu, Afyon.

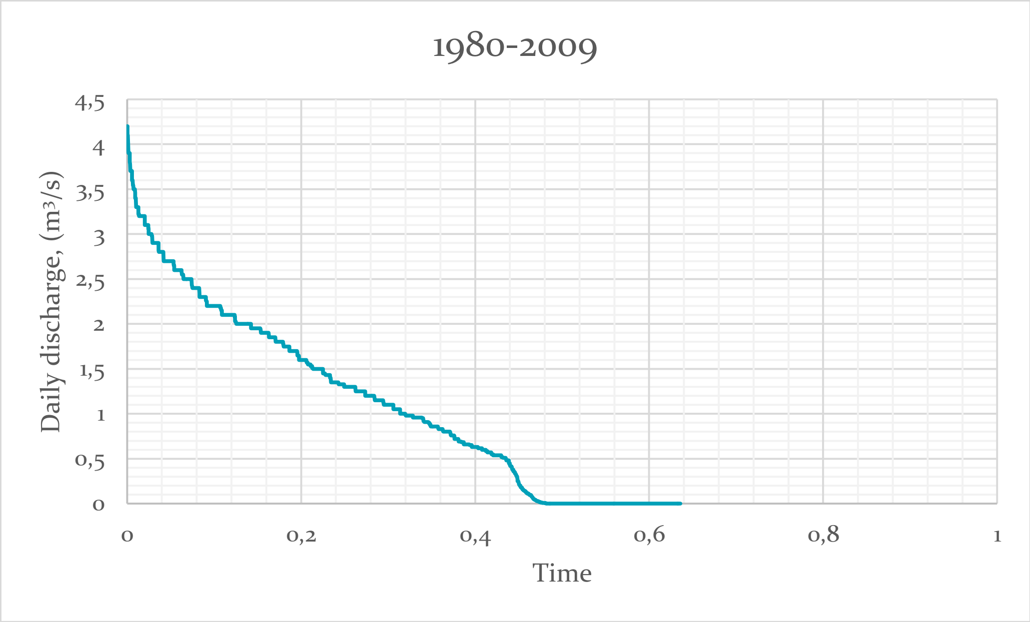

Figure B.5 : Flow duration curve of BMW gauging station no: 12007026, Irgıllı Sulama Kanalı, Dinar Suyu, Afyon.

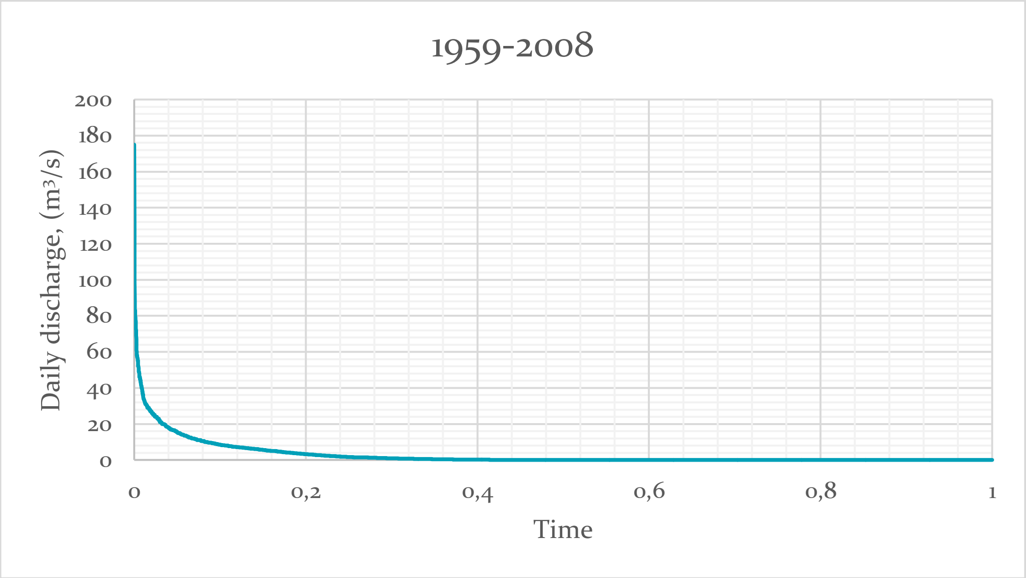

Figure B.6 : Flow duration curve of BMW gauging station no: 12007003, Işıklı Köprüsü, Kufi Çayı, Denizli.

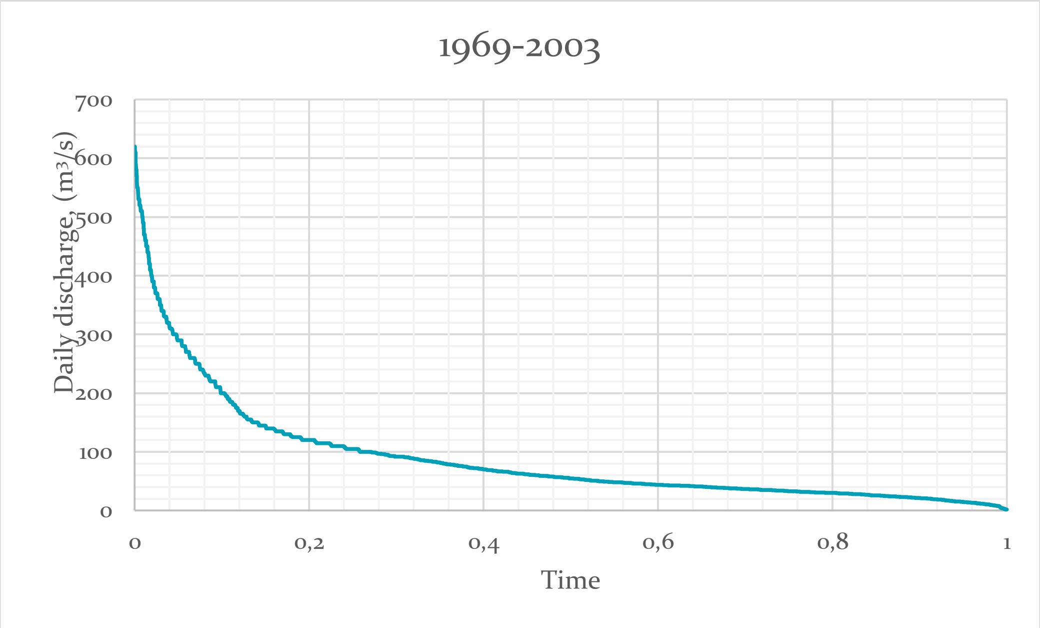

Figure B.7 : Flow duration curve of BMW gauging station no: 12007062, (weakly regulated), Koçarlı Köprüsü, Büyük Menderes Nehri, Aydın.

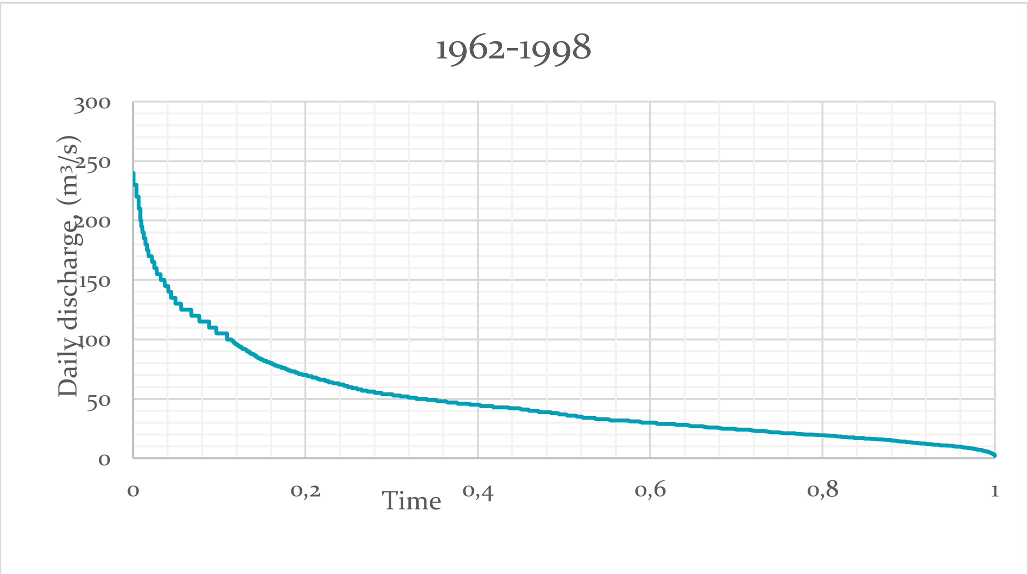

Figure B.8 : Flow duration curve of BMW gauging station no: 12007032, (weakly regulated), Nazilli Köprüsü, Büyük Menderes Nehri, Aydın.

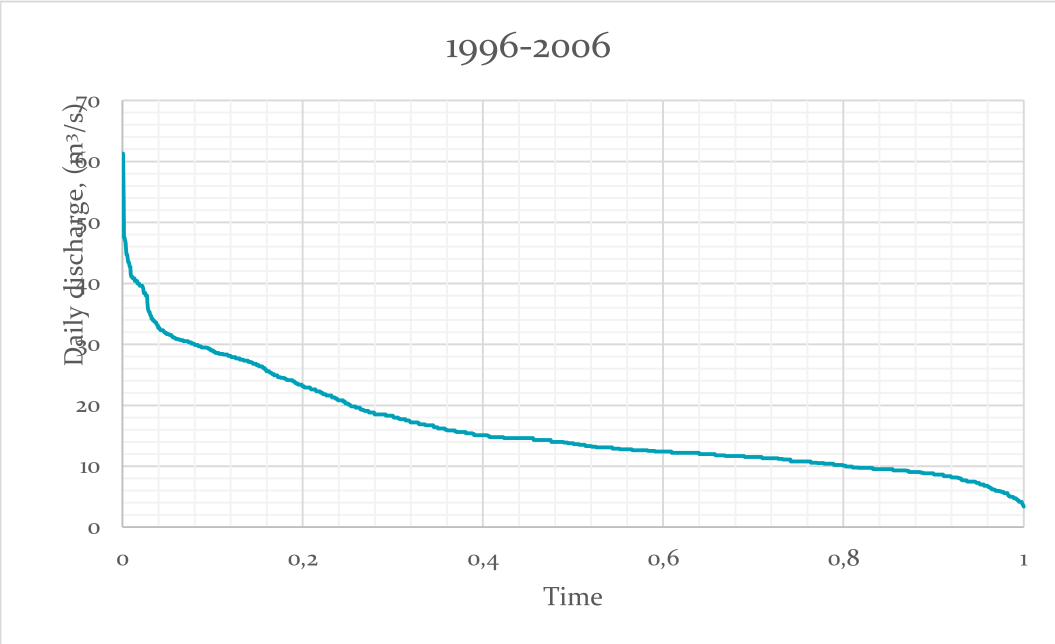

Figure B.9 : Flow duration curve of BMW gauging station no: 12007081, (weakly regulated), Sarayköy Köprüsü, Büyük Menderes Nehri, Denizli.

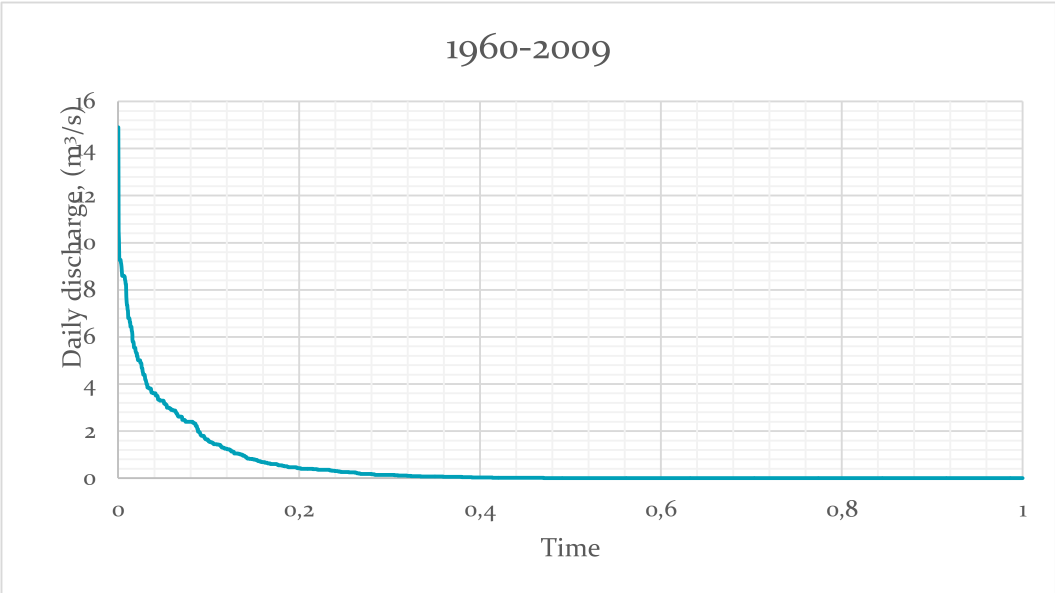

Figure B.10 : Flow duration curve of BMW gauging station no: 12007015, (weakly regulated), Aydın Tersip Bendi, Tabakhane Deresi, Aydın.

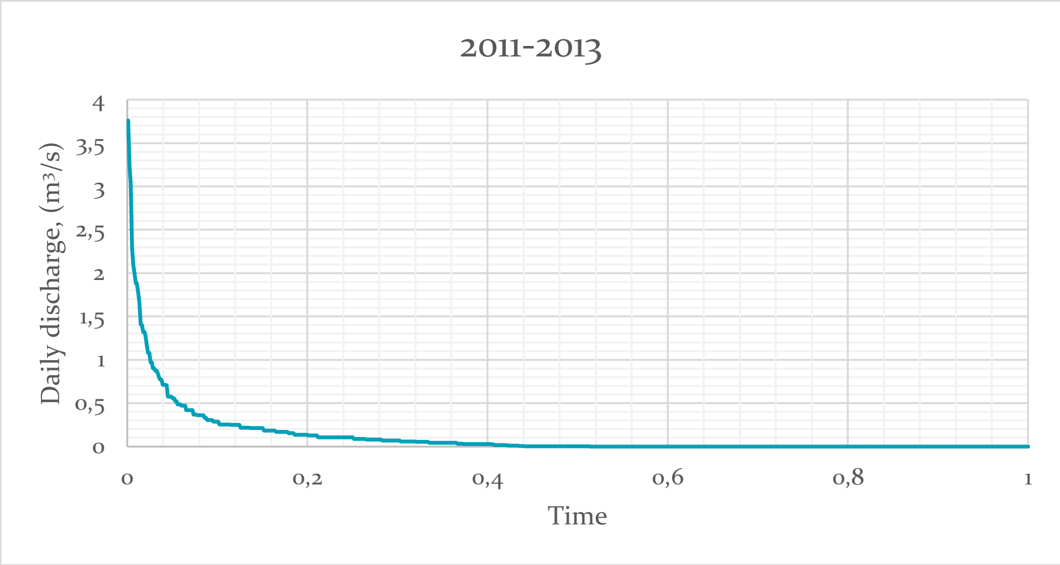

Figure B.11 : Flow duration curve of BMW gauging station no: 12007059, (weakly regulated), Yukarı Samlı, Küçüksu, Denizli.

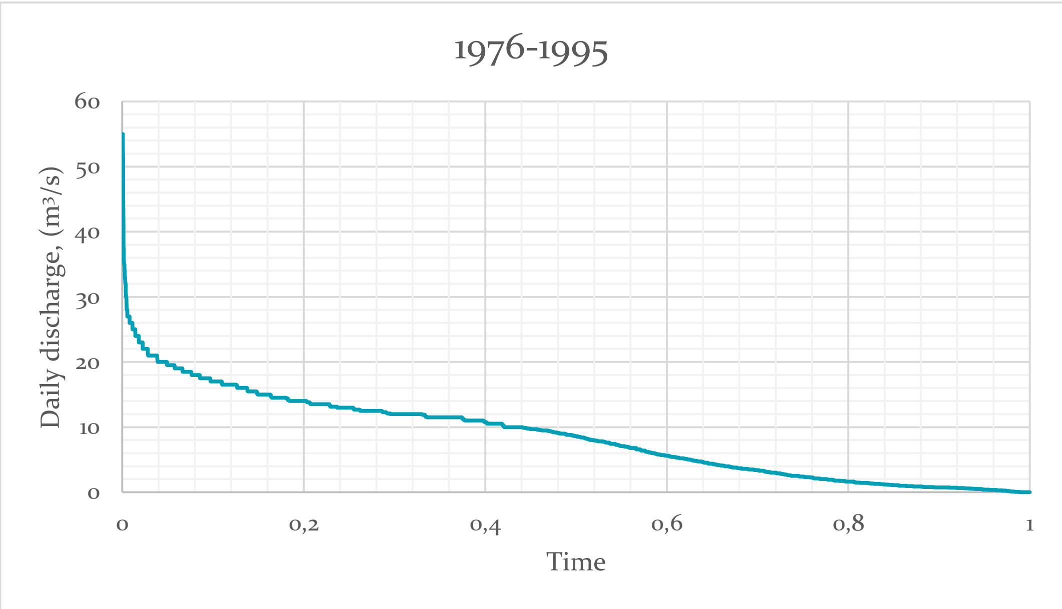

Figure B.12 : Flow duration curve of KMW gauging station no: 12006047, Yaylaköy, Sudeğirmeni Deresi, İzmir.

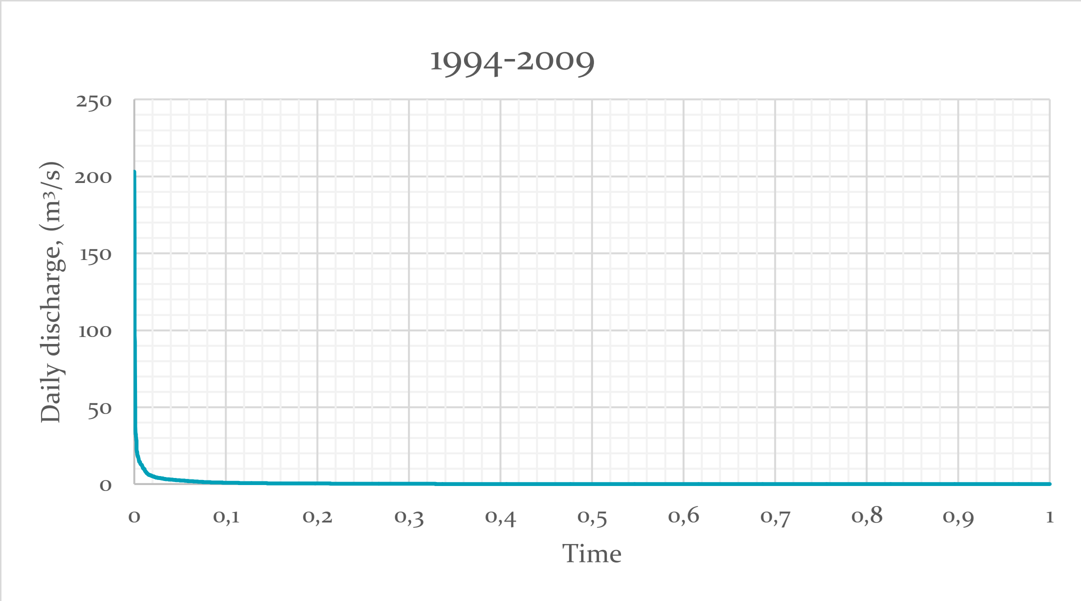

Figure B.13 : Flow duration curve of KEW gauging station no: 12004036, Zeytinli, Zeytinli Çayı, Balıkesir.

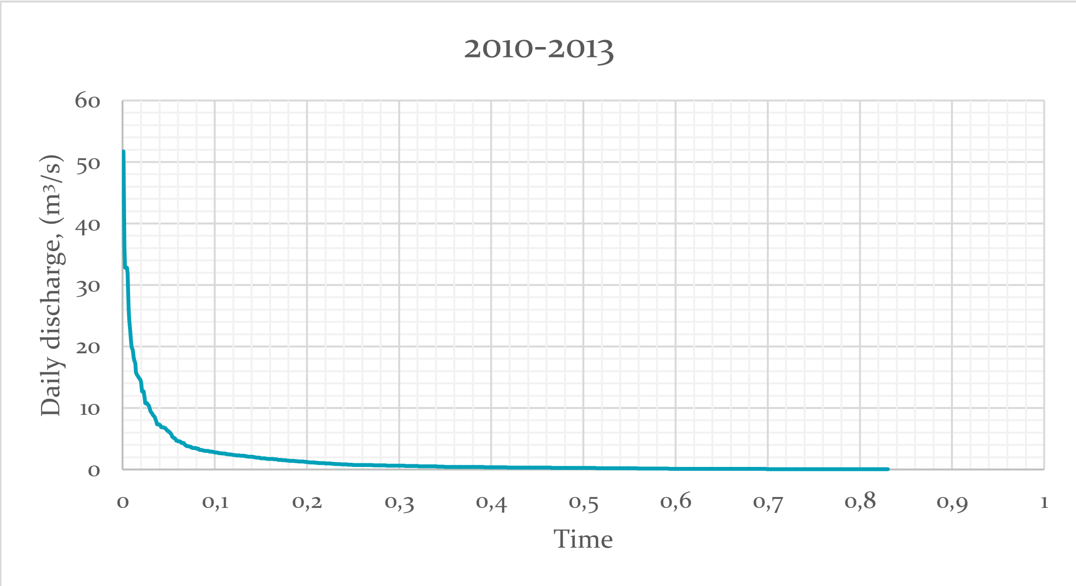

Figure B.14 : Flow duration curve of KEW gauging station no: 12004017, Reşitköy, Karınca Dere, Balıkesir.

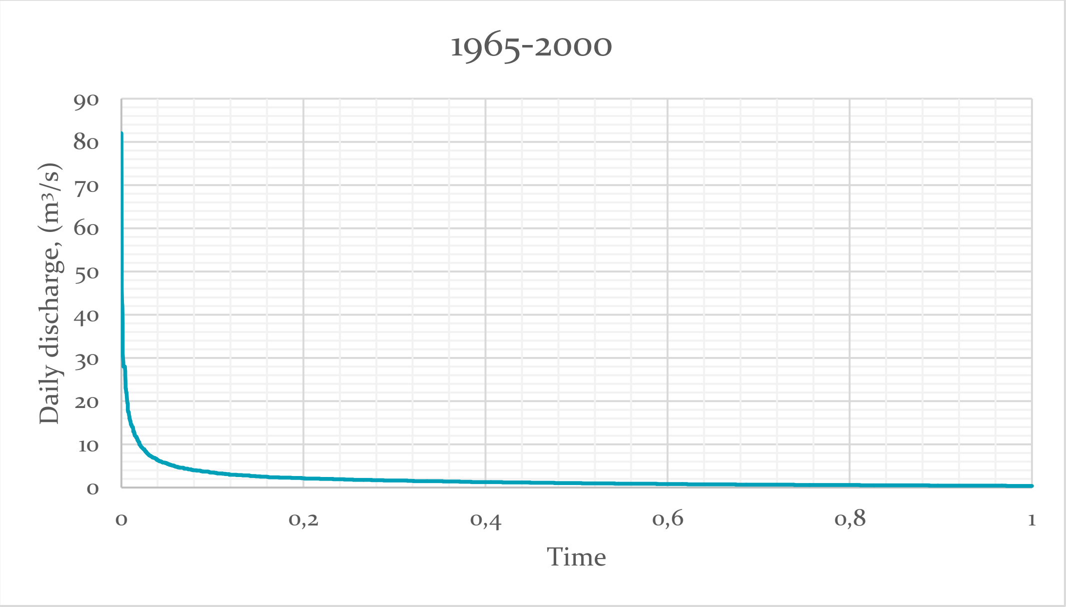

Figure B.15 : Flow duration curve of KEW gauging station no: 12004058, Kocaömerli, Karadere, İzmir.

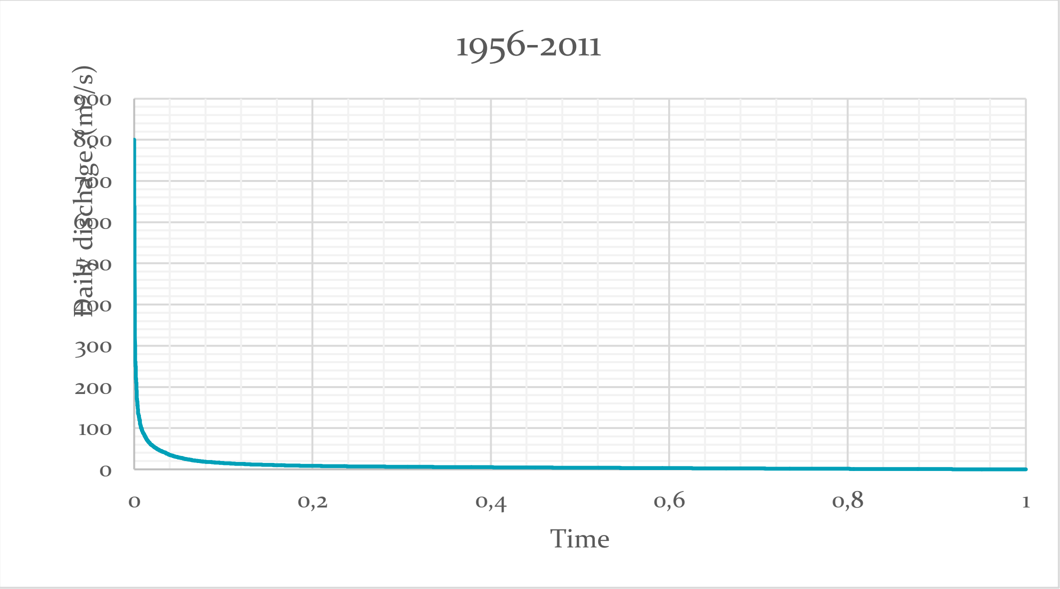

Figure B.16 : Flow duration curve of MEW gauging station no: 12001008, Lüleburgaz, Ergene Nehri, Kırklareli.

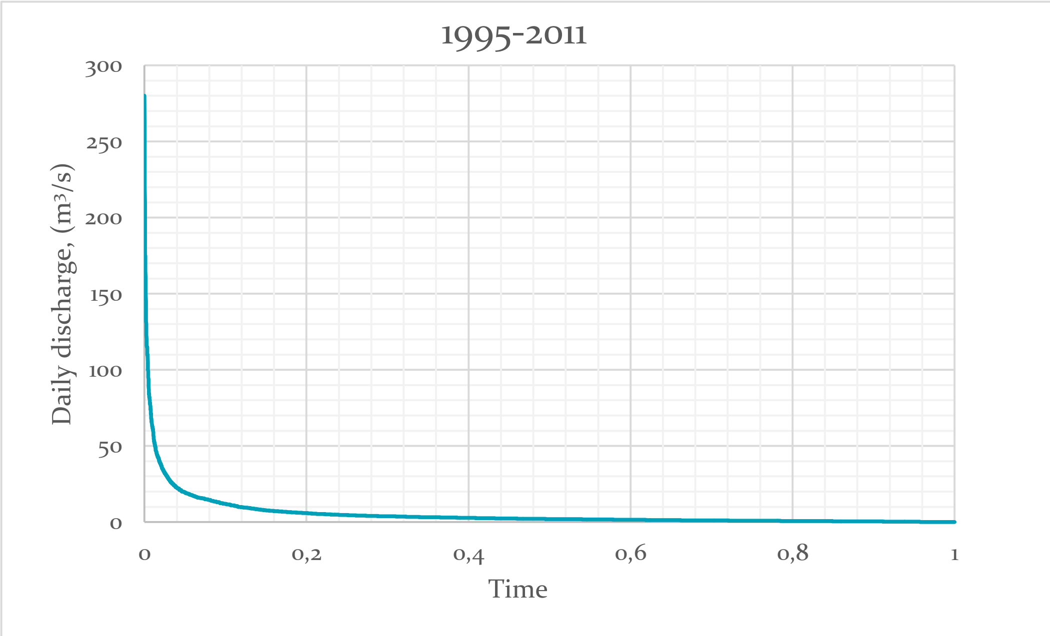

Figure B.17 : Flow duration curve of MEW gauging station no: 12001020, İnanlı, Ergene Nehri, Tekirdağ.

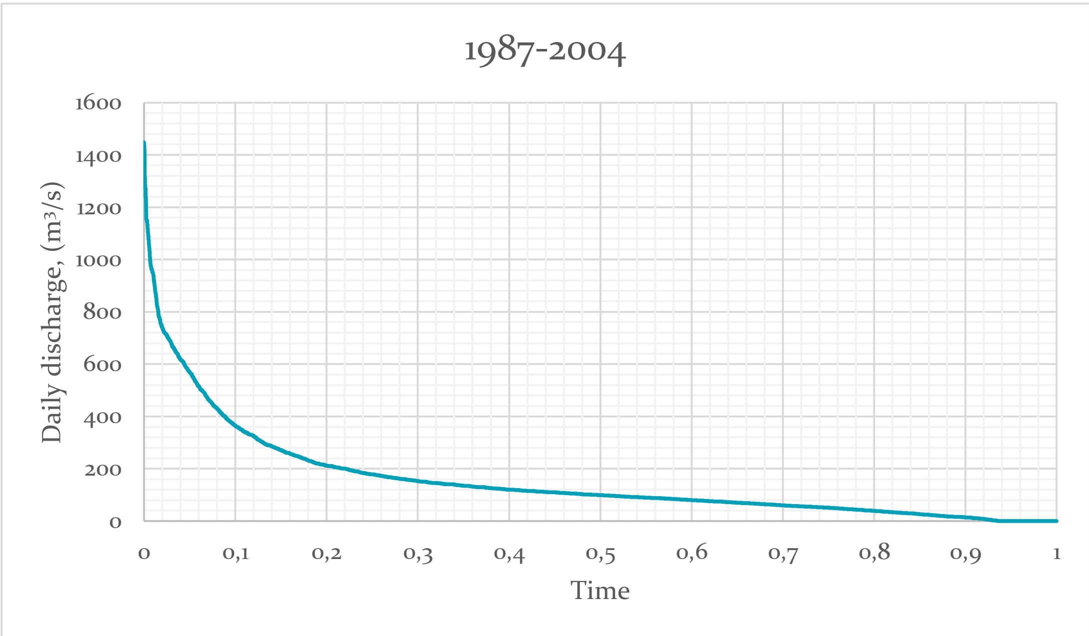

Figure B.18 : Flow duration curve of MEW gauging station no: 12001057, Ferek Köprüsü, Meriç Nehri, Edirne.

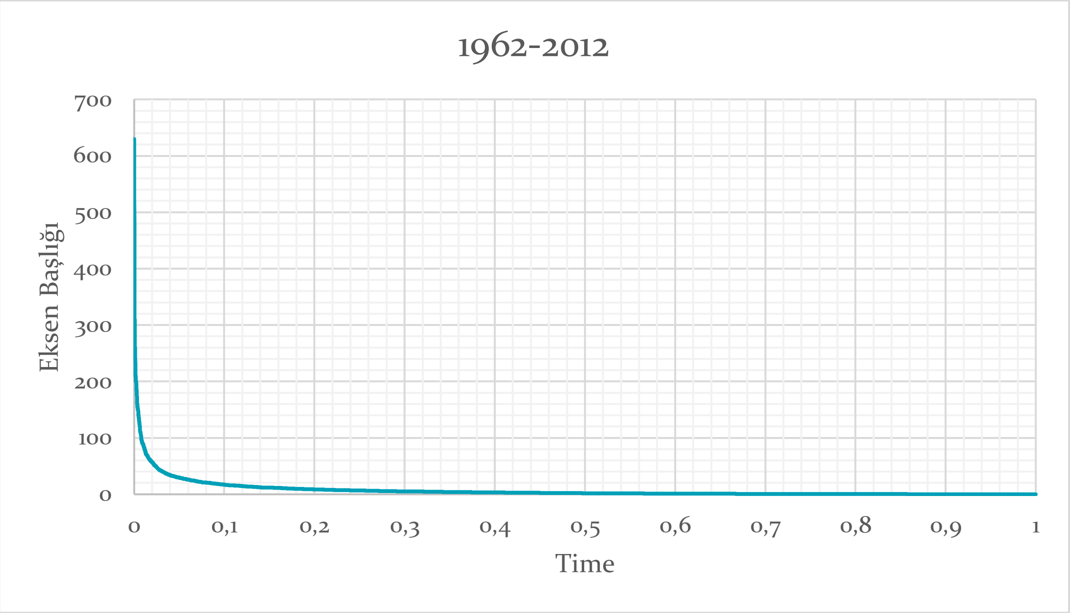

Figure B.19 : Flow duration curve of SW gauging station no: 12003008, Kahve, Madra Çayı, Balıkesir.

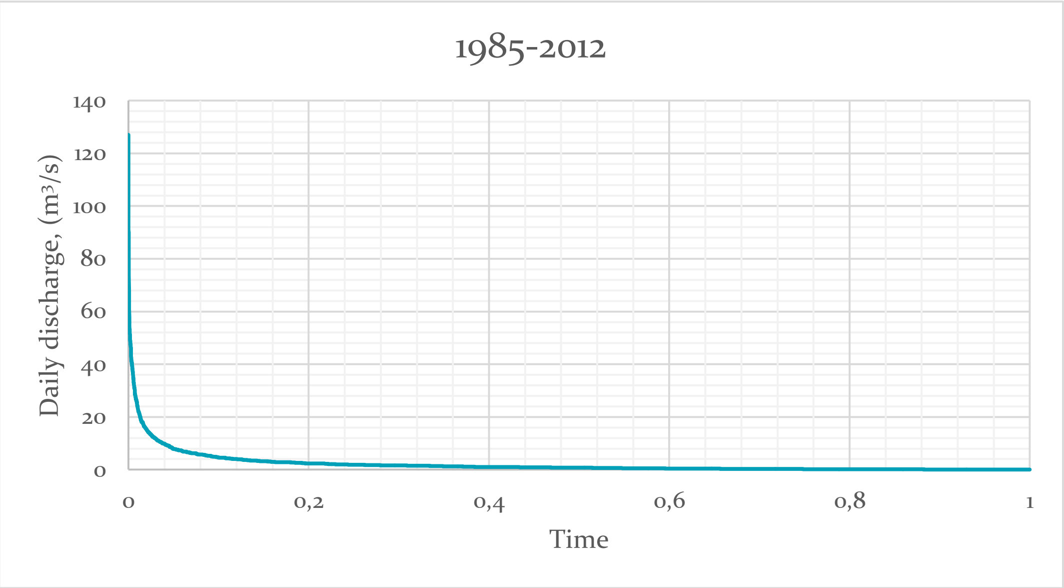

Figure B.20 : Flow duration curve of SW gauging station no: 12003081, Mürvetler, Mürvetler Deresi, Balıkesir.

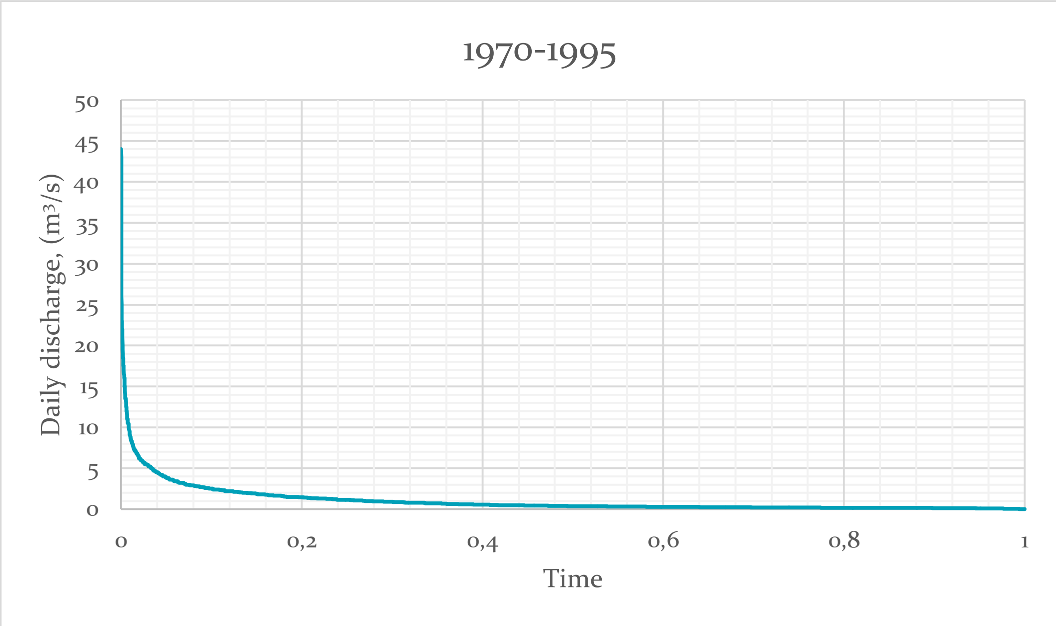

Figure B.21 : Flow duration curve of SW gauging station no: 12003129, Aşağıyağcılar, Dursunbey Çayı, Balıkesir.

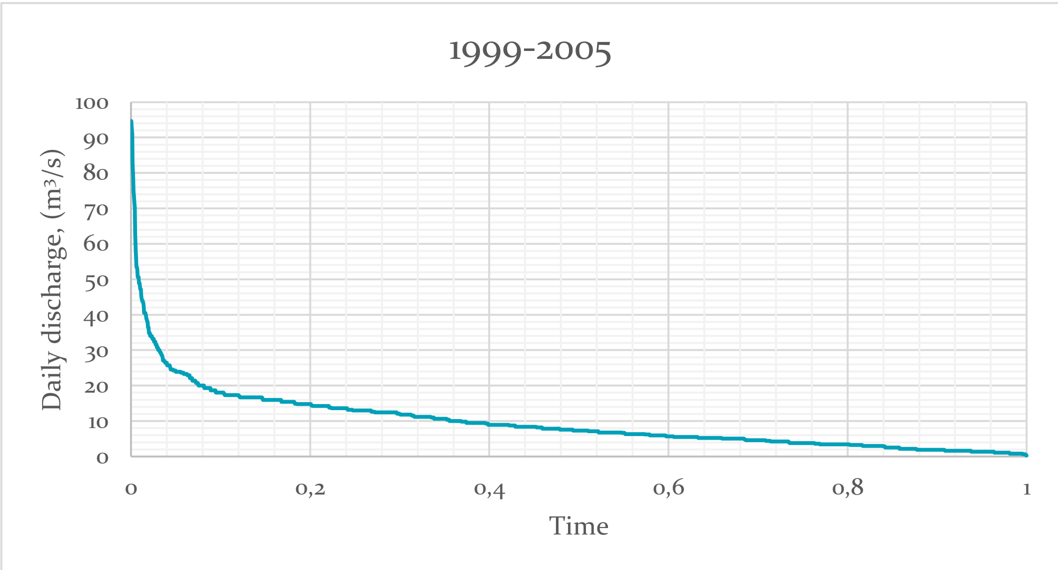

Figure B.22 : Flow duration curve of SW gauging station no: 12003128, (weakly regulated), Kadıköy Köprüsü, Simav Çayı, Balıkesir.

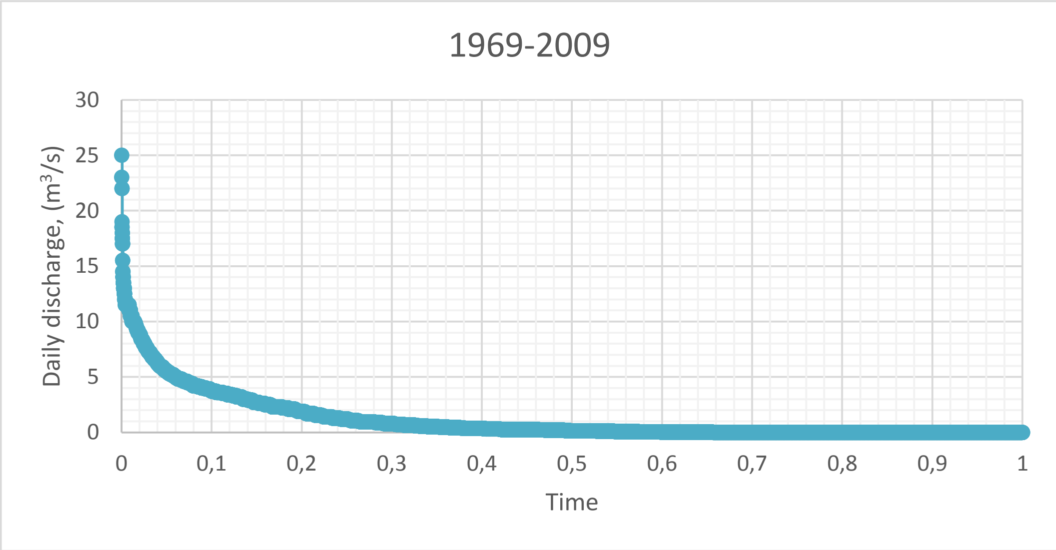

Figure B.23: Flow duration curve of GW gauging station no: 12005021, Çaltılı, Tabak Dere, Manisa.

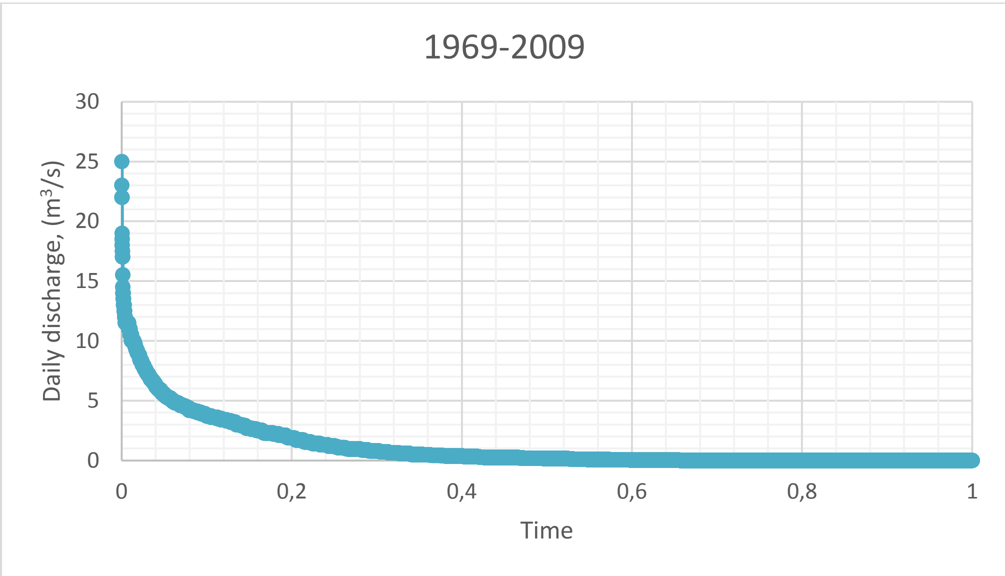

Figure B.24: Flow duration curve of BAW gauging station no: 12008061, Mümür, Mümür Deresi, Antalya.

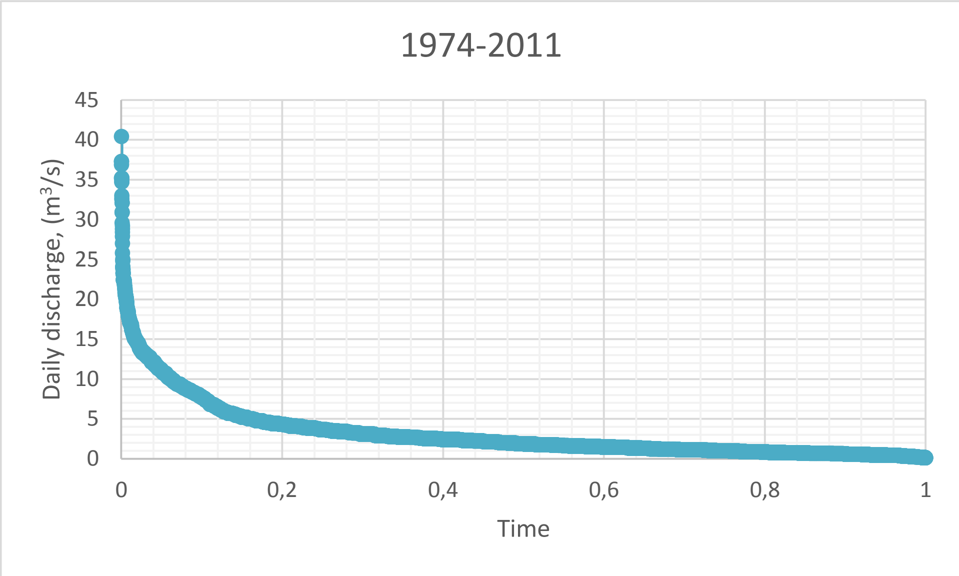

Figure B.25: Flow duration curve of BAW gauging station no: 32008008, Çatallar, Başgöz Çayı.

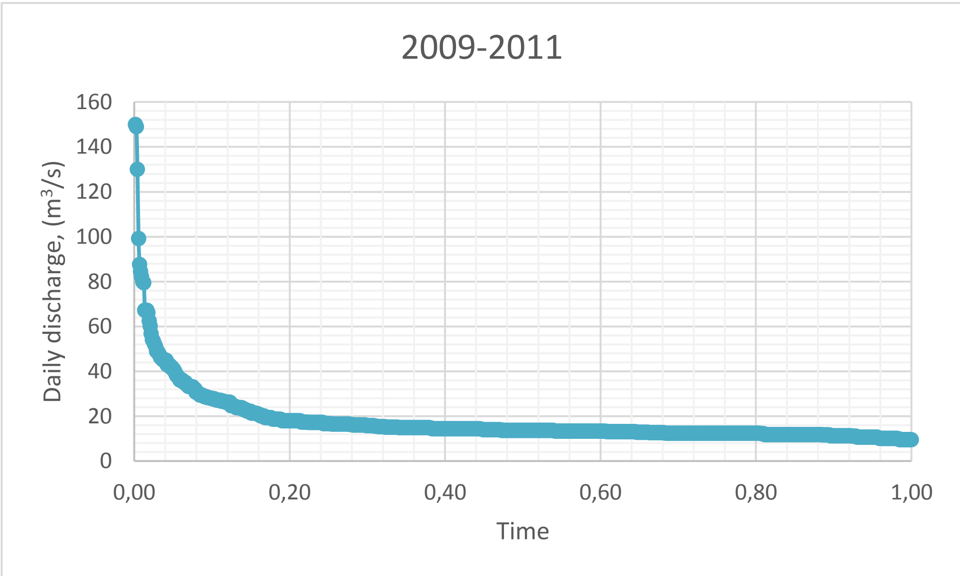

Figure B.26: Flow duration curve of BAW gauging station no: 32008018, Kayadibi, Karaçay.

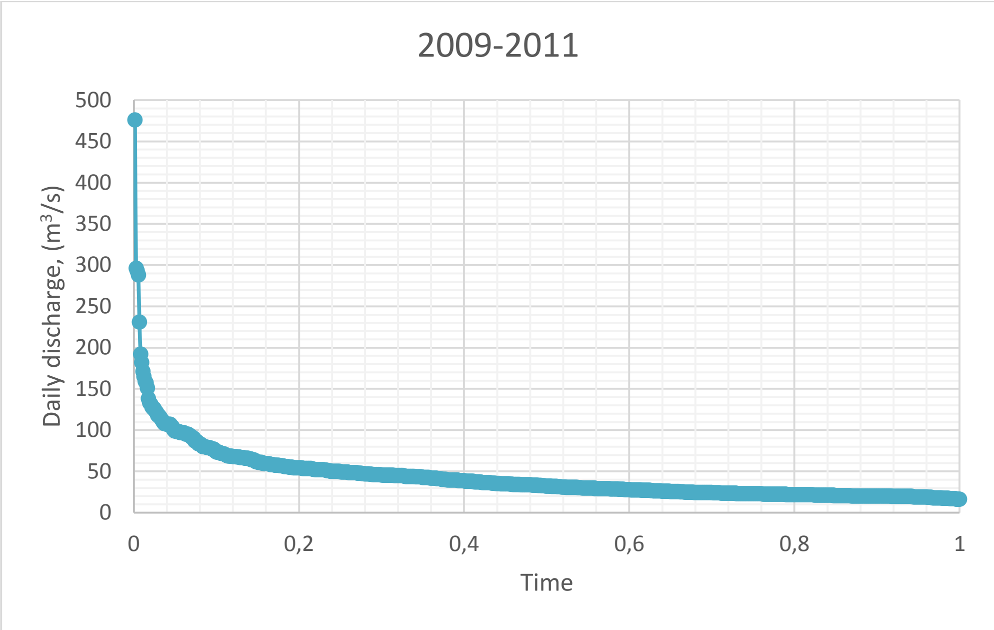

Figure B.27: Flow duration curve of BAW gauging station no: 32008015, Kınık Eşen Çayı.

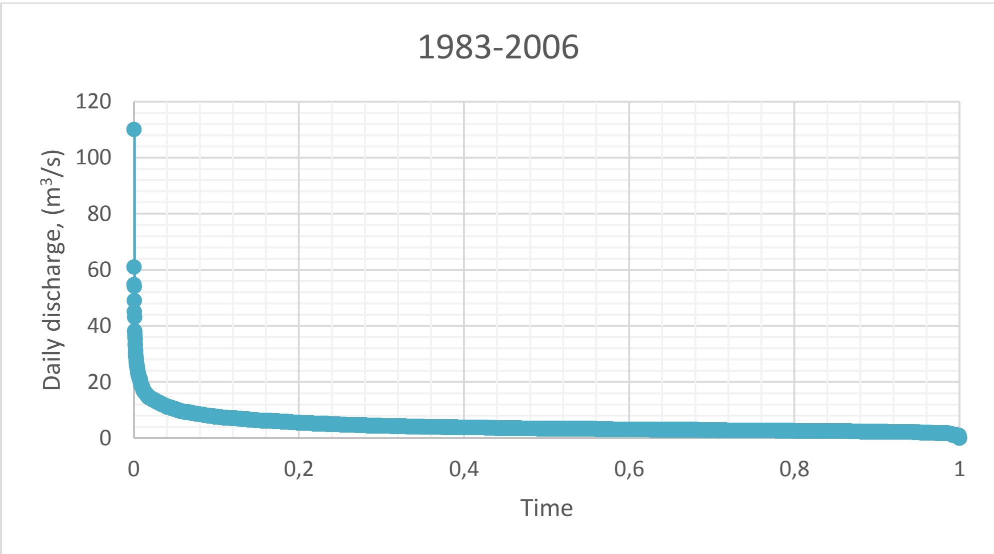

Figure B.28: Flow duration curve of BAW gauging station no: 12008089, Yanıklar, Kargı Çayı.

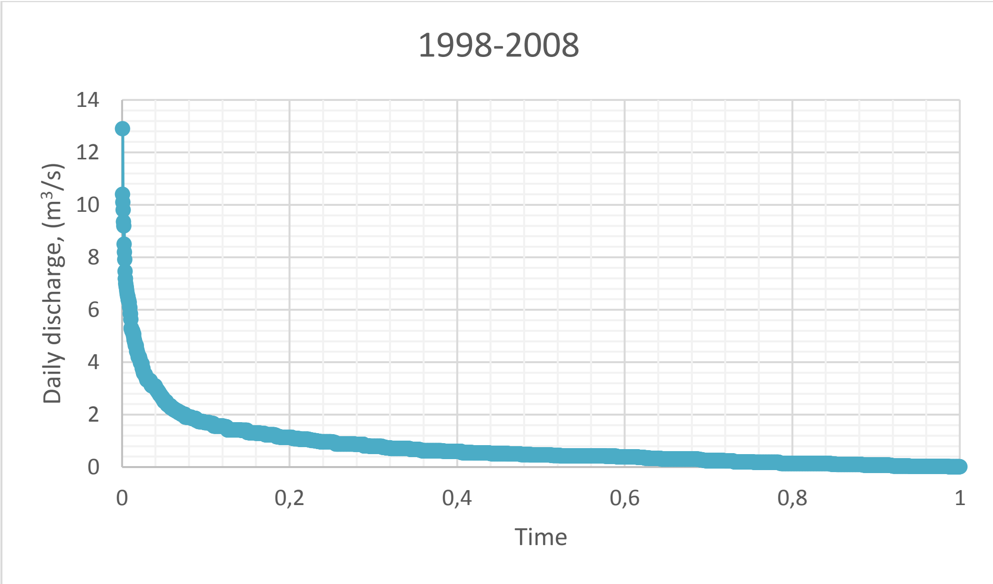

Figure B.29: Flow duration curve of BAW gauging station no: 12008140, Köyceğiz, Kargıcak Deresi.

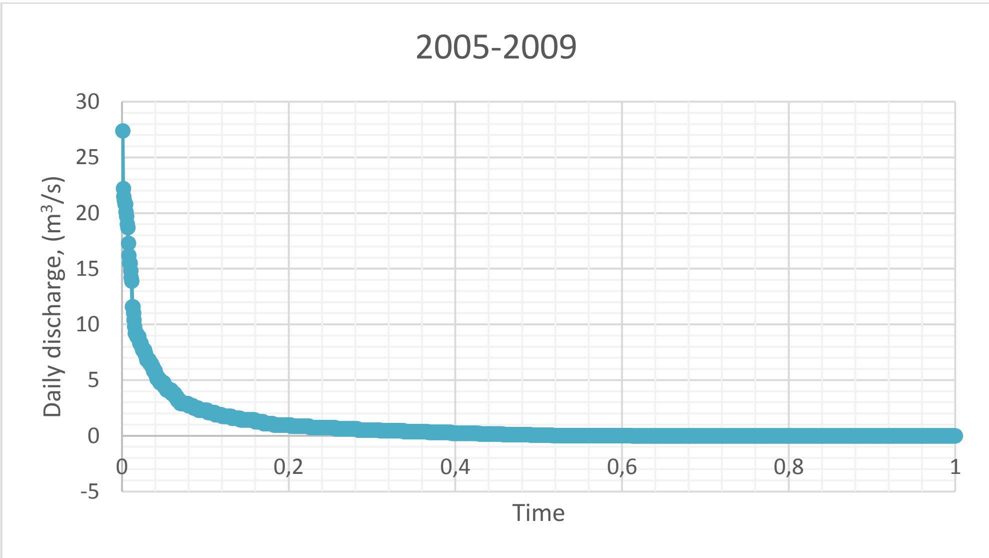

Figure B.30: Flow duration curve of BAW gauging station no: 12008143, Ören Milas, Kocaçay.

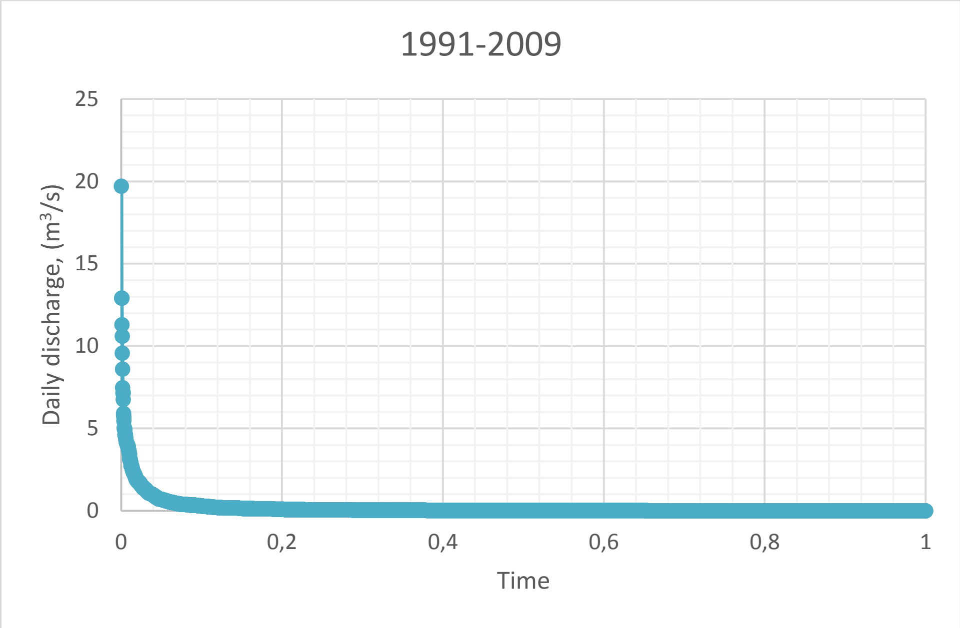

Figure B.31: Flow duration curve of BAW gauging station no: 12008121, Karaova, Batış Deresi,

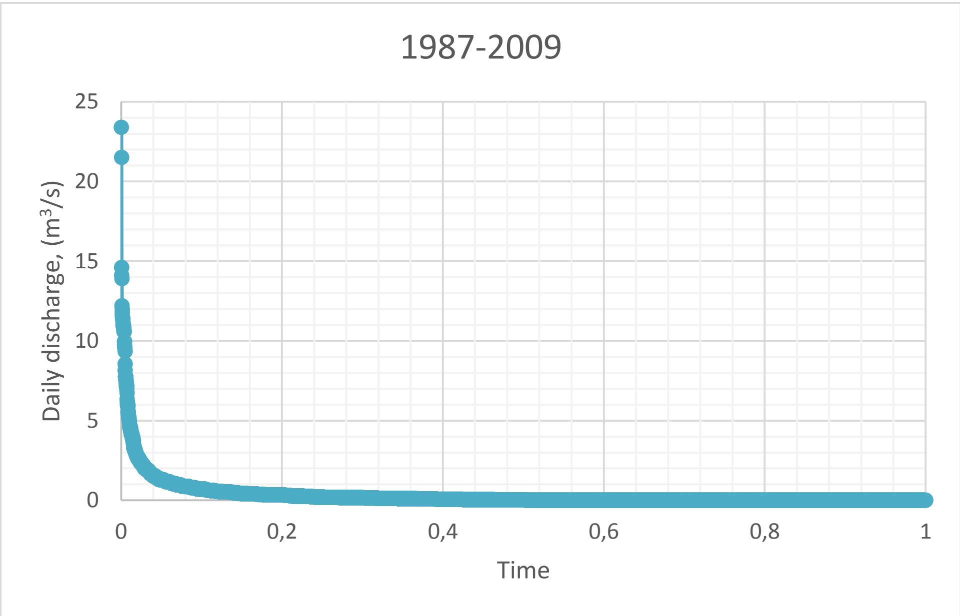

Figure B.32: Flow duration curve of BAW gauging station no: 12008097, Derince, Derince Deresi

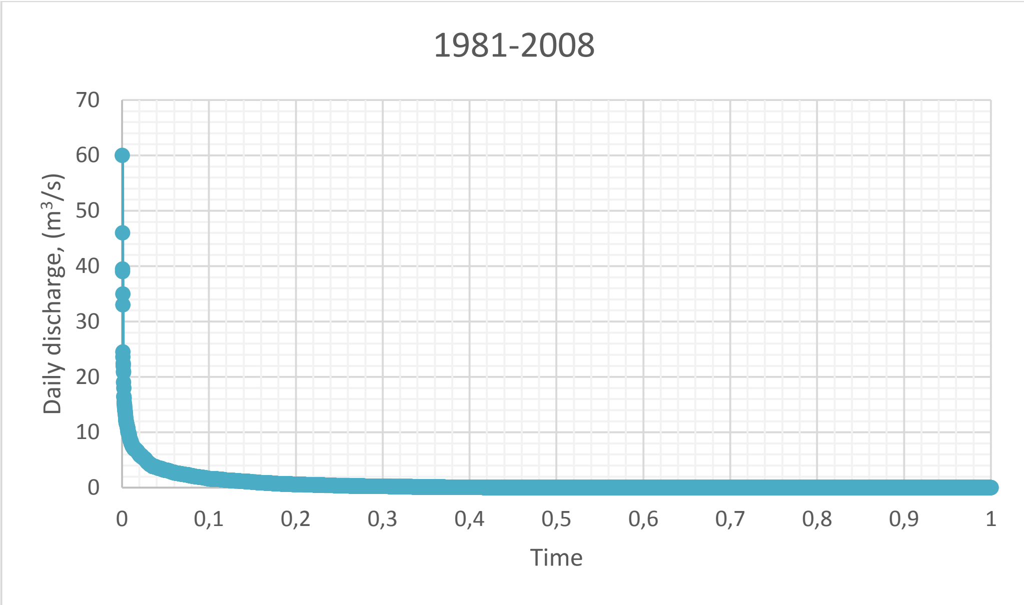

Figure B.33: Flow duration curve of BAW gauging station no: 12008087, Karadam, Değirmen Deresi,

APPENDIX C: Top 10 Maximum Mean Annual Discharges of Six River Basin SGS

Table C.1 Top Ten Maximum Mean Annual Discharges (m^3/s) of the Record Period of BMW 12007108

1996	1997	1998	1999	2000	2001	2002	2003	2004
15,2	23,6	7,11	13,6	11	22,5	10,8	8,98	28,1
13,2	13,8	5,48	12	7,79	18,5	8,47	7,11	12,2
7,45	8,47	3,85	10,2	7,62	11	5,08	5,2	9,15
6,18	6,04	3,63	7,96	5,76	10	5,08	3,46	9,15
3,85	4,93	3,52	6,46	4,8	8,81	4,12	3,32	8,98
3,63	3,19	3,41	5,76	3,3	8,47	4	1,83	5,34
2,86	2,97	3,41	5,76	2,66	8,47	3,91	1,67	4,36
2,66	2,86	2,97	4,53	2,37	8,3	3,55	0,874	3,73
2,53	2,75	2,37	4,26	2	6,77	3,37	0,648	3,19
2,37	2,75	1,36	3,99	1,42	6,32	2,82	0,544	3,01

Table C.2 Top Ten Maximum Mean Annual Discharges (m^3/s) of the Record Period of BMW 12007120

2005	2006	2007	2008	2009
2,75	1,03	1,23	0,265	3,61
2,75	1,03	1,23	0,172	3,61
2,7	1,03	1,23	0,172	3,61
2,6	1,01	1,23	0,172	3,56
2,5	1,01	1,23	0,172	3,56
2,4	1,01	1,23	0,172	3,56
2,35	1,01	1,23	0,172	3,56
2,35	1,01	1,23	0,172	3,5
2,35	1,01	1,23	0,159	3,5
2,35	0,962	1,23	0,159	3,5

Table C.3 Top Ten Maximum Mean Annual Discharges (m^3/s) of the Record Period of BMW 12007103

1993	1994	1996	1997	1998	1999	2000	2001
15	22	57,7	28,1	24,6	73	55,2	19,4
11,8	18	53,4	19,2	20,2	38,5	40	8,8
11,8	16,8	17,4	18,5	14,8	31,9	23,8	8,18
8,5	11,8	10	17,8	13,7	29,5	21,5	7,45
2,24	10,3	9,56	16	11,7	29,1	21,3	4,17
1,7	10	8,6	11,9	11,6	28,4	18,8	3,96
1,14	9,25	6,06	11,9	11	23,8	17,8	3,96
0,74	9,25	5,72	11,7	10,2	23,8	16,4	3,5
0,48	9	3,86	11,3	9,56	23	15,7	2,06
0,28	7,5	3,3	10,5	9,14	18,8	15,1	1,91

Table C.4 Top Ten Maximum Mean Annual Discharges (m^3/s) of the Record Period of BMW 12007062

1969	1970	1971	1972	1973	1974	1975	2000	2001	2002	2003
620	610	530	370	510	510	580	235	114	125,5	278,5
610	580	490	310	490	490	530	232	93,2	117	264,5
610	580	480	230	440	390	420	195	56,2	112,5	259,5
590	560	470	220	400	390	310	187	47,4	106,75	256
590	550	460	200	310	360	300	162	44	103,75	251
570	550	440	195	290	350	290	138	43,6	93,6	247,5
550	520	420	180	290	340	290	117	43,6	91,8	244
550	520	380	180	250	340	260	110	42,7	90	244
550	500	360	155	230	300	260	109	42,7	81	240,5
530	480	360	155	210	290	250	93,2	42,3	75,3	239,5

Table C.5 Top Ten Maximum Mean Annual Discharges (m^3/s) of the Record Period of BMW 12007081

1996	1997	1998	1999	2006
33,3	32,3	27,3	43,3	61,3
33,1	31,7	27	39,3	53,7
32,3	31,7	26,4	35,3	47,5
32,3	31,5	26,4	34,7	47,5
32,1	31,3	26,1	33,9	47,1
31,9	30,9	25,6	33,7	46,7
31,7	30,3	25,1	33,7	45,1
31,7	30,3	24,9	33,5	44,7
31,1	29,9	24,6	32,7	44,7
30,9	29,5	24,6	32,7	43,9

Table C.6 Top Ten Maximum Mean Annual Discharges (m^3/s) of the Record Period of BMW 12005059

1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1995
55	13,5	46	35	34	41	22	53	35	26	26	31	32	38	16,4	13,3
55	12,5	33	30	34	36	21	28	34	26	19	21	26	19,3	14,6	13,2
55	12,5	30	28	30	33	19	24	32	26	16,5	21	25	16,8	13,5	12,6
51	12,5	30	27	27	32	19	24	27	25	16,5	18	21,3	16,4	12,9	12,4
26	12,5	27	27	26	28	19	24	27	24	16	18	21	15,4	12,7	11,8
19,5	12,5	27	27	26	28	19	23	27	24	15,5	17	21	15,2	12,7	11,4
19,5	12	27	27	25	28	18,5	21	26	22	15,5	16,5	19,5	14,4	12,7	11
16	12	26	26	25	27	18,5	21	26	21	15	16	19,5	14,1	12,5	10,9
15	12	26	26	25	27	18,5	20	26	21	15	16	18,8	14,1	12,5	10,5
14,5	12	26	25	25	27	18,5	20	25	20	15	16	18,5	14,1	12,3	10,5

Table C.7 Top Ten Maximum Mean Annual Discharges (m^3/s) of the Record Period of BMW 12007010

1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
3,8	5,7	4,2	6,7	4,7	6,4	6,7	5,4	7,4	11	6,6	4,9	4,1	3
3,3	4,1	4,1	6,5	4,1	5,6	6,6	5,3	7,2	7,9	6,5	4,8	4	2,9
3,2	3,5	4	6,5	4,1	5,6	6,5	5,2	7	7,7	6,4	4,8	4	2,9
3,2	3,5	3,9	6,5	4	5,5	6,4	5,2	7	7,7	6,4	4,8	3,9	2,9
3,2	3,4	3,9	6,5	4	5,4	6,4	5,2	6,8	7,7	6,4	4,8	3,9	2,7
3,2	3,4	3,9	6,3	4	5,4	6,4	5,2	6,8	7,6	6,4	4,8	3,9	2,7
3,2	3,3	3,8	6,3	4	5,4	6,1	5,2	6,8	7,5	6,4	4,8	3,9	2,6
3,2	3,2	3,7	6,2	4	5,4	6,1	5,2	6,7	7,5	6,4	4,8	3,8	2,6
3,2	3,1	3,7	6,1	3,9	5,4	6,1	5,2	6,4	7,5	6,4	4,8	3,8	2,6
3,2	3,1	3,6	6,1	3,9	5,4	6,1	5,2	6,3	7,5	6,3	4,8	3,8	2,6

1975	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
2,5	3,1	3,1	4,2	5	4,1	3,1	2,94	4,7	4,8	3,73	2,94	4,8
2,4	3,1	3,02	4,2	5	3,91	3,02	2,94	4,7	4,8	3,73	2,86	4,8
2,3	3,1	2,94	4,2	5	3,64	3,02	2,94	4,7	4,7	3,64	2,86	4,8
2,3	3,1	2,94	4,2	5	3,55	3,02	2,94	4,6	4,7	3,64	2,86	4,8
2,3	3,1	2,94	4,2	4,9	3,55	2,94	2,94	4,6	4,7	3,64	2,78	4,7
2,3	3,02	2,78	4,1	4,8	3,46	2,86	2,94	4,6	4,7	3,55	2,78	4,6
2,3	3,02	2,78	4,1	4,8	3,46	2,86	2,86	4,5	4,7	3,55	2,78	3,37
2,3	3,02	2,78	4,1	4,8	3,46	2,86	2,86	4,5	4,6	3,55	2,78	3,28
2,3	3,02	2,7	4,1	4,8	3,46	2,78	2,86	4,4	4,6	3,55	2,78	3,1
2,3	3,02	2,7	4,1	4,7	3,46	2,78	2,86	4,4	4,6	3,55	2,78	3,1

Table C.8 Top Ten Maximum Mean Annual Discharges (m^3/s) of the Record Period of BMW 12007026

1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	2008	2009
2	4,1	4,2	3,7	4,2	3,2	2,9	3,9	2,8	1,35	0,54	1,53	2,65	1,5	1,7	2,7	0,912	3,78
1,7	4	3,7	3,4	4,1	3,2	2,8	3,6	2,8	1,35	0,54	1,53	2,65	1,43	1,65	2,7	0,864	3,78
1,45	4	2,9	2,9	4,1	3,2	2,8	3,3	2,8	1,3	0,54	1,5	2,6	1,3	1,55	2,7	0,768	3,7
1,15	3,9	2,9	2,9	4	3,2	2,8	3,2	2,8	1,3	0,54	1,43	2,6	1,25	1,55	2,7	0,768	3,7
1,05	3,9	2,8	2,9	3,9	3,2	2,7	3,2	2,7	1,3	0,54	1,43	2,55	1,15	1,53	2,7	0,768	3,7
0,96	3,9	2,8	2,9	3,9	3,1	2,7	3,2	2,7	1,25	0,54	1,43	2,55	1,1	1,5	2,7	0,768	3,7
0,95	3,9	2,8	2,8	3,9	3	2,7	3,2	2,7	1,15	0,54	1,43	2,55	1,1	1,5	2,7	0,72	3,54
0,84	3,9	2,7	2,7	3,7	3	2,7	3,2	2,7	1,15	0,54	1,43	2,55	1,1	1,5	2,7	0,72	3,54
0,69	3,8	2,7	2,7	3,7	2,9	2,6	3,2	2,7	1,15	0,54	1,43	2,55	1,05	1,5	2,4	0,72	3,54
0,31	3,7	2,7	2,7	3,7	2,9	2,6	3,2	2,7	1,15	0,54	1,43	2,55	1,05	1,5	2,4	0,72	3,54

Table C.9 Top Ten Maximum Mean Annual Discharges (m^3/s) of the Record Period of BMW 12007003

1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
46	29	57	78	115	130	87	99	23	175	88	41	43
38	28	41	57	60	82	69	83	22	110	79	35	27
29	27	40	48	60	73	61	81	22	80	77	35	24
25	25	25	44	58	51	60	72	22	75	62	32	24
24	23	25	42	58	49	58	67	20	75	57	31	23
22	22	25	37	56	37	57	57	20	70	53	31	20
20	19,5	24	33	55	30	52	55	20	55	52	27	19
16,5	18	21	33	55	30	49	47	16,5	52	52	27	18
14	17,5	21	31	51	21	46	44	16	46	49	26	18
13,5	17,5	19,5	28	51	18,5	45	43	15	45	47	25	17,5

1972	1973	1974	1975	1996	1997	1998	1999	2000	2003	2006	2007	2008
19,5	32	43	24	28	14	30	83	28,5	13,1	13,4	18,2	16,7
16	29	26	13,5	20,6	8,44	29,5	77	28	12,2	12,2	16,7	9,72
15,5	29	20	12,5	16,7	7,28	29	62,4	23,4	11	10,7	13,1	6,5
14,5	27	18,5	10	16,1	7,02	28	46	20,2	10,4	7,02	12,8	6,5
14	20	17,5	10	15,2	6,76	27	40	18,6	10	6,76	7,02	4,98
11,5	18	14,5	9	13,4	6,76	27	36,5	18,2	9,08	6,5	6,24	4,54
9,6	17	14	7,3	13,4	6,5	26	31,5	17	9,08	5,72	5,2	4,32
9,3	15,5	13,5	7	13,4	6,5	25,5	29	16,4	8,44	5,2	4,54	4,1
9,3	14,5	13,5	6,7	13,1	4,54	24,6	28	14,6	7,54	4,76	4,32	3,06
9,3	12,5	12,5	6,4	12,5	3,06	24,2	26,5	14	7,28	4,32	3,84	2,62

Table C.10 Top Ten Maximum Mean Annual Discharges (m^3/s) of the Record Period of BMW 12007032

1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1996	1997	1998
200	105	170	240	230	160	230	220	210	150	120	195	190	81	38,2	56,6	44,2
200	110	170	240	230	160	230	220	210	150	120	195	190	81	38,2	56,6	44,2
180	110	145	240	230	150	230	220	200	140	105	175	185	80	37,8	54,4	42,9
180	100	145	230	230	150	230	220	200	140	105	175	185	80	37,8	54,4	42,9
170	92	130	230	230	140	230	210	195	135	99	125	97	79	37,5	37,8	42,6
170	85	130	230	230	140	230	210	195	135	99	125	97	79	37,5	37,8	42,6
155	84	125	230	230	140	230	195	195	125	95	91	93	73	29,9	37,8	36,7
155	83	125	230	230	140	230	195	195	125	95	91	93	73	29,9	37,8	36,7
150	87	115	230	230	140	230	185	190	125	95	90	89	67	24,2	36,7	34,9
150	110	115	220	230	140	230	185	190	125	95	90	89	67	24,2	36,7	34,9

Table C.11 Top Ten Maximum Mean Annual Discharges (m^3/s) of the Record Period of BMW 12007015

1960	1961	1962	1989	1990	1991	1992	1996	1997
26	14	13,5	3,64	6,8	3,55	3,1	4,17	5,37
15,5	11,5	10,5	3,47	3,81	2,8	1,72	3,57	4,77
11	11	10,5	3,3	3,81	1,49	1,49	2,53	4,17
9,5	11	9	3,14	3,26	1,05	1,49	2,36	3,77
7,9	10,5	8,8	3,14	3,1	1,05	1,27	2,19	3,57
5,6	9,3	8,6	2,48	2,97	1,05	1,16	2,19	3,15
5,4	8,8	7,2	1,98	2,95	1	1,05	1,69	3,15
3,7	8,8	6,2	1,54	2,7	1	1	0,674	3,15
3,6	8,8	6,2	1,32	2,64	0,9	1	0,559	3,15
3,6	8,4	4,8	1,21	2,64	0,9	0,9	0,444	2,95
2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
0,63	2,74	7,97	5,57	6,08	14,9	6,8	4,7	9,28
0,63	2,74	7,37	5,37	2,96	9,17	6,44	3,8	9,28
0,63	1,38	6,97	5,17	2,96	8,24	6,08	3,8	9,28
0,63	0,63	6,77	5,17	2,45	7,7	5,72	3,35	9,28
0,63	0,526	5,57	4,77	2,32	7,34	5	2,6	9,28
0,63	0,526	4,57	4,685	1,12	6,62	5	1,88	9,1
0,63	0,526	4,57	4,17	0,952	6,44	5	1,19	8,56
0,526	0,526	4,57	4,17	0,49	5,9	4,4	1,13	8,56
0,526	0,444	4,37	3,77	0,49	5,54	4,1	0,956	8,38
0,37	0,444	4,37	3,77	0,17	5,54	2,45	0,94	7,48

APPENDIX D: w/d versus Channel Forming Discharges

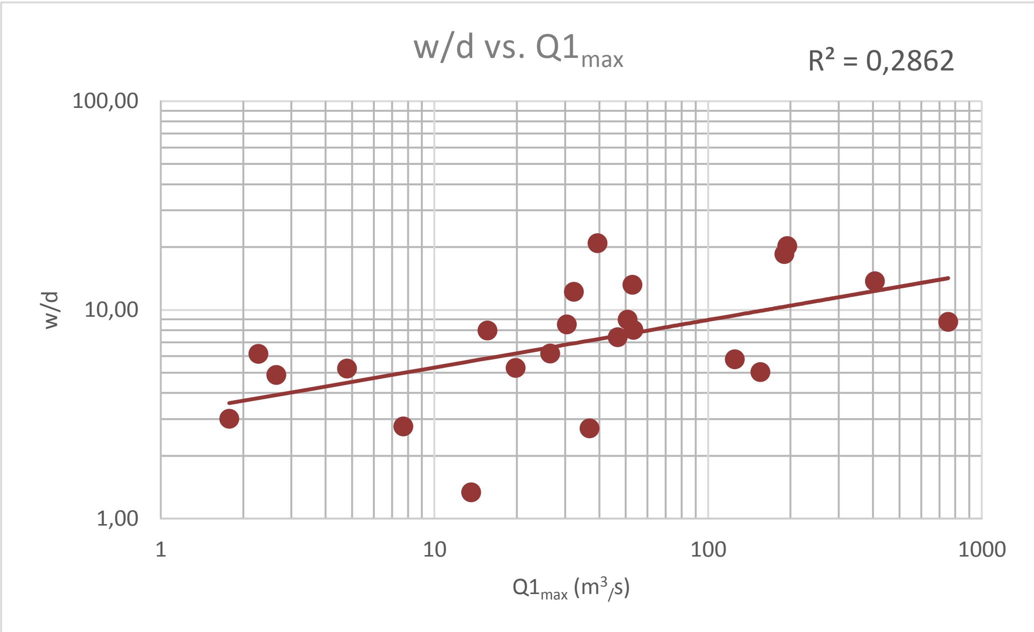

Figure D.1 Relationship between $Q1_{max}$ and Western Turkey River Basins cross-section geometry.

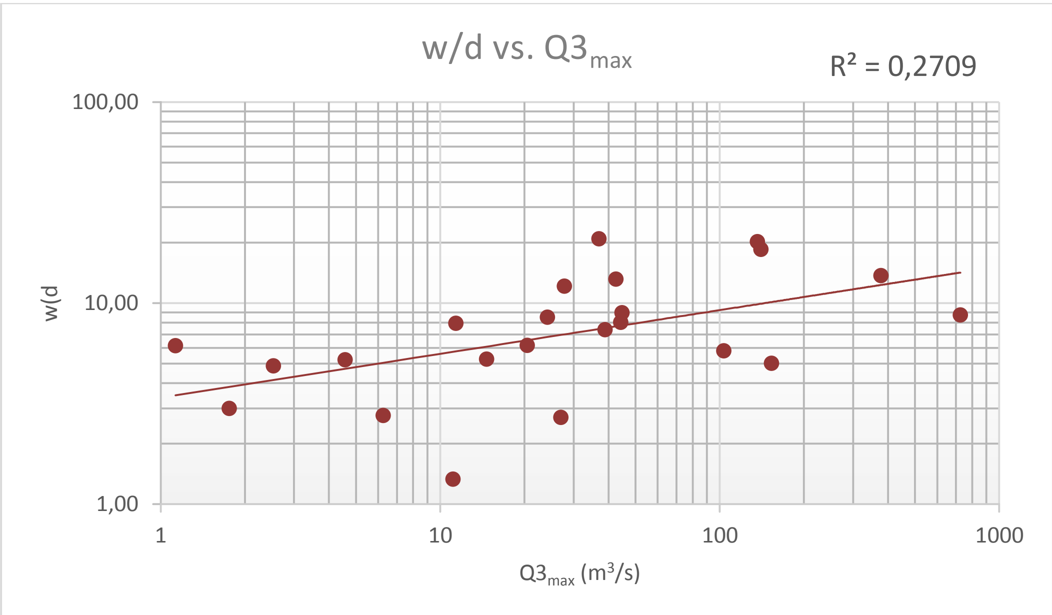

Figure D.2 Relationship between $Q3_{max}$ and Western Turkey River Basins cross-section geometry.

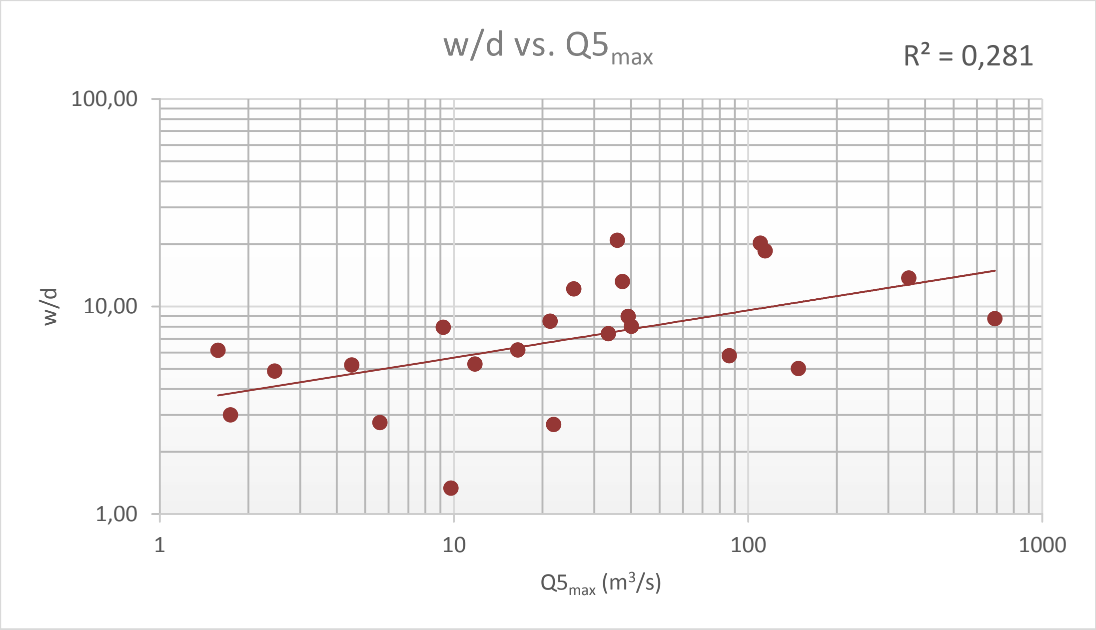

Figure D.3 Relationship between $Q5_{max}$ and Western Turkey River Basins cross-section geometry.

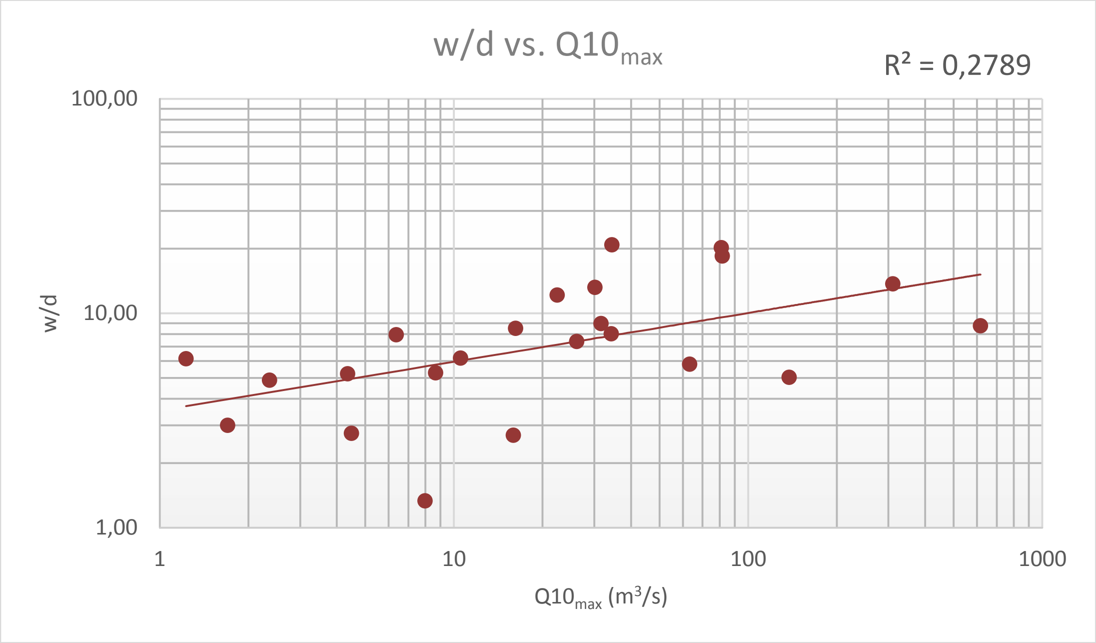

Figure D.4 Relationship between $Q10_{max}$ and Western Turkey River Basins cross-section geometry.

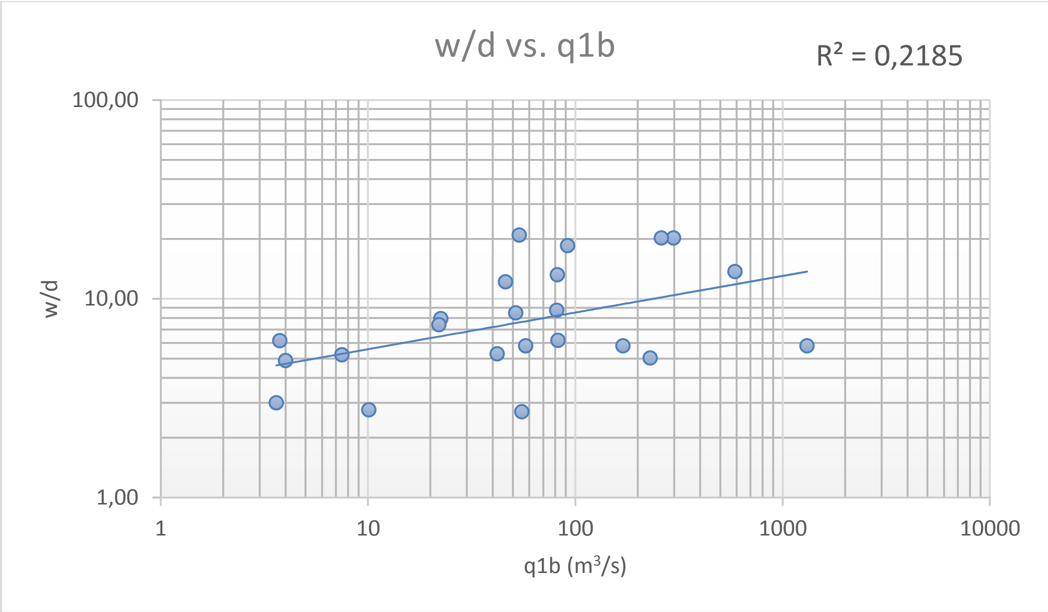

Figure D.5 Relationship between q1b and Western Turkey River Basins cross-section geometry.

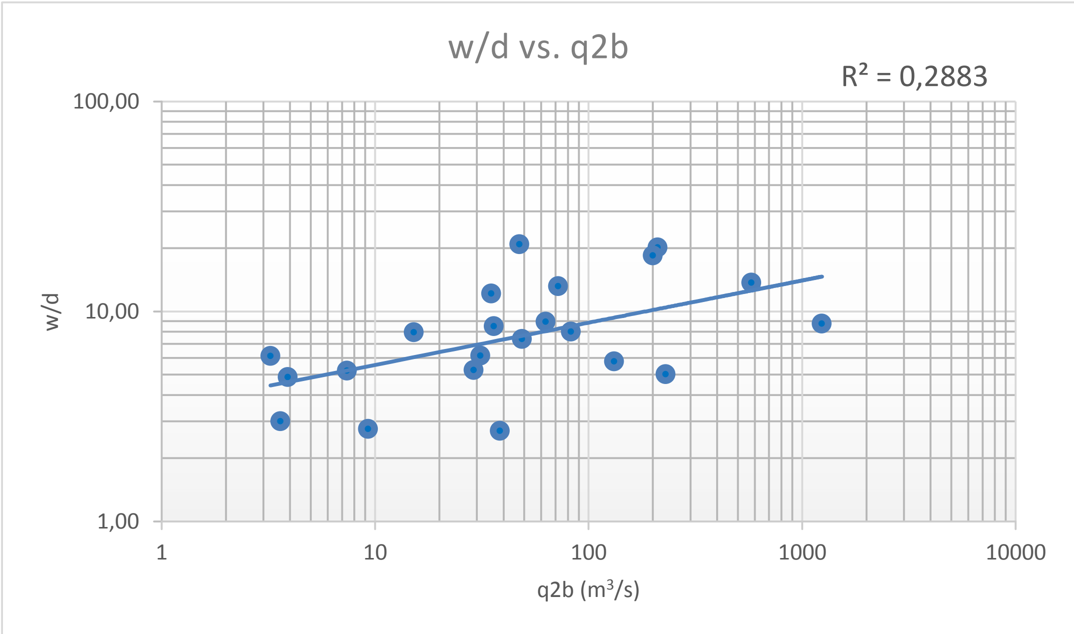

Figure D.6 Relationship between q2b and Western Turkey River Basins cross-section geometry.

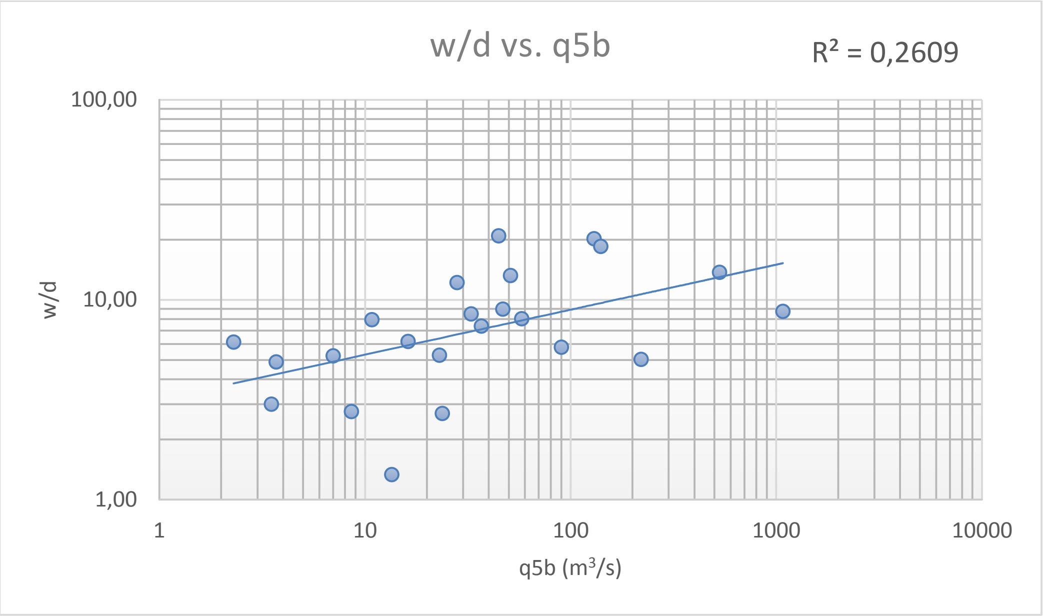

Figure D.7 Relationship between q5b and Western Turkey River Basins cross-section geometry.

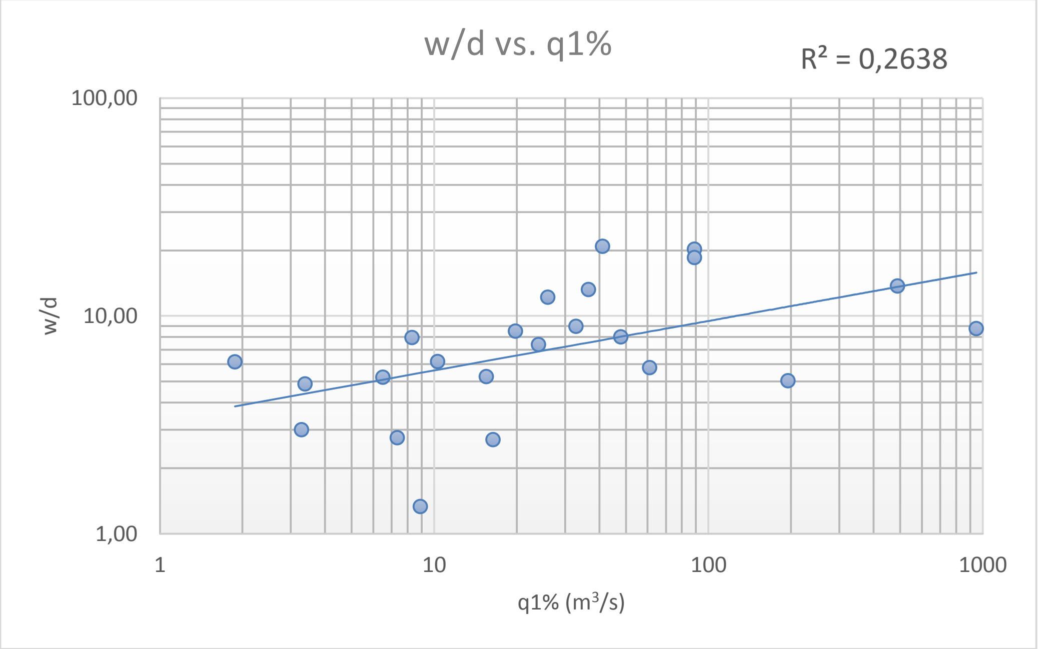

Figure D.8 Relationship between q1% and Western Turkey River Basins cross-section geometry.

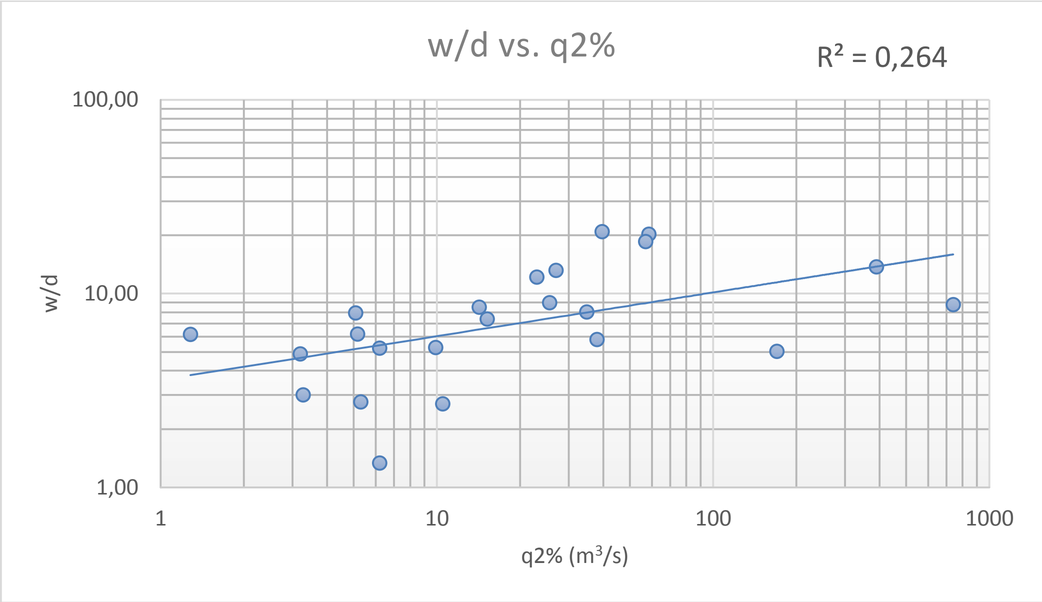

Figure D.9 Relationship between q2% and Western Turkey River Basins cross-section geometry.

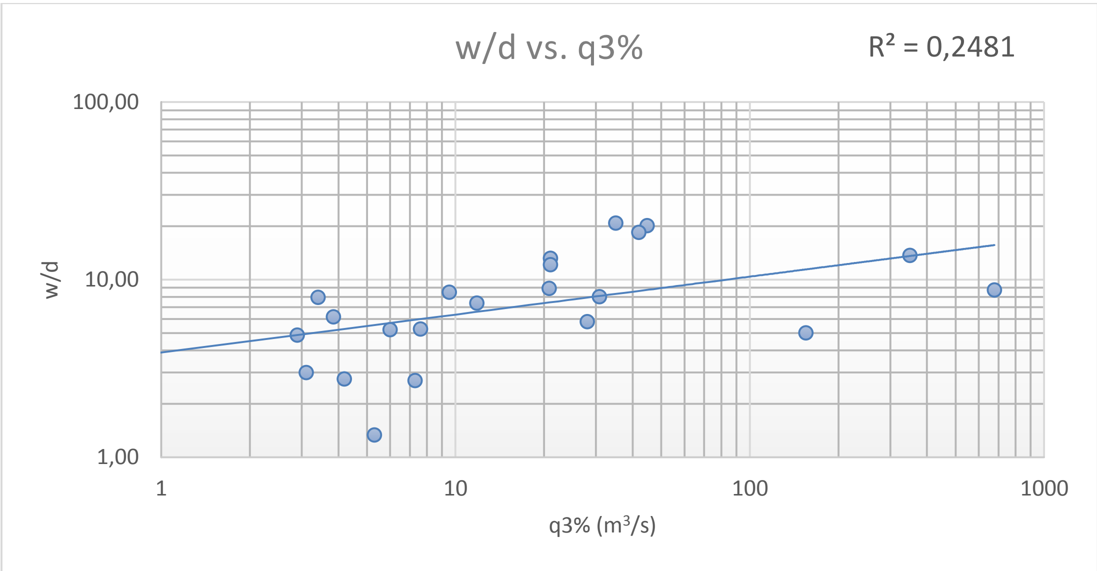

Figure D.10 Relationship between q3% and Western Turkey River Basins cross-section geometry.

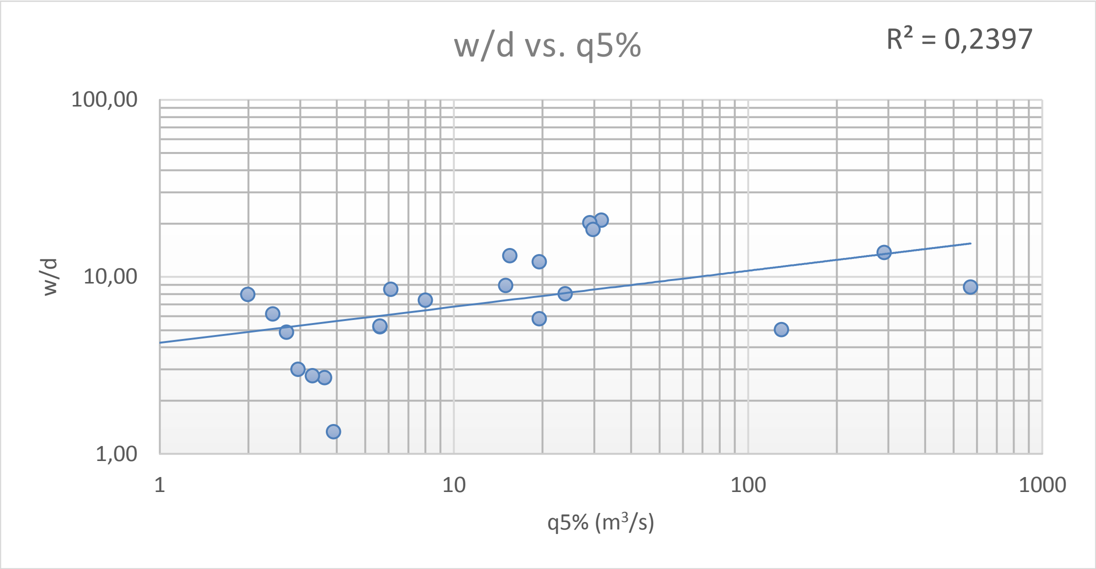

Figure D.11 Relationship between q5% and Western Turkey River Basins cross-section geometry.

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PUBLICATIONS/PRESENTATIONS ON THE THESIS

I. 5th International Conference on Meteorology and Climatology of the Mediterranean
   - *The Quantification of The Relationship Between Hydraulic Geometry of Rivers in Western Anatolia and The Formative Discharges (Proceeding)*

II. 9th World Congress of EWRA "Water Resources Management in a Changing World: Challenges and Opportunities"
   - *Investigating Hydraulic Geometry of Rivers in Western Turkey For Sustainable River Management (Proceeding)*