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STUDY ON DEVELOPING A METHODOLOGY FOR IDENTIFYING THE MINIMUM FLOW - APPLYING TO THE VU GIA – THU BỒN RIVER SYSTEM

SPECIALIZATION: WATER RESOURCES ENGINEERING

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ABSTRACT OF DOCTORAL THESIS

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The thesis has been completed at Vietnam Academy for Water Resources

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The thesis can be found at:

- The National Library
- The Library of Vietnam Academy for Water Resources

LIST OF PUBLICATIONS

[1] Nguyen Thi Kim Dung, Dao Kim Luu, *The drought of Red River Delta and mitigating solutions*, Vietnam Journal of Earth Sciences, ISSN: 0866 – 7187, pp. 32, vol. 32, No. 3 (2010).

[2] Nguyen Thi Kim Dung, Nguyen Van Tinh, *The results on the water balance calculation for the Vu Gia – Thu Bồn river basin*, Water Resources Science and Technology Journal, pp. 34, No. 29 (Dec/2015).

[3] Nguyen Thi Kim Dung, *Minimum flow as a tool for integrated water resources management in Vu Gia - Thu Bồn river basin*, Proceedings of the international conference on water resources security in the context of climate change in Vietnam, Hanoi, April 2017.

[4] Nguyen Thi Kim Dung, *Developing a method for determining the minimum flows following an integrated approach of hydrological, hydraulic, and ecological factors*, Water Resources Science and Technology Journal, pp. 73, No. 39 (July/2017).

[5] Nguyen Thi Kim Dung, *Some results of calculating the minimum flows for Vu Gia - Thu Bồn river system based on the integrated approach of hydrological, hydraulic, and ecological factors*, Water Resources Science and Technology Journal, pp. 18, No. 42 (Feb/2018).

PREAMBLE

1. The urgency of the thesis

Water is an essential resource for life, human health and for ecosystems, and is the most important factor in every country for socio-economic development. Significant reductions in the dry season flow and the groundwater level coupled with an increase in the sea-level rise are leading to the increasing extension of saltwater intrusion, which can greatly affect the supply of water for domestic use and for production activities. All of these problems have been making the challenges of water resources to become more complex and unpredictable, and the issues of water resources management in general and river basin management, in particular, poses many new challenges that need to be addressed.

From 2008, the Government has promulgated a number of legal documents instituting procedures for the maintenance of mimimum flows (MF) in the river channel downstream of reservoirs. Since then, there have been a number of studies on the MF, ranging from the studies on applying the rapid assessment methods based on hydrological and hydraulic calculations to the studies that tend to apply the integrated approach, or using the mathematical modeling tools. However, until now, the concepts and methods for the assessment of the MF are still being very differently understood, often not to fully mention the factors affecting the production, life, environment, and ecosystems.

Vu Gia – Thu Bồn (VG-TB) is a large river system in the Central Coast region of Vietnam with a total basin area of 10,350 km^2. In the VG-TB river basin, there are currently about 756 reservoirs and dams supplying irrigation water for about 40,000 hectares of cultivated land,

and many water resource exploitation facilities serving industrial development, aquaculture and domestic water supply. Particularly in recent years, many large hydropower projects in the basin have been newly built and put into use. The research on identifying the MF for the VG-TB river system in order to maintain the river flow, to ensure the normal development of ecosystems, and to ensure the minimum level of exploitation activities for the development of the different economic sectors is very important.

Therefore, the thesis topic ***"Study on developing a methodology for identifying the minimum flows - Applying to the Vu Gia – Thu Bồn river system"*** has great scientific and practical significance.

2. The purpose of the research

Developing a methodology to determine MF for the river system that is affected by the upstream water resource exploitation facilities and has the competition in water use.

Applying for the calculation of MF of the Vu Gia – Thu Bồn river system.

3. The objective and scope of the research

The research objective of the thesis: Research on the flow (water quantity, water quality) for any river or sections of a river that affected by the upstream water resource exploitation facilities and has the competition in water use.

The research scope of the thesis: The thesis will focus on researching the downstream of the river basin, where concentrated the most water resource exploitation activities for agriculture, industry and domestic use in the basin, which also is directly affected by the regulatory activities of upstream reservoirs. Applying research results to calculate the MF of the Vu Gia – Thu Bồn river system for segments

from Thành Mỹ to Cửa Hàn (of Vu Gia river), and from Nông Sơn to Cửa Đại (of Thu Bồn river).

4. The research methodology

The thesis uses some scientific research methods such as: (1) inheritance historical method; (2) field survey method; (3) method using hydrological, hydraulic, and water quality modeling; and (4) statistical analysis method.

5. Scientific and practical significance

Scientific significance: The method for determining the minimum flow following an integrated approach of hydrological, hydraulic and ecological methods will complementarily contribute to the system of theoretical foundations using for the research and calculation activities, as well as the integrated use of water resources in an effective and substainable way.

Practical significance: Result of the research in determining the minimum flow for the VG -TB river basin is a valuable and scientific database for integrated water resources management in the river basin in response to harmonize benefits between water users and river ecological environment protection and management, that contributing to sustainable socio-economic development. In addition, this is also a practical basis for the development and replication of the minimum flow calculations for other river systems.

6. New contributions of the thesis

(1) The method of determining the minimum flow was developed for the river system based on the integrated approach of hydrological, hydraulic and ecological factors.

(2) The result of the research in determining the minimum flow was applied to the VG-TB river system, as the practical basis for

expansion and development of the minimum flow calculations for other river downstream areas.

7. The structure of the thesis:

The thesis consists of 149 pages, 50 tables, 61 graphical materials (charts, pictures, etc.) and 57 references. Besides the preamble and conclusion parts, the thesis has the following structure:

Chapter I. Overview of the minimum flows;

Chapter II. Scientific basis, content, and method of determining the minimum flows;

Chapter III. Minimum flow calculation results for Vu Gia - Thu Bồn river basin.

Chapter I. OVERVIEW OF THE MINIMUM FLOWS

1.1. Some concepts and definitions

Environmental Flow (EF) : According to the International Union for Conservation of Nature (IUCN) launched in 2003 *"An EF is the water regime required within a river, wetland or coastal estuary zone to maintain water ecosystems and their values, especially where there are competing in water uses and where flows are affected by the regulation activities"*.

The 10th International Riversymposium and International EF Conference, held in Brisbane, Australia, on 3-6 September 2007 with the participation of more than 750 delegates from 50 nations proclaimed that *"EFs describe the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems"*

MF: According to the Law No. 17/2012/QH13 on Water

Resources approved in 2012 *"Minimum flow means the flow at the lowest level necessary for maintaining a river or river section, ensuring the normal development of aquatic ecology and the minimum level for water resource exploitation and use by water users in accordance with the priorities defined in the national river basin planning"*

1.2. Overview of researching on minimum flows in the world

Until now, many methods for identifying the EF and MF have been developed and applied. Many scientists have also studied the classification of methods for identifying the EF and MF, especially including the following studies:

- The IUCN's study (Dyson et al., 2003) classified the methods based on the approach and assessment framework. Accordingly, there were 4 groups of methods for determining EF and MF: (1) Look-up tables method; (2) Desk-top analysis method; (3) Functional analysis method and (4) Habitat modeling method.

- The WB's study (King and Brown, 2003) classified the methods based on the approach with 4 groups of methods: (1) Hydrological index method; (2) Hydraulic rating method; (3) Expert panel method and (4) Holistic approach.

- The IWMI's study (Tharme, 2003) classified as 4 groups of methods: (1) Hydrological method; (2) Hydraulic rating method; (3) Habitat simulation method and (4) Holistic methodology. About 207 methods for identifying the EF were counted by Tharme's studies. The scientists also said that there is no single best method, approach or framework to determine the EF. The choice of a particular method is mainly determined by the data available, type of issue to be addressed, timing and budget.

Some methods are being widely applied in the world:

The hydrological method including: The Tennant method; the Flow Duration Curve Analysis method (FDCA); the 7Q10 index method; and the Range of Variability Approach (RVA).

The hydraulic rating method including: The wetted perimeter method; and the R2Cross method.

The habitat modeling method including: The Instream Flow Incremental Methodology (IFIM).

The holistic approach method including: The Buiding Block Methodology (BBM); and the Downstream Response to Imposed Flow Transformations (DRIFT).

1.3. Overview of researching on minimum flows in Vietnam

In our country, researches on the MF for sustainable management and development of water resources had been implemented since 2003. IUCN (2003) collaborated with the International Water Management Institute and the Hương River Management Board in order to study the application of the simplified DRIFT method for quick assessing the EF of Hương river. Nguyễn Văn Thắng (2004) applied the approach in combination of the hydrological method (Tennant method), hydraulic method (wetted perimeter method) and ecological method (area of fish habitat) to calculate the EF of Ba and Trà Khúc river basins. Trần Hồng Thái (2007) studied the scientific basis for the EF assessment using the RVA method and wetted perimeter method to calculate the EF of the river section from Hòa Bình Hydropower Plant to Trung Hà confluence. Phan Thị Anh Đào (2009) applied the approach in combination of three methods (Tennant, wetted perimeter và DRIFT methods) to assess the EF of the downstream river section in Cầu river basin. Nguyễn Văn Hạnh

(2008) researched to determine both ecological flows based on the relation among the discharge, water level and area of fish habitat, and the exploitation discharge providing agriculture, industry, aquaculture, and environmental protection for determining the EF of the Hồng (Red) - Thái Bình river system. Prof. Ngô Đình Tuấn (2008) studied to initiate the concepts and components of minimum flow including the unconsumed EF and consumed EF. Nguyễn Văn Nghĩa (2011) studied the approach in analysis the MF following three components: (1) river maintenance flow; (2) flow ensuring the normal development of the aquatic ecosystem; and (3) flow ensuring the minimum level for water resources exploitation and use of other water users. Pilot applying for the mainstream of Ba river. Nguyễn Văn Tỉnh, Nguyễn Quang Trung (2015) identified the MF for the Vu Gia - Thu Bồn river basin based on the Tennant method in combination with the mathematical modeling method in order to calculate the needed flows for the exploitation and use of water resources by water users.

Thus, besides the rapid assessment method, there is a number of studies used a combination of different methods in considering the hydrological, hydraulic and ecological factors to determine the MF but the component of flows has not been fully researched. At present, no one approach or method for identifying the MF is uniformly applied as well as is considered to be the best.

Through the overview of researches on the MF in the world and in the country, the author found that the overall integrated approach is considered as the most advanced method at present. *Therefore, the thesis selected the overall integrated approach to determine the minimum flow for the river/ river section affected by the regulatory activities of upstream water exploitation facilities. In*

particular, the thesis developed a comprehensive methodology and deeply focused on full analyzing three main factors: Hydrology, Hydraulics, and Ecology of rivers in order to determine the MF of the river system base on the integrated use of water resources in an effective and substainable way.

Chapter II: SCIENTIFIC BASIS, CONTENT AND METHOD OF DETERMINING THE MINIMUM FLOWS

2.1. The scientific basis for determining the minimum flows

The thesis uses the holistic approach from the "bottom up" starting from the determination of base flow, then adding other componential flows based on the characteristics of flow regime, aquatic ecosystems and the needed flows for the exploitation and use of that river/ river section. Following this approach, the MF consists of three main components:

Component (1): The river maintenance flow is the necessary flow to keep the river "alive", this flow should be maintained even during cases of severe water shortage or drought. Signs: Q_{DTS}, $H_{DTS.}$

Component (2): The ecological flow is the necessary flow to maintain the environmental condition of the river/ river section in order to ensure the normal development of the aquatic ecosystem. This is "the water volume needed for ecology" because the water uses for maintaining the aquatic ecosystem also contributes to maintaining the landscape and health of the river. Signs: Q_{ST}, $H_{ST.}$

Component (3): The exploitation and use flow is the necessary flow for the exploitation and use activities of water resources by water users in the rivers or downstream river sections. Signs: Q_{KTSD}, $H_{KTSD.}$

Among these components, the water volume for the exploitation

and use activities including all consumed or unconsumed water demand (including quality and quantity) on the studied rivers or river sections such as water for irrigation in agriculture; water supply for people daily lives; water for industries and services; water for livestock; water for aquaculture; water for hydropower; water for transport, tourism, and pushing salty water, etc.

Thus, the MF of the i^{th} river section is defined as follows:

$$Q_{TT}(i,t) = f(Q_{DTS}(i,t), Q_{ST}(i,t) ,Q_{KTSD}(i,t)) \quad (2\text{-}1)$$

$$H_{TT}(i,t)= f(H_{DTS}(i,t), H_{ST}(i,t), H_{KTSD}(i,t)) \quad (2\text{-}2)$$

Note that the MF will be defined including discharge, water level and maintenance time (t).

The timing period of the MF calculation is the dry season. Maintenance time can be determined by monthly, 10 days, or weekly depending on fluctuations in amplitude of river flow regime and water exploitation demand in the river basin.

The MF on the river must be defined at a specific cross-sectional area or in other words, the minimum fows is defined at each location and is calculated on the whole river or each river section. These locations are generally known as the MF control points of rivers or river sections. The MF control points of a river section or a river must represent the flow regime, the habitat of the aquatic ecosystem, the water use and exploitation activities on the selected river or river section. In addition, the selection of the MF control points should have high social characteristic, it means the positions of the MF control points must have “the consensus” to achieve the target objectives as well as to meet the actual needs of the competition living. With this above points of view, the definition of the MF control points needs to be based on scientific and social criteria.

2.2. Content and method of determining the minimum flows

2.2.1. Research content and calculation

Based on the requirement contents, and the specific criteria for calculating the MF, the process of determining and calculating the MF of the river system will be carried out according to the block diagram as follows (Figure 2.4).

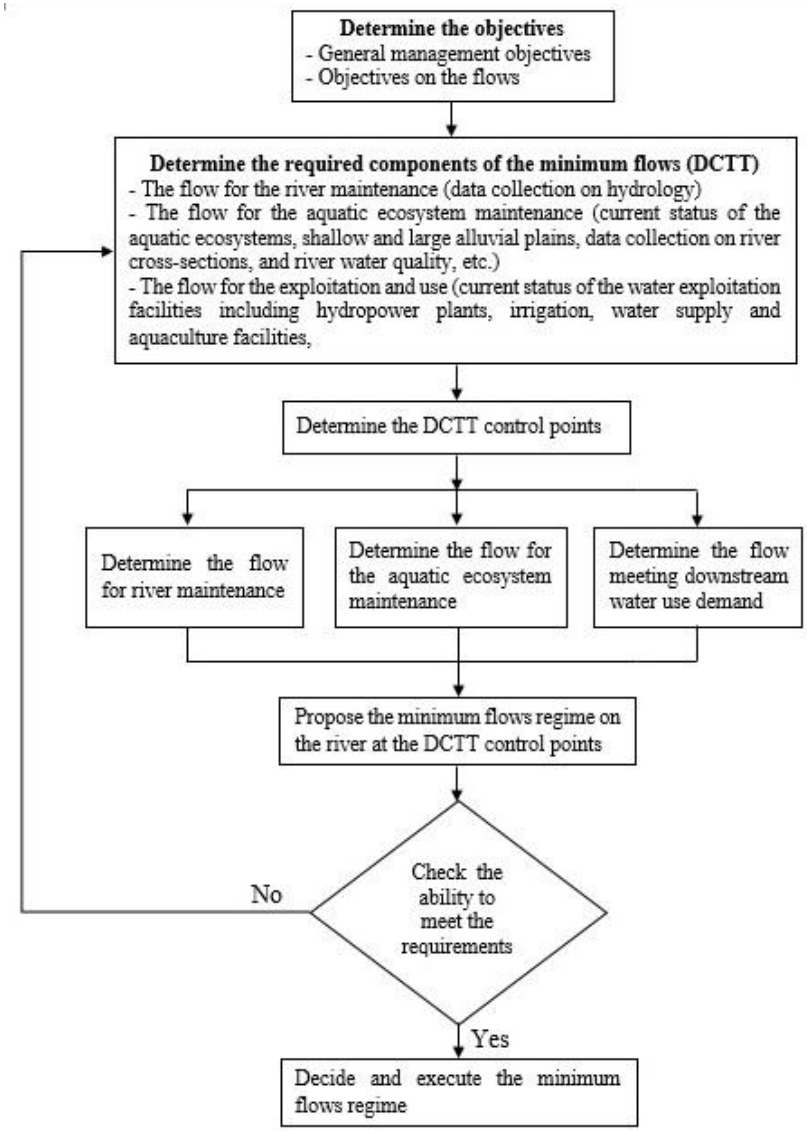
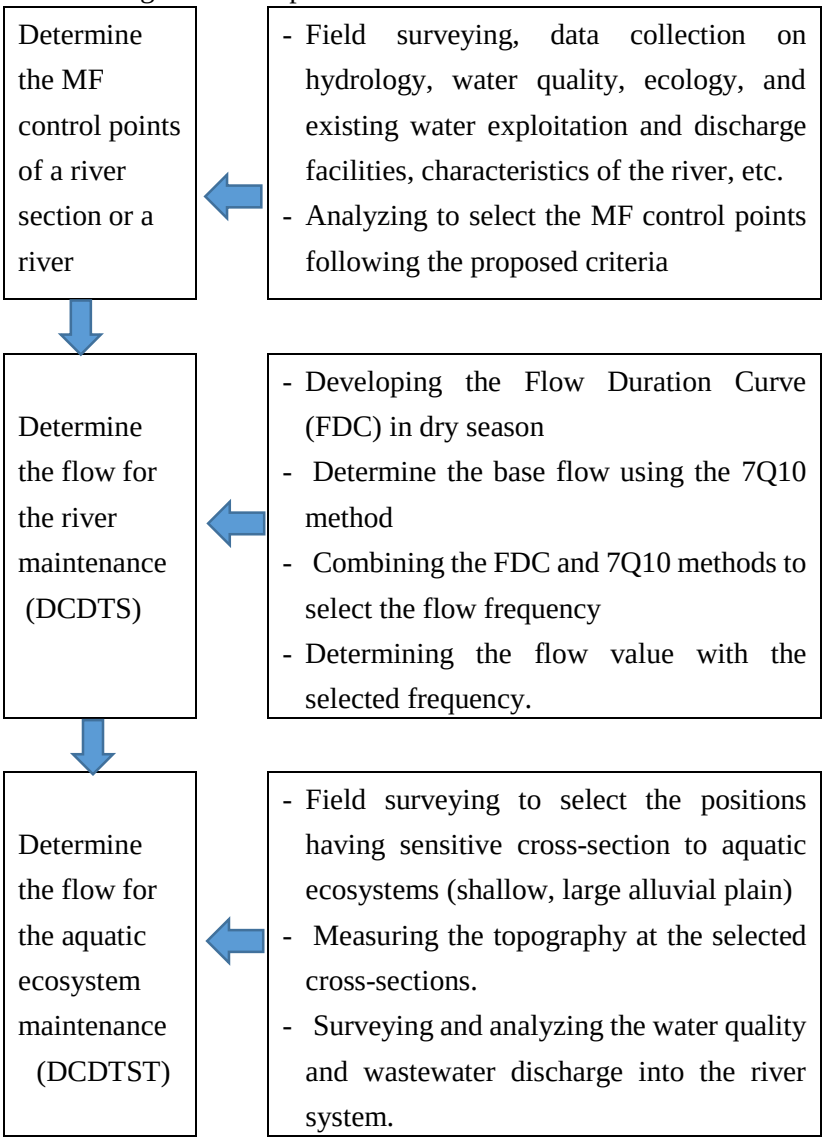


Figure 2.4: The process of determining and calculating the MF of the river system

2.2.2. Method for determining the components of the minimum

flows

Figure 2.5: Steps to determine the minimum flows



	- Applying the MIKE 11 modeling to develop the relation curves: H~ χ , Q~ χ and determine H_{max}, and H_{min} values in the dry season at the selected cross-sections. - Applying the wetted perimeter method to determine the ecological flow (by defining the inflection point on the relation curves: H~ χ , Q~ χ). - Applying the MIKE Ecolab modeling to calculate the water quality in the river system corresponding to the case of the river discharge was determined by the wetted perimeter method, comparing the river water quality with the QCVN 08: 2015 to determine the ecological maintenance flow.
Determine the flow for the exploitation and use (DCKTSD)	- Applying the MIKE BASIN modeling to calculate the water balance. Determine the levels of water shortage over time and space. - Applying the MIKE 11 modeling to determine the ensuring water level, and flow rate to supply for pushing salty water, irrigation, livestock, industry, and domestic activities at the control points.
Determine	- Combining the determined DCDTS,

the MF at the main control points	DCDTST, and DCKTSD following the principle of water resources distribution priorities to determine the MF.

2.3. Introduction to the study area

The Vu Gia – Thu Bồn (VG-TB) is a large river system in the Central Coast region of Vietnam. The whole river basin is located at the eastern side of the Trường Sơn Mountain Range with a total basin area of 10,350 km^2. The whole river basin is bounded by 16 °03' to 14°55' North latitude and 107°15' to 108°24' East longitude.

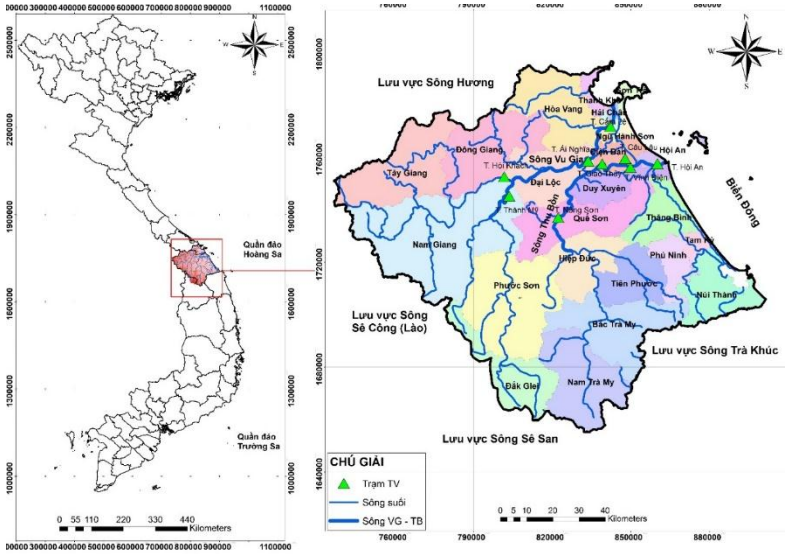


Figure 2.6: Map of the Vu Gia - Thu Bồn river basin

The VG - TB river system consists of two major rivers: VG and TB

Annual flow: Due to the abundant rainfall in the basin, the surface river flow is quite high. The annual average flow module ranges from 38.8 ÷ 75.9 l/s.km^2. Total annual flow is about 20.4 billion m^3. The flow during the year is divided into two distinct seasons: the flood season and the dry season. The flood season starts from September to

December, flood season flow accounts for about 65% of total annual flow amount.

Dry season flows: the dry season starts from January to August every year. The smallest flow in the basin mostly appears in April, with the years of little or no rainfall in May and June, then the smallest flow occurs in July and August.

The highest salinity usually occurs in March and the lowest salinity usually occurs in August.

In the basin, there are currently 761 surface water exploitation facilities for agricultural production with 86 reservoirs, 491 dams, 182 pumping stations and 2 canal systems. The VG - TB river system is also the water source supplying for industrial zones and especially for domestic water use in Đà Nẵng and Hội An cities. There are presently 11 large hydropower plants either in operation or under construction, the operation of the hydropower plants has directly affected on the natural flow of the river, negative affecting to downstream water supply activities.

CHAPTER III: MINIMUM FLOW CALCULATION RESULTS FOR VU GIA - THU BỒN RIVER BASIN

3.1. Determine the minimum flow control points in the Vu Gia – Thu Bồn river basin:

On the basis of the area subdivision, the criteria for the control points, and the results of the field survey, the author proposes 4 minimum flow control points for the VG-TB river system including:

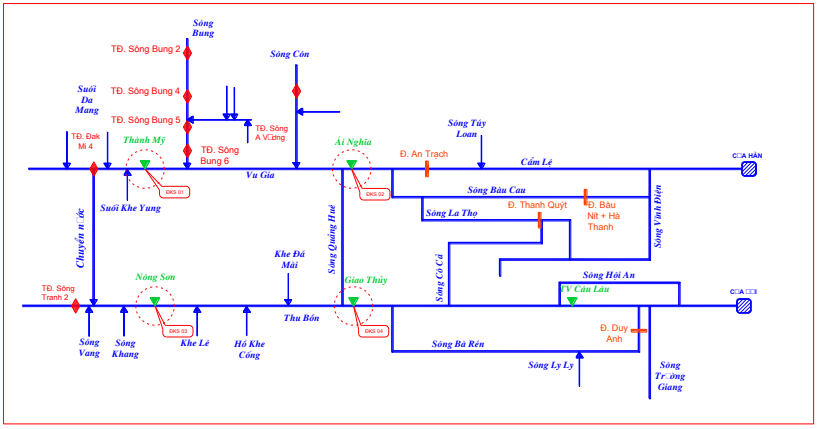
- Control point no.1 located at Thành Mỹ hydrological station on Vu Gia river represents the river section from the Thành Mỹ station to the upstream of Vu Gia - Quảng Huế river confluence.

- Control point no.2 located at Ái Nghĩa hydrological station represents the river section from the Ái Nghĩa station to Cửa Hàn.

- Control point no.3 located at Nông Sơn hydrological station represents the river section from the Nông Sơn station to the upstream of Thu Bồn – Quảng Huế river confluence.

- Control point no.4 located at Giao Thủy hydrological station represents the river section from the Giao Thủy station to Cửa Đại.

Figure 3.1: Mainstream flow diagram of Vu Gia - Thu Bồn river basin



3.2. Minimum flow components calculation results

3.2.1. Calculation cases and conditions

The dry season in the basin starts from January to August every year. Therefore, the MF will be determined by monthly period, from January to August. The water balance calculation results show that May is the highest water demand month, the next highest month is April. Therefore, May is selected as the month for calculating the minimum flow in the period of increased water supply, and April is selected as the representative month for calculating the MF in the period of the normal water supply (the remaining 7 months)

3.2.2. River maintenance flow calculation results

i/ Calculate the river maintenance flow following the Flow Duration Curve Analysis method (FDCA):

The average annual rainfall in the VG - TB river basin varies from 2000 to 4000 mm, the average water amount per person reaches 10,390 m^3/person/year classifying as the water-rich river basin. The author chooses an assurance frequency of 90% to calculate the river maintenance flow

The river maintenance flow is determined by the smallest monthly flow corresponding to the assurance frequency of 90% from the observed flow series. The observed flow series from 1977 to 2008 at both Nông Sơn and Thành Mỹ hydrological stations before the operation of the large hydropower reservoirs are selected to assess the river maintenance flow. The results of the calculation are as follows:

Q_{90} Nông Sơn = 40.1 (m^3/s)

Q_{90} Thành Mỹ = 27.3 (m^3/s)

The Q~H relations are developed for the Nông Sơn and Thành Mỹ hydrological stations corresponding to the water level of 10.26 m at Thành Mỹ station and 3.31 m at Nông Sơn station.

ii/ Calculate the river maintenance flow following the 7Q10 method:

The observed daily flow series in 30 years (from 1977 to 2006), when the downstream flow regime was not affected by the upstream hydropower plants are selected to calculate the river maintenance flow using the 7Q10 method. The results of the calculation are as follows:

$Q_{(7Q10)}$ Nông Sơn = 23.2 (m^3/s)

$Q_{(7Q10)}$ Thành Mỹ = 19.3 (m^3/s)

As a result, the river maintenance flow values calculated by the

7Q10 method is lower than the values calculated by the Flow Duration Curve Analysis method (FDCA). For safety, the calculation results of the FDCA method were selected as the river maintenance flow.

3.2.3. Ecological maintenance flow calculation results

Table 3.6: The results of the ecological maintenance flow at the control points following the wetted perimeter method

No.	River name	Ecological control points	Ecological maintenance flow (determined by the wetted perimeter method) H(m)
1	Cái (Vu Gia)	Thành Mỹ hydrological stations	9.60
2	Vu Gia	Ái Nghĩa hydrological stations	2.38
3	Thu Bồn	Nông Sơn hydrological stations	4.05
4	Thu Bồn	Giao Thủy hydrological stations	1.16

Applying the MIKE Ecolab modeling to calculate water quality parameters in the case of proposed flow in table 3.6 gives the following results:

Table 3.7: The results of water quality calculation at control points

Control points	Criteria	Unit	Ái Nghĩa HS	Giao Thủy HS	QCVN 08:2015 (column A1)
-$Q_{Ái\ nghĩa}$ = 37.1 m^3/s	Min_DO	mg/l	7.46	6.60	$\geq$ 6
	Max_NH_4	mg/l	0.12	0.06	0.3

$-Q_{Giao\ Thủy=}$ 128 m^3/s	Max_NO_3	mg/l	1.98	1.56	2
	Max_BOD_5	mg/l	15.78	14.95	4

Thus, the ecological maintenance flow values calculated by the wetted perimeter method (Table 3.6) satisfy the requirements of water quality for aquatic life protection as regulated in the QCVN 08: 2015, column A1 with the DO, NH4+, and NO3- indicators. Particularly, the BOD5 indicator is exceeded 3 ÷ 4 times. In analyzing the water source capacity, the plan to increase the flow for dilution is not feasible, so the measures in reducing the concentration of waste water to control BOD5 in the two above control points are necessary. Specifically, at the location of Rồng bridge (M1), Tuyên Sơn bridge (M3), Hòa Xuân bridge (M4), Cửa Đại - the sea lights position (M9), Tam Hiệp commune - Quảng Huế - Thu Bồn confluence (M12)), and Ái Nghĩa hydrological station (M15).

From the results of the ecological maintenance flow calculation following the wetted perimeter method and the results of the water quality assessment according to the National Technical Regulation: QCVN 08: 2015, the ecological maintenance flow at the control point is proposed as follows: $H_{MT,ST}^{Thành\ Mỹ}$ =9.60 m, $H_{MT,ST}^{Ái\ Nghĩa}$ = 2.38m, $H_{MT,ST}^{Nông\ Sơn}$ = 4.05 m, $H_{MT,ST}^{GiaoThủy}$ = 1.16 m.

3.2.4. Exploitation and use flow calculation results

The amount of water that required for exploitation and use activities including all consumed or unconsumed water demand on the studied rivers or river sections. Based on the current status of water exploitation, and use, the author focus on studying the water demand for the following sectors: water for irrigation in agriculture; water supply for people daily lives; water for industries and services; water for livestock; water for aquaculture; water for hydropower; and water

for pushing salty water.

3.2.4.1. Water balance calculation results

The dry season in the VG -TB river basin starts from January to August. For the current water demand, the flow frequency of 85% only meet the demand for water use in three regions including: upstream Vu Gia river to Thành Mỹ station; upstream Thu Bồn river to Giao Thủy station; midstream Vu Gia river to Ái Nghĩa station. The remaining two areas including: downstream Thu Bồn - Ly Ly river; downstream Vu Gia - Túy Loan river are lacked water flow in a number of months, the amount of water is mainly lacked in March, April, May, and August, in which, May is the most water shortage month.

3.2.4.2. The water demand ensuring the water level at the control points

The water level at the main water taken points in downstream Thu Bồn - Ly Ly river depends mainly on discharge, water level at the Giao Thủy control point.

The requirement of water level at the main water taken points in downstream areas is calculated by gradual testing method with different flow rates in the upstream Vu Gia – Quảng Huế river ($Q_{TL-VG-QH}$) and the upstream Thu Bồn – Quảng Huế river confluence ($Q_{TL-TB-QH}$) resulting in Table 3.21.

3.2.4.3. The water demand ensuring the salinity level for domestic water supply and for agricultural irrigation

Saltwater intrusion into the mainstream of Thu Bồn, Vĩnh Điện, and Bà Rén rivers affects to the irrigation pumping stations and the Vĩnh Điện water supply plant. Two large pumping stations that mostly affected by the saltwater intrusion are selected to calculate the water

flow demand for pushing salty water including: (1) Xuyên Đông pumping station on Bến Giá river; (2) Tứ Câu pumping station on Vĩnh Điện river.

Table 3.21: The results of the exploitation and use flow calculation at the control points

No.	Demand	Increased water supply period		Normal water supply period	
		$H_{Ái\ Nghĩa}$ (m)	$H_{Giao\ Thủy}$ (m)	$H_{Ái\ Nghĩa}$ (m)	$H_{Giao\ Thủy}$ (m)
1	Ensuring the water level for irrigation water supply and for domestic water supply.	2.71	0.89	2.31	0.74
2	Pushing salty water	2.84	1.29	2.34	1.18
	Exploitation and use flow	**2.84**	**1.29**	**2.34**	**1.18**

3.3. Combining for determing the minimum flows

The calculation results of component flows are summarized as in Table 3.22 below:

Table 3.22: The calculation results of component flows at the control points

Control points	River maintenance flow		Ecological maintenance flow		Exploitation and use flow (Increased / Normal)	
	Q (m^3/s)	H (m)	Q (m^3/s)	H (m)	Q (m^3/s)	H (m)
Thành Mỹ	27.3	10.26	13.0	9.60	-	-

hydrological stations						
Ái Nghĩa hydrological stations	-	-	-	2.38		2.84/ 2.34
Nông Sơn hydrological stations	40.1	3.31	99.6	4.05	-	-
Giao Thủy hydrological stations	-	-	-	1.16	-	1.29/ 1.18

The assurance level for maintaining the MF are evaluated to check whether the proposed MF values is appropriate for the water resources condition and for the ability of the upstream reservoirs regulation.

Proposing for checking the calculation of assurance level as follows:

- Checking the assurance level of flow at Nông Sơn, Thành Mỹ, Ái Nghĩa and Giao Thủy hydrological stations in the case of all 5 existing large hydropower works cascades in the basin are in operation;

- Checking the assurance level of the MF on the water level at Ái Nghĩa and Giao Thủy hydrological stations.

The calculation results show that:

The MF at the control point located in Thành Mỹ hydrological station is proposed as 27.3 m^3/s ranging from the smallest monthly flow to the smallest monthly average flow in both (1977 ÷ 2008) and (2009 ÷ 2016) calculation periods. Thus, the value of the proposed MF

is appropriate to the conditions of the water resources.

The MF at the control point located in Nông Sơn hydrological station is proposed as 99.6 m^3/s which exceeds the range from the smallest monthly flow to the smallest monthly average flow in the (1977 ÷ 2008) calculation periods but falls within the upper limit in the (2009 ÷ 2016) calculation periods, and which also is much lower than the dry season average flow in both above calculation periods. Thus, the value of the proposed MF is appropriate to the conditions of the water resources.

The MF water level at the control point located in Ái Nghĩa hydrological station is proposed as 2.38 m in the normal water supply period, as 2.84 m in the increased water supply period. In comparing with the average monthly water level data recorded in the Ái Nghĩa station in the (1977 ÷ 2008) period, the number of years ensuring the proposed MF for April and May is not so high. However, in the (2009 ÷ 2016) period, the number of years that not so high ensuring the proposed MF threshold is only in May with a shortage water level of (0.23 ÷ 0.04) m. However, the proposed MF still falls within the upper limit of the minimum 3-month average water level and the dry season average water level.

The MF water level at the control point located in Giao Thủy hydrological station is proposed as 1.18 m in the normal water supply period, as 1.29 m in the increased water supply period. In comparing with the average monthly water level data recorded in the Giao Thủy station in the (1977 ÷ 2008) period, the proposed MF falls within the upper limit of the minimum 3-month average water level and the dry season average water level. However, in the (2009 ÷ 2016) period, the proposed MF doesn’t fall within the upper limit. Addressing this issue

will require the introduction of a number of comprehensive solutions for integrated water resources management of the VG – TB river basin such as developing the upstream water storage facilities, changing the operational process of the hydropower plants, etc.

Table 3.28: Proposing the minimum flows at the control points

No.	Control points	Increased water supply period (in May)		Normal water supply period (from January to April, June to August)	
		Q (m^3/s)	H (m)	Q (m^3/s)	H (m)
1	Thành Mỹ hydrological stations	27.3	10.26	27.3	10.26
2	Ái Nghĩa hydrological stations	53.3	2.84	34.0	2.38
3	Nông Sơn hydrological stations	99.6	4.05	99.6	4.05
4	Giao Thủy hydrological stations	-	1.29	-	1.18

CONCLUSION AND RECOMMENDATION

Conclusion

Sustainable development, in general, and management, exploitation and efficient use of water resources, in particular, is one of the most important requirements in the development of all nations. In which, the maintenance of the MF for a river or river section has a special meaning and significance. However, currently, no single best method to determine the EF is uniformly or universally applied.

The thesis has approached the points of analysis, integrated evaluation and use of advanced research tools to develop the method for determining the MF of the river system that previous studies often doesn't fully mention the factors. The thesis has also applied the results of other researches on the methods for determining the MF to calculate the MF for the VG - TB river systems.

Specifically, the thesis has proposed the MF control points for the VG - TB river system; the river maintenance flow was determined; Applying the wetted perimeter method in combination with the the mathematical modeling tools to assess the river water quality in order to determine the ecological maintenance flow; Analyzing the relationship among the upstream discharge and the length of saltwater intrusion in the mainstream of the Vu Gia, Thu Bồn, and Vĩnh Điện rivers, the water supply activities in the downstream of the river basin to calculate the assurance flow for the downstream water demand. The calculation of the MF for the VG-TB river system has not only scientific significance but also high economic, political and social significance.

The thesis has newly contributed as follows:

(1) The method of determining the MF was developed for the river system based on the integrated approach of hydrological, hydraulic and ecological factors.

(2) The result of the research in determining the MF was applied to the VG-TB river system, as the practical basis for expansion and development of the MF calculations for other river downstream areas.

Although each river system will have its own characteristics, which differ in terms of natural conditions, ecosystems, and water use demand, etc. However, with the new approaches, research methods,

and calculation tools, the research results of the thesis can be applied to determine the MF for different rivers or river sections after updating, modifying and adding these rivers or river sections databases. The determination of the MF for the rivers/ river sections will significantly contribute to the integrated management and exploitation of water resources in an effective and substainable way.

Recommendation

In order to further improve the method for determining the MF using the synthesized approach, it is needed to study the development of assessment indicators on socio-economic efficiency and the development of indicators for assessing the importance levels of river ecosystems.

The MF is one of the good tools for sustainable management of water resources in the river basin. Therefore, the requirements on the MF should be integrated into the upstream reservoirs operation processes. The implementation of the minimum flow requires the consensus among stakeholders.