UNIVERSITY OF GAZIANTEP
GRADUATE SCHOOL OF
NATURAL & APPLIED SCIENCES

THE DESIGN OF A PROGRAM FOR OPEN CHANNEL OPTIMIZATION

M.Sc. THESIS
IN
CIVIL ENGINEERING

BY
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The Design of a Program for Open Channel Optimization

M.Sc. Thesis
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Supervisor
Asst. Prof. Dr. Mazen KAVVAS

by
Andam Mohsin MUSTAFA
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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

THE DESIGN OF A PROGRAM FOR OPEN CHANNEL OPTIMIZATION

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The work in this thesis involves the development of a program by Visual Basic 6.0 for the optimization of the design of lined open channel lateral cross-section. The optimum values for the section variables, such as channel side slope, bottom width, and water depth for trapezoidal, rectangular and triangular channels are found by the computer program using an embedded optimization process that considers imposed limitations/constraints on the previously mentioned variables as well as other variables such as the velocity and top width. Also, the optimization considers priorities regarding three targets, which are the wetted perimeter, the cross-sectional area, and the exposed surface. This program enables for total priority of only one of these three targets, and also, enables for the selection of different ratios of priority for each of these three targets depending on the local conditions of the project. The developed program considers the flow being uniform and based on the production of many probable cross-sections and selects only the optimum one according to the constraints and ratios of the priority order of the targets specified in advance by the user.

Keywords: Open Channel, Optimum Cross-section, Irrigation, Canal, Optimization.

ÖZ

AÇIK KANAL OPTİMİZASYONU İÇİN PROGRAM GELİŞTİRİLMESİ

MUSTAFA, Andam
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83 Sayfa

Bu tez çalışması Visual Basic 6.0 ile bir program, kaplamalı açık bir kanal yanal enine kesitinin tasarım optimizasyonu içingeliştirilmiştir. Trapez, dikdörtgen ve üçgen kesitin değişkenleri, kanal yan eğim, alt genişlik ve su derinliği gibi, en uygun değerleri bir bilgisayar programı içinde yerleştirilmiş bir optimizasyon işlem yolu ilebulunabilir. Bu optimizasyon işlemi, sözü edilen değişkenler ve diğer değişkenler, hız ve üst genişliği gibi,zorunlu kısıtlamaları dikkate alır. Ayrıca, optimizasyon üç hedeflerle ilgili önceliklerini dikkate alır; bunlar, ıslak çevre, kesit alanı, ve maruz kalan yüzeyidir.Projenin bölgesel koşullarına göre, program bu üç hedeflerin birine öncelik olanağı sağlar, ayrıca, bu üç hedefler her biri için farklı öncelik oran seçimi için olanak sağlar. Bu proje yerel koşullara bağlıdır. Geliştirilen program üniform akışa göre tasarlanmış, veönce kullanıcı tarafından belirtilenkısıtlamalara ve hedeflerin önemlilik oranlarına göre birçok muhtemel kesitten sadece optimum olanını seçer.

Anahtar Kelimeler: Açık Kanal, Optimum Kesit, Sulama, Kanal, Optimizasyon.

This thesis is dedicated to my beloved Dad, Mom, Aunt, My Brothers and Sister for their endless love, support and encouragement.

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LIST OF SYMBOLS

b	Bottom Width [m];
z	Side Slope;
y	Water depth [m];
A_c	Calculated cross-sectional area [m²];
P_c	Calculated wetted perimeter [m];
P_f	Wetted perimeter above the water level [m];
P_T	Total wetted perimeter (summation of calculated wetted perimeter and wetted perimeter above the water level [m];
T_c	Calculated top width [m];
R	Hydraulic radius flow;
V_c	Calculated velocity [m/s];
n	Manning coefficient;
S_o	Bed Slope [m/m];
$V_{max.}$	Maximum velocity limits [m/s];
$V_{min.}$	Minimum velocity limits [m/s];
Q_c	Calculated discharge [m³/s];
Q	Inputted discharge [m³/s];
ε	Increment for discharge which is 0.001
F	Freeboard [m];
C	Freeboard coefficient;
A_F	Calculated area above freeboard [m²];
A_T	Total area (summation of calculated cross-sectional area and

calculated area above freeboard [m²];

C_e	Calculated excavation cost [$/m³];
c_e	Excavation price [$];
C_L	Calculated lining cost [$/m²];
c_L	Lining price [$];
C_T	Total cost (summation of calculated excavation cost and lining cost) in meter per longitudinal length of channel[$/m];
R_A	Cross-sectional area ratio;
R_P	Wetted perimeter ratio;
R_T	Top width ratio;
O_{CS}	Optimum cross-section.

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CHAPTER 1

INTRODUCTION

Water is the most required item to life continuity. Its precedence for human beings has determined the history of the world. Specifically after quitting nomadism and beginning to cultivation, the civilization settlement by the effect of water presence. The agricultural facilities of human beings started with the problems of water. One of these difficulties was the conveyance of water from one position to another position.

Throughout the history, the above problem has showed not only for agricultural requirements but also for municipal and power needs. Together with different solutions the most commonly used were the formers of recently used channel solutions (Aksoy, 2003).

1.1 Principal Objective

Any man made water flow that is conveyed in such a manner that top surface is exposed to the atmosphere is defined as open channel flow. While the methods and materials used in the construction of conveyance lines has changed, channels still keep their pleasant appearance in transportation of water. They are simple and economical solution of water transmission elements. They may be constructed on different soil types and topographies with different cross-sections and longitudinal profiles. Nowadays, the most commonly used channel sections are trapezoidal, rectangular, and triangular sections (Aksoy, 2003).

It is very imperative for engineers or students to fully understand the methodologies behind hydraulic calculations. Once these concepts are learned however, the solution progression can become tedious and repetitive the type of procedure that is well suited to computer analysis.

The design of an ideal open channel lateral cross-section that satisfies all the desirable aims is practically far from easy. This is due to the interdependent variables involved in the process, and also due to the constraints that are usually encountered in the region in concern.

The main idea in this thesis is design of a program in Visual Basic 6.0. The purpose of it is to optimize the lateral cross-section of lined open channels. The probable targets of the optimization are either the wetted perimeter or cross-sectional area or exposed surface, or, a ratio of each of them according to the priority order specified by the user. For example, in some countries, the exposed surface is a constraint because of hot weather. Accordingly, minimizing top width it cause to increasing other variables like water depth. Also, in some regions, the depth and flow velocity need to have constraints because of nearby human activities and the accompanied risk of drowning. In such case, water depth and velocity should be designed with clear and strict limitations, especially if fencing the channel is not feasible for any reason and/or the education level within the region in concern is not up to the required standard. Obviously, such constraints impose changes on the optimized channel cross-section and very likely would deviate the cross-section to some limits from its theoretical optimum when obtained by direct optimization formulas without consideration to the local constraints. In fact, this kind of work is new in a way that the constraints are considered and only accordingly the optimization process was performed.

Also, the freedom in selecting the constraints in several variables with significantly wide range of choices made it possible to make the optimization process more realistic and practical rather than being theoretical as observed in most previous researches. The use of computer enabled for approaching the optimization process in a way different than the classical mathematical way, which is to produce many probable cross-sections with very small increments on each variable in sequence, store the resultant cross section probabilities data, and then, select the optimum available among this data.

The developed program is named 'Open Channel Optimizer' allow us to design optimal open channel by means of the common Manning's equation for the following cross-sections:

1. Trapezoidal.
2. Rectangular.
3. Triangular.

1.2 Layout of Thesis

The contents of each chapter can be explained as follows:

Chapter 1 Introduction: Introducing a brief history of open channels and its necessity to human being as well as explaining the principal objectives and layout of the thesis.

Chapter 2 Open Channel Design: Deals with, general information about the design of open channels, the importance of channels in irrigation and water resources, explaining flow in open channels and their types, the variables that have role in the design of open channels and their constraints.

Chapter 3 Open channel Optimization: Define optimization and the description of optimization process in open channels.

Chapter 4 Previous Works: A literature survey is conducted on the optimization in open channels. The previous studies on the optimal channel cross-sections concerning minimum cross-sectional area, minimum wetted perimeter, minimum exposed surface, and minimum cost.

Chapter 5 A Computer Program for Open Channel Optimization: Explaining the importance of using computer programs in the calculation process in open channel design. Optimization algorithm in ‘Open Channel Optimizer’, define the ‘Open Channel Optimizer’, used formulas and terms in the program flowchart of the ‘Open Channel Optimizer’, and how to run it.

Chapter 6 Conclusion: Includes comments and evaluation of the work and results of the thesis as well as presenting ideas for future work in this field.

CHAPTER 2

OPEN CHANNEL DESIGN

An open channel is defined as a man-made channel constructed upon the ground to transfer water from a river, another channel or a reservoir to the consumption point. Usually, channels have a trapezoidal, rectangular and triangular cross-section (Figure 2.1).The selection of channel alignment, size, shape of the lateral cross-section, longitudinal slope and the type of lining material are involved in open channel design. The design of an ideal open channel cross-section that satisfies all the desirable aims is practically far from easy. This is due to the interdependent variables involved in the process, and also, due to the constraints that are usually encountered in the region in concern.

Figure 2.1. An Irrigation Open Channel (Canals and Navigable Rivers, 2012)

2.1 Classification of Open Channels

Generally, trapezoidal cross-section is the most common section when compared with the other alternative sections. According to the nature of water source, a channel can be either an inundation or a permanent channel. An inundation channel takes its supplies from a river only throughout the high stages of the river. Such channels do not have any head-works for diversion of river water to the channel, but are provided with a channel head regulator. Usually, a permanent channel has a continuous source of water supply. Such channels are also called perennial channels. Channels can be classified, according to their function as follows:

1. Irrigation channels: An irrigation channels carries water from a source to demand point for agricultural purpose.
2. Power channels: For generation power carries water from a source.
3. Feeder channels: It is used to feed sub-channels (two or more channels).
4. Navigation channels: A deeper channel cut into the sea or river bed, for transporting goods.

An irrigation channel system includes channels of different sizes and capacities as shown in Figure 2.2. Irrigation channels may be classified as follows (Asawa, 2008):

1. Main channel: Takes its supplies directly from the river through the head regulator and acts as feeder channel supplying water to branch channels and major distributaries. Usually, direct irrigation is not carried out from the main channel.
2. Branch channel: Take their supplies from the main channel. Branch channels generally carry a discharge higher than $5m^3/s$and works as a feeder for major and minor distributaries. Large branches are rarely used for direct irrigation. However, outlets are provided on smaller branches for direct irrigation.

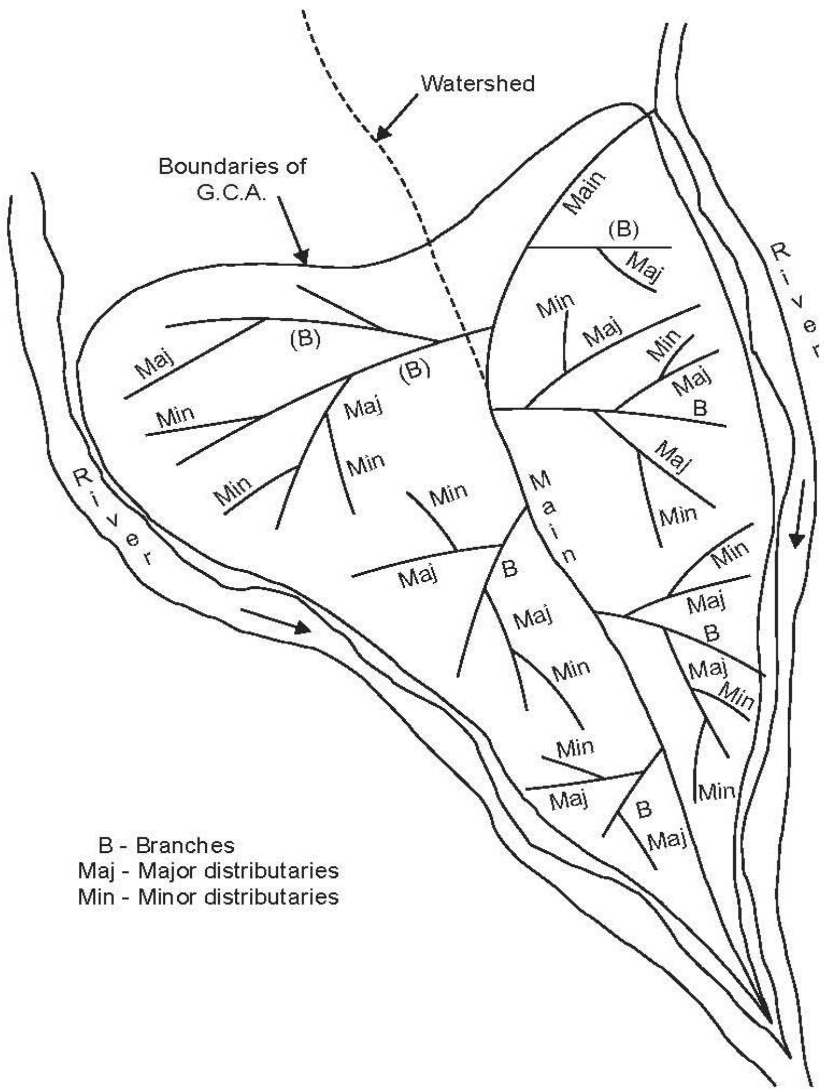

Figure 2.2. Layout of An Irrigation Channel System (Asawa G. L., 2008).

3. Major distributaries: Carry 0.25 to 5m^3/s of discharge. These distributaries take their supplies generally from the branch channel and sometimes from the main channel. The distributaries feed either watercourses through outlets or minor distributaries.
4. Minor distributaries: Are small channels which carry a discharge less than 0.25m^3/s and feed the watercourses for irrigation. Generally, they take their

supplies from major distributaries or branch channels and rarely from the main channel.

5. Watercourse: Is a small channel which takes its supplies from an irrigation channel (generally distributaries) through an outlet and carries water to the various parts of the area to be irrigated through the outlet.

2.2 Open Channel Flow

The flow of water in an open channel is a familiar sight, whether in a natural channel like that of a river, or an artificial channel like that of an irrigation ditch. Its movement is a difficult problem when everything is considered, especially with the variability of natural channels, but in many cases the major features can be expressed in terms of only a few variables, whose behavior can be described adequately by a simple theory. The principal forces at work are those of inertia, gravity and viscosity, each of which plays an important role (Calvert, 2012).

Open channel flow occurs when the water is only partially restricted by its solid boundaries. The water has a free surface that is in dealing with the atmosphere and is not under any pressure aside from that caused by its own weight and by atmospheric pressure. The influencing force over open channel flow is gravity. This type of flow could be observed in rivers, gravity sewer systems, drainage, irrigation channels and many other examples in nature. Flow in open channels or a duct in which water has a free surface differs from the flow in pipes in so far as the pressure at the free surface is constant (normally atmospheric) and does not vary from point to point in the direction of flow, as the pressure can do in a pipeline. A further difference is that the area of cross-section is not controlled by the fixed boundaries, since the depth can vary from section to section without restraint.

2.3 Types of Open Channel Flow

Investigating types of open channel flow finds several functions in civil engineering, and also, in some other branches of engineering; for example, chemical and mechanical. Open channel flow can be described and classified in different ways according to the variation in flow depth with respect to time and space(Figure 2.3). If the space is used as a criterion, the flow of open channels will divide by two, uniform flow and non-uniform flow (Figure 2.4).

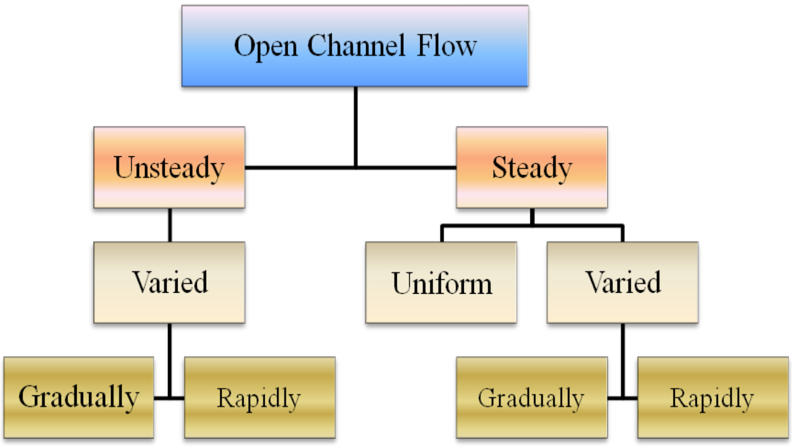

Figure 2.3. Types of Open Channel Flow (Kumar, 2012)

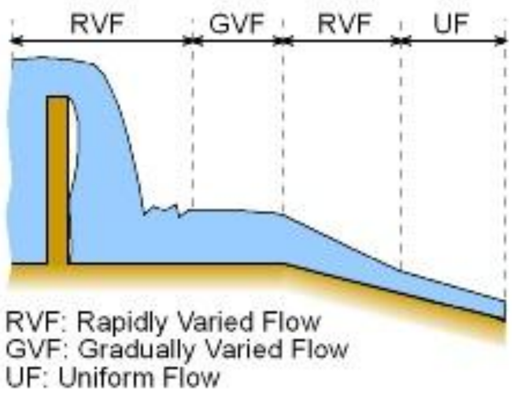

Figure 2.4. Classification of Open Channel Flow (eCourses, 2012)

2.3.1 Uniform Flow

Uniform flow is the state in which flow parameter (velocity, water depth, and discharge) are not varied in the longitudinal distance; i.e., there is no spatial variation. Figure 2.5 explains the uniform flow in an open channel. Uniform flow can be divided into two categories; steady state or unsteady state. Steady state depends on constant water depth with time, while, whenever discharge and depth of flow changes with time, the flow is termed unsteady.

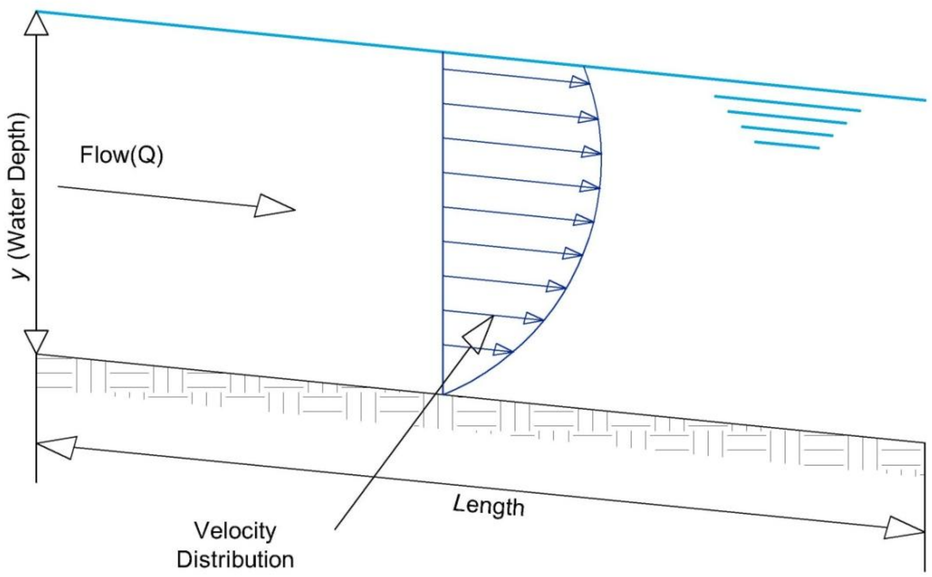

Figure 2.5.Uniform Flows in Open Channels.

Water flow in the laboratory can be flowing to be closely uniform, and outdoors like those in long open channels are often also close to being uniform. But uniformity is an abstraction: real flows are never uniform perfectly, because, regardless of how closely the conditions of flow are modulation, there are always resource free-surface effects that extend downstream from the source of the flow and upstream from the sink for the flow, or upstream and downstream from places where the channel geometry changes, like dams or bridge piers (Mitopencourseware, 2012).

Although it is special to find completely uniform flows in nature, many flow situations may be approximated as uniform flows. For instance flow in long reach of a prismatic channel non uniform.

By using Manning equation, velocity can be found in uniform flows. When the water depth, bed slope and Manning coefficient are given:

$$V = \frac{1}{n} R^{2/3} S_o^{1/2} \tag{2.1}$$

By means of using Manning formula, it is possible to find a dependable estimate velocity only if the discharge, cross-section, bed slope and roughness are constant over a suitable distance to demonstrate uniform flow conditions. Precisely speaking, uniform flow conditions rarely, if ever, happen in nature because channel sections change from station to station. However, for practical purpose in water resource engineering, Manning equation can be applied to most stream flow problems by making judicious assumptions (Federal Highway Administration, 2005).

2.3.2 Non-Uniform Flow

Non-uniform flow is the state of flow, when the depth of water varies along the length of the channel or occurs in transitions where there is change in obstruction or cross-section in channel. Non-uniform flow can be technically either steady or unsteady; further, can be classified as either rapidly or gradually varied.

A non-uniform flow can be classified further into gradually varied and rapidly-varied flows, depending on whether the variations along the channel are gradual or rapid. Flow is said to be gradually varied whenever the depth changes gradually along the channel, it is such that pressure distribution can be considered hydrostatic. Whenever the flow depth changes rapidly along the channel the flow is termed rapidly varied flow, it is such that pressure distribution cannot be assumed to be hydrostatic.

2.4 Discharge

An irrigation channel conveys water from the source of water to the demand point. The rate at which water is transported by a channel is called discharge, and the maximum quantity of discharge that any channel can convey is channel capacity (Food and Agriculture Organization, 1992). The discharge amount is selected by the farmers or the agricultural engineers. In drainage channels, there are methods for calculating amount of discharge. The capacity for open channels shall be determined by procedures applicable to the purposes to be served. Surely, the amount of discharge has effect on the all section variables. Especially on the water depth, bottom width and side slop.

2.5 Velocity

Velocity is one of the significant characteristics that have function on the design of optimal open channel cross-section. The minimum permissible velocity and the limiting (maximum permissible) velocity are to be taken in account to the requirements for the designing uniform flow open channels. The minimum permissible velocity or the non-silting velocity is the lowest velocity that will not initiate sedimentation and will not induce the growth of vegetation. Sedimentation and growth of vegetation decrease the carrying capacity and increase the maintenance cost of the channel. However, high velocities may cause scour and erosion of the boundaries. In rigid boundary channels the maximum permissible velocity or the limiting velocity (m/s) that will not cause erosion depends on the channel surface material (Chin, 2006).Table 2.1 lists the limiting velocities for different type of channel surface materials (Sharma and Chawla, 1975; Bureau, 1982; Subramanya, 1997).

Table 2.1. Limiting Velocities for Channel Surfaces (Swamee, et al., 2002)

Channel Surface	**Limiting Velocity (m/s)**
Sandy soil	0.3 0 - 0.6
Black cotton soil	0.6 – 0.9
Muram and hard soil	0.9 – 1.1
Firm clay and loam	0.9 – 1.15
Gravel	1.0 – 1.25
Boulder	1.0 – 1.5
Disintegrated rock	1.3 – 1.5
Brunt clay tile	1.5 – 2.0
Concrete tile	2.0 – 2.5
Concrete	2.5 – 3.0
Hard rock	3.0 – 4.0

2.6 Bed Slope

Bed slope of the channels could be defined as the slope of the ground. The minimum permissible velocity and the maximum allowable velocity shear stress on the channel lining are depending on the longitudinal slope. Sometimes if bed slope is very steep, it is possible to decrease its effect on the velocity by meandering the channel alignment throughout the steep slope.

Usually, laying the channel on a slope equal to the slope of the ground surface, it will cause to minimizing excavation. However, if the resulting flow velocity is less than the minimum permissible velocity, then steeper slope that produce a higher velocity must be used, within the allowable shear stress limits on the channel lining (Chin, 2006).

The longitudinal slope of the channel influences its capacity too. The steeper the slope of a channel, the faster will flow the water and thus the larger will be its capacity. See Figure 2.6, (Food and Agriculture Organization, 1992).

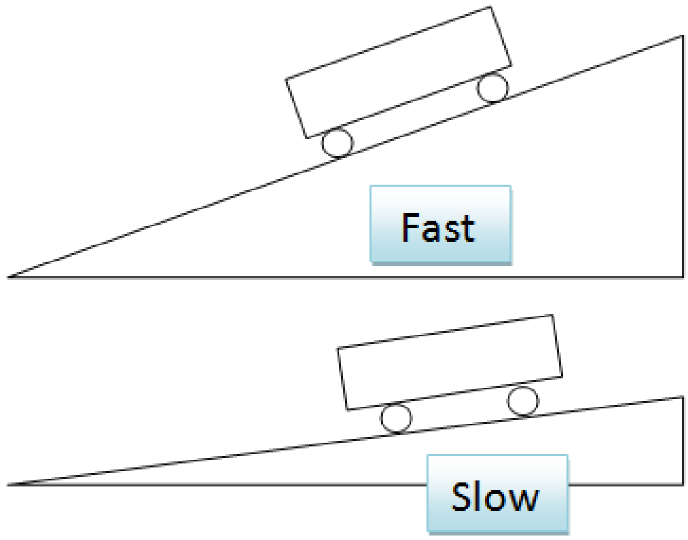

Figure 2.6. Longitudinal Slope and Velocity

2.7 Channel Lining

Earthen irrigation channels in permeable soils can lose a lot of water through seepage. Large losses through bed and side slope of channel lead to low conveyance efficiency; that is, the ratio of water reaching farm turnouts to that released at the source of supply from a river or reservoir. Earthen channels also get clogged up with weeds which reduce the water-carrying capacity.

Lining is an important procedure to save open channels from some problem, for example, losing water, decreasing maintenance cost and the like, see (Figure 2.7). The most important purpose and the most common reason are to reduce seepage losses and this may be for a variety of reasons. The assumption that lining will solve seepage problem is often unfounded, simply because poor maintenance practices (especially with concrete linings) will allow cracking, panel failures, tears and puncture in flexible membranes.

Sometimes, only the bottom width of a channel is lined when most of the seepage has been found to be in the vertical direction.

Figure 2.7. Lining Process in Open Channels (Worksafe awards, 2012).

Lining process in open channels is important because of (Merkley, 2004):

1. To minimize piping through and under the channel banks.
2. To diminish hydraulic roughness (flow resistance).
3. To settle down channel bed and bank (reduce erosion).
4. To protect water from losing (reduce seepage).
5. To avoid water-logging of adjacent land.
6. To control of the weed growth.
7. To encourage movement, rather than deposition, of sediments.
8. To decrease movement of contaminated groundwater plumes.

9. To decrease maintenance costs and simplify cleaning.

2.8Open Channel Cross-Section Variables

2.8.1 Water Depth

Depth is one of the variables that enter to the calculation of the open channel cross-section design. The depth of water flow, y, is the depth in Y-direction, for example, perpendicular to the bottom width. Water depth has a big function in the design of open channels. For example whatever water depth increases, it will cause to increasing the excavation consequently it cause increasing the cost of construction. When open channel has a deep and narrow cross-section. It has advantages and disadvantages:

A. Advantages:

1. Less evaporation.
2. Less probability of weed and moss growth.
3. Less occupies surface area.

B. Disadvantages:

1. Higher risk of drowning.
2. Probability of groundwater interference.
3. Difficulty in excavation, especially in rocky grounds.
4. Difficulties in maintenance.

2.8.2 Bottom Width

This is the channel width at the bottommost point of the cross-section. For natural channels, it is impossible to find a bottom width due to the irregularity of the cross-section. However, we may approximate the shape to a regular shape. In triangular channels, the bottom width is zero (Srivastava, 2008).

Bottom width as a variable has an effective role in the optimization process in open channels. For example, it is important during optimization process according to the minimum wetted perimeter or the minimum exposed surface. Because, decreasing in the bottom width, surely, it cause to decreasing in wetted perimeter and exposed surface. When open channel has a wide and shallow cross-section. It has advantages and disadvantages.

A. Advantages:

1. Low risk of drowning.
2. Easier to excavate.
3. Lower probability of groundwater interference.

B. Disadvantages:

1. Higher rate of evaporation.
2. Larger occupied area.
3. Higher probability of moss and weed growth.

2.8.3 Side Slope

The side slopes of excavated channels are affected by the earth in which the channel is excavated. Proper side slopes for channel excavated in various types of material are shown in Table 2.2.

Table 2.2. Channel Side Slope with Types of Material (David Chin, 2006).

Material	**Side slope (H : V)**
Rock	Nearly Vertical
Peat soils and muck	0.25 : 1
Stiff clay	0.5 : 1 to 1 : 1
Silt, sand mixtures and firm compacted clay or soils having clay.	1.5 : 1
Loam, silt, and sandy soils	2 : 1
Porous clay, sandy loam, and fine sand	3 : 1

These values are recommended for preliminary design. In deep cuts, side slopes are often steeper above the water surface than below the water surface, and in small drainage ditches, the side slopes are often steeper than they would be in an irrigation channel excavated in the same material. When concrete it used as a lining material, then side slopes greater than (1: 1) usually require the use of forms, and for side slopes greater than (0.75H: 1V) the lining must be designed to withstand earth pressure. A (1.5H: 1V) slope for the usual sizes of concrete-lined channel recommended by the U.S Bureau of Reclamation (Chin, 2006).

2.8.4 Top Width / Exposed Surface

Top width or exposed surface is the width of water flow that directly exposed to atmosphere (Figure 2.8). For rectangular channels, top width will be the same as the bottom width. The expose surface in other shapes of channels will depend on the water flow depth and the channels side slope. It is an important parameter since it determines the rate of increase of flow area with change in flow depth.

Figure 2.8. Top Width or Exposed Surface (StructureHUB, 2009).

Generally by increasing water flow depth, top width will increase directly, but in some cases, for example in circular open channel flowing more than half full, it may decrease with increase in depth (Srivasrava, 2008).

Because top width is exposed to the atmosphere, it has significant role in water loss through evaporation. For example, if the channel passes throughout a hot weather region, in this case the designer must give the exposed surface a first priority characteristic in the design process to be the channel has a minimum top width. When the design is constrained by exposed surface, in this case the designer could decrease the bottom width and side slope.

2.8.5 Cross-Sectional Area

The area that is occupied by water prism in open channel geometries is called cross-sectional area (Figure 2.9). Cross-sectional area is calculated by area formulas for open channel sections for example trapezoidal, rectangular and triangular, section variables that participate in this calculation are water depth, bottom depth and side slope.

For a particular discharge, cross-sectional area and velocity have direct relation. In other words, when the cross-sectional area is relatively small, the velocity needs to be relatively higher in order to enable the inflow to continue, and vice versa.

Another object that must be mentioned here with cross-sectional area is excavation volume and its cost. Because excavation volume of the open channels depend on the cross-sectional area and longitudinal slope, so that whenever cross-section area increase excavation will increase directly.

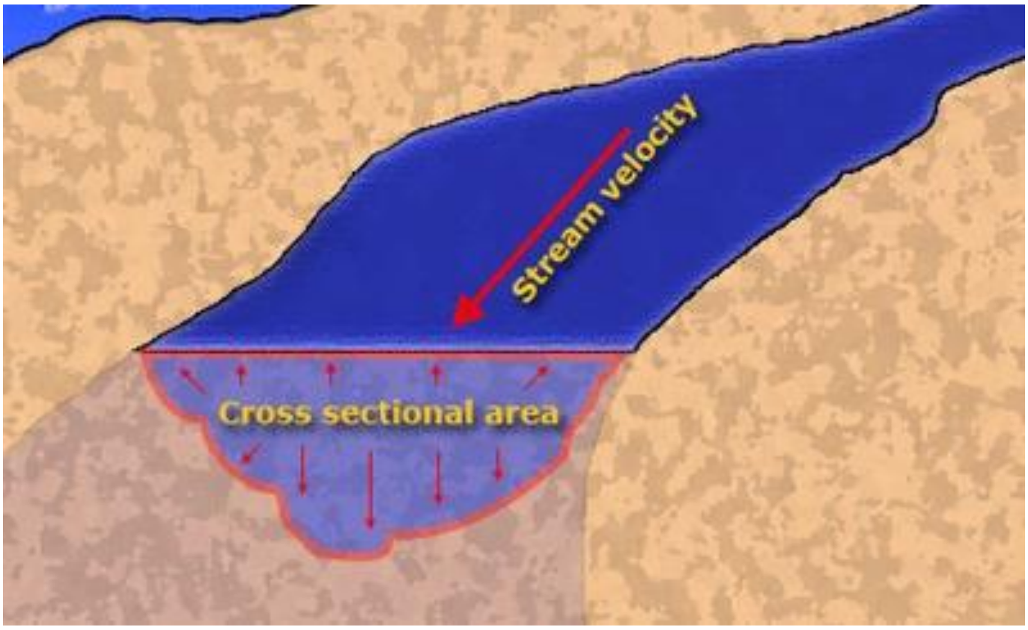

Figure 2.9. Cross-Sectional Area (Stary, 2011)

2.8.6 Wetted Perimeter

Is the length of the line where water is in direct contact with the channel body (Figure 2.10).When wetted perimeter increases, friction head-loss increases.

There is a lineal impinge between water and the wetted perimeter. So that wetted perimeter has a big role in lining cost of channels. When wetted perimeter increases, lining cost will increase.

Also it plays significant role in open channel flow since the resistance to flow by reason of the boundary shear is directly proportional to the wetted perimeter. Obviously, by increasing the flow of the channel wetted perimeter will increase (Srivastava, 2008).

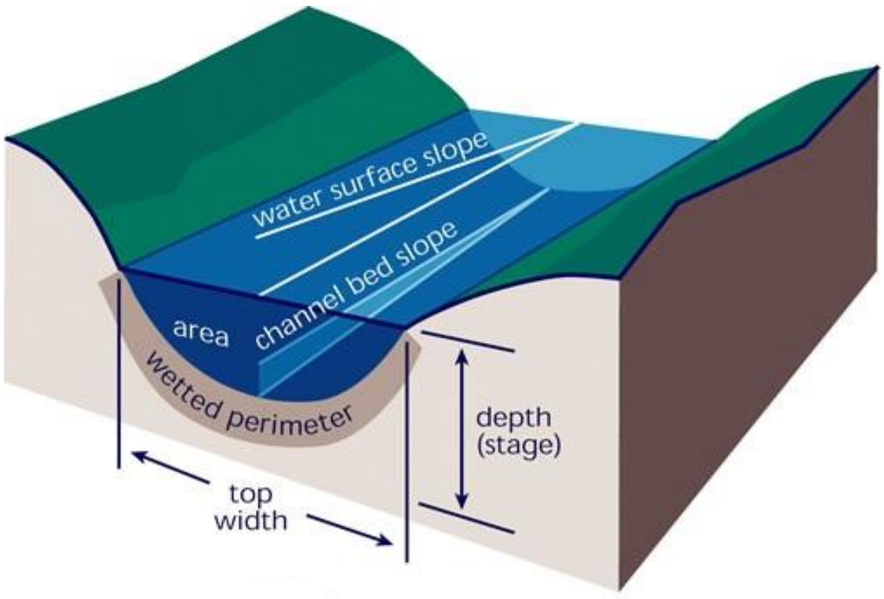

Figure 2.10. Wetted Perimeter (Coolgeography, 2012).

CHAPTER 3

OPEN CHANNEL OPTIMIZATION

Optimization is a discipline that uses mathematics as a mean to find the best choice among many alternative probable solutions. Being the best choice means it is offering the optimum value of one or more target variable/s among the different variables involved in the process in concern.

During the recent decades, the use of computer enabled speeding the process of mathematical calculations and enabled for different approaches to the implementation of the optimization process where manual calculations without computer were theoretically possible but practically close to the impossible.

3.1 Optimization in Open Channels

Optimization in open channels it is a complicated process. This is due to most of the variables involved being of the interdependent type rather than being independent. Also, the priorities of the optimization targets are to be considered. When, minimizing in one of the variables is necessary, of course it has effect on the other variables.

The design of an ideal open channel that satisfies all the desirable aims is practically far from easy. This is due to the interdependent variables involved in the process, and also, due to the constraints that are usually encountered in the region in concern. Of course, the priority of the variables during optimization, type and degree of constraints encountered vary with the variation of the conditions of the region of the project.

Firstly, optimization in the longitudinal section of the channel alignment, which depends on the topography of the region, is important, because it has a significant impact on the amount of cut and fills, and also, on minimizing the probability of coming across natural and/or man-made obstructions. Consequently, selecting the alignment of the channel is the first step in the design, which is an essential step in the whole process of the design of open channels. Designer should select the alignment of the channel in a way that would minimize excavation procedures. In other words, the excavation and fill volumes should be as close in value to each other, and also, to be physically as close as possible to each other in order to minimize transportation costs.

In fact, in the process of channel design, all variables act in an interrelated way so that changing one single variable is likely to result in a need to either change the other variables in order to satisfy the required design flow. In this case, changing the alignment of the path of the channel is likely to change the longitudinal slope of proposed channel in a way that the slope would be imposed, and the lateral cross-section has to be designed according to that imposed slope. However, there are limits to the variation that could be made on the configurations of the lateral cross-section in a way that the resultant velocity may appear to be lower or higher than the desired one.

It is also important to know how to optimize the lateral cross-section of channel. However, it is essential to define the optimization targets, because, there are several different targets which the designer would like to optimize. Among these targets, minimizing cross-section area in order to minimize the cost of excavation, minimizing wetted perimeter in order to minimize the lining cost and minimizing the friction between water and channel surface, and minimizing the exposed surface in order to minimize evaporation losses as well as minimizing the occupied land.

Although reaching the optimum value of all different targets is not feasible from the practical point of view, simply because while optimizing one target, it is inevitable that the other targets would deviate from their optimum values to some limits. Therefore, it is essential to focus on a particular essential target as number one priority in the optimization process while observing the changes that are occurring on the other targets in a way that none of the other targets would be too far from the acceptable range, otherwise, it may be necessary to sacrifice with a section of the main target in order to keep the other less essential targets within the acceptable limits.

The selection of the objective target depends on the designer, which in turn, makes his/her decision depending on the locally imposed requirements. It should be noted that optimum targets and its priority are local and vary from one region to another and from one country to another.

The minimum area, the maximum velocity cross-section, minimum evaporation and minimum execution cost are frequently considered the main objectives for the design and construction of lined channels. Such optimal section is economically most efficient because it involves the least amount of earthwork and the least lining surface as well as the minimum probable evaporation within the region in concern.

Sometimes, the imposed conditions on the designer may impose the need to minimize channel cross-sectional area in order to decrease the excavation volume.

Thus, the designer should decrease the variable that has influence on the minimization of cross-section area, which in this case appears to be minimizing water depth and bottom width. Minimization the cross-section area is an important process due to its influence on the excavation cost, and consequently, on the total cost of the channel.

In hot weather regions, the design of open channels imposes minimizing the exposed water surface. Optimization in the cross-section of channels in order to have minimum top width is dependent on water depth, side slope, and bottom width. For example, in trapezoidal and triangular cross sections, when water depth increases the exposed surface increases with direct proportional relation.

Another matter that must be optimized in the design of open channels is the types of materials which used in the lining process. This is because different lining materials have different roughness coefficients. Also, different materials may have different degrees of impermeability, which in turn, influences any probable seepage losses. It is important to select a material for lining with minimum probability of being cracked due to the local weathering effects and/or due to the imposed weight of water load. Another important property of the lining is that it should minimize any probability of weed and moss growth because such growth would increase the friction losses significantly.

Of course, the price of the material should be taken in account, because lining cost is one of the main factors influencing the total cost of channel execution.

3.2 Common Methods of Optimization

Optimization methods are used to find the 'best/optimal' values of objective function due to variables and constraints involved in the process. There are several methods of optimization in open channels, optimization methods in open channel cross-sections depend on the variables/constraints involved in the process. These variables are, like water depth, bottom width, side slope, and velocity, all of these variables, has in the direct relation to each others, for example, if one of the variables changed, it cause to changing the others variables. These types of variables could be optimizing by using nonlinear optimization models, where nonlinear optimization is the process of solving a system of equalities and inequalities, collectively termed constraints, over a set of unknown real variables, along with an objective function to be maximized or minimized, where some of the constraints or the objective function are nonlinear. Here, some types of optimization methods, which used in the optimization of open channel cross-section, as follows:

3.2.1 Powell’s Method

Powell's method or Powell's conjugate direction method is probably the most successful and popular direct search method used in many engineering optimization problems. The basic idea is to create a set of N linearly independent search directions and perform a series of unidirectional searches along each of these search directions, starting each time from the previous best point. The procedure guarantees to find the minimum of a quadratic function by one pass of N unidirectional searches along each search direction. In other functions, more than one pass of N unidirectional searches are necessary (Deb, 2005).

The method is useful for calculating the local minimum of a continuous but complex function, especially one without an underlying mathematical definition, because it is not necessary to take derivatives.

3.2.2 Lagrange Multiplier Method

The method of Lagrange multipliers (named after Joseph Louis Lagrange) provides a strategy for finding the local maximum and minimum of a function subject to equality constraints.

One of the most common problems in calculus is that of finding maximum or minimum of a function, but it is often difficult to find a closed form for the function being extremized. Such difficulties often arise when one wishes to maximize or minimize a function subject to fixed outside conditions or constraints. The method of Lagrange multipliers is a powerful tool for solving this class of problems without the need to explicitly solve the conditions and use them to eliminate extra variables (Steuard, 2012)

3.2.3 Genetic Algorithm

Genetic Algorithms are a family of computational models inspired by evolution. These algorithms encode a potential solution to a specific problem on a simple chromosome (parameter)-like data structure and apply recombination operators to these structures as to preserve critical information. Genetic algorithms are often viewed as function optimizer, although the ranges of problems to which genetic algorithms have been applied are quite broad (Mathew, 2012).

Genetic algorithms works with a set of individuals, representing possible solutions of the task, the selection principle is applied by using a criterion, giving an evaluation for the individual with respect to the desired solution. The best-suited individuals create the next generation.

CHAPTER 4

PREVIOUS WORKS

Many methods were proposed for performing the process of optimization open channel design. These approaches considered one target at a time, with no consideration for the other targets that may be of some importance to the designer besides the specified main target. As explained in previous chapters, the common targets for the designer of open channels are minimizing wetted perimeter, minimization in cross-sectional area, and minimizing exposed surface.

The following sections include presentation to the commonly known approaches to the optimization of open channels regarding different targets.

4.1 Cross Section Optimization

Optimization in cross-section of open channels is the significant process, because the cross-section has essential role on the total cost of open channels. Which cross-section cause to minimization and maximization in both of wetted perimeter and cross-sectional area, directly, it has effect on the increasing and decreasing area of lining and volume of excavation. The minimum wetted perimeter, minimum cross-sectional area, minimum cost and minimum evaporation are generally considered for lined open channels. Optimizing all of these variables is difficult and it needs accuracy because of high number of the variables involved in the process.

The maximum velocity, or the minimum area cross-section, is usually adopted for lined irrigation channels. Swamee (1995) obtained clear equations for the design variables of different irrigation channel sections. Channels involving the minimum amount of earthwork and the minimum lining surface, these sections are economically most efficient. He used the most common formula, Manning's resistance equation.

$$V = -2.457\sqrt{gRS_0}\,\text{In}\left(\frac{\varepsilon}{12R} + \frac{0.221\nu}{R\sqrt{gRS_0}}\right) \quad (4.1)$$

Also, he obtained some sectional shape coefficients (Table 4.1), which are used with the derived equations from resistance formula like coefficients of: cross-section area, wetted perimeter, velocity, bottom width, water depth, and diameter of parabolic channel.

Table 4.1. Properties of Optimal Channel Section (Swamee, 1995)

Section Shape (1)	Side Slope m (2)	Section-Shape Coefficients				
		k_b or k_D (3)	k_y (4)	k_P (5)	k_A (6)	k_V (7)
Triangular	1.0000	0.0000	0.5070	1.4340	0.2570	3.8904
Rectangular	0.0000	0.7170	0.3585	1.4340	0.2570	3.8904
Trapezoidal	0.5774	0.4369	0.3784	1.3108	0.2489	4.0177
Semicircular	------*	0.7850	0.3925	1.2331	0.2420	4.1322

* Not applicable.

Applying the concept of duality, the most efficient open channel cross-section can be obtained by minimizing the excavated channel cross-sectional area depend on a specified design discharge or maximizing the flow capacity subject to a specified channel excavated area (Guo, 2004).

4.1.1 Minimum Excavation

Minimum excavation, also could be state it as minimum cross-sectional area, which is mainly depends on the water depth. Frequently, any minimization in cross-section area will cause to minimization in excavation cost or vice versa. It means the relation between cross-sectional area and excavation cost is the directly proportional relation. On the other hand, when the channel have been laid on the steeper bed slope, It will cause to increasing average velocity at the same time the cross-section will be small, it means the minimum earthwork and minimum excavation cost.

The cost of any channel can be divide by two; excavation cost and lining cost. The minimization of the cross-sectional area is generally adopted for open channels. Design of a minimum earthwork cost channel section involves minimization of the earthwork cost, which depend on the excavation depth subject to uniform flow condition in the channel (Swamee, et al., 2001).

If the cost of excavation is analyzed, it will be obvious that it depends on the volume of fill and cut. Also it depends on the strata that to be excavated and the distance of carriage if it necessary in transporting the excavated materials.

Swamee, et al, (2001) presented obvious design formulas and section shape coefficients (Table 4.2) for the minimum earthwork cost channels of trapezoidal, rectangular, triangular and circular shapes. These equations and coefficients have been founded by applying non-linear optimization method. Using the optimal design equations along with the tabulated section shape coefficients, the optimal variables of a channel and the corresponding cost can be getting in single step calculation.

Table 4.2. Coefficients and Exponents for Minimum Earthwork Cost Sections (Swamee, et al., 2001).

Entity	Coefficients or exponents	Section shapes			
		Trapezoidal	Rectangular	Triangular	Circular
Normal Depth	k_{ye}	0.37592	0.35568	0.50301	0.39032
	t_{yr}	0.2088	0.2550	0.02797	0.0161
	r_{yr}	0.8123	0.7422	0.7127	0.7196
	S_{yr}	1.0280	1.0375	4.3600	6.0000
Bed Width or Diameter	k_{be} or k_{De}	0.43407	0.71136		0.78065
	t_{br} or t_{Dr}	0.3195	0.1122		0.07023
	r_{br} or r_{Dr}	0.9342	0.7143		0.9014
	S_{br} or S_{Dr}	1.0712	2.3759		3.2330
Side Slope	k_{me}	0.57735		1.0000	
	t_{mr}	10.000		0.2572	
	r_{mr}	1.2586		0.8613	
	S_{mr}	0.08069		1.1525	
Cost	k_{ce}	0.24476	0.25302	0.25302	0.23932
	t_{cr}	0.2277	0.2234	0.2451	0.2124
	r_{cr}	0.9544	0.9233	1.0637	0.9744
	S_{cr}	0.6855	0.7107	0.6212	0.7440

4.1.2 Minimum Lining

Control of seepage saves water for further extension of the irrigation network as well as reduces the water logging in the adjoining areas. The smooth surface of lining decreases the friction slope, which enables the channel to be laid on a flatter bed slope. This increases the command area of the channel. On the other hand, as the lining allows higher velocities, the channel can be laid on the steeper slopes to save earthwork in formation (Swamee, et al., 2000).In spite of the above observation, lining can significantly reduce conveyance losses.

Lined channels have a smaller surface area for a given discharge than unlined channels. Typically a lined channel will have 40% of the unlined surface area for a given discharge. Therefore even at the loss rate per unit area there will be a saving in water. When estimating the reduction in losses from a lining, this should be based on the combination of a reduced cross-section and a reduced seepage rate per unit area (Thandaveswara, 2012).

Swamee, et al,(2000) are investigated and obtained explicit equations and section shape coefficient (Table 4.3) for the design of section variables of minimum cost lined channel section for trapezoidal, rectangular, triangular and circular by applying the nonlinear optimization. Their method avoids the trial and error method of open channel design and overcomes the complexity of the minimum cost design of lined channels. But their method concentrate only on the minimum lining, which is not possible to give 100% priority to one optimization target and neglecting the others.

Table 4.3. Properties of Optimal Channel Sections (Swamee, et al., 2000).

Entity	Coefficients or exponents	Section shapes			
		Trapezoidal	Rectangular	Triangular	Circular
Normal Depth	k_{y0}	0.37592	0.35568	0.50301	0.39032
	k_{yL}	14.2274	15.0234	15.0389	12.9379
	k_{yr}	0.22332	0.30657	0.13973	0.12631
Bed Width or Diameter	k_{b0} or k_{D0}	0.43407	0.71136		0.78065
	k_{bL} or k_{DL}	14.2425	15.0284		13.6232
	k_{br} or k_{Dr}	0.15121	0.22772		0.19375
Side Slope	k_{m0}	0.57735		1.00000	
	k_{mL}	14.2772		15.0491	
	k_{mr}	0.12485		0.30389	
Cost	k_{cL}	0.24476	0.25302	0.25302	0.23932
	k_{cr}	1.30367	1.42396	1.42486	1.22652
	k_{cr}	0.03723	0.03961	0.03965	0.03712

4.1.3 Minimum Water Loss

4.1.3.1 Minimum Evaporation

Open channel has a free surface to atmosphere, so that in the design procedures of open channels the exposed surface has a heavy weight, especially, when the project location is restricted by the weather of the region and nearby to the occupation area.

Open channel losses water by the seepage and evaporation. Whereas seepage loss is subject to the channel geometry, evaporation loss is depends on the top width/exposed surface. Evaporation loss relies on:

1. Warm effectively that will cause to evaporation.
2. The ability to transport the vapor away from the evaporating surface, which in turn depends on the wind velocity over the surface and the specific humidity gradient in the air above the water surface.

Swamee, et al., (2002) are obtained a formula for calculating evaporation in open channels:

$$E = (e_s - e_d)f_w \tag{4.2}$$

Where E = evaporation discharge per unit free surface area (m/s), e_s = saturation vapor pressure of the air at the temperature of the water surface (Pa), e_d = saturation vapor pressure of the air at the dew point (Pa) and f_w = wind function (m/s/Pa). The difference between the saturation vapor pressure of the air at the temperature of water surface and at the dew point $(e_s - e_d)$, (Cuenca,1989):

$$e_s - e_d = 610.78 \left[\exp\left(\frac{17.27\theta_w}{237.3 + \theta_w}\right) - R_h \exp\left(\frac{17.27\theta_a}{237.3 + \theta_a}\right)\right] \tag{4.3}$$

Where θ_w = water surface temperature in °C; θ_a= mean air temperature in °C; and R_h = relative humidity expressed as fraction. The winds function for a flowing channel in m/s per Pa (Fulford, 1984):

$$f_w = 3.704 * 10^{-11}(1 + 0.25u_2) \tag{4.4}$$

Where u_2 = wind velocity in m/s at 2 m above the free surface. The final equation of calculating seepage loss, as below:

$$E = 2.262 * 10^{-8}(1 + 0.25\ u_2)$$

$$\left[\exp\left(\frac{17.27\theta_w}{237.3 + \theta_w}\right) - R_h \exp\left(\frac{17.27\theta_a}{237.3 + \theta_a}\right)\right] \tag{4.5}$$

By using equation (4.5) with the resistance equation for uniform flow, they formulated some explicit design equations and optimal section shape coefficients for trapezoidal, rectangular and triangular shapes.

4.1.3.2 Minimum Seepage Loss

Channel cross-section should be designed in such a shape and dimensions that decrease the seepage loss. By the time the water reaches the demand point in unlined channels, it has been estimated that the seepage losses are of the order of 45% of the water supplied at the head of the channel (Sharma and Chawla, 1975). Seepage from a lined channel occurs at a reduced rate. The perfect lining would prevent most of the seepage loss, but a channel lining deteriorates with time. An examination of channels by (Wachyan and Rushton, 1987) indicated that even with the greatest care the lining does not remain perfect. A well-maintained channel with a 99% perfect lining reduces seepage about 30–40% (Wachyan and Rushton, 1987); seepage from a channel cannot be controlled completely.

The seepage loss from channels is governed by hydraulic conductivity of the subsoil, channel geometry, and potential difference between the channel and the aquifer underneath which in turn depends on the initial and boundary conditions. Seepage losses are also influenced by clogging of the channel surfaces depending on the suspended sediment content of the water and on the grain size distribution of the suspended sediment particles. The clogging process can decrease the seepage discharge both through bottom and slopes.

The seepage loss from a channel in a homogeneous and isotropic porous medium, when the water table is at a very large depth, can be expressed as:

$$q_s = k.y.F \tag{4.6}$$

Where q_s = seepage discharge per unit length of canal (m^2/s), k = hydraulic conductivity of the porous medium (m/s), y = depth of water in the canal (m), F = function of channel geometry (dimensionless).

Thus, the problem of determination of the shape of the minimum seepage loss channels section is reduced to minimize Equation (4.6)

Subject to $$\phi = 2.457A\sqrt{gRS_0}\ln\left(\frac{\varepsilon}{12R} + \frac{0.221\nu}{R\sqrt{gRS_0}}\right) + Q = 0 \tag{4.7}$$

Where ϕ = equality constraint function. The constrained optimization problem Equation (4.6) and (4.7) was solved by minimizing the augmented functionψ given by:

$$\psi = q_s + p\phi^2 \tag{4.8}$$

Where p = penalty parameter. Adopting small p, Equation (4.8) was minimized using the grid search algorithm. Increasing p fivefold, the minimization was carried through various cycles until the optimum stabilized.

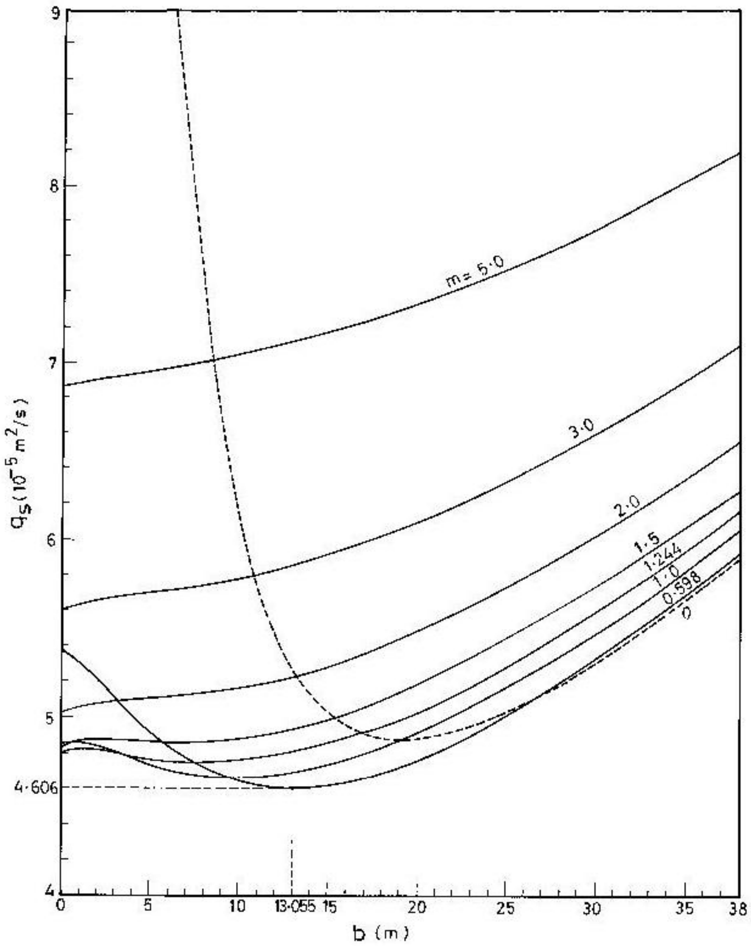

Figure 4.1. Variation of Seepage Loss with Bed Width and Side Slope(Swamee, et al., 2000)

For b ranging from 0 to 40m and m, which is side slope, ranging from 0 to 5, the normal depths were obtained using Equation (4.7). Furthermore, seepage losses were calculated by Equation (4.6). Figure (4.1) shows the variation of q_s with b and m. It can be seen that the seepage loss from a trapezoidal section with side slope of 0.598 and bed width of 13.055m is the global minimum. Furthermore, the optimum is less sensitive to the increase in bed width and more sensitive otherwise. This trend of sensitivity continues for $0 < m < 1.5$. For $m \geq 1.5$ the optimum shifts to $b = 0$ (triangular section). However, as seen in Figure4.1 the optimum for a rectangular section ($m = 0$) is highly sensitive to a decrease in bed width.

Simplified functions in terms of channel geometry have been given for computing seepage losses from triangular, rectangular, and trapezoidal channels. These functions, which replace accurately the cumbersome evaluation of improper integrals with unknown implicit state variables, have been obtained using previously derived equations by Vedernikov and Morel-Seytoux. The seepage function for a trapezoidal section supplements Vedernikov's graphs for computation of seepage. The section shape coefficients for all three channel shapes have been obtained to facilitate design of the minimum seepage loss channels. Seepage from a triangular channel is minimum for m = 1.244. A rectangular channel with a ratio of bed width to normal depth = 2.513 has minimum seepage. Among the optimal sections, the optimal trapezoidal section (m = 0.598 and bed width to normal depth ratio = 1.646) loses the least seepage.(Swamee, et al., 2000).

4.2 Cost Optimization

Most of the previous studies analysis the cost of channels as follows:

Considering the earthwork for the flow section, the earthwork cost C_e (\$/m) was given by:

$$C_e = c_e + c_r \, . A . \bar{y} \tag{4.9}$$

Where c_e = cost per unit volume of earthwork at ground level (\$/m^3), c_r = increase in the unit excavation cost per unit depth (\$/m^4), A = flow area (m^2); and $\bar{y}$ = depth of centroid of area from the free water surface.

Considering the cost per unit surface area of lining c_L ($/m^2) as independent of the depth of placement, the cost of lining C_L ($/m) was expressed as:

$$C_L = c_L . P \tag{4.10}$$

Where P is flow perimeter (m).

Cost of water loss as seepage and evaporation:

$$C_w = \frac{3.156 * 10^7 c_w}{r} (k y_n F_s + ET) \tag{4.11}$$

Where k = hydraulic conductivity of the porous medium (m/s), y_n= normal depth of water in the channel (m), and F_s = seepage function (dimensionless), which is a function of thechannel geometry. Also, T = width of free surface (m), and E = evaporation discharge per unit surface area (m/s). In the mass transfer equation, E is a function of wind velocity over the evaporating surface, water surface temperature, air temperature, and relative humidity of the air above the water surface.

Unit length Channel cost will be the summation of Equation 4.9, 4.10 and 4.11 as follows:

$$C = C_e + C_L + C_w \tag{4.12}$$

The design engineer needs to select a channel cross-section that is efficient in hydraulic performance and economical in construction cost (Blackler and Guo, 2009).

The total cost of open channel construction is consisting of three elements:

1. Excavation cost for cross-sectional area.
2. Lining cost for cross-sectional surface.

3. Land acquisition.

These three cost elements are directly related to the channel width and flow depth. This fact implies that both efficient and least-cost channel cross sections can be formulated and optimized by the channel width to depth ratio.

Before optimizing the b/y ratio, the longitudinal slope, S_o, has to be predetermined by the allowable permissible flow velocity using a drop structure (Guo, 2004). According to Manning's formula, the channel hydraulic efficiency can be related to the b/y ratio. The most efficient channel cross-section had been formulated as (Chow 1959; Guo and Hughes 1984):

$$b / y = 2 \left(\sqrt{1 + z^2} - z\right) \quad (4.13)$$

According Blackler and Guo, (2009),Equation 4.13 could be reformulated as below:

$$b / y = 2(1 - R)\left(\sqrt{1 + z^2} - z\right) \quad (4.14)$$

Where R = cost factor determined by channel lining to land cost ratio and z is side slope.

Many previous studies indicate that the most efficient channel cross-section can be defined by the b/y ratio. In the research performed by Blackler and Guo, (2009),the most efficient channel cross-section is not necessary to provide the least-cost cross-section. Also, the latest channel cost record was collected and analyzed to provide the cost function directly related to the channel cross-sectional geometry. Using the optimization approach, the channel least-cost function is formulated using a dimensionless cost factor and the b/y ratio. The b/y ratio for the least-cost channel section is always smaller than that derived for the most hydraulically efficient section. The difference decreases as the lining to land cost ratio increases.

CHAPTER 5

COMPUTER PROGRAM FOR OPEN CHANNEL OPTIMIZATION

5.1 The Need of a New Approach

In fact, the optimization process of lateral cross-section design in open channels has been investigated previously by many researchers; however, due to the high number of variables involved in the process, and also, due to the existence of more than one optimization target, there is a clear need for more work and progress in the optimization process. The most common target is to optimize channel lining; another one is to optimize the cross-section in order to obtain the maximum flow; also, it is clearly preferred to minimize the exposed surface in order to minimize both evaporation and seepage losses.

It is possible to observe that, through going through previous works in the field of optimizing the design of open channel cross-section, that the practical side of the design process is not given enough attention. In other words, in every design, there are certain ranges to the variation of several variables (input or output) that could be tolerated according to the local conditions of the project in concern. These ranges appear not to be taken into consideration in the design using the different methods proposed in previous works. It is thought that the main reason for the lack of such consideration could be the huge number of probable solutions needed to select the optimum one among them.

The idea explained in the previous paragraph lead to the thought using computer in a way that would enable for the input of different variables with tolerated ranges that are specified by the designer, and let a computer program produce the huge number of probable solution with tiny increments applied on each variable separately, and then, select the optimum solution among the available ones according to the target specified/selected by the designer/computer user.

The previous proposal may lead to two methods in approaching the problem. The first is to select one single target as the only variable value to optimize regardless of the resultant values of the output variables which may include some other targets that have priorities relatively less than the priority of the selected one. The drawback of this method is that when optimizing one single essential target, the other relatively less essential targets may deteriorate to unacceptable limits.

The latter conclusion in the previous paragraph automatically leads to the consideration of the second method where a group of targets may be considered with different priority orders, specified by the designer/computer user. Thus the computer should search, among the huge number of alternative solutions produced by the tiny increments on each variable as explained previously, for the optimum solution that would satisfy the optimization of the targets according to the specified ratios of the different targets.

It is also necessary to indicate that it is nearly impossible to achieve an optimum value to several targets at the same time in the one single cross-section. In other words, when one target is optimized, this optimization is likely to lead to some degree of deterioration in one or more of the other targets. Therefore, it appears essential to specify a single target as priority number one, and preferably, to specify the degree of priorities of the rest of targets, at least to prevent having severe deterioration in the rest of the targets if target number one is considered alone.

As explained earlier in this section, the computer should be instructed/programmed in a way that should cancel any resultant solution/s that produces one or more of the output variables that appear to be out of the acceptable range specified in advance by the computer user.

The main work in this thesis is involved in the design of a computer program that would solve the problem of the design of open channel lateral cross-section with the consideration of the existence of constraints in both input and output variable.

This program is written in Visual Basic 6.0 language. This language is thought to be more suitable for such aim because of being user-friendly as well as for being capable of executing complicated mathematical processes.

5.2 Computerized Solution for Open Channel Optimization

Before the time when computers were affordable and/or when there were no suitable programs for each problem, engineers used to make rough assumptions with the aid of their experience both in the field and design office (action and reaction). Performing a huge number of solutions that depend on many different assumptions to the same variable, and repeating the process yet again for a huge number of other assumptions for other variables, was out of the question due to the abnormally long time and effort required for the calculations.

Previously, the common practice is to avoid complicated mathematical solution in the design of open channel cross-section and make assumptions that would help in the design to make it ‘reasonable’ in terms of being economic and safe. The problem was that what an engineer used to consider as ‘reasonable’ for both the assumptions and/or the output may not have been considered reasonable for other engineers. Worse than that is when all engineers agree about a particular solution that is doing the job right while it could have been done better from the design and/or the performance and/or the cost point of views.

Relatively recently, computers have the advantage of speeding up the period required for the solution of mathematical problems, and thus, create the opportunity to perform huge number of alternative solutions to select from according to the requirements of the user. This property is thought extremely useful in this research due to the type of the problem which includes huge number of iterations that can never be performed manually.

There are several advantages of using computerized solutions for usual hydraulic problems:

1. Reduce the time that carry out in the calculation process.
2. Computer solutions can be more detailed when compared to hand calculations. Carrying out solution by hand repeatedly requires many simplifying assumptions.
3. The solution progression may be less error-prone.
4. The solution is without difficulty documented and reproducible.
5. Because of the speed and accuracy of a computer model, more evaluations and design trials can be carried out in less time than what single computation would take by hand. This results in the investigation of more design options, which finally leads to better more professional designs.

5.3 Optimization Algorithm in Open Channel Lateral Cross-Section

An optimization model generally consists of an objective function and various constraint functions which control the value of the objective function. The objective function is the function which is generally to be minimized or maximized provided that all the constraints are satisfied. In the domain of the optimization model, the objective function may have different local optimum values which all satisfy the constraints. The exact optimum value should be the one which is optimum in the whole domain of the model, i.e. the global optimum value.

Selection of the section variables such as channel water depth, bottom width and side slope for open channel sections varies according to the objective of the designer and the project requirements. For different optimization targets, it is possible to have different values of the same section variables.

5.3.1 Trapezoidal Section

The most widely used open channel cross-sections in engineering is trapezoidal cross-section. For carrying large amount of discharges, the rectangular and triangular cross-sections are not preferred. Nearly all of the main water channels conveying lines have trapezoidal cross-section (Özcan, 2005).

The extremely important point in using of trapezoidal cross-section is their being relatively easier for construction. Alongside their constructional advantage, they have furthermore beneficial of high hydraulic efficiency. Consequently, it is not unexpected that most of the open channels and discharge lines have been constructed in trapezoidal geometry.

Here, to define a trapezoidal cross-section, three variables should be defined i.e., bottom width, side slope, and water depth (Figure 5.1). The optimum values of these variables, which result in the optimized cross-section for a given discharge and bed slope, can be computed by using the optimization algorithm.

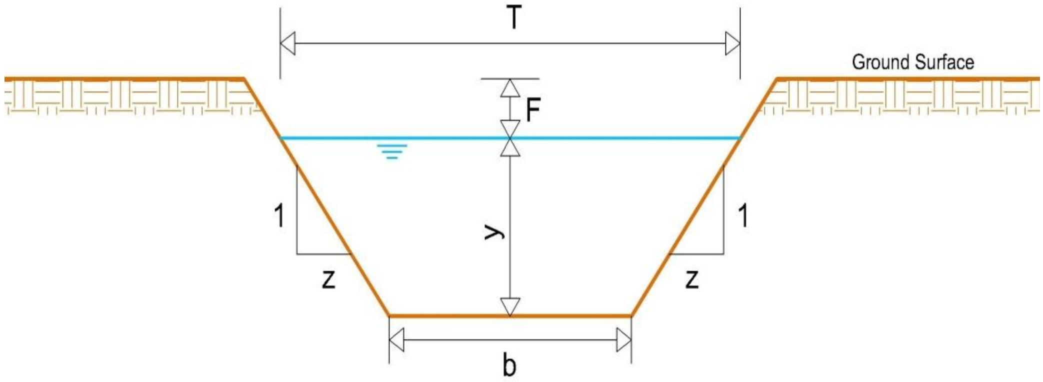

Figure 5.1. Trapezoidal Channel Section.

The geometrical parameters of a trapezoidal section in terms of section variables can be articulated as follows, for finding cross-sectional area, wetted perimeter and exposed surface:

$$A_c = (b + z\,.\,y)\,y \tag{5.1}$$

$$P_c = b + 2\,y\,\sqrt{1 + z^2} \tag{5.2}$$

$$T_c = b + 2\,(z.\,y) \tag{5.3}$$

$y_{i+1} = y_i + h$, $b_{j+1} = b_j + h$ and $z_{k+1} = z_k + h$

For i, j and $k \in 0, 1, 2, \ldots$ and h is the step size.

Where y is the depth of water flow, b is the bottom width, z is the side slope of excavated earth, A_c is the calculated cross-sectional area, P_c is the calculated wetted perimeter, and T_c is the calculated top width of the channel.

Hydraulic radius is defined as the ratio of the channels calculated cross-sectional area of the flow to its calculated wetted perimeter:

$$R = A_c / P_c \tag{5.4}$$

By the using of Manning formula, the velocity (m/s) can be find:

$$V_c = \frac{1}{n} R^{2/3} S_o^{1/2} \tag{5.5}$$

$V_c \in [V_{min}, V_{max}]$

Where V_c the calculated velocity, n is the Manning's roughness coefficient, R is the hydraulic radius, S_o is the bed slope of the channel, V_{min} is the minimum allowable velocity and V_{max} is the maximum velocity.

The discharge (m^3/s) can be calculated by the using of continuity equation:

$$Q_c = V_c A_c \tag{5.6}$$

Where Q_c is the calculated discharge and the acceptedQ_c satisfies the following condition:

$$Q - \varepsilon \leq Q_c \leq Q + \varepsilon$$

Where$\varepsilon$is equal to 0.001

USBR recommends this formula to finding the freeboard (USBR, 1963):

$$F = C \cdot y_c \tag{5.7}$$

Where F is the freeboard and the value of the coefficient C depends on the value of the discharge. C varies from 0.46 for channel capacity of 0.56(m^3/s) to 0.76 for channel capacity of 85(m^3/s).

$$A_f = (T_c + z\,.\,F)\,F \tag{5.8}$$

$$A_T = A_c + A_f \tag{5.9}$$

In these formulas, A_f is the cross-sectional area above the freeboard, and A_T is the total area (summation of the calculated cross-sectional area and cross-section area above thefreeboard).

In order to find the cost of channel lining the total wetted perimeter P_T can be found by adding the value of the wetted perimeter of the flow cross-section P_c to the value of the length of the banks P_f relevant to the freeboard F, found from formula (5.7), as follows:

$$P_f = 2\,.\,F\,.\sqrt{1 + z^2} \tag{5.10}$$

$$P_T = P_c + P_f \tag{5.11}$$

The total cost of channels includes the cost of the excavation ($/$m^3$) and cost of channel lining ($/$m^2$), and in meter per longitudinal length of channel ($/m):

$$C_e = (A_T c_e).1 \tag{5.12}$$

$$C_L = (P_T c_L).1 \tag{5.13}$$

$$C_T = C_e + C_L \tag{5.14}$$

Where C_e is the excavation cost per meter volume, C_L is the cost of lining per meter square, c_e is the excavation price, and c_L is the lining price.

The optimized cross-section can be found by selecting the minimum value of the total target ratios as follows:

$$O_{cs} = R_p P_c + R_A A_c + R_T T_c \tag{5.15}$$

Where O_{cs} is the total of the values of all optimization targets of the optimum cross-section. In this formula, R_p is the ratio of wetted perimeter target, R_A is the ratio of cross-sectional area target, and R_T is the ratio of exposed surface target.

By means of Equation 5.15, the user of 'Open Channel Optimizer'program can find the optimum cross-section according to the required/imposed local constraints, for the trapezoidal cross-section. An important point is the user can increase and decrease the optimization target ratios that cause to maximizing and minimizing the results. For example, when the user increases the wetted perimeter ratio, which means giving the priority to wetted perimeter, the program will optimize the lateral cross-section in order to obtain a minimum wetted perimeter and other calculated parameters are changes accordingly. It is preferable to enter the constraints and input dataset are near to each other and it must be logical.

5.3.2 Rectangular Section

The other one of the widely used in channels construction is the rectangular cross-section. Rectangular cross-section is applicable for water conveyance in irrigation and municipal purposes, flood protection structures, stilling basins of spillways, and other applications (Özcan, 2005).

The difference point between rectangular sections with the others shapes, that rectangular cross-sections have, for a particular discharge, the advantage of being constructed by minimum exposed surface usage. This advantage of rectangular channels makes them desirable for the projects where the allocated area for construction is restricted, for example hot weather or being nearby human activities.

It should be remembered that rectangular channel cross section has two important disadvantages makes it second preferred after the trapezoidal one. The first is having the same evaporation rate for any flow less that the design discharge. The second is the frequent need for the reinforcement of channel sides for being vertical in order to minimize the probability of side collapse due to the outside pressure of soil in case of being under ground level, and in order to prevent being collapsed due to water pressure from the inside in case the channel is being constructed above earth level.

Rectangular section can be defined by two section variables, depth of water flow y and bottom width b (Figure 5.2).

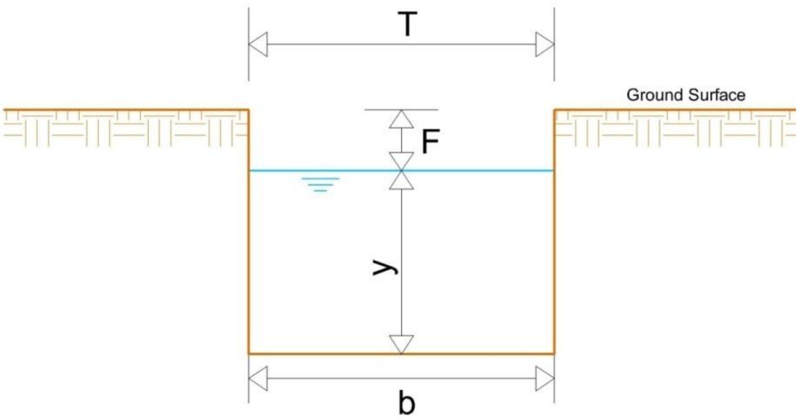

Figure 5.2. Rectangular Channel Section.

The geometrical parameters of a rectangular section in terms of section variables can be articulated as follows, for finding cross-sectional area, wetted perimeter and exposed surface:

$$A_c = b \,.\, y \tag{5.16}$$

$$P_c = b + 2\,y \tag{5.17}$$

$$T_c = b \tag{5.18}$$

$y_{i+1} = y_i + h$ and $b_{j+1} = b_j + h$

For i and $j \in 0,1,2,\dots$ and h is the step size.

Hydraulic radius is defined as the ratio of the channels cross-sectional area of the flow to its wetted perimeter:

$$R = A_c \,/\, P_c$$

By the using of Manning formula, the velocity (m/s) can be find:

$$V_c = \frac{1}{n} R^{2/3} S^{1/2}$$

$V_c \in [V_{min}, V_{max}]$

The discharge (m³/s) can be calculated by the using of continuity equation:

$$Q_c = V_c A_c$$

$$Q - \varepsilon \leq Q_c \leq Q + \varepsilon$$

Where εis equal to 0.001

USBR recommends this formula to finding the freeboard (USBR, 1963):

$$F = C \,.\, y_c$$

The value of the coefficient C depends on the value of the discharge. C varies from 0.46 for channel capacity of 0.56(m³/s) to 0.76 for channel capacity of 85(m³/s), then:

$$A_f = T_c . F \tag{5.19}$$

$$A_T = A_c + A_f$$

In order to find the cost of channel lining the total wetted perimeter P_T can be found by adding the value of the wetted perimeter of the flow cross-section P_c to the value of the length of the banks P_f relevant to the freeboard F, found from formula (5.7), as follows:

$$P_f = 2\,.\,F \tag{5.20}$$

$$P_T = P_c + P_f$$

The total cost of channels includes the cost of the excavation ($/m³) and cost of channel lining ($/m²), and in meter per longitudinal length of channel ($/m):

$$C_e = (A_T c_e) * 1$$

$$C_L = (P_T c_L) * 1$$

$$C_T = C_e + C_L$$

The optimized cross-section can be finding by this object function:

Minimum $O_{cs} = R_p P_c + R_A A_c + R_T T_c$

The process of optimization in rectangular sections are the same with trapezoidal sections, the difference between them is in rectangular channels side slope is zero.

5.3.3 Triangular Section

Triangular open channel cross-sections are generally appropriate for relatively low discharges. This may be applicable in drainage facilities of roadways, laboratory experiments and the like.

Triangular section can be defined by two section variables, depth of water flow y and side slope z as shown in Figure 5.3 below.

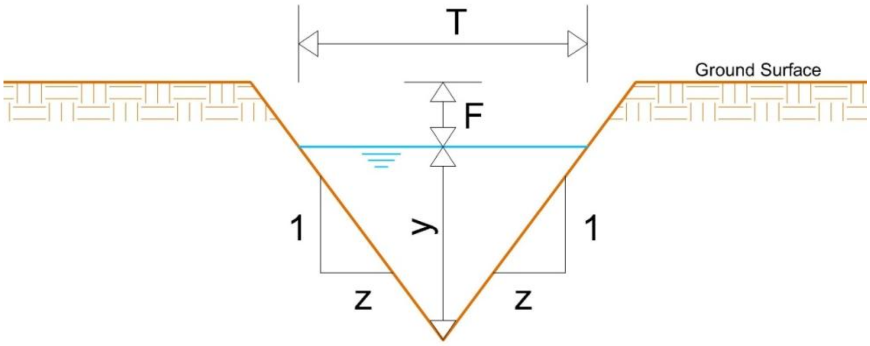

Figure 5.3. Triangular Channel Section.

The geometrical parameters of a triangular section in terms of section variables can be articulated as follows, for finding cross-sectional area, wetted perimeter and exposed surface:

$$A_c = (z \, . \, y) \, y \tag{5.21}$$

$$P_c = 2 \, y \sqrt{1 + z^2} \tag{5.22}$$

$$T_c = 2 \, (z \, . \, y) \tag{5.23}$$

$y_{i+1} = y_i + h$ and $z_{j+1} = z_j + h$

For i and $j \in 0,1,2, \ldots$ and h is the step size.

Hydraulic radius is defined as the ratio of the channels cross-sectional area of the flow to its wetted perimeter:

$$R = A_c \, / \, P_c$$

By the using of Manning formula, the velocity can be find:

$$V_c = \frac{1}{n} R^{2/3} S^{1/2}$$

$V_c \in [V_{min}, V_{max}]$

The discharge (m^3/s) can be calculated by the using of continuity equation:

$$Q_c = V_c A_c$$

$$Q - \varepsilon \leq Q_c \leq Q + \varepsilon$$

Where ε is equal to 0.001

USBR recommends this formula to finding the freeboard (USBR, 1963):

$$F = C \, . \, y_c$$

The value of the coefficient C depends on the value of the discharge. C varies from 0.46 for channel capacity of 0.56(m^3/s) to 0.76 for channel capacity of 85(m^3/s), then:

$$A_f = (T_c + z.F)\, F$$

$$A_T = A_c + A_f$$

In order to find the cost of channel lining the total wetted perimeter P_T can be found by adding the value of the wetted perimeter of the flow cross-section P_c to the value of the length of the banks P_f relevant to the freeboard F, found from formula (5.7), as follows:

$$P_f = 2 \, . \, F \, . \, \sqrt{1 + z^2}$$

$$P_T = P_c + P_f$$

The total cost of channels includes the cost of the excavation ($/$m^3$) and cost of channel lining ($/$m^2$), and in meter per longitudinal length of channel ($/m):

$$C_e = (A_T c_e) * 1$$

$$C_L = (A_c c_L) * 1$$

$$C_T = C_e + C_L$$

The optimized cross-section can be finding by this object function:

Minimum $O_{cs} = R_p P_c + R_A A_c + R_T T_c$

Optimum cross-section for triangular shapes is the same procedures, like, trapezoidal and rectangular shapes. But the most important different between them, in triangular shapes, bottom width is zero. In fact, the difficulties experienced in clearing the bottom from any probable settlement of sedimentation is the main disadvantage of triangular cross section, where adding even a narrow bottom to the triangular cross-section makes it turn to be trapezoidal with much easier accessibility for maintenance purposes. However, for the same triangular cross-section designed for a particular design discharge, this triangular cross-section has the same advantage as the trapezoidal for having less evaporation rate with the decrease of flow.

The optimization according to the principle explained previously is more realistic than the other procedures explained in previous works. This is because the optimization process in open channels depends on local conditions and requirements and cannot be considered to be global. This point makes the approach to solving the problem of optimization in open channel different from other approaches in a way of being more realistic and has more flexibility in regional application.

5.4 Introduction to 'Open Channel Optimizer' Program

'Open Channel Optimizer' is an engineering program that deals with optimizing the design of lateral cross-section of open channels. The program depends on the commonly used Manning formula for the design of lateral section of open channels.

The program is user-friendly for engineers who wish to obtain the optimum open channel cross-section for irrigation or any other purposes. ‘Open Channel Optimizer’ is given the logo shown in Figure 5.4.This program was written by using Visual Basic 6.0 language for being relatively the most suitable for the objective. The size of this version of the program is 1.24 MB which is extremely little when considering the memory capabilities of computers in recent years.

Figure 5.4. Logo of the ‘Open Channel Optimizer’

5.5 Program Calculations and Flowcharts

In this section, the method and logic of all what is related to the calculations are explained along with the explanation of the steps followed in the sequence of calculations in the flowcharts, and also, the flowcharts themselves are presented.

5.5.1 Used Formula in the Program

One of the most commonly used equation governing open channel flow is Manning’s equation. It was introduced by the Irish engineer Robert Manning in 1889 as an alternative to the Chezy equation. The Manning’s equation is an empirical equation that applies to uniform flow in open channels and is a function of the channel velocity, flow area and channel bed slope.

$$V = \frac{1}{n} R^{2/3} S_o^{1/2} \qquad (5.24)$$

Where Vis the velocity in m/s, R is the hydraulic radius defined as the ratio of the flow area A to the wetted perimeter P, S_o is the channel bed slope, and n is the coefficient of roughness, especially known as Manning Coefficient.

5.5.2 The Determination of the Limits of the Input and Output Variables

Practically speaking, all problems have implicit limits or constraints regarding their input and out variables in a way that if an out of the ordinary input value was given to the computer, it is likely that the results of the computer run will appear abnormal too. In order to save time, it was thought to clarify the limits within which some variables could be dealt with or be input in a way that a reasonable output could be expected from the computer within a reasonable period of time.

In this section, the limits thought to be suitable for the input variables are explained. It is thought to consider the limits in a way that the program would be practically as useful for most purposes as possible while minimizing the probability of any run with input variables that could lead to an extremely long period of solution, or, of a solution with output that cannot be practically applicable.

The following are the limits and/or constraints that are thought to be reasonably acceptable for practical applications:

1. The discharge: between 0.1m^3/s for laboratory purposes up to 10m^3/s for relatively large channels.
2. Bed slope: thought to consider the very gentle slope of 0.00005 m/m for the cases when water is sediment free and likely to flow with very low velocity,

up to 0.009 m/m which is considered to be a relatively steep slope for open channel design.

3. Velocity of the water flow: is given tolerance between 0.2m/s for sediment free flow up till 3m/s which is considered to be high velocity and applicable only for lined channels.
4. Water depth: considered from as low as 0.1m to 4m depth for relatively large channels.
5. Bottom width: limited to 0.2m to as wide as 8.0m.
6. Side slope: considered as steep as 0.3 to as flat as 3 (horizontal/ 1vertical).
7. Top width: because of being an output with no control for the minimum level, only the maximum limit was imposed in a way that the user could have the chance to establish clear limits to the cost of the occupied land as well as to the amount of water lost through evaporation. Here the maximum top with was selected to be 10m, which could be considered generously wide for large channels.

The target of the optimization is another input variable. However, as explained previously, the program has specified three probable targets. These are: wetted perimeter, cross sectional area, and the exposed surface.

5.5.3 The Logic of the Variable Increments and Iterations of the Program

The logic of the program is to compute a huge number of probable solutions for the design of lateral cross-section of a proposed open channel, which has input values within the limits explained and shown in the screen of the program, and select an optimum one solution among them. Thus, the selected solution would satisfy the selected target, or, the selected ratios of the different presented targets.

The iteration process in the program of a trapezoidal cross-section is explained below. However, it should be noted that the iteration in the program for both rectangular and triangular cross-sections are very similar with the difference that the side slope is not iterated in the rectangular cross-section for being vertical, and the bottom width is not iterated in the triangular cross-section for being zero.

The basic principle of the iterations within the program is to start in calculating the cross section that results from the minimum limits of all variables that are input by the user and check whether the calculated discharge equals the calculated one, of course, with defined negligible tolerance of $0.001m^3/s$. Moreover, the resultant top width and velocity are checked to be within the limits defined by the user before the start of the run. If this step of calculations appears to satisfy these conditions, then, this resultant cross-section is considered to be only one of the probable cross-sections among the huge number that will be produced in the following steps/iterations

The following iterations could be explained briefly by using all probable values within the ranges of three variables for finding a solution to the cross-section. These three variables are the side slope, the bottom width, and the water depth. Each range of these three variables could produce many probable values by adding defined tiny increment and repeating the whole thing. The number of solution probabilities in such case could be found by multiplying the number of possible increments in the range of the first variable (the side slope) by the probable increments in the second variable (the bottom width), and finally, multiplied by the number of increments in the third variable (the water depth).

After the computer stores all successful probable solutions, the following step is to simply select the one that satisfies the required target or targets. If the target is selected as being absolute without other targets, this means that the target is independent from other targets and it has the only super priority, which is 100%. In this case, the computer will search for the optimum solution among the available huge number of probable solutions. In case the target is minimizing wetted perimeter, then, the cross section with the least wetted perimeter would be selected among all the rest of the solutions. In case the target is minimizing excavations, then, the cross-section with the least cross-sectional area would be selected. Similarly, in case the target is minimizing the exposed surface, then, the cross-section with the least top width would be selected. In case the user defines more than one target (two or three), all probable cross section solutions would be applied to perform the Equation 5.15 for the optimization of multi-target optimization process, and the minimum value of the equation results would be selected to represent the required optimum cross-section.

5.5.4 Flowchart

The flowcharts in this section explain all details of the steps followed by the program for the optimization of open channel lateral cross-section. Since there are three choices of cross-sections among which the user is free to select, three independent flowcharts are designed to explain the flow of processes in each of these choices.

5.5.4.1 Trapezoidal Flowchart

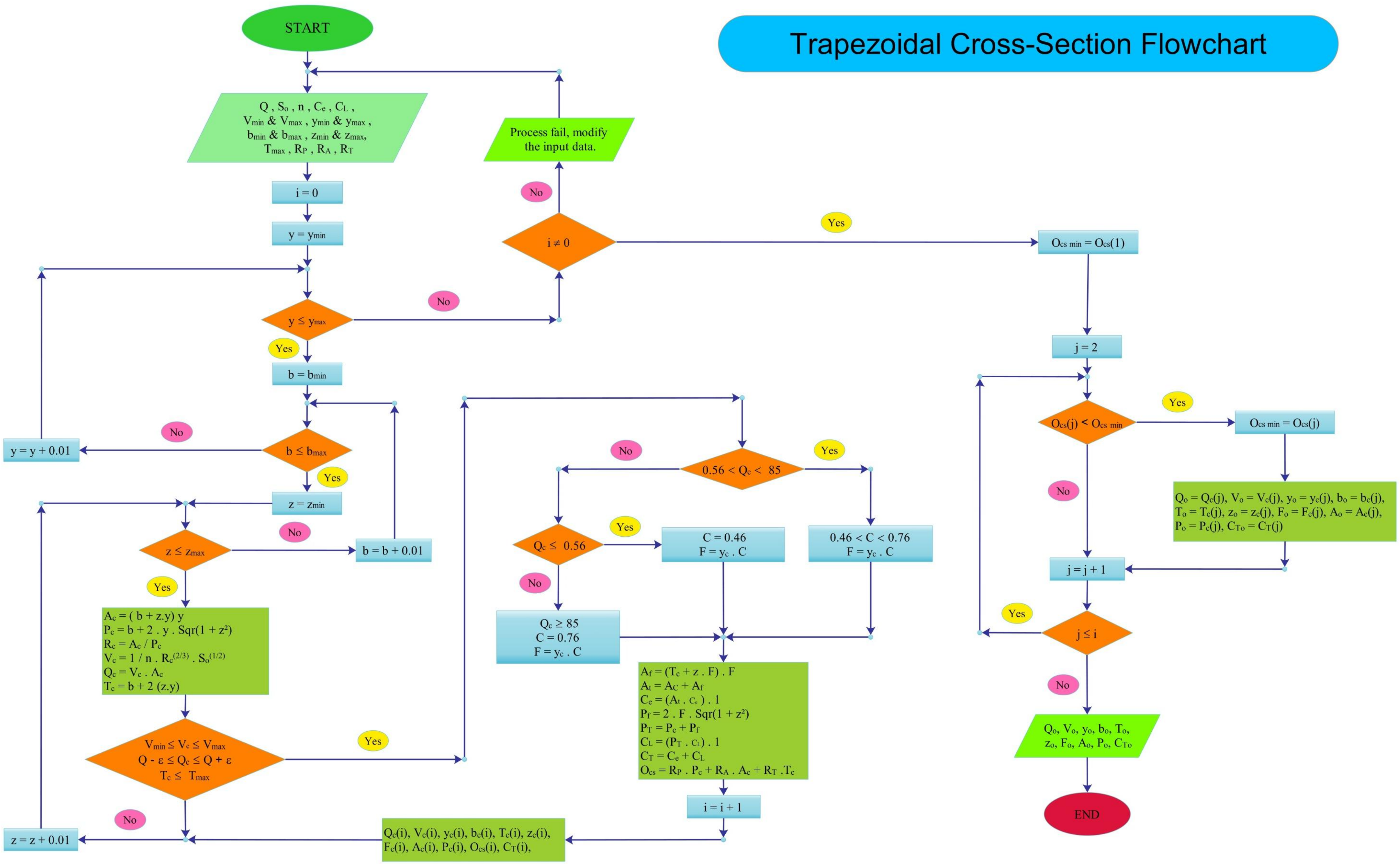

Figure 5.5. Trapezoidal Flowchart

5.5.4.2 Rectangular Flowchart

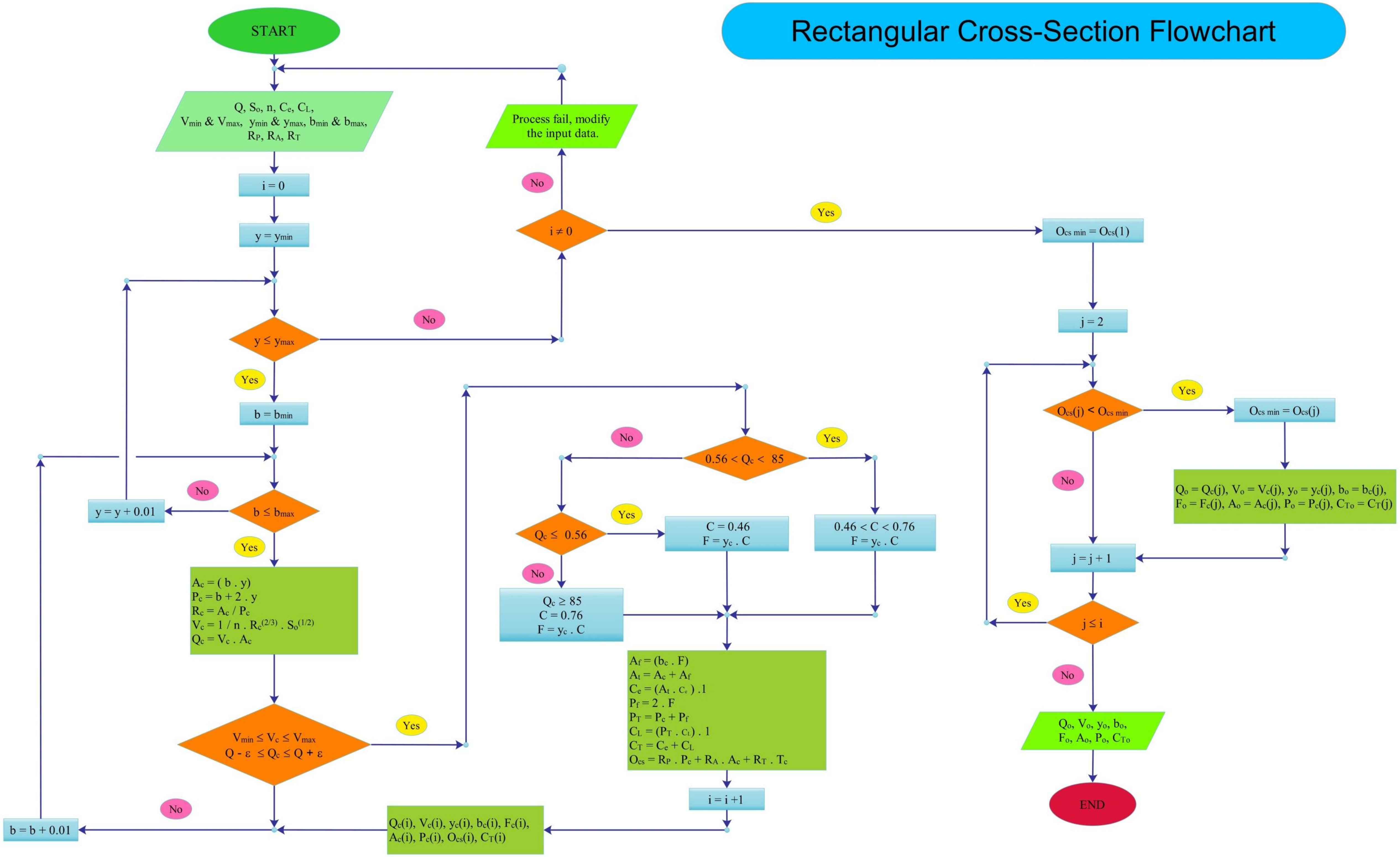

Figure 5.6. Rectangular Flowchart

5.5.4.3 Triangular Flowchart

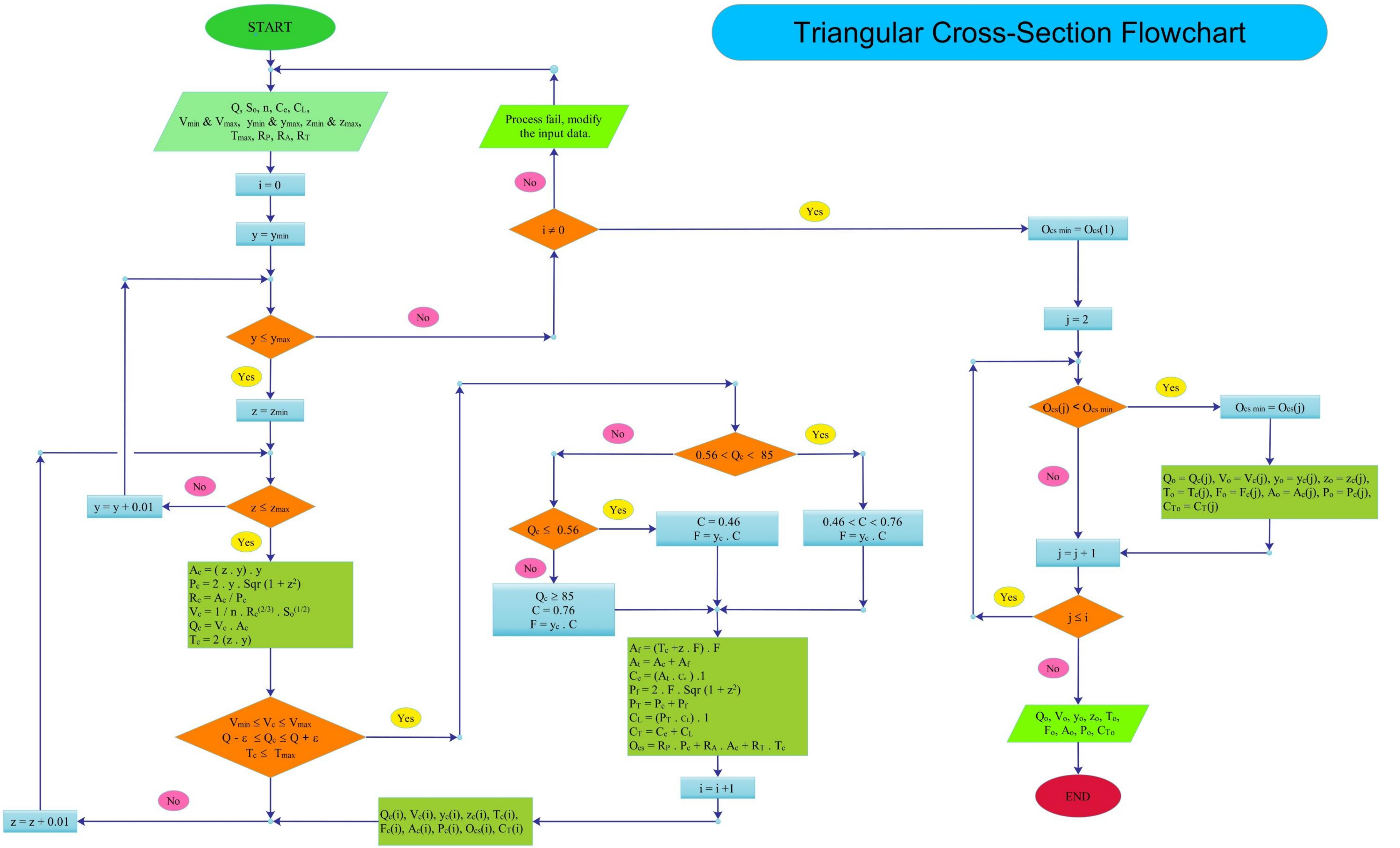

Figure 5.7. Triangular Flowchart

5.6 Properties of the Program

1. ‘Open Channel Optimizer’ has a visual and useful interface for users. It is a user-approachable program. Easily entering or changing input parameters during design process of optimum open channel cross-section.
2. Computerized computations are more fast and effortless to solve than hand classical calculations. By the use of ‘Open Channel Optimizer’ an engineer can assess the characteristics parameters (water depth, bottom width, side slope etc.) of an open channel easily.
3. Manning roughness coefficient values are embedded in the program. The user is free to use the available given list in the program by clicking on the command button beside to the input textbox or enter own value for absolute roughness.
4. After clicking on the ‘Design’ button, the results will be written inside private textboxes. Also, the user can see a typical shape of cross-sections inside the forms.
5. Internet provider and calculator are available in the program. User can use it whenever it necessary.
6. ‘Open Channel Optimizer’ is able to help engineers who deal with design of optimum open channel cross-section like irrigation and drainage channels.
7. The input data is divided to two types, invariable data (Input data) and variable data (constraints). Invariable data likes; discharge, manning coefficient and bed slope. Variable data likes; velocity, water depth, bottom depth, side slope and top width. Optimization process is depends on the user objective, the user free in giving priority to optimization targets.

5.7 Running the Program

The starting page of the program 'Open Channel Optimizer' is shown in Figure 5.8.

Figure 5.8. Starting Screen.

For any reason, if the user wishes to exit the program, there is an 'Exit' button to be clicked for this purpose. In order to initiate the use of the program, the button 'Enter' should be clicked. This will lead to the following screen for the selection of the required section geometry as shown in Figure 5.9.

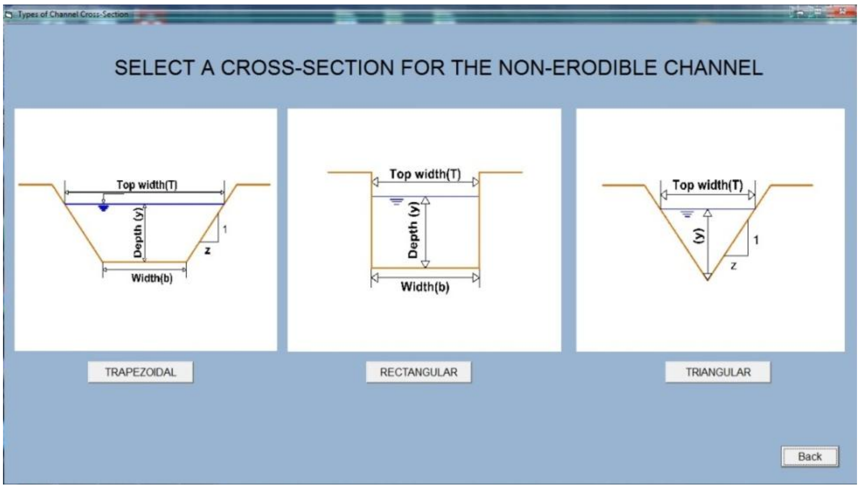

Figure 5.9. Selecting Section Geometry.

If the user decides to design and optimize an open channel cross-section, user can click on the one of the section geometry buttons. Also the user can close the program by clicking on the 'Exit' program button.

Steps to optimize and design an open channel lateral cross-section, are as follows:

A. When the trapezoidal shape is selected, a new screen will appear as shown in Figure 5.10.

Figure 5.10. Trapezoidal Section Design.

B. Here the user will start to write and enter the input data and constraint to the program as shown in (Figure 5.11).

Figure 5.11. Entering Input Data and Constraints to Trapezoidal Section.

C. Within the limits shown on the screen, the values of the design discharge and bed slope should be entered. The estimated value of Manning coefficient should be selected from the table that appears through clicking the relevant button, and also, after defining the price of excavation and lining. After that, the extreme allowable limits should be defined by the user for some variables according to the local conditions of the project regarding all its aspects. These variables are the flow velocity, the water depth, the bottom, top width, and the side slope. The last input is to enter the variable targeted for optimization, or the percentage of priority in case being more than one. The latter case offers three targets with a box near each for writing the percentage of priority for each

After all required data is input by the user, the button 'Design' should be clicked in order to initiate the run. Since the calculations required for the different alternative cross-sections are usually many thousands, a temporary screen will appear asking the user to wait, as shown in Figure 5.12.

Figure 5.12. The Screen Appearing After Clicking the 'Design'Button.

D. The user can see a typical shape of a trapezoidal cross-section as shown in Figure 5.13.

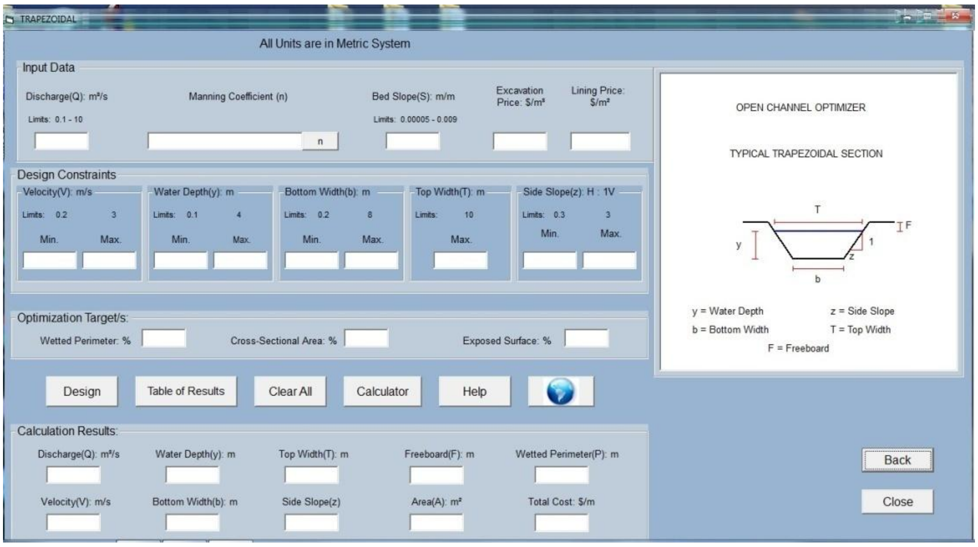

Figure 5.13. Appearing Typical Shape.

5.8 Recommendation for the Users of 'Open Channel Optimizer'

1. The input data and constraint should be between the limits of the program otherwise, an error message would appear for reminding the user to repeat entering the wrong value of variable within the defined limits. Also, another error message will appear if the values were within the allowable limits but with reversed order, such as the maximum value being less than the minimum, or, such as entering negative values etc.

2. In order to obtain the results within a relatively short period, it is recommended to decrease the range of the variables regarding their minimum and maximum limit. For example instead of (0.1 - 3), it is preferable to enter (0.1 -1).The latter range would significantly decrease the number of increments within this range, and thus, decrease the number of required iterations and reduce the required time of the run.

3. If an inexperienced user input a narrow range for the different variables in a way that lacks logic (i.e. having a steep slope and defining a narrow limit of a relatively slow velocity, or, vice versa), the program is likely to show an error message recommending the modification of the defined limits of the input data.

4. The total value of the ratios of priorities of optimization target (percentage) must be 100 percentages. Any total other than this will result in a warning message to remind the user to correct the values and renter them.

5. During the run time, while the calculations are performed in the computer, and while the window 'Please Wait' appears on the screen, the user should wait and not click any button until the screen of the results appear, otherwise, the run will be interrupted and the run would certainly fail.

6. The typical of open channel lateral cross-section will appear and not a scaled figure. The main aim is to indicate the meaning of the variables.

7. At any time of using 'Open Channel Optimizer', for browsing about open channels, the user can use the browsing button that connects the user with internet.

8. For any help about the program or how to use the program, by clicking on the 'Help' button, the user can get help.

9. For checking any results by calculator, by one click the user can use the 'Calculator' inside the program.

5.9 Design Example and Results

The following is a typical example of the design of lateral cross-section in open channels. In order to present the relation between the different targets when varying their priority order and ratios, it is thought to repeat the same input values with step by step variation of these ratios, and thus, the plotted results would show the influence of raising the ratio of priority of a particular target on the other two targets. This is essential for the user to know when allocating full priority to only one single target.

The input values along with the local constraints are defined, and then, these values are used for performing a run on the 'Open Channel Optimizer'. The results of the run are shown:

Design a trapezoidal open channel that carries a discharge 0.5m^3/s, with bed slope of 0.0001 and Manning coefficient of 0.013. The excavation price is 3\$/m^3, and the price for unit lining is 7\$/m^2.The local conditions of the region of the project impose the following constraints:

Variable	Min.	Max.
Velocity (m/s)	0.3	1.8
Water Depth (m)	0.1	1
Bottom Width (m)	0.5	1.3
Side Slope	0.4	1.8
Top Width (m)		2.3

The screen showing all input values entered is shown in Figure 5.14.

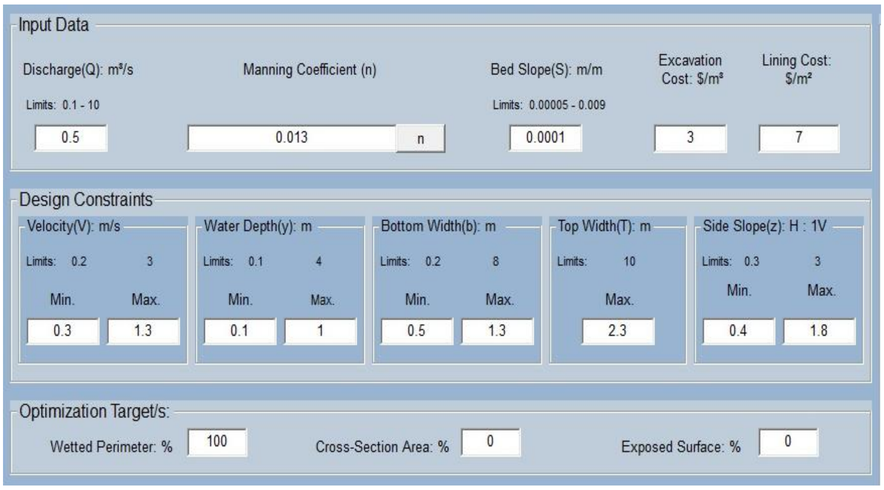

Figure 5.14. Entering the Input Data into the 'Open Channel Optimizer'.

The run of the program was performed several times on the input data explained in the previous paragraph and table. However, it is thought to repeat the run with systematic variation of the priorities of the three targets (i.e. wetted perimeter, cross sectional area, and exposed surface). Obviously, the design results vary with the variation of the priority ratio of the targets. The results of all attempts, with the different priority orders of the targets, are shown in Table 5.1.

Table 5.1. Results of the Run

Cases	Optimization Target Ratios			Discharge (m^3/s)	Velocity (m/s)	Water depth (m)	Bottom Width (m)	Top Width (m)	Side Slope	Free board (m)	Cross-Sectional area (m^2)	Wetted Perimeter (m)	Total Cost ($/m)
	Wetted Perimeter (%)	Cross Section Area (%)	Top Width (%)										
Case 1	100	0	0	0.499	0.426	0.830	0.940	1.886	0.570	0.382	1.173	2.851	25.88
Case 2	90	5	5	0.499	0.425	0.840	0.960	1.834	0.520	0.386	1.173	2.854	25.85
Case 3	80	10	10	0.499	0.425	0.840	0.960	1.834	0.520	0.386	1.173	2.854	25.85
Case 4	70	15	15	0.499	0.425	0.870	0.960	1.743	0.450	0.400	1.176	2.868	25.91
Case 5	60	20	20	0.499	0.423	0.900	0.950	1.670	0.400	0.414	1.179	2.889	26.04
Case 6	50	25	25	0.499	0.423	0.900	0.950	1.670	0.400	0.414	1.179	2.889	26.04
Case 7	40	30	30	0.500	0.422	0.960	0.850	1.618	0.400	0.441	1.185	2.918	26.36
Case 8	30	35	35	0.500	0.422	0.960	0.850	1.618	0.400	0.441	1.185	2.918	26.36
Case 9	20	40	40	0.500	0.421	0.980	0.820	1.604	0.400	0.451	1.188	2.931	26.49
Case 10	10	45	45	0.500	0.421	0.980	0.820	1.604	0.400	0.451	1.188	2.931	26.49
Case 11	0	50	50	0.500	0.421	0.980	0.820	1.604	0.400	0.451	1.188	2.931	26.49

5.10 Comparison of 'Open Channel Optimizer' with Other Approaches

The optimization process in open channel is a complicated mathematical process. The approach to the optimization process may be performed through more than one method. Several researchers investigated the optimization process in the design of open channel lateral cross-section.

But the important point that should be mentioned is that previous works concentrated on the optimization of only one target at a time. In fact, the reality during design stages indicates that there are several targets that should be simultaneously considered for optimization. As an example to this observation, it is easy to observe in the work of Swamee, et al., 2001, that the target was minimizing the volume of earthwork in the construction of channel cross-section. Also, the same researcher produced in 2002 an article for minimizing water-loss in channel cross-section.

In order to perform a comparison between the performance of the 'Open Channel Optimizer' with another approach, it appeared better to seek one which implements more than one target at a time, like the work of Guo and Hughes in 1984, where they found a formula that optimizes the cross section with the consideration of minimizing the wetted perimeter as well as the excavation cost (without allocating a particular ratio as the 'Open Channel Optimizer' does). The formula proposed by the latter researchers is Equation 4.13 explained previously as follows:

$$\frac{b}{y} = 2\left(\sqrt{1 + z^2} - z\right)$$

The comparison is thought to be performed by proposing two sets of input data and comparing the results both through the program as well as the Equation 4.13. The first set of input data includes fixed longitudinal slope with several values of discharge, while the other one includes fixed value of discharge with several values of longitudinal slope.

The comparison started by applying both sets of data on the computer with special care to allow maximum applicable range of constraints in order to allow the program to find the really best optimized results, and thus, enable for more realistic comparison with the other method. Here, it should be clarified that the freeboard height is not considered in the equation method, and accordingly, the influence of the freeboard in the program on the results was cancelled. Also, despite the fact that the 'Open Channel Optimizer' program enabled for a variety of ratios for three targets, and for the purpose of making this comparison more realistic and fair, it is thought to give 50% to both wetted perimeter and cross sectional area targets and 0% to top width target. This is due to this situation being equivalent to the case followed during the finding of the equation in concern.

Table 5.2.a. Results of 'Open Channel Optimizer' program runs

Q (m^3/s)	S_o	V (m/s)	y (m)	b (m)	z	b/y	$2\left(\sqrt{1+z^2}-z\right)$	Cost
0.6	0.0002	0.578	0.780	0.870	0.590	1.115	1.142	22.919
1.1		0.672	0.980	1.100	0.580	1.122	1.152	30.101
1.6		0.738	1.130	1.250	0.590	1.106	1.142	35.782
2.1		0.790	1.250	1.400	0.580	1.120	1.152	40.655

Table 5.2.b. Results of 'Open Channel Optimizer' program runs

Q (m^3/s)	S_o	V (m/s)	y (m)	b (m)	z	b/y	$2\left(\sqrt{1+z^2}-z\right)$	Cost
1	0.0005	0.925	0.790	0.940	0.540	1.190	1.193	23.468
	0.0009	1.154	0.720	0.800	0.560	1.111	1.172	20.618
	0.002	1.556	0.600	0.710	0.600	1.183	1.132	17.334
	0.005	2.194	0.520	0.600	0.530	1.154	1.204	14.261

After obtaining the results of the program, which are shown in Tables 5.2a and 5.2b, the following step was to take results of the program regarding the ratio b/y as it is and find the relevant side slope z that would be produced when the left hand side of the formula.

Table 5.3.a. Results of Equation 4.13 application

Q (m^3/s)	S_o	V (m/s)	y (m)	b (m)	z	b/y	$2\left(\sqrt{1+z^2}-z\right)$	Cost
0.6	0.0002	0.578	0.780	0.870	0.618	1.115	1.115	23.145
1.1		0.672	0.980	1.100	0.611	1.122	1.122	30.438
1.6		0.738	1.130	1.250	0.628	1.106	1.106	36.288
2.1		0.790	1.250	1.400	0.613	1.120	1.120	41.158

Table 5.3.b. Results of Equation 4.13 application

Q (m^3/s)	S_o	V (m/s)	y (m)	b (m)	z	b/y	$2\left(\sqrt{1+z^2}-z\right)$	Cost
1	0.0005	0.925	0.790	0.940	0.540	1.190	1.193	23.468
	0.0009	1.154	0.720	0.800	0.622	1.111	1.111	21.065
	0.002	1.556	0.600	0.710	0.55	1.183	1.183	17.053
	0.005	2.194	0.520	0.600	0.578	1.154	1.154	14.482

After that, the construction cost of one meter length of the channel (except land acquisition cost) is compared between both methods. Tables 5.3a and 5.3b show the results of the optimization using the formula with the consideration of b/y as an input.

Comparing the results in the two sets of tables produced by the program and formula, it is possible to observe that the cost of channel construction is, generally, lower when performing the optimization process through the 'Open Channel Optimizer'.

CHAPTER 6

CONCLUSIONS

6.1 Conclusion

This study is focused on the design a program for the design optimum open channel lateral cross-sections. The research also aimed to identify the optimization process in cross-section of open channels such as trapezoidal, rectangular and triangular with the consideration of the priority order of three targets. The following conclusions are made from this study:

1. In this thesis, the design of the program was performed by means of Visual Basic 6.0 language using the name of 'Open Channel Optimizer'. The design of the program is based on a new approach to the optimization method through which a huge number of alternative solutions is produced, and then, the optimum one is selected according to the required ratio of three different targets. In this aspect, previous works were different and aimed to find one single target through a direct calculation using particular formula/s.

2. "Open Channel Optimizer" is able to calculate the commonly required parameters for the design like water depth, bottom width, side slope, velocity, cross-section area, wetted perimeter, top width, besides being able to calculate the freeboard, and total cost of channel construction.

3. The program is able to optimize open channel cross-sections according to three targets in the same time with different priority ratios. These are, the wetted perimeter, cross-sectional area, and exposed surface. The simultaneous consideration of three targets was not approached in previous works, which makes this work original and represents a step forward in this field.
4. This program enables the designer to the freedom of defining the real constraints that should not be exceeded according to the local conditions of the project, and thus, directly reaching the final optimized design without the need to repeat the calculation in case the results show values of one or more of the variables being outside the acceptable range for the local conditions. This means saving time and offering more choice to the designer.
5. Comparing the results of optimization using the 'Open Channel Optimizer' with the results of another approach shows that the former gives relatively less cost for one meter length of channel construction.

6.2 Recommendations

1. In this work, the shapes in concern during the design an optimal open channel cross-section in 'Open Channel Optimizer' are trapezoidal, rectangular, and triangular. The program may be developed for the other shapes, such as semi-circle, oval, and ellipse.
2. The optimization process is a comprehensive process. 'Open Channel Optimizer' optimizes open channel design for its lateral cross section. Obviously, the longitudinal cross section still needs similar work in the same field of optimization.

3. In the thesis, open channel design parameters were computed only for uniform flow. Future work may be developed following similar steps for non-uniform flows in open channel.

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