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THE IMPLEMENTATION OF GIS IN OPTIMIZING THE ALIGNMENT OF OPEN CHANNELS

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The Implementation of GIS in Optimizing the Alignment of Open Channels

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Supervisor

Assist. Prof. Dr. Mazen KAVVAS

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Alaa ALNUAIMI

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Alaa Omar Ali ALNUAIMI

ABSTRACT

THE IMPLEMENTATION OF GIS IN OPTIMIZING THE ALIGNMENT OPEN CHANNELS

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This research involves the attempt to implement Geographic Information System (GIS) to obtain the optimum route/path between given source and demand points that will be lined by an open channel for water conveyance. This kind of route finding is usually performed manually by experienced engineers. The aim here is to minimize the difficult manual side of this process by means of maximizing the use of GIS based computer software. The results of the research shows that the direction of this research is still fresh and that there is a lot of work to be done to improve benefiting from such kind of software, both through understanding the behavior of the software, and also through allocating the performance of such task only to experienced engineers that are familiar with manipulating the software as well as with the different aspects of the optimization of the targeted optimum route. The results of the research were encouraging and prove that besides the success of software in optimizing the route of roads, railways, and pipelines, such software can even be successfully used for the optimization of open channels, where the alignment can move only downwards while considering the target of minimizing the total cut and fill volumes as well as trying to make them as equal as possible.

Key words: Open Channel; GIS; Optimization; Alignment; Cut and Fill

ÖZET

AÇIK KANAL GÜZERGAHI OPTIMIZASYONUNDA GIS KULLANIMI

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Bu araştırma, Coğrafi Bilgi sistemlerini; su iletimi için kullanılacak kaplamalı kanalların kaynak ve talep noktaları arasındaki optimum güzergahı belirlemede kullanılmasını içerir. Bu rota belirleme genel olarak deneyimli mühendisler tarafından manüel olarak yapılmaktadır.

Buradaki amaç bu işlemi manüel olarak yapmanın zorluklarını en aza indirgemek ve coğrafi bilgi sistemi tabanlı bilgisayar programlarının kullanımını yaygınlaştırmaktır.

Sonuçlar gösteriyor ki, bu araştırmanın ulaşması gereken noktanın şu anda başındayız ve bu tip programlardan yeterli faydayı almak için daha fazla araştırma yapılmalı, bu işi yapacak olan mühendisin bu tip programlar konusunda iyi bilgiye sahip olması ayrıca bilgisayar programı olmadan da bu projelerin optimum güzergahını bulma konusunda tecrübeli olması gerekmektedir.

Bu araştırmanın sonuçları gösteriyor ki program, yolların, demiryollarının, boru hatlarının güzergahını bulmakta başarılı olmakta, aşağı doğru giden açık kanalların güzergahı belirlenirken dolgu ve yarmaların eşit ve minimum olması tercih edilir, program bu konuda da başarılı olabilmekte fakat daha fazla araştırma yapılmalıdır.

Anahtar Kelimeler: Açık kanal; GIS; Optimizasyon; Güzergah; Kazı ve Dolgu

This thesis is dedicated to my beloved father, mother, wife, my children, and my family for their endless support and encouragement.

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LIST OF SYMBOLS

b	Bottom Width [m];
z	Side Slope;
y	Water depth [m];
A	Cross-sectional area [m^2];
P_c	Calculated wetted perimeter [m];
P_f	Wetted perimeter above the water level [m];
T	Calculated top width [m];
R	Hydraulic radius flow;
V	Calculated velocity [m/s];
n	Manning coefficient;
S_o	Bed Slope [m/m];
Q	Discharge [m^3/s];
F	Freeboard [m];
GIS	Geographic Information System;
DEM	Digital Elevation Model;
TIN's	Triangular Irregular Networks;

CHAPTER 1

INTRODUCTION

In irrigation systems, water is conveyed to the field through a network of canals, sub-main canals and distributaries. The design process of open channel involves dealing with many variables most of which are interdependent. This makes the design process far from easy, and indicates the need for continuous research and development.

Practically speaking, optimizing the design includes several aspects of more or less equal importance as follows:

a- Maximize the efficiency of the project.

b- Minimize the cost of the project.

c- Maximize the age of the project.

d- Minimize the need for maintenance.

e- Maximize the safety of the project.

However, finding the solution that offers the best efficiency for the lowest cost, according to the local conditions of the project, appears to be the main challenge. Channel design requires substantial investigations depending on lateral cross section as well as on the alignment. Optimizing lateral cross-section through finding the best relation among the different variables (i.e. water depth, bottom width, velocity, wetted perimeter, side slope, freeboard and hydraulic radius) that suits and/or accommodates the given design discharge (demand) that needs to be conveyed for the proposed path/alignment between the source and destination points.

Applying the concept of duality, the most efficient channel cross-section can be obtained by minimizing the excavated channel cross-section area subject to a specified design flow or maximizing the flow capacity subject to a specified channel excavated area (Guo, 2004). However, when the channel construction cost is more complicated than the earth volume excavation, the least-cost channel cross section is different from the most efficient because different objective functions are used in the optimization process (Guo and Hughes, 1984).

The optimization of the selected alignment is governed by more than one factor. These are basically, the bed slope limits (or practical range), the velocity range that that does not enable the settlement of sediment in the flowing water (if sediment loaded), and also, does not cause damage/erosion to the canal structure due to turbulence or high velocity. In fact, there is mutual influence between the selected alignment and the acceptable velocity limits/range, which is indirectly related to bed slope. Therefore, it is essential to select the alignment in a way that would satisfy the given velocity range, and also, minimize encountering one or more of the following:

1- Essential man-made structures that cannot be moved away from the proposed path/alignment.
2- Natural obstacles that cannot be tolerated economically.
3- Historical or other places of sentimental values (cemetery).
4- Steep or flat sections of the probable alignment.
5- Locations where large volumes of cut and fill may be required.

6- Occupying lands where human activities are high (risk of drowning and/or risk of being partially or fully damaged).
7- Occupying lands that are expensive to buy from the owners.

Obviously, the previously explained factors should be cared for while paying most of the attention to select the shortest alignment possible.

To some limit, the selection of the alignment of a proposed canal may resemble the process of selecting the alignment of a proposed road. However, the essential difference between both is the capability of cars to move in an upwards sloping road as well as downwards, while canal water is capable of moving only downwards. Thus, it could be useful to go through the researches that were performed on the selection/optimization of the alignment of a proposed road in order to get whatever may be similar regarding the canal case, of course, while paying attention to the practical differences between both.

Cowen studied an econometric routing model to explore the railway route, which will be use construction expenses such as; the cut and fill costs, road and river crossings and railway track costs as input parameters, (Cowen et al, 2000). They have used high accuracy (DEM) Digital Elevation Model data derived from LIDAR, to indicate that the approximations of GIS Geographic Information System can be balanced by the using high resolution and accurate data. Best-direction surface is use to draw the least cost path from the departure point to the destination point (Lee and stucky, 1988). Thus, considering the minimization of the time spent for decision making and reduction in the cost in order to find the optimum least-cost path automatically, or semi-automatically, between two points within reasonable time is a very important problem to be solved. The solution of this problem, which is formed of simultaneous optimization of multiple conflicting criteria, is not always possible with the full satisfaction of all target functions. Therefore, using GIS, or other similar programs, to reduce the analysis time and improve the accuracy of the analysis by integrating digital data is thought worth being investigated.

1.1 Principal Objective

Finding the optimum route/alignment for channels, roads, and pipes, in the light of the independent emergence of GIS as a professional discipline, is to determine how to use GIS in a useful fashion, either by linking elevation and slope model to GIS or/and rethinking by digital elevation model DEM in spatial terms so that better GIS based triangulated irregular network can be created. The question arises as how one could use GIS to find the least cost path between two points.

The objective of this study is to estimate least cost path between two points and calculating all earth-wok, by two programs ArcGIS with its tools, under the light of GIS. This research is complete work to find many economic paths and select the best least cost path from its rather than calculating cut and fill works, also the methodology of its can be use in channel roads and pipes.

CHAPTER 2

STAGES IN THE DESIGN OF OPEN CHANNEL

Open channel can be defined as man-made channel constructed upon the ground to transfer water from a river, a well, another channel or reservoir to the consumption point. Open channels may be constructed of several shapes, such as rectangular, trapezoidal, circular and triangular cross-sections Figure 2.1.

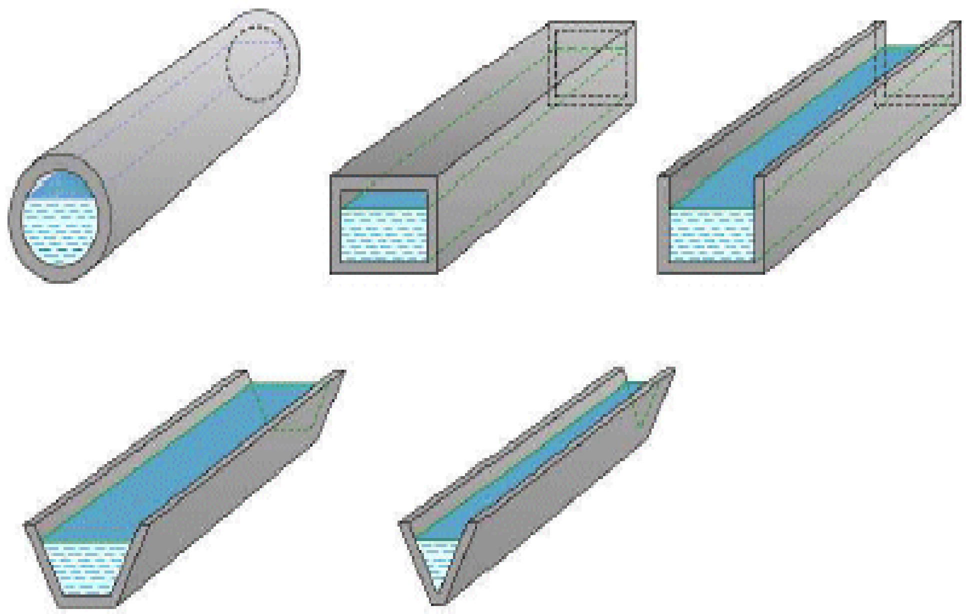


Figure 2.1 An Open Channel Cross-Section Shapes.

2.1 The Data Required for the Design of Typical Open Channel Project

The data required may be divided into several sections as follows:

2.1.1 Discharge

Open channel discharge is the flow of water through the proposed channel, conduit or water way while in contact with atmosphere as shown in Figure 2.2. Flow is measured in terms of volume over time, such as cubic meter per second. The discharge amount is determined by the farmer/s or the agriculture engineers responsible for the region to be irrigated. The value of discharge has clear influence on most other variables relevant to the design procedures.

It should be noted that discharge variation is an essential matter in the design of open channel. Despite that the design of the lateral cross section depends mainly on the maximum predicted discharge (with some safety factor added), the variation or fluctuation of the discharge may affect the selection of the shape of the cross section and/or even the other variable as well, such as the bottom width and depth etc.

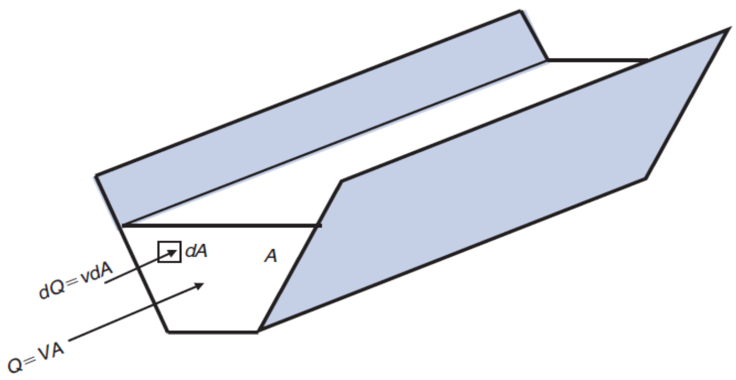


Figure 2.2 Definition of Discharge.

2.1.2 Soil Relevant Variables

Investigating the type of soil means the analysis of non-deformed samples taken from boreholes throughout the proposed alignment of the canal. The analysis should include particle size distribution, shape of soil particles, the binding forces, organic content, soil moisture, void ratio.

Another side of the investigation should be performed in the laboratory. That is to test the changes on soil structure (volume in particular) that may result from changes on soil moisture. This is termed as swell and/or settlement (collapse) of soil. The latter is most dangerous not only for open channel structures but for all other structures alike. Any swell or settlement on soil due to a change in moisture contents is likely to result in cracks in the bottom and/or sides of the channel. This event is particularly serious when soil is non-homogenous due to the differential settlement or swell that would crack the soil and/or the lining.

The reliability of soil tests, and consequently, the side slope recommended by the soil specialists is relevant to the following factors:

- a- The quality of the instruments of the laboratory and whether being maintained and calibrated regularly.
- b- The number of soil samples taken from the site of the project. It should be satisfactory regardless of the cost.
- c- The qualifications of soil specialists as well as the technicians in the laboratories.

In fact, depending on the degree of reliability of soil tests, as explained previously, the channel design engineer/s should determine the degree of safety factor to be added to the angle of side slope recommended by the soil specialists. Of course, safety factor goes for flatted angle.

2.1.3 Available Machinery

The decision taken regarding the shape and size of the channel leads to the decision regarding the types and number of machinery to be implemented during the execution process. The excavation of the canal prism is usually performed larger than the real required cross section channel due to the incompatibility between the automatic excavators and the required channel cross section, or, due to the channel passing through a bend. Also, side slopes may be increased (flatter side slope) in order to facilitate enough space for the requirements of the construction.

2.1.4 Available Materials of Construction

Frequently, open channels deliver water from source to agricultural lands on stages while passing through these land. In the other word, it is extremely difficult and/or inconvenient for farmers to borrow soil from nearby lands in order to fill a depression, or, to dump excavated soil onto other land owners simply because both cases would damage the agricultural land where the borrowing and/or dumping take place. This leads to the essential need to search for the least cost path that makes the cut and fill as minimum as possible, and simultaneously, as equal as possible with the consideration of a given longitudinal slope with minimal variation according to the given tolerance. The investigation of the available material for construction within the region of the project should be assessed in order to ease for the designer the selection of the best material to be implemented for the construction of the channel.

2.1.5 Available Hydrologic Data

The hydrological data is essential in relevance to more than one aspect. One of the main factors is learning the probable type, intensity and duration of precipitation within the region in concern. The other side of the effect of precipitation on canal design is the type, size and number of the needed protective structures that should be constructed on the alignment of the canal. Also, the specific location of each protective structure should be specified in advance.

One more essential need for hydrological data is indirectly relevant to the determination of the maximum probable design discharge. The coordination between the required irrigation water needs during the times when precipitation is unexpected is totally dependent on hydrological statistics.

Any model that may be used for finding the probable overland flow after a precipitation event depends on the available hydrological data.

One more important issue that is relevant to the hydrological data is the influence of precipitation on the behavior of groundwater, which is in turn may affect the design depth of the proposed canal.

2.1.6 Available of Geological Data

The geology of the project area helps to identify the possibility of stable foundation of the hydraulic structure. Geological formation like faults, fractured zones, Shear zones, fissures, solution cavities, seismicity, slide zones, should be studied.

Geological data is directly relevant to topography, which represents the surface formation over which the canal alignment is to be selected. Thus, it is not only essential to determine the optimum alignment of the channel within the given topographic map, but also, the selected alignment should guarantee a rigid base where canal structure will not suffer settlement, swell, or even cracks in the lining.

It should be made clear for the designer which locations may form a natural obstacle (too high or too low). This is particularly important during the determination /selection of the canal alignment, where non-feasible obstacles (too expensive to fill or excavate) should be avoided.

2.1.7 Assessment of Water Needed for Diversion

The amount of water required to be diverted with the consideration of the basic needs (e.g. agricultural, industrial or domestic) within the predicated age of the canal structures should be determined carefully. This would enable the designer to establish a well-proportioned diversion structure for the proposed channel from the main water source (dam reservoir, lake, river, and the like).

2.1.8 Limitation on Water Withdrawal

In the most of water sources (rivers, dam reservoirs, groundwater, and the like), the amount of water may not be sufficient at least during some seasons to satisfy all the potential demands. Also, it is really important to estimate or predict, as accurately as possible, the predicated age of water source. This is essential for the determination of the age of canal project.

2.1.9 Sediment- Relevant Data

Sediment-relevant data may be divided into two categories. The first is to determine sediment concentration through drying a sample with known volume, and thus, find sediment concentration in gram/m^3 (some describe concentration as ppm units). The second is to determine particle size distribution of the sample. Generally, the latter test needs only hydrometer test analysis because sediment contents may not contain particles larger than 75 microns; otherwise, a sieve test may be applied. However, the final particle size analysis curve should give a good idea about sediment contents regarding the velocity within which sediment content may start to settle. This is particularly essential for the determination of the limits within which the design of the proposed canal should be performed.

2.1.10 Existing and Future Man-Made Structures

It is important to identify any probable man-made restrictions or constraints that must obstruct the alignment of the proposed channel. The constraints may have the effect of required variation on the channel lateral dimensions (depth, width, side slope) as well as on the longitudinal slope. On the one hand, the presence of a road, building/s, railways, or non-removable structures may limit the choice in selecting the alignment of the channel.

It is essential to consider extra precautions when the channel alignment being close to an important structure. This is in order to prevent any probable harm that may be cause to that important structure due to leakage from the nearby channel, and vice versa. Sometimes, the vibration generated by a train passing nearby the channel may cause fractures in the lining, and even may cause settlement on the soil below.

2.1.11 Accessibility to the Site of Works

It is essential to have easy access to the site where all kinds of probable works may be needed throughout the alignment of the proposed channel. Thus, the selected alignment should ease such accessibility in a way that would make it feasible and economic at the same time. This accessibility is important even after the completion of all works because of the repeated control, maintenance, and repairs that may be required along all the alignment of the proposed channel.

2.1.12 Available Financial Sources and Technical Skills

It takes a lot more than good wish to develop a successful channel project. It is really essential to know, at an early stage, the available financial sources that may be allocated for the proposed project. This is directly relevant to the quality of skills that can be implemented as well as to the quality of machinery and technological skills of the operators that could be used throughout the project.

Feasibility study is very important to the project of open channel in limiting and defining the total cost of the project. Once you an initial idea of what technical skills and machinery will be need for a project, it is relevantly easy to estimate the approximate cost of the project.

The stability of the financial support (continuous flow of financial support) throughout the period of the project is essential and should be guaranteed, especially for projects that consume relatively long time to be completed. This is important in particular in countries where the political and/or financial conditions are not stable.

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 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 adequately by a simply 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. The 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.

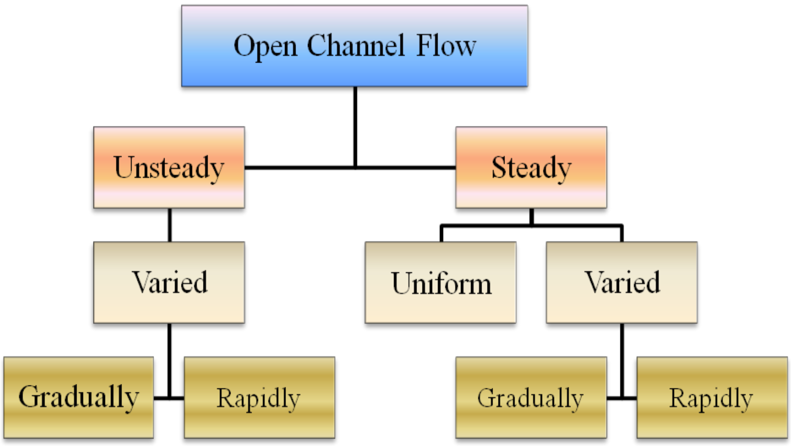


Figure 2.3 Types of open Channel Flow (Kumar, 2012).

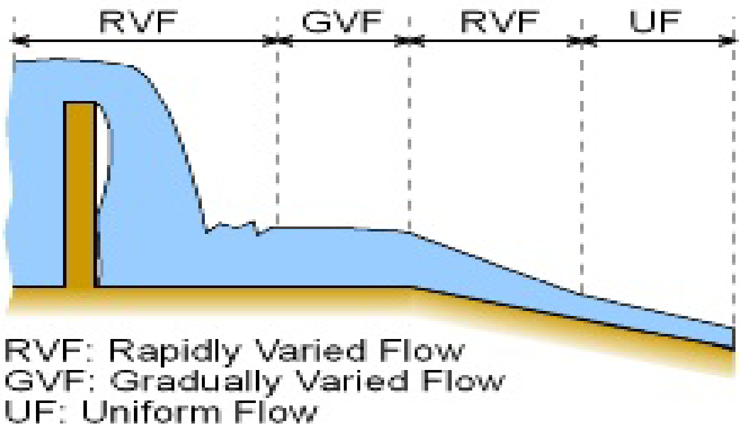


Figure 2.4 Classification of Open Channel Flow (eCourses, 2012).

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 divided in 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.

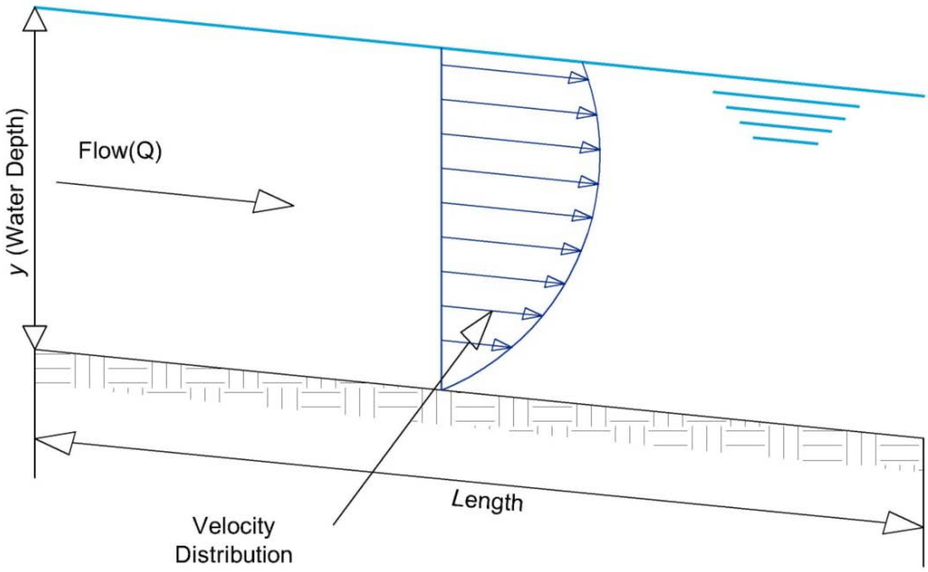


Figure 2.5 Uniform Flows in Open Channels.

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 flow 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 approximate 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 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 Velocity

At any point in an open channel, the flow may have velocity component in all three directions. Velocity usually refers to the velocity component in main flow direction. The velocity varies in a channel section due to the friction forces on the boundaries and the presence of the free-surface. Use the term point velocity to refer to the velocity at different points in channel section Figure 2.6 shows the typical distribution of point velocity V in a trapezoidal channel.

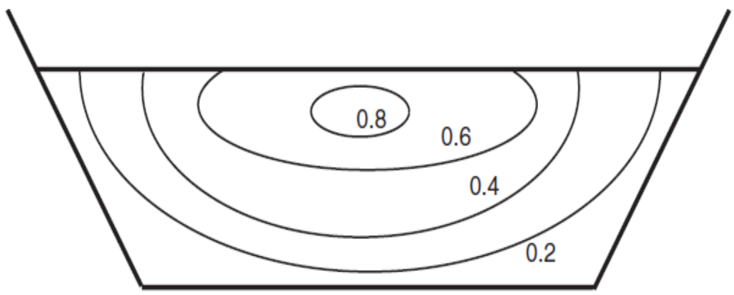


Figure 2.6 Distribution of Point Velocity in Trapezoidal Channel.

2.5 Bed Slope

Channel slope is the slope of channel bottom through the stream reach being studied or designed. It is measured in meter per meter or percent. The bottom slope (bed slope) of channel does not appear on the drawing of cross-section but on the longitudinal section. It is clear that water flows more rapidly in the steeper slope and water flows slowly in the less slope as shown in Figure 2.7.

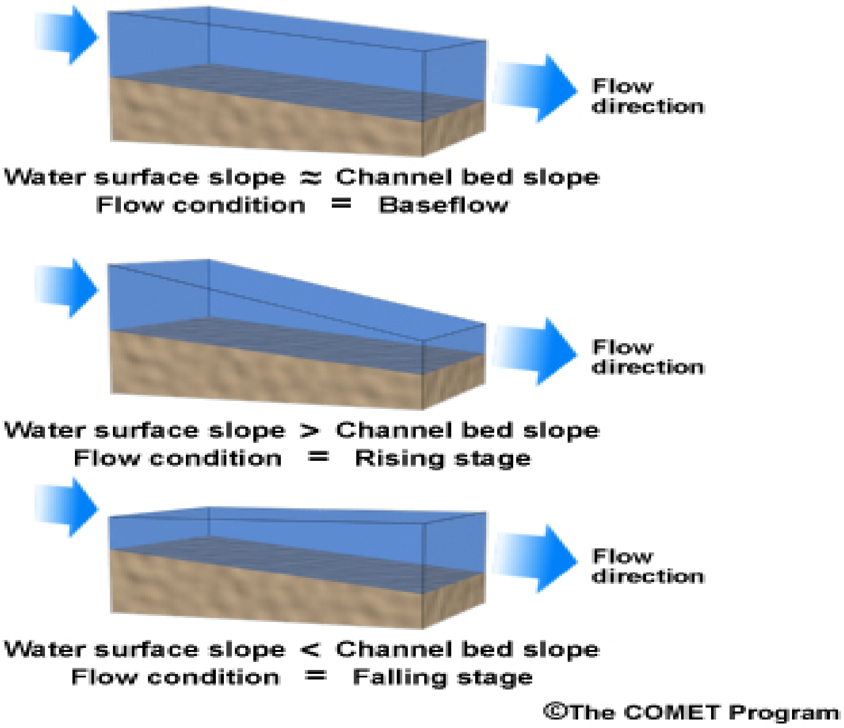


Figure 2.7 Longitudinal Slope of Channel.

Usually, laying the channel on a slope equal to the slope of ground surface, it will result in minimizing excavation, which is obviously a preferable option. However, if the resulting flow velocity is less than the minimum allowable limit for velocity, then, steeper slope that produces a higher velocity must be implemented, of course, within the allowable shear stress limit on the channel lining (Chin, 2006)

2.6 Manning Friction Coefficient

Manning friction coefficient n is an important variable in open channel flow computations. Variation in this variable can significantly affect discharge, depth and velocity values. Since Manning coefficient values depend on many different physical characteristics of natural and man-made channel materials, particularly soil and concrete, recommended Manning's values for artificial channel with rigid, unlined, temporary and riprap lining are presented for use in Table 2.1.

Table 2.1 Manning's n Values (Chow, 1959).

Channel Material	**Manning Roughness (n)**
Concrete	0.013 - 0.015
Grouted riprap	0.028 - 0.040
Soil cement	0.02 - 0.025
Asphalt	0.016 - 0.018
Bare soil	0.02 – 0.023
Rock cut	0.025 – 0.045
Fiberglass roving	0.019 – 0.028
Woven paper net	0.015 – 0.016
Jute net	0.019 – 0.028
Synthetic mat	0.021 – 0.030

2.7 Open Channel Geometric Properties

Sometimes, it is useful to apply an efficient cross-section to maximize channel capacity by optimizing the coordination between the selected variables, of course within the limitation of the imposed constraints.

In fact, most of the variables involved in the design process have limitations to the allowable variation due to different reasons that are related to the local conditions. These variables are bed slope, side slope, velocity, top width, and water depth.

The relation among these variables is interdependent in a way that when any of these variables change or vary, most of the rest of variables suffer changes in different directions. However, there are some variables that are strictly imposed with nearly no chance to vary during the design process. Sediment load is one of these variables, and in this case, the design should consider the maximum sediment load regarding the concentration as well as the predicated particle size distribution. Also, the good design should consider even the probable variation in sediment load. Bed slope is frequently a strictly imposed variable where changing it may result is large undesirable consequences (i.e. excavation and/or fill). Side slope may tolerate variations in only one direction (flatter) where the steeper direction may exceed the safety limits and cause risk of side collapse. Obviously, the flatter the side slope is the larger the top width would be, and consequently, the more evaporation loss would result.

The common cross-section shapes are trapezoidal, rectangular and circular. An inspection of manning formula, Equation (2.1) reveals that, when everything else remaining constant, the discharge carried under the normal flow condition will increase with decreasing wetted perimeter P. Thus, for a given flow area, the channel section having the least wetted perimeter will have the maximum conveyance capacity. Such a channel section is called the best hydraulic section. Although the best hydraulic section is not necessarily the most economic section, as shown by (Chow, 1959), the best trapezoidal section with fixed side slopes (m) has the following flow depth to bottom ratio:

$$\frac{b}{y} = 2\left(\sqrt{1 + (m^2}\right) - m) \tag{2.2}$$

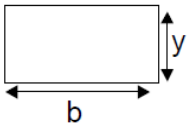
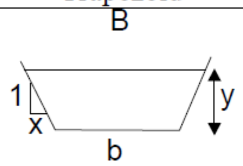
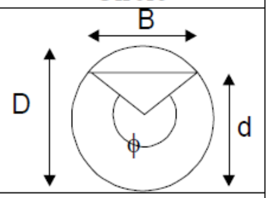
Where:

b = bed width of channel.

y = depth of water in channel.

m = side slope of channel

Table 2.2 Equations for Rectangular, Trapezoidal and Circular of Channel.

	Rectangle	Trapezoid	Circle
			
Area, A	by	$(b+xy)y$	$\frac{1}{8}(\phi - \sin\phi)D^2$
Wetted perimeter P	$b+2y$	$b+2y\sqrt{1+x^2}$	$\frac{1}{2}\phi D$
Top width B	b	$b+2xy$	$(\sin\phi/2)D$
Hydraulic radius R	$by/(b+2y)$	$\frac{(b+xy)y}{b+2y\sqrt{1+x^2}}$	$\frac{1}{4}\left(1-\frac{\sin\phi}{\phi}\right)D$
Hydraulic mean depth D_m	y	$\frac{(b+xy)y}{b+2xy}$	$\frac{1}{8}\left(\frac{\phi-\sin\phi}{\sin(1/2\phi)}\right)D$

2.7.1 Water Depth

Water depth d (or y) is the vertical distance from the lowest point of channel section to the free surface of water. It also represents the potential energy.

The consequences of increasing water depth in canal cross section may be classified in to desirable and undesirable. Desirable ones are decreasing the occupied land, decreasing evaporation losses, and decreasing the probability of weed growth. The undesirable consequences are the increase in the cost of excavation, particularly, the likelihood of encountering either a solid strata or groundwater table; also, the increase in the risk of drowning, the need to make the side slope as steep as possible, which may result in increasing the probability of collapse.

2.7.2 Bottom Width

Representing the bottom width of channel cross-section at the bed of the regular shape, it cause to decreasing and increasing in the wetted perimeter and exposed surface. Bottom width has effective role in the design process in open channel cross-section. When cross-section of channel has a relatively wide bottom, this indirectly means relatively less water depth, and this means easier excavation, lower probability of groundwater interference. However, the accompanied disadvantages are represented by higher rate of evaporation, larger occupied area, and higher probability of weed growth.

The experience curve in Figure 2.8 shows the average relationship between bottom width and canal capacity for lined trapezoidal section as recommended by the US Bureau of Reclamation and presented by (Chow, 1959). The experience curve can be used as a guide to select the bottom width of the channel. For given design discharge Q in m^3/s.

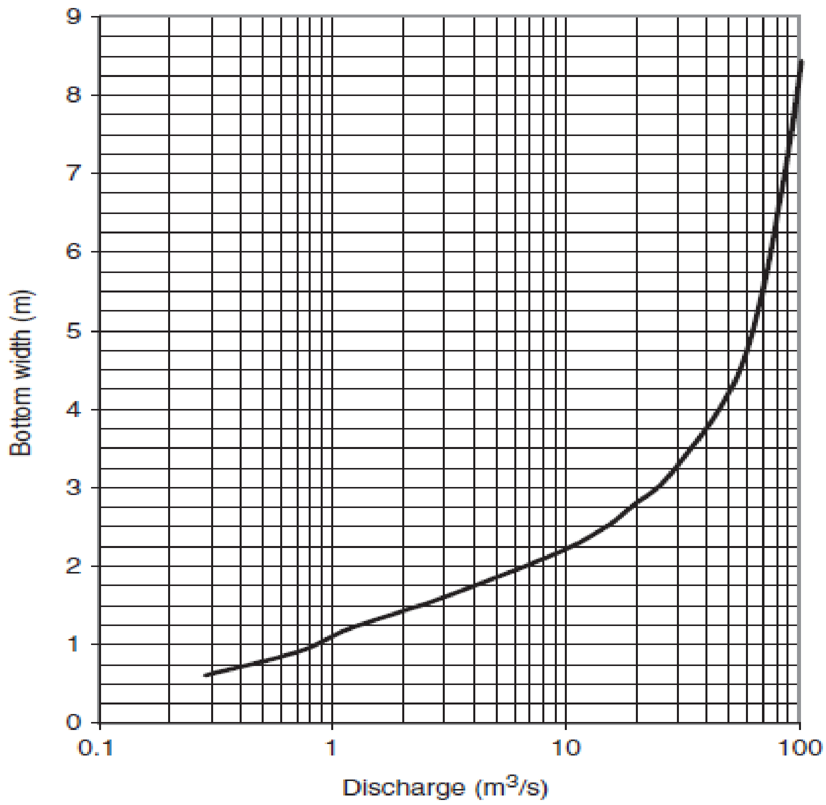


Figure 2.8 Experience Curve (Chow, 1959).

2.7.3 Side slope

For the trapezoidal cross-section, side slope (H: V) is usually varies between zero to two; while the common side slope for rectangular cross section varies from one to two. There are tradeoffs between low and high value of side slope as follows:

1- Channel with low side slopes occupy less land area.
2- High side slopes are more stable and may required less maintenance.
3- High side slopes are safer, if animals or people could fall into the channel because easier to climb out.
4- Rectangular cross-section can be simpler to build for small cross section when lined with concrete.

5- It may be easier to built and install structures and transition for rectangular cross-sections.

6- Medium-range side slopes correspond to greater hydraulic efficiency.

Table 2.3 Side Slope of Channel (Chow, 1959).

Material	**Side slope, m**
Rock	0 – 0.25
Earth with concrete lining	0.5
Stiff clay or earth	1.0
Soft clay	1.5
Loose sandy soil	2.0
Light sandy, sandy loam	3.0

2.7.4 Freeboard

Freeboard means the extra depth of a channel section, above the water surface for 100% flow rate capacity, usually for uniform flow conditions. A freeboard value should be added to the maximum expected depth to allow for:

1- Deviations between design and construction.

2- Post-construction, non-uniform land settlement.

3- Operational flexibility, including operation mistakes.

4- Accommodate transient flow conditions.

5- Provide a more conservative design in terms of flow capacity.

6- Increase in hydraulic roughness due to lining deterioration weed growth.

7- Wind loading.

8- Unexpected/unplanned fall of foreign bodies in the channel.

2.7.5 Hydraulic Radius and Wetted Perimeter

Two of the main variables in open channel hydraulics are wetted perimeter P and hydraulic radius R. Wetted perimeter can be defined as the length of the wetted contact between stream flow and its containing conduit or channel, measured in a plane at right angle to the direction of flow. Hydraulic radius is represented by the cross-sectional area of flowing water divided by the wetted perimeter as shown in the Figure 2.9.

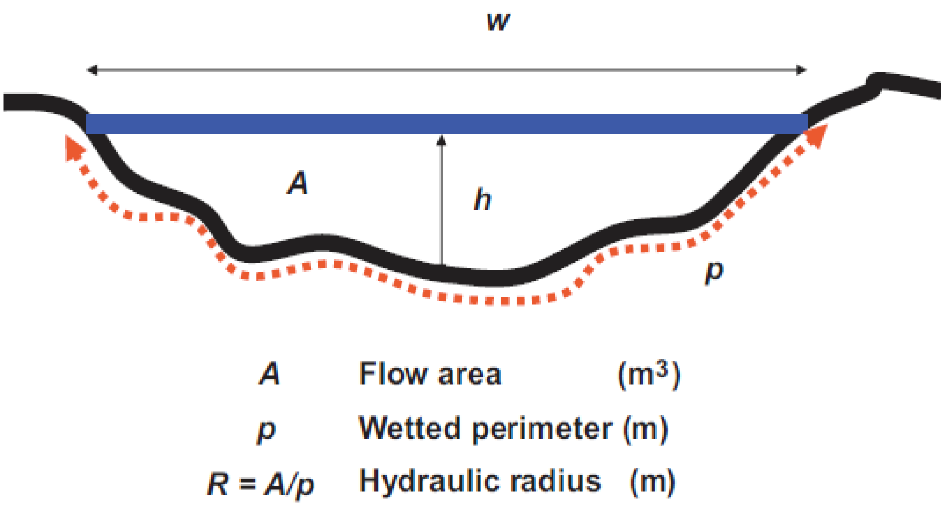


Figure 2.9 Hydraulic Radius and Wetted Perimeter.

2.7.6 Top width

Top width represents the exposed surface width of water flow that is directly exposed to atmosphere. For rectangular channels, top width will be equal to bottom width, while top width in other channels depends on the depth of water flow and channel side slopes.

Because top width is exposed to the atmosphere, it has significant role in water loss through evaporation. If the channel passes through hot weathered region, in this case, the designer should give top width (exposed surface) an essential priority characteristic in the design process to be the channel has a minimum top width.

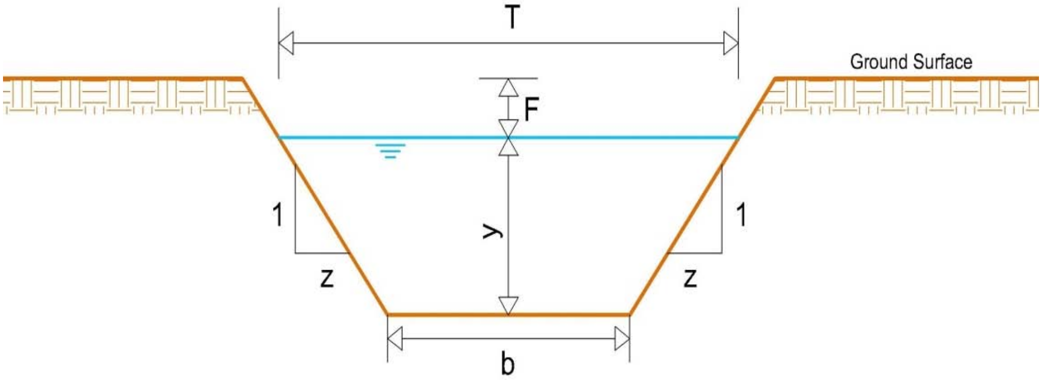


Figure 2.10 Top Width T in a Typical Trapezoidal Channel.

2.8 Channel Relevant Structures

Several channel relevant structures are required for the control and measurement of water flow. The flow of water in the channels must always be under control. In order to regulate the flow and deliver the correct amount of water to the different branches of the system, there are four main types of structures as briefly explained in the following sections:

2.8.1 Erosion Control Structures

Channel bottom slope and water velocity are closely related, as the example following, a cardboard sheet is lifted on one side (3cm) form the ground, a small ball is placed at the edge of the lifted side of the sheet, it is starts rolling downwards, following the slope direction. The sheet edge is now lifted (6cm) form the ground, creating steeper slope. The same ball placed on the top edge of the sheet rolls down-word, but this time much faster. The steeper the slope is, the higher the velocity of the ball would be.

2.8.2 Drop Structures and Chutes

Drop structures or chutes are required to reduce the bottom slope of the channels. Lying on steeply sloping land in order to avoids high velocity of the flow and risk of erosion. These structures permit the channel to be constructed as a series of relatively flat sections, each at a different elevation. Drop structure takes the water abruptly from a higher section of channel to a lower one. In chute, the water does not drop freely but is carried through steep, lined channel Section. Chutes are used where there are big differences in the elevation of the channel.

Figure 2.11 Chute Structure.

2.8.3 Distribution Control Structures

Distribution control structures are required for easy and accurate water distribution within the irrigation system and on the farm. Divided into

2.8.3.1 Division Boxes

Division boxes are used to divide or direct the flow of water between two or channel. Water enters the boxes through an opening on one side and flows out through openings on the other sides. These opening are equipped with gates.

2.8.3.2 Turnouts

Turnout is constructed in the bank of a channel. This diverts part of the water from the channel to a smaller one. Turnouts can be concrete structure or pipe structure.

2.8.3.3 Checks

To divert water from the field ditch to field, it is often necessary to raise the water level in the ditch. Checks are structures placed across the ditch to block it temporarily and to raise the upstream water level; checks can be permanent structures or portable.

2.8.4 Crossing Structures

Crossing structures used to carry irrigation water across roads, hillsides and natural depressions. Crossing structures, such as flumes, culverts and inverted siphons.

2.8.4.1 Flumes

Flumes are used to carry irrigation water across gullies, ravines or other natural depressions. They are open channels made of wood (bamboo), metal or concrete

which often need to be supported by pillars.

Figure 2.12 Flumes.

2.8.4.2 Culverts

Culverts are used to carry the water across roads the structure consists of masonry or concrete headwalls at the inlet and outlet connected by a buried pipeline.

2.8.4.3 Inverted Siphons

When water has to be carried across a road which is at the same level as or below the channel bottom, an inverted siphon is used instead of a culvert. The structure consists of an inlet and outlet connected by a pipeline. Inverted siphons are also used to carry water across wide depressions.

2.8.5 Water Measurement Structures

By measuring the flow of water, a farmer knows how much water is applied during each irrigate. The principal objective of measuring irrigation water is to permit

efficient distribution and application. In irrigation schemes where water costs are charged to the farmer, water measurement provides a basis for estimating water charges. The most commonly used water measuring structures are weirs and flumes. In these structures, the water depth is read on a scale which is part of the structure. Using this reading, the flow-rate is then computed from standard formulas or obtained from standard tables prepared specially for the structure. Water measurement structures are divided to

2.8.5.1 Weirs

A simplest, form, a weir consists of a wall of timber, metal or concrete with an opening with fixed dimensions cut in its edge. The opening, called a notch, may be rectangular, trapezoidal, or triangular.

Figure 2.13 Weirs.

2.8.5.2 Parshall Flumes

The Parshall flume consists of a metal or concrete channel structure with three main

Sections:

1- A converging section at the upstream end.
2- A constricted or throat section.
3- A diverging section at the downstream end.

Depending on the flow condition, the water depth readings are taken on one scale only or on both scales simultaneously.

2.8.5.3 Cut-Throat Flume

The cut-throat flume is similar to the Parshall flume, but has no throat section, only converging and diverging sections. The Parshall flume, cut-throat flume has a flat bottom. Because it is easier to construct and install, the cut-throat flume is often preferred to the Parshall flume.

Figure 2.14 Cut-Throat Flume.

2.9 Water Loss in Channels

When water comes in contact with an earthen surface, regardless of being artificial or natural, the surface absorbs water. This absorbed water percolates deep into the ground and is the main cause of the loss of water carried by a channel. In addition, some channel water is also lost due to evaporation. In unlined channels, a rough estimation of the loss due to evaporation may range about 10 per cent due to seepage loss varies with the type of material through which the channel runs. Obviously, the loss is relatively greater in coarse sand and gravel, less in loam, and even less in clay soil. If the channel carries silt-laden water, the pores of soil are sealed in course of time and the channel seepage reduces with time. In almost all cases, the seepage loss constitutes an important factor which must be accounted for determining the water requirements of a channel.

Between the headworks of the channel and the watercourses, the loss of water on account of seepage and evaporation is considerable. This loss may be of the order of (20 to 50) per cent of the water diverted at the headworks depending upon the soil through which channel runs and the climatic conditions of the region.

For the purpose of estimating the water requirements of a channel, the total loss due to evaporation and seepage, also known as conveyance loss, is expressed as (m^3/s) per million square meters of either wetted perimeter or exposed water surface area. Conveyance loss can be calculated using the values given in Table 2.4, where the total loss due to seepage and evaporation per million square meters of water surface varies from (2.5 m^3/s) for ordinary clay loam to (5.0 m^3/s) for sandy loam.

Table 2.4 Conveyance Losses in Channel.

Material	**Loss in m^3/s per million square meters of wetted perimeter (or water surface)**
Impervious clay loam	0.88 to 1.24
Medium clay loam underlaid with hard pan at depth of not over 0.60 to 0.90 m below bed	1.24 to 1.76
Ordinary clay loam, silty soil or lava ash loam	1.76 to 2.65
Gravelly or sandy clay loam, cemented gravel, sand and clay	2.65 to 3.53
Sandy loam	3.53 to 5.29
Loose sand	5.29 to 6.17
Gravel sand	7.06 to 8.82
Porous gravel soil	8.82 to 10.58
Gravels	10.58 to 21.17

CHAPTER 3

ESSENTIAL VARIABLES IN THE DESIGN OF OPEN CHANNEL

Open channels are designed to carry a particular discharge, termed as design discharge, in a safe and economic way. Here, the design discharge should take into consideration the total losses throughout the whole alignment of the channel, including evaporation and seepage losses, in a way that the water reached to the demand point would be exactly as required from the consumer side. Open channels are usually designed for uniform or normal flow conditions.

Designing an open channel involves the following variables:

1- Alignment of channel.
2- Shape of cross section and its detailed dimensions.
3- Longitudinal slope.
4- Type of lining material.

In the design of an open channel, it is essential to consider several hydraulic feasible alternatives and compare them in order to determine the safest, best functional and most cost-effective alternative solution/design. Practically speaking, optimizing the design may be divided into two sections of equal importance, the first is to make the structure function with as high efficiency as possible, and the second is to decrease the cost as much as possible. Usually, when each of these two properties is improved, the other one goes into opposite direction.

However, finding the solution that offers the best efficiency for lowest cost according to the local conditions of the project is the difficult task.

It is obvious that the preferable way to convey water is by gravity flow and not through pumping. In fact, pumping should be the very last solution to be chosen if gravity flow does not appear to be feasible for any reason. This is because of the endless disadvantages of pumping. Among these disadvantages:

a- The cost of fuel to operate the pumps.
b- The risk of storing fuel (if operated by fluid fuel).
c- The risk of electricity cuts if being operated by electricity, and the high cost of the generator for tolerating electricity shortages.
d- The cost of the operator.
e- The risk of the pump/s being stolen.
f- The cost of the guard (not the operator).
g- The cost of having a standby pump system in case the main pump goes out of order.
h- The cost of maintenance and repairs of pumping system.
i- The difficulty in clearing any settlement sediment in pipes.

Obviously, avoiding the need of pumping saves the project all the risks and costs explained in the previous section. However, at this stage, it may be better to explain the advantages of pumping when compared with open channel flow in offering extra freedom in selecting more tolerated alternative alignments regardless of the essential need for a steady slope downwards as in the gravity flow. In other words, the pressurized flow of water in pipes enables for the flow upwards as well as downwards unlike that in open channel which has only the downwards alternative.

The following sections deals with the needs and logic behind the optimization of the different variables related to the design of open channels. Of course, it should be noted that some of the variables are imposed while leaving some tolerance for the rest of variables to be optimized according to the local conditions of the project.

3.1 Alignment

After data collection, the selection of channel alignment is the first step in the design of an open channel. Generally, the following factors are the essential ones that has to be investigated and coordinated in order to determine the optimum alignment:

a- The topography of the relevant region in general, which enables for the approximate proposed path that needs to be investigated.

b- The available width that can tolerate the path of the channel along with whatever needed for the relevant construction works.

c- The right-of-way, which includes whatever may be changed with legal application and/or those sections of the alignment where there is no chance to change their location due to any reason. This should include not only the existing structures and lands, but also, any future structures or lands that may be of importance to the Government and cannot be tolerated regarding changing its location. Here, the period of the feasible future considered for application is the same as the predicted life length of the project.

d- The existing topographic obstacles, such as depressions and hills that may encountered across a proposed alignment.

In hilly areas, the conditions are vastly different in compared to those of plains. Rivers flow the valleys well below the watershed or ridge, and it may not be economically feasible to take the channel on the watershed. In such situations, contour channels Figure 3.1 are constructed. Contour channel follow a contour while maintaining the required longitudinal slope. It continues like this and as river slopes are much steeper than the required channel bed slope the channel encompasses more and more distance between itself and the river.

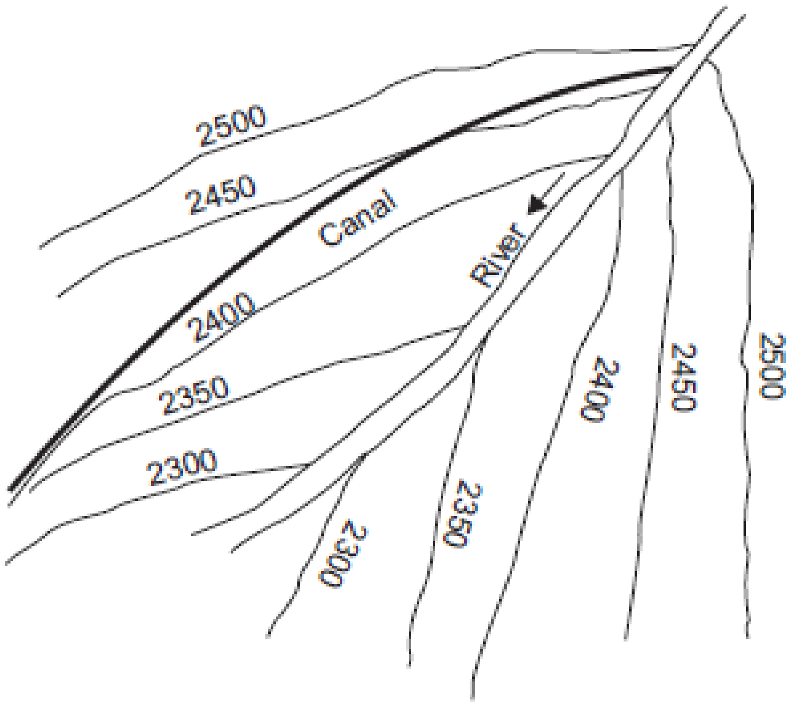


Figure 3.1 Alignment of Main Channel in Hills (Asawa, 2008).

Because of the economic and other consideration, the channel alignment does not remain straight all through the length of channel, and curves or bends have to be provided. The changes in velocity on account of cross currents depend on approach flow condition and characteristics of curve. The permissible minimum radius of curvature for channel depends on the type of channel, dimensions of cross-section, velocities, during full-capacity operations, earth formation along channel alignment and dangers of erosion along the paths of curved channel. Table 3.1 indicates the values of minimum radius of channel curves for different channel capacities.

Table 3.1 Radius of Curvature for Channel Curves (Asawa, 2008).

Channel Capacity (m^3/s)	Minimum Radius of Curvature (m)
Less than 0.3	100
0.3 to 3.0	150
3.0 to 15.0	300
15.0 to 30.0	600
30.0 to 85.0	900
More than 85	1500

In the design of channel alignment, when the desired bed slope is flatter that the natural ground slope, as is usually the case, a channel fall has to be provided well before the channel bed comes into filling and full supply level becomes too much above the ground level.

In any region, it is of essential importance to select the alignment of the open channel in a way that the required excavations through the relatively high selection be as equal as possible to the volume of fill required in the lower section. Obviously, in case the volumes of excavation and fill are significantly different, there will be a certain need either to bring form distant regions soil to complete the required fill in the case the volume of the fill appear to be larger than that of the excavation, or, to dump the surplus soil far away in case of opposite.

Optimization in the section of channel alignment, which depends on the topography of the region, is important because it has a significant impact on the amount of cut and fill, and also, on minimizing the probability of coming across natural and/or manmade obstruction. Consequently, after data acquisition, selecting the alignment of channel is the first and most essential step in the whole process of the design of open channel. The designer should select the alignment of the channel in a way that that would minimize the excavation procedures, and simultaneously, the excavation and fill volumes should be close in their value to each other as much as possible.

3.2 Lateral Cross Section of the Channel.

The designed open channel cross section is likely to impose the need for cut and/or fill throughout the proposed alignment. This cut and fill process may vary significantly in degree throughout the alignment from zero to full. In other word, the alignment may pass through regions where all the execution works are performed after full excavations and vice versa, and also, there are cases where the situation includes both cut and fill in the same place. The latter situation is the most favorable one because whatever is cut (or most of it) could be used in the fill for the same location. When the ground level is higher than the full supply level of the channel, the channel said to be in cutting Figure 3.2. a. If the channel bed is at or higher than the surrounding ground level, channel is in filling Figure 3.2. b. When the ground level is in between the supply level and the bed level of channel, the channel is partly in cutting and partly in filling Figure 3.2. c.

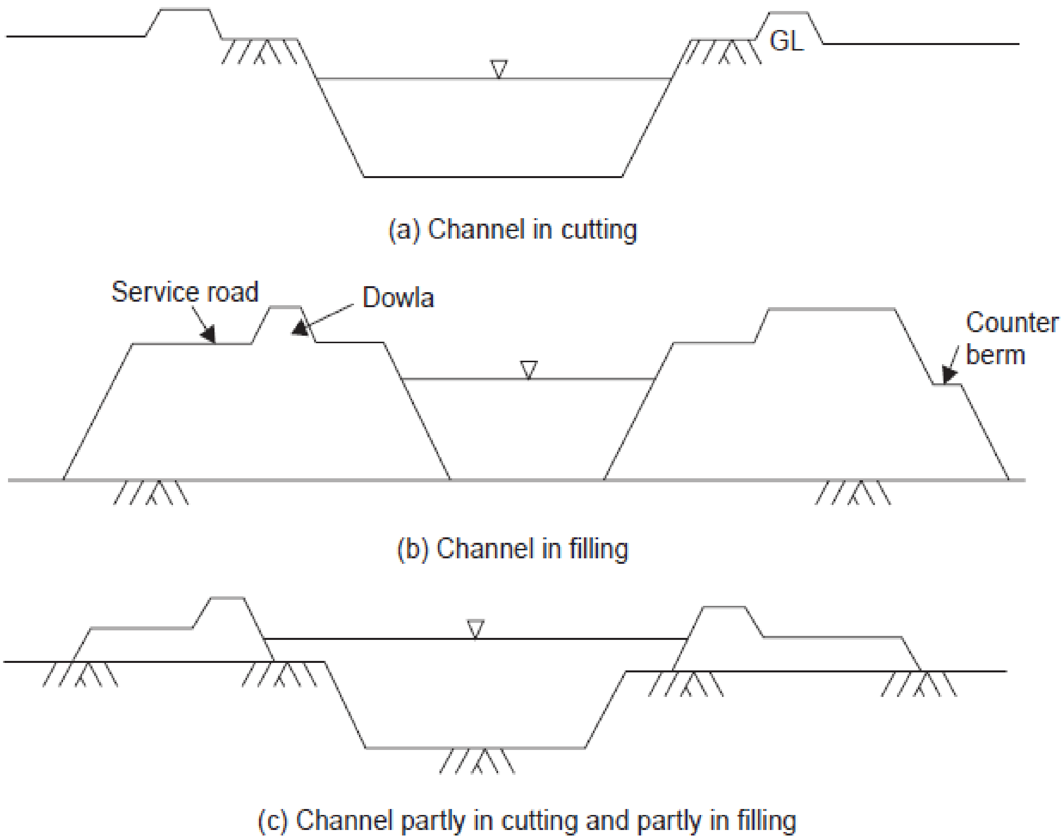


Figure 3.2 Typical Cross-Sections of Irrigation Channels.

The application of optimization process in all aspects of life is frequently performed without calculations or clear analysis of the variables involved in the process. This way, the ‘experience’ of the person from the observation and previous applications would be the main guide for the current optimization application. The results of the optimization in this case, may be satisfactory. However, if defining the variables involved in the process is performed and mathematical analysis is applied on the process, then, the results would be close to perfect as much as the approach to the analysis is correct.

It is important to know how to optimize the lateral cross-section of the channel. However it is essential to define the optimization targets because, these targets are more than one with different weight of importance/priority.

For imposed bed slope and limited flow velocity range, among these targets are the following:

a- Maximizing the flow capacity within the designed cross section.

b- Minimizing cross-sectional area in order to minimize the cost of excavation.

c- Minimizing wetted perimeter in order to minimize the lining cost and minimizing the friction between the water and channel surface

d- Minimizing the exposed surface in order to minimize evaporation losses as well as minimizing the occupied land.

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

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

Generally, the main targets are minimizing the cross sectional area, minimizing evaporation loss through minimizing the top width, and minimizing the excavation. These targets are essential to satisfy while keeping the velocity within the acceptable imposed limits, and also, keeping good balance between the volumes of excavation and fill.

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.

3.3 Types of Lining Material.

Channels are often lined to prevent the sides and bottom of the channel from suffering erosion due to the shear stress caused by the flow. The types of channel linings can be categorized as follows:

1- Concrete lining.
2- Shotcrete lining.
3- Precast concrete lining.

4- Lime concrete lining.
5- Stone masonry lining.
6- Boulder lining.
7- Asphaltic lining.
8- Earth lining.

A lined channel decreases the seepage loss and, thus, reduces the chance of water logging; it also saves water which can be utilized for additional irrigation. A lined channel provides safety against breaches and prevents weed growth thereby reducing the annual maintenance cost of the channel. Because of the relatively smooth surface of lining, a lined channel requires a flatter slope, this results in an increase in the command area. The increase in useful head is advantageous in case of power channel also (Asawa, 2008).

The cost of lining a channel is, however, the only factor against lining. While channel lining provides a cost-effective means of minimizing seepage losses, the lining itself may rapidly deteriorate and require recurring maintenance inputs if they are to be effective in controlling lining channel.

Another side of the optimization in the design of open channels is in selecting the optimum types of material which to be used in the lining process. This is because different lining materials have different roughness coefficients, different costs, and different ages. 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.

3.4 Longitudinal Slope.

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

The longitudinal slope of a channel should be such that if result in balanced earthwork, which mean that the amount of excavated soil is fully utilized in the fillings. This with minimize the necessity of borrow pits. In irrigation channel longitudinal slope is governed by topography of region. The longitudinal slope of the channel influences its capacity too, the steeper slope of channel the faster will flow the water and thus the larger will be capacity.

CHAPTER 4

THE DETERMINATION OF CHANNEL ALIGNMENT

The problem of designing a perfect lateral cross section of a proposed canal is far from easy. That is due to the involvement of several variables in the process as well as to these variables being interdependent. The same could be said about the selection of the canal alignment for a proposed canal, where for a region with topography of medium irregularity, several alternative routes may be selected. Frequently, it is difficult to select the best alignment among the proposed alternatives. Usually, experienced engineers select the best alignment that is 'likely/appears' to be more reasonable and economic that the other alternatives.

Despite that the alignment selected through good experience may function properly and appear to be within reasonable cost, still, this chosen alternative may not be really the very best among other probable alternatives. This is simply because investigating the feasibility of all proposed alternative in a detailed way likely to consume a lot of work and time. In general, the current method for the determination of the optimum alignment still depends basically on the 'experience' of the design engineer/s, whereas the implementation of a computerized search for the optimum solution is likely to offer quicker and more reliable results.

The previous paragraph leads to the clear direction in the need to implement computer programs for the purpose of finding the optimum canal alignment within a given topographic region with accompanied data relevant to whatever may influence the selected alignment, such as man-made or natural obstacles, and the like. Optimizing the alignment of proposed canals started about one decade ago. Within this period, the development of computer programs that is relevant to such subject progressed exponentially, and long with this development, the search for the optimum alignment of roads and canals through computer programs accelerated. However, the optimum alignment selection through computer programs-based systems went far ahead of that is relevant to canal alignment matters.

Briefly, the previous work and progress made for the search of the optimum alignment of a proposed canal within a specific region is still relatively little and requires a lot of more work. The latter means more work in improving the existing relevant programs as well as in attempting to implement these programs in this direction.

In fact, the improvement of computer programs in way to achieve the target of optimizing the alignment of a proposed canal can be made only through close relation between engineers specialized in canal design and professional computer programmers. Unfortunately, this link is still less than satisfactory, and this is the main reason for the delay in reaching the target.

GIS (Geographic Information System) is a system that is used for solving problems in extremely wide variety of science fields depending on the objective target and the available geographic and other data base.

The GIS system, with the aid of recently developed computer programs, seems to go in the direction where it could be useful for the problem of determination of canal alignment. This direction is still under construction although some software companies declare reaching a satisfactory stage in this field.

Observations and investigations in the recently developed GIS-relevant software programs reveal that the computerized optimization of road alignment selection is really well advanced; however, the matter is not the same for canal alignment determination.

A challenge for the finding least cost path between two points in the light of independent emergence of GIS, as professional discipline is to determine how to use GIS in a useful way. Planning for the optimum route requires an extensive evaluation process to identify the best possible route. The selected route should comply with requirement of other variables in channel like, cross-section, longitudinal profile (longitudinal slope), cost, efficiency and age of a channel project.

The longitudinal slope of the alignment may suffer variation duet to the variation of the topography and/or other reasons such as the existence of some obstacles.

The importance of finding the least cost path for a proposed channel is recently assisted by the GIS technology and integrated in the decision support system. ArcGIS and other GIS-relevant programs provide a broad range of useful spatial modeling and analysis features, where the designer can create, query and analyze cell based on raster data. Using GIS programs, designers can also derive information about geospatial data such as terrain analysis, relationships, and suitable locations. In order to reach this aim, the designer should know the way and logic to find the least cost path.

Due to the obvious limitations of available computer programs that may aid the finding of channel alignment, it seems convenient to start in defining the supply and consumption points for the proposed channel, and then, to divide the probable general alignment into segments where each segment represents an independent supply and consumption points.

4.1 The Various Applications in GIS

Before starting to understanding what really is geographic data, let us see that needs to use this data in a GIS.

1- Municipalities use this data to maintain large and complex databases that contain water and sewer lines.
2- Geologists use them to record locations of rock and resource information etc.
3- The military use highly classified databases for many uses.
4- Emergency services use them for maintaining address and location databases for quick location.
5- Cartographers use them for map making and storing.
6- Civil engineers use them for site selection and earthwork manipulations.

And more, (Burrogh and Rechael, 1998)

4.1.1 GIS Implementation in Water Resources

Geographic information systems (GIS) are strongly impacting the field of water resources engineering, environment science, and related disciplines. GIS tools for spatial data management and analysis are now considered state of the art, and application of these tools can lead to improved analysis and design. Familiarity with this technology may be a prerequisite for success in our efforts to create reliable infrastructure and sustain our environment.

GIS rapidly changing the ways that engineering planning, design, and management of water resources are conducted. Advances in data-collection technologies using microprocessor-based data-collection platforms and remote sensing provide new ways of characterizing the water environment and our built facilities. Spatial data bases containing attribute data and imagery overtime provide reliable and standardized archival and retrieval functions and they allow sharing of data across the internet. GIS analysis functions and linked mathematical models provide extensive capabilities to examine alternative plans and designs.

Map-oriented visualizations in color, three-dimensional, and animation formats help communicate complex information to a wide range of participants and interest groups. Moreover, interactive GIS database and modeling capabilities permit stakeholders to participate in modeling activities to support decision making. GIS is an all encompassing set of concepts and tools that provides a medium for integrating all phases of water resources engineering planning and design. GIS have become an increasingly important means for understanding and dealing with the pressing problems of the water and related resources management in our world. GIS concepts and technologies help us collect and organize the data about such problems and understand their spatial relationships. GIS analysis capabilities provide ways for modeling and synthesizing information that contribute to supporting decisions for resources management across a wide range of scale, from local to global. A GIS also provides a mean for visualizing resource characteristics, thereby enhancing understanding in support of decision making.

Water-supply and irrigation systems are fundamental infrastructure components sustaining public health and agricultural productivity. In any specific locale, there are distinctive circumstances of climate, topography, and geology that control the amounts of water available and provide the backdrop on opportunities for its capture and distribution. Water-supply system designs are also strongly influenced by the prevailing legal, administrative, and political (i.e., jurisdiction boundary) factors, which may limit the range of choice.

The primary elements of an irrigation system are similar to those for municipal water supplies, except raw-water treatment is typically not necessary. Source supplies arise from surface water, which is captured in reservoirs, and groundwater. Conveyance of supplies from the source is made through canals, ditches, and pipelines to the point of delivery. Diversion structures split canal flow into portions for the various irrigation projects. Other hydraulic equipment, including pumps, valves, and siphons, may be used to carry water from a well to field. Considerable labor is involved in operating an irrigation system, various demand categories. Capacity and costs of pipes, storage reservoirs, pumps, and other facilities are determined for alternative designs using forecasts of demands and flows, scheduled over design lifetimes. In a given locale, estimates based on recorded records in the city under study or data from similar cities are the best guide in selecting values for water-supply demand for planning. (Lynn E Johnson, 2009)

4.1.2 Geographic Data

It is data that is spatially referenced. This means that the data is identified according to the locations. The most obvious type of spatial reference is a map. We can have maps indicating many types of data. We may need to know details about a piece of land in order to construct some structure. What is the type of soil available, what is the slope of the land, how far is the land from a road, these are questions to ponder on before getting down to decisions. At national level we need to have data about different areas in order to decide on priority requirement.

There are two important components of geographic data. The geographic position and attributes or properties related to that position.

1- Geographic position gives the location by using a coordinate system.
2- Attributes refer to properties of spatial entities. They are follows,
    a- Identity (town, road, canal etc.)
    b- Ordinal (ranking such as class 1, 2 etc.)
    c- Scale (elevation, length, width etc.)

(Burrogh and Rechael, 1998)

4.1.3 Raster and Vector Data

A GIS database will store spatial feature data in a raster and vector format.

1- In the vector format, positions are stored in the form of coordinate (X, Y, sometimes Z)
    a- A point is described by a single X, Y coordinate pair and its name or label.
    b- Although a line is actually an infinite set of points, in practice a line is described by straight-line segment described by a set of coordinate pairs and the name or label.
    c- An area also called a polygon is described by a set of coordinate pairs and by its name.

A vector format represents the location and shape of features and boundaries precisely provided they are accurate at the point of input.

2- Raster data the grid-based format generalizes map features as cells or pixels in a grid matrix. The space is defined by a matrix of points or cells organized into rows and columns. If the rows and columns are numbered, the position of each element can be specified by the column and row numbers. These can be linked to coordinate positions through the introduction of a coordinate system. Each cell has an attribute value (a number) that represents a geographical phenomenon or nominal data such as elevation, land use etc. The fineness of the grid or in other words the size of cells in the matrix, will determine the level of detail in which map features can be represented.

4.1.4 Surfaces

Surfaces represented phenomena that have values at every point across their extent. The values at the infinite number of points across the surface are divided from a limited set of sample values. These may be based on direct measurement, such as height values for an elevation surface. Surfaces can also be mathematically derived from other data such as slope and aspect surfaces derived from an elevation surface.

Surfaces can be represented using contour lines or isolines, arrays of points, Triangular Irregular Networks (TINs) and raster, however, most surface analysis in GIS is done on raster or TIN data.

The computation of least-cost-path is, perhaps, one of the most potentially useful applications of geographic information system. Finding a minimum path over a surface partitioned into regions of different frictions to movement has two aspects:

1- Creation of an accumulated cost surface from a cost-of-passage where the frictions are stored.

2- Tracing a slope line down the accumulated cost from a departure point to a destination (Douglas, 1994)

In a GIS environment the cost-of passage surface is a grid where the values associated to the cells are used as weights for calculating the least-cost-paths. These weights represent the friction to across the cell, and may be cost, time, distance or risk.

4.2 Least Cost Path Algorithm

Integration of an accumulated cost surface from a cost of passage surface requires a spreading function that begins at the previously defined destination of the path. At the start of the procedure only the destination point cell has a defined value of accumulated cost, and the spreading algorithm searches its eight neighboring cells, stopping on the first one not previously assigned a value. From that one, the algorithm begins another search of its eight neighbors to find the ones with defined values of accumulated cost. For each of them the cost-of-passage of the cell is added, and the smallest of it is recorded as the accumulated cost of the cell. The procedure is repeated until every cell has been assigned a cumulative cost value (Douglas, 1994).

Once a cumulative cost surface is created a new surface can be created, assigning each cell that indicates the least costly direction to the ending point, following slope lines over the cumulative cost surface. This best-direction surface is used to draw the least cost path from the departure point to the destination (Lee and Stucky, 1998).

This procedure is an adaptation of algorithms such as Dijkstra's. That are traditionally applied to solve network problems, like the one in Figure 4.1.a using a raster data structure, each cell may be seen as a node linked to its eight neighbours, and the resulting network over the raster surface is depicted in Figure 4.1.b.

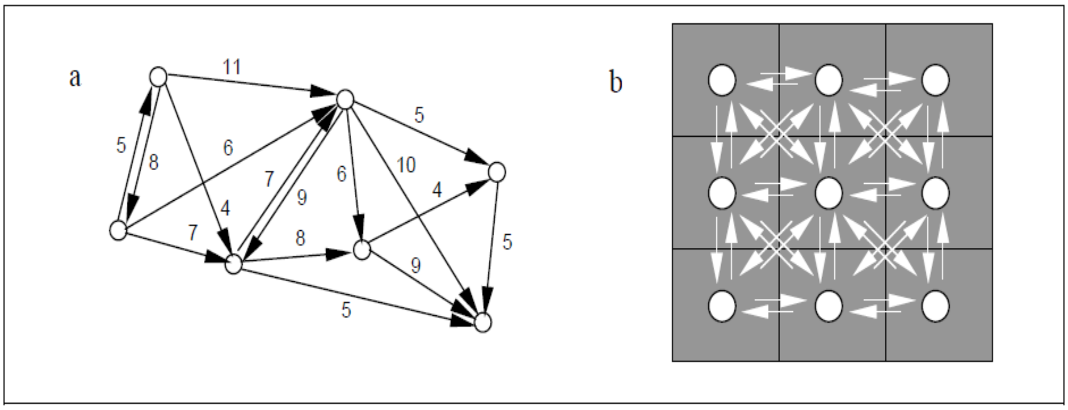


Figure 4.1. a. Classical Network with Weighted Links Connecting Punctual Nodes; **b.** Network Consideration of Raster Data with 8 Links from Each Cell.

4.3 The Main Layers of a Least Cost Path

The main Layers of the finding least cost path are divided as follows:

4.3.1 Digital Elevation Model (DEM) Layer

The most common digital data of the shape of the earth's surface is cell-based digital elevation models (DEM's). This data is used as input to quantity the characteristics of the land surface. A DEM is a raster representation of a continuous surface, usually referencing the surface of the earth. The accuracy of this data is determined primarily by the resolution (the distance between sample points). Other factors affecting accuracy are data type (integer or floating point) and the actual sampling of the surface when creating the original DEM.

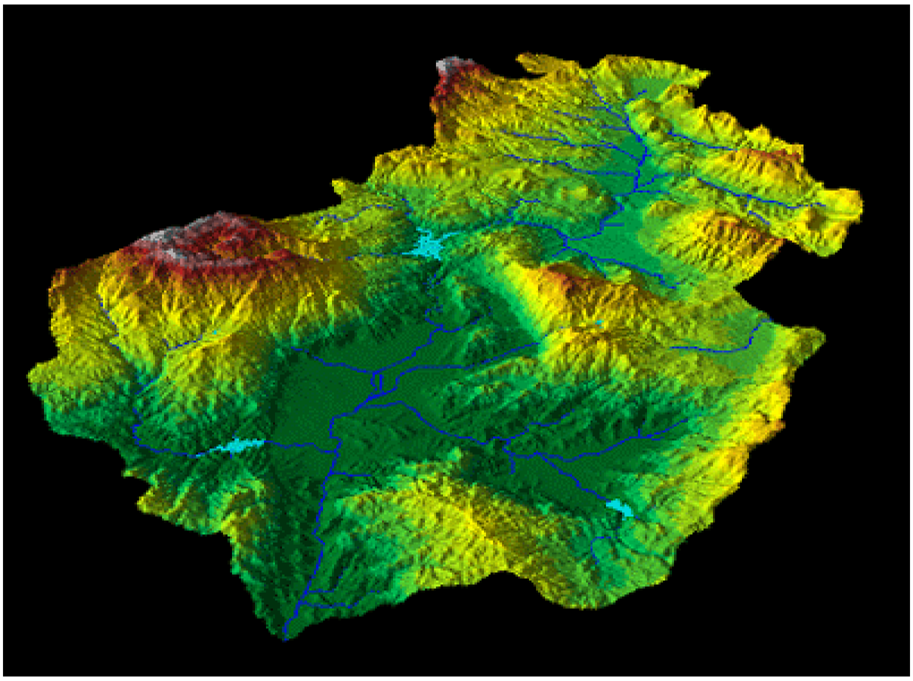


Figure 4.2 Digital Elevation Model.

Errors in DEMs are usually classified as follows:

1- Sinks

A sink is an area surrounded by higher elevation values and is also referred to as a depression or pit. This is an area of internal drainage. Some of these may be natural, particularly in glacial or karst areas (Mark, 1988) although many sinks are imperfections in the DEM.

2- Spike

Is an area surrounded by cells of lower value, these are more commonly natural feature and are less detrimental to the flow calculation of flow direction. Error such as these, especially sinks, should be removed before attempting to derive any surface information. Sinks, being area of internal drainage, prevent down slope flow routing of water.

4.3.2 Slope Layer

Raster and TINs model a surface's slope and aspect in different ways. In a raster, slope and aspect are calculated for each cell by fitting a plane to Z-values of each cell and its eight surrounding neighbors. The slope or the aspect of plane becomes the slope or aspect value of the cell in a new raster. In a TIN, each triangle face defines a plane with a slope and an aspect. These values are quickly calculated, as needed, when you query or render the face. The following illustrates slope and aspect. In the Figure on the left, the darker shades of red indicate steeper slopes. In the Figure on the right, west-facing slopes are dark blue, and southeast-facing slopes are yellow.

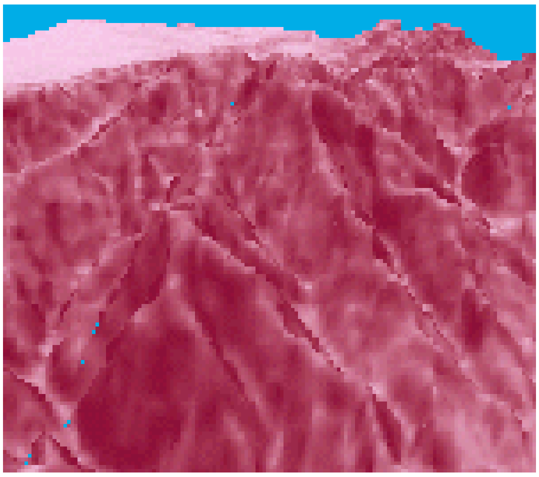


Figure 4.3.a Slope layer.

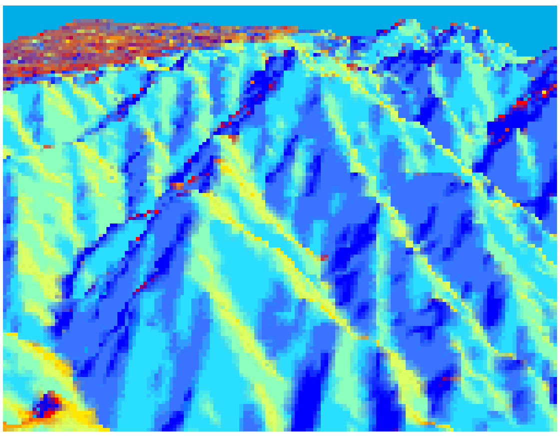


Figure 4.3.b Slope layer.

4.3.3 Cost Distance Layer

The cost functions are similar to Euclidean functions, but instead of calculating the actual distance from one point to another, the cost functions determine the shortest weighted distance or accumulated travel cost from each cell to the nearest cell in the set of source cells. The weighted distance functions apply distance in cost units, not in geographic units.

All weighted distance functions require a source raster and cost raster. A source raster can contain single or multiple zones, which may not be connected. All cells that have a value including zero are processed as source cells. All non source cells must be assigned no data in the source raster.

The cost distance function creates an output raster in which each cell is assigned the accumulative cost to the closest source cell. The algorithm utilizes the node/link cell representation. In the node/link representation, each center of cell is considered a node is connected to its adjacent nodes by links.

Every link has impedance associated with it. The impedance is derived from the costs associated with the cells at each end of the link from the cost surface and from the direction of movement. The cost assigned to each cell represents the cost per unit distance for moving through the cell. Thus, each cell is multiplied by the cell resolution while also compensating for diagonal movement to obtain the total cost of passing through a cell.

4.3.4 Cost Back link Layer

Defines the neighbor that is the next cell on the least accumulative, cost path to the nearest source, while, accounting for surface distance and horizontal and vertical cost factors. The output Back link raster identifies, for each cell to move or flow into on its way back to the source that will be least costly to reach. The values range from (0 to 8). These source cells are assigned 0 since they have reached that goal (the source). If the least costly path is to pass from the existing cell location to the lower right diagonal cell, the existing cell will be assigned 2, if the traveling directly down or south, the existing cell would receive the value 3, and so forth Figure 4.4. The back link is used to reconstruct the least-cost path from every cell of a raster.

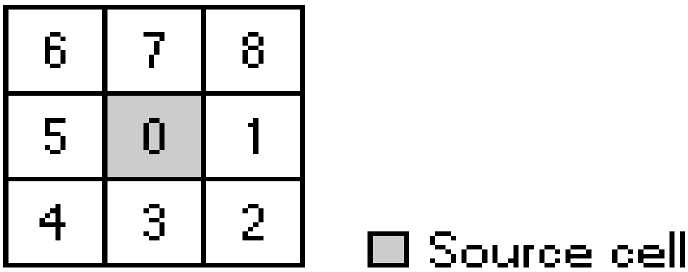


Figure 4.4 Cost BackLink .

4.4 The Search for the Least Cost Path

The selection of the alignment of a proposed canal may resemble the process of selecting the alignment of a proposed road and pipeline. However, the essential difference between them is the tolerance of road and pipeline alignments to progress upwards and downwards with defined limits, while the case is different for channel alignment which must go downwards continuously with defined variation to the slope and velocity. However, it is still useful to go through the researches that were performed on the selection and optimization of the road and pipeline alignment in order to benefit from the sides of the design and computer use where there are similarities, such as the determination of the radius of bends and avoiding the defined man-made and natural obstructions.

The investigation about previous work in the finding of the least cost path for roads, pipelines, and channels reveals to being limited, particularly in the field of channel least cost path finding. However, a brief presentation of the works performed for the finding of least cost path is presented in the following section.

In optimizing the route relevant to canals and roads, Collischonn and Pilar (2000) found that the cost-of-passage from the considered cell to each of the eight neighbor cells to be calculated as a function of slope and distance between these cells. Slope is calculated simply as the elevation difference divided by the distance between them. Cost is obtained from a pre-defined cost vs. slope function. Hypothetical forms of these functions are given in Figure 4.5 in the case of canals. A negative slope would represent movement uphill, and should be avoided with a cost penalty.

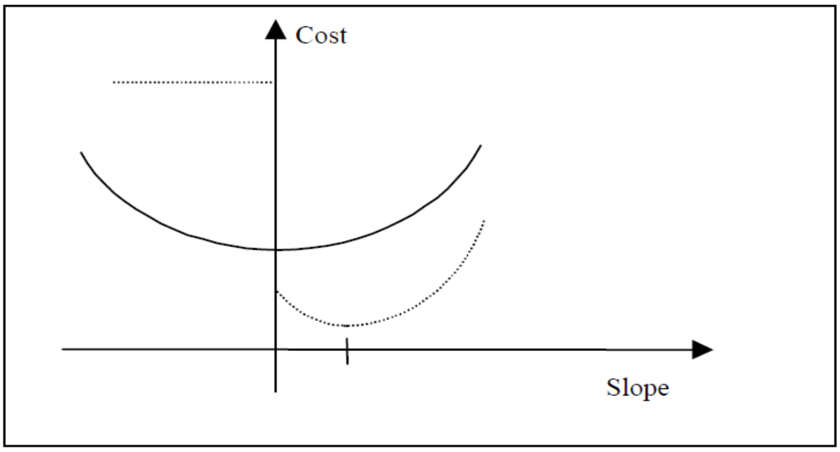


Figure 4.5 Proposed General Forms of Cost vs. Slope Functions for Roads and Canals.

The same researchers performed a test performed with the algorithm and implemented in a computer program for a typical irrigation canal routing. The test was designed to be a hypothetical case of irrigation canal design, where the best route to follow, form a starting to an ending point, over a DEM representing topography, is required. They indicated that the best route has to be short, has an almost constant slope and should never go uphill.

The starting and ending points were located at places intended to turn difficult the route finding. The end point is in a valley and the starting point is behind a mountain. The 60 columns by 70 lines sample DEM was extracted from a 1km times 1km. The result is shown in Figure 4.6 where the darker tones correspond to lower terrain and lighter tones represent higher terrain.

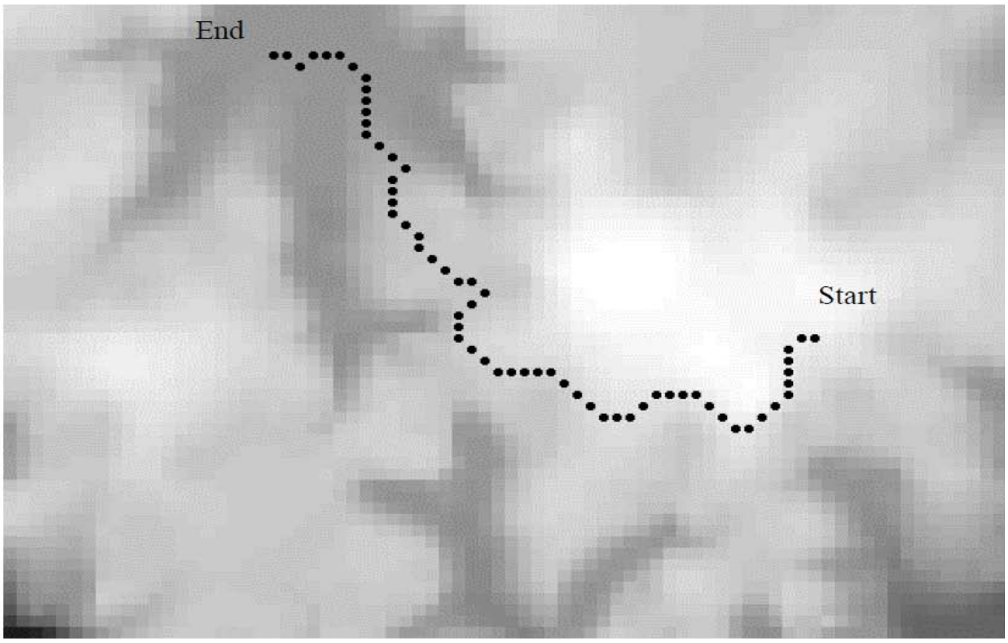


Figure 4.6 Best Route of an Irrigation Channel.

Gozel etal (2011) found that in roads, the highway route analysis between two cities and deployment route of a military unit along a 20 km terrain requires different resolution input, and consequently, the output will be in a different resolution. During the test studies, using the application developed on the algorithm, a highway route analysis between Ankara and Izmir (approx. 500 km distance) and the forbidden zones (protected sites, military zones, mine fields, inconvenient terrain, visible area, and the like) within the study area can be set on the algorithm as a constraint to prevent the route analysis from passing through them. The researchers proposed criteria zonal weights as shown in Table 4.1.

Table 4.1 Criteria Zonal Weights.

CRITERIA ZONE NAME	WEIGHT (%)
FOREST LANDS	30
DECELERATING LANDS	15
RESIDENTIAL LANDS	40
CRITERIA NAME	**WEIGHT (%)**
SLOPE	15
ELEVATION	0
LATERAL SLOPE	0
	∑ 100

The calculations/runs with the results found through the use of Netcad program and Corridor Tool were performed on a standard desktop computer. These results are shown in Figure 4.7.

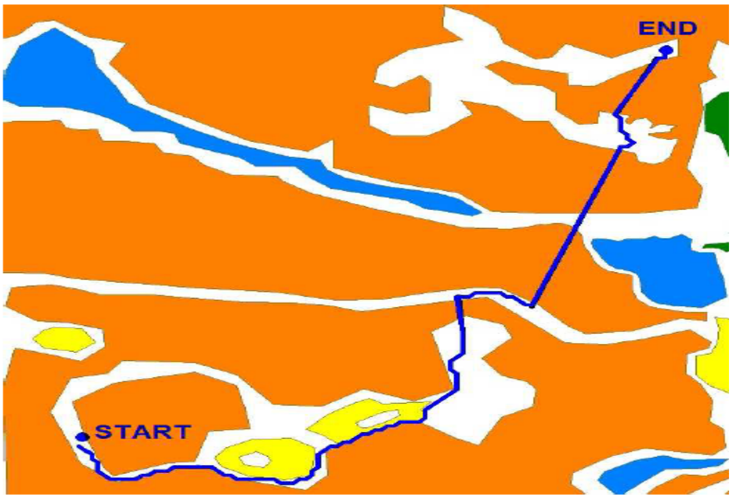


Figure 4.7 Proposed High Way between Ankara and Izmir.

Alsamari etal (2010) investigated the route optimization of a pipeline by means of using ArcGIS. The attempts produced a path route for pipeline to convey petroleum between two points, named Sabkha A and Sabkha B, in Saudi Arabia about 900 km length as explained in Figure 4.8.

Figure 4.8 Least Cost Path between Sabkha A and Sabkha B.

They concluded in their research that the main goal of generating the optimum route was to assure safety in design, construction, operation, maintenance and emergency response. They concluded that with the consideration of the complexity that accompany high quality planning, pipeline routing needs to be more sophisticated in terms of raster.

The ArcGIS Spatial Analyst module can be used in the optimum route selection of the pipeline process in order to minimize impacts on back pressure and costly aspects during the construction phase. People and software are the key elements to any geographic information system and are equally important to a successful and enhanced routing process.

CHAPTER 5

OPTIMIZING THE ROUTE BETWEEN THE SUPPLY AND DEMAND POINTS OF A CHANNEL

A region is selected for investigating the behavior and capabilities of the ArcGIS program. Obtaining a digital map (DEM) with resolution less than 90m appeared to be difficult due to several reasons. The requirements and purpose of the research seemed to be unfamiliar to the source/s of the data which made the matter time consuming to a limit that seriously affected the period of the research. Eventually, a region from Mosul with resolution of 85.5m was selected to be operated upon.

The research plan aimed to test the behavior of the Arc GIS program in several ways by means of applying variation on the priority order of the essential variables that influence the process of optimization. Also, another aim is to repeat the process after changing the length of the predicted route as well as the topography over which the optimization is applied.

The aim of the attempts to optimize the route between source and demand points of a water conveying channel (for irrigation purpose and the like) is to observe the degree which the ArcGIS program would function in a way to save the designer engineer the burden of such optimization when performed manually. Although may not be far from being perfect, the aim here is to seek the perfect solution with minimum effort

and time consumption.

As explained in previous chapters, little work is performed in the field of optimizing the route between supply and demand points of a proposed channel. Even the books that are relevant to the ArcGIS programs as well as its ‘Help’ manual facility do not explain the details of the case in concern for this research. Only relatively, more work has been made in relevance to such optimization for the path of roads and highways and railways. The essential difference between the latter group and the determination of open channel route is that channels have no tolerance in going upwards, and can go only downwards.

The aim in this research is not only to search for the shortest route of open channels, but also to find the one with minimum cut and fill. Of course, there are other relatively minor factors to be considered in real projects, such as avoiding man-made (important structures that cannot be removed easily: buildings, army campus, highways, railways, and the like), or, natural obstructions, or, even historical locations that should be preserved. These relatively minor factors were neglected in this research due to the limited period of the research with the hope that it will be investigated later on by the same researcher or by others.

5.1 Stages of the Research

The work aims to find an optimum route of an open channel between supply and demand points by means of implementing GIS method through the ArcGIS program version 9.3. The behavior of the program for such purpose in this aspect appeared not to be available neither in the ‘Help’ menu nor in the books relevant to the program nor in previous works. This meant that the matter of such finding is a kind of ‘adventure’ with unpredicted degree of success, and also, unpredicted time consumption till satisfactory results would be reached. The researcher decided to go on with the investigation regardless of the risk of going through closed tunnel.

The research was not easy regarding all its stages including the finding of a suitable region for investigation with acceptable resolution, and also, regarding it suitability from the topographic point of view. In other words, the region is not supposed to be too flat with smooth gentle slope, or else, the solution would be too easy in a way that the usefulness of the program may not appear clearly (not much different from a simple manual solution), and also, should not be too irregular in a way that the program would be confused and consequently give unclear error messages.

After obtaining a region for investigation with reasonable resolution, the work was in the direction of understand the behavior of the program particularly regarding the search for the optimum route of an open channel between supply and demand points. That was not easy due to the complete lack of any examples in this field. The previous works appeared to be related to the same target but for roads and highways, which have the tolerance of having variable slopes (upwards and downwards), while the case is certainly different for the case of open channels that can go only downwards with limited range of slope. The latter limited range is due to the velocity being abrasive in case being too high, and also enabling the sediment content (if and when water is sediment loaded) to settle and cause undesirable extra bed and side friction as well as decrease in the channel cross section.

The work went on continuously till reaching reasonably satisfactory results. The researcher thinks that the results along with the method of solution has the chance for improvement through more research and attempts. However, the limited time of the research did not enable for more than the stages that were achieved.

The work in the search for optimum route between supply and demand points is thought to be divided in four essential and distinguished stages. These stages are presented in the following sections. Since there are many numeric details that should be presented throughout each of the four stages, it is thought better to briefly explain the work performed in the first, second and third stages with minimum numeric values and concentrate on the assumption and performance as well as the results, and explain the reason for moving into the following stage. The detailed numeric values are explained only in the four and final stage where satisfactory results seem to have been obtained. The reason for not explicitly presenting all numeric values in the first, second and third stages is simply to decrease the time of the reader to reach the final and satisfactory results. After all, these numeric values in the first, second and third stages have little scientific importance for being unsatisfactory results.

5.1.1 First Stage

The work started in using complete DEM of Mosul city in Iraq, as explained previously, with supply point A and destination point B at the north east of the selected region as shown in Figure 5.1. The straight distance between them is 7250m, and the elevation difference between these two points is 11m. The topography within the region, and particularly between points A and B, is observed to be too irregular. This is thought, at the start of the work, to be a heavy test to the program regarding showing its capabilities in finding a solution. In fact, the results of the attempts to find a solution (optimum route between A and B) showed that the output was unsatisfactory and unreasonable just as much as a manual solution could be and may be worse. In other words, the runs on the ArcGIS program showed that the cut and fill volumes were clearly unsatisfactory and/or impractical.

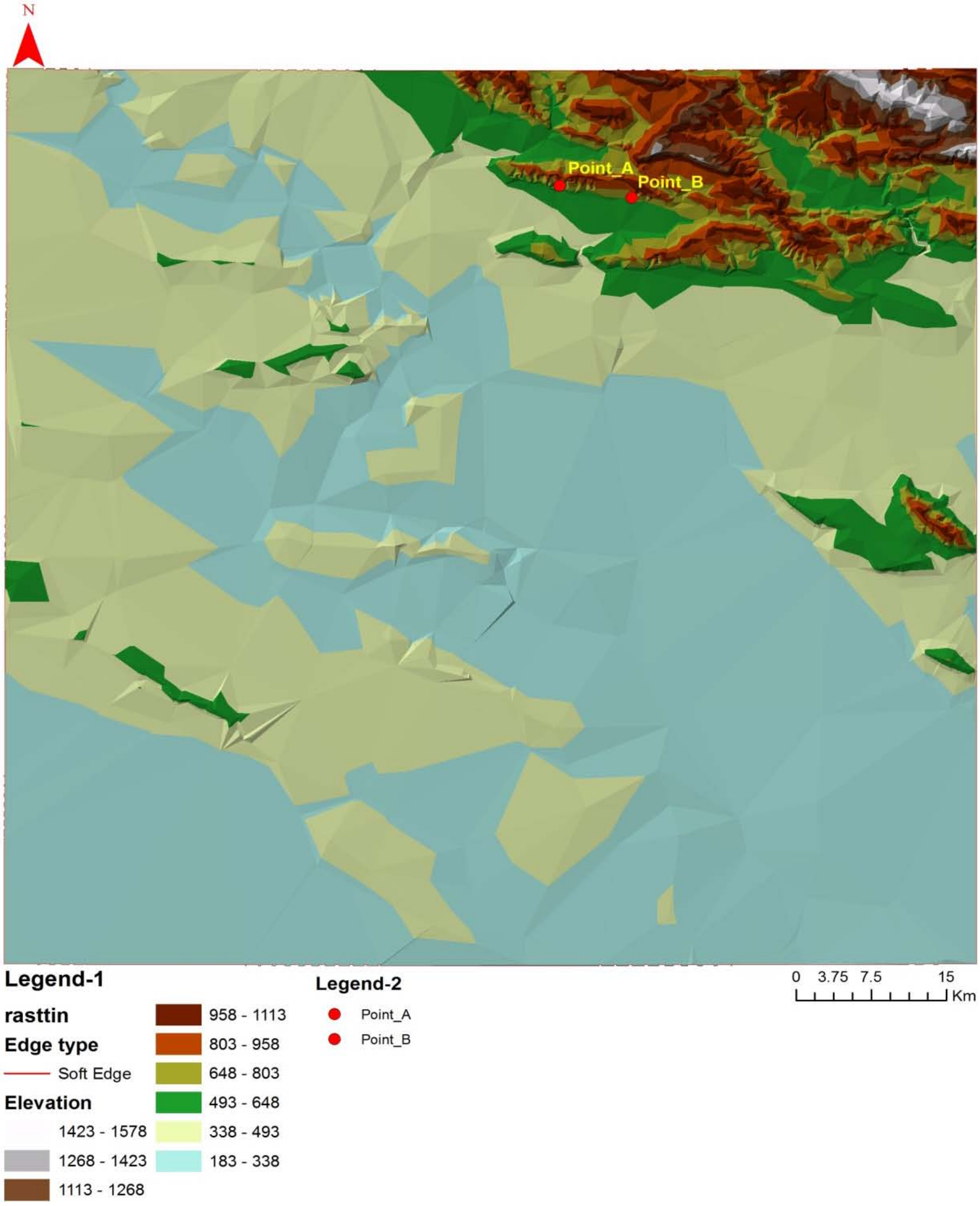


Figure 5.1 Main DEM with Demand Point A and Destination Point B in the First Stage in Form TIN.

5.1.2 Second Stage

This stage seeks the attempt where the supply and demand points are selected within a relatively more plane region, and also, the straight distance between them is relatively shorter in comparison with the case in the first stage. This change is thought to make some improvement on the results. Here, it is of essential importance to emphasize that the very same region and size was selected for the stage just as what was selected in the first one. In other words, the elevation variation for the region is the same in both first and second stages. Obviously, the supply and demand points were different from those in the first stage. They are shown in Figure 5.2 to the south west of the selected region. The straight distance between them is 6250 m, and the elevation difference between these two points is 8.5m.

The runs on the ArcGIS program showed that the results are still unsatisfactory despite being relatively better than those obtained from stage one. The selected routes still seemed to require unbalanced excavation and fill with unacceptable volumes.

The researcher thought that the elevation range of the region is so large (183-1578m) that is likely to be the main reason for the low quality of the results. This thinking lead to the idea of extracting the small section surrounding the supply and demand points from the main region. Thus, the elevation variation within this smaller region would be automatically far less in a way that is likely to give better results.

The latter thinking about the elevation range lead to the work explained in the third stage.

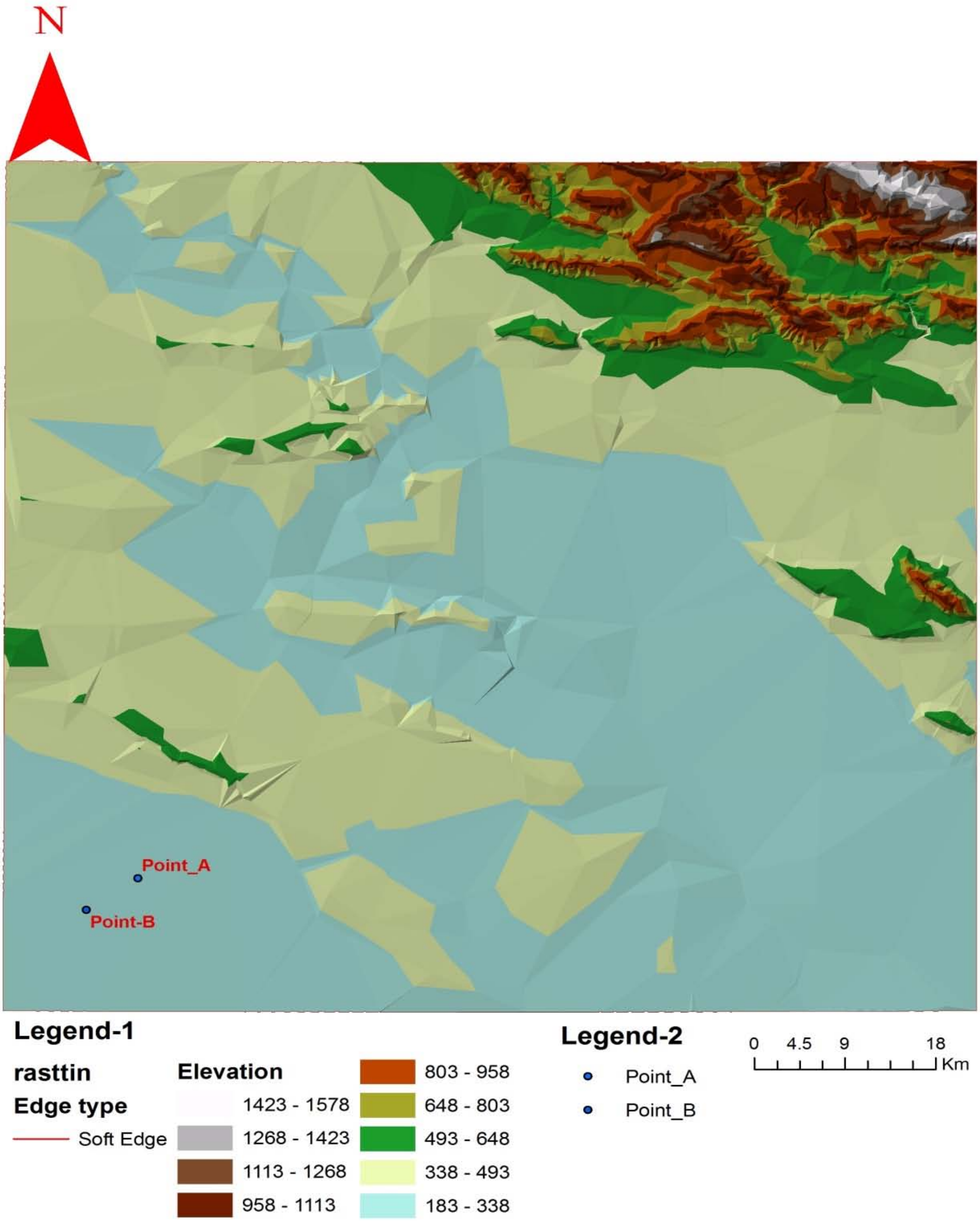


Figure 5.2 Main DEM with Demand Point A and Destination Point B in the Second Stage in Form TIN.

5.1.3 Third Stage

In this stage the work went in the direction of repeating the same stages followed in the second stage. However, the big change is in deducting the south west section of the original map/region used in the attempts explained in both the second and third stages. The deducted section appears on the main region in Figure 5.3 in different color, and also, magnified independently as shown in Figure 5.4. These two figures give an idea about the way the smaller section was deducted for the aim of this attempt.

The new smaller deducted section shown in Figure 5.4 appeared to have relatively far smaller range of elevation (244-275m) when compared with the elevation range related to the whole region (main DEM) during the attempts explained in the first and second stages (183-1578m).

The improvement of the results of the runs appeared to be obvious in every aspect. This proved the accuracy of the analysis of the behavior of the program which is not declared previously in any research, book, or article. In fact, this step in improving the results helped the researcher to gain more confidence regarding the direction of the works in improving the research even more.

Thorough investigation to the results obtained in this stage, using the visual judgment and experience of the researcher, lead to the thinking that even a better route could be selected somehow. This was the reason for investigating yet another way that would decrease the elevation range even more. It appeared obvious that in order to decrease the elevation range even more through deducting a smaller section of the region shown in Figure 5.4 is not practically possible. The thinking was in the direction of attempting to ‘eliminate’ a specific range of the total elevation range of the region in concern. In other words, it is thought to eliminate the relatively severely low elevations from the region shown in Figure 5.4. If, a way is found to apply this approach, this should save the program wasting time in thinking to go through that region (if the route is selected there, it would require lots of fill), and also, increase the chance of finding the route in a more logic and sensitive way.

The new idea of eliminating the data related lowest region of the total section shown in Figure 5.4 lead to the attempts to apply it numerically before the usual runs on the computer. A way was found to cancel/neglect the elevation data related to the contours/elevations below 257m and work on the range left of 257-275m.

This stage of work is explained in the following stage with all the details of the results, figures, and numeric calculations because the fourth stage seems to represent the most satisfactory attempt/run in this research.

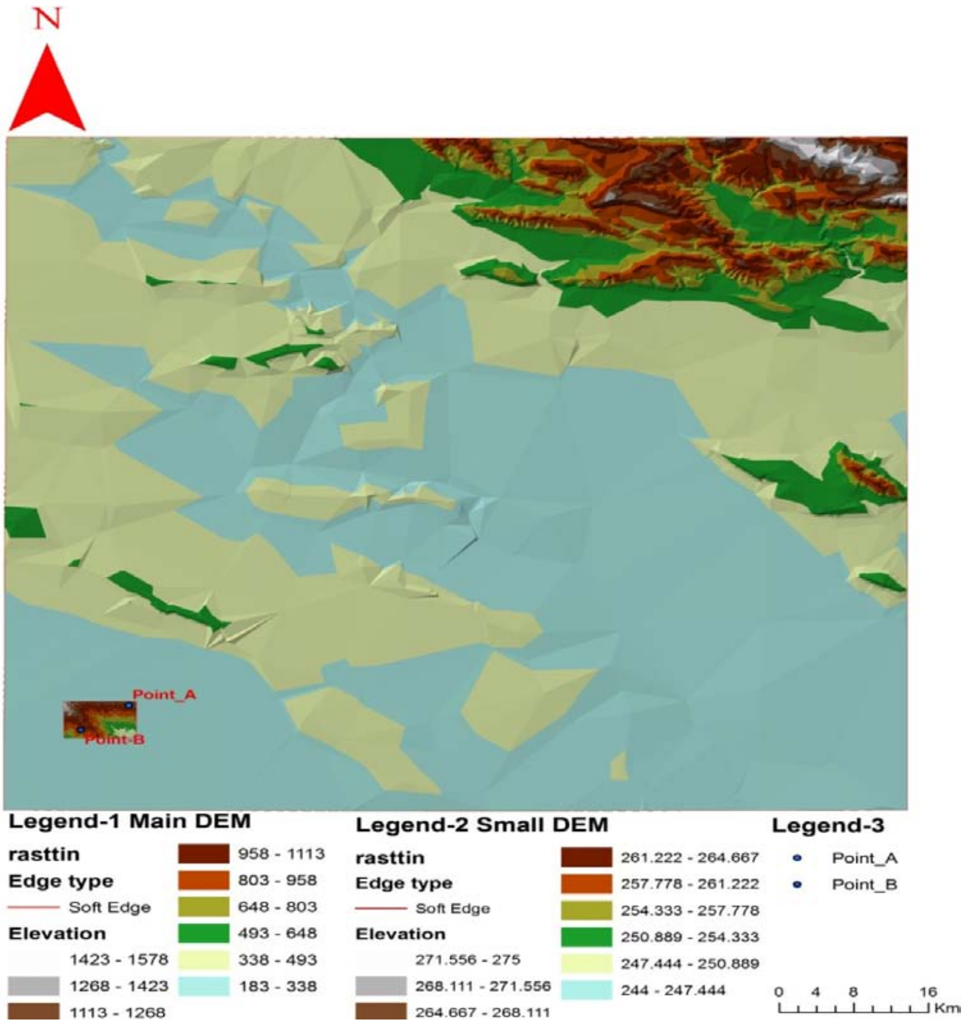


Figure 5.3 Small DEM of Work Inside Main DEM of Mosul in TIN Form.

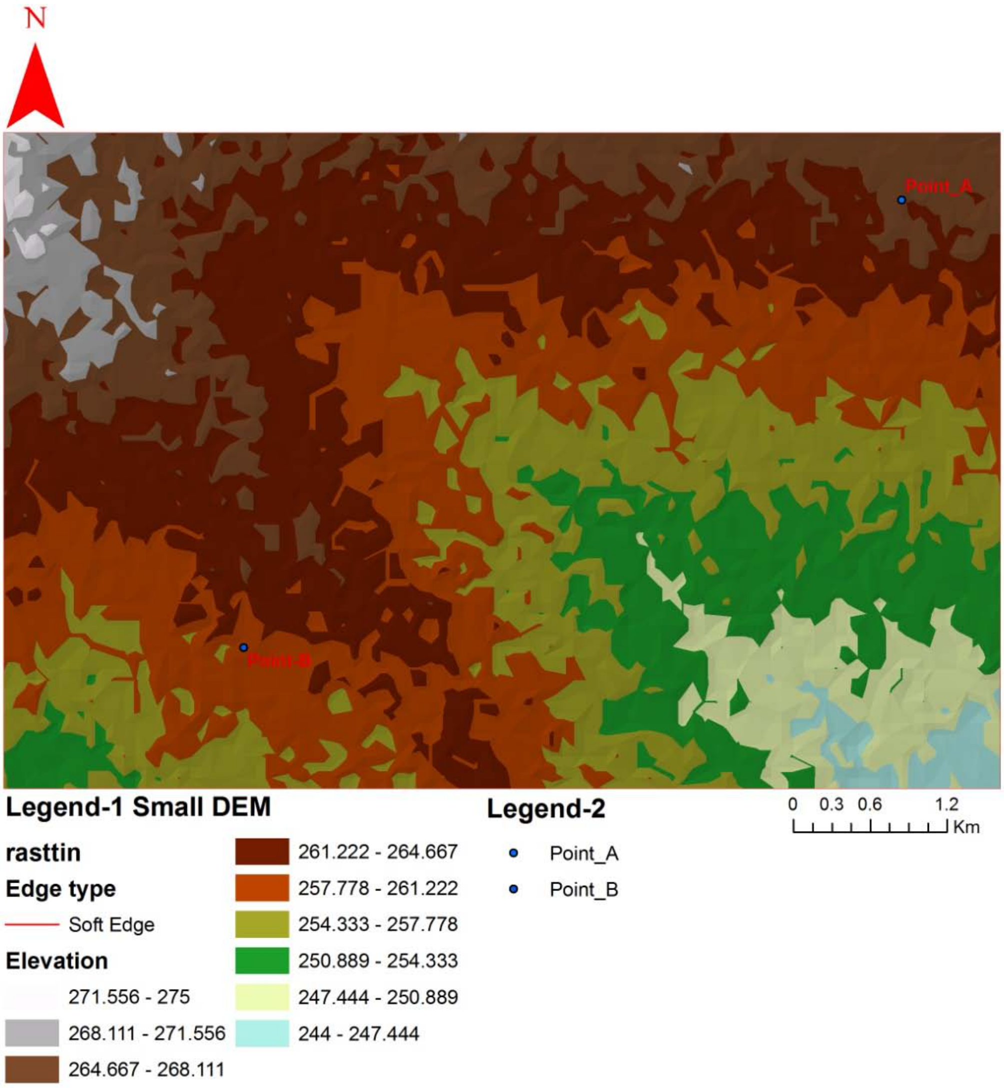


Figure 5.4 A Small DEM for the Area of Work in TIN Form.

5.1.4 Fourth Stage

After performing the elevation 'filtering' in the data of the input relevant to the region in concern, the runs on the ArcGIS appear to give relatively even better results where the improvement could be even visually distinguished.

The results showed relatively more balance between the cut and fill volumes, and also, the route appeared to go though gentle slope through relatively shorter distance between the source and demand points.

The region with the section of data that is filtered is shown in Figure 5.5. In this figure, the source and demand points are clearly shown, and also, the region of the filtered data appeared as blank (no color). This filtered section represents the range 1 in the 10 classification of the elevation ranges. The legend in Figure 5.5 shows clearly that the classification 1 does not exist (all figures and legends are produced automatically by the program).

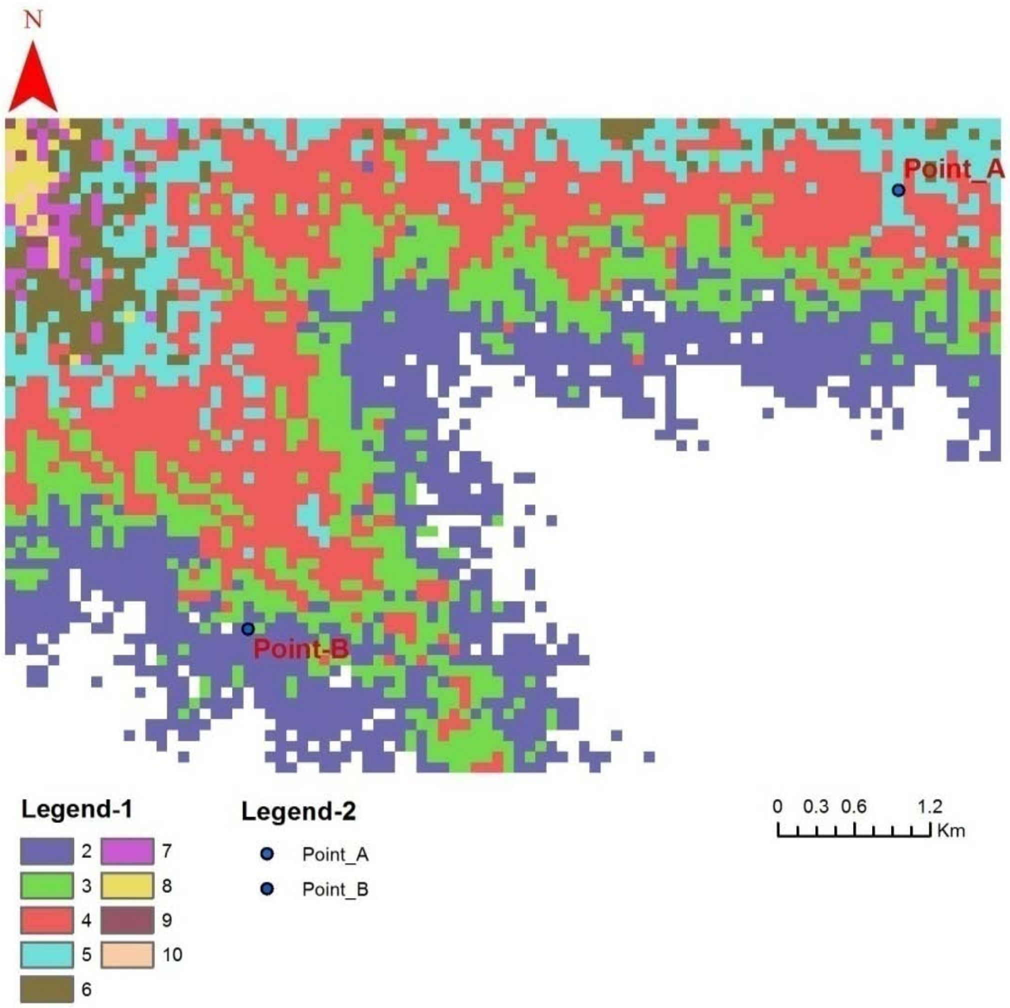


Figure 5.5 Reclassify of a Small DEM with Missing Data.

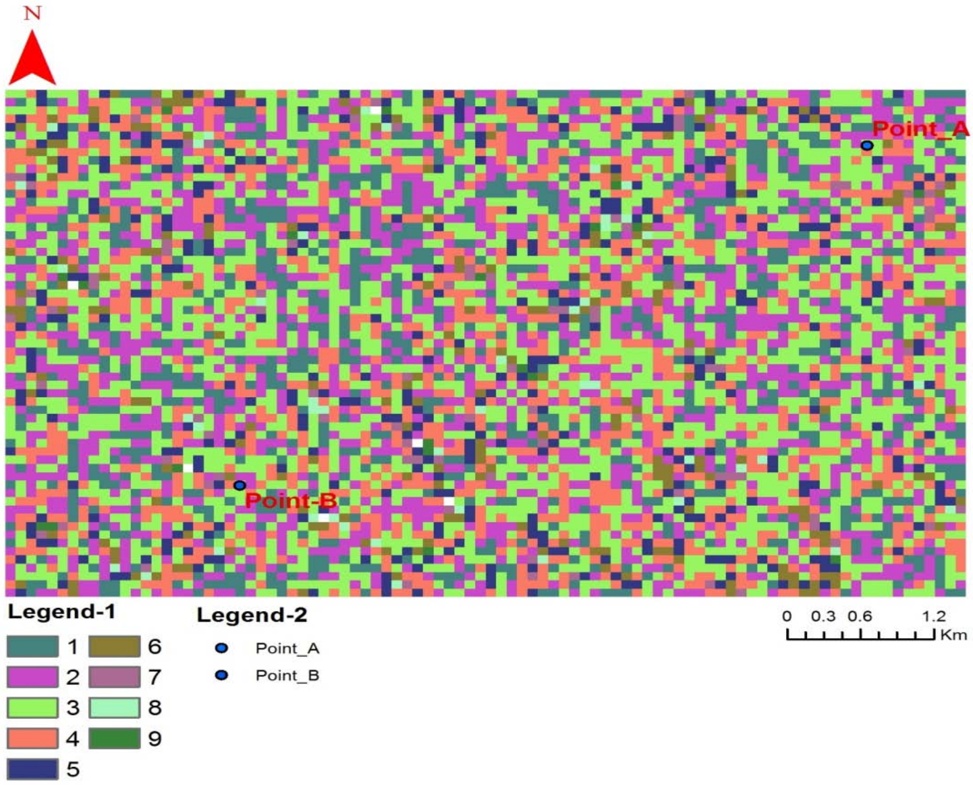


Figure 5.6 Reclassify of a Slope with the Missing Data.

In Figure 5.6, the slope classification is presented as different colors. This, in fact, is a useful view that helps the user to understand the behavior of the program even more. This figure was produced in all attempts throughout the research to analyze and evaluate the results as well as to try to consider the way to improve the method of finding even a better optimum route. Only in this attempt the figure is shown due to this fourth stage being the most successful one.

In Figure 5.6, the number of slope classifications was reduced from 10 ranges, as was performed in all previous attempts, into 9. This change is thought to be useful in order to ease the way to find a smoother slope. This should ease the coordination between the elevation and slope ranges during the selection of the route.

The severe slope in the region (class 10) that is omitted in as shown in Figure 5.6 (scattered little number of white/blank pixels with no color).

In this research, the results of the fourth stage appeared to be satisfactory, and the details of the input data along with all what is relevant to the program runs and results are explained in details in the following sections.

5.2 The Selection of the Region

At the start of the research the attempts tried on a Main Raster Digital Elevation Model (DEM) shown in Figure 5.7, then, because the results appeared not to be as satisfactory as expected. The main reason for this low quality results appeared to be the consideration of the program to the maximum and minimum elevations within the allocated region. After thorough investigation to find the reason of the low quality results, it appeared that the range of elevation of the region seems to affect the quality of the results/optimized route. In other words, the larger the elevation range is, the less the sensitivity would be in optimizing the route of the channel.

After this stage, the decision was to limit the size of the investigated region to the range within which the source and demand points exist. This is shown in the raster Small-DEM as in the Fig 5.7 (greenish colored). This process seemed to improve the results of optimization to a noticeable extent. Still, the results were improved even better through another step of filtering the elevation range. This latter step will be explained in later sections within this chapter.

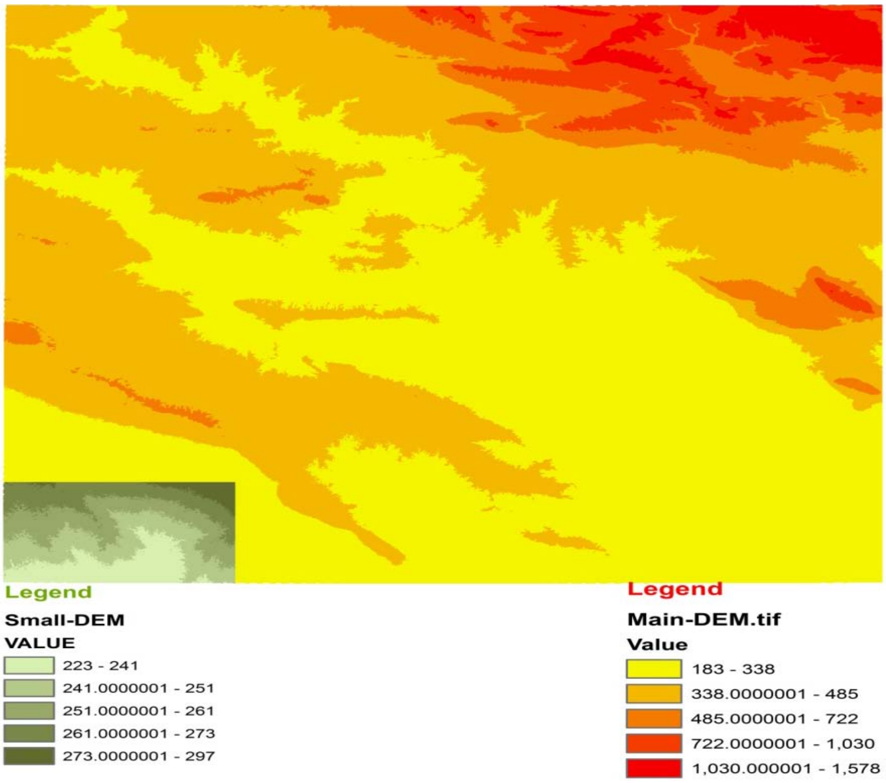


Figure 5.7 The Small-DEM Clipped from Main-DEM.

A- The information of the Main-DEM is as follows:

Columns and rows: 1180, 1153

Cell Size (X, Y): 85.5, 85.5

Format: TIFF

Extent: Top 4090810, Left 264760, Right 365685, Bottom 3992195

Spatial Reference: WGS_1984-UTM-Zone-38N

Linear Unit: Meter (1.000000)

Datum: D_WGS_1984

B- The information of the Small-DEM as follows:

Columns and rows: 92, 61

Cell Size (X, Y): 85.5, 85.5

Format: TIFF

Extent: Top 4009558, Left 273741, Right 281610, Bottom 4004340

Spatial Reference: WGS_1984-UTM-Zone-38N

Linear Unit: Meter (1.000000)

Datum: D_WGS_1984

5.3 Determining the Location of the Source and Demand Points

The determination of the location of the source and demand points is a sensitive matter in this aspect of the research. This is because the locations should implicitly have logic characteristics that would enable the program to find the optimum route with reasonable accuracy without any chance of fault. This means that the source must be higher that the demand point, and also, the difference in elevation must be reasonable enough to enable for a reasonable slope that enable for reasonable velocity (not too high and not too low). Of course, the assumption here implicitly assumes no drops or special locations/points to be avoided during the search for the optimum route. The selection of the location of these two points influences and shows the capability of the program to find the optimum route/s. If the selection were to be determined on a relatively plane region, the behavior and capability of the program may appear clearly due to the easiness of the solution. This is why the researcher intended to select a region with relatively irregular topography. The selected source A and demand B points are shown in Figure 5.8. Also the elevation of point A is 266m, and for B is 260m. The straight line between both points is measured to be 6264m.

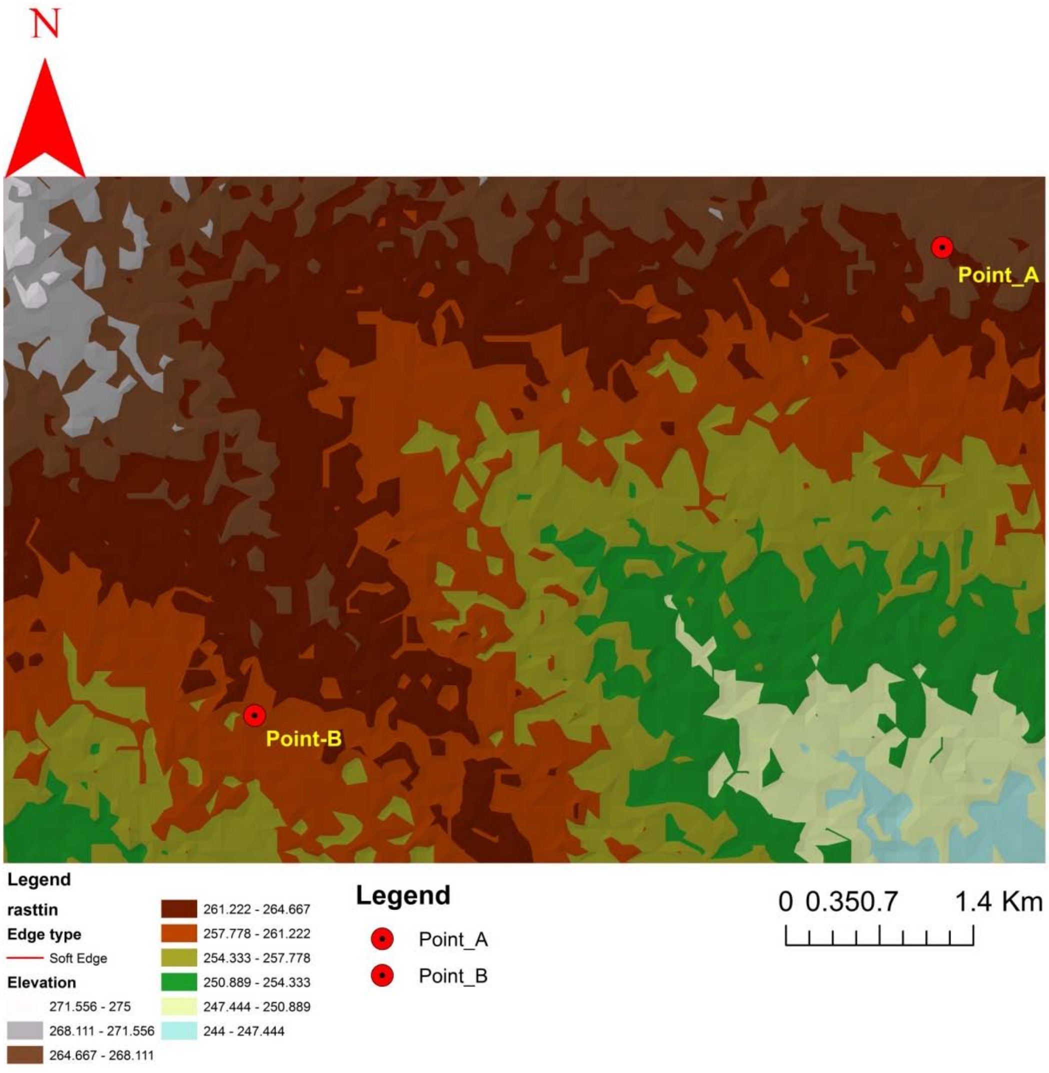


Figure 5.8 Locations of Point A and Point B in a Small TIN.

Figure 5.8 shows that if the route is drawn as a straight line from point A to point B, it has to go through severe depressions, also, if the route is drawn through the south region of the selected frame, the same problem of depressions will be worse, while if the route is drawn through the northern section, there will be minimum depressions.

In fact, it would be much better if the user of the program is an experienced engineer and should also have complete knowledge of the region in concern. This is simply because only an experienced engineer has the capability of evaluating the quality of the program results and/or able to detect any abnormality in failure runs, especially when the program gives unacceptable results with no error messages.

5.4 Performance of the Route Optimization Process

In order to ease the understanding of the performance of route optimization process, it is thought to divide the process into the following section:

5.4.1 The Creation of Route Layers

This step is the first step during the different stages required to perform the route optimization process. This stage includes the production of the several layers as explained in the following sections:

5.4.1.1 Layer of the Source and Demand points

This vector layer is essential for the determination of the optimum route between the source and demand points. In fact, similar processes for the finding of the optimum route of roads, pipeline and the like require this layer at the start of work. Figure 5.8 shows this layer with the source and demand points located on it.

5.4.1.2 The Creation of TIN Layer from the Available DEM

The TIN layer that is derived from the DEM one enables the user of the program to have good visual opinion about all what is relevant to the input and even the output. Thus, this enables to evaluate the results in a developed way and consequently, to improve the process if there is any way to do that in future runs/projects.

Figure 5.8 shows the elevations in triangular form, and the colors of these triangles are explained in the legend of the figure. This layer can be used in the following steps for observing all the natural ground elevations of the stations along the optimized route.

5.4.1.3 The Creation of Slope Layer

As it explained in the chapter 4, this Raster layer along with the TIN model produces a visually distinguished surface slope and aspect in different ways. In a raster, slope and aspect are calculated for each cell by fitting a plane to Z-values of each cell and its eight surrounding neighbors. The slope or the aspect of plane becomes the slope or aspect value of the cell in a new raster.

Here, the raster slope is converted from the main DEM raster to explain the slope of each cell and its neighbors by percentage value.

5.4.1.4 Reclassification of DEM Layer

In order to reclassify the DEM raster, the user has to manually determine the ranges of elevations (usually 10 ranges) within which all elevation values in the region would be transferred into one of these determined classifications. In other words, the real elevation values in the region will be replaced by its relevant classification.

Here, it should be explained that this reclassification process enables the user, after defining the ranges of the classifications, to ignore one or more of the classifications that were determined. This process of ordering the program to ignore/cancel the existence of one or more classification may be needed in case the user wishes to eliminate the probability of the computer going through the unwanted/cancelled classification. This cancelling process was performed for class 1 among the ten classification determined for the elevation range 244-257m as shown in Figure 5.9, which led to the improvement of the results in the Fourth Stage explained in Section 5.1.4. This explains the non-existence of the classification 1 among the rest, and the Legend in Figure 5.9 clearly starts from class 2.

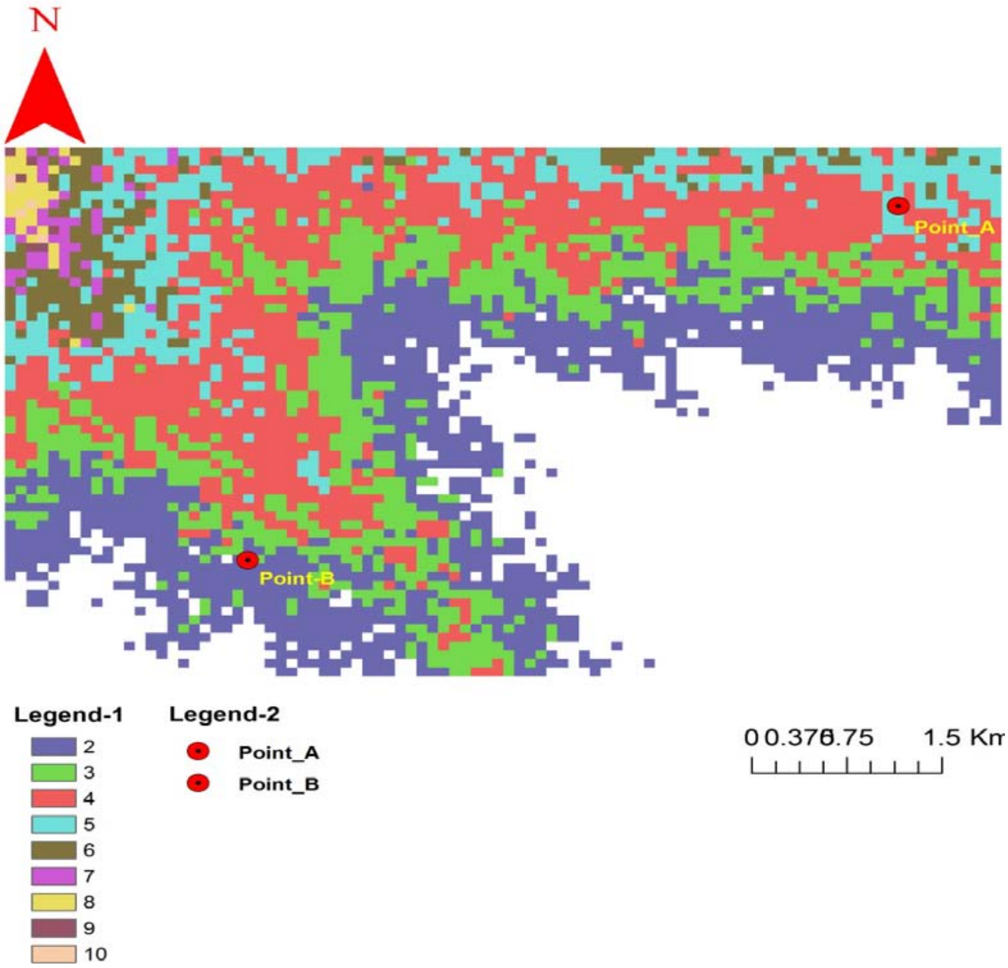


Figure 5.9 Reclassification of DEM Layer.

5.4.1.5 Reclassification of Slope Layer

The aim of the production of the reclassified slope layer is, somewhat, similar to the aim of the one explained in the previous section. The only difference is that the classification is determined by the computer user for slope ranges. Thus, in this process, each real numerical slope in the region between two pixels is replaced by one of the classifications (usually ten), and accordingly, the program will perform the search for the optimum route.

In Figure 5.6, which is again relevant to the Fourth Stage explained in 5.1.4, shows no existence to the tenth classification (slopes between 3.05% and 3.4%), and thus, only the classifications from 1 to 9 are presented in the relevant legend.

5.4.1.6 Cost Surface Layer

The overlaying of the reclassified DEM layer as well as the reclassified slope layer leads to the creation of the cost surface layer. The optimization process requires that the program user, before running the program, should determine the priority percentages distributed between both the elevation and slope. In other words, each run should have two independent values for the determined priority given to the elevation and slope where the total would be 100. Obviously, the priority order given to both the elevation and slope may vary depending on the user needs regarding the conditions of the project. Thus, a relatively high percentage value given to the elevation priority would result in giving less priority to the slope during the search for the optimum route, and vice versa.

This researcher decided to perform five runs with different priority ratios for the elevation and slope. Since the aim of the research is to understand the behavior of the program, the repetition of the runs with different ratio combinations is, in fact, meant to clarify even more the reaction of the program towards these changes.

Table 5.1 presents the five selected combination of the elevation and slope ratios.

These ratios were selected after many other attempts with different ratios. Particularly, the 0-100 and 100-0 combinations were not selected previously; however, it appeared that these extreme ratios have significant influence that should not be neglected as will be explained in later section.

Table 5.1 Influence Percentage for the Cost Surface Layers.

Cost Surface No	Influence % for Re-DEM Layer	Influence % for Re-Slope Layer
1	100%	0%
2	75%	25%
3	50%	50%
4	25%	75%
5	0%	100%

5.4.1.7 Cost Distance Layer

The cost functions are similar to Euclidean functions, but instead of calculating the actual distance from one point to another, the cost functions determine the shortest weighted distance or accumulated travel cost from each cell to the nearest cell in the set of source cells. The weighted distance functions apply the distance in cost units and not in geographic units.

In this work, in order to determine the winning optimization among the five runs of the program (for the five different priority percentage combinations), it appeared essential, at this stage of the research, to evaluate the success of each run according to how little the total volume of cut and fill that are relevant to that particular run. In other words, among the five runs, the least cost of cut and fill (least volume of cut and fill) would be the winner solution. Accordingly, five cost layers were produced for this purpose. The cost layer relevant to the fifth run, with 0% elevation and 100% slope combination, is shown in Figure 5.10.

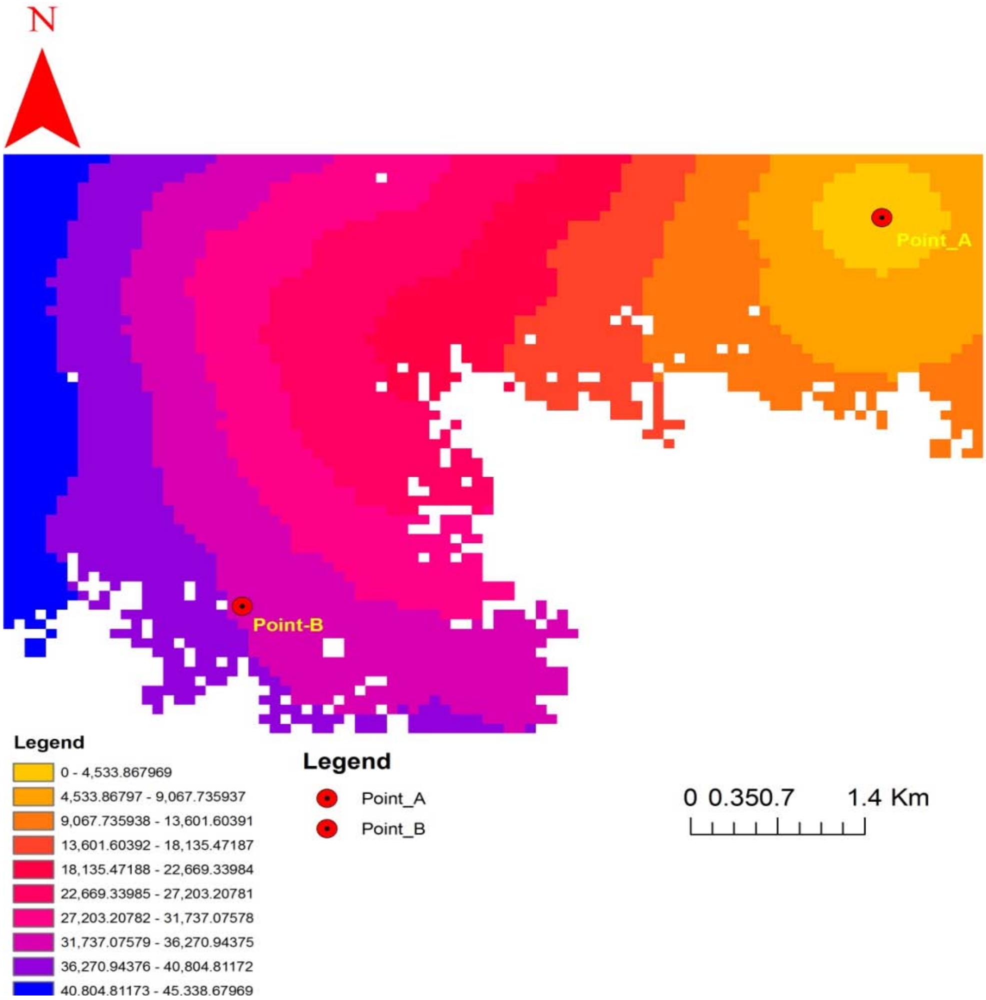


Figure 5.10 Cost Distance Layer for 0% Elevation 100% Slope Combination.

5.4.1.8 Cost back Link Layer

The output Back link raster identifies, for each cell to move or flow into on its way back to the source that will be least costly to reach. The values range from (0 to 8). These source cells are assigned 0 since they have reached that goal (the source). If the least costly path is to pass from the existing cell location to the lower right diagonal cell, the existing cell will be assigned 2, if the traveling directly down or south, the existing cell would receive the value 3, and so forth. The cost back link layer relevant to the first run, with 100% elevation and 0% slope combination, is shown in Figure 5.11.

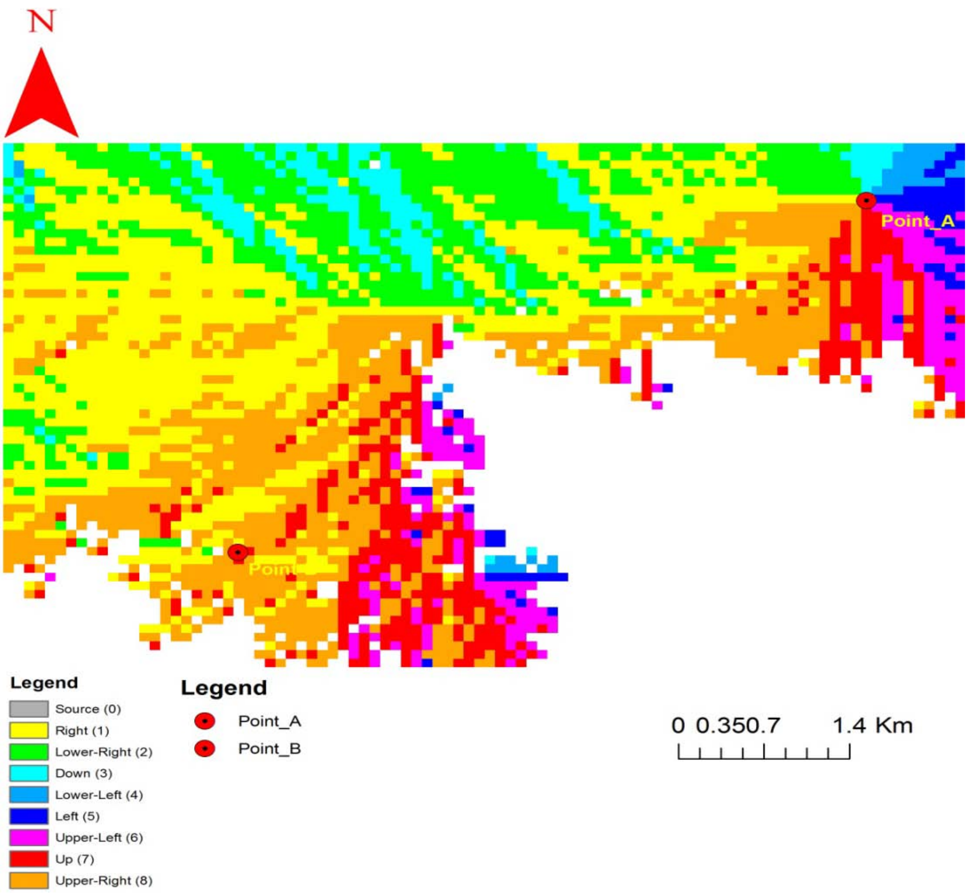


Figure 5.11 Cost Back Link Layer for 100% Elevation and 0% Slope Combination. 1

5.4.1.9 Cost Path Layer

The cost path layer is used to calculate the least cost path from a source point to a destination point. The 'Cost Path' tool produces an output raster that records the least-cost path/paths from selected locations to the closest source cell defined within the accumulative cost surface, in terms of cost distance. When the input destination data is a raster, the set of destination cells consists of all cells in the input raster or feature destination data that have valid values. The cells that have no-data values are not included in the source set. The value zero is considered a legitimate destination. A destination raster can be easily created using the ‘Extract by Tool’. One or more of the weighted cost functions (Cost Distance, Cost Back Link, or Cost Allocation) are generally required to run prior to running Cost Path to create the input cost distance raster and the input cost back link raster. These are mandatory input raster to Cost Path. The path of this layer will be an output like raster layer as shown in the **Figure 5.12** for the fifth trial.

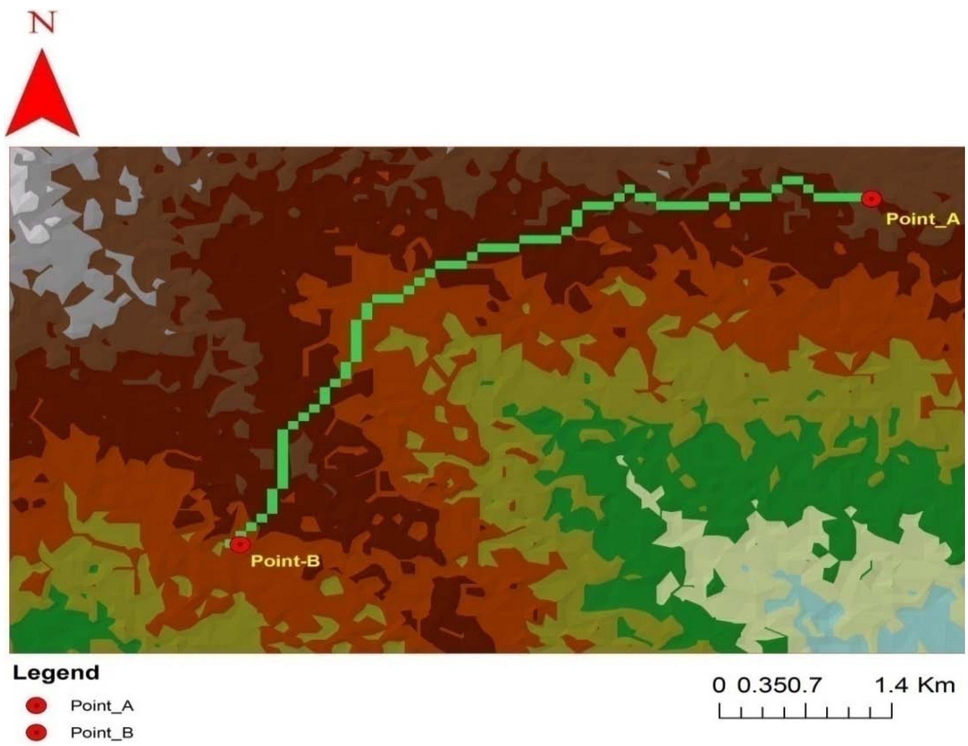


Figure 5.12 Raster Layer for Least Cost Path for 0% Elevation and 100% Slope Combination.

5.4.1.10 Route Layer

Route layer refers to a shape file layer. It is a conversion from raster to vector form through which the selected route can be visually seen as a line/curve on the map. The selected route from the fifth run, with 0% elevation and 100% slope combination, is shown as a vector layer in Figure 5.13

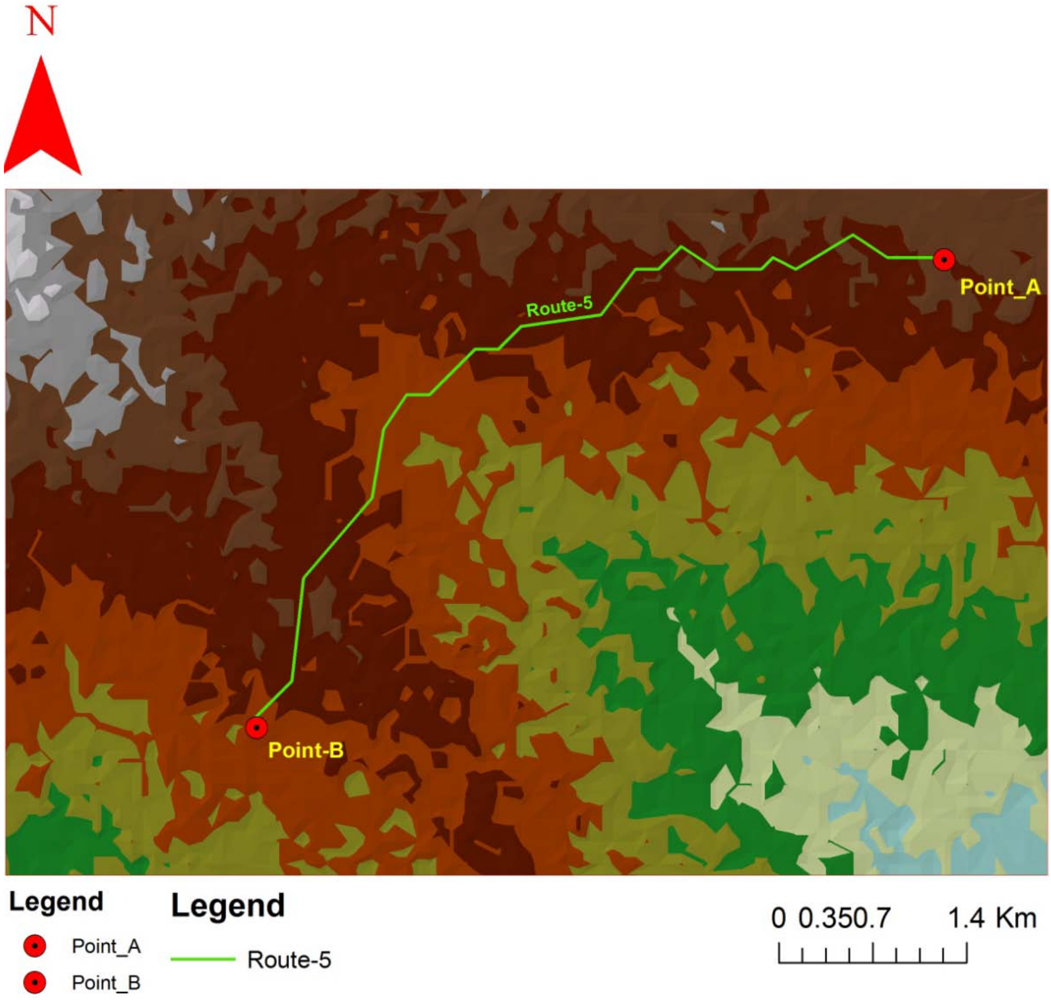


Figure 5.13 Route Layer of the Fifth Run 0% Elevation and 100% Slope Combination.

5.4.1.11 Stations Layer

The Stations layer refers to points dropped along each path/route that results from the run of the program. The distance between each successive two points is taken as 50m. Each point has three coordinates (X, Y, Z) as shown in Figure 5.14 for the fifth path. The usefulness of the coordinates of these points/stations is to represent the Natural Ground Level for the route/path altogether, which will be needed for the calculations relevant to the cut and fill using Excel, as will be explained in later sections.

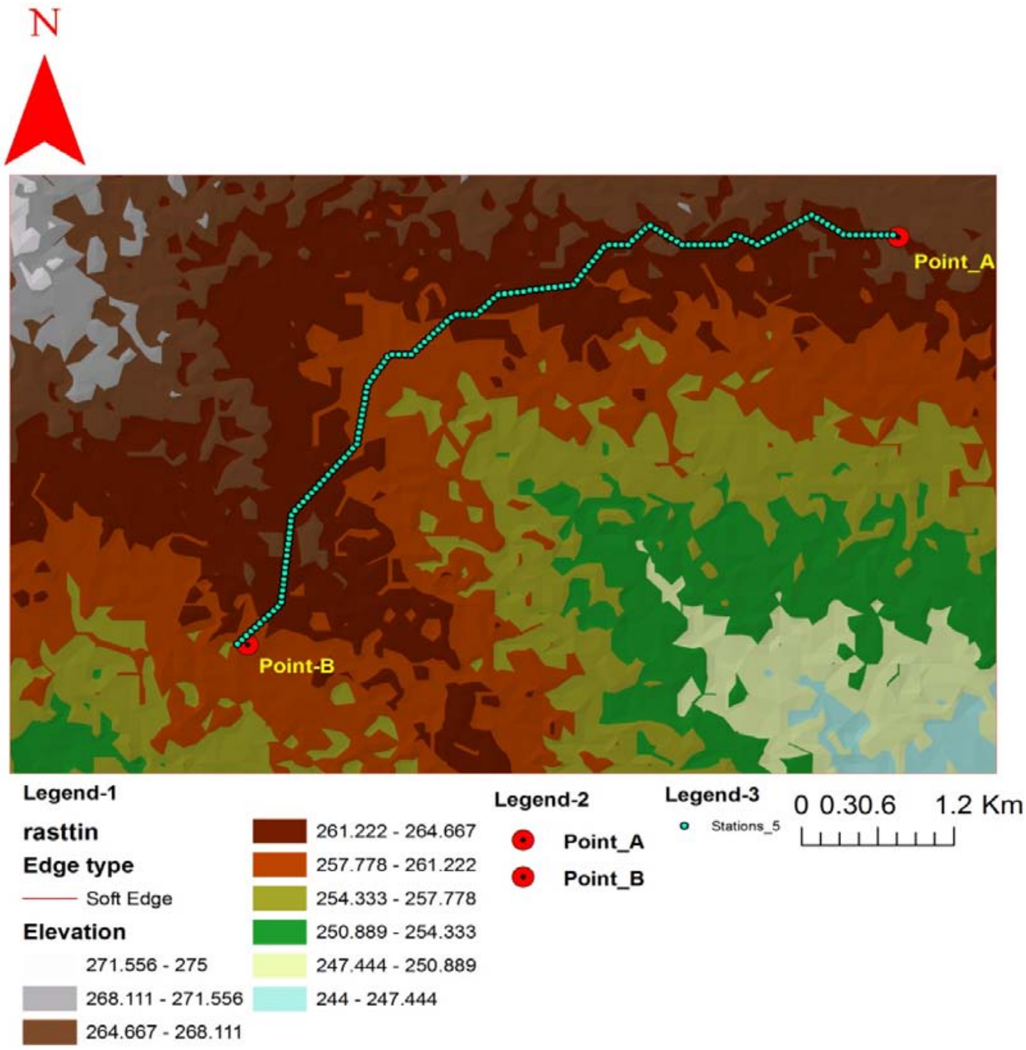


Figure 5.14 Stations Layer for the Fifth run 0% Elevation and 100% Slope Combination.

5.4.2 Calculating Cut and Fill Works Using Excel

After the natural ground level (N.G.L.) for each of the five routes from the station layers created through ArcGIS program, the work was converted to Excel program in order to calculate the cut and fill values. The steps relevant to this stage are explained in the following sections.

5.4.2.1 Symbols Used in Excel Relevant Procedures

1- Stations = Longitudinal section of the channel in meter.

2- Length of Section = Length-parts of the longitudinal section in meter.

3- N.G.L. = Natural ground level in meter.

4- N.G.L$_{av}$. = Average natural ground level between start and end-points of the longitudinal section in meter.

5- B.L. = Design level of channel-bed in meter.

6- B.L$_{av}$. = Average design level of channel-bed between start and end-points of the longitudinal section in meter.

7- D = Difference height between average natural ground level and average bed level in meter.

8- H = Height of the channel from bed level to top level in meter.

9- M = Difference height between height of channel and the difference level between average natural ground level and average bed level in meter.

10- Z = Side slope

11- B.W. = Bed width of the channel in meter.

12- E.W. = Embankment width of the channel in meter.

13- T.W. = Top water-width of the channel in meter.

14- AOTC = Area of totally cutting.

15- AOTF = Area of totally filling.

16- AOPC = Area of partially cutting.

17- AOPF = Area of partially filling.

18- VOTC = Volume of totally cutting.

19- VOTF = Volume of totally filling.

20- VOPC = Volume of partially cutting.

21- VOPF = Volume of partially filling.

22- SVOC = Sum volumes of cutting.

23- SVOF = Sum volumes of filling.

24- L.S. = Length of section.

5.4.2.2 Classification of Cut and Fill Cases

1- Case (AOTF)

If (D < 0)

In this case AOTF = if (D < 0, AOTF, 0)

AOTF = (1) * ((2 * ((E.W * H) + (Z (H ^ 2)))) + (((4 * Z * H) + (2 * E.W) + (B. W)) * (-1 * (D)) + ((Z * (D^2))) = Negative Fill

D = (N.G.L) – (B.L) = Negative, Fill

This case shown in the Figure 5.15-A

2- Case (AOTC)

If (D > H)

In this case AOTC = If (D>H, ATOC, 0)

AOTC = ((B.W * H) + (Z * H^2) + ((((2 * E.W) + T.W) * M_1) + (Z * (M_1^2))) = Cut, Positive.

M_1 = (D – H)

D = (N.G.L) – (B.L) = Positive, Cut

This case shown in the Figure 5.15-B

3- Case of partially cutting and partially filling when (D <= H and D >= 0)

M_2 = (H-D)

D = (N.G.L) – (B.L)

Case A if (and (D <= H ,D >= 0), AOPC,0)

AOPC = ((B.W * D) + (Z * (D^2)))

Case B if (and (D <= H, D >= 0), AOPF,0)

AOPF = (-1)* (2 * ((E.W * M_2) + (Z * (M_2^2))))

This case shown in the Figure 5.15 (C)

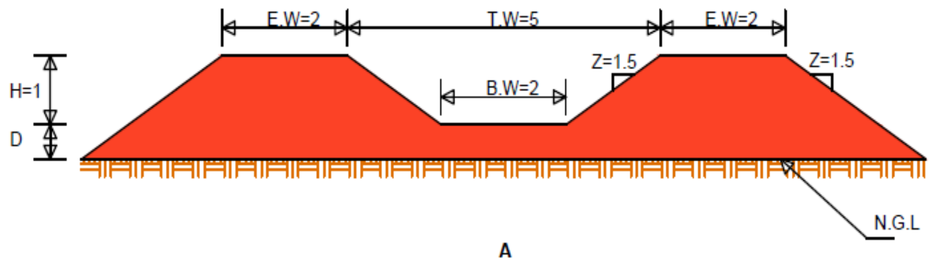


Figure 5.15-A Cross-Section of the Channel in Case (AOTF).

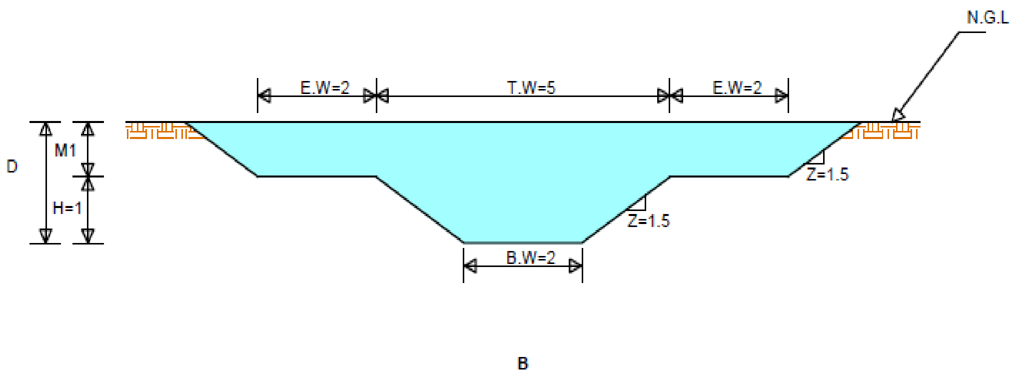


Figure 5.16-B Cross-Section of the Channel in Case (AOTC).

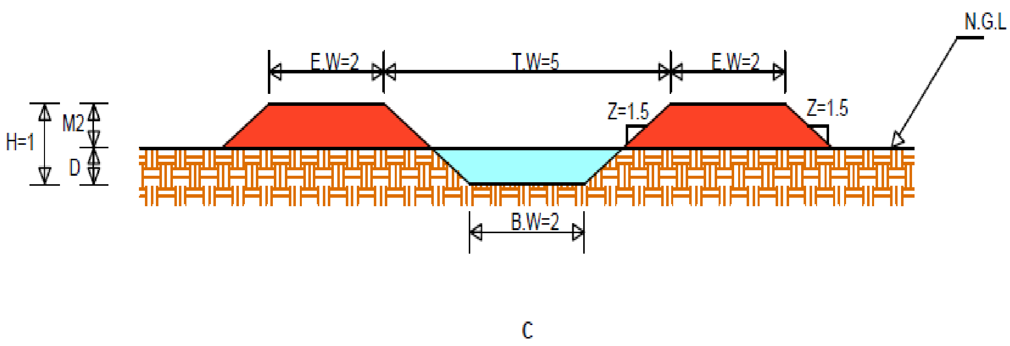


Figure 5.17-C Cross-Section of the Channel Channel in partially cutting and partially filling All Dimensions in Meter.

5.4.2.3 Cut and Fill Equations

1- VOTC = if (D > H, (AOTC * LS), 0)

2- VOTF = if (D < 0, (AOTF * LS), 0)

3- VOPC = if (and (D <= H, D>= 0), AOPC * LS, 0)

4- VOPF = if (and (D <= H, D >= 0), AOPF * LS, 0)

5- SVOC = (VOTC + VOPC)

6- SVOF = (VOTF + VOPF)

5.4.2.4 Tables of Excel Sheets

The tables resulting from the Excel work sheets are too large to be presented within the text of this chapter, both regarding the size of the sheets as well as the number of these sheets. Therefore, the researcher decided to present only the resultant sheet of the fifth run, which is the optimizing process winning run among the others, in the Index at the end of this thesis.

5.4.3 Presentation of the Optimum Routes Resulting from the Five Runs

The results of the five runs may be classified into two categories as follows:

A- The Results of ArcGIS Runs

The results of the ArcGIS five runs are presented in five paths, each represent the optimum route relevant to the specified priority combination as explained in Table 5.1. These five routes are clearly shown in Figure 5.16.

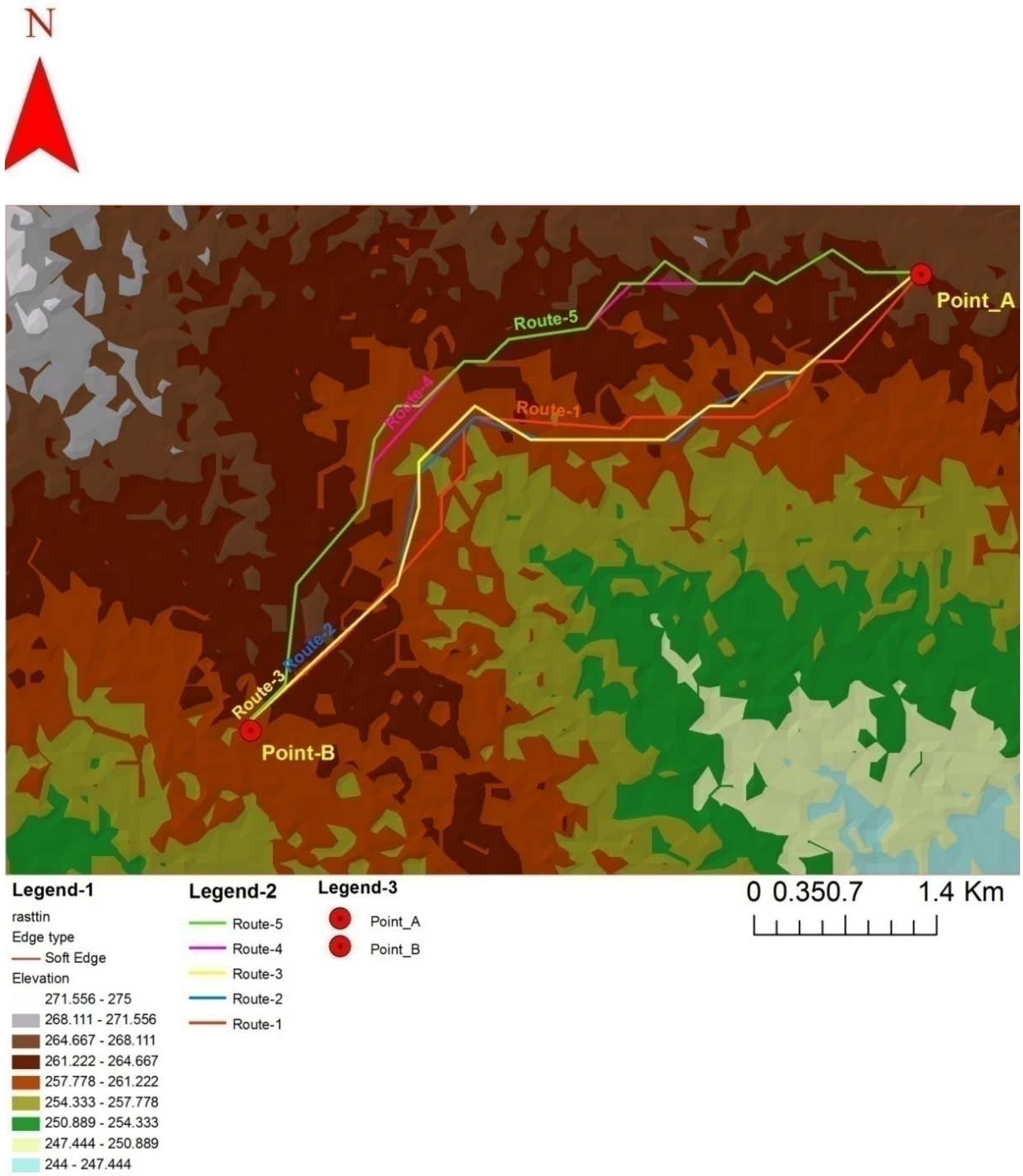
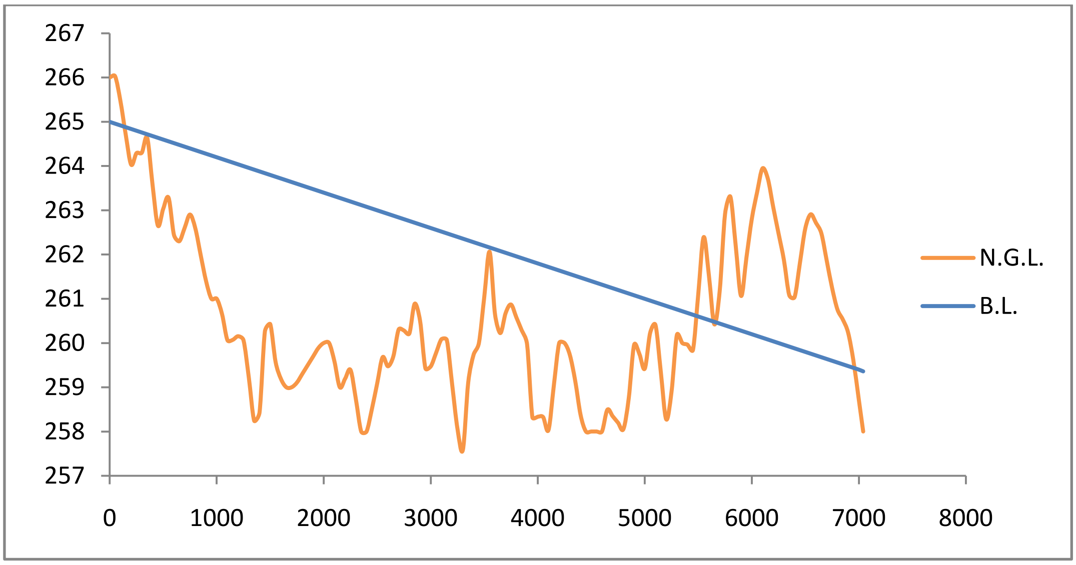


Figure 5.16 The Results of ArcGIS Program Five Route/Paths.

B- The Results of Excel Runs for the Determination of Cut and Fill

The results produced by ArcGIS program of the five paths are converted to Natural Ground Level and transferred to Excel sheets for each path, with stations of 50m distance steps, are shown in the Figures from 5.17 to 5.21. These figure are shown in the following pages.

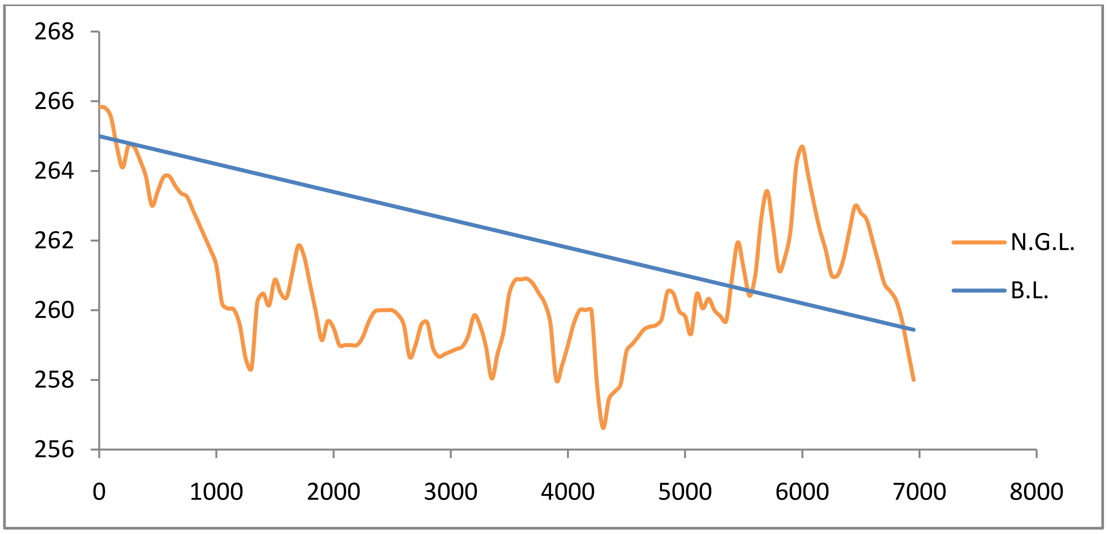
Elevation (m)



Distance (m)

Figure 5.17 Relation between Stations, B.L. and N.G.L. (Path-1).

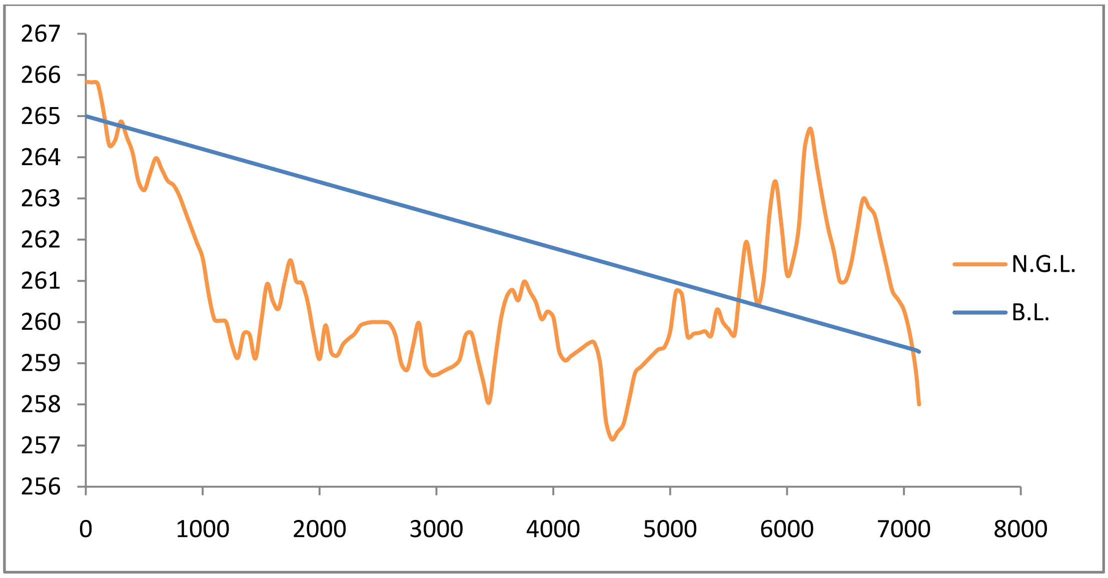
Elevation (m)



Distance (m)

Figure 5.18 Relation between Stations, B.L. and N.G.L. (Path-2).

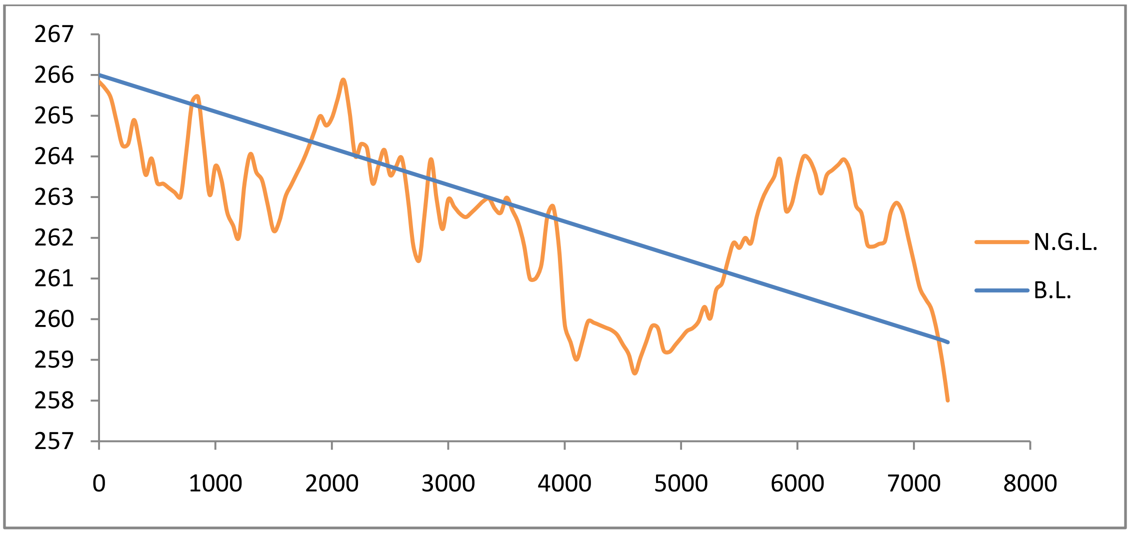
Elevation (m)



Distance (m)

Figure 5.19 Relation between Stations, B.L. and N.G.L. (Path-3).

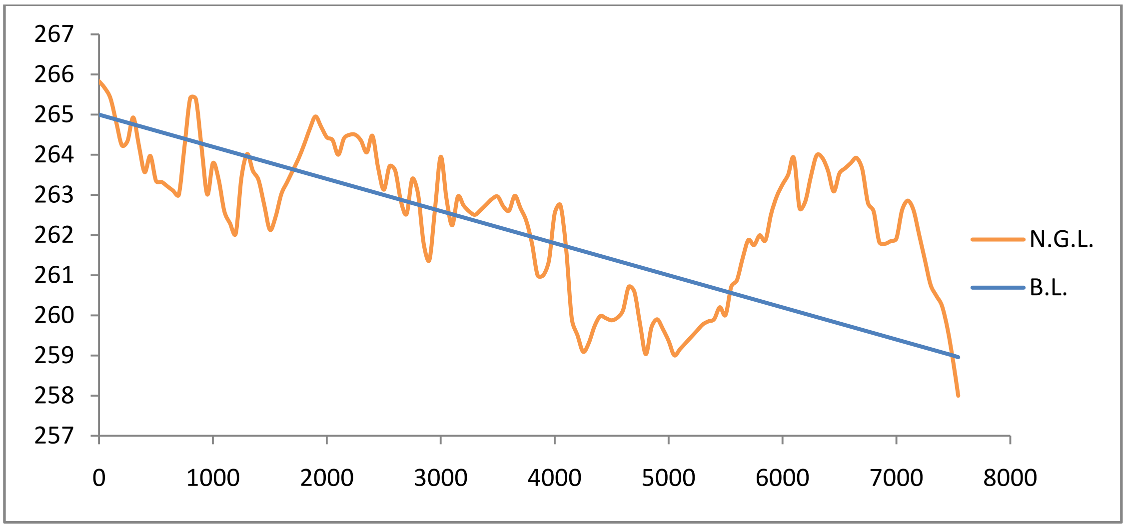
Elevation (m)



Distance (m)

Figure 5.20 Relation between Stations, B.L. and N.G.L. (path-4).

Elevation (m)



Distance (m)

Figure 5.21 Relation between Stations, B.L. and N.G.L. (Path-5).

5.4.4 The Determination of the Optimum Route among the Five Runs

After performing five runs with different combinations of elevation and slope priority order combinations, and after completing the calculations of the cut and fill calculations using Excel program. Also, after obtaining the complete set of drawings of the results regarding the route alignments and the relevant longitudinal cross sections, it is necessary to determine the best route among the five ones.

The optimum route among the five alternatives is thought to be the one that produces the least total volume of cut and fill, and also, the solution that produces the closest values between the cut and fill volumes. The purpose of the latter consideration could be explained in the principle of making sure that there will be minimum need for disposing of surplus soil volumes and/or minimum need to import soil for fill purpose from outside the location of the project.

This decision in considering the winning solution is taken this way according to the stage of this research, whereas, it is obvious that other factors may be taken into consideration when going further in this research.

Table 5.2. presents the final results of the work. It can be seen in the table that, according to the principle of optimization explained at the start of this section, the path number 5 appears to be the best among the rest of the solutions, especially when observing the individual values of the cut and fill, and also, when observing the sum of these two values. In fact, comparing the different longitudinal cross sections shown in Figures 5.16 to 5.20 confirms this idea even before reviewing the resultant numerical calculation values.

Table 5.2 Finding the Optimum Path/Route from Calculations.

Path No	Length of Path (m)	% Influence of ReClass DEM	% Influence of ReClass Slope	Cutting Works (m^3)	Filling Works (m^3)	Sum of Cut & fill (m^3)	Longitudinal Designer Slope
1	7041	100	0	22496	-287708	310204	0.0008
2	6954	75	25	21397	-266108	287505	0.0008
3	7129	50	50	24054	-263353	287407	0.0008
4	7290	25	75	34426	-133331	167757	0.0009
5	7543	0	100	52046	-76752	128798	0.0008

CHAPTER 6

CONCLUSION

This research confirms that most of the programs that have wide range of use, such as ArcGIS, need to be well understood from the behavior point of view regarding different groups of input data with specific conditions. After understanding the way the program behaves during the calculations stage and its response to the specific type/group of input data, the stage of manipulating the input data in a way that would fit the way the program works and aids to result in output that is as close as possible to the results required by the user regarding both the quality and quantity of the results.

This research confirmed that solving complicated problems with several interdependent variables, particularly when some of these variables may not be defined easily as numerical values, can be only ‘assisted’ by the recently available modern computer programs (of course, dating up till the production of this research). In fact, this clearly indicates that the experience of the engineer is always extremely important during the design stage of the project regardless of the frequently exaggerated sophistication declared by the company that produced computer programs. After all, one should never forget that software companies never declare any guaranty/responsibility for any unacceptable consequences/losses/damages that may result from the use of its software products. This indirectly means that the final responsibility lays on the design engineer, which is never an easy task, especially when simultaneously taking into consideration both the safety and economic measures. The latter two factors frequently oppose each other in their influence. In other words, increasing the cost may help to increase the safety, while keeping the cost under pressure may lead to significant decrease in safety.

At the star of the research, it was intended to obtain DEM of an already executed irrigation canal in order to attempt the creation of a set of optimum routes by the ArcGIS, and then, to compare the selected solution produced by the software with the already executed project. Unfortunately, this appeared not to be possible due to many reasons. However, it is thought that selecting a DEM from a moderately irregular region may be an alternative to investigate the behavior of the program in concern. The latter was applied with reasonably useful results that are likely to ease the way of design for future engineers.

The results of the research indicate the importance of the following points:

a- The designer must be significantly experienced in both the use of the software in concern, along with its capabilities, as well as in being capable of designing the relevant project totally manually without the use of the software. Only this would enable the full evaluation of the software results, and also, would enable to manipulate the input data in a way that would produce the maximum of the required results from the quality and quantity point of views.

b- The research revealed that the ArcGIS software seems to have so many alternative choices during the process of feeding the input data that only a very experienced user in the field of open channel, and also, in the use of the program can wisely make decisions regarding the way to feed the input. This indirectly means that there is a danger in assigning an ordinary/inexperienced user to make decisions during data feed process, which may result in obtaining output that may seem acceptable while being far from the optimum, or, from the really optimum output that can be produced by an experienced program user.

c- The experiments on the ArcGIS showed that decreasing the elevation range of the section selected for investigation significantly influence the quality of the selected route in the positive direction. Therefore, it is recommended for the user to decrease the elevation range as much as possible before performing the run. This process in decreasing the elevation range may be performed on the extreme elevations (too high and/or too low) within which the optimum route is either unlikely to go through, or, the user does not wish that optimum route to interfere with the sub-region that includes these extreme elevations.

d- The recommendation explained in the previous paragraph may be repeated in the same way regarding the range of slopes in the region, where unwanted extreme slopes should be cancelled from the sub-region in the same way.

e- In the overlay process (cost surface layer), it is recommended to instruct the computer to start its elevation priority from the range that contains the elevation of the supply point.

f- It may be practically recommended to review the software results from the visual and numerical point of views in order to make slight alterations manually that would improve the optimum route even better. Such improvement is likely to concern the cut and fill values being either more equal, or, to decrease their values. Also, the same process may solve the problem of avoiding a particular point/location within the route produced by the software. The latter process may be needed in case the automatic solution in avoiding sensitive points/locations to be avoided does not seem to be practically available in the near future.

g- In relevance to the previous paragraph, it may be possible to minimize the volumes of the cut and fill and/or to try to decrease their total value by means of proposing the construction of some hydraulic structures on the way of the selected route. Examples of such structures may be a drop, chute, and also, through decreasing the elevation of the supply point or increasing the elevation of the demand point.

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APPENDIX 1: Tables of Excel Sheets of the Fifth Run

How to Calculate Quantity of Cut and Fill in the Earth Work(Path-5)

Stations (M)	Length of Station (M)	N.G.L (M)	(N.G.L)av (M)	(B.L) (M)	(B.L)av (M)	D=(N.G.L)av -(B.L)av (M)	H (M)	M1=D-H (M)	M2=H-D (M)	Z side slope	B.w (M)	E.w (M)	T.w (M)	AOTC (M²)	AOTF (M²)	AOPC (M²)	AOPF (M²)	VOTC (M³)	VOTF (M³)	VOPC (M³)	VOPF (M³)	SVOC (M³)	SVOF (M³)
0		265.833		265																			
50	50	265.664	265.74872	264.96	264.98	0.7687185	1	0	0.231282	1.5	2	2	5	0	0	2.4238	-1.086	0	0	121.19	-54.28	121.1915	-54.27997
100	50	265.408	265.53587	264.92	264.94	0.5958735	1	0	0.404127	1.5	2	2	5	0	0	1.7243	-2.106	0	0	86.217	-105.3	86.21724	-105.32303
150	50	264.823	265.11536	264.88	264.9	0.2153565	1	0	0.784644	1.5	2	2	5	0	0	0.5003	-4.986	0	0	25.014	-249.3	25.01403	-249.27851
200	50	264.238	264.53076	264.84	264.86	-0.3292385	1	0	0	1.5	2	2	5	0	-11.113	0	0	0	-555.7	0	0	0	-555.67295
250	50	264.346	264.2923	264.8	264.82	-0.527703	1	0	0	1.5	2	2	5	0	-13.75	0	0	0	-687.5	0	0	0	-687.50708
300	50	264.931	264.63843	264.76	264.78	-0.1415725	1	0	0	1.5	2	2	5	0	-8.7289	0	0	0	-436.4	0	0	0	-436.44671
350	50	264.227	264.57887	264.72	264.74	-0.1611275	1	0	0	1.5	2	2	5	0	-8.9725	0	0	0	-448.6	0	0	0	-448.62366
400	50	263.569	263.89815	264.68	264.7	-0.8018525	1	0	0	1.5	2	2	5	0	-17.587	0	0	0	-879.3	0	0	0	-879.33406
450	50	263.975	263.77196	264.64	264.66	-0.8880425	1	0	0	1.5	2	2	5	0	-18.839	0	0	0	-942	0	0	0	-941.97196

The values between the upper and lower sections are repetition of the same way the calculations were performed as shown at the top of the columns as well as explained within the text of Chapter 5.

7100	50	262.86	262.74213	259.32	259.34	3.402126	1	2.402126	0	1.5	2	2	5	33.7744	0	0	0	1688.7	0	0	0	1688.722	0
7150	50	262.627	262.74365	259.28	259.3	3.443652	1	2.443652	0	1.5	2	2	5	34.45	0	0	0	1722.5	0	0	0	1722.501	0
7200	50	262.007	262.31711	259.24	259.26	3.057108	1	2.057108	0	1.5	2	2	5	28.3615	0	0	0	1418.1	0	0	0	1418.076	0
7250	50	261.387	261.69705	259.2	259.22	2.477052	1	1.477052	0	1.5	2	2	5	20.066	0	0	0	1003.3	0	0	0	1003.3	0
7300	50	260.767	261.077	259.16	259.18	1.896996	1	0.896996	0	1.5	2	2	5	12.7799	0	0	0	638.99	0	0	0	638.9933	0
7350	50	260.493	260.63019	259.12	259.14	1.490188	1	0.490188	0	1.5	2	2	5	8.27212	0	0	0	413.61	0	0	0	413.6059	0
7400	50	260.24	260.36676	259.08	259.1	1.26676	1	0.26676	0	1.5	2	2	5	6.00758	0	0	0	300.38	0	0	0	300.3791	0
7450	50	259.654	259.94681	259.04	259.06	0.8868075	1	0	0.113192	1.5	2	2	5	0	0	2.9533	-0.491	0	0	147.66	-24.56	147.6628	-24.560381
7500	50	258.827	259.24013	259	259.02	0.2201275	1	0	0.779872	1.5	2	2	5	0	0	0.5129	-4.944	0	0	25.647	-247.2	25.64696	-247.20467
7543	43	258	258.41338	258.96	258.98	-0.566624	1	0	0	1.5	2	2	5	0	-14.281	0	0	0	-614.1	0	0	0	-614.08653
																						52046.78	-76752.654