BE CIVIL ENGINEERING
FINAL YEAR PROJECT

EVALUATION OF DIFFERENT CANAL LINING TECHNIQUES

Project submitted in partial fulfilment of the requirements for the degree of
BE Civil Engineering

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This is to certify that

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Final Year Project entitled

EVALUATION OF DIFFERENT CANAL LINING TECHNIQUES

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Has been accepted towards the partial fulfilment of the requirements for Bachelor of Engineering in Civil Engineering Degree.

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DEDICATION

This project is dedicated to our parents and teachers who taught us that what is learned for its own sake is the best kind of knowledge, who taught us how to make things happen with dedication.

ACKNOWLEDGEMENT

Beginning with the name of ALLAH Who is the most Merciful and the most Beneficent.

We bow our heads before **ALLAH ALMIGHTY** for providing us with an opportunity to capitalize the available resources and for empowering us with the strength and courage to terminate our research work.

We also owe our sincere gratitude to our project advisor **Col. Khurram Sattar Khan** for inspiring, encouraging and guiding us throughout the duration of the research work. We are also grateful to all other faculty members and laboratory staff for guiding and helping us. Special thanks to our parents for their unconditional love and prayers.

ABSTRACT

Water is an essential element which is required to sustain life on earth. However, it’s depleting at an alarming rate due to which it will become a serious problem in the near future for the world. Pakistan is among the list of countries which are considered as “Water Stressed”. Since, Pakistan is an agricultural country, its economy is completely dependent on the agricultural sector and almost 70% of the workforce is employed in it. A vast network of canal system is present in the country which is considered as largest in the world, is responsible for providing access of water to various farms throughout the country. However, almost 60% of the water entering in this canal system is lost due to various factors with major losses occurring due to seepage, even before it reaches its destination. This study aims on evaluating one of the many methods and techniques i.e. canal linings, which are employed to counter these losses. A comparison is done in this study between different types of lining in order to determine the most efficient and cost friendly that can be used to line the water channels in a specific region.

CHAPTER 1

INTRODUCTION

Chapter 1

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1.1 General

Canals are man-made hydraulic systems constructed on the ground for the purpose of carrying water, which may be for the purpose of transportation or for irrigated agriculture. The oldest and most widespread type of canals are irrigation canals which are used for the purpose of bringing water from a source, such as a river or dam to the agriculture fields.

The requirement of canals is essential for modern agriculture as only the land near to a water source such as a lake, river or dam can be made cultivable. In order to make land away from these sources arable, water needs to be brought to them through these systems. Furthermore, for within field irrigation, canals on a smaller level, known as waterways are required so that all the crops in the field are irrigated. These structures are not very efficient in their intended purpose if they are simply constructed in the ground without treatment. This can result in loss of water during its journey from the source to the field, which can reduce the area irrigated by a canal. In order to reduce this loss and gain other benefits, impermeable materials are applied to the boundaries of the canals and this is known as lining.

1.2 Background

Pakistan currently houses a population of approximately 210 million, which is the 6^{th} largest in the world and 2.83% of the world population. Once a country with abundant hydrological resources, Pakistan is now facing a severe shortage of this resource as its population continues to soar and mismanagement of existing resources continues to exist. About 91.6% of the available water in the country is being utilized for irrigated agriculture, 2.5% for industrial use and the remaining 2.6% for the domestic sector. Of the water utilized for agriculture, more than 60% is lost during conveyance and application in the fields (Soomro et al., 2018).

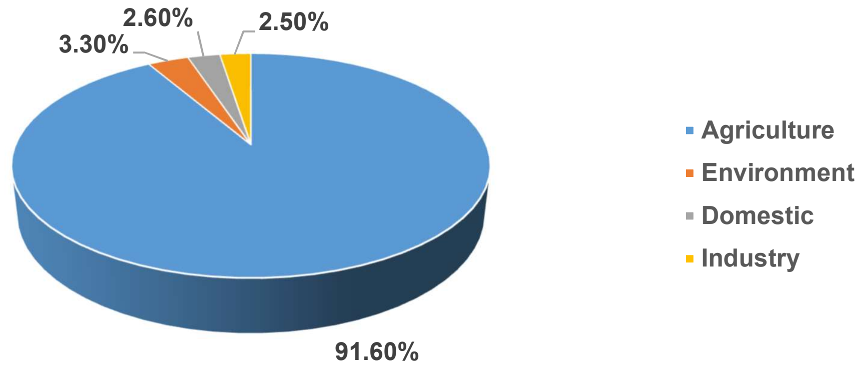

Figure 1.1 Sector wise usage of fresh water in Pakistan.

Currently the per-capita water availability in Pakistan is around the figure of 1000m^3 per capita.

Year Wise Capita Water Availability (m^3)			
Country	**1955**	**1990**	**2025**
China	4600	2400	1800
Mexico	11400	4200	2600
Philippines	13500	5150	3100
Iraq	18400	6030	2400
USA	15000	9900	7700
Pakistan	2500	1650	840

Table 1.1 Per Capita Availability in Selected Countries (Population Action International, 1993)

This situation puts the country in nearing conditions of chronic water-stress. Meanwhile, the gap between demand and supply of water has increased to levels where it is becoming a cause of concern for the future generations.

Population and Water Availability in Pakistan		
Year	**Population (millions)**	**Availability per capita (m^3)**
1951	34	5300
1961	46	3950
1971	65	2700
1981	84	2100
1991	115	1600
2000	148	1200
2013	207	850
2025	221	659

Table 1.2 Population and Water Availability in Pakistan Source: (Draft State of Environment Report 2005)

1.3 Problem Statement

Conveyance losses in irrigation channels are responsible for a loss of major portion of water which may otherwise be more efficiently used in agriculture or to fulfil other requirements, especially in Pakistan where the mainstay of the economy is agriculture. The study aims to maximize the conveyance potential of water channels built in specific soil type by studying the efficiency of various types of channel lining materials and their ability to minimize the seepage losses.

1.4 Scope

This project will integrate our knowledge of civil engineering with various civil disciplines which include surveying, hydrology, soil mechanics, project management, quantity survey etc.

The scope of the project is as follows:

a. To perform test on local soil conditions of Risalpur.
b. Find suitable site and construct test models.
c. To evaluate the losses in each model.
d. To analyze the data and determine the most cost effective method.
e. Calculate the required cost and materials of each model.

1.5 Objectives

The objectives of this study are as follows:

a. Evaluate the importance and necessity of canal linings.
b. Analyze the effectiveness and cost of each lining design for water channels in area under study.

1.6 Research Methodology

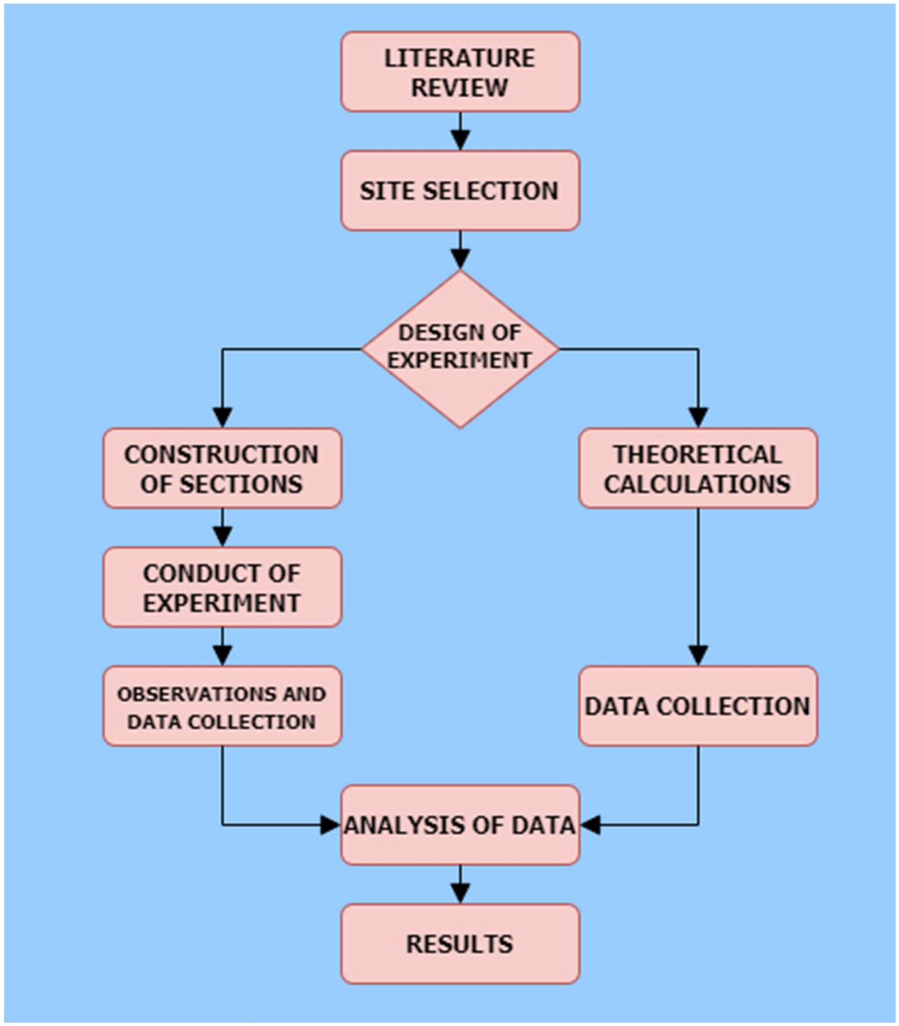

Figure 1.2: Flow chart of Research Methodology

1.7 Layout of Research

The following chapters are defined using research work undertaken in a stepwise procedure:

a. **Chapter 1** Introduction
b. **Chapter 2** Literature Review
c. **Chapter 3** Data Collection and Methodology
d. **Chapter 4** Analysis of Linings
e. **Chapter 5** Conclusion and Recommendations

1.8 Conclusion

This chapter presents a brief background of the research work being undertaken. The purpose and requirement of this research in Pakistan is explained along with the scope and details of the project work. Why it was required and the details of the research. The proposed methodology which the research team will follow and the sequence in which the research work will be performed is briefly elaborated.

CHAPTER 2

LITERATURE REVIEW

Chapter 2

LITERATURE REVIEW

2.1 Background

Being an agro-based country (having 4th highest area of irrigated land and amongst top 10 food producers); Pakistan has a dire need for an efficient irrigation system. This is reflected in the vast irrigation network of the country, ranked largest in the world. This network, built during the colonial era still serves the agricultural areas of Pakistan and continues to be built upon.

Canals lose their water volume due to evaporation and seepage into the ground. This can be reduced by covering the canals and lining the walls with suitable material. Average water loss from unlined canals is 66 percent compared to 43.5 percent from lined watercourses. This estimate means that lining can reduce water loss by at least 23.5%. The study clearly shows an increased efficiency in canal water supply by lining the walls of the canal. In Pakistan, Agricultural Information Assistant Director Naveed Asmat Kahloon while speaking to "*The Express Tribune"* in 2016 shared that at least 40% water losses had been reported due to poor maintenance and dilapidated condition of irrigation system in the country. This further emphasizes on the need to improve this system.

Agriculture is the main stay of the Pakistani economy and the country is dependent on its agricultural produce for self-sustainment and for export.

2.2 Agriculture in Pakistan

Pakistan's principal natural resource is arable land and water, which naturally makes it dependent on agriculture for sustaining itself. This has been the case since ancient times and the region is widely regarded as the breadbasket of the world. According to Pakistan Board of Statistics, the agriculture sector in Pakistan plays a central role in the economy by contributing 19 percent to GDP and employs 42.3 percent of the available labor force. It is also an important source of foreign exchange earnings and stimulates growth in other sectors.

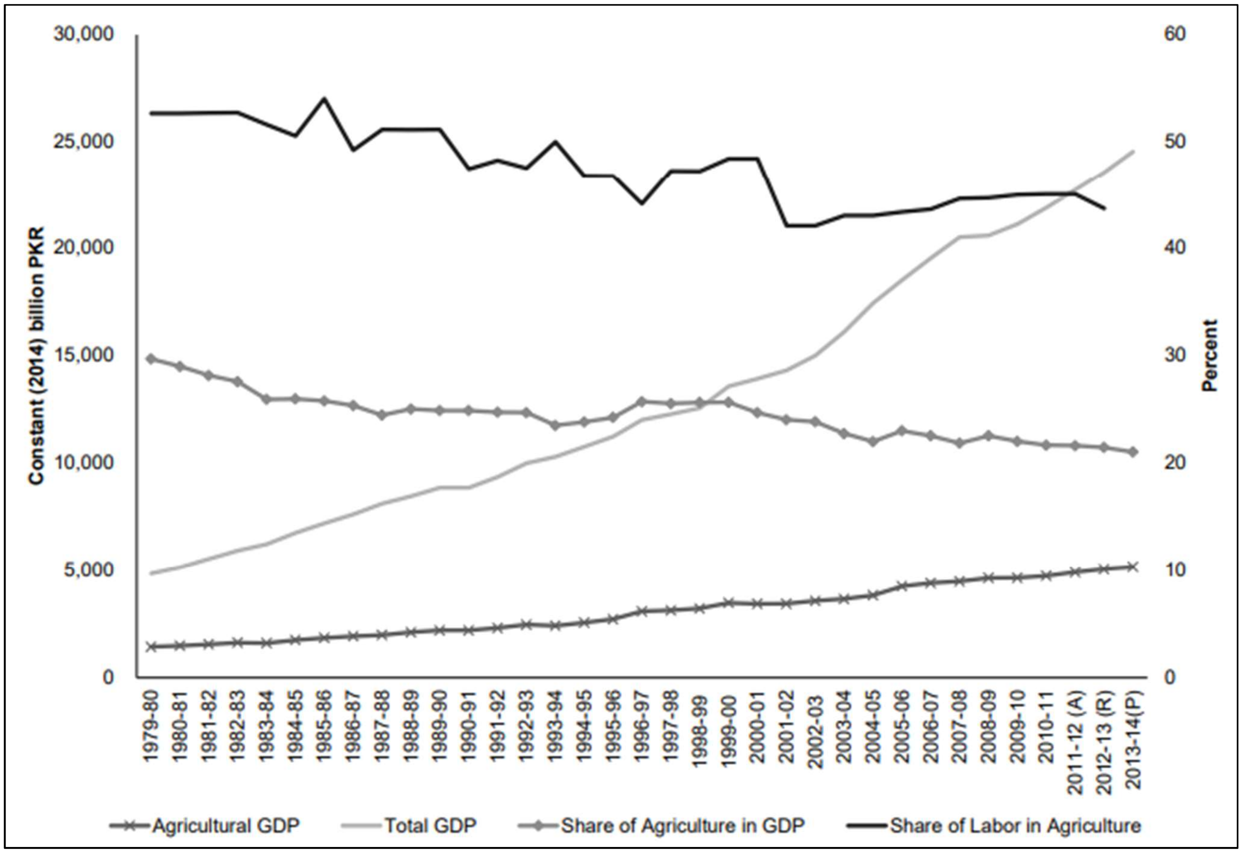

Figure 2.1: GDP, agricultural GDP, and share of labor in agriculture in Pakistan, FY 1980–2014

The figure shows the GDP, share of agricultural in GDP and the percentage of labor force employed by the sector. It is perceived from the figure that despite a declining trend in the contribution of agriculture to GDP, it still contributes more than 20% to it directly. The employment of labor force also has a similar declining trend but over 45% of the country's labor is still employed by this sector. This concludes that even in the modern era, agriculture is still a major role player in the country's economy.

2.3 Irrigation

Irrigation is defined as man-made supply of water to land for vegetation/agriculture. It provides a reliable substitute to inadequate or unreliable rainfall. Essential nutrients required for plant growth may also be applied to the crops through this process. Irrigation systems are also used for dust suppression, disposal of sewage, and in mining. Irrigation is often studied together with drainage, which is the natural or artificial removal of surface and sub-surface water from a given area.

2.3.1 History of Irrigation

The history of agricultural system may be traced back to 6000 BC in Egypt and Mesopotamia where the water of flooded river Nile was diverted to fields of farmers to grow crops where it would otherwise be impossible. The floodwater of Tigris and Euphrates were used in the same way in Mesopotamia whereas terrace irrigation was practiced in the Americas, China and India.

In the Indian Sub-continent, irrigation was developed somewhere around 4500 BCE according to Rodda & Ubertini (2004).,With time, these methods were eventually improved and some methods like Charsa, Shaduf, and Persian wheel were developed which can still be seen used even today.

2.3.2 Types of Irrigation

There are two broad types of irrigation depending on where the irrigation water is applied to the crops. These types are:

2.3.2.1 Surface/Flow Irrigation: The water is brought and distributed over the crop fields by the action of gravity. This is the oldest and most utilized method of irrigation in the world due to its ease of use and minimum cost. However, this method is responsible for maximum water loss. Its further sub-types are:

i. Basin Irrigation: The fields are flooded and submerged with water.
ii. Furrow Irrigation: Landscaping is done to make a corrugated pattern and only a portion of the ground is wetted. It is comparably a less wasteful method than Basin method.

2.3.2.2 Lift Irrigation: Water is supplied to the crops/fields by pumping it from a lower level to a higher level by expending energy through animal, fuel or electric power. This method is more localized and keeps water losses to a minimum. Tube-wells are an example of lift irrigation.

2.3.2.3 Drip Irrigation: A modern technique where the water is directly applied to the root of every plant in the system. The plant gains its nutrition and water directly from the soil in contact with the roots and only limited amount of water is applied.

2.3.2.4 Sprinkler Irrigation: Water is scattered across the field by high pressure sprinkler guns from a central position or from a moving platform. This can be achieved through fixed or movable platforms.

2.3.2.5 Center Pivot Irrigation: Water is scattered through land by a machine of sprinkles that move on wheeled towers in 360 degrees pattern or a circle that can move around the land and sprinkle water.

2.4 Irrigation System of Pakistan

Currently, the two sources of irrigation water in Pakistan are

i. Surface Water
ii. Ground Water

Surface water sources includes rivers, rain and melting glaciers whereas ground water resources include water abstraction from tube wells. Both Surface and sub-surface methods are practiced in Pakistan. Surface irrigation methods primarily used include four main variations:

i. Flooding
ii. Bed/Border method
iii. Furrow method
iv. Basin method

Similarly, modern techniques like Drip or trickle irrigation or sprinkler/overhead irrigation are preferred over sub-surface irrigation.

2.4.1 Pakistan Canal Irrigation System

Pakistan has an extensive canal irrigation system that sources water from the Indus river system and provides it to agricultural areas all over the country. Currently Pakistan has 3 large dams, 85 small dams and around 19 barrages to meet water needs of the country. There exist around 12 inter-river link canals and 40 major canals that command over 120,000 watercourses. Around 0.7 million tube wells have also been installed to source groundwater.

Area Irrigated by Canals 2013-14			
Province	**Total (mil Ha)**	**Canals (mil Ha)**	**Percentage**
Punjab	14.88	3.35	22.5%
Sindh	1.68	1.32	78.6%
KPK	0.95	0.72	75.8%
Balochistan	1.08	0.43	39.8%
Total	18.59	5.95	32%

Table 2.1 Area irrigated by canals in Pakistan

According to the Pakistan Bureau of Statistics, the table above shows the area irrigated by canals (both private and government) for the year 2013-14. This does not include tube-well canals.

The figure below shows the irrigation network across the country. The vast majority of the network is spread throughout the province of Punjab, followed by Khyber Pakhtunkhwa and Sindh. The locations of major dams, rivers, head works and canals are also shown.

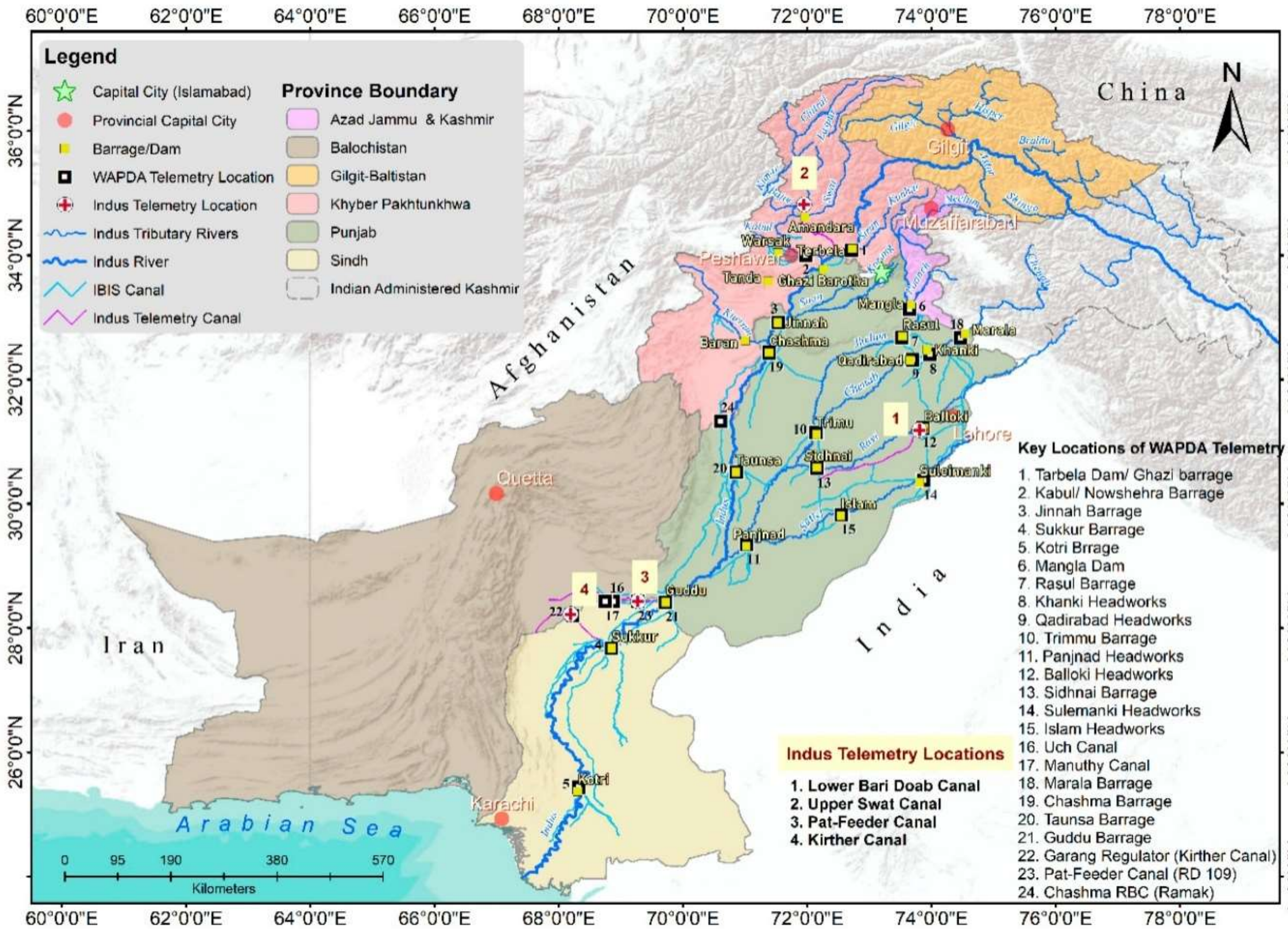

Figure 2.2: Canal system of Pakistan

Source: *(https://www.mdpi.com/water/water-11-02315/article_deploy/html/images/water-11-02315-g001.png)*

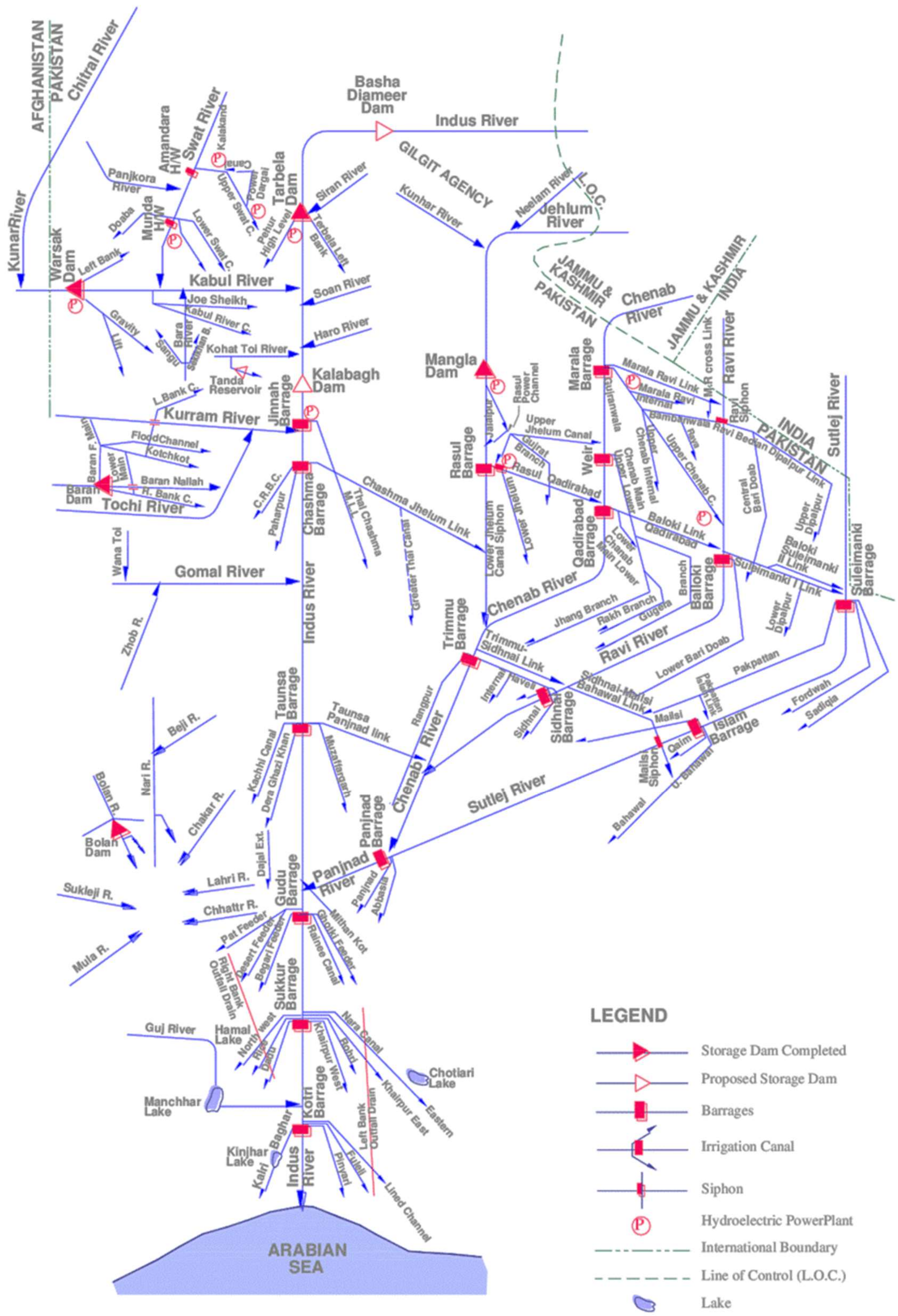

Figure 2.3: Line Diagram of Indus Basin Irrigation System
Source: WAPDA

The aforementioned figure shows the extent and reach of the Irrigation network of the Indus Basin.

2.4.2 Types of Irrigation Canals in Pakistan

Following are the types of irrigation canals in Pakistan:

i. **Perennial Canals**: These canals provide of water supply all year round.
ii. **Non-Perennial Canals**: These canals run only in monsoon season and in summer.
iii. **Inundation Canals**: These canals carry 'extra' water from rivers during rainy season or floods.

2.4.3 Important Canals of Pakistan

River Indus, Jhelum and Chenab are the main sources of water for Pakistan. The canals of these rivers can be classified as follows:

i. **The Canals of River Ravi:** Sidhnai canal originates from the head-works built on the left bank of the Ravi. Upper Bari Doab and Lower Bari Doab are the other two major canals of Ravi.
ii. **The Canals of River Chenab:** Trimmu headworks is the origin for the haveli system of canals in the Rachna Doab. Upper Chenab canal flows from Marala in Sialkot district and lower Chenab flows from Khanki.
iii. **The Canals of River Jhelum:** Chaj Doab has two important canals i.e. Upper Jhelum and Lower Jhelum. These canals irrigate a large part of the Triple Canal Project. These two canals along with lower Ban Doab link the three rivers i.e. Jhelum Chenab and Ravi.
iv. **The Canals of River Sutlej:** Three head-works have been built on the river Sutlej. These are Feroze-wala, Sulaimanki and Islam. They irrigate areas of Bahawalpur and surroundings.
v. **The Canals of River Indus:** The canals originating from Jinnah Barrage near Kalabagh irrigate the desert area of Thar. Taunsa barrage and Guddu barrage also have canals which irrigate vast areas. At Sukkur Barrage four canals flow from the right bank and three from the left bank of the river Indus.

In Pakistan, the link canals have a total length of around 800 Km (and a capacity of around 100,000 cusecs). These transport water to eastern rivers to counter water shortage as a result of the Indus Water Treaty.

2.5 Losses in Canals

The Water losses can seriously reduce the efficiency of water delivery to fields. Water may be lost by seepage, leakage, or both. The canal water tries to seep into the soil. Moreover, the canals are exposed to the atmosphere at the surface. The water also goes to the atmosphere in the form of vapor. A substantial part of usable water in irrigation canals is lost. By the time the water reaches the field, more than half of the water supplied at the head of the canal is lost due evaporation and seepage. The losses in irrigation canals are mainly:

i. Evaporation loss
ii. Absorption loss
iii. Percolation loss
iv. Transpiration loss

2.6 Evaporation Losses

2.6.1 General

Exposure of the surface of water body due to atmospheric conditions causes the water to vaporize through evaporation. This loss however is a negligible part of the overall water losses in a canal or reservoir, with the main part comprising of seepage. Planning and Development Department of Punjab reports the range of water loss due to evaporation in a range of 0.25-1 percent of the total discharge of a canal. Considering the scale of the irrigation network of Pakistan, this small percentage of losses still comprises a great amount of water loss. The following factors determine the rate of loss of water in the process of evaporation:

i. Temperature of the region
ii. Prevailing wind velocity of the region
iii. Humidity
iv. Area of water surface exposed to the atmosphere

Temperature is the dominant factor on which the rate of evaporation depends. However, a variety of other factors combine together to form this phenomenon. The wind velocity, responsible for carrying vapor from surface of water to the atmosphere also determines the rate. The greater the area of the water body, the more area is provided for the water molecules to leave the surface of the water body. This means evaporation is more for shallow water bodies with large area than deep water bodies with smaller area. Evaporation is mainly a climatic phenomenon depending on the environment of the area in which it takes place. It is not possible to calculate the exact evaporation, however different methods have been derived, both physical and theoretical. Each has its own merits and application in a specific field.

2.6.2 Measurement of Evaporation Losses

The evaporation loss in a reservoir or channel can be measured by a variety of methods, which are empirical and practical. Some of the most common methods used are as follows:

2.6.2.1 Pan Evaporation: It is a practical measurement method in which a pan containing water is exposed to the atmosphere. The loss of water from these pans is measured at regular intervals and other parameters such as humidity, wind velocity, temperature is also recorded. A standard pan, such as USWB Class "A" Evaporation pan or ISI Standard Pan may be used.

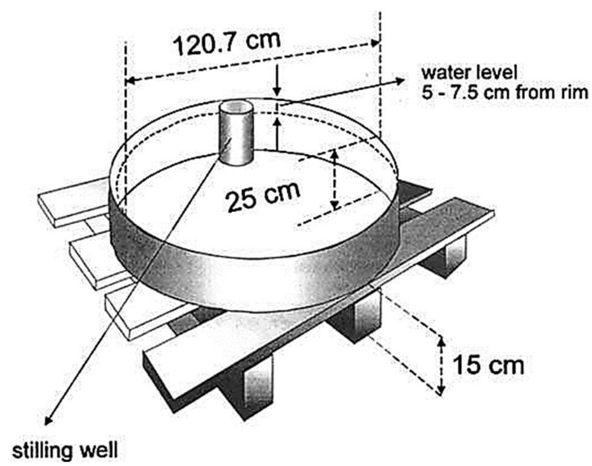

Figure 2.4 USWB Class "A" Evaporation Pan
Source: (FAO)

As the pan cannot replicate the exact conditions of a reservoir, a pan coefficient value is multiplied by the recorded value to obtain a more accurate value.

Evaporation = Pan Coefficient x Pan Evaporation

2.6.2.2 Blaney-Criddle Method: It is a relatively simple empirical method which provides a rough estimate of evaporation loss. It is based on only the mean temperature and mean daily percentage of annual daytime hours.

$$ETo = p\,(0.46\,T\,mean + 8)$$

T mean = mean daily temperature (°C)
p = mean daily percentage of annual daytime hours

2.6.2.3 Atmometer: This practical method involves the use of a device known as an Atmometer. The device simply works on the principle of evaporation. Once it is filled with water, the water level is noted through a graduated sight and after a specific time interval, water level is again noted. The difference between the two readings gives the evaporation loss.

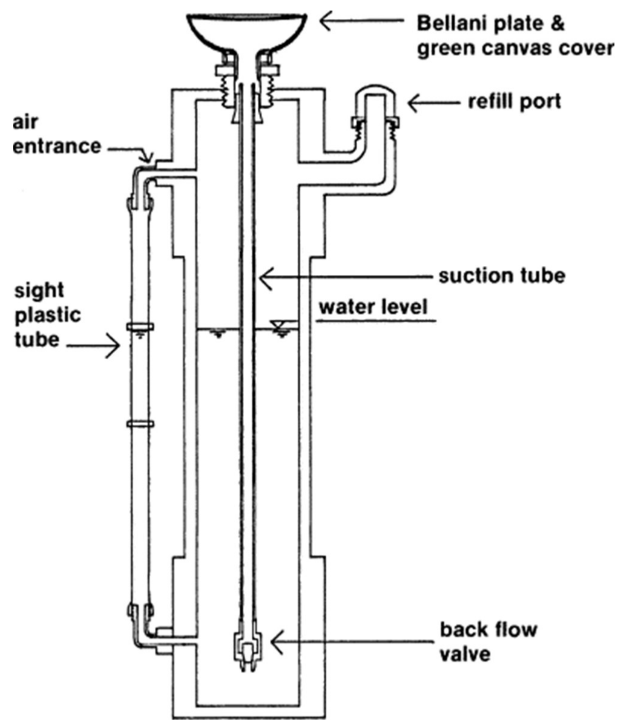

Figure 2.5 A typical atmometer device

2.6.2.4 Jensen-Haise Equation: This empirical relation combines the effect of temperate on evaporation with that of solar radiation. This method is relatively accurate when the heat transfer is minimum (Grace & Quick, 1988).

$$PE: Ct\ (T - Tx)\ Ks/L$$

T = Avg. daily temperature
Tx = Constant for given location
Ks = Daily Solar Radiation
L = Latent Heat of Vaporization
Ct = Temperature Coefficient

2.6.2.5 Penman Equation: This empirical relation describes evaporation using daily mean temperature, wind speed, air pressure and solar radiation. This equation has multiple variations. Compared to other methods, this equation is more accurate and complicated due to the number of parameters involved.

2.7 Seepage Losses

Seepage is affected by a number of factors significant ones being depth of canal bed, characteristics of soil of canal bed, amount of sediment contained in water, depth of water in canal. Biological factors also influence seepage and because of so many variables contributing to the phenomenon it is difficult to segregate what factor contributes how much in the phenomenon and also because of this variability no satisfactory formulae have been computed to calculate seepage losses.

Seepage occurs under gravity and is also affected by soil moisture tension gradient both have a combined effect on seepage. When water is first put in a dry canal the moisture tension gradient has a greater impact on seepage than gravity up until soil reaches saturation then moisture tension gradient becomes relatively small. This is the reason that soil initially loses a lot of water as seepage is affected by both factors. Permeability is perhaps the most important factor in contributing to seepage losses namely permeability of the bed forming the canal. Permeability is the capacity of a porous medium to transmit water. It is influenced by pore size and percentage of pores namely porosity.

Rate of seepage is influenced by different factors such as the water head to push water through the soil, water depth in the canal, depth to ground water as well as the materialistic nature of the substance forming the bed. Temperature also influences seepage rate, increase in temperature decreases viscosity of water particles thus encourages rate of seepage. If the underlying soil has low permeability it will cause the water to seep laterally and if the soil has high permeability, then water seeps downwards and is affected by both gravity and soil moisture tension gradient.

2.8 Canal Lining

Canal lining is a technique used to fix water losses through seepage. Canal lining provides an impermeable layer to the sides and bed of the canal which stops the water from seeping into the soil and causing water losses. In addition to this, linings provide multiple other advantages in the long term, which are stated below.

Advantages of linings (Garg, 2011) are:

i. Control of seepage losses.
ii. Prevention of water logging.
iii. Increase in channel carrying capacity.
iv. Safety against flood damage.
v. Less maintenance.
vi. Increase in command area.
vii. Elimination of flood dangers.

2.8.1 Mud Lining

To prepare the mud for lining the clay is pugged afterward with a spade it is mixed into plastic state with water, for further enhancements coarse sand or grit is also added. The mud is lined about 10 inches at the sides and nearly 3ft thick at the bottom. In order for this lining to work efficiently and properly the canal should be kept wet at all times The clay is laid down in the canal and afterward compacted in order to get the best results. The clay is laid by a tool of rectangular shape called a ‘pun’ or ‘punner’, and is compacted using an excavator. This lining also called Puddle Clay lining.

Figure 2.6 Puddle Clay Lining being applied to Montgomery Canal, England

2.8.2 Brick and Cement Mortar Lining

For this lining although bricks can be prepared form near excavation site first class brick, but they should be having a rectangular shape and sharp corners. The lining is prepared by laying double layer brick with a cement mortar of composition (1:6) over the compacted sub-grade. After the first part of the lining is done the surface of the lining is finished with a cement plaster having composition (1:3). For better results curing should be done perfectly.

Figure 2.7: Brick Lining being applied to a canal

2.8.3 Plain Cement Concrete (PCC) Lining

This lining is widely accepted for canal in full banking. PCC lining can efficiently fix scouring, erosion, support a velocity flow up to 2.5 m/s and can completely fix the issue of weed growth. PCC lining is done in the following steps:

i. The sub grade is properly spread with a layer of sand (15 cm).
ii. Then slurry of cement and sand having a composition of (1:3) is spread.
iii. Now cement concrete of grade M15 is spread according to the desired thickness (generally 100mm – 150mm)
iv. The concrete is gently tapped until slurry appears.
v. To eradicate the chances of damages by temperature changes expansion joints are provided at appropriate places.
vi. Curing is done for two weeks.

Figure 2.8: PCC lining being applied to Muzzafargarh Canal, Pakistan

2.8.4 Pre-Cast Concrete Lining

This lining is composed of slabs of precast which are laid on sides and bed of the canal to prevent water losses and other disadvantages mentioned above. The lining is done under the following conditions:

i. This consists of pre-cast slabs having different dimensions as per requirement.
ii. Thickness varies from slab to slab generally in the line of 5 – 6.5 cm.
iii. Blocks are prepared in an interlocking pattern.
iv. The surface to be lined is prepared and compacted well.
v. Slabs are laid on well prepared and compacted subgrade to attain best results.

2.8.5 Geo-membrane Lining

Geo-membrane Lining lies in the category of Plastic lining. It is a new technique which provides a fast and speedy construction if needed. It is in the form of membranes which is laid inside the canal. The steps include:

i. The sub-grade is prepared as such to that a 'V' is made.
ii. The 'V' helps anchor the plastic membrane.
iii. The layer of plastic is then laid on the well prepared sub grade.
iv. The film is afterwards covered with protective soil cover.

Figure 2.9: Geo-membrane lined canal in New Zealand.

2.9 Loss Measurement Methods

2.9.1 Ponding Method

This is a method for measuring seepage in a stationary body. In ponding method, we calculate the water levels in a pond for a certain interval for a certain time period. Since the observation can be made accurately the readings it gives should at some extent also be accurate. However, an issue arises that water seeps more in stationary bodies than in those in motion but this issue can be neglected keeping in mind the invariabilities produced in other method for measuring seepage. In order to eliminate wind affect water levels should be measured at both ends of the pool and an average should be taken. All leaks, evaporation and rainfall should be accounted for and corrected otherwise great errors can occur. This method produces the best results and is especially useful in calculating small seepage losses (Sarki, Memon, & Leghari, 2008). However certain issues arrive when applying this method such as the canal should be idle when applying this method and if not a temporary dam has to be made which becomes quite expensive and impractical. Providing water to the pool also poses difficulties as the pool may have to be filled several times until the seepage rates are stabilized. Transferring water on the pool either by pumping or manually is a hassle in itself.

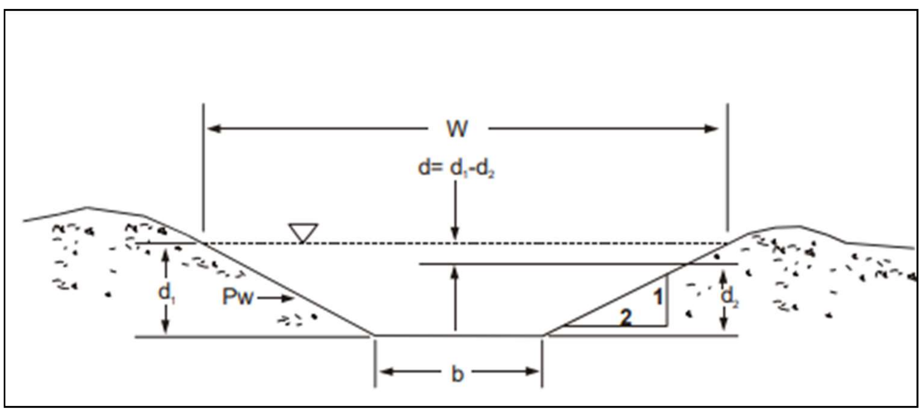

Figure 2.10: Ponding Method.

Where:

S = seepage rate ($m^3\ m^{-2}\ d^{-1}$)

w = b + 2 zd_2 = depth of water at d_2

b = bed width (m)

z = side slope (horizontal : vertical) (m : m)

L = length of test boundary

d_1 = initial depth of water (m)

d_2 = depth of water after 24h period (m)

d = $d_1 - d_2$ = change in depth after 24h (m)

$P_w = b + d_2 (1 + z^2)^{1/2}$ = wetted perimeter (m)

2.9.2 Darcy's Law

Flow velocity is directly proportional to head consumed and also the permeability of the material when flowing through water bearing material. The assumption made for this law are that the materials are saturated, flow is laminar and the pores are capillary sized. For seepage the formula is as:

$$\mathbf{Q = KIA}$$

Q = water lost per unit time (m^3/sec)
K= coefficient of permeability
I = Hydraulic Gradient
A = wetted area

2.9.3 Inflow Outflow Method

The inflow outflow method requires measuring inflow and outflow velocity in a test length and determining their difference. Certain conditions should be catered for when applying this formula such as the canal length should be long and with as minimum diversions as possible and a significant amount of seepage occurring as to get a more accurate result. All diversions and leakages should be accounted for or else it will produce great errors in the results. Current meters are usually used to measure flow velocity at both ends. The measurements for this method are quite easy and it does not affect the flow or mechanics of the canal flow. This method however is not applicable where the water is stationery or the discharge is very low.

CHAPTER 3

METHODOLOGY AND DATA COLLECTION

Chapter 3

METHODOLOGY AND DATA COLLECTION

3.1 Introduction

In order to determine the most suitable material or method to reduce the seepage losses from the canal, an experiment is devised which will consist of construction of canal models of a standard design and the losses from them would be measured by means of Ponding method. This experiment would be carried out in Military College of Engineering, NUST, Risalpur.

3.2 Site Selection

Multiple sites were examined for their usage in construction of the test models within the premises of Military College of Engineering, NUST. The current site, near the Concrete Testing Laboratory was selected on basis of its accessibility and topography which would aid in the conduct of the experiment. The topography of the area, which is relatively flat and free of tall vegetation was best suited as it would incur minimum additional cost during the clearing phase of the model construction.

3.3 Site Investigation

3.3.1 Soil Data

Soil samples were collected from the project site and taken to Geotechnical Laboratory of Military College of Engineering, Risalpur. Testing of the samples was carried out in the laboratory under the supervision of the laboratory staff to classify the soil and determine its characteristics. The following tests were conducted on the soil samples:

1. Classification Tests
   a. Grain Size Analysis
      1) Sieve Analysis
      2) Hydrometer Analysis
   b. Atterberg Consistency Limits
   c. Soil Classification
2. Permeability (Hydraulic Conductivity Test)

3.3.1.1 Classification Tests

The collected soil samples were classified according to the standards of ASTM D-2487. The required data as per standards was consistency limits of sample and grain size distribution (sieve analysis and hydrometer analysis). The soil would then be classified as per the Unified Soil Classification System (USCS).

3.3.1.1.1 Grain Size Analysis. Grain size analysis is one of the most important characteristics of the soil sample. It includes sieve analysis and hydrometer analysis

3.3.2.1.1.1 Sieve Analysis. Sieve analysis test is performed to determine the grain sizes distribution of the soil sample. For this test, #4, #10, #20, #60, #100, #200 sieves were used. The test was performed as per the ASTM standards and the results were compiled in the form of grain size distribution curves which are attached along with the report.

3.3.2.1.1.2 Hydrometer Analysis. If a large amount of sample is passing through the #200 sieve, it is necessary to perform Hydrometer Analysis to determine amount of silt and clay. The sample collected from the site contained high quantities of clay and silt i.e. content passing through #200 sieve hence hydrometer analysis was carried out.

The samples collected were treated with sodium hexameta – phosphate for a period of 24 hours and then hydrometer analysis was performed as per the standards laid down by ASTM.

3.3.1.1.2 Atterberg Consistency Limits. Atterberg limits is the measure of the critical water content of fine-grained soils. Depending on the water content of a soil, it may appear in four stages: soils, semi-solid, plastic and liquid. This test includes shrinkage limit, plastic limit and liquid limit as per ASTM D4318. Three readings each were taken and they are tabulated as follows.

Atterberg Limits				
Sr. No.	**Consistency Limit**	**Reading #1**	**Reading #2**	**Reading #3**
1	Liquid Limit	25.6	25.5	25.7
2	Plastic Limit	18.1	18.0	18.3
3	Plasticity Index	7.5	7.5	7.4

Table 3.1: Atterberg Limits of Soil Sample

Range

Liquid Limit	25.6 - 25.7
Plastic Limit	18.0 - 18.1
Plasticity Index	7.4 - 7.5

3.3.1.1.3 Soil Classification. Grain size analysis and consistency limits determined previously are used to classify the soil as per standards laid down in ASTM D-2487 (Laboratory Classification).

The soil is determined to be ***Inorganic Silty Clay.***

3.3.1.2 Permeability

Permeability test is performed in order to get the values for hydraulic conductivity of the soil under testing. The two most common methods which are used for this are:

- Constant Head Permeability Test Method
- Falling Head Permeability Test Method

The choice of the method depends on the soil. The constant head method is used for granular soils while falling head method is used for cohesive soils. As the collected sample contained high quantity of fines so the falling head method to find the permeability was employed as per the specifications laid down in ASTM D-2434. Following steps were involved in conducting this test:

The value of permeability came out to be ***2.555 x 10-3 cm/sec***. This showed that the soil has clay silt and sand mixtures. According to Hazen's empirical relation for permeability (1930),

K (cm/sec) = C $(D_{10})^2$, where C = 0.4 – 0.12 and D_{10} is in mm. Here D_{10} = 0.0035 and C = 0.8 (average). k = 9.8 x 10-6 cm/sec

There is a huge difference, but it falls in the same category of soils i.e. containing a mixture of clays, silts and sands as laid down in Munni Budhu (1999), which reports that soils with k = 10.3 – 10.6 cm/sec contain silts and clays.

Soil Type	K_z (cm/s)
Clean gravel	>1.0
Clean sands, clean sand and gravel mixtures	1.0 to 10^{-3}
Fine sands, silts, mixtures comprising sands, silts, clays	10^{-3} to 10^{-7}
Homogenous Clays	< 10^{-7}

Table 3.2: Category of soil based on value of permeability.

3.4 Design and Construction of Test Sections

For the purpose of the research work, 4 canal linings were selected for testing purposes. These were:

i. Brick lining in Cement Mortar
ii. Pre-cast cement
iii. Plain Cement Concrete
iv. PVC Geo-membrane

Along with these 4 linings, a control section would also be constructed. This was done in order to set a benchmark for relative comparison of the sections. The design phase of these sections was carried out keeping various considerations in mind.

3.4.1 Design of Sections

The test sections were designed with the same dimensions. This approach would make it easier to compare the results from each section. Although this would be difficult to construct, it would provide a more accurate comparison of the effectiveness of the linings. The general design of the sections is shown below.

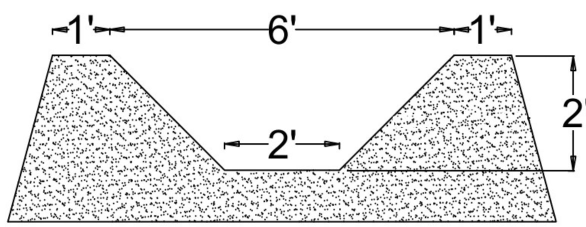

Figure 3.1 General Design Section

Each section would have the following characteristics.

Dimension	Design
Top Width	6 ft
Bottom Width	2 ft
Depth	2 ft
Freeboard	0.25 ft
Length	15 ft
Side slope	1:1
Wetted Perimeter	6.95 ft
Wetted Area	116.5 ft^2

Table 3.3 Design characterists of sections

Free board of 0.25 ft would be provided on each section. A side slope of 1:1 would be used in each section. Although this exceeds the recommended side slopes as per FAO standards for irrigation canals, an assumption is made that due to smaller scale of the sections, the steeper side slope would not be of much concern.

Type of Soil/Lining	Side Slope not Steeper Than
Light Sand, Wet Clay	3:1 or 18°
Loose earth, silt, silty sand	2:1 or 26°
Ordinary Earth, soft clay	1.5:1 or 33°
Stiff Earth or Clay	1:1 or 45°
Alluvial soil, firm gravel	0.5:1 or 63°
Stone lining, cement blocks, cast in place concrete	1:1 or 45°
Buried Membrane	2.5:1 or 22°

Table 3.4 FAO recommended side slopes for canals

All the five test sections would be arranged parallel to each other in the test site with a space of 4 ft between each canal. The purpose of leaving this space is to avoid the water from any section to saturate the soil adjacent to a neighboring section. This would ensure that each neighbouring canal remains unaffected from the adjacent section and an accurate degree of results may be obtained.

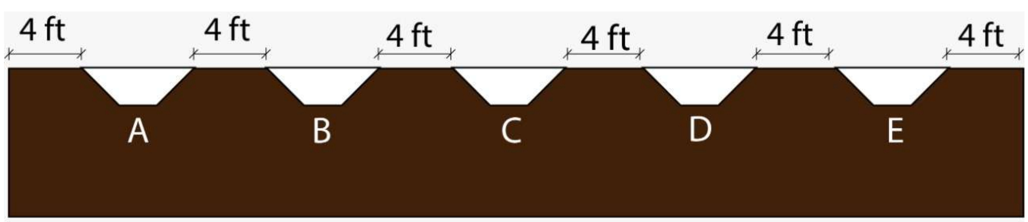

Figure 3.2 Cross section view of section in experiment site
A = Control
B = Brick with Cement Mortar
C = Cast in-situ PCC
D = Pre-Cast cement Slabs
E = Geomembrane

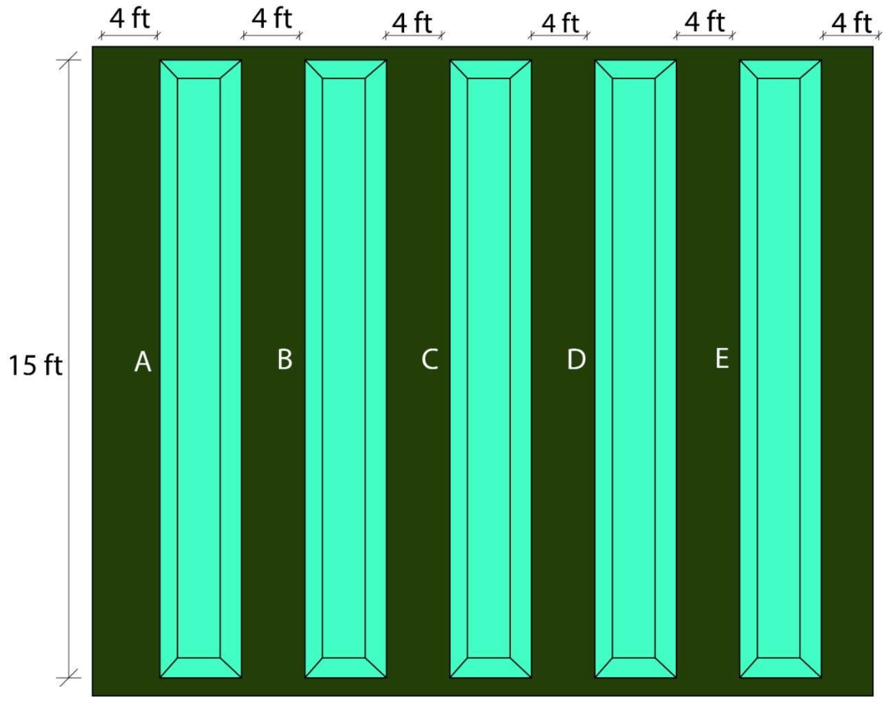

Figure 3.3 Site Plan of the experiment site

3.4.2 Construction of Sections

The construction phase of the canal sections was under process when the COVID-19 epidemic started. This hampered the process of recruiting skilled labour and machinery capable of undertaking the construction of these sections. Due to limitation of time and uncertainty regarding the normalization of situation, it was decided that only theoretical work would be carried out based on research carried out previously. The procedure which would be adopted for the construction of the canal sections is however, mentioned in detail below.

3.4.2.1 Unlined Canal

Manual excavation through use of shovels would be carried out. The required shape and size of the section would be achieved through filling and then compacted using a tamping rod. Water would be periodically applied to the surface.

3.4.2.2 Brickwork in Cement Mortar Canal

Manual excavation would be carried out using shovels. Bricks (9 in x 4.5 in x 3 in) soaked in water for 48 hours would be placed longitudinally along the length of the canal in a single layer. Cement mortar (1:4) would be prepared and used to fill the joints and plaster the exposed surface of bricks with a 13mm layer. Wate would be periodically applied to the lining everyday for two weeks.

3.4.2.3 Pre-Cast Cement Tile Canal

Manual excavation would be carried out using shovels. Pre-cast cement concrete tiles of dimension 30cm x 15cm x 5cm obtained from the market would be placed longitudinally along the length of the canal. Cement mortar (3:1) would be prepared and used to fill the joints between the tiles. Water would be applied periodically to the lining everyday for two weeks.

3.4.2.4 Cast in-situ Cement Concrete Canal

Manual excavation would be carried out to make the canal. A similar procedure are used for unlined canal would be adopted. A 2 in layer of 1:4:8 concrete mix cement would be placed on the prepared surface such that the capacity of the canal would remain unaffected. The concrete layer would be cured for a period of 2 weeks to allow for the concrete to gain sufficient strength.

3.4.2.5 Geo-membrane Canal

A canal similar to the unlined canal would be prepared. 2 mm thick (300gsm) PVC Geo-membrane would then be placed over the surface of the canal.

3.4.2.6 Conformity to Specifications

In order to ensure accurate collection of data, it is necessary that each canal section would conform to the design specifications. Each dimension would be checked using a measuring tape. 0.25 in deviation from design value would be allowed. The bed slope of the sections would be checked using a spirit level.

After the curing period is over, each canal would be filled with water upto a depth of 1.75 ft. This would allow for the saturation of soil surrounding the canal to emulate conditions which are encountered in a real canal.

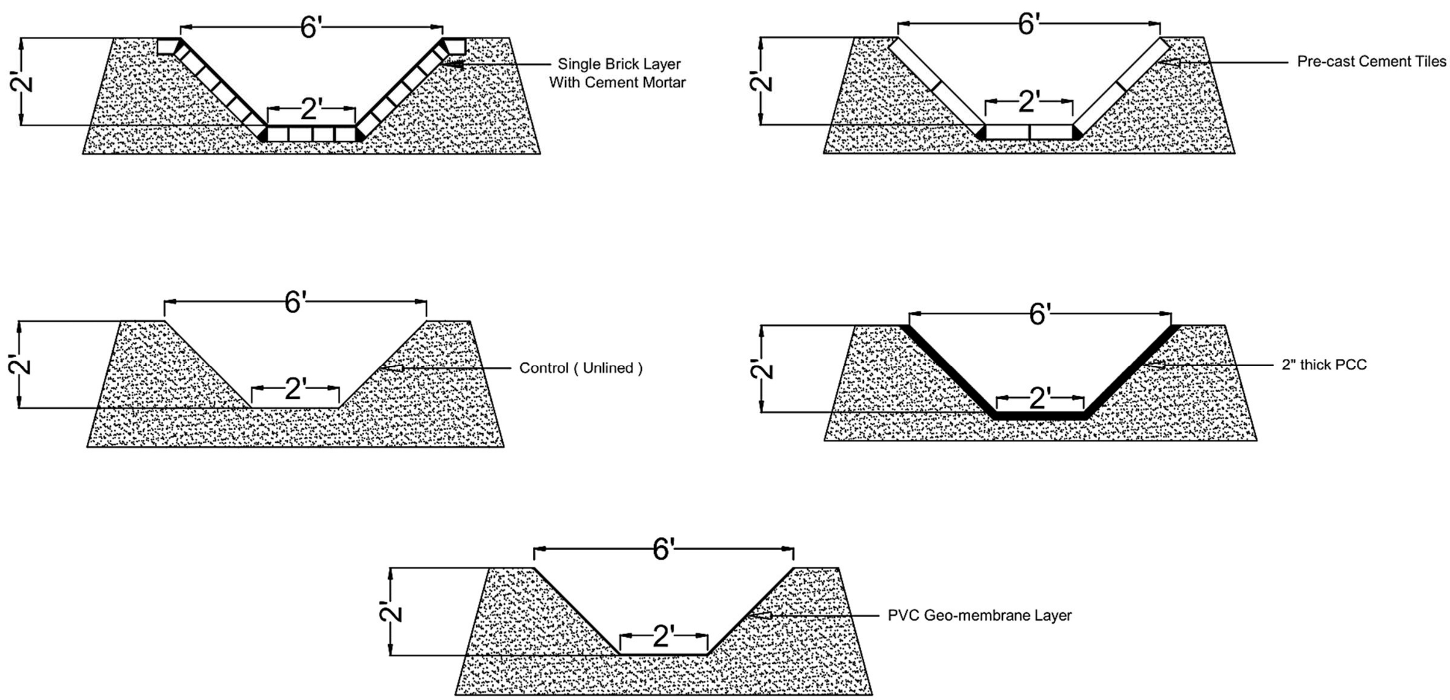

Figure 3.4 Sections of the five proposed canals

3.4.3 Experiment Data Collection

In order to measure seepage losses from canals we employ the Ponding Test method. After construction of the sections, staff gauges are set up on either sides of the canal sections. Water level of initially 1.75 ft is filled up in the pond. After that, water level measurements would be taken from both staff gauges and averaged to compensate for wind or other factors. Water levels would be measured at an interval of 8 hours over several days. Temperature would also be recorded against each water level reading. In case of rainfall, the depth of rainfall would be recorded and subtracted from the water level from each reading. The rainfall would be recorded by means of a self-made rain gauge.

Sr.	Reading Time			Water Level					
	Day	Hour	Temp	Control	Brick	PCC	Pre-Cast	PVC	HDPE
1	1	0-8							
2		8-16							
3		16-24							
4	2	0-8							
5		8-16							
6		16-24							

Table 3.5 Sample table for purpose of data collection

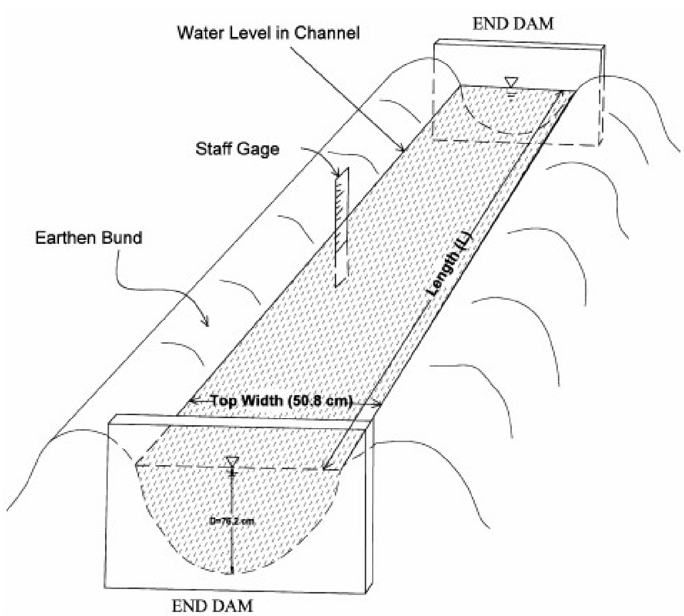

Figure 3.5 Visual representation of ponding method

We would use the following equation to calculate rate of total water loss:

$$Q = rWL = Gal/day = (iA \times fA) /(t \times 7.48)$$

Where:

iA = initial area of cross section

fA = final area of cross section

t = time duration of test (hours)

7.48 = conversion factor

rWL = rate of water loss

The rate of water loss can be multiplied by the time duration of the experiment to calculate the total water loss.

For the purpose of calculating the loss due to evaporation, the Jensen-Haise equation would be used. The constants used in the equation for location are available online and site data would be taken from the nearest weather station.

$$PE = C_t (T - T_x) K_s/(Lt)$$

T = Avg. daily temperature

T_x = Constant for given location

K_s = Daily Solar Radiation

L = Latent Heat of Vaporization

C_t = Temperature Coefficient

t = Time duration

The volume of water lost to seepage can then be calculated as follows:

$$Q_s = Q_T - Q_{PE}$$

Q_s = Rate of seepage loss

Q_T = Rate of total loss

Q_{PE} = Rate of evaporation

As mentioned earlier however, these results could not be obtained due to the COVID-19 pandemic. Keeping that in mind, an alternate approach is used to obtain the rates of seepage. Experimentally obtained values of permeability for materials used in this research were collected (Thandaveswara, B.S.).

Material	Permeability ‘k’ m/sec
Brick Lining in Cement Mortar	3.54×10^{-6}
Cast in-situ P.C.C.	0.33×10^{-6}
Pre-Cast Cement Tiles	2.99×10^{-6}
PVC film	0.14×10^{-7}

Table 3.6 Coefficients of permeability for various lining materials

The permeability of pre-cast cement tiles was assumed to be the average of brick and P.C.C lining. This is due to the reason that joints exist between the tiles similar to brickwork whereas they also retain the properties of cement and are less porous than bricks.

The method used by Swamee et al. (2009) for calculating seepage through a trapezoidal canal is then utilized. According to this approach, the steady seepage loss from an unlined or lined canal can be defined as:

$$q_s = k\, y_n\, F_s$$

Where

q_s = *seepage discharge per unit length* (m^2/sec)
k = *coefficicent of permeability (m/s)*
y_n = *normal depth of flow in the canal (m)*
F_s = *Seepage function, a function of channel geometry*

The seepage function F_s can be calculated for different conditions of a canal with a specific geometry and dimensions. The analytical form of these solutions, is not suitable for calculating the seepage loss of existing canals or while designing new canals due to implicit variables and integrals. These make the equations very difficult to solve. However, these methods have been simplified using numerical methods for easy computation of seepage function by Swamee et al. (2009). For trapezoidal section, seepage function is given by:

$$F_s = \left[\{\pi(4-\pi\}^{\frac{1}{3}} + (2m)^{\frac{1}{3}}\}^{\frac{(0.77+0.462\quad)}{(1.3+0.6m)}} + (\frac{b}{y})^{\frac{(1+0.6m)}{(1.3+0.6m)}}\right]^{\frac{(1.3+0.6m)}{(1+0.6m)}}$$

Here,

m = side slope
b = bed width of channel
y = depth of flow

In our scenario, the values will be:

m = 1
b = 2 ft = 0.6096m
y = 1.75 ft = 0.5334m

Using this analysis, we obtain the following results for seepage from our different sections: It is assumed that the compacted control section would be reduce the seepage by 80%. This is in line with the findings carried out by Burt et al, (2010).

Type of Canal	k	y_n	F_s	q_s (m²/sec)	Q_s (m³/sec)
Unlined Un-compacted	2.55×10^{-5}	0.5334	4.68727	6.38×10^{-5}	2.92×10^{-4}
Unlined Compacted	5.1×10^{-6}	0.5334	4.68727	1.28×10^{-5}	5.84×10^{-5}
Brickwork with cement mortar	3.54×10^{-6}	0.5334	4.68727	8.85×10^{-6}	4.04×10^{-5}
Cast in-situ P.C.C.	0.33×10^{-6}	0.5334	4.68727	8.25×10^{-7}	3.77×10^{-6}
Pre-cast P.C.C. Tiles	2.99×10^{-6}	0.5334	4.68727	7.48×10^{-6}	3.42×10^{-5}
PVC Sheet	0.14×10^{-7}	0.5334	4.68727	3.50×10^{-8}	1.60×10^{-7}

Table 3.7 Seepage discharge for each type of lining

3.6 Cost Estimation of Sections

The process of cost estimation is the prediction of the quantity and cost of the material, labor and other additional services which be utilized in the project. Before the cost can be predicted, the quantity of material or labor employed in construction of the sections must be calculated. MES Schedule of Rates 2014 is utilized for the purpose of preparing the material and cost estimate. For items not available in the Schedule, the prices in the market have been used.

3.6.1 Calculation of Materials

Brickwork with Cement Mortar (1:5)				
Volume of lining		=	43.1	cft
		=	1.22	cum
		=		
1 cum		=	500	bricks
	1.22 cum	=	610	bricks
CM (1:4) 1cum		=	2.44	bags
	1.22 cum	=	2.98	bags
1 bag of cement		=	0.04	cum
	2.98	=	0.1	cum
Sand		=	1.12	cum
Pre-Cast Cement Slabs				
Area		=	148	sft
		=	13.8	sqm
Tiles (30cm x 15cm x 5 cm)		=	306	tiles
Include 5% wastage		=	320	tiles
Cast in-situ PCC				
Volume of Lining		=	24.7	cft
		=	0.7	cum
Cement		=	1.66	bags
Sand		=	0.22	cum
Aggregate		=	0.44	cum
PVC Geomembrane				
Area		=	148	sft
		=	13.8	sqm

Table 3.8 Material estimate for construction of sections

3.6.2 Cost Estimate of Sections

Control Section

S/No.	Description	Quantity	Unit	Rate	MES 2014 SI	Amount PKR
1	Excavation for Section	3.4	cum	181.15	1 1	615.91
2	Compaction upto 90% AASHTO	11.78	sqm	13.88	1 33	163.51
3	Extra labour cost	150	sqft	5	Market Rate	750.00
TOTAL						1529.42

Brickwork in Cement Mortar Section

S/No.	Description	Quantity	Unit	Rate	MES 2014 SI	Amount PKR
1	Excavation for Section	5.01	cum	181.15	1 1	907.56
2	Compaction upto 90% AASHTO	13.52	sqm	13.88	1 33	187.66
3	BB Work in CM (1:4)	0.87	cum	9992.7	4 5	8693.65
4	13mm Cement Plaster (1:4)	11.41	sqm	219.01	13 5	2498.90
5	Extra labour cost	150	sqft	10	Market Rate	1500.00
TOTAL						13787.77

Pre-Cast Cement Tiles Section

S/No.	Description	Quantity	Unit	Rate	MES 2014 SI	Amount PKR
1	Excavation for Section	4.87	cum	181.15	1 1	882.20
2	Compaction upto 90% AASHTO	12.94	sqm	13.88	1 33	179.61
3	Pre-Cast Cement tiles (30cm x 15cm x 5cm)	320	Tiles	30	Market Rate	9600.00
4	Pointing of Pre-Cast tiles	16.01	sqm	163.57	3 70	2618.76
5	Extra labour cost	150	sqft	5	Market Rate	750.00
TOTAL						14030.56

Csst in-situ PCC

S/No.	Description	Quantity	Unit	Rate	MES 2014 SI	Amount PKR
1	Excavation for Section	4.95	cum	181.15	1 1	896.69
2	Compaction upto 90% AASHTO	13.67	sqm	13.88	1 33	189.74
3	PCC Slab	1.11	cum	4537.59	3 1	5036.72
5	Extra labour cost	150	sqft	15	Market Rate	2250.00
TOTAL						8373.15

Geo-membrane Section

S/No.	Description	Quantity	Unit	Rate	MES 2014 SI	Amount PKR
1	Excavation for Section	3.4	cum	181.15	1 1	615.91
2	Compaction upto 90% AASHTO	11.78	sqm	13.88	1 33	163.51
3	PVC Geo-membrane cost	150	sqft	90	Market Rate	13500.00
5	Extra labour cost	150	sqft	15	Market Rate	2250.00
TOTAL						16529.42

Table 3.9 Estimated construction costs for each section

CHAPTER 4

ANALYSIS OF LININGS

Chapter 4

ANALYSIS OF LININGS

4.1 Introduction

On the basis of the data gathered in the previous chapter, the results will be analyzed to compare the various techniques with each other in terms of different parameters. This chapter will deal with the analysis portion of the research project. As such, the effectiveness of each lining material to prevent seepage losses, its cost and its capacity would be compared to give an overall picture of the suitability of the lining for agricultural projects.

4.2 Comparative Seepage Loss

The efficiency of the linings is determined by their rates of seepage. The higher the rate of seepage, the less efficient the lining is in terms of reducing the seepage loss. The rates of seepage obtained in the previous chapter were compared with each other. It can be seen that the PVC Geo-membrane has the least seepage rate, followed by PCC slab, Pre-cast cement tiles, Brickwork and then the compacted control section.

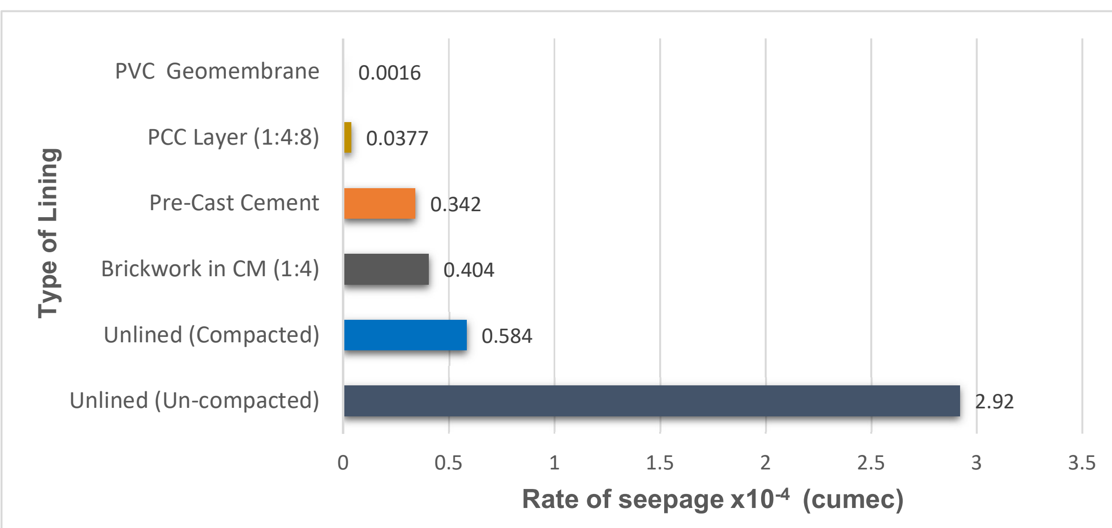

Figure 4.1 Rate of seepage through various lining materials

The efficiency of each lining can be determined by comparing its rate of seepage with that of the unlined, un-compacted section. The compacted control was assumed to have 80% efficient in line with research carried out by Burt et al. (2002). Brickwork in cement mortar, Pre-Cast Cement Tiles, PCC and PVC Geo-membrane had efficiencies of 86.16%, 88.29%, 97.4% and 99.92% respectively. It can be gathered from the results that lining of the canal walls has a profound effect on the seepage losses.

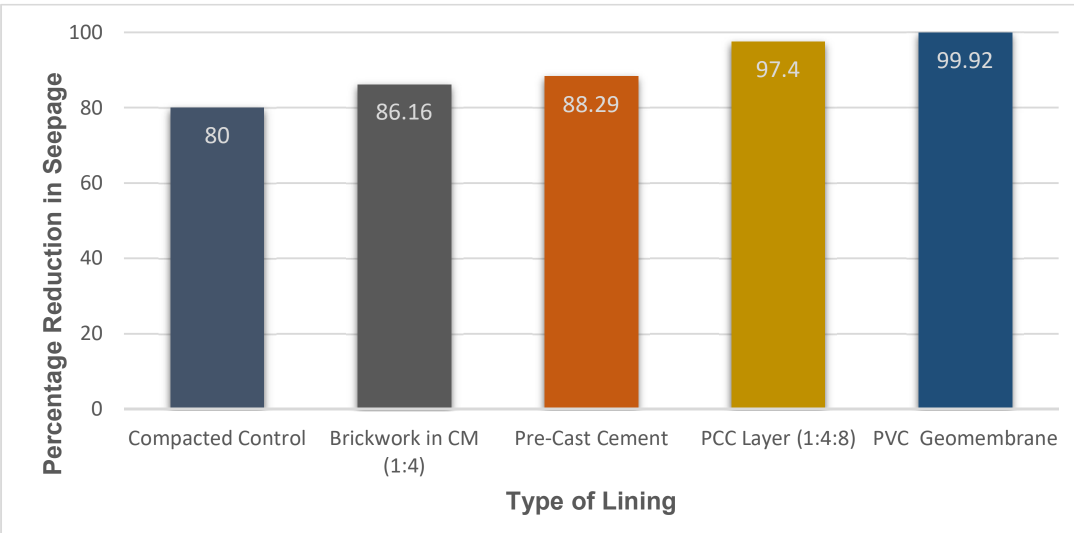

Figure 4.2 Percentage reduction of seepage for each lining material

4.3 Channel Capacity of Sections

Manning's equation governs the discharge through a channel depending on its roughness coefficient and its design characteristics. Different materials used in construction of the sections will have different roughness coefficients and this will determine the capacity of that channel. Chow (1959) has determined these Manning's coefficients for various materials. The channel capacity of these sections can hence be found using the design characteristics. The slope of sections is assumed to be 1 in 1000.

Material	n	A (ft²)	P (ft)	S	Q(cusec)
Unlined Control	0.025	6.56	6.95	0.001	8.075
Brick Lining in Cement Mortar	0.018-0.020	6.56	6.95	0.001	11.233
P.C.C. Lining	0.015	6.56	6.95	0.001	13.48
Pre-Cast Cement Tiles	0.018-0.020	6.56	6.95	0.001	11.233
PVC Geo-membrane	0.010	6.56	6.95	0.001	20.22

Table 4.1 Discharge capacity of channel sections

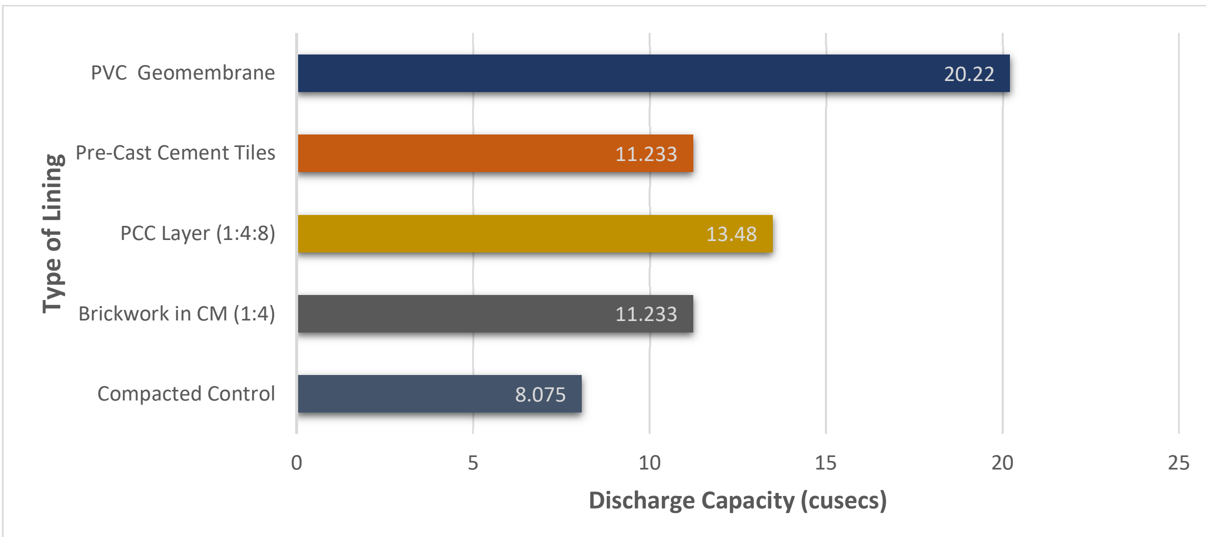

Figure 4.3 Graphical representation of Discharge Capacity

The analysis results show that PVC geo-membrane can carry the discharge compared to other lining followed by the cast in-situ PCC. These results means that for the provided dimensions of the same channel, the velocity of flow and hence more volume of water can be carried by a section with smoother walls, i.e. lower Manning's coefficient.

4.4 Comparative Cost of Sections

Cost is a major driving factor in construction projects. Especially in a developing country like Pakistan, monetary restraints are responsible for selection of the material and method used for construction. Based on the costs calculated for each section, we can determine the cost per running length of each section of uniform design.

Material	Cost per meter (PKR)
Unlined Control	334.5
Brick Lining in Cement Mortar	3015.7
Cast in-situ P.C.C.	1831.4
Pre-Cast Cement Tiles	3068.8
PVC Geo-membrane	3615.4

Table 4.2 Cost per running meter of each lining material

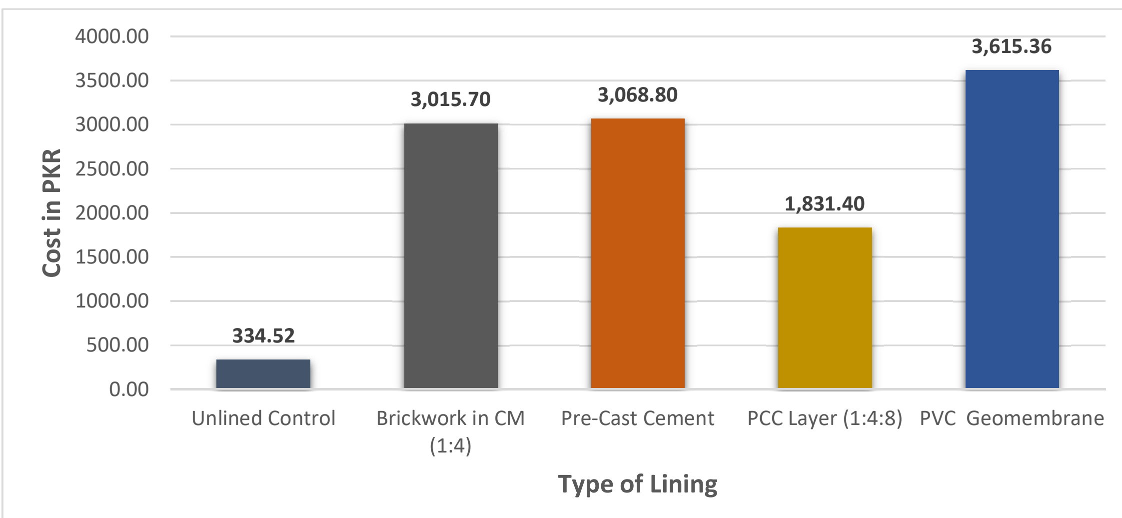

FIgure 4.4 Cost per running meter of lining materials

It can be concluded that PVC Geo-membrane is the costliest of all the alternatives. Pre-cast cement tiles and brick masonry cost approximately the same for construction. Cast in-situ PCC lining is lesser of all the alternatives and half the price of the most expensive material, i.e. PVC Geo-membrane.

4.5 Effective Life Span

The effective life span is the length of time during which the canal as per its design specifications without considerable changes in its performance. The higher cost of a type of lining material can be offset by its long term performance. This factor is dependent on a variety of other factors as well which includes quality of construction, environmental conditions, and maintenance. However, the table below shows an average range of life-span according to research previously carried out. The following values have been taken from the FAO manual for canal design.

Material	Life span (Years)
Compacted Soil	<5
Brick Lining in Cement Mortar	10
Cast in-situ P.C.C.	50
Pre-Cast Cement Tiles	30
PVC Geo-membrane	20-30

Table 4.3 Average life span of canal linings

Compacted soil although cheap, does not have an economical life span. Its longevity is highly dependent on factors such as type of soil, degree of compaction, environment, intensity of use etc. It can be effective up to 5 years in ideal conditions. It is also difficult to ascertain the life of bricks linings as environmental factors can deteriorate its effectiveness.

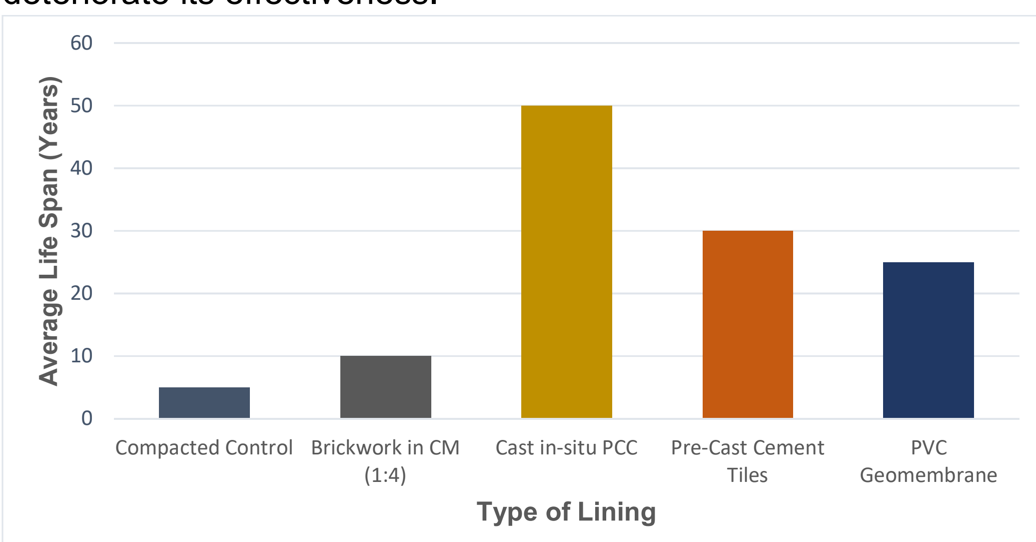

Figure 4.5 Average life span of canal linings

4.6 Weed Growth

Material	Weed Growth
Compacted Soil	High probability
Brick Lining in Cement Mortar	Minimum growth if joints properly sealed
Cast in-situ P.C.C.	No weed growth unless cracks appear
Pre-Cast Cement Tiles	Minimum growth if joints properly sealed
PVC Geo-membrane	No weed growth

Table 4.4 Weed growth in canal linings (Arnold, 1935)

Weed growth in canals is detrimental to the structure itself and also reduces it discharge capacity. The increase in weed growth can form cracks in the walls or bed and cause reduction in the life span and functionality of the canal. Compacted soil has the maximum probability of weed growth as there is no barrier to prevent growth. All other types of linings have good potential to stop weed growth. However, care must be taken during the construction of the brick and tile lining as improper filling of joints with mortar can provide gaps for weeds.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

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5.1 Importance of Canal Linings

The lining of canals is an essential requirement of an irrigation system. As canal irrigation takes up a large portion of the water requirement of the country, a large amount of water can be conserved and saved which is otherwise wasted, as the research work carried out has shown. The function of linings is not limited to conserving water, rather they are an essential requirement to combat water logging in some areas and also to mitigate flooding.

5.2 Research Results

The research was aimed at evaluating the performance of different lining materials while also comparing their relative cost, long term use and suitability to the region. Experimental methodology could not be used due to the COVID-19 pandemic and theoretical methodology was employed to compare the different linings. All the types of linings under study reduced seepage losses by over 80% and increased the discharge capacity of the channel sections. PVC Geo-membrane lining has been shown to be the most efficient in reducing seepage but its advantage is offset by its cost and maintenance issues. Cast in-situ Plain Cement Concrete lining is equally effective as PVC Geo-membrane, but durable and cheaper. The materials used for its construction are readily available and it does not require the employment of specialized labor, unlike PVC Geo-membrane. Brick and pre-cast cement tiles exhibit similar performance in stopping seepage, increasing channel capacity, inhibiting weed growth and life span.

5.3 Recommendations

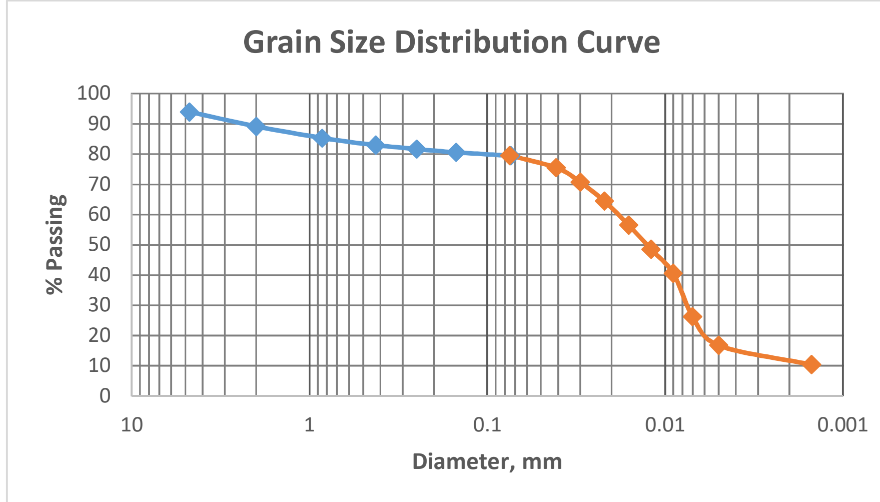
Plain Cement Concrete lining is the most recommended for use in lining of canals in the area, if sufficient funds are available. The lining will be effective in reducing water loss due to seepage and also prevent water logging of cultivated areas near the canals where the water table may be high. Minimum maintenance would be required for this lining and it is invulnerable to damage from livestock or most human activities, making the project a long-term investment. However, other factors which are not within the scope of this study are also required to be factored in once a decision is being made.

ANNEXURE A

(Details of soil classification)

GRAIN SIZE DISTRIBUTION

Sieve No	Sieve Dia (mm)	Mass of soil retained (gm)	Cumulative % Retained	% Passing
4	4.75	6	6	94
10	2	4.79	10.79	89.21
20	0.85	3.87	14.66	85.34
40	0.425	2.36	17.02	82.98
60	0.25	1.31	18.33	81.67
100	0.15	1.09	19.42	80.58
200	0.075	1.08	20.5	79.5
Pan		79.5	100	0



Elapsed time, T (min)	Actual Hydrometer reading (HR)	Composite correction Rw	R=HR - Rw Hyd. Reading with comp. corr	Temp (C)	Effective depth of Hydro. (L, cm)	Value of K from Table	Dia of soil particle mm(k*(L/T)^5	Soil in suspension P %=R*a*100/50	Actual % finer with ref. to total soil mass
									79.5
1	51	3.5	47.5	25	8.7534	0.01401	0.074	95.0	75.53
2	48	3.5	44.5	25	9.2532	0.01401	0.041	89.0	70.76
4	44	3.5	40.5	25	9.9196	0.01401	0.03	81.0	64.4
8	39	3.5	35.5	25	10.7526	0.01401	0.022	71.0	56.45
15	34	3.5	30.5	25	11.5856	0.01401	0.016	61.0	48.5
30	29	3.5	25.5	25	12.4186	0.01401	0.012	51.0	40.55
60	20	3.5	16.5	25	13.918	0.01401	0.009	33.0	26.24
120	14	3.5	10.5	25	14.9176	0.01401	0.007	21.0	16.7
240	10	3.5	6.5	25	15.584	0.01401	0.005	13.0	10.34
1440	6	3.5	2.5	25	16.2504	0.01401	0.0015	5.0	3.98

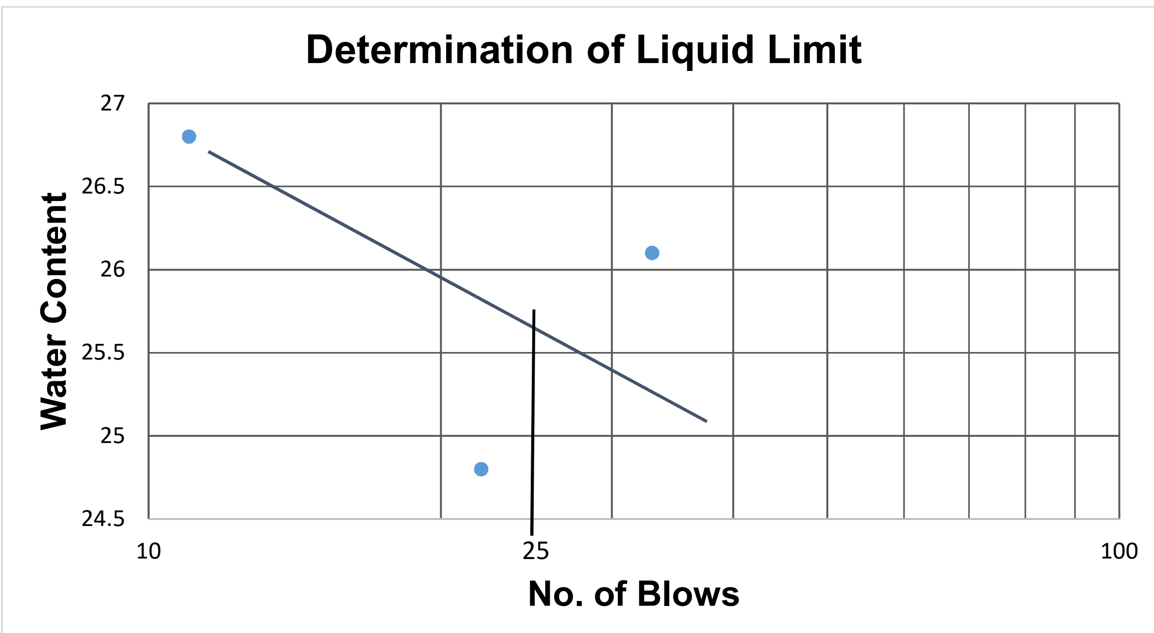
Sand %	20.5	Retained % on #200 Sieve
Silt %	68.75	Retained % at 0.005mm Passing 0.075mm
Clay %	10.74	Passing 0.005mm
CF %	9.48	Passing 0.002mm

*C.F = Clay Size Fraction

Result: INORGANIC SILTY CLAY

CONSISTENCY LIMITS

No. of Blows	11	22	33	Plastic Limit
Mass of wet soil + can	22.6	26	26.4	22.2
Mass of dry soil + can	20.4	23.4	23.5	20.68
Mass of can	12.2	12.9	12.4	12.3
Mass of water	2.2	2.6	2.9	1.52
Mass of solids	8.2	10.5	11.1	8.38
Water Content	26.8	24.8	26.1	18.1



Liquid Limit = 25.6%
Plastic Limit = 18.1%

PERMEABILITY
(FALLING HEAD METHOD)

Parameter	Value	Unit	Value	Unit
Dia of specimen	4	in	10.16	cm
Length of specimen	5	in	12.17	cm
Area of specimen	12.57	in^2	81.1	cm^2
Volume of Sample	0.0364	ft^3	1030	cm^3
Cross-sectional area of burrette			1	cm^2
Temperature of discharge			20	°C
Weight of Specimen + Mould			3038	gm
Weight of mould of Sample			1276	gm
Weight of Specimen			1762	gm

Test no.	h1 (cm)	h2 (cm)	T (sec)	K(C)cm/sec	K 20C (cm/sec)	K 20C (m/s)
1	1	7.1	120	0.002555	0.00203378	2.03E-05

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