Technical Document

WATER HARVESTING AND ARTIFICIAL RECHARGE

RAJIV GANDHI NATIONAL DRINKING WATER MISSION
DEPARTMENT OF DRINKING WATER SUPPLY
MINISTRY OF RURAL DEVELOPMENT
GOVERNMENT OF INDIA

December, 2004

भारत सरकार
ग्रामीण विकास मंत्रालय
पेय जल आपूर्ति विभाग
Government of India
Ministry of Rural Development
Department of Drinking Water Supply
247, A Wing, Nirman Bhawan, New Delhi-110011
Tel. : 23010207, 23010245, Fax : 23012715
E-mail : secydws@nb.nic.in

V.K. DUGGAL
SECRETARY

Foreword

The decline in the availability of fresh water and over-exploitation of groundwater – the major source of rural water supply, leading to both drying up of sources and worsening of water quality are matters of great concern. Due stress has to be laid on the sustainability of sources, without which the rural water supply will not be sustainable.

Rain water harvesting is an eco-friendly, affordable, adoptable and acceptable method for augmenting availability of water. The traditional wisdom of our people in rainwater harvesting, can be refined through scientific approach with more focus on innovative technologies of water harvesting, conservation and augmentation. This route ensures support to the initiatives of the Government to usher in a participatory approach to water supply programmes.

I trust this exhaustive treatise covering all aspects of rain water harvesting - right from planning, designing, construction in various agro-climatic zones, viz., hard rock, coastal, hilly and desert areas, present practices, case studies, requirement of human resource development and modalities of implementation, monitoring and evaluation of rain water harvesting structures will be of immense help to all those involved in the implementation of the rural water supply programme.

M/s WAPCOS, a premier Consultancy Firm in the country, whose field experience and through knowledge of the various practices prevalent in the country, in capturing information on the traditional methods of water harvesting and following it through to the modern times has given more value to the document.

This document intends to provide a fund of information and the necessary technical expertise to the implementing agencies for adopting in their respective field of activities; and, I hope it will receive wider acceptance.

(V.K. Duggal)

New Delhi
November 22, 2004

राकेश बिहारी
संयुक्त सचिव
RAKESH BEHARI
JOINT SECRETARY

भारत सरकार
पेय जल आपूर्ति विभाग
(राजीव गांधी राष्ट्रीय पेयजल मिशन)
Government of India
Department of Drinking Water Supply
(Rajiv Gandhi National Drinking Water Mission)

Preface

In continuation of the tradition of the Department of Drinking Water Supply of rendering technical assistance to implementing agencies in States, this Technical Document on Water Harvesting and Artificial Recharge fulfils a long felt need of authentic and comprehensive documentation of existing and recommended practices in the field. The issue of sustainability of sources has assumed critical importance because of the growing need of water for various purposes, often resulting in indiscriminate exploitation of this precious resources. The problem is particularly acute in the rural drinking water sector, which predominately depends on ground water resources.

Government of India have been stressing upon State Government to promote rain water harvesting. The response of some of State Governments has, however, not been very encouraging. One of the reasons could be lack of technical expertise. The experience of the State who have implemented rainwater harvesting successfully can be of great value for these States. To enable all those involved in Water Supply Programmes to promote Water Harvesting and Artificial Recharge of ground water, WAPCOS has been engaged for preparing a comprehensive Technical Document on Water Harvesting and Artificial Recharge. I compliment WAPCOS for preparing a very useful and informative document.

The document gives a good account of the historical perspective of the age – old tradition followed by our ancestors for becoming self – reliant in water supply. The traditional wisdom of our people can be improved through scientific approach and innovative technologies developed elsewhere. The replicable technologies/methodologies can be used to adopt our traditional practices to suit everyone's requirement. This document is intended to inform the layman as well as planners and implementing agencies to translate the dream of availability of fresh water to everyone into a reality.

It is hoped that, like the Handbook on Rain Water Harvesting published by the Department earlier, this document will also help the policy makers, planners and implementers to successfully follow water harvesting and artificial recharge practices for most efficient use of this valuable and irreplaceable natural resource.

(Rakesh Behari)

New Delhi
November 22, 2004

Paryavaran Bhawan, 9th Floor, CGO Complex, Lodhi Road, New Delhi-110003.
Tel. : 24361043, Fax : 24364113, E-mail : jstm@water.nic.in

CONTENTS

Page

CHAPTER - 1

Introduction

1.0 BACKGROUND

The population of the country has already crossed the 1 billion mark and is expected to reach 1.64 billion by the year 2050. Towns and villages are expanding rapidly, new hamlets are coming up and existing ones are turning into villages – all requiring and demanding drinking water for sustenance of life. In terms of sheer volumes, the rural drinking water requirement in 2050 would be 29 billion cubic metres (BCM) against the present requirement of about 10 BCM. With lakhs of villages and hamlets spread over high hills and mountain slopes, deep forested valleys, barren deserts, degraded lands and ravines, along saline coastal belts, denuded rocky plateau and other inaccessible remote areas, providing safe drinking water for all is a challenging task.

Ground water, the major source of rural water supply is depleting fast in many areas due to large-scale exploitation for expanding irrigated agriculture. Out of a total of 5,711 blocks in the states of Andhra Pradesh, Gujarat, Haryana, Punjab, Rajasthan, Karnataka, Tamil Nadu, and Uttar Pradesh, 310 blocks are already over-exploited with ground water extractions being in excess of the net annual recharge. Besides, a much larger number of blocks, presently categorised as "dark" are likely to become "over-exploited".

The fast deteriorating situation of water availability is gradually acquiring an even more dangerous and frightening dimension of worsening water quality. Rapid lowering of ground water table in many areas has given rise to ingress of sea water into aquifers which has rendered the water from wells, hand pumps etc. unfit for human consumption. According to a recent (1997) finding arsenic contamination in ground water is high in about 1,000 habitations in West Bengal, Fluoride levels are above permissible limits in Andhra Pradesh, Tamil Nadu and Madhya Pradesh affecting 14 million people in 28,000 habitations. High level of iron contamination is affecting 29 million people in 50,000 habitations in northeastern and eastern states. Salinity is high in Gujarat, Haryana, Karnataka, Punjab, Rajasthan and Tamil Nadu.

Besides various natural factors, rapid urbanisation, industrialisation and increased use of fertilizers and pesticides in agriculture have also adversely affected ground water quality. With more and more untreated or partially treated effluents being discharged by the industry and municipalities into the water bodies the ground water quality is deteriorating alarmingly.

This being the situation of rural water supply today, the prospects of augmenting it almost three fold by 2050 and improving its quality to desired levels appear bleak unless radical changes are brought about in our water management strategy.

1.1 WATER HARVESTING – THE WAY AHEAD

The usual approach of augmenting water availability through major, medium and minor schemes has its own techno-economic limitations. The main problem is not only that of collecting and storing water in huge quantities but also that of providing it within easy reach of the large rural population spread over lakhs of villages and hamlets especially in remote areas.

Our experience of thousands of years since the dawn of civilisation, has shown that minimum water requirements of every household anywhere can be easily met by the traditional methods of collecting rain water locally in village/ community ponds and large manmade containers, diverting and storing water from local streams/ springs and tapping sub-surface water below river/ stream beds. These basic techniques have been successfully applied in many different ways by the people in different parts of the country depending upon the local climate, type of soils and rocks both above and below the land surface and the nature of land forms viz. plains, hill slopes, hill tops, valleys, plateau etc. These traditional methods, called "Water Harvesting" in modern times, are environment-friendly and can be easily adopted by the villagers themselves at affordable costs.

1.2 ADVANTAGES OF WATER HARVESTING

- A water harvesting system collects and stores water within accessible distance from place of use.
- Assures a more continuous and reliable access to water.
- Surface water storage structures like ponds/ tanks augment ground water recharge, which improves the yield of hand pumps and wells.
- Provides an alternative source of good quality water where ground water or surface water is contaminated with harmful chemicals, salts or bacteria.
- Easy to construct with locally available material and labour.
- Investment requirements are low and, therefore, structures can be built by the village communities themselves.
- Environment friendly.

CHAPTER - 2

Water Harvesting – Our Age Old Tradition

2.0 HISTORICAL OVERVIEW

India is a country with very deep historical roots and strong cultural traditions. These are reflected in our social fabric and institutions of community life. In spite of social movements of varied nature through the millennia we have retained the spirit and essence of these traditions and have remained attached to our roots. Some of our traditions, evolved and developed by our forefathers thousands of years ago have played an important role in different spheres of life. Most important among these is the tradition of collecting, storing and preserving water for various uses.

It all started at the dawn of civilization with small human settlements coming up on the banks of rivers and streams. When due to vagaries of nature the rivers and streams dried up or the flow dwindled, they moved away to look for more reliable sources of water. In due course of time large settlements came up along perennial rivers that provided plentiful water. As the population increased, settlements developed into towns and cities and agriculture expanded, techniques were developed to augment water availability by collecting and storing rain water, tapping hill and underground springs and water from snow and glacier melt etc. Water came to be regarded as precious and its conservation and preservation was sanctified by religion. Various religious, cultural and social rituals prescribed, interalia, purification and cleansing with water. Water itself had many applications in different rituals. Development of reliable sources of water like, storage reservoirs, ponds, lakes, irrigation canals etc. came to be regarded as an essential part of good governance. Emperors and Kings not only built various water bodies but also encouraged the village communities and individuals to build these on their own. Wide-ranging laws were made to regulate their construction and maintenance and for conservation and preservation of water and its proper distribution and use.

2.1 MYTHOLOGY AND FOLKLORE

Our ancient religious texts and epics give a good insight into the water storage and conservation systems prevailing in those days. For instance, the sage Narad during his visits to different kingdoms would invariably enquire about the state of the ponds and other water bodies and whether these had enough water for the population. In the Ramayana, Lord Hanuman is wonder struck by the beauty and grandeur of Lanka especially its well-maintained lakes, baolis, wells, gardens, orchards and forests.

In our villages there are countless stories from mythology, folklore and songs extolling the glory of our sacred rivers and lakes. The story of Bhagirath single handedly training the mighty Ganga has been told from generation to generation.

By all accounts, there was no water problem in those days and every household could meet its minimum water requirements through these rudimentary local water collection and management measures. It was this basic infrastructure, which served as the foundation for building large and powerful empires. World history, as indeed our own, is replete with instances of rise and fall of empires and civilizations as a direct result of the strength or weakness of this foundation. Let us go back in time and take a quick view of the entire water scenario in a historical perspective, ponder over the present water crisis and draw lessons for future course of action.

2.2 INDUS VALLEY CIVILIZATION

In India, the first major human settlements started in the Indus Valley (3000-1500 B.C.) in the north and western India. Evidence of water systems is found in different writings of this period. There are archaeological evidence of irrigation and drinking water supply systems from a large number of wells with brick lining. Dholavira, an important site of Indus Valley had several reservoirs to collect rain water. Similar evidences have been found at Mohanjodaro and Harappa. In Lothal (Gujarat) and Inamgaon (Maharashtra) and other places in north and western India small bunds were built by the local people to store rain water for irrigation and drinking.

2.3 MAURYAN EMPIRE

The Arthashastra of Kautilya gives an extensive account of dams and bunds that were built for irrigation during the period of the Mauryan Empire. The water supply systems were well managed within the framework of strict rules and regulations. Different types of taxes were collected from the cultivators depending upon the nature of irrigation. The tax rate was 25% of the produce in respect of water drawn from natural sources like rivers, tanks and springs. For water drawn from storages built by the King the tax rate varied according to the method of drawing water. For instance, it was 20% of the produce for water drawn manually, 25% for water drawn by bullocks and 33% for that diverted through channels. Exemptions from payment of water rates were given for building or improving irrigation facilities. The period of exemption was 5 years for new tanks and bunds, 4 years for renovating old works and 3 years for clearing the works over-grown with weeds.

Water bodies like reservoirs, bunds and tanks were also privately owned and the owner was free to sell or mortgage them. The owner could also sell water to others in return for a share of the produce. In the absence of the owner, the water bodies were to be maintained by the people of the village. A set of punishments were prescribed for various violations of water laws like :

- Causing damage to another's ploughed or sown field by letting water overflow from a tank/reservoir.
- Causing damage to gardens, parks and bunds.
- Owner of the higher tank preventing the filling of the lower tank.
- Failure to maintain the water body.
- Out-of-turn drawing of water from a tank.

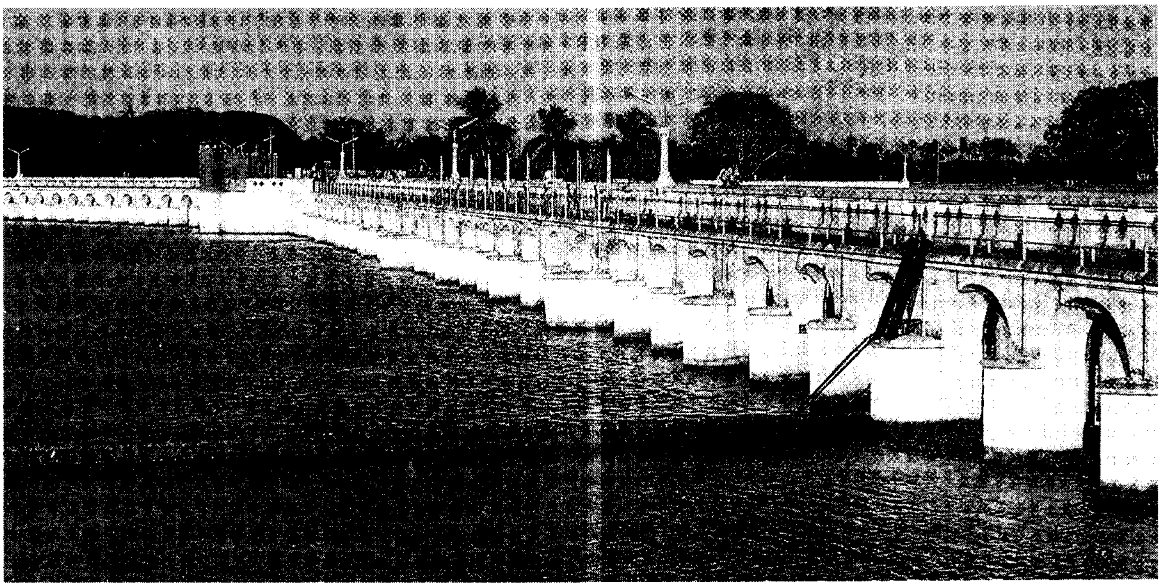
- Building a well or a tank on someone else's land.
- Selling or mortgaging a water body meant for charitable purposes.
- Death penalty was prescribed for breaking a reservoir or tank full of water.

2.4 DEVELOPMENT DURING 1ST CENTURY B.C. AND 15TH CENTURY A.D.

The Satvahanas (1st Century B.C.-2nd Century A.D.) introduced the brick and ring wells. Lake and well irrigation was developed on a large scale during the time of Pandya, Chera and Chola dynasties in south India (1st-3rd Century A.D.) and large structures were built across Cauvery and Vaigai rivers. Irrigation tanks were built, many of these by developing large natural depressions. Water resources development on a large scale took place during the Gupta era (300-500 A.D.). In the south, the Pallavas expanded the irrigation system in the 7th Century A.D. The famous Cauvery anicut was built during this period. Large-scale construction of tanks (Tataka) for tapping rain water was also done in Tamil Nadu. The Chola period (985-1205 A.D.) witnessed the introduction of quite advanced irrigation systems, which brought about prosperity in the Deccan region. This included not only anicuts across rivers and streams but also chain-tanks i.e. a number of tanks with connecting channels. This new system was more reliable in terms of water availability and provided better flexibility in water distribution.

The Rajput dynasty (1000-1200 A.D.) promoted irrigation works in northern India. The 647 sq.km Bhopal lake was built under King Bhoja. In eastern India Pal and Sen Kings (760-1100 A.D.) built a number of large tanks and lakes in their kingdoms. Rajtarangini of Kalhana gives a detailed account of irrigation systems developed in the 12th Century in Kashmir.

In the Medieval period, Mohammad Bin Tughlaq (1325-1351 A.D.) encouraged the farmers to build their own rain water harvesting systems and wells. Feroze Shah Tughlaq (1351-1388 A.D.) built the Western Yamuna Canal in 1355 to extend irrigation facilities in the dry land tracts of the present-day Haryana and Rajasthan. Emperor Shahjahan built many canals prominent among these being the Bari Doab or the Hasli Canal. Under the rule of Rangila Muhammad Shah, the Eastern Yamuna Canal was built to irrigate large tracts in Uttar Pradesh.



Cauvery Anicut

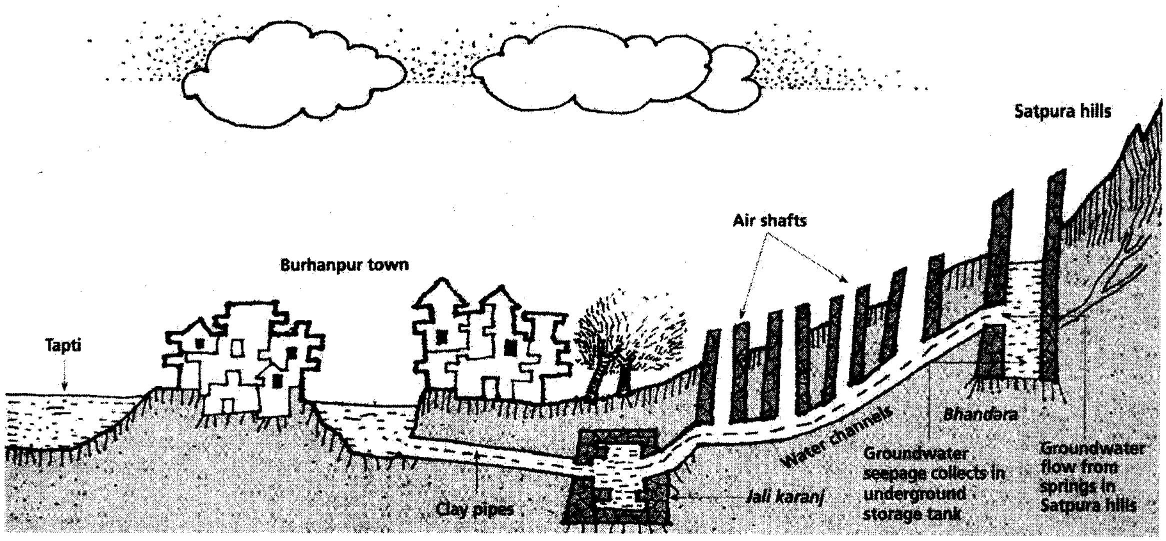
The Vijaynagar Kingdom (1336-1546 A.D.) in the south took keen interest in building large and small storage tanks. Anantraj Sagar tank was built with a 1.37 km long earthen dam across the Maldevi river. The well-known Korangal dam was built under King Krishnadevraya. The Bahamani rulers (1388-1422 A.D.) introduced canal irrigation for the first time in the eastern provinces of the Deccan. Sultan Zain Uddin (1420-1470 A.D.) introduced extensive network of canals in Utpalpur, Nadashaila, Bijbihara and Advin areas of Kashmir.

2.5 WATER FOR DOMESTIC USE

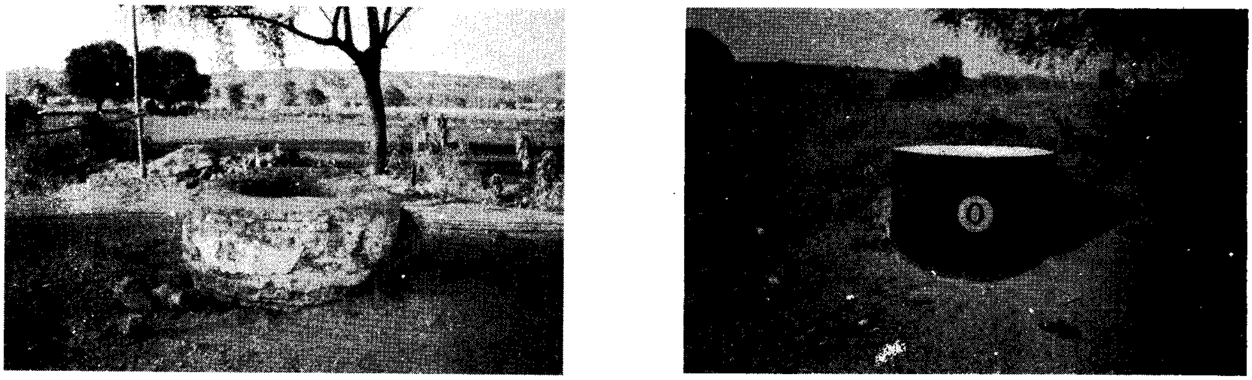
Though the large number of reservoirs and tanks built in different times by the Kings, village communities and individuals were mainly for irrigation, these also provided water for the cattle and domestic use either directly or indirectly through charging of wells. In fact, wells were invariably built close to the tanks, lakes, canals etc. In the arid and semi-arid areas of northwest India, rain water was collected in underground storage tanks called Tanka, Kunds or Kundis. However, the first known construction of a Kund was in 1607 by Raja Sur Singh in village Vadi-Ka-Melan. In 1755, Maharaja Udai Singh built a large Kund in his fort at Jodhpur. Subsequently, during the famine of 1895-96 construction of these storage structures was taken up on a large scale.

The city of Delhi, founded in the early eleventh century near the present Suraj Kund in Haryana, used to get its water supply from Suraj Kund, which was built to impound rain water from the Aravalli hills. During the Sultanate period that followed, several cities were built in the vicinity of the Aravallis and all these had elaborate rain water harvesting systems to meet the domestic water requirements. The prominent among these is the Hauz-e-Sultani built by Sultan Iltutmish (1210-1236 A.D.).

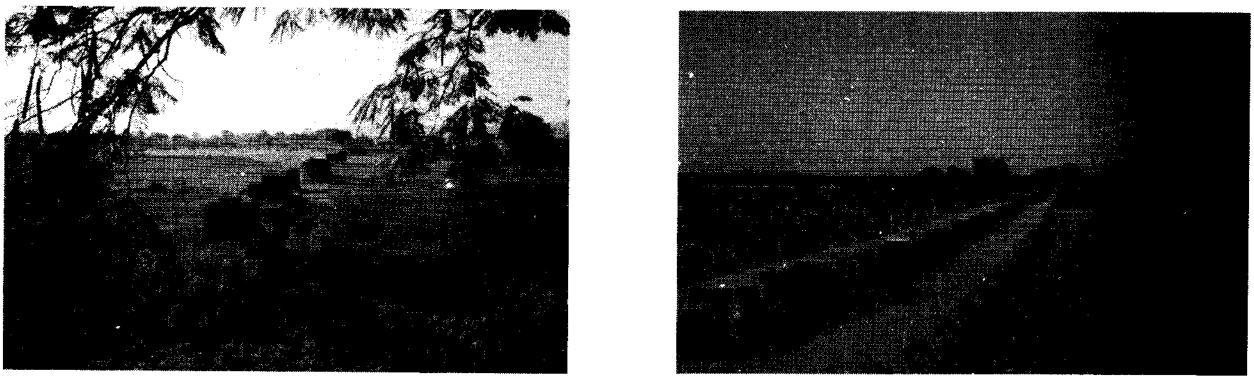
In 1615, during the Mughal rule, Abdul Rahim Khan built a unique water supply system of the Burhanpur town (Madhya Pradesh). The system involved construction of long lines of underground tunnels with vertical airshafts to tap the underground water flow from the nearby Satpura hill ranges to the Tapi river lower down. The system is still functioning well and is adequate to meet the entire water requirements of the town.



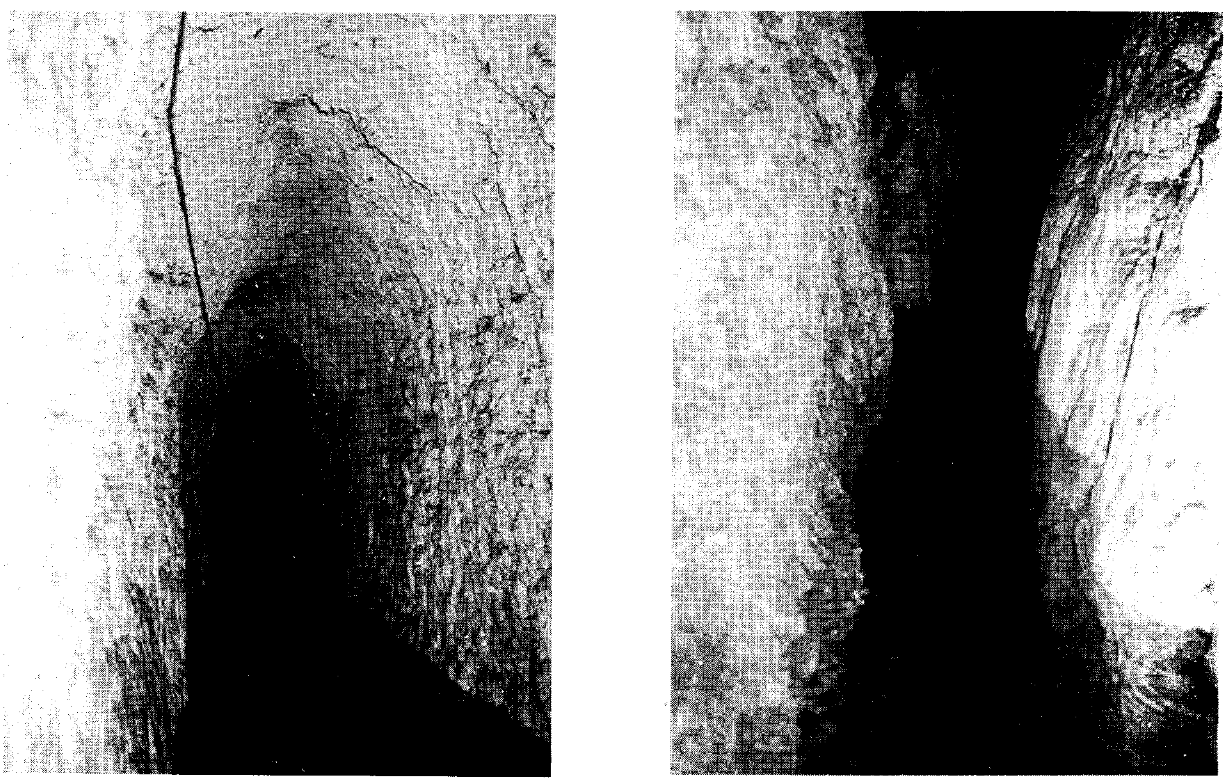
Engineering Marvel of Burhanpur



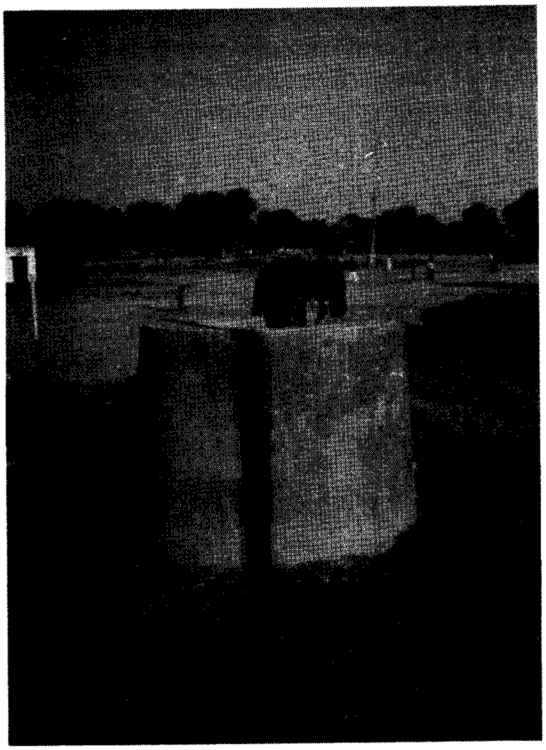
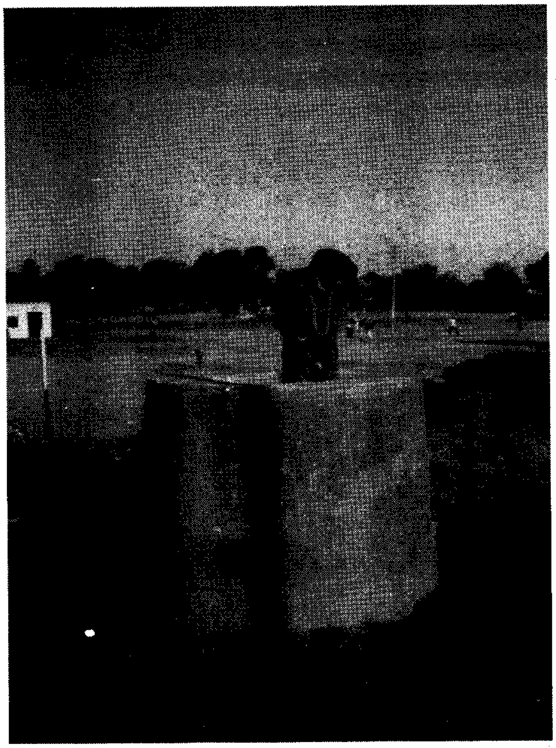
Air Shaft in Original Condition (left) and after repair (right)



Series of Air Shafts



Horizontally Dug Water Channels (Tunnels)

Villagers use these Air Shafts like wells as water flows through the tunnels throughout the year

During 4th and 8th Century Dasmatisagar was built near Titlagarh in Orissa. During the same period two large reservoirs were built in Mayurbhanj district. The erstwhile Patna state also had 6 major reservoirs for water supply. All these were zealously maintained and cattle grazing and agriculture were not permitted in their vicinity.

Under the Nizam Shahi Kings (1490-1635 A.D.) 15 channels were built to supply water to the city of Ahmadnagar from deep wells at the foot of the nearby hills. Similar systems were built by various Kings for the towns of Vadgaon, Junnar, Karad etc.

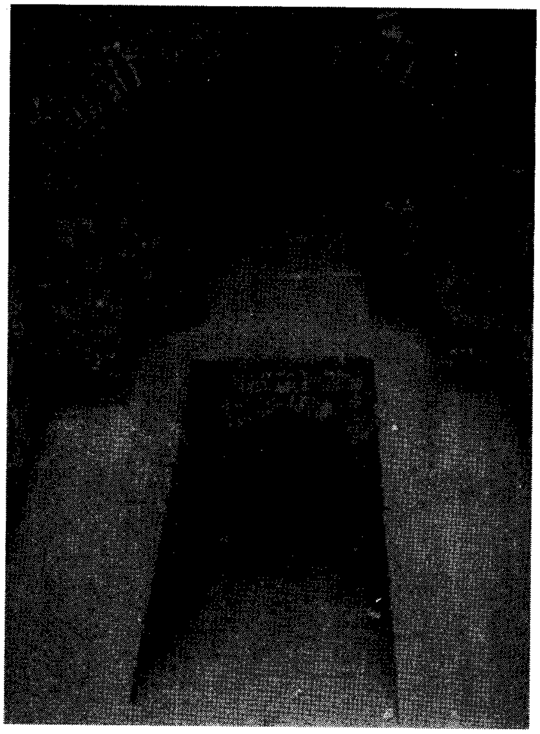
In the low rainfall areas of present-day Karnataka a large number of tanks were built during the 15th Century for both irrigation and drinking water, prominent among these were the Kempambudhi, Dharmambudhi, Sampangi and Siddikatte Kere tanks built by Kempe Gowda.

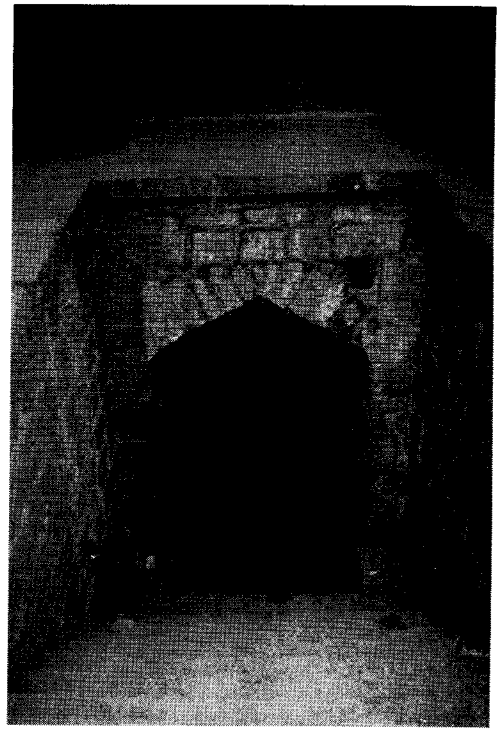
The city of Hyderabad (Andhra Pradesh) has a glorious tradition of tanks built by its ruler Mohammad Quli Qutub Shah in the 16th Century. The first source of water supply to the town was the Hussain Sagar lake built by Hussain Shah Wali in 1562. In the hills near Daulatabad, two reservoirs were built by the Hindu Kings, in ancient times to meet the water requirements of the city.

A number of tanks were built in Palanpur, Ahmedabad, Bharuch, Surat and Vadodara areas of Gujarat during the 15th Century for both irrigation and drinking water.

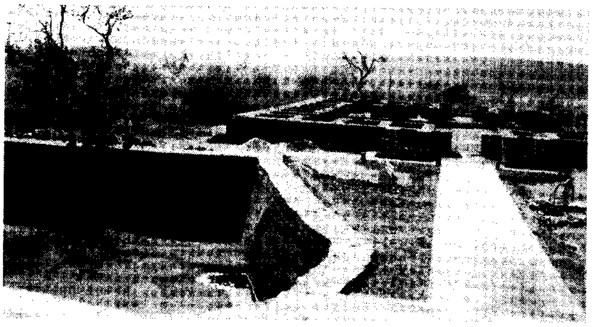
2.6 WATER FOR FORTS AND PLACES OF WORSHIP

All forts, built in different terrains and climatic conditions, had elaborate arrangements for drinking water. Those built on hilltops or in rocky terrain depended mainly on rain water harvested from surrounding hills.





Baolis to tap underground springs in Panhala Fort

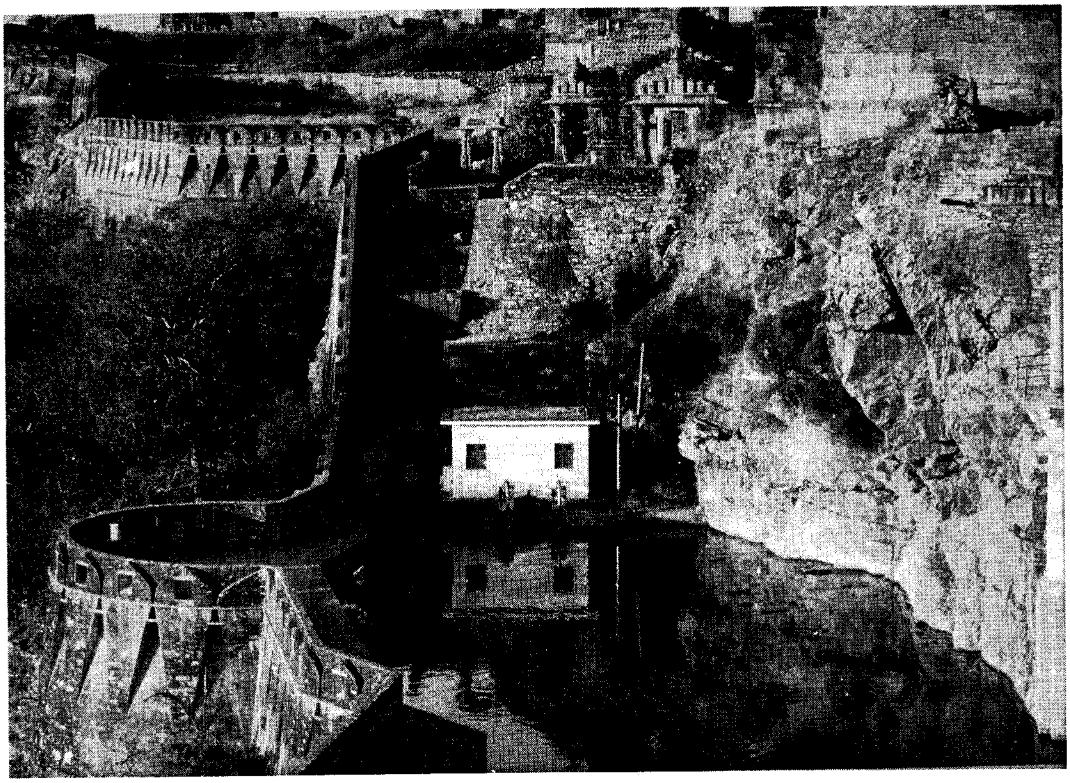


Ancient Tanks on the Buddhist site of Sanchi dating back to the 3rd Century B.C,

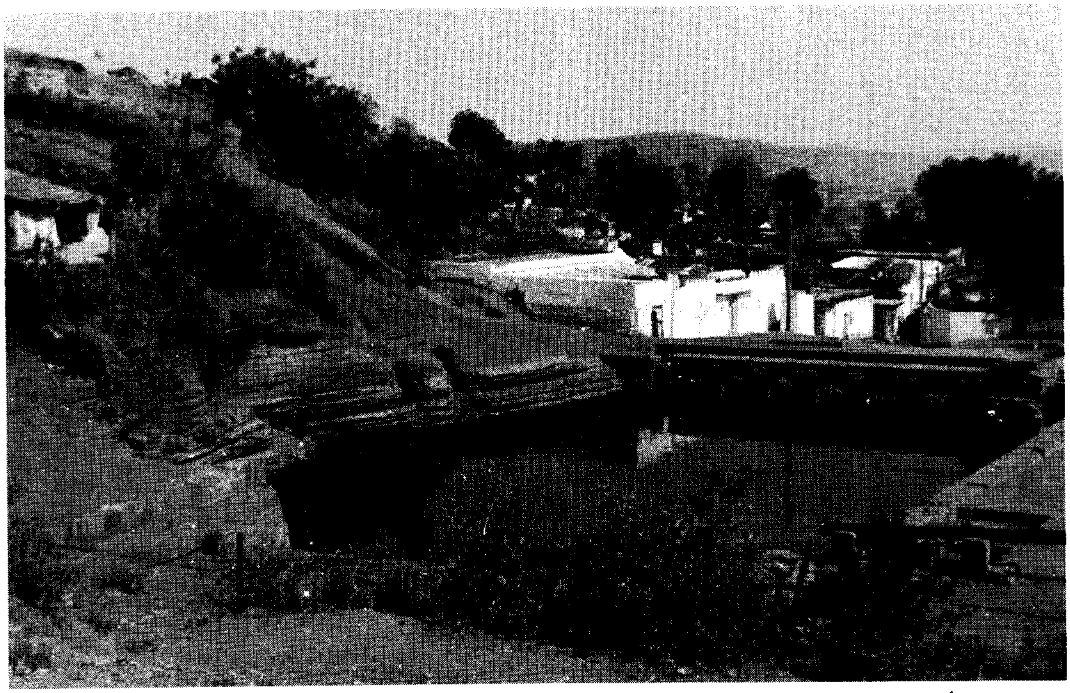
The Amber Fort near Jaipur built about three centuries ago is a classic example of such a system. It has an automatic arrangement for desilting and aeration of harvested rain water before its entry into the large storage tank. The Jodhpur fort in western Rajasthan had water harvesting arrangements to tap both rain water and groundwater. The Panhala Fort of Maharaj Shivaji built on a hillock near Kolhapur in Maharashtra had Baolis and wells to tap underground springs originating in nearby higher hill slopes. The fort at Chittor on top of a hill has a large reservoir formed from the harvested waters of springs.

At the Buddhist site of Sanchi (Madhya Pradesh) dating back to the 3rd Century B.C., there are three ancient tanks to store rain water from the hill slopes.

Most of the old temples in south India built centuries ago have large tanks in their premises. These tanks are either fed by harvested rain water or by tapping underground springs. In Tamil Nadu alone there are 39 temple tanks with areas varying from 0.25 to 3 hectares. These are all fed by rain water. Though these were used mainly for bathing and religious purposes, these also recharged the drinking water wells.



Spring Water Harvesting in Fort of Chittor



Baori Constructed in the Fort of Raisen

2.7 ROLE OF COMMUNITIES AND INDIVIDUALS

In those days, centuries ago, the state built only large storages essentially for irrigation and water supply for the capital cities and important towns. These were obviously not enough and therefore the village communities and individuals were encouraged to build their own water harvesting devices to meet their basic domestic requirement of water. The communities being closely knit had a strong culture of providing voluntary labour and material contributions for building these facilities for the common good. The social norms for civilized behaviour, interalia, enjoined on the community members to maintain these facilities, conserve and protect water from pollution and ensure its equitable and fair distribution.

Social scientists, historians and scholars have found that there was no problem of water scarcity where the community organizations were strong and the people relied upon their own efforts to build water harvesting structures. On the other hand, the situation was bad where the people depended entirely on the state for water.

2.8 LESSONS FROM HISTORY

This in short, is the history of our glorious tradition of water harvesting by the village communities and individuals with strong support and encouragement from the state. More importantly this history reflects the ingenuity and wisdom of our forefathers who made harvesting of water and its management an integral part of the native culture and community life. This meant that these practices were perceived by the common man as his sacred duty and by the communities as part of good local self-governance and social responsibility. This Water-Wisdom at all levels of society ensured adequate availability of water for all, which in turn, formed the basis for all round development and prosperity. Let us revive and expand this old wisdom for the benefit of all our people especially in the rural areas. We can do it.

CHAPTER - 3

Interaction of Ground Water and Surface Water

3.0 GENERAL

Hydrological processes involved in managing water resources needs to understand in detail for harvesting rain water through various techniques. The ground water and surface water interact throughout all types of landscapes from mountain to sea. The ground water moves along flow paths of varying lengths in transmitting water from area of recharge to discharge.

The small scale geologic features in the bed of surface water bodies & lakes affect recharge patterns. The size, shape and orientation of sediments & grain sizes in surface waterbeds affect seepage pattern. Often the surface waterbed consists of sand; the inflow seepage is greatest at the shoreline & decreases away from it. The geology of land units of varying permeabilities also affect water seepage in surface waterbeds.

The ground water seepage to surface water is greatest near shore. Infiltrating rain water passes rapidly through a thin unsaturated zone adjacent to the shoreline which produces a mound of water table adjacent to surface water body as "focussed recharge", which results in increased ground water inflow to surface water bodies.

The ground water recharge therefore is commonly focused initially where unsaturated zone is relatively thin at the edges of surface water bodies and beneath depressions in the land surface.

3.1 INTERACTION OF GROUND WATER AND STREAM

The streams interact with ground water in all types of landscapes. The streams lose water to ground water by outflow through the streambed. For surface water to seep into ground water, the altitude of water table in the vicinity of stream should be lower than the altitude of stream water surface. The interaction between ground water and stream takes place in nearly all streams. Depending upon the magnitude, intensity, and frequency of stream flow and increase in stream stage, some streams and adjacent aquifers are in continuous interaction. If level of water in stream is more than its bank, the flood water recharges ground water throughout the flooded area.

The reservoirs behind check dams are designed primarily to control flow & proper distribution of surface water. Like stream, such reservoir (lakes) also have fluctuating water levels & also loose water to water table to recharge ground water. The interaction of ground water and surface water is also shown diagrammatically in Figure 3.1.

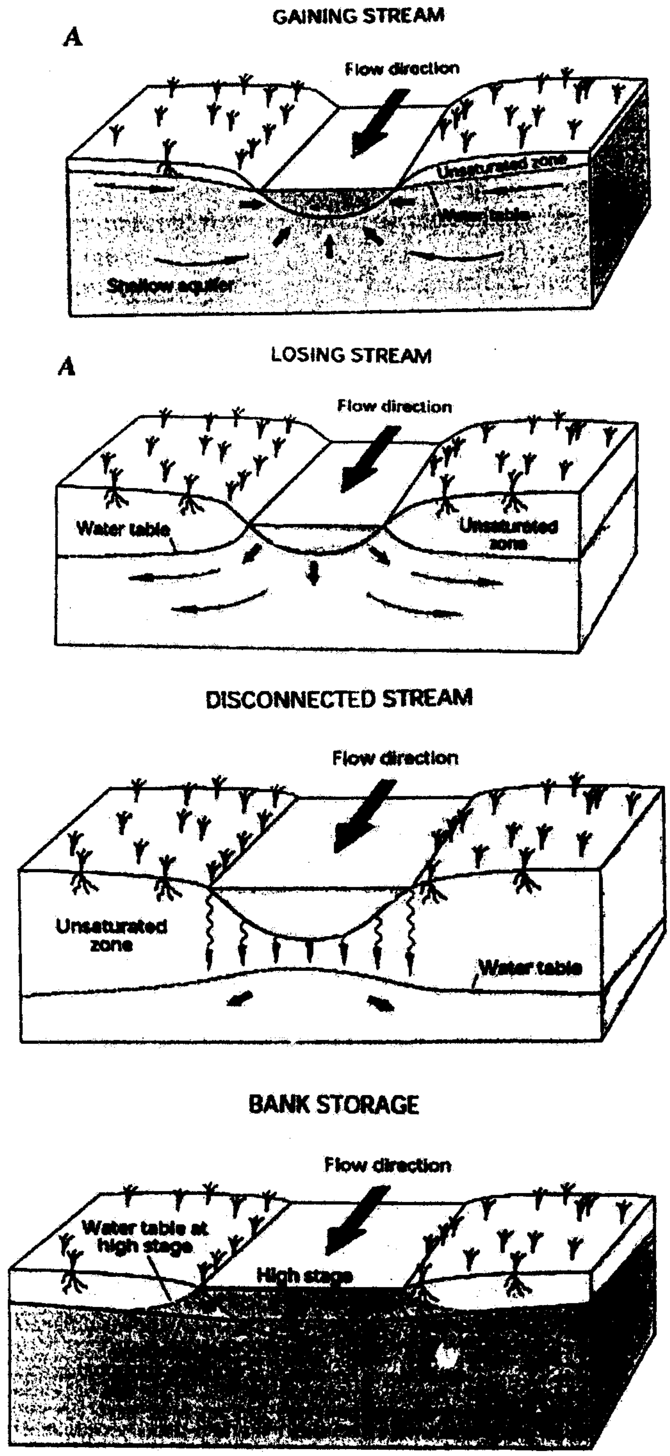


Figure 3.1 : Interaction of Ground Water and Surface Water.

CHAPTER - 4

Infiltration Recharge Systems

4.0 GENERAL

The study of geology, soils in the selection of sites for water spreading or infiltration recharging system are rather more important than for any well recharging systems.

The basic aspects, which are considered, are:

- Moving the water through the vadose zone
- Making the water move through aquifer away from infiltration recharge sites so as to raise water buildup of ground water mound or ridge

Therefore, for infiltration recharge systems the following area characteristics are desirable

- The soils on ground surface should be permeable to conduct infiltration
- The 'Vadose' or unsaturated zone must be permeable and free from clay layers
- The aquifer to be recharged must be unconfined and permeable and sufficiently thick to avoid rise of ground water mounds close to land surface
- Ground water table must be deep & may be beyond 8 to 10 meters below ground surface.

4.1 HYDROLOGIC CONSIDERATIONS

Infiltration rates of soil & hydraulic conductivities of water transmission are required to be considered in constructing infiltration recharge system.

Hydraulic Conductivities (K-values)

Normally, the values of 'K' are field measured or determined in laboratory. The values of K-for different types of soils which serve purposes for assessing the final infiltration rates of soils which are close to these values are given below. These can be used in the absence of measured values of soils under recharge. K-values, however, must be measured for a particular site for efficient results as far as possible. Hydraulic conductivities (K-values) of various soils in m/day are given in table below :

Table : Hydraulic Conductivities

Sl. No.	Soils	K-values (m/day)
1.	Clay surface	0.01-0.2
2.	Deep clay layer	10^{-8}-10^{-2}
3.	Loam	0.1-10
4.	Fine sand	1-5
5.	Medium sand	5-20
6.	Coarse sand	20-100
7.	Gravel	100-1000
8.	Sand and gravel	5-100
9.	Clay, sand & gravel	0.001-0.1

For infiltration systems, the 'K' must be measured in vertical direction. The infiltration rates for various types of surface soils which facilitate entry into vadose zone are given in table below:

Table: Infiltration rates of soils

Sl.No.	Sand types	Infiltration rates (m/hr)	High/low rate
1	Coarse sand, fine sand, Loamy sand, coarse sandy loam	2 in/hr.	High
2	Sandy loam fine sandy Loam, loam	0.6-2 in/hr.	Intermediate
3	Silt, Loam, sandy clay loam, clay loam, salty clay, sandy clay, clay	<0.6 in/hr.	Low

4.2 GEOLOGICAL CONSIDERATIONS

The suitable sites, on geological consideration, for recharging are to be found in flood plain of rivers, alluvial fans, bajadas & piedmont plains, sand dunes, weathered zones, permeable vadose zones & in outwash plains of glacial origin. Often the permeable soils are covered with a few meter thick clay layers, which should normally be removed and infiltration basins/pond may be excavated in underlying permeable deposits.

4.3 SOILS

While infiltration rates of soils of various types are important, must important is the hydraulic conductivity of such soils. Therefore estimates of initial infiltration rates are must for predicting hydraulic conductivities of infiltration system as basins

The Aquifer to be recharged using any water recharging device must have information about its depth to water table, thickness of saturated zone & its transmission value. These parameters are essential in determining the heights of a mound which should always be at 0.5 to 1 meters below the water spreading or recharge basins. Fig 4.1 shows the formation of a recharge mound below a recharging basin.

Fig 4.2 is a nomograph for use in determining the dimension of a spreading basin and settling basin.

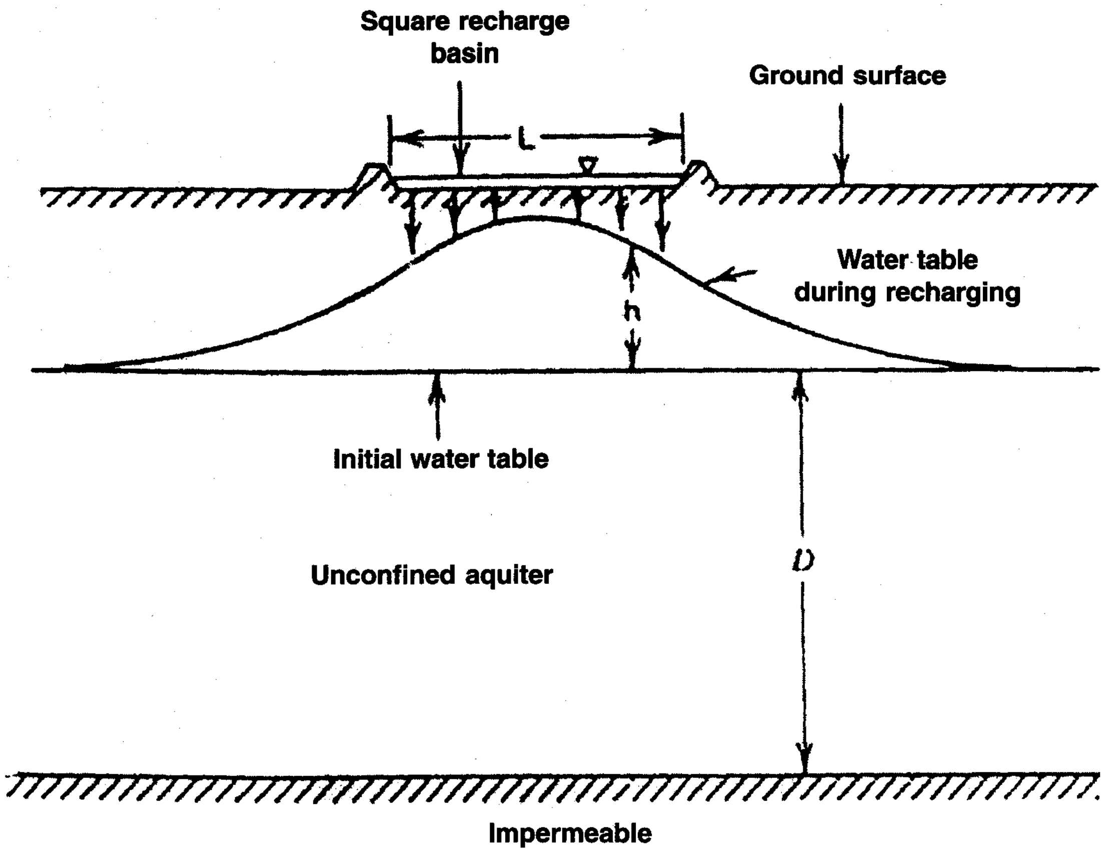


Figure 4.1 : Formation of a recharge mound below a recharging basin.

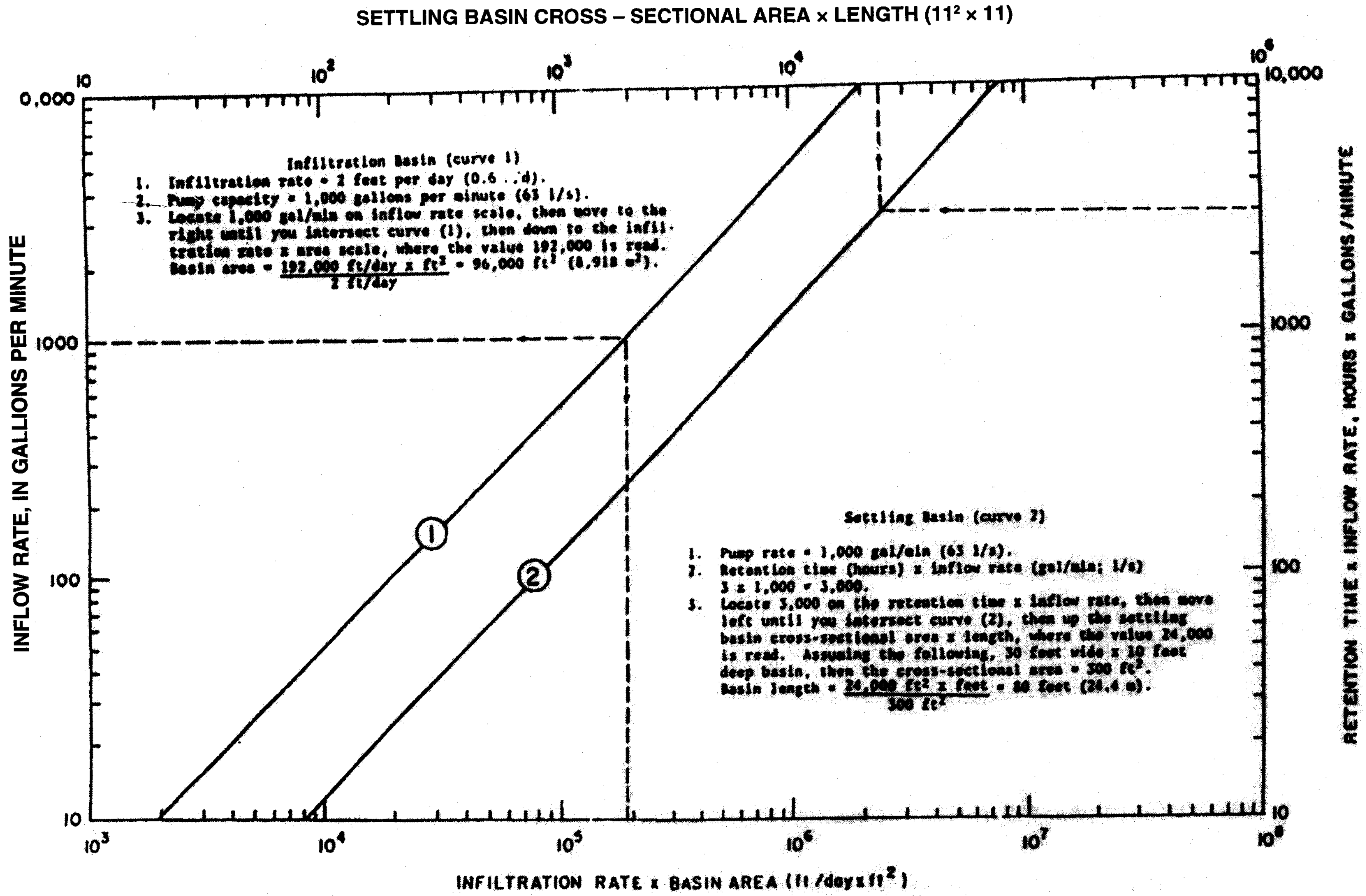


Figure 4.2 :Nomograph for use in determining the dimension of a spreading basin and settling basin.

CHAPTER - 5

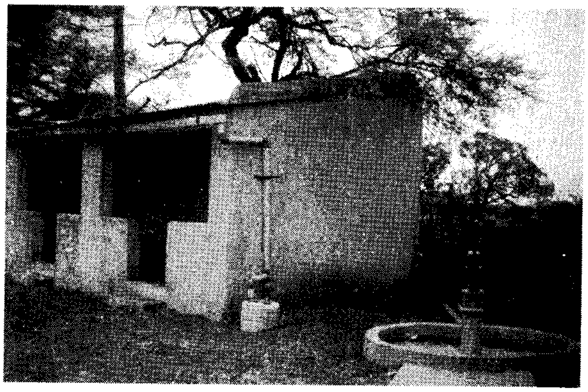
Water Harvesting – Present Practices

5.0 PRACTICES IN VOGUE

Inspite of large-scale development of surface and ground water through major, medium and minor projects by the government, the rural people in different parts of the country still have to depend on traditional water harvesting to meet their water requirements. The techniques and methods used vary from region to region depending upon their specific problems, nature of terrain, climate, hydrogeological conditions etc. Though the objective of water harvesting in most cases is to augment water availability for irrigation, these also afford indirect benefits for recharging drinking water wells and hand pumps. In many areas, where water harvesting has been practiced together with afforestation and other methods of watershed development and land improvement, dried up aquifers have been charged and water is available in abundance from ground water sources. In some arid and semi-arid regions rain water is harvested only for drinking purposes. Various methods of water harvesting presently in vogue in different parts of the country are discussed in the following paras.

5.1 ROOF TOP HARVESTING

This system is useful mainly for drinking water purposes. In this system, rain water falling on roofs of houses and other buildings is collected through a system of pipes and semi-circular channels of galvanized iron or



Roof Top Rain Water Harvesting in Villages of Madhya Pradesh

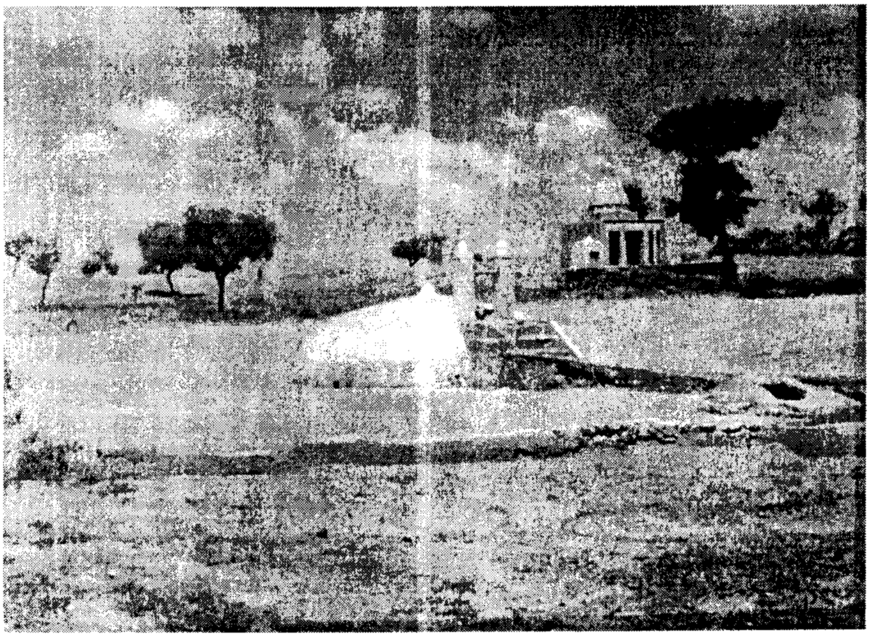
PVC and is stored in tanks suitably located on the ground or underground. The practice is in vogue at the individual household level in remote hilly areas with high rainfall and also in some semi-arid areas in the plains.

This system can be seen in the northeastern states of Arunachal Pradesh, Assam, Meghalaya, Manipur and Nagaland. This is also in use in Bikaner, Jaisalmer and Jodhpur districts of Rajasthan. In recent years, at the initiative of the Central and State Governments, the practice has been increasingly adopted in many cities and towns in different parts of the country.

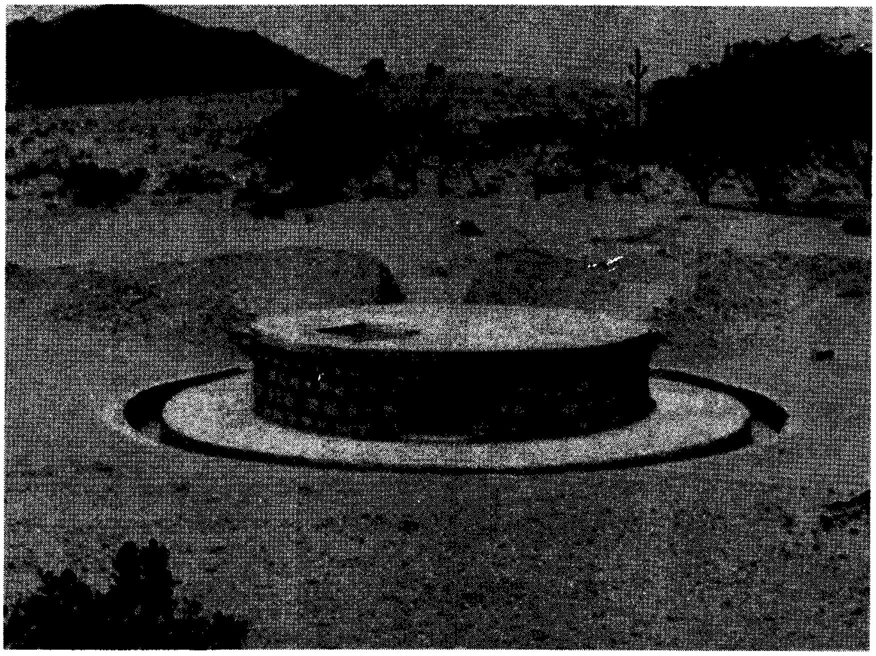
5.2 TANKA/ KUND/ KUNDI

In the desert and arid areas of Rajasthan people build unique underground structures of various shapes and sizes to collect rain water for drinking purposes. These structures called Tankas, Kunds or Kundis are constructed in a variety of places like court yards, in front of houses and temples, in open agricultural fields, barren lands etc. These are built both for individual households as well as for village communities using locally available materials. While some structures are built in stone masonry with stone slab coverings, others are built with only rudimentary plastering of bare soil surfaces of the tank with cement or lime and covering with Zizyphus Numularia thorns. Some Kuccha structures have a convex covering of local wood with mud plaster. Inlet holes are provided in the convex covering at the ground level to facilitate entry of rain water into the tank. In case of Pacca structures (called Tanka) the wall of the tank is kept projecting above the ground to provide inlet holes.

Though this rain water harvesting method is said to be in vogue since time immemorial, the first known construction of a Kund in western Rajasthan was in 1607 by Raja Sur Singh in village Vadi-ka-Melan. In the Mehrangarh Fort in Jodhpur, a Kund was constructed in 1759 by Maharaja Udai Singh. Subsequently, during the famine of 1895-96 construction of Kunds was taken up on a large scale. Today these are the primary sources of drinking water in the water scarce areas of Churu, Bikaner, Jodhpur, Jaisalmer and Barmer districts.



Traditional Tanka with Treated Catchment in Churu District



An Improved Tanka Designed and Constructed by CAZRI

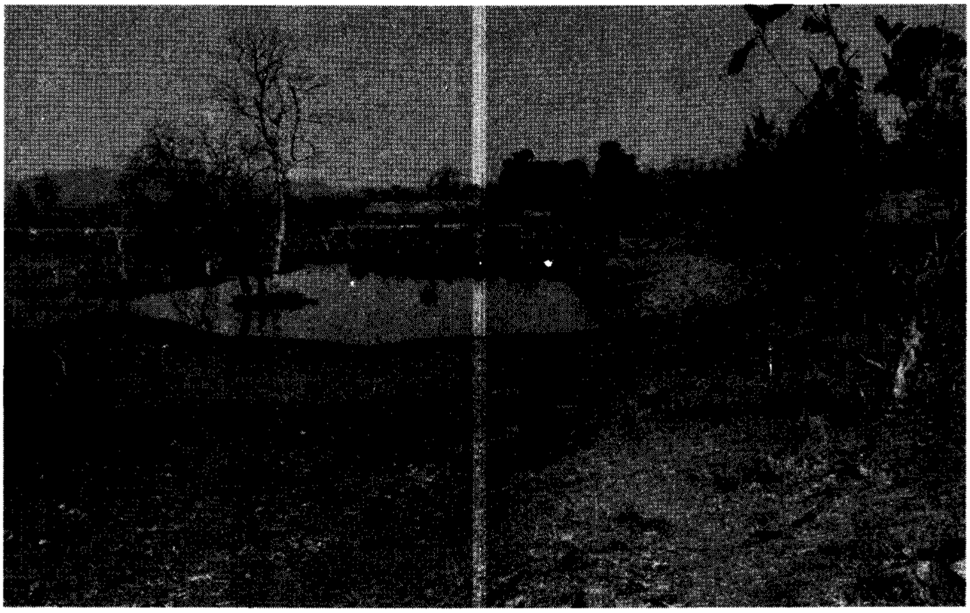
Since Tankas are the main source of drinking water in these areas, people zealously protect and maintain them. Just before the on-set of the monsoon, the catchment area of the Tanka is cleaned up to remove all possible pollutants, and human activity and grazing of cattle in the area is prohibited. Even though the average annual rainfall in these areas varies from 200 mm to 300 mm with minimum of as low as 120 mm, these structures provide enough drinking water to tide over the water scarcity during the summer months. In many cases the stored water lasts for the whole year. These simple traditional water harvesting structures are useful even during years of below-normal rainfall.

5.3 PONDS/ TANKS

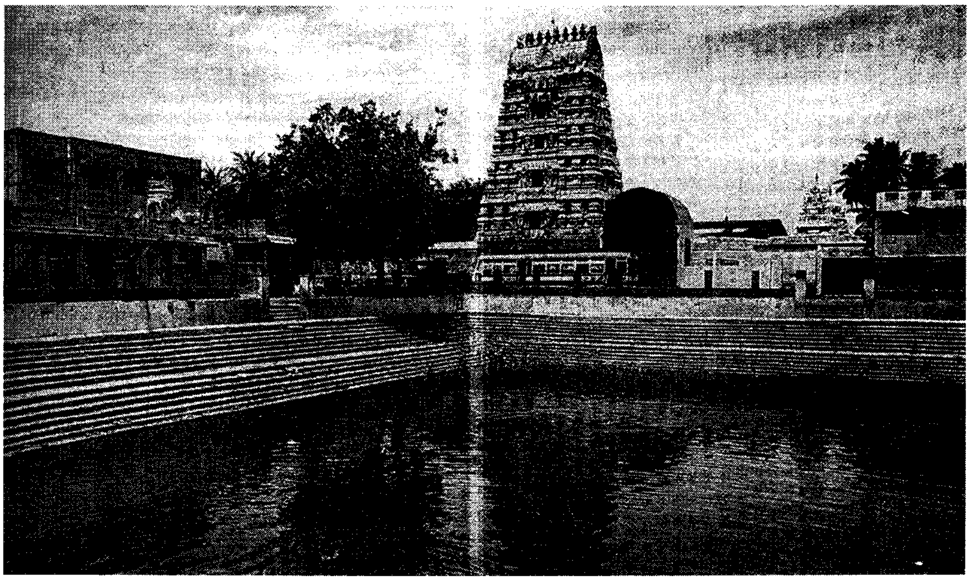
This is by far the most commonly used method to collect and store rain water in dug ponds or tanks. Most ponds have their own catchments, which provide the requisite amount of water during the rainy season. Where the catchments are too small to provide enough water, water from nearby streams is diverted through open channels to fill the ponds. In some places water from irrigation canals is also used to fill ponds.

Ponds are excavated in different shapes and sizes depending upon the nature of the terrain, availability of land, water requirements of the village community etc. These are known by different names in different regions viz. Dong in Bodo area of Assam, Talab, Johad or Pokhar in Uttar Pradesh. In Rajasthan these are called Johad or Nadi. Talab is a popular word for a pond in a valley or natural depression. Other variants are called Dhab, Toba or Talai. Small tanks in Ladakh are called Zing. In Jammu region, these are called Chhapris. The people of Sikkim call them Khup. In Bihar rectangular catchment basins called Ahars are built by building earthen embankments to impound rain water. Some times these are built at the lower end of a small seasonal rivulet. The channels for drawing water from the Ahars are called Pynes. Large storages across streams are called Katas, Mundas and Bandhas. In other areas, the ponds are called by names as follows :

Nagaland	–	Zabo
Gujarat	–	Kunda (Sacred Ponds)
	–	Jheel
Orissa	–	Katas, Mundas (As in Bihar)
Maharashtra	–	Bandharas (Bunds across small streams)
Karnataka	–	Volakere (Small pond fed by shallow channel)
	–	Katte or Kunte (Pond with bund mainly for bathing)
	–	Kola or Kunda (Natural Pond) Kalyani (Temple Pond)
Andhra Pradesh	–	Tank (Mainly for irrigation)
Kerela	–	Tank (Mainly for irrigation)



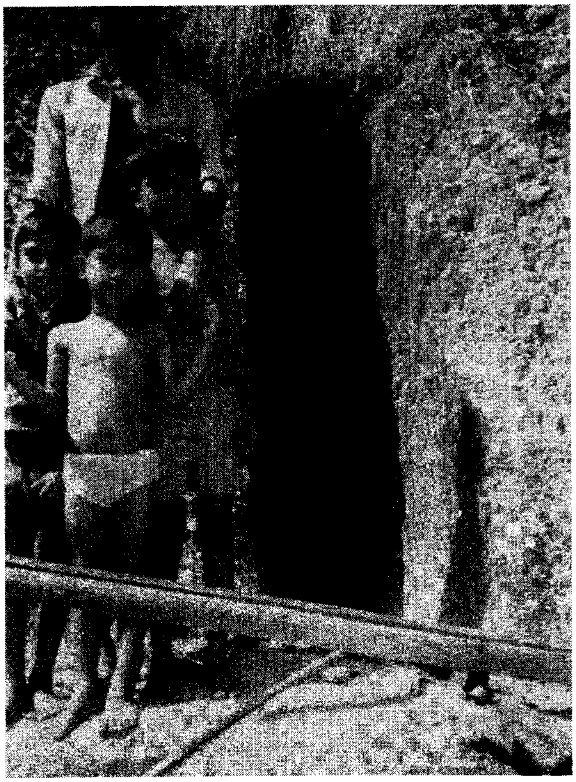
Pond/Tank



Temple Tank

5.4 GROUND WATER HARVESTING

In hilly areas of Uttaranchal, the people harvest ground water by making stonewall across ground water streams. These are called Naula or Hauzi. For various reasons, there has been a steady decline in the construction of these structures, the main reason being drying up of underground streams due to large-scale deforestation and increased human activity in the hills. Similar practice is in vogue in parts of Kerela where the ground water is collected by excavating long deep trenches across a gentle slope. These are called Surangam. In Punjab shallow wells called Jhalars are dug near streambeds to trap seepage water. In Rajasthan these are called Beris. In earlier times, Baolis were built by kings but now these are not in vogue. In Gujarat shallow wells dug in depressions to tap ground water are called Virdas. In Tamil Nadu Ooranis were built earlier but are not built any more.



Surangam in Kasaragod Taluka in Kerala

5.5 KHADIN

Khadin is a system basically innovated for runoff farming by the Paliwal Brahmin Community in Jaisalmer area in the 15th Century. In Jaisalmer the ruler used to encourage people to develop this system at suitable sites for agriculture and share the part of crop with ruler, who would remain the owner of those structures. There are as many as 500 big and small Khadins in Jaisalmer district, which are productive, even with 40 mm rainfall.

Rocky-hill-terrain around a valley including the valley slopes, constitute the catchment area of a Khadin. Stony gravels, wasteland with gentle slope in the form of valley can also form the catchment area of such structures.

At the lower point of the valley, earthen bund is constructed to arrest the runoff. The stored water helps the crops as well as recharging of ground aquifer. Spillway of stone masonry is provided in the bund to let out the excess runoff. A sluice is provided at bed level to drain out standing water, if any at the time of bed cultivation.

Khadin is a system of storing rain water in an agricultural field by building a "U" shaped earthen bund at the lower end of the field. A drainage pipe is provided in the embankment to evacuate surplus water. The practice is very common in the arid and semi-arid areas of Jaisalmer and Barmer districts of Rajasthan. A dug well is often provided immediately downstream of the earthen bund to take advantage of the water seepaging into the ground. Some people dig the well within the Khadin. The parapet wall around the well is kept sufficiently high to prevent entry of muddy water into the well.

A similar system called Haveli is used in some parts of Madhya Pradesh. In this system, the field is enclosed on all four sides by earthen bunds called Bandhan to retain rain water. This practice is also in vogue in the drought prone districts of Orissa especially Kalahandi, Bolangir and Koraput.

5.6 HILL SLOPE COLLECTION

In this system, which is in vogue in many hilly areas with good rainfall, lined channels are built across the hill slopes to intercept rain water. These channels convey water for irrigating terraced agricultural fields. The water is also used to fill small ponds for domestic use and the cattle. These practices can be seen in Uttaranchal, Himachal Pradesh, Meghalaya, Arunachal Pradesh etc.

5.7 SPRING WATER HARVESTING

In the Lahaul and Spiti areas of Himachal Pradesh, water from hill streams are diverted through small excavated channels, called Kuls, for domestic use and irrigation. In Jammu region they pronounce it as Kuhals. This practice can also be seen in Arunachal Pradesh, Meghalaya, Nagaland, Manipur, Sikkim and Darjeeling area of West Bengal. Where the springs are merely in the form of water trickling through layers and joints in rocks, split bamboo channels are used to trap and convey water upto the village/ hamlet for drinking purposes.

Spring water is a highly desirable source of community water supply. Since the water emerges at the ground surface through cracks and loose joints in rocks under internal pressure of the ground water system, no pumping is required. More over the water is fresh and free from pollution obviating the need for artificial purification. However, such sources are available mostly in hilly terrain, foothill areas or intermontane valleys.

A typical spring water harvesting system is shown in Figure 5.1.

One relatively easy means of storing and distributing spring water is through a device known as a spring box. Built usually into a hillside and deep enough to access the spring-water source, this device allows water to enter from the bottom (as depicted in Figure 5.1) and fill upto a level established by an overflow or vent pipe. Hydraulic pressure then maintains the level in the spring box. The outflow pipe near the base of the device may be connected via pipe to a larger storage system (such as a tank) closer to the point of use or tapped directly at the location of the box. This device can be constructed using local materials, and if built carefully and protected can provide many years of reliable operation. Depending on local water requirements and conditions, a number of these spring boxes may be constructed to provide year-round supply or used to recharge other community water storage systems.

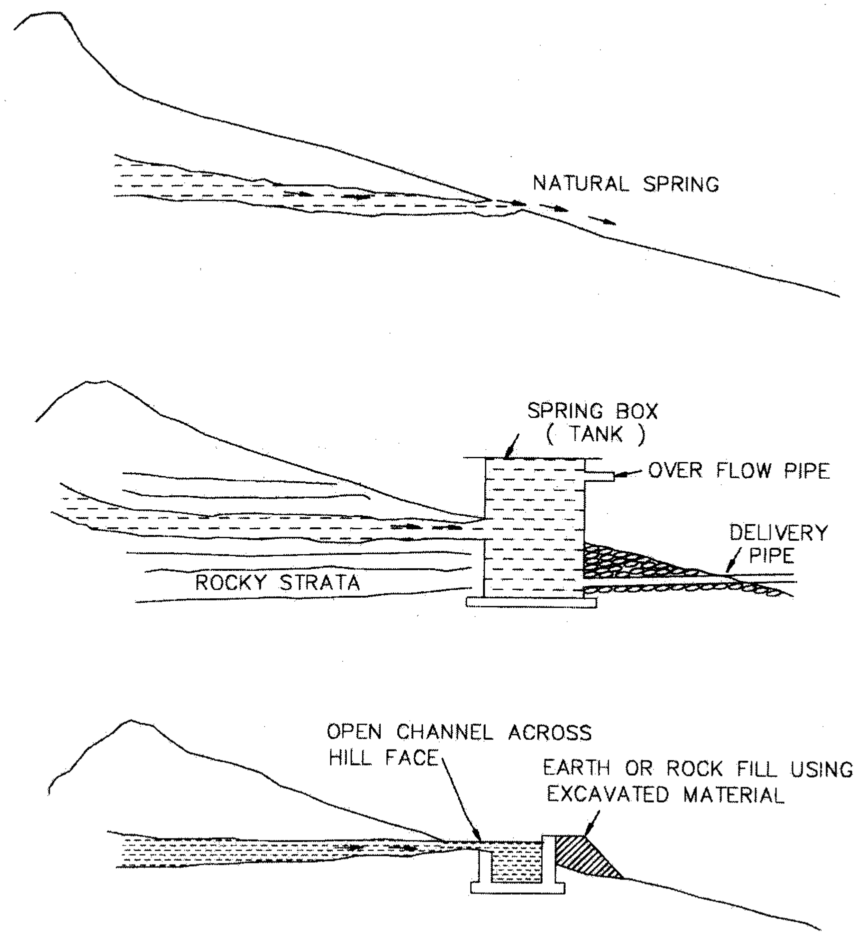


Figure 5.1 : A Typical Spring Water Harvesting System

Alternatively, a variation on the spring box concept may also be employed known generally as an infiltration gallery. A long perforated pipe or box (3 to 6 inches or more in diameter) may be placed across the water-bearing layer of the hillside to gather spring water. Back-filled with gravel or another sufficiently porous medium, the pipe or box is connected to an outflow pipe(s).

5.8 MODERN STRUCTURES

During the last 100 years there has been considerable technological development, interalia, in the design and construction of water harvesting structures for various purposes. The structures, which are commonly built for surface storage and/ or ground water recharge are :

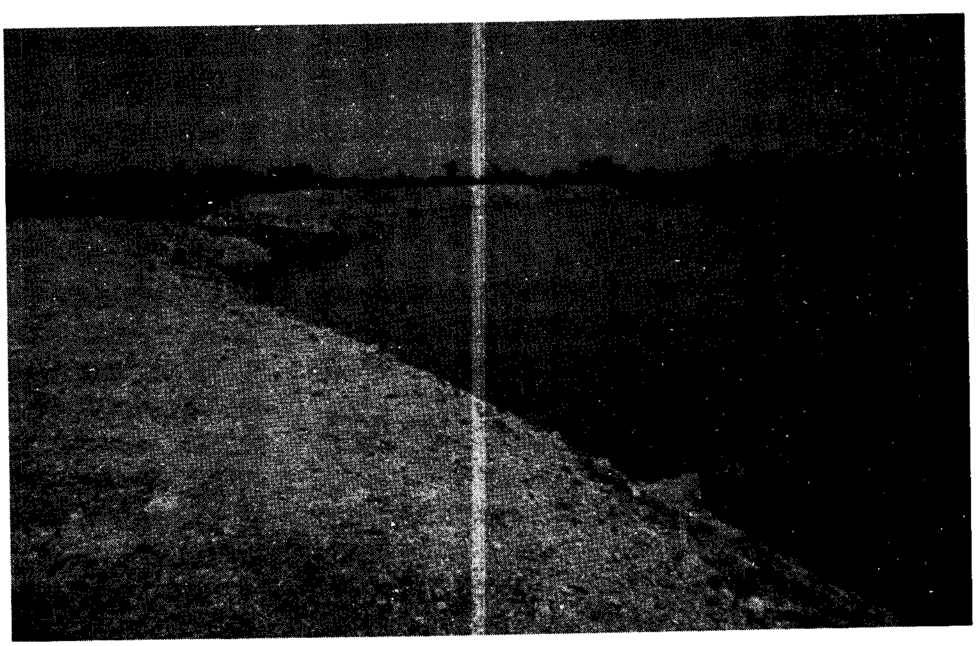
(i) *Check Dams* : These are concrete or masonry structures built across small streams for surface storage and incidental benefit of ground water recharge. The design of these structures are done taking into consideration the volume of water that can be stored in the stream channel upstream, the surplus flood discharge that must be evacuated safely, stability of the structure against various forces and the likely ground water recharge.

These are usually built by the State Government agencies like the departments of Irrigation/ Water Resources, Agriculture and Forests. These are the modified and improved versions of the traditional

Check Dam

temporary or semi-permanent structures that people in the villages usually build across natural streams or drainage channels.

(ii) *Percolation Tanks* : These are built mainly to impound monsoon runoff over a large area to augment ground water recharge. Moderate to high porosity of soil and/ or underlying rocky strata is the main criteria for the choice of percolation tanks. Ponding is achieved in much the same way as is done in case of check dams except that the height of the bund is low but the length is large.



Percolation Tank

The design aims at filling the pond as many times as possible during the rainy season in such a way that most of the water impounded during one spell of rain percolates into the ground before the next spell starts. In actual field conditions, however, this ideal operation is rarely achieved. These are also built by the government agencies since these require special skills in hydrogeology.

(iii) *Sub-Surface Dykes* : These are impermeable walls or barriers in masonry, concrete and/ or clay built below the bed level across natural streams to arrest sub-surface flow of water to improve the yield of existing wells and hand pumps in the upstream.

Besides these direct methods of water harvesting some indirect methods have also been developed. These aim at augmenting soil moisture retention and preventing soil erosion and land degradation. These are :

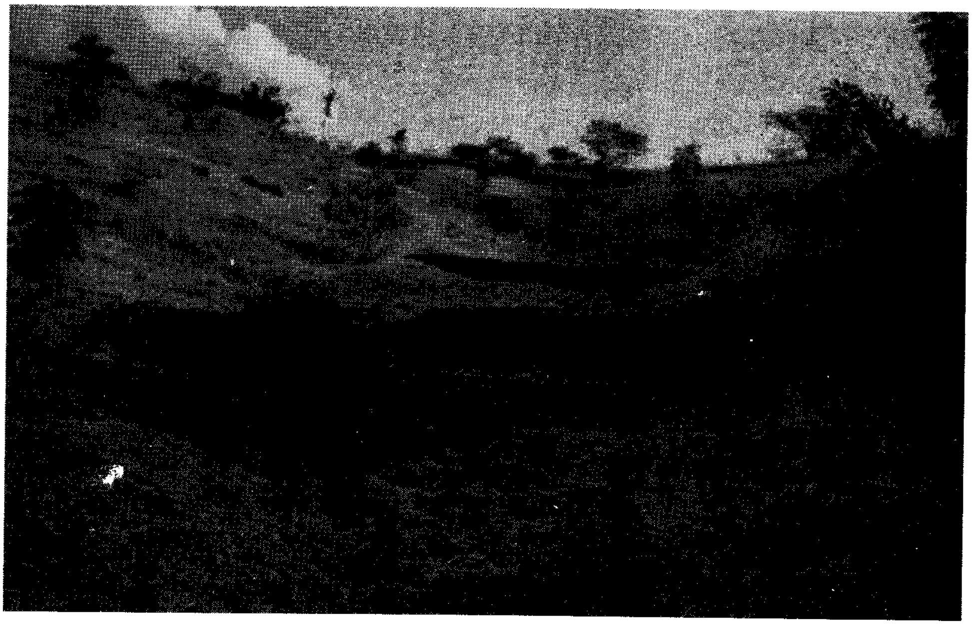
(i) *Contour Bunding* : These are small earthen bunds built horizontally in parallel rows across the hill slope. These help in augmenting soil moisture and prevent erosion of topsoil.

(ii) *Gully Plugging* : These are soil and water retaining structures built across gullies in hilly areas. These are built with locally available materials like stone boulders, earth, brushwood etc.

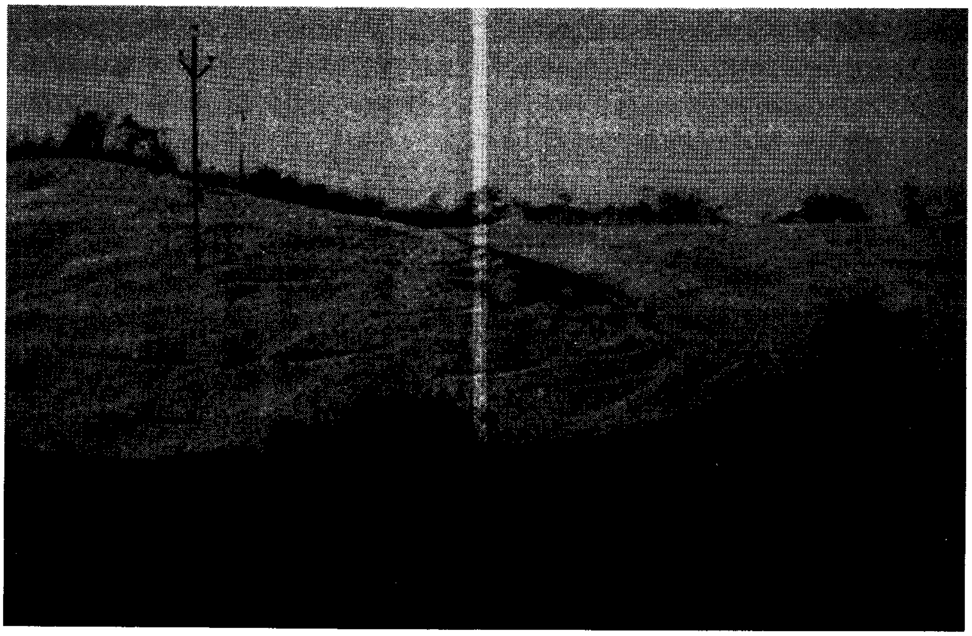
Both contour bunding and gully plugging are part of watershed improvement works. The other works in this category are :

- Bench Terracing
- Contour Cropping
- Contour Trenching

Various water harvesting and watershed improvement measures mentioned above are discussed in greater detail in Chapter 4 and 5.



Gully Plugging using Boulders



Contour Trenching

5.9 SOME CASE STUDIES OF RAIN WATER HARVESTING

Though there are many sporadic studies, but some studies that need special mention are given below for purpose of reference and information:

5.9.1 General Studies by State Govt. Organisation/NGOs

- Watershed management programme launched by the Govt. of Madhya Pradesh in 1995 has led to rising water levels in many areas. More than 1000 check dams, 1050 tanks and 1100 community lift irrigation schemes have been implemented in Jhabua district. Food production in the district has gone up by 38% in the past five years.
- A micro-watershed project implemented in Ghelhar Choti village in Jhabua district Madhya Pradesh has led to recharging of ground water. Because of this, the cultivate area has increased and the yield per ha has doubled. This has only been possible due to people's participation.
- District Rural Development Administration in Rajkot implemented 50 micro-watershed projects under the watershed management project launched by the Govt. of Gujarat in 1995-96. Rise in ground water levels has been reported from wells in areas, where these projects have been implemented.
- A number of percolation tanks and check dams have been constructed in Andhra Pradesh. About 80 percent of these structures were constructed in four chronincally drought affected districts of Rayelseema region.
- An experiment on low cost small farm reservoirs along with improved crop and soil management systems was conducted in Chhattisgarh region, Madhya Pradesh. The rain water thus collected helped in saving paddy from water stress during extended dry spells in 1990-91 and 1991-92. Crops in the micro-catchment of the reservoir did not face drought due to their ability to exploit subsoil moisture reserves. The reservoir water also contributed to ground water storage.

- More than 70,000 percolation tanks have been built in Maharashtra after the severe drought of 1971-72. All such small catchments of percolation tanks have been converted into green patches. A study conducted by Central Ground Water Board on the effectiveness of 12 percolation tanks is lost as evaporation, 40% as seepage and 50% recharges ground water. The study indicated that the recharge to ground water can go upto 70% by selecting the site and designing the tank properly.
- Underground bandharas have been constructed in various parts of Maharashtra, viz. 87 tehsils of DPAP areas with 400-700 mm annual rainfall located in parts of Sangli, Satara, Pune, Sholapur, Ahmednagar, Nashik, Aurangabad, Usmanabad, Beed and Buldana districts; Vidarbha and Amravati divisions where there are no surface sources and parts of Konkan area with high well density. Assessment of benefits from recharged ground water indicates that cost benefit ratio would not be less than 1:1.5.
- Sadguru Water & Development Foundation who is functioning in Dahod district of Gujarat has constructed a number of concrete check dams with the help of local residents to impound rain water for irrigation in Thunthi Kankasiya village. The Foundation has also implemented watershed management measures such as trenching, bunding, terracing and planting trees. With the result, water is available to the villagers round the year and ground water levels have risen considerably. The average household income has been raised from Rs. 8,000 per year to Rs. 35,000 per year. Entire population of the village is above poverty line now.
- In Dhoraji village of Rajkot district, Gujarat, the farmers have started recharging their wells. They are able to cultivate crops even during drought and the crop production has also increased several time.
- Saurashtra Jaldhara Trust is working in about 100 villages in Amravati, Bhavnager, Jamnagar, Junagarh and Rajkot districts. The trust has motivated the villagers to build rain water harvesting structure, In Khopala village of Bhavnagar district, the villagers have built 210 low cost check dams on streams in and around the village. Despite less than average monsoon in 1999, the streams were seen overflowing.
- In parts of Dhar district, Madhya Pradesh, where watershed management measures have been implemented, crops and ground water table have not been much affected by the drought.
- Micro-watershed projects implemented by Development Support Centre in Gujarat have helped in solving the problem of drinking water to a great extent.
- Raj-Samadhiyala village in Rajkot district, which was once declared a desert area is not a water scarce village now. This has been possible due to watershed management projects taken up by the villagers under the leadership of their Sarpanch. The villagers built 12 check dams between 1986 and 1988. This has brought prosperity and social well being to the village.
- Residents of Gandhigram village in Mandvi taluk of Kutch district, Gujarat have been facing drinking water crisis for the past 10 years. The over-exploration of ground water has led to sea water ingress making the ground water aquifers saline. The villagers have constructed a dam on Khari river and have undertaken a micro-watershed project. With the help of rain water harvesting, the district Administration in Dewas, Madhya Pradesh has banned tubewell drilling and made roof top rain water harvesting mandatory for all houses having tubewells. The water thus harvested is recharged into the aquifers. The dugwells were recharged, existing tanks were repaired and deepened and fresh ponds were constructed to maintain water level during summers. This has helped in improving the moisture content in soil and recharging shallow aquifer. Roof top rain water harvesting, nallah bunding and percolation pits have proved to be effective measures.
- In Chennai, Chennai Metro Water Board has made it mandatory under the city's building regulations for all new buildings to have water harvesting mechanisms primarily to recharge ground water aquifers.

Implementation of rain water harvesting measures have resulted in rising trends of ground water levels.

- The town of Avadi in Tamil Nadu is using rain water harvesting to augment its source ground water resources. This is being practiced not only where ground water levels are declining but also where ground water quality has deteriorated. The total cost for a small system is Rs. 5,000/- which includes a cost of Rs. 3000/- towards sinking percolation pit. The houses have started employing rainwater harvesting.
- The Delhi Administration has also made Roof top rainwater harvesting mandatory in Delhi for atleast in new buildings measuring 500 sq.ft. or more.

5.9.2 Results of Water Harvesting & Recharging Experiments by CGWB

Results obtained by water harvesting & recharging structures through joint efforts of CGWB and state Govt. agencies are given below. Only some case example-results are quoted.

Name of the scheme	Structures constructed	Cost on lakhs	Additional recharge	Rise in water level	Area benefited
Watershed TE-17, Yaval Taluka, Jalgaon, Maharashtra	Percolation tanks-6Subsurface shaft-2Injection well-1Dug-cum-recharge well-1	23.55 1.38 4.50 0.10	681.38 CTM 12.00 TCM 3.77 TCM 6.58 TCM	1-5 meters	545 ha 4.70 ha 0.75 ha 1.30 ha
Watershed WR-2 Warud Taluka, Amravati district, Maharashtra	Percolation tank-3 Cement Plug-10	76.98 9.32	298.32 TCM 46.743 TCM	4-10 m 0.5 to 4 meters	280 ha 86-105 ha
JNU, IIT and Sanjay Van Area of NCT Delhi	Check dam-4Rooftop rain water harvesting-1	43.58 2.47	75.72 TCM 830 cum	0.33-13.7m 2.29-2.87	75 ha 1 ha
Roof top rain water harvesting at CSIO complex, Chandigarh	Rooftop rain water harvesting		3794 cum	2 m	
Artificial recharge studies in Karnataka	Percolation tank-1 Watershed treatment Gravity recharge well-2 Point recharge structure-4 Roof top rain water harvesting at Gauribindinaur Percolation tank Watershed treatment	10.35 8.45 4.05 0.80 17.50 1.94 1.03	These structures provided additional ground water recharge and sustainability of ground water extraction structures 2 to	1-3.5 meters	Crop intensity increased to 2 to 3 crops annually and cash crops are now being grown in the area

Name of the scheme	Structures constructed	Cost on lakhs	Additional recharge	Rise in water level	Area benefited
	Point recharge structure at Mulbagal		3 times. Crop intensity increased to 2 to 3 crops annually		
Artificial recharge in TE-11, Watershed Jalgaon, Maharashtra	Wadri Percolation tank Sanghavi percolation tank	9.02 17.58	14000 cum 24000 cum	0 to less than 1 m 0 to less than 1 m	0.5 sqkm 1.0 sqkm
Artificial Recharge to ground water from Dhuri link drain, Dhuri Block, district Sangrur, Punjab	Lateral shaft 250 meter length with three injection wells & 28 vertical shafts	34.20	Yet to be assessed	0.22-1.38 meters	Average rate of recharge through the Dhuri link drain is 16.51 lps
Artificial recharge to ground water from Dhuri drain II, Dhuri block, Sangrur, Punjab	10 lateral shaft, 20 shafts & 30 injection wells in 295 meters lateral shaft	39.10	To be assessed	0.15 to 0.33 meters	Average rate of recharge through the Dhuri link drain is 94 lps
Artificial recharge studies on the impact of different recharge structures constructed in Purulia I,II, Mainbazar and Jhala blocks, Purulia district, West Bengal	10 farm ponds, 8 nala bunds and 2 subsurface dykes	50.54	Net volume of water available is 65 TCM	0.15 meters average	Direct benefit for agriculture purpose is 28.44 ha of land during Kharif and Rabi over and above sustainable greenery in an area of 110 ha due to increase in ground water level by constructing 10 farm ponds and 8 nala bunds

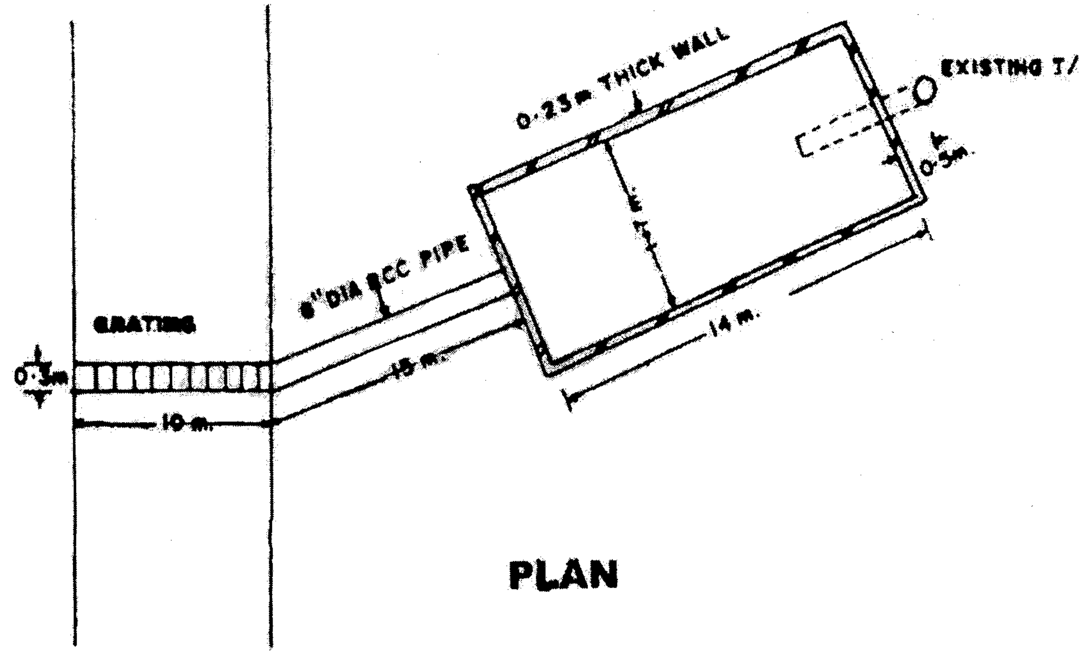
Name of the scheme	Structures constructed	Cost on lakhs	Additional recharge	Rise in water level	Area benefited
Recharge of ground water by constructing sub surface dykes in Tulin, Jhalada-I block, Purulia	5 sub surface dykes	0.38	0.82 MCM	0.15 meters	Area benefited 0.21 ha
Artificial recharge studies on the impact of subsurface dykes constructed for improvement of watershed in part of Saltora block, Bankura district, West Bengal	Subsurface dyke Gully plug Nala bund Farm pond	0.992	2.6 MCM	0.45 meter	Area benefited 195 ha
Roof top rain water harvesting in Dewas city, Madhya Pradesh	At roof of 1000 buildings	6.00	Due to deficit rainfall in Dewas district, full impact could not be assessed		There is marked increase in discharge of tubewells and improvement in quality of water obtained from tubewells utilising roof top rain water harvesting

Typical Case Studies of Water Harvesting & Recharging in NCT Delhi

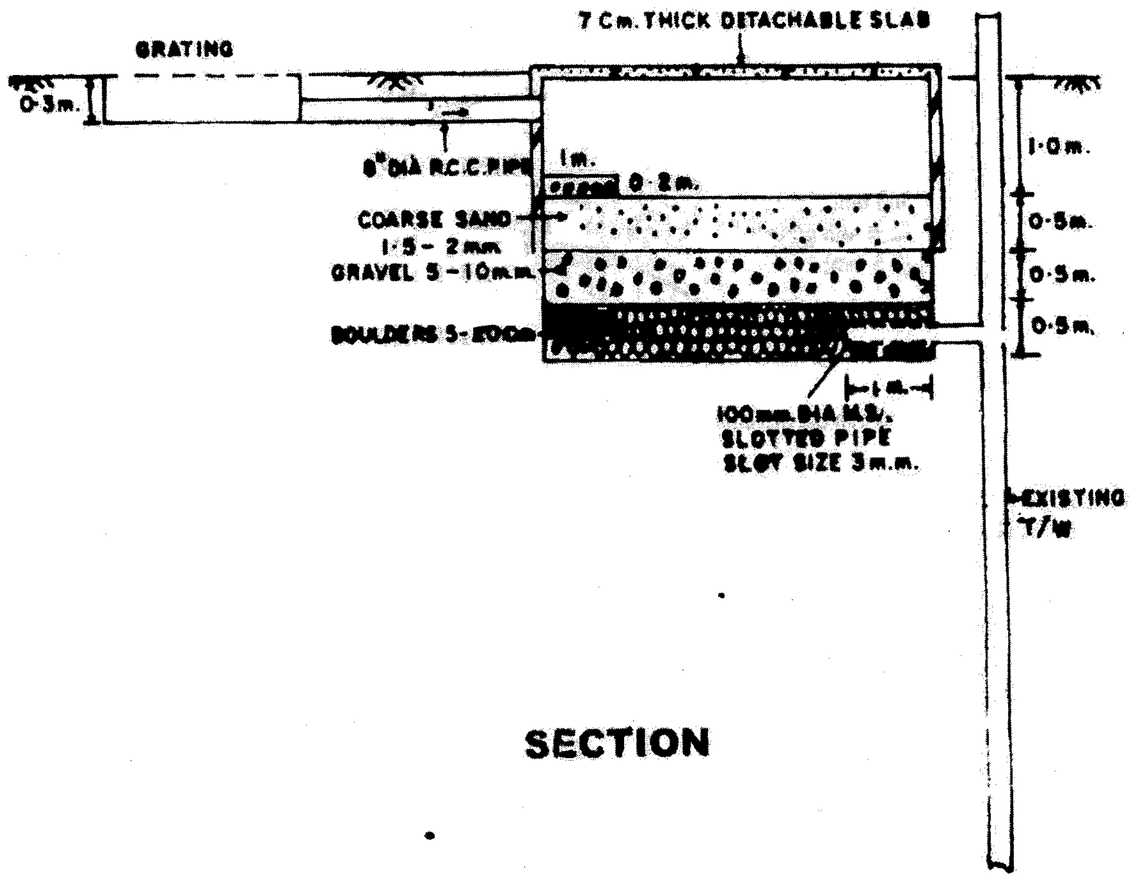
1) Central Park, D-Block, Vasant Vihar, Southwest district

Vasant Vihar is a residential colony consisting of six blocks with utility services including shopping complex, parks etc. Water supply in this colony is mainly based on ground water resulting into alarming rate of decline in ground water levels. To arrest the decline ground water levels, CGWB has taken up Artificial recharge to Ground water in D-block. Rainfall Runoff generated i.e. 9400 cum. from the catchment area of 36375 sq.m. comprising of houses and roads in the vicinity of central park is utilised to recharge the ground water by constructing two trenches with recharge wells and one trench with abandoned tubewell. This scheme is implemented by CGWB and system has been tested and found to be working very effectively.

RECHARGE THROUGH EXISTING TUBE WELL



PLAN

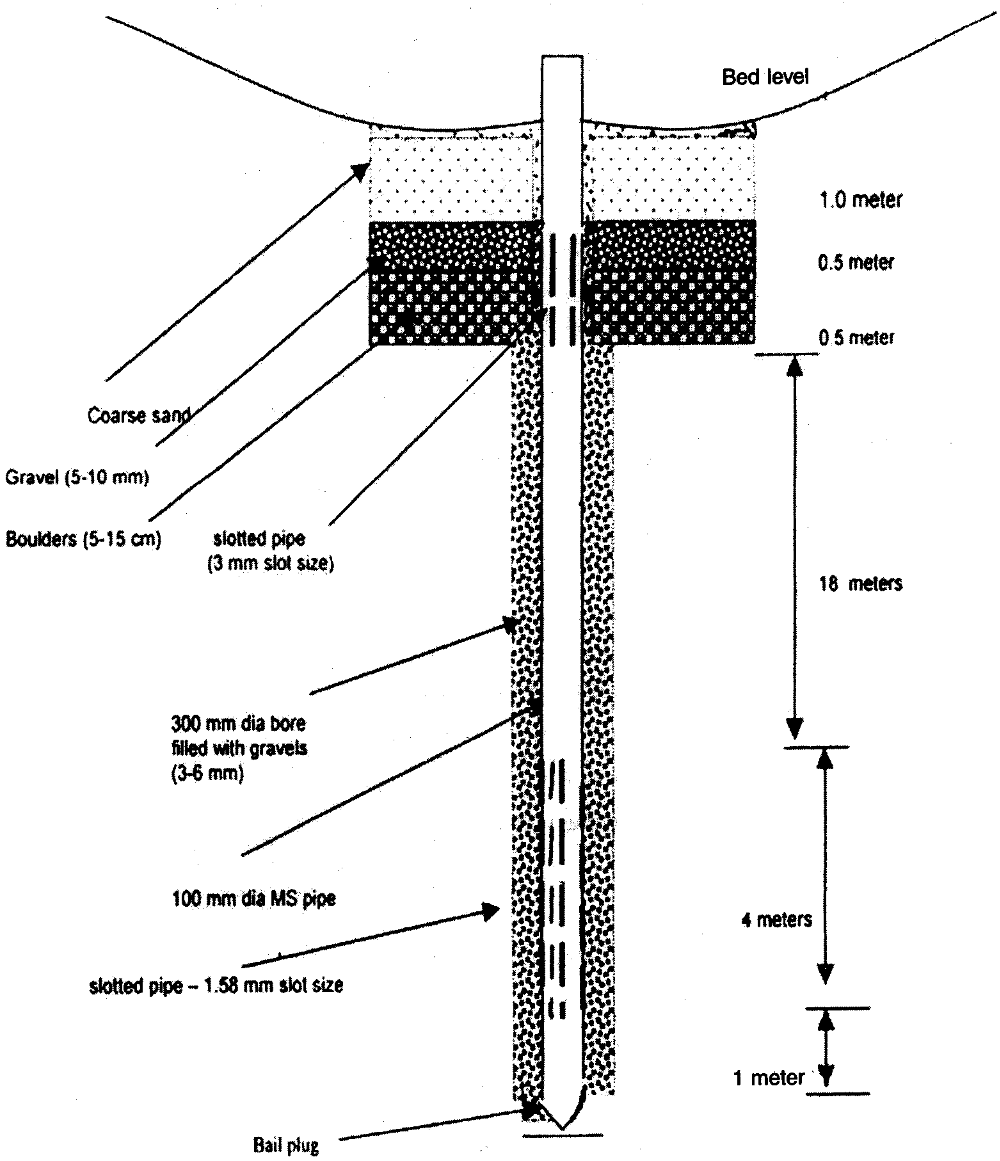


SECTION

2) Sultan Garhi Tomb, South of Vasant Kunj

Sultan Garhi Tomb, a monument is located near Rangpuri, South of Vasantkunj area having rugged topography and is underlain by hard rock. Depth to water level is ranging between 20-40 meter below ground level. Whole area is considered as a watershed having catchment area of 0.99 sq.km. which generates 64925 cum. runoff in a normal rainfall year. The runoff generated is diverted to the ground water system through three existing quarries with two recharge pits with tubewell/borewell. This scheme is jointly implemented by CGWB and DDA. This type of projects are also implemented in other colonies like Jorbagh colony and Pushp Vihar colony.

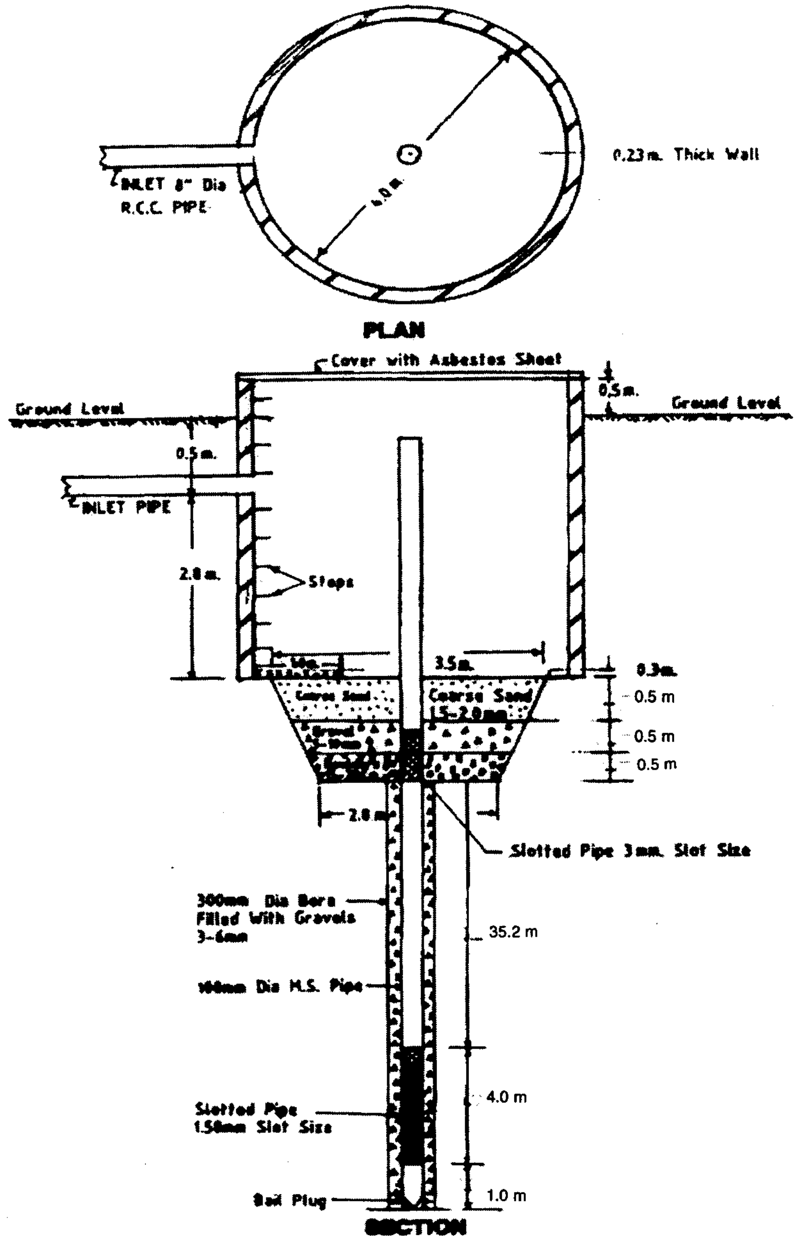
RECHARGE PIT WITH TUBE WELL



3) DTC Central Workshop-II, Okhla

CGWB has prepared a proposal for rain water harvesting and artificial recharge to ground water for Central Workshop-II, Okhla of Delhi Transport Corporation. DTC workshop having catchment area of 6.18 hectares is underlain by weathered and fractured quartzites and generates about 10355 cum runoff annually. Depth to water level in the area varies from 35-40 meters below ground water level. The proposed recharge structures are one trench and four shafts with recharge well. This pilot scheme is funded by CGWB and to be implemented by DTC. Other industrial establishments like Nirula's production centre in Okhla, Q-H Talbros, Gurgaon are also implementing this type of rain water harvesting schemes with their own funds.

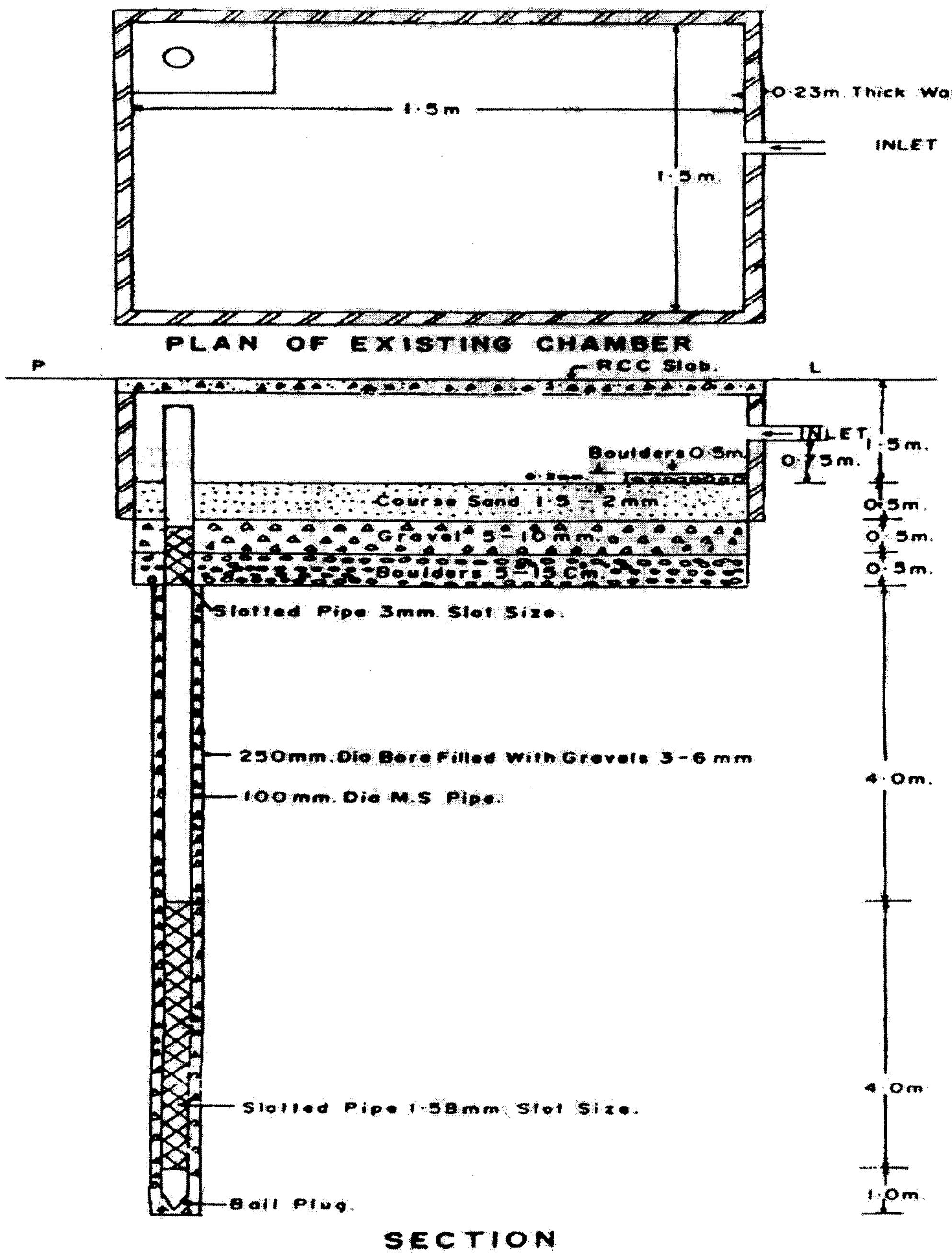
RECHARGE SHAFT WITH TUBE WELL



4) Abhiyan apartments, Plot no. 15, Sector-12, Dwarka, South West district, New Delhi

CGWB has taken up one pilot project in Group Housing Society i.e. Abhiyan apartments, Sector-12 Dwarka. The area is underlain by alluvium formation and depth to ground water level varies from 6 to 8 meters below ground level. This is a multi-storied housing complex having campus area of 6355 sq.m. which generates 3050 cum annual runoff. CGWB has constructed two trenches with recharge well, one pit with borewell and one existing storage chamber with recharge well. System is under study.

CHAMBER WITH TUBE WELL



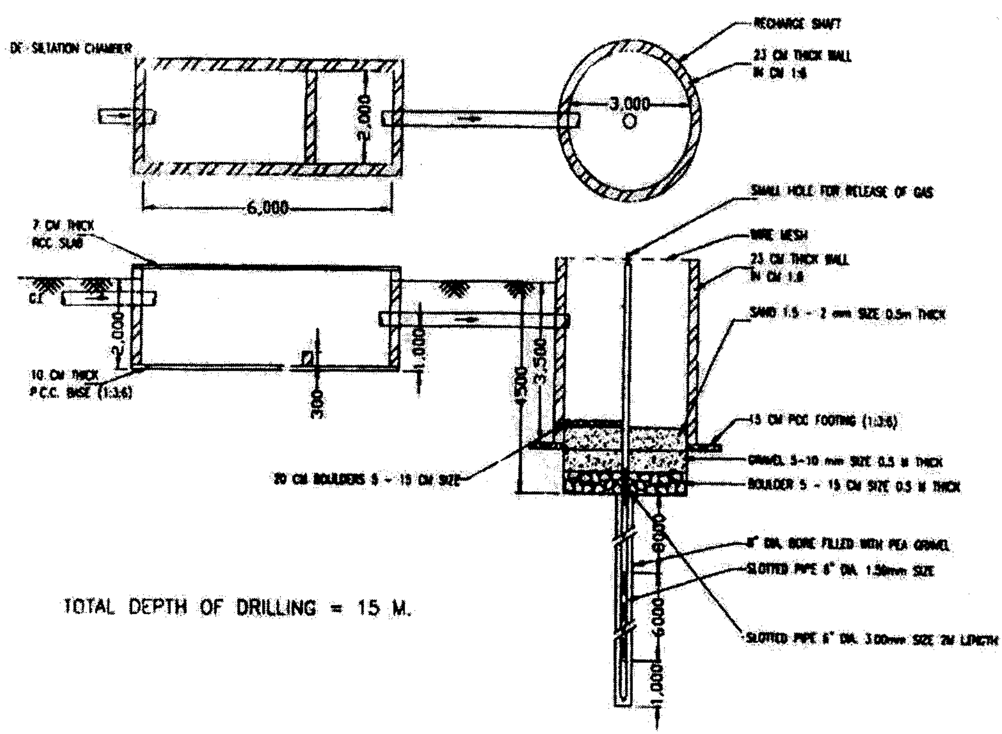
5) Gold Croft Co-Operative Society Ltd. At plot no. 4, sector-11, Dwarka, Delhi

The Gold Croft Co-Operative Society is under construction in Sector-11, Dwarka. The area is underlain by older alluvium mainly consist of unconsolidated inter-bedded sand, clay and silt mixed with varying proportions of gravel and kankar. Depth to ground water ranges from 10 to 11 m. bgl. The total area of the society plot is 19,771 sq.m. out of which about 18735.14 sq.m. of area is contributing runoff generation to be utilised for recharge to ground water. Runoff from the rest of the area is going outside the campus and cannot be diverted to the recharge structures. The annual rainfall in the area is 793.9 mm out of which about 699 mm of rainfall occurs during monsoon period in an average of 30 days. It is estimated that about 6303.62 cu.m. of rainfall runoff is available in the area. The two recharge structures along with de-silting chambers were recommended in the society. The rainwater collected in de-silting chambers will be utilised for horticulture purposes. A number of group housing societies located in South and Southwest district are implementing the schemes.

RECHARGE SHAFT WITH DE-SILTING CHAMBER

RECHARGE STRUCTURE - I&II

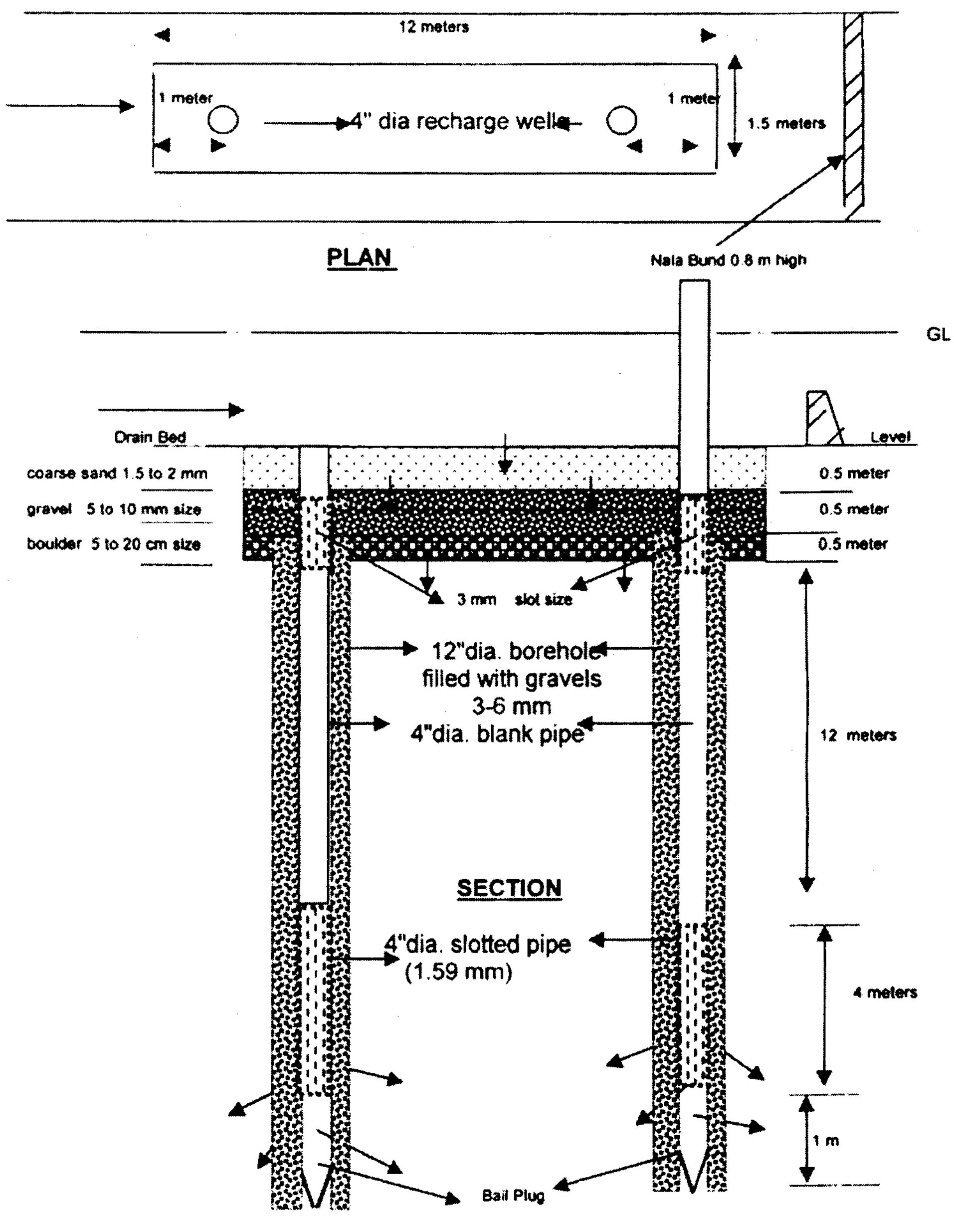
THE GOLD CROFT CO-OP CGHS Ltd. SECTOR -11 DWARKA.



6) IGI Airport South West district, New Delhi

Area is underlain by alluvium and hard rock formation. Depth to ground water varies from 15-24 meters below ground level. The campus area of the airport is 5.59 sq.km. which generates about 6,14,125 cu.m. rainfall runoff. Considering the amount of runoff and nature of catchment 24 trenches with recharge wells are proposed to harness the available runoff in the area. Scheme is being implemented by Airport Authority of India.

TRENCH WITH RECHARGE TUBE WELLS



7) Location: JNU, New Delhi

	Catchment Area (Km^2)	Height of check Dam (m)	Storage Capacity (m^3)	Submergence Area (Sq. m)	Approximate Cost (lakh)
Check Dam I	0.45	4.0	15,333	17,140	12.00
Check Dam II	0.58	3.6	22,180	20,243	14.00
Check Dam III	0.66	2.0	6,925	11,300	13.50

8) Location: IIT, New Delhi (Civil Engg., Deptt.)

Roof Top Catchment (Sq. m)	Rainfall (mm)	Volume of water recharged (m3)	Water level rise (m)	Area benefited (Hectare)
1,666	821	830	0.29-0.87	1 ha

The Case-Study of a Percolation Tank at Dangard-I, TE-11 Watershed, Jalgaon district, Maharashtra

A tank was constructed by CCWB at Dangarda village in 2001. The catchment have medium to coarse teetered soils & the site is located in piedmont plain fringing Satpura foot-hills. The tank is located on 2nd order stream with catchment area of 0.425 sqkm.

The tank was to measure for daily water level. The area capacity curves were drawn showing gauge reading, water spread and storage capacity. A water balance was compiled based on data analysed as given in table below:

Table – Water Balance of Dongard –I Percolation tank, T.E. – 11 Watershed, Jalgaon

Period	Water Content in tank (m^3)	Infiltration in the tank (Th M^3)	Net Storage (Th M^3)	Evaporation losses (Th M^3)	Net percolation (Th M^3)
June	6.6	9.1	15.7	0.19	15.51
July	0.3	1.3	1.6	0.007	1.593
August	Dry	Nil	Nil	Nil	Nil
September	Dry	Nil	Nil	Nil	Nil
October	2.6	5.0	7.6	0.10	7.5
Total	9.5	15.4	24.9	0.279	24.603

It can be seen that maximum storage and percolation of water took place in the month of June followed by July and October. The net percolation from the tank is estimated as 24.603 TCM. The ground water levels exhibited a rize of 1 to 4 meters. An area of 0.3 km^2 was observed to be benefited from percolation tank causing farmers the availability and opportunity to use water for initiated agriculture. Similar Percolation Ponds were constructed by State Government in Collaboration with CGWB, and the features as well as cost of construction of such water harvesting and recharging structures in TE 11, Watershed in Jalgaon district of Maharashtra is given in following table.

Percolation Tanks in Jalgaon district, Maharashtra (features and appropriate cost of construction) (Watershed TE-11)

S. No	Features	Percolation Tanks				
		Wadri	Sangvi	Dongarda (i)	Dongarda (ii)	Dongarda (iii)
1	Rainfall (mm)	674.37	674.37	678.942	678.688	767.652
2	Run-off (TCM/mm)	75.50	75.55	76.72	76.72	76.24
3	Catchment Area (km²)	4.27	1.30	0.43	1.00	1.24
4	Submergence Area (mm²)	42.00	34.76	14.9	12.35	26.96
5	Terrain	Piedmonts	Piedmonts	Piedmonts	Piedmonts	Piedmonts
6	Storage Capacity (TCM at FSL)	98.03	71.7	32.32	25.56	58.28
7	Max. Flood Discharge (m3/sec)	178.26	36.12	11.90	28.00	35.00
8	Dam Wall Total length (m)	510	510	195	270	380
9	Max Height (m)	9.5	8.5	9.54	9.52	13.86
10	Top Width (m)	2.00	2.00	3.00	3.00	3.00
11	Waste Weir Length (m)	60.00	45.00	15.00	17.00	29.00
12	Flood Height (m)	1.45	0.60	0.60	1.00	1.00
13	Cost of construction (Rs.)	8,96,825	10,75,252	9,87,120	10,75,510	24,84,055
14.	Year of construction	2000	2001	2001	2001	2001

The Case Study from Gujarat State

The Mehsana area in Gujarat in severely affected by ground water over exploitation leading to declines in the levels of ground water. Two main experimental studies lead to construction of water spreading basin & injection wells. The shallow aquifer below Saraswati river bed was used as a source water for pressure injection well recharge test. The injection well experiment was done for 225 days by a UNDP aided CCWB Pilot Recharge Project. A quantity of water at the rate of 225 m^3/day was pressure-injected. A rise in water level of 5 meters in injection well & of 0.5 to 1.0 meters in observative wells at 150 meters distance from injection well site was observed. A continuous high rate of pressure injection was sustained by storage space created by contemporaneous withdrawal of ground for irrigation in the area.

The water spreading method of recharge was done using canal water. A spreading channel of 3.3 m width x 400m length with 1:1 side slope was constructed in which canal water was fed for 4 days. A build up of ground water of about 1.4 to 2 m was noticed upto 15m from recharge channel and of 0.20m at a distance of 200m. Using an infiltration rate of 17 cm/day, a recharge rate of 260 m^3/day was achieved. The recharge method of 1.42m was dissipated in 15 days.

An experiment through a recharge pit (1.7m x 1.7m x 0.75m) at Dabhu in central part of Mehsana was also done using canal water as source water. The recharge was affected at the rate of 17.3m^3/day with an infiltration of 0.5 m/day. A rise of 4 meters in levels of ground water was observed at a distance of 5 meters from the experimental recharge pit.

Some Case Examples of Foreign Countries

1.	Japan :	Some 25 local governments in Japan are subsidising rain-water-harvesting projects as a way to prevent Urban floods and to overcome water shortages. One of these is the Sumida Ward of Tokyo which offers subsidies ranging from JPY 25,000 to JPY 1 million depending on the size of rainwater storage tanks. Rainwater harvesting is being promoted by the council for Local Governments on Rainwater utilisation, which was set up in 1996. Tokyo Metropolitan Government is promoting the use of RWH in the city.
2.	Canada :	In certain parts of Canadian Province of Nova Scotia ground water quality for individual dwellings is not reliable. In these situations rainwater cistern system have been used and as such 500 dwellings are severed by rainwater cistern systems. The system consists of a roof, which severs as a collection surface and gutters and downspouts that are connected to storage reservoir.
3.	Australia :	A survey over South Australia determined that rain water is the main source of water for drinking. In the Metropolitan area, 25% households use rain water for drinking whereas in rural areas 81% of households use rain water.
4.	Argentina :	Artificial recharge has been widely used in Latin American Countries. In Argentina, a system of canals and infiltration basin has been used in the provinces of San Juan, Mendoza and Santa Fe with success.
5.	Texas, USA:	According to Texas Water Development Board, the rainwater quality always exceeds that of surface or ground water. Their experiences of guttering houses and use of storage tanks have simply found the best as alternative to available water supply. For bathing and cleaning UV-light filters or disinfectant are used and for drinking and cooking Reverse Osmosis is practiced.

Cost Estimate for Trench with Injection Well

S. No.	Description of items of work	Quantity	Unit Rate (Rs.)	Amount (approx. in Rs.)
A	**Trench: (10m x 2m x 3m)**			
1.	Earthwork (3m x 2m x 1m)	60 m^3	100	6000.00
2.	Back filling with pebbles (10 x 2 x 1m)	20 m^3	1000	20000.00
3.	Back filling both gravel (10 m x 2 x 1 m)	20 m^3	1000	20000.00
4.	Filling with coarse sand (10 m x 2 x 1m)	20 m^3	1000	20000.00
5.	Provisioning of Nylon Net between gravel and sand bad	20 m^2	50	1000.00
6.	Providing Heavy duty HDPE sheet along side wall	96 m^2	100	9600.00
7	Brick work (0.23m at periphery of trench 0.50 m deep & 0.25 m over ground)	4m^3	1000	4000.00
8.	Earth Work for (7) above	3.6 m^3	100	360.00
9.	RCC Slab cover for trench	1.55 m^3	2500	3875.00
		Sub total (A)		**84835.00**
B.	**Injection Well Bore**			
1.	Pilot Borehole (380 mm dia of 30 m depth)	30m	400.00	12000
2.	Lowering 22 m MS Pipe	22m	400	8000
3.	Lowering of 152 mm dia Johnson Screen 1 mm Slot size-8m	8m	1500.00	12000
4.	Lowering of 152 mm M.S pipe bail plug-3m	3m	500.00	1500
5.	Grave filling	2.70 m^3	1000.00	2700
6.	Wall development (10 hrs.)	10 Hrs.	500.00	5000

7.	Misc (Lump Sum)	-	1000.00	1000
		Sub Total		**43000**
C	**Providing & Fixing of PVC Pipes (80 m)**	80m	250	20,000
D	**Desilting Chamber (1.5m x 1.5m x 1.5m)**		1500	15000
E	**Cost of Channelising Rainwater & connecting to shafts (Lumpsum)**		15000	15000
		Grand Total (A+B+C+D+E)		**177835**

Say Rs. 1.75 lakhs approx

Cost Estimate for Groundwater Recharge Structures by CGWB

S. No.	Type of Recharge Structures	Approximately Cost (Rs.)
1.	Recharge Pit	5000
2.	Recharge Trench	5000-10000
3.	Recharge using handpump	2500
4.	Recharge through Dug Well	5000-8000
5.	Injection Well	50000-80000
6.	Recharge Shaft-Vertical with performed boreholes	60000-85000
7.	Lateral recharge shaft with performed boreholes as recharge well	Trench cost : 2000-4000 Recharge well : 25000-35000

CHAPTER - 6

Water Harvesting Structures Planning, Design and Construction

6.0 INTRODUCTION

As mentioned in Chapter-5, there are many ways of harvesting water. All these methods basically fall under three main categories viz.:

- Surface water collection
- Ground water collection
- Augmentation of ground water through recharge

The methods which are particularly useful in augmenting drinking water availability especially in the rural areas and which can be easily adopted at a moderate cost with the involvement of the local people are discussed in the following paras.

6.1 ROOF TOP HARVESTING

Rain water may be harvested in areas, having rainfall of considerable intensity, spread over the larger part of the year e.g. the Himalayan areas, Northeastern states, Andaman Nicobar, Lakshadweep islands and southern parts of Kerela and Tamil Nadu. This is an ideal solution of water problem where there is inadequate groundwater supply and surface sources are either lacking or insignificant. Rain water is bacteriologically pure, free from organic matter and soft in nature.

In this system, only roof top is the catchment (see Figure 6.1, 6.2 and 6.3). The roofing should be of galvanized iron sheets (G.I.), aluminium, clay tiles, asbestos or concrete. In case of thatch-roof, it may be covered with waterproof LDPE sheeting. For collection of water, a drain is provided (Gutter) along the edge of the roof. It is fixed with a gentle slope towards down pipe, which is meant for free flow of water to the storage tank. This may be made up of G.I. sheet, wood, bamboo or any other locally available material. The down pipe should be at least 100 mm diameter and be provided with a 20 mesh wire screen at the inlet to prevent dry leaves and other debris from entering it.

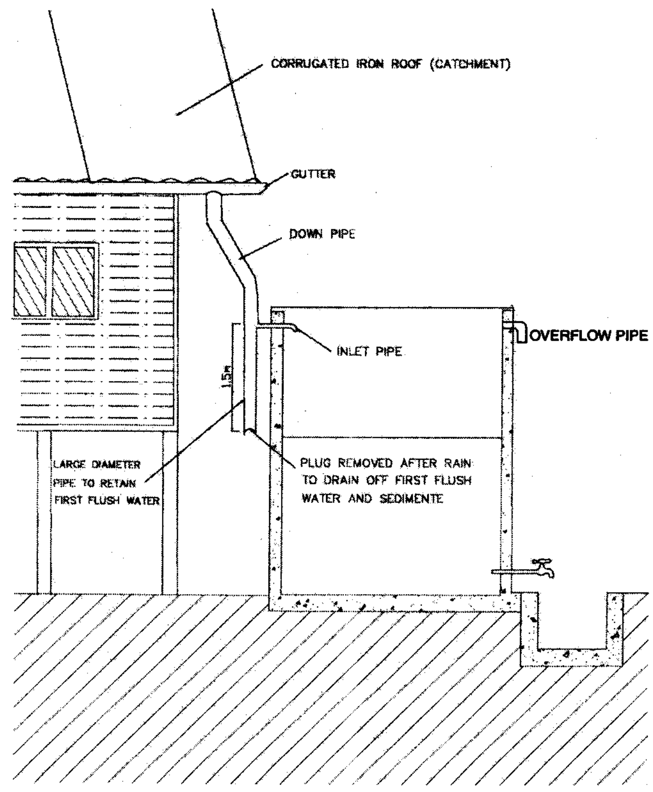


Figure 6.1 : Typical Roof Top Harvesting Structure

During the period of no rain, dust, bird droppings etc. accumulate on the roof. These are washed off with the first rains and enter the storage tank to contaminate the water. This can be prevented by two methods :

(a) Simple diversion of foul water

(b) Installation of foul flush system

Under method (a), the down pipe is moved away from the inlet of the storage tank initially during the rains, until clean water flows. Under method (b), storage provision for initial rain is kept in a pipe. These are cleaned off after each heavy rain. These are provided between down pipe and the storage tank. Filter materials such as sand, gravel or coconut/ palm/ betalnut fibre etc. are used as filter media.

Storage tank can be constructed underground or above ground. The underground tank may be masonry or R.C.C. structure suitably lined with water proofing materials. The surface tank may be of G.I. sheet, R.C.C., Plastic/ HDP or Ferrocement Tank placed at a little higher elevation on a raised platform. To facilitate cleaning of the tank, an outlet pipe may be fitted and fixed in the tank at bottom level. The size of the tank will depend upon the factors such as daily demand, duration of dry spell, catchment area and rainfall.

The tank is provided with :

- a manhole of 0.50 m × 0.50 m size with cover
- vent pipe/ over flow pipe (with screen) of 100 mm dia.
- drain pipe (100 mm dia.) at bottom

Choice of the tank depends on locally available materials and space available. When the tank is constructed underground, at least 30 cm of the tank should remain above ground. The withdrawal of water from the underground tank is made by installing hand pump on it. In case of surface tank, tap can be provided. The overflow pipe should be connected to drain/recharge pit.

Before the tank is put into use it should be thoroughly cleaned and disinfected with high dosage of chlorine. Since the water shall remain stored for quite a long time, periodical disinfection of stored water is essential to prevent growth of pathogenic bacteria. Typical drawings of roof water harvesting structures are shown in Figure 6.1, 6.2 and 6.3.

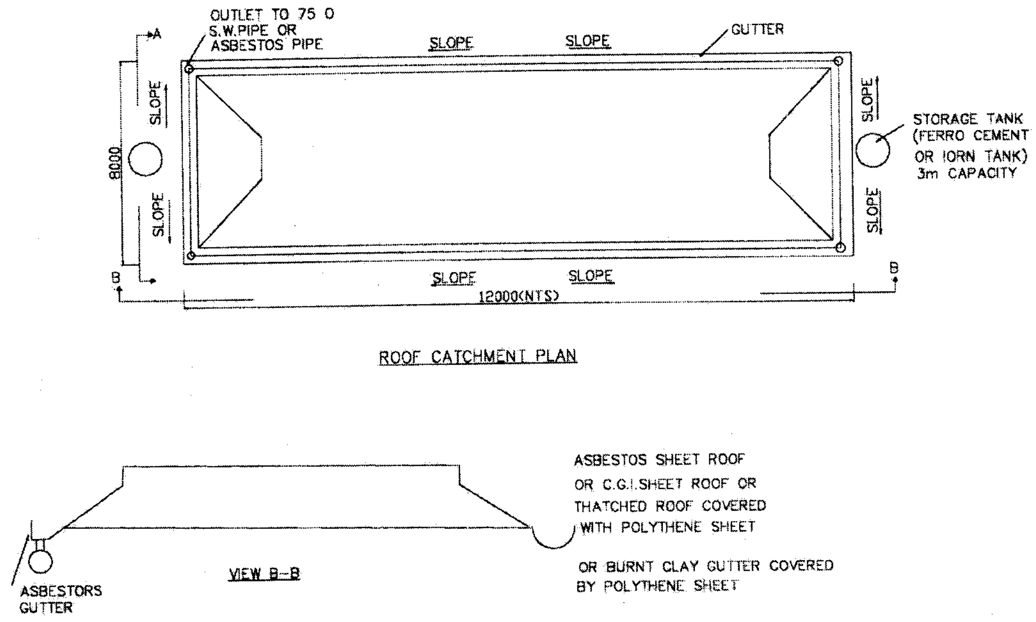


Figure 6.2 : Roof Water Harvesting Scheme

6.1.1 Water Availability

Since the available roof area is usually limited, the system is used to meet water requirements during the summer months i.e. about 100 days. Water availability for a given roof top area and rainfall can be determined from Table A-1.1 of Appendix-I.

6.1.2 Site Assessment

Assessing the site conditions together with the future tank owners is the first step towards a sound system design. The five main site conditions to be assessed are :

- availability of suitable roof catchment
- foundation characteristics of soil near the house
- location of trees
- estimated runoff to be captured per unit area of the roof
- availability and location of construction material

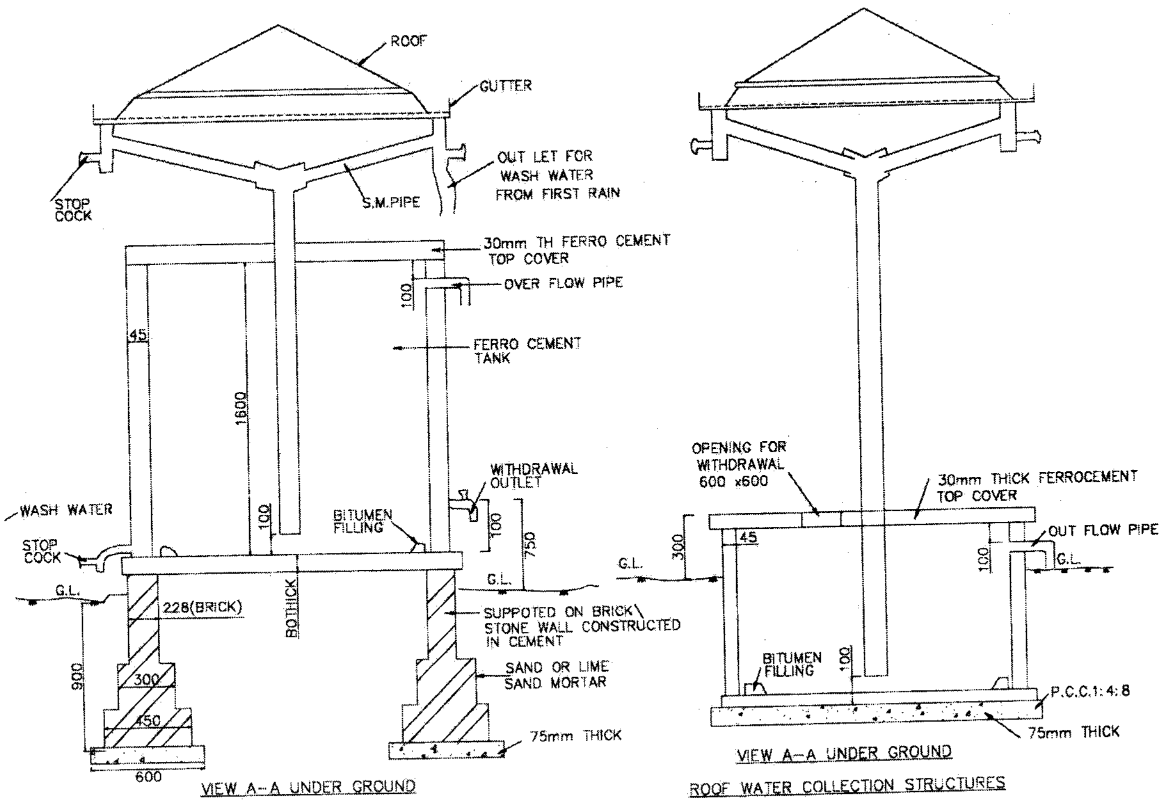


Figure 6.3 : Roof Water Collection Structure

6.1.3 Estimating the Size of the Required Systems

In actual field conditions, the size of the collector and storage system is dictated by the available roof area and the rainfall. Both these factors are beyond our control except that some modifications can be made in the type of roof covering to improve runoff. The water harvested from the available roof area, therefore, is more or less fixed and has to be judiciously used. In rare cases we have the real option of building enough roof area to meet the predetermined per capita requirement of a given family or community. However, for the purpose of illustration, the planning and design procedure for such a system is discussed below :

The size of the catchment area and tank should be enough to supply sufficient water for the users during the dry period. Assuming a full tank at the beginning of the dry season (and knowing the average length of the dry season and the average water use), the volume of the tank can be calculated by the following formula :

$$V = (t \times n \times q) + et$$

Where,

V = Volume of tank (litres)

t = Length of the dry season (days)

n = Number of people using the tank

q = Consumption per capita per day (litres)

et = Evaporation loss during the dry period

Since evaporation from a closed storage tank is negligible, the evaporation loss (et) can be ignored (=zero)

6.1.4 Design Example

If, for example, 20 lpd (q) is agreed upon and a dry period of 100 days (t) is normally not exceeded, a storage volume of 10 m^3 would be required for a family of 5 members (n).

[V = 100 (t) x 5 (n) x 20 (q) = 10,000 litres or 10 m^3]

The required catchment area (i.e. the area of the roof) can be determined by dividing the volume of the tank by the accumulated average rainfall volume (in litres) per unit area (in m^2) over the preceding wet months and multiplying this with the runoff coefficient, which can be set at 0.8 for galvanized iron or tiled roofs.

Experience shows that with the water storage tanks next to their houses, people use between 20-40 litres of water per person per day (lpd). However, this may rise in time as people relax their water use habits because of easy access. This contrasts with a maximum of l0 lpd consumption levels under similar environments with people fetching water from distant sources. Together with the community/ family, a decision must be taken on how the water will be used or what affordable service level can be provided.

6.1.5 General Design Features

Rooftop water harvesting systems can provide good quality potable water if the design features outlined below are taken into account.

- The substances that go into the making of the roof should be non-toxic in nature.
- Roof surfaces should be smooth, hard and dense since they are easier to clean and are less likely to be damaged and release materials/ fibres into the water.
- Roof painting is not advisable since most paints contain toxic substances and may peel off.
- No overhanging trees should be left near the roof.
- The nesting of birds on the roof should be prevented.
- All gutter ends should be fitted with a wire mesh screen to keep out leaves, etc.
- A first-flush rainfall capacity, such as detachable down pipe section, should be installed.
- A hygienic soak away channel should be built at water outlets and a screened overflow pipe should be provided.
- The storage tank should have a tight fitting roof that excludes light, a manhole cover and a flushing pipe at the base of the tank (for standing tanks).
- There should be a reliable sanitary extraction device such as a gravity tap or a hand pump to avoid contamination of the water in the tank.
- There should be no possibility of contaminated wastewater flowing into the tank (especially for tanks installed at ground level).
- Water from other sources, unless it is reliable source, should not be emptied into the tank through pipe connections or the manhole cover.

6.1.6 Design of System Components

A rooftop catchment system has three main components, viz. a roof, a guttering and first flush device and a storage tank.

(a) *Roof* : The roof should be smooth, made of non-toxic substances and sufficiently large to fill the tank with the available rainfall conditions. Existing roofs of houses and public buildings can be used for a rooftop catchment system. In some cases enlarged or additional roofed structures can be built.

(b) *Guttering and first-flush device* : Guttering is intended to protect the building by collecting the water running off the roof and direct it, via a down pipe, to the storage tank. Gutters should have a uniform slope of 0.5 percent large enough to collect the heavy runoff from high-intensity rain.

With all roof catchment tanks, the first rainwater running off the roof should be discarded. This helps keep the water potable because this first flush of rainwater contains large quantities of leaves and bird droppings. The importance of such first flush devices became clear from a study undertaken in Malaysia. The study showed how the faecal coliform count in runoff water was reduced from 4 to 60 per litre to zero, as the first five litres of runoff washed a roof measuring 15 m^2.

(c) *Tank* : Water tanks using ferrocement technology come in different designs with volumes ranging between 2 and 200 m^3. For example, a freestanding cylindrical tank can be built in sizes between 10 and 30 m^3, while a capacity of upto 200 m^3 is possible with sub-surface covered tanks. The latter is most economical when the capacity exceeds 50 m^3.

The principles of construction of ferrocement tanks involving the use of a corrugated iron moulds are widely adopted (see Figure A-2.1 of Appendix-II). An alternate design avoiding framework involves erecting a circular frame made of welded-mesh bars spaced at 15 cm and covered with chicked wire mesh (2.5 cm gauge) onto a reinforceu concrete base. This is then covered on the outside with sacks or cloth and two coats of a 1.5 cm layer of mortar (1 part cement, 3 parts sand) plastered along the inner walls to produce the tank wall. Two further coats of plaster are added, one on the outside after removing the sacks and one on the inside to provide a tank wall thickness of 5 cm. A waterproof coat of just cement and water is then added to the tank's inner wall.

When the wall is complete, a wooden frame is constructed inside the tank to support the metal template made from old oil drums, which forms the mould for the domed roof. The roof is also reinforced with welded-mesh and chicken wire. For quality, the floor, walls and the roof need to be cured by moistening their surface for at least a week. This should start immediately after each component is ready.

The Principles of Construction, Material and Design of Ferrocement Tank are explained in Appendix-II.

6.1.7 Management and Maintenance

Roof top catchment tanks, like all water supply systems, demand periodic management and maintenance to ensure a reliable and high quality water supply. If the various components of the system are not regularly cleaned, water use is not properly managed, problems are not identified or necessary repairs not performed, the roof catchment system will cease to provide reliable, good quality supplies.

On the following page is a rough timetable of maintenance and management requirements that gives a basis for monitoring checks.

1. During the rainy season, the whole system (roof catchment, gutters, pipes, screens, first-flush and overflow) should be checked before and after each rain and preferably cleaned after every dry period exceeding a month.
2. At the end of the dry season and just before the first shower of rain is anticipated, the storage tank should be scrubbed and flushed of all sediment and debris (the tank should be re-filled afterwards with a few centimetres of clean water to prevent cracking). Ensure timely service (before the first rains are due) of all tank features, including replacement of all worn screens and servicing of the outlet tap or hand pump.

6.1.8 Water Use Management

Control over the quantity of water abstracted from the tank is important to optimise water use. Water use should be managed so that the supply is sufficient to last through the dry season. Failure to do so will mean exhausting all the stored water. In effect it will mean going back to where the user began, i.e. trekking long distances for poor quality water. On the other hand, underutilization of the water source due to severe rationing may leave the user dissatisfied with the level of the service provided.

6.2 TANKA/ KUND/ KUNDI

Tanka is generally circular in shape and is constructed in stone masonry in 1:3 cement-sand mortar. While small Tankas of 3 to 4.22 m diameter and about 21-59 cum capacity are built by individual households, larger ones of 6 m diameter and 200 cum capacity are built for the village communities. In both these cases the depth is kept equal to the diameter. The catchment of the Tanka is treated in a variety of ways to increase the rain water collection. The commonly used materials are murrum, coal ash, gravel, pond silt, Bentonite, soil-cement mix, lime concrete, sodium carbonate etc. Because of the constraints of availability of large open areas around the Tanka and the unit cost of treatment, a circular strip of land of 12 m width around the Tanka is usually treated, the slope of which is kept as 3% i.e. a fall of 3 cm in a length of 1 m. This provides bulk of the requisite amount of water to fill the Tanka. Remaining water is received from the natural catchment outside the treated area. Reference Tables and Design Example for Tanka are given in Appendix-III.

6.2.1 Site Selection

Tanka of about 21 cum capacity for an individual household should preferably be built in front of the house in an open area of about 10 m x 10 m size. Since the rainwater from this area is to be collected in the Tanka, the area should be such that human activity and cattle grazing may be prevented during the monsoon season to prevent pollution of water.

For community Tanka of about 200 cum capacity the size of the open area should be at least 30 m x 30 m.

In both the cases the land surface should be firm and sandy with gentle slope of about 3 % i.e. with a fall of 3 cm in 1 metre length.

6.2.2 Site Preparation

The selected area should be cleared of all vegetation i.e. grass, shrubs, bushes etc. A circle of 10 m diameter in case of the household tanka and 30 m diameter in case of community tanka should be drawn to mark the rain-water-collection area (catchment area).

In case of the smaller Tanka the catchment area should be suitably dressed to provide an inward slope of 3 cm in 1 metre length towards the centre.

For the community Tanka, the desired slope can be provided even in one direction i.e. in the general direction of the natural ground slope. In this case entry of rain water into the Tanka is ensured by building a semi-circular earthen bund at the lower end of the catchment area.

6.2.3 Planning and Design Criteria

1. *Water Requirement*

A Tanka of 21 cum capacity is usually adequate to meet the minimum drinking water requirements of a family of 6 persons for one year. Community Tankas, however, have only a supplemental role since these can only partially meet the requirements depending upon the size of the community and the availability of land for constructing the Tankas. Viewed in this light, water requirement of the community is not necessarily a governing criterion for design of a Tanka scheme. Instead, conservation of available water and its proper distribution and use are of crucial importance.

2. *Water Availability*

(a) Untreated Catchment

Some part of the rainwater is lost due to evaporation and seepage into the ground. This loss varies with the amount of rainfall. For low rainfall the losses are high and for high rainfall these are low. Availability of rainwater for a Tanka from a natural catchment can be computed from the Table A-3.1 of Appendix-III.

(b) Treated Catchment

Volume of rain water that can be collected from a treated catchment around the Tanka can be worked out from the Table A-3.2 of Appendix-III.

3. *Structural Design*

(a) Individual Household Structure of 21 cum capacity (see Figure 6.4)

(i) Foundation excavation: Area 3.9 m diameter and 3.5 m deep

(ii) Foundation concrete: 1:3:6 CC 250 mm thick over an area of 3.9 m diameter

(iii) Tanka Wall: 1:2:4 CC Wall 150 mm thick with 5 mm Cement Plaster

(iv) Tanka Cover: Stone slab roof, at height of 1.0 m from G.L.

(v) Apron around Tanka: 1:3:6 CC Apron, 1.0 m wide and 100 mm thick

(vi) Deep Catch Pit at the bottom of Tanka: Size 1000 x 250 mm

(vii) Slope of artificial/ treated catchment around Tanka: 3% to 4% - a fall of 3 cm in a length of 1 m

(viii) 3 Inlets and 1 Outlet in Tanka wall at apron level: Size 0.6 x 0.3 m with Iron Bars and Expanded Metal

(ix) Opening at the top (for drawing water): Size 1.0 x 1.0 m

(b) Community Structure of 200 cum capacity (see Figure 6.5)

(i) Foundation excavation: Area 9.15 m diameter and 6.32 m deep

(ii) Foundation concrete: 1:3:6 CC 230 mm thick over an area of 9.15 m diameter

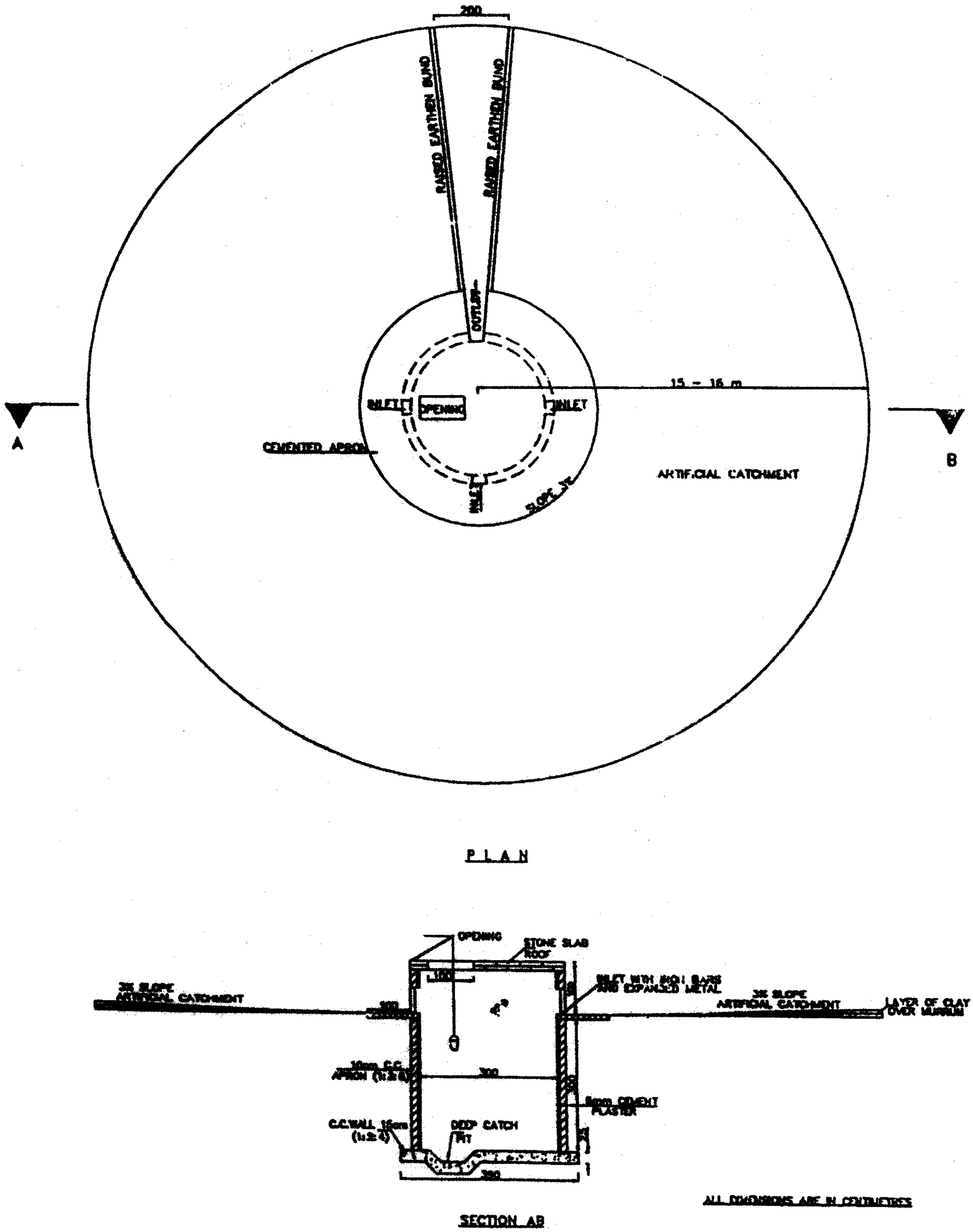


Figure 6.4 : Plan and Sectional Detail of 21 cum Capacity Tanka

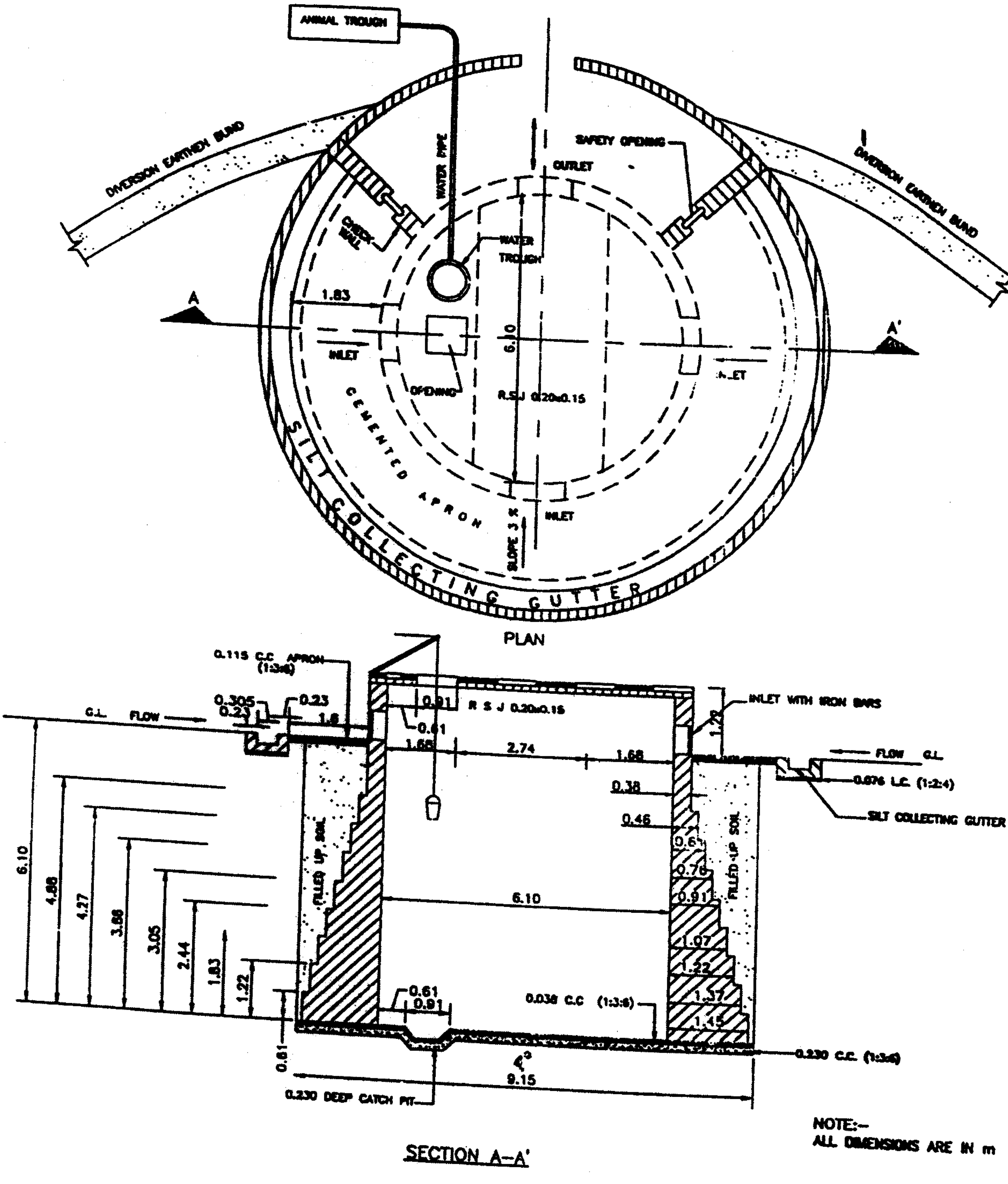


Figure 6.5 : Plan and Sectional Detail of 200 cum Capacity Tanka

(iii) Tanka Wall: RR masonry 1.45 m thick at bottom in 1:3 cement-sand mortar gradually reduced in steps to 0.38 m at the top

(iv) Tanka Cover: Stone slabs over 3 Nos. R.S. Joists of size 0.20 x 0.15 m

(v) Apron around Tanka: 1.6 m wide and 115 mm thick

(vi) Deep Catch Pit at the bottom of Tanka: Size 915 x 230 mm

(vii) Silt Collecting Gutter: Size 305 x 305 mm, bottom 75 mm thick 1:2:4 Lime Concrete and 230 mm thick RR masonry, sides 230 mm thick RR masonry

(viii) Slope of treated catchment around Tanka: 3% to 4% - a fall of 3 cm in a length of 1 m

(ix) 3 Inlets and 1 Outlet in Tanka wall at apron level: Size 0.6 x 0.3 m with Iron Bars

(x) Opening at the top (for drawing water): Size 0.9 x 0.9 m

Note:

(i) For rain water yield from natural catchment outside the treated area refer Table A-3.1 of Appendix-III.

(ii) Catchment should be treated for increasing rain water collection into the Tanka.

(iii) For catchment treatment refer Table A-3.2 of Appendix-III.

4. *Data Requirement*

(a) Primary data/ information

- Land surface characteristics
  - Should be gently sloping or flat
  - Sandy and firm
  - Moderate absorption of water
  - Easy to excavate upto about 6.5 m depth for Community Tanka and 3.5 m depth for household Tanka
- Availability of material for catchment treatment (Refer Table A-3.2 of Appendix-III for choice of treatment)

(b) Secondary data

- Monthly rainfall for about 10 years (Source: District Statistical Organisation)
- Percentage of utilizable rainfall i.e. Runoff coefficient (Source: State Water Resources Organisation or Central Water Commission)

6.2.4 Advantages

(i) Since the rainwater flows over gently sloping (3 to 4 % slope) sandy terrain, very little sediment flows into the storage tank. However, the sediment comprising only sand particles quickly settles down at the bottom of the tank and therefore clear and clean water is available for drinking. With the tank fully covered at the top, the evaporation losses are negligible.

(ii) This method of rainwater harvesting being cheap, environment-friendly and effective, can be used widely to solve the problem of drinking water scarcity.

6.2.5 Disadvantages

(i) Requires constant vigil during the rainy season to prevent entry of cattle and human activity with in the catchment area to prevent contamination of water.

(ii) Requires pre-monsoon cleaning of the Tanka and the catchment.

(iii) Special care is required to prevent entry of reptiles and small animals into the Tanka through the inlets/ outlet and the opening at the top.

6.2.6 Geo-climatic Requirements/ Constraints

(i) Tanka/ Kund/ Kundi can be built in any climatic region where the land slopes are gentle and the surface is sandy and/ or rocky with out any harmful salts/ minerals.

(ii) These are not useful in areas with steep slopes and where land surface has clayey soils.

6.3 PERCOLATION TANKS

Percolation tanks are artificially created surface water bodies, submerging a land area with adequate permeability to facilitate sufficient percolation of impounded surface runoff to recharge the ground water. These have come to be recognized as a dependable mode for ground water recharge in the hard rock terrain covering two-third of the country. The hard rock areas with limited to moderate water holding and water yielding capabilities often experience water scarce situations due to inadequate recharge, indiscriminate withdrawal of ground water and mismanagement. These are quite popular in the states of Maharashtra, Andhra Pradesh, Madhya Pradesh, Tamil Nadu, Karnataka and Gujarat. The percolation tank is more or less similar to check dams or nala bund with a fairly large storage reservoir. A tank can be located either across small streams by creating low elevation check dams or in uncultivated land adjoining streams, through excavation and providing a delivery canal connecting the tanks and the stream.

6.3.1 General Guidelines

(i) Percolation tanks should normally be constructed in a terrain with highly fractured and weathered rock for speedy recharge. In case of alluvium, the bouldary formations are ideal. However, the permeability should not be too high that may result in the percolated water escaping in the downstream as regenerated surface flow.

(ii) The aquifer to be recharged should have sufficient thickness of permeable Vadose zone to accommodate recharge. The Vadose zone should normally be about 3 m below the ground level to minimize the possibility of water logging.

(iii) The benefited area should have sufficient number of wells, hand pumps etc. A minimum well density of 3 to 5 per square kilometres is desirable. The aquifer zone should extend upto the benefited area.

(iv) Submergence area should be uncultivated as far as possible.

(v) The nature of the catchment is to be evaluated based on Strange's Table for classification under Good, Average and Bad Category. It is advisable to have the percolation tank in a good/ average catchment.

(vi) Rainfall pattern based on long-term evaluation is to be studied so that the percolation tank gets filled up fully during monsoon (preferably more than once).

(vii) Soils in the catchment area should preferably be of light sandy type to avoid silting up of the tank bed.

(viii) The location of the tank should preferably be downstream of runoff zone or in the upper part of the transition zone, with a land slope gradient of 3 to 5%.

(ix) The yield of a catchment area is generally from 0.44 to 0.55 MCM/sq.km in a low catchment area. Accordingly, the catchment area for small tanks varies from 2.5 to 4 sq.km and for larger tanks from 5 to 8 sq.km.

(x) The size of percolation tank is governed more by the percolating capacity of the formation under submergence rather than the yield of the catchment. Therefore, depending on the percolation capacity, the tank is to be designed. Generally, a percolation tank is designed for a storage capacity of 2.25 to 5.65 MCM. As a general guide the design capacity should normally not be more than 50 percent of the total quantum of utilizable runoff from the catchment.

(xi) While designing, due care should be taken to keep the height of the ponded water column about 3 to 4.5 m above the bed level. It is desirable to exhaust the storage by February since evaporation losses become substantial from February onwards. It is preferable that in the downstream area, the water table is at a depth of 3 to 5 m below ground level during the post monsoon period, implying that the benefited area possesses a potential shallow aquifer.

(xii) Construction-wise there is not much difference between a percolation tank and a minor irrigation tank, except for providing outlets for surface irrigation and the depth of the cut-off trench. The cut-off trench is to be provided below the earthen bund with depth limited to one fourth of the height between bed level and full storage level.

6.3.2 Design Aspects

The design of percolation tanks involves detailed consideration of the following aspects:

(i) The catchment yield is to be calculated for long-term average annual rainfall, using Strange's Table. Table A-3.1 of Appendix-III gives the yield from 1 hectare of Catchment for different values of monsoon rainfall.

(ii) The design of the dam is to be done on the basis of (a) the topographical setting of the impounded area, to calculate the height and length of the dam wall, its gradient, width and the depth of the foundation, taking into account the nature of the underlying formation; (b) details of the cut-off trench, to reduce seepage losses; (c) height of stone pitching on the upstream slope to avoid erosion due to ripple action and on the down stream slope from rain by suitable turfing; (d) upstream and downstream slopes to be moderate so that shear stress is not induced in the foundation beyond a permissible limit; and (e) stability of the dam.

(iii) Percolation tanks are normally earthen dams with masonry structures only for the spillway. Construction materials consist of a mixture of soil, silt, loam, clay, sand, gravel, suitably mixed and laid in layers and properly compacted to achieve stability and water tightness. The dam is not to be over-tapped, by providing adequate length of waste weir and adequate free board.

(iv) A waste weir is provided to discharge surplus water when the full pond level is reached. Maximum permissible discharge from the catchment is to be calculated using the formula approved by the competent authority based on local conditions. In the absence of such a formula, Inglis, or Dicken's formula may be used based on the observed or design discharge and catchment areas for local culverts under road or railway bridges. Once the discharge is known the length of the waste weir is decided depending on the maximum flood discharge and permissible flood depth the crest of waste weir.

(v) Finally, measures indicated for the protection of catchment areas of rock dams hold good in the case of percolation tanks also.

(vi) The percolation tanks in a watershed may not have enough catchment discharge though a high capacity tank is possible as per site conditions. In such situations stream from nearby watershed can be diverted with some additional cost and the tank can be made more efficient. Such an effort was made in Satpura Mountain front area at Nagadevi, Jalgaon district, Maharashtra. The existing capacity of the tank of 350 TMC was never utilized after its construction. This could however be filled by stream diversion from adjacent watershed.

The Design Example of Percolation Tank with Drawings is given in Appendix-IV.

6.3.3 Experience So Far

Evaluation studies carried out on the functioning of the percolation tanks in Maharashtra state have indicated that a properly located, designed and constructed percolation tank can have an efficiency ranging from 78 to 91% with respect to recharge of ground water, leaving the balance for seepage losses (from nil to 8%) and evaporation losses (upto 8%). If the tank is filled more than once during the monsoon, enhancing utilization upto 150% of the storage capacity, optimal efficiency of the percolation tank is ensured. Generally, the zone of the influence in the downstream side extends up to 1 km. There is a strong case for propagating percolation tanks as a tool for managing ground water in hard rock areas, since it serves the dual purpose of water harvesting and ground water recharging. Percolation tanks put into actual practice the much talked about integrated development of surface and ground water for their conjunctive use.

6.4 CHECK DAMS/ CEMENT PLUGS/ NALA BUNDS

Check dams are constructed across small streams having gentle slope and are feasible both in hard rock as well as alluvial formations. The site selected for check dam should have sufficient thickness of permeable bed or weathered formation to facilitate recharge of stored water within short span of time. The water stored in these structures is mostly confined to stream course and the height is normally less than 2 m. These are designed based on stream width and excess water is allowed to flow over the wall. In order to avoid scouring from excess run off, water cushions are provided at downstream side. To harness the maximum run off in the stream, series of such check dams can be constructed to have recharge on regional scale.

A series of small bunds or weirs are made across selected nala sections such that the flow of surface water in the stream channel is impeded and water is retained on pervious soil/ rock surface for longer body. Nala bunds are constructed across bigger streams of second order in areas having gentler slopes. A nala bund acts like a mini percolation tank.

6.4.1 Site Characteristic and Design Guidelines

For selecting a site for Check Dams/ Nala Bunds the following conditions may be observed.

(i) The total catchment of the nala should normally be between 40 to 100 Hectares though the local situations can be guiding factor in this.

(ii) The rainfall in the catchment should be less than 1000 mm/annum.

(iii) The width of nala bed should be atleast 5 meters and not exceed 15 metres and the depth should not be less than 1 metre.

(iv) The soil downstream of the bund should not be prone to water logging and should have pH between 6.5 to 8.

(v) The lands downstream of check dam/ bund should have irrigable land under well irrigation (This is desirable but not an essential requirement).

(vi) The Nala bunds should be preferable located in area where contour or graded bunding of lands have been carried out.

(vii) The rock strata exposed in the ponded area should be adequately permeable to cause ground water recharge through ponded water.

(viii) Nala bund is generally a small earthen dam with a cutoff core wall of brick work, though masonry and concrete bunds/ plugs are now prevalent.

(ix) For the foundation for core wall a trench is dug 0.6m wide in hard rock or 1.2 metres in soft rock of impervious nature. A core brick cement wall is created 0.6 m wide to stand atleast 2.5 metres above nala bed and the remaining portion of trench is back filled on upstream side by impervious clay. The core wall is buttressed on both sides by a bund made up of local clays and on the upstream face, stone pitching is done.

(x) Normally the final dimensions of the Nala bund are : length 10 to 15 metres, height 2 to 3 metres and width 1 to 3 metres, generally constructed in a trapezoidal form. If the bedrock is highly fractured, cement grouting is done to make the foundation leakage free.

(xi) Dams should be built at sites that can produce a relatively high depth to surface area so as to minimise evaporation losses.

(xii) Rocky surfaces should not be fractured or cracked, which may cause the water to leak away to deeper zones or beneath the dam.

(xiii) Dam foundation must be of solid impermeable rock with no soil pockets or fracture lines.

(xiv) Convenient location for user groups.

(xv) No soil erosion in the catchment area.

(xvi) Dams should be sited along the edges of depressions or directly across the lower ends of deep gullies into the rock.

The check dams are also popular and feasible in Bhabar, Kandi and talus scree areas of Uttar Pradesh, Punjab and Maharashtra and have had substantial impact on augmentation of ground water.

The Design Example of Check Dam with Drawings is given in Appendix-V.

6.5 POND/TANK

Size of a pond is usually dictated by the availability of adequate land in the vicinity of the village. In rare cases do we have the option to design and build a pond of a desired size to meet the water requirements of the community. Where we have such an option, the first step is to work out the water requirement for various needs. The next step is to determine the catchment area, above the pond site, from where the monsoon run off would be available to fill the pond. Thereafter the location, alignment and height of the earthen bund are decided, as also the location and size of the spillway to evacuate the surplus monsoon discharge.

6.5.1 Water Requirement and Gross Storage

Unless otherwise prescribed for an area, following general guidelines may be used to determine the water requirements of a village community and the gross storage capacity of the pond.

a. *Irrigation* : Provide about 0.67 hectare metre of capacity for a hectare of irrigation.

b. *Animal Needs* : Provide at the following rates:

Beef Cattle : 54-68 litres/day

Dairy Cows : 68 litres/day (drinking)

Dairy Cows (drinking + barn needs) : 158 litres/day

Pigs : 18 litres/day

Sheep : 9 litres/day

c. *Domestic Water Needs* : 40 litres per capita per day (lpcd)

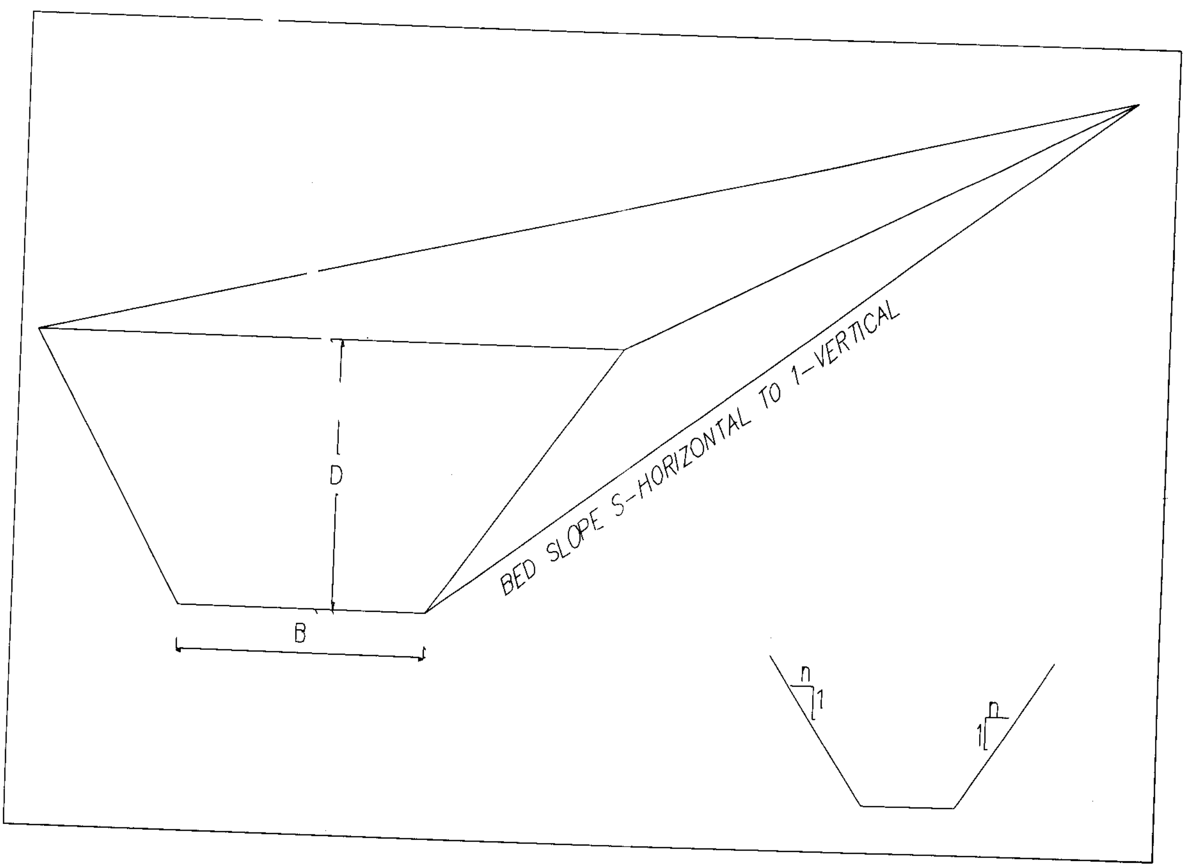
d. *Fish Culture* : Ensure about 1.85 m depth to provide proper temperature environments.

The storage capacity should be at least double the total water requirement to take care of evaporation and seepage losses. As a rough guide, 10 per extra storage may be provided for sediment deposition. For example, if the total annual water requirement is 10,000 cum and pond will have only one filling, its gross capacity should be 22000 cum (2 x 10,000 + 10%).

6.5.2 Runoff and Storage Volume

A detailed survey is usually required to estimate the size of the catchment area and the reservoir storage for different water levels. Where the surveys are likely to be expensive or other wise not feasible, catchment area can be roughly computed from Survey of India toposheets to the scale of 1:25,000 or 1:50,000. However, for computing approxi iate reservoir storage volumes certain rudimentary field surveys have to be carried out using inexpensive (quipment and ordinary local skills. The procedure for these field surveys is discussed in Appendix-VIII.

Since a pond is usuall built by putting a bund (earthen or masonry) across the flow path of a natural drainage, the paramete s required for computing approximate storage volumes, for different pond levels are :



Where,

Channel width B (meters) at bund site

Bank slopes of the channel – n : 1 (Fall of 1 metre in a length of n metres)

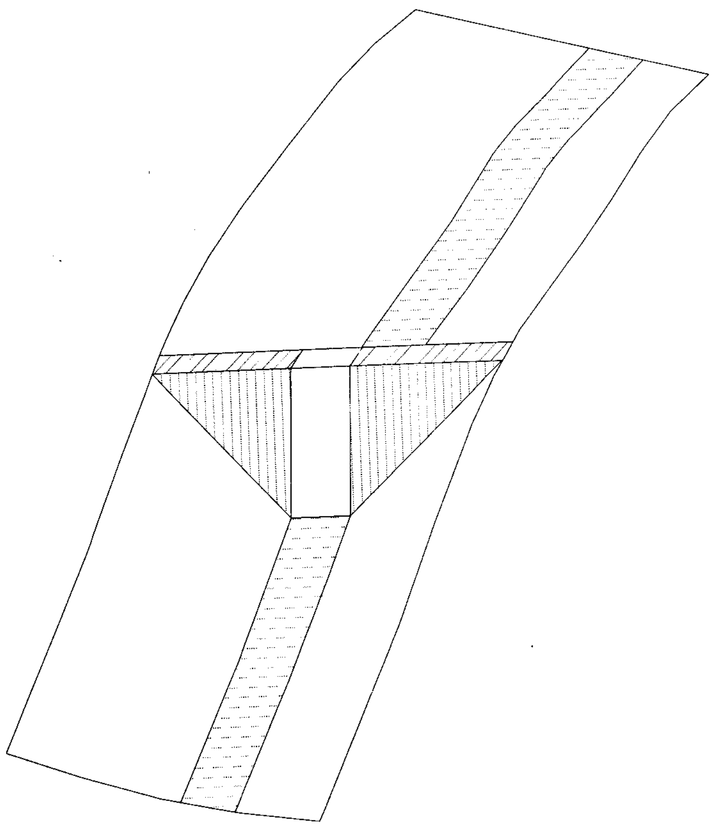
Bed slope of the channel – S : 1 (Fall of 1 metre in a length of S metres along the channel bed)

Depth of water above the channel bed at the bund site – D (metres)

Storage volume is approximately computed by using the formula

$$V = \frac{SD^2}{2}(B + nD)$$

For ready reference, storage volume for different values of S, D, B and n are given in Appendix-VI.



6.5.3 Traits of a Good Pond Site

A good pond site should possess the following traits:

(i) It should be a narrow gorge with a fan shaped valley above: so that a small amount of earthwork gives a large capacity.

(ii) The capacity catchment area ratio should be such that the pond can fill up in about 2-3 months of rainfall. The capacity should not be too small to be choked up with sediments very soon.

(iii) The pond should be located where it could serve a major purpose e.g. if for irrigation, it should be above the irrigated fields.

(iv) Junction of two tributaries, depressions and other sites of easily available fill material and favourable geology should be preferred.

(v) The site should not have excessive seepage losses.

(vi) The catchment area should be put under conservation practices.

6.5.4 Spillway Dimension for the Mechanical Spillway

In low rainfall areas peak discharges during rainy season are too meagre to required evacuation through a concrete or masonry spillway. Instead a pipe spillway may be provided. Normally the pipe should be large enough to pass the peak monsoon discharge without considering any moderation due to the reservoirs. Storage effect of small ponds of capacity of 0.123 to 0.246 is usually neglected. However, where the reservoir is large with considerable storage capacity the moderation effect may be considered using the following formula:

$$\frac{Qo}{Q} = 1.25 - \left(\frac{1500\,V}{R\,A} - 0.06\right)^{1/2}$$

Where,

Qo = Rate of outflow when the pipe first flows full in cumecs

Q = Peak rate of inflow in cumecs (cubic metre per sec.)

V = Available storage in ham (hectare metre)

R = Runoff in mm, and

A = Drainage area in hectares (same as watershed area)

The above equation provides a rough guide to estimate of the size of the mechanical spillway pipe required.

For ready reference Appendix-VII may be used to determine the diameter of the pipe for known values of Q, V, R and A.

6.5.5 Structural Design

The following general guidelines are kept in view for the structural design and construction of the pond:

(i) Angle of repose is less for wet soil than for dry soils: so provide for flatter gradient on the waterside of the earthfill. For very small ponds uniform slopes on both upstream and downstream sides can be provided (2½:1). For other provide a minimum slope of 3:1 on the waterside.

(ii) Remove all vegetation, roots, and organic matter from the fill area: scrape the upper 30 cm of the sol to get rid of the excessive roots: remove all tree stumps at the construction site (to come under the fill).

(iii) Provide a 1.5 m wide bottom key trench with 2:1 side slopes, to give a good bondage with the original earth.

(iv) Lay the earthwork in horizontal layers of not more than 8 centimetres at a time: water them to have a 14% moisture content: use sheep-foot roller for maximum compaction. Bulldozers fill earth in heaps, which cannot be easily completed. Use them for site clearance but not for earth fill.

(v) Place the conduit pipe of the mechanical spillway before starting the earthfill.

(vi) Use topsoil and fertilisers to establish a quick grass cover on the earthfill. Do not let trees or bushes come up on the embankment.

(vii) At the inlet of the inflow runoff provide a measuring structure (triangular weir), drop structure, or a sod chute so that when the pond is low, the inflow does not cause gullying. Cut all excavation on 2:1 or at least 1:1 side slopes.

(viii) The road on the crest should be provided with a gravel metal, middle camber and drains on sides (lead the road runoff safely down the slope in pipes or masonry/ concrete flumes or chutes. This can be otherwise a cause of gullying).

(ix) Provide for constant level livestock watering tank.

6.5.6 Selection of Site

From an economic view point, the bund should be located where maximum storage volume is obtained for minimum volume of earthfill, since the major share of the cost goes into the earthfill. This condition, generally, can be met at a site where the stream/ or drainage channel is narrow, steep, side slopes are steep and stable, and the stream bed is of consolidated and nearly impervious formation. Such sites also minimise the pond area.

6.5.7 Design of Earthen Bund

The various components of an earthen bund include (a) foundation including key trench or cut-off, (b) height of bund, (c) free board, (d) settlement allowance, (e) top width and (f) side slopes.

It is possible to construct a stable and economical earthen bund on any foundation. Sites with foundation conditions requiring relatively expansive construction measures should be avoided. The most satisfactory foundation is one that consists of, or is underlain at a shallow depth by a thick layer of relatively impervious consolidated material. Such foundations cause no stability problems. Where a suitable layer occurs at the surface no special measures are required. It is sufficient to remove the top soil (with vegetation and roots) and plough the area to provide a good bond with the new fill material of the bund.

Where the impervious layer is overlain by pervious material (sand), a compacted clay cut-off extending from the surface of the ground into the impervious is required to prevent excessive seepage and to prevent possible failure by piping.

(a) Foundation Cutoffs

Usually a cut-off joining the impervious stratum in the foundation with the base of the dam is needed. The most common type of cutoff is one constructed of compacted or puddled clay material. A trench, also called key-trench, is cut parallel to the central line of the bund to a depth that extends well into the impervious layer. The trench should have a bottom width of not less than 1.5 meters but adequate to allow the use of mechanical equipment if necessary, to obtain proper compaction. The sides of the trench should be filled with puddled clay or with successive thin layers of relatively impervious material each layer being properly compacted.

(b) Height of Bund

The height of bund will depend upon the volume of runoff to be stored and topography of the reservoir area. The high of the bund should also be selected in such a way that its cost per unit of storage (cum volume) is minimum. While calculating the cost corresponding to any height some allowance for settlement and free board, and temporary flood storage may be added to give the actual bund height or in other words the actual quantity of earth work.

(c) Free Board

It is the added height of the bund provided as a safety factor to prevent waves and flood runoff from over-topping the embankment.

(i)	Minimum free board (F.B.) for length of pond upto 400 m	50 cm
(ii)	F.B. for length of pond upto 800 m	75 cm
(iii)	F.B. for length of pond more than 800 m	100 cm

(d) Settlement Allowance

This includes the consolidation of the fill materials and the foundation materials due to the weight of the bund and increased moisture caused by the storage of water.

Hand compacted (manually constructed) fill	10% of design height
Machine compacted	5% of design height

(e) Top Width of Embankment

Adequate top width is provided to the bund so that it can be used as road way and communication routes adjoining villages or watersheds. Simple formulae for top width (T.W.) as a function of height (H) may be used.

Upto 10 m height, T.W. = H/5+2
10 to 15 m height, T.W. = H/5+3

Where,

H = Maximum height in m

T.W. = Top width in m

(f) Side Slope of Bund

Adequate upstream and downstream side slopes of the embankment must be provided to satisfy the stability requirements of reservoir filled with water, sudden drawdown to minimise the erosion, and to facilitate establishment of good sod forming grass. The maximum side slopes recommended in case of small earth dams are given below in Table 6.1.

Table 6.1 : Maximum Side Slopes recommended in case of Small Earth Dams

Depth of Fill (Height)	Side Slopes	
	Upstream	Downstream
Upto 5 m	2:1	2:1
5 to 10 m	(i) 2.5:1 (ii) 3.0:1	2:1 or 2.5:1 2.5:1
10 to 15 m	3:1	3:1

When fill material consists of more clay and silt, flatter slope of 3 : 1 on the upstream is always recommended.

(g) Steps in Construction

i) Site clearing-striping vegetation, pervious top earth

ii) Staking for the base and key trench

iii) Key trench digging and filling

iv) Preparation of earth fill material with optimum moisture

v) Placement and compaction of earth in layers

vi) Provision and completion of irrigation outlet and spillway

vii) Trimming slopes to correct angle

viii) Protection of upstream and downstream slopes

(h) Maintenance

A properly designed and constructed bund is well protected by sod and requires, least maintenance. Particular attention should be given to surface erosion, the development of seepage areas on the downstream face of below the top of the dam, evidence of piping, wave action and damage by cattle and human beings and corrective steps should be taken in time.

6.6 GABION STRUCTURE

This is a kind of check dam being commonly constructed across small stream to conserve stream flows with practically no submergence beyond stream course. The boulders locally available are stored in a steel wire mesh and are tied up in the form of rectangular blocks (Figure 6.6). This is put up across the stream to make it as a small dam by anchoring it to the stream banks (Figure 6.6). The height of such structures is around 0.5 m and is normally used in the streams with width of about 10 to 15 m. The excess water overflows this structure storing some water to serve as source of recharge. The silt content of stream water in due course is deposited in the interstices of the boulders to make it more impermeable. These structures are common in Maharashtra, Madhya Pradesh, Andhra Pradesh etc.

6.7 GROUNDWATER DAMS OR SUB-SURFACE DYKES OR UNDERGROUND BANDHARAS (UGB)

These are basically ground water conservation structures and are effective in providing sustainability to ground water structures by arresting sub-surface flow. A ground water dam is a sub-surface barrier across stream, which retards the natural ground water flow of the system, and stores water below ground surface to meet the demands during the period of need (Figure 6.7). The main purpose of ground water dam is to arrest the flow of ground water out of the sub-basin and increase the storage within the aquifer. By doing so the water levels in upstream part of ground water dam rises saturating the otherwise dry part of aquifer.

The underground dam has following advantages:

- Since the water is stored within the aquifer, submergence of land can be avoided and land above reservoir can be utilized even after the construction of the dam.

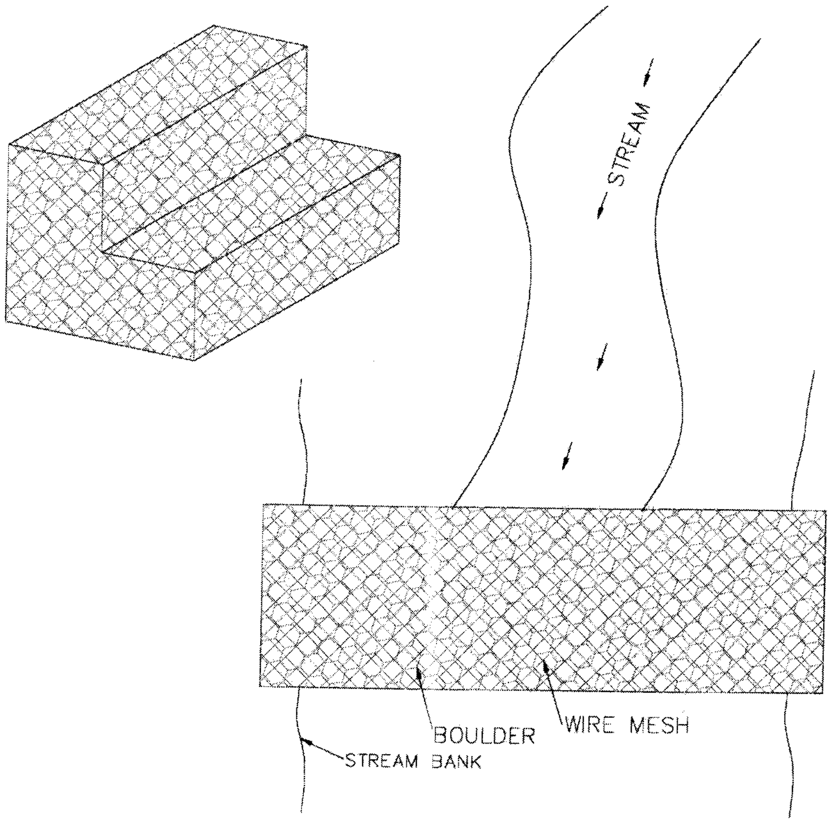


Figure 6.6 : Gabion Structure

- No evaporation loss from the reservoir takes place.
- No siltation in the reservoir takes place
- The potential disaster like collapse of dams can be avoided.

Such dykes are also useful across the perennial streams. Dykes of 30 cm thick brick-cement or stone cement, extending down to the compact bedrock, with mud or clay fillings in excavated portions on both sides of the wall provide a perfect impermeable barrier.

6.7.1 Management and Maintenance

The quality of water in groundwater dams is generally better than water from other water harvesting systems since water here is stored in the ground and filtered as it moves through the sandy soil. However, the shallow groundwater risks contamination from seepage of surface pollutants.

Once the clay wall groundwater dam is built, it demands very little maintenance. However, the user community should check the dam site for erosion after each large flood. Any erosion should be corrected by refinishing the clay wall and protecting it with large rocks, which cannot be moved by smaller flows. With masonry groundwater dams, any channel erosion that might undermine or expose the dam should be arrested by filling it with large boulders and using silting traps to catch sandy material. It is a similar prescription for raised dams. With the raised dam, the gravity pipe should be checked frequently along its length for signs of damage or leaks and the tapping station should be kept in good order. Also with groundwater dams there may be a need to control water use, thus requiring supervision, clear agreements among the users and

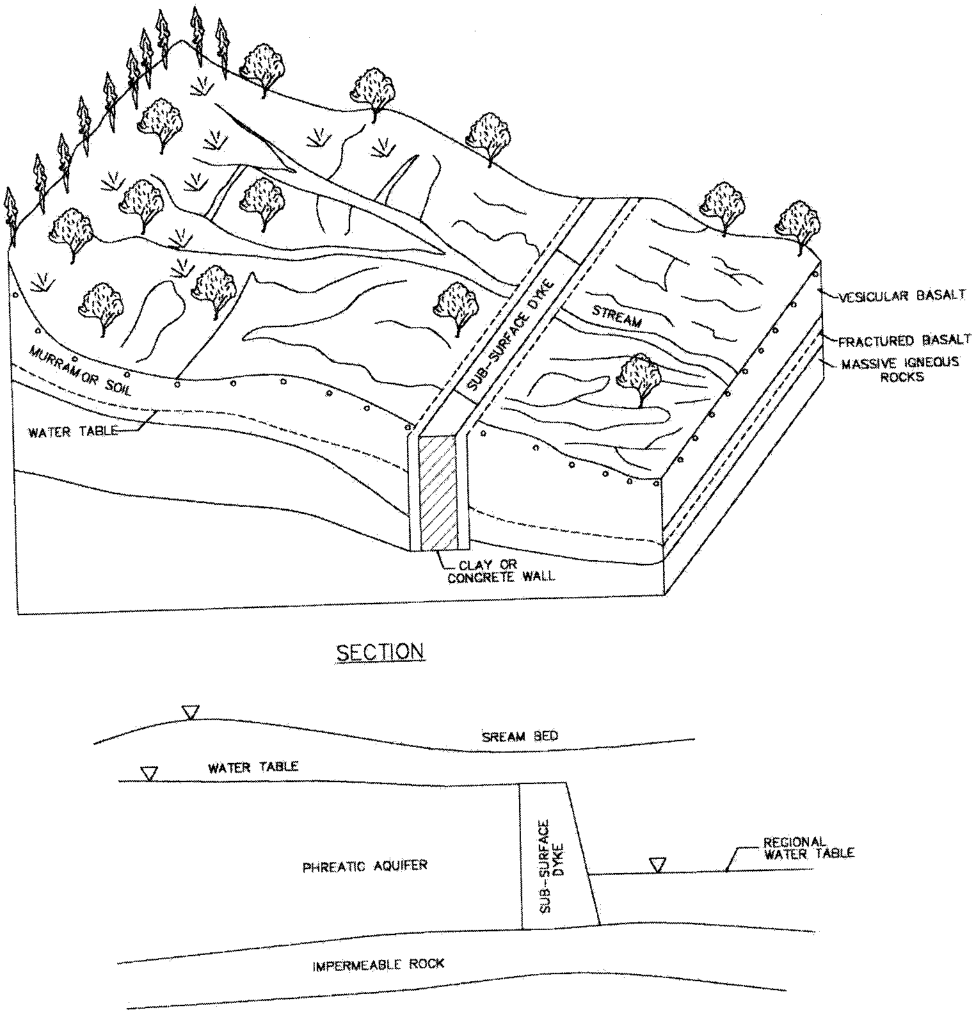


Figure 6.7 : Artificial Recharge through Underground Bandhara

monitoring of the available storage. For the latter, a piezometer may be installed, which allows a caretaker or watchman to estimate how much water is left and if rationing has to be made more strict.

The precautions to manage and maintain water quality and reliability in sub-surface and sand dams and to reduce the risk of contamination are:

- Ensure there is no open defecation in/ near the river bed upstream
- No tethering of donkeys at the well
- Check bathing/ laundry upstream of the dam
- There must be no pit-latrines on the bank upstream
- There must be no unprotected wells in the river bed near the protected well
- Regular maintenance of the protected well-site and the hand pump must be assured
- Ensure use and maintenance of a downstream gravity out-take
- Avoid use of pesticides/ chemicals upstream of the dam site

6.8 NADIS

Nadis are small excavated or embanked village ponds, for harvesting meagre precipitation, to mitigate the scarcity of drinking water in the Indian desert. Water from these is available for periods starting two months to a year after rain, depending on the catchment characteristics, the amount of rainfall received and its intensity. This is an ancient practice and the Nadis are the most important water sources of the region. The first recorded masonry Nadi was constructed in 1520 A.D. near Jodhpur during the regime of Rao Jodhaji. Since Nadis are the vital water sources in the Indian arid zone, each village has one or more of these, depending on the water demand and availability sites.

Location and size of a Nadi depends on the catchment area it commands. It should be located in areas with lowest elevation to have the benefit of natural drainage and need for minimum excavation of earth. Surface of catchment area should preferably be impermeable. If necessary, the catchment area may be prepared artificially by soil condition wherever possible. Silt Trap should be provided at the inlet point to prevent sediment load form entering the Nadi. The size of the silt trap should be designed keeping in view the site conditions, duration and intensity of rainfall. Silt Trap should be cleaned regularly. The inlet should be stone pitched to prevent soil erosion. A mesh should be provided at the inlet to prevent floating material from entering the Nadi. The slope of the sides shall depend on the soil condition. In order to prevent seepage losses through sides and bottom, these are lined with LDPE sheeting. This should be embedded properly. The outlet should be stone-pitched to prevent soil erosion. An exploitation well should be constructed at a suitable point of Nadi to facilitate withdrawal of water. The well has to be constructed by raising two masonry wing walls and one front wall. A suitable platform fitted with iron fixtures for Pulley and Hand Pumps is necessary.

Table 6.2 : Effect of Rainfall on Nadi Volume/ Catchment Area Ratiounder different Physiographic Settings

Physiographic Setting	Nadi Volume m³ per ha of Catchment Area for Various Rainfall Figures				
	250-300	300-350	350-400	400-450	450-500
Dune Complex	55.3	110.5	53.0	37.1	-
Sandy plain	120.4	128.0	131.1	137.3	-
Younger alluvial plain	-	-	-	349.9	1066.9
Rocky/ gravel pediment	491.7	518.9	785.5	1644.7	2264.7

The traditional Nadis are affected by heavy sedimentation, high evaporation and seepage losses and water pollution.

The highest Nadi volumes per unit of catchment areas were observed on dunes and sandy plain area with slopes of 1-2% (Table 6.3). In younger alluvial plains, rocky/ gravel pediments, Nadi volumes per unit of catchment area, increase with increasing slope. Similarly, the Nadi volumes per unit of catchment are under different rainfall zones are given in Table 6.2. In dune complexes, the Nadi volumes were highest in the 300-350 mm rainfall areas because of stabilisation of the sands with grass.

Nadi usually have large surface areas compared to the volume of water stored and heavy losses occur since evaporation is a function of surface area. On the other hand, seepage increases with the depth of the stored water. LDPE lining was found to be useful in avoiding seepage losses (Figure 6.8).

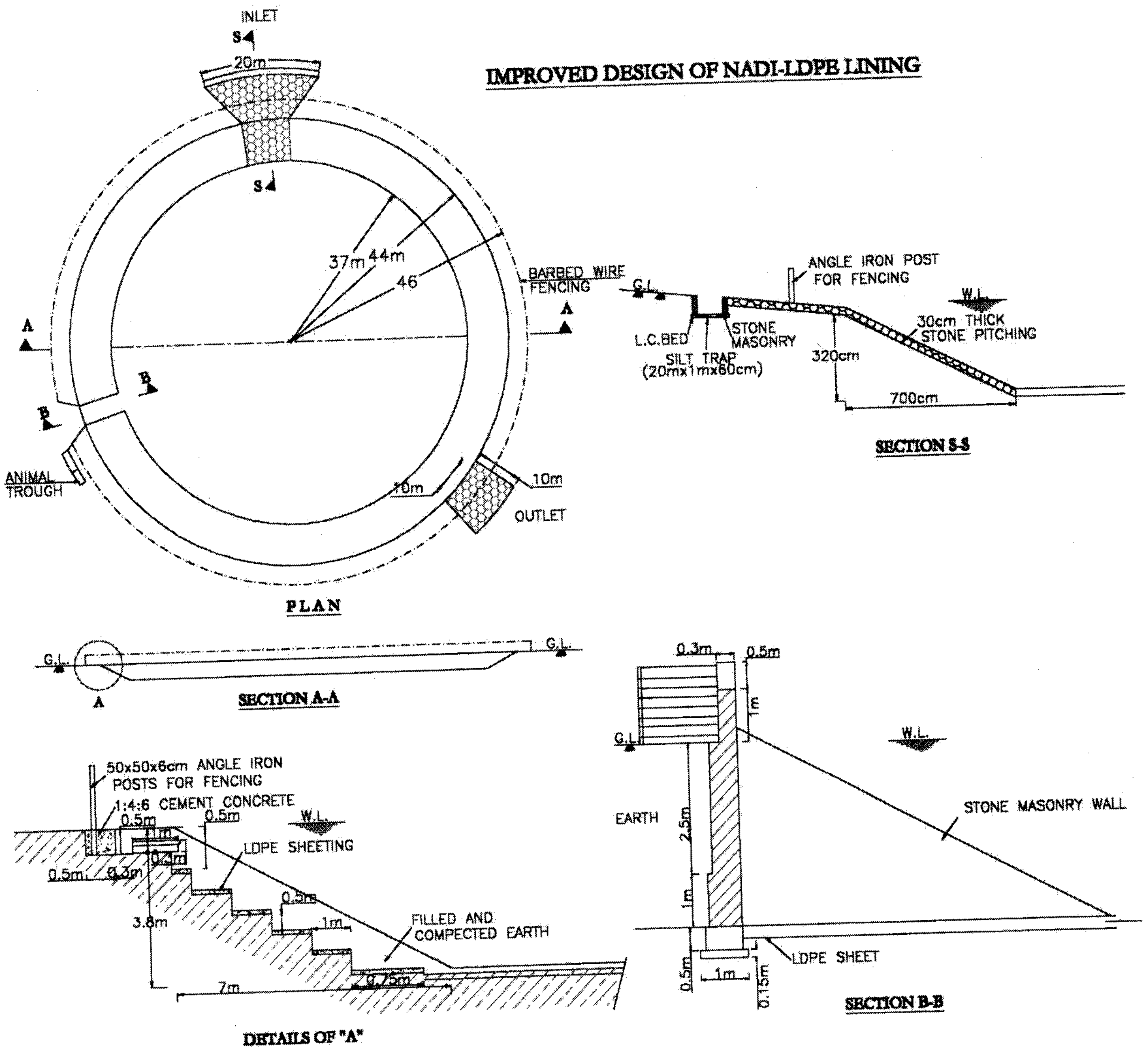


Figure 6.8 : Improved Design of Nadi — LDPE Lining

Table 6.3 : Effect of Ground Slope on Nadi Volume/ Catchment Area Ratio under different Physiographic Settings

Physiographic Setting	Nadi Volume m³ per ha of Catchment Area in Different Slope Groups (%)					
	<-1	1-2	2-3	3-4	4-5	>-5
Dune complex	54.3	108.2	45.7	29.0	-	13.8
Sandy plain	110.6	154.2	121.1	-	-	-
Younger alluvial plain	466.4	578.5	731.8	-	-	-
Rocky/ gravel pediment	51.4	421.5	724.7	945.9	-	1236.5

Precaution should be taken while adopting Nadis due to poor maintenance and improper utilisation, the Nadi water is highly polluted and is not free from health hazards. Guinea worm, water hyacinth, mosses, algae are invariably present in large quantities. Infectious diseases like guinea worm are associated with the village where nadi water has been in use.

6.9 KHADIN

The system is site specific needing a large natural, high runoff potential catchment in proximity of plain valley land. The ratio of Khadin area to catchment area, depending on type of catchment, varies from 1:12 to 15. Since a decade, irrigation department of State has started making many new Khadins at various locations. Under Desert Development Programme also new Khadins are being constructed. Figure 6.9 shows plan and section of a typical Khadin. However, these need proper management.

Before starting the construction of Khadin, bund position is aligned and then about 15 cm layer of natural ground surface is scrapped out. The earth work is done in layers of 30 cm thickness and then compacted by ramming with hand hammer, sheep foot roller or road roller. For providing shape to the bund, a profile at every 20 m length of bund is erected. Provision is made for over flow by providing cement-concrete spill-over structure with stone pitching, downstream to check erosion. Pipe outlet is also provided at centre of bund to drain out standing water. After completion of Khadin, levelling of land near bund is done for uniform spreading of water. Seeding of grass on bund during rainy season is done for its stabilisation.

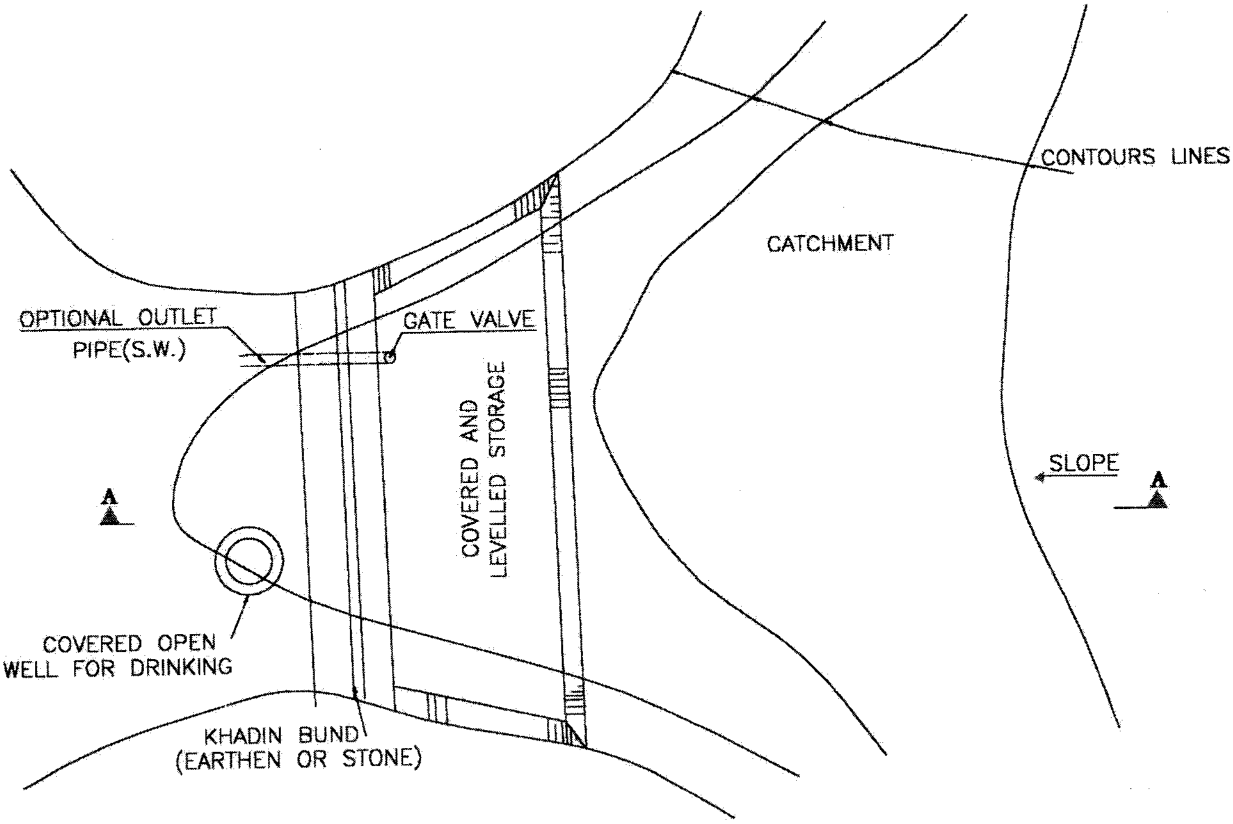
In big Khadins, making small dug wells outside Khadin bund is an innovative method developed by ancient people to have conjunctive use of water as also to encourage seeping out of saline water to prevent salinity development in Khadin in course of time.

Following improvements in construction of Khadin are suggested:

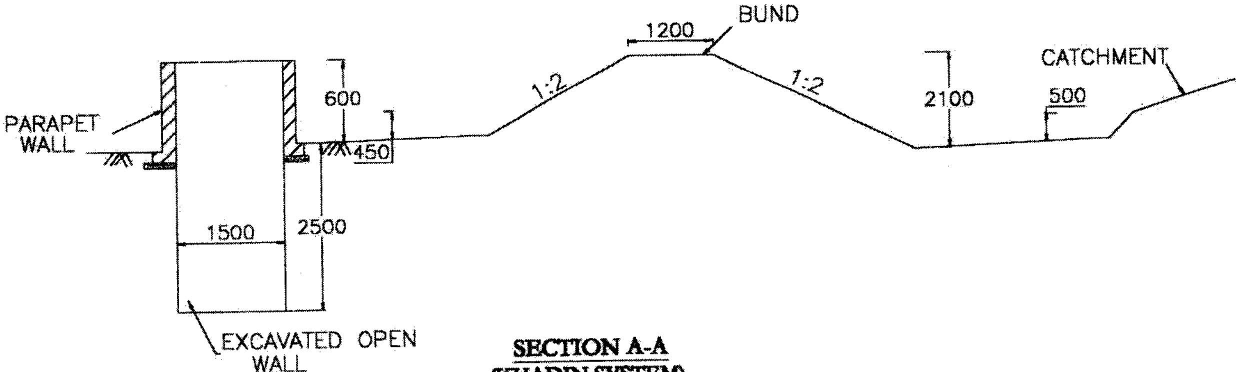
(i) Khadin is basically a runoff agricultural system. Though site specific, with good management it can make arid wasteland productive. Modern experience is however limited to few isolated projects. Intensive techno-economic evaluation in several regions with different climates, soils and crops are needed to identify its potential for the future.

(ii) To make runoff agriculture more effective, there is a need to develop crops better suited to this system.

(iii) Though it is primary runoff agriculture, a lot of water gets stored on the land, partly going down deep, side ways and much is lost through evaporation. For conservation and conjunctive use of such collected water, research work on models for suppression of evaporation losses, is needed. The feasibility of dug wells around Khadins for drinking water supplies can be explored.



PLAN



SECTION A-A
(KHADIN SYSTEM)

Figure 6.9 : Khadin System.

CHAPTER - 7

Watershed Development and Management

7.0 CONSEQUENCES OF WATERSHED DEGRADATION

In nature there is perfect balance and harmony between land, vegetation and water. If we disturb this balance, the consequences are serious for human and cattle life. We all know that vegetation depends on land and water. We know this from our experience of how agricultural crops, trees, plants, grasses etc. grow. On the other hand water, both surface and sub-surface, depends on land and the vegetative cover on it. Land with thick soil cover especially with a natural layer of humus absorbs good amount of rainwater, which gradually seeps deeper into lower strata of soils/ rocks to recharge ground water. Thick vegetative cover not only prevents erosion of the topsoil but also traps considerable amount of rainwater thereby enhancing the recharge. It is this water, which we draw from wells and hand pumps and part of it appears as flow in streams and rivers.

Over the last about a hundred years, and more so since Independence, the increasing pace of developmental works and steep rise in population has led to large scale deforestation. This, in turn, has had many adverse effects on land viz. drastic reduction in water holding capacity, increased intensity of drainage of rainwater and excessive erosion of land surface. The drainage areas of rivers and streams, known as "Watersheds" have been particularly worse affected by this process. This has resulted in excessive loss of topsoil, increased intensity of floods during monsoon season, alarming lowering of ground water table and reduction in lean-season flow in rivers and streams. This in turn has reduced availability of both surface and ground water causing the present water scarcity in many parts of the country.

Unfortunately, in nature the degradation process continues unabated. Once the land deteriorates beyond a limit, it cannot support enough and right type of vegetation to prevent further deterioration. Thus the land continues to deteriorate till it becomes totally barren with even worse implications for surface and ground water sources. The economic cost of mindlessly disturbing the delicate balance in nature is enormous and the consequent human suffering is appalling.

This process of environmental degradation is irreversible in nature and corrective measures are very tedious and expensive and are often only partially effective.

7.1 NEED FOR TIMELY ACTION

If corrective measures are not taken in right earnest to improve the condition of our watersheds and maintain them, we may face a serious water crisis in not too distant a future. The objectives of these measures are to reduce soil erosion, augment soil moisture and retard the drainage of rainwater. These measures have two main components viz.

- Restoration of the vegetative cover to bring the watershed close to its original pristine condition.
- Artificial land treatment to strike a balance between the needs of development on one hand and protection of watershed on the other.

These measures, if taken up on a large scale to cover the entire drainage area (or watershed) of a stream, can significantly improve lean season flow in the stream and augment the yield from ground water sources like wells, hand pumps etc.

7.2 WATERSHED UNIT FOR PLANNING

In the context of water harvesting, watershed improvement and management should cover any small drainage area of a local khud or gully or waterway of a drainage channel or a depression where rainwater concentrates after a heavy rain. The size of a drainage area or watershed for planning purposes should be about 40-50 ha so that it could be developed and managed by the village community.

7.3 GENERAL PLANNING APPROACH

Each watershed has unique characteristics and problems. Its treatment and management would therefore require careful consideration of various site specific factors like topography (shape, configuration and slope of the land), nature and depth of soil cover, type of rocks and their pattern of formation and layout, water absorbing capacity of land, rainfall intensity, land use etc. However, as a general rule watershed improvement measures are taken in the following manner as shown in Table 7.1.

Table 7.1 : Watershed Improvement Techniques

Nature of Terrain	Improvement Techniques
• Hill tops and upper reaches of watershed	Afforestation
• Steep hill slopes a little lower down	Development of grass lands
• Lower parts of watershed	(i) Contour bunding and terracing of agricultural fields
	(ii) Contour trenching
	(iii) Contour cultivation
	(iv) Strip cropping
	(v) Gully plugging
	(vi) Stream bank protection against erosion
	(vii) Farm ponds
	(viii) Control & regulation of grazing

Contour Trenching

This consists of excavating shallow/ intermittent trenches across the land slope and forming a small earthen bund on the downstream side. Plantation is done on the bund to stabilize the bund. The trenches retain the runoff and help in establishment of the plantations made on the bund.

Trenches are useful where the land surface is fairly porous and rainwater collected in trenches can quickly percolate into the ground. The spacing of trenches and their size i.e. length, width and depth should be adequate to intercept about 50% of the peak rainfall in semi-arid regions i.e. with annual rainfall of about 400-550 mm.

The trenches should be cleaned and desilted periodically.

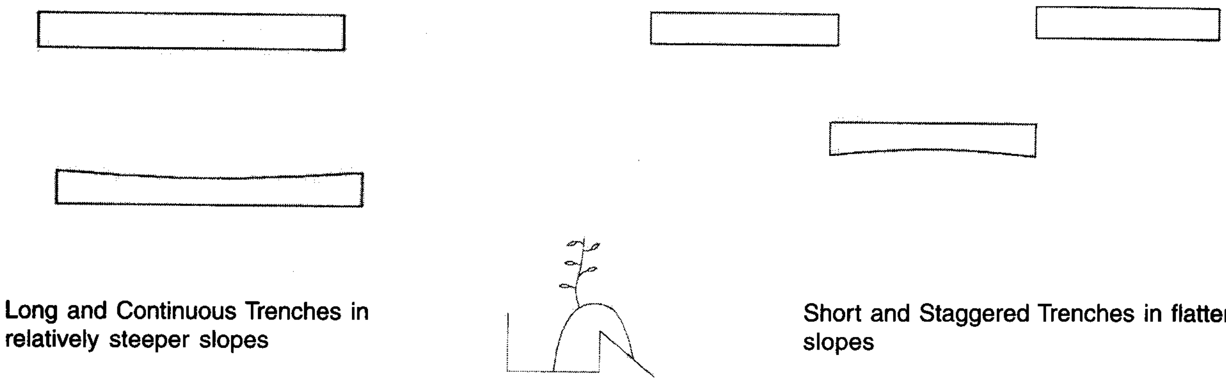


Figure 7.1 : Contour Trenches

Controlled Grazing

Grazing of hill slopes by cattle denudes the vegetative cover and accelerates soil erosion. As such, grazing of hill slopes should be allowed in controlled manner. For this it is necessary to develop pastures separately and to adopt stall-feeding of cattle.

Bench Terraces

These consist of series of platform excavated on the slope. Depending upon the rainfall conditions and crops to be grown, terraces are constructed flat, sloping inwards and sloping outwards.

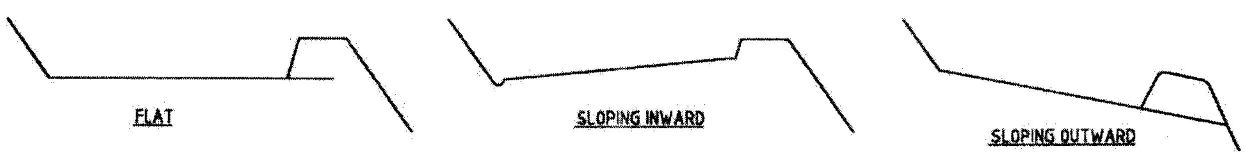


Figure 7.2 : Bench Terraces

Continuous bench terraces differ from the tree-crop or orchard terraces. There are no idle spaces between terraces in the former case while they are prominent in the later. On a hill slope, bench terraces for vegetable and short-term crop usually are continuous. The lower terrace starts exactly from the line where the upper terrace ends. In other words, the cut section of the lower terrace begins where the fill section of the upper terrace ends. So we see benches between the riser slopes in a continuous manner. Unless the soil is extremely porous, such terraces have down-the-slope outlets, like a grassed channel with wooden drops or a prefabricated concrete channel with short drops or any other erosion control structures on the steep channel. The terraces have about 5 percent hillward grade. The riser slopes vary with the land slope (upto 30% land slope 1:1, above 30% and upto 60% land slope 0.75:1 and above 60% land slope 0.5:1). A longitudinal grade of about 1% is provided to lead the terrace water to the outlet. Riser slopes are grassed.

Contour Cultivation

This consists in carrying out different agricultural operations like ploughing, planting and inter-culture in horizontal lines across the sloping land. Such practices help in retaining rainwater and retarding erosion. These measures are effective when land slope is about 2% and less.

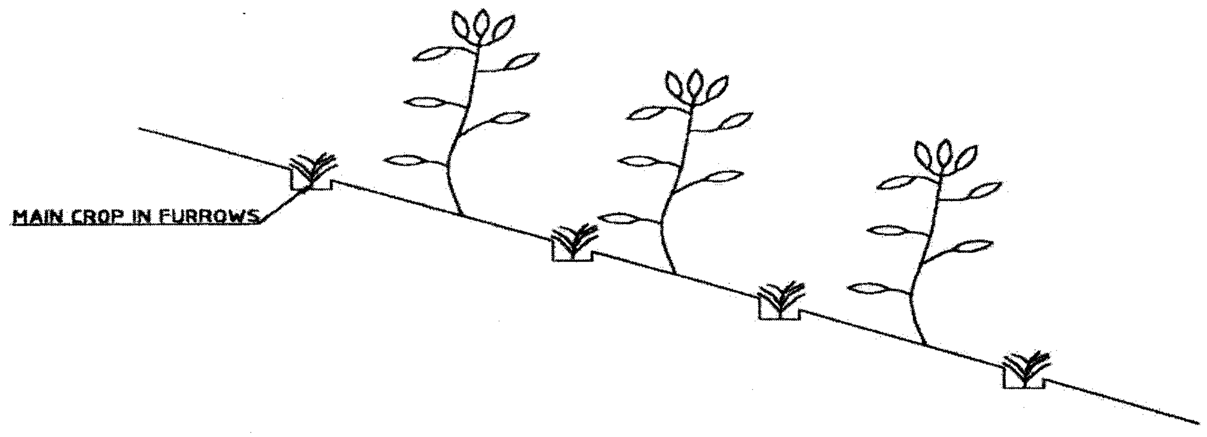


Figure 7.3 : Contour Cultivation

Strip Cropping

This involves growing parallel rows of erosion resisting crops to control loss of surface soil, with other crops grown in between.

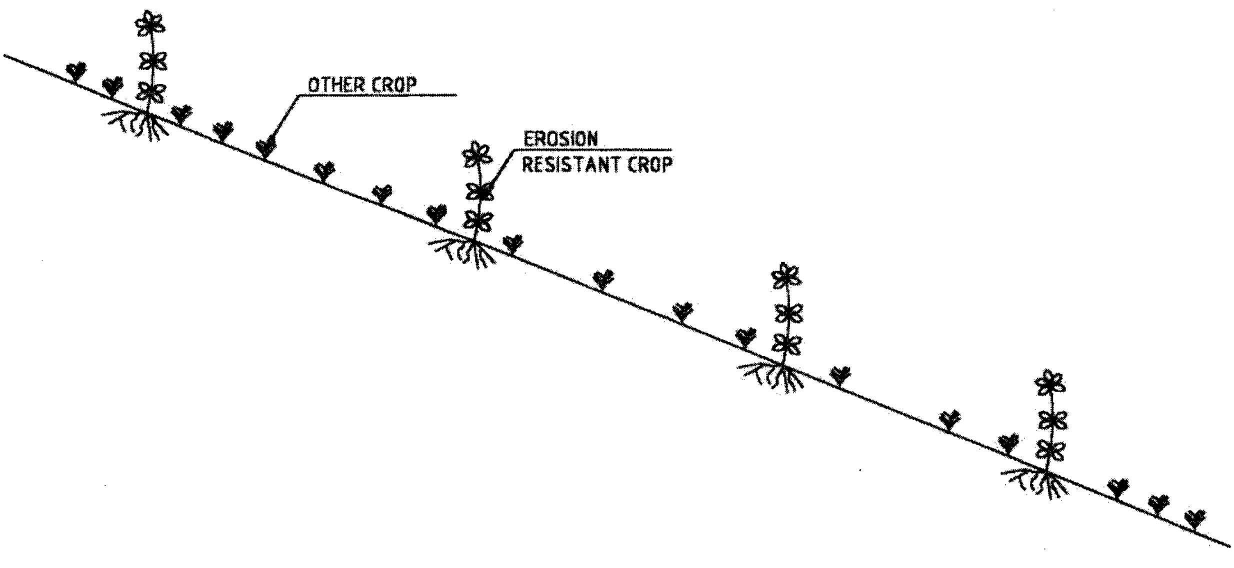


Figure 7.4 : Strip Cropping

Gully Plugging

Gullies are a symptom of functional disorder of the land, improper land use and are the most visible result of severe soil erosion. They are small drainage channels, which cannot be easily crossed by agricultural equipment.

The gully plugging measures include vegetative plantings and brushwood check dams, boulder bunds, brick masonry and earthen bunds or a combination of both, sand bag plugs etc. The specifications for gully plugs are given in Table 7.2.

Table 7.2 : Specifications for Gully Plugs

Slope of Gully Bed %	Width of Gully Bed(m)	Location	Type of Gully Plug	Vertical Interval
0-5	4.5	Gully bed	Brush wood	3.0
	4.5-10.5	Gully bed	Earthen	2.25-3.0
	7.5-15.0	At the confluence of two gullies	Sand bag	
	7.5-15.0	At the confluence of all branches of a compound gully	Brick masonry	
5-10	4.5	Gully bed	Brush wood	3.0
	4.5-6.0	Gully bed and side branch	Earthen	1.5-3.0

For gullies in which no significant runoff is expected from upstream, earthen gully plugs of 1.1 m cross-section with a grassed ramp of 22.5 cm below the top level are provided at 45-60 m intervals. For gullies in which excessive runoff from the top is expected, an earthen gully plug of 2.2 m cross-section is provided with a pipe outlet. The diameter of the R.C.C. spun pipe is 15 cm for a discharge of 0.03 to 0.09 cumecs coming from a catchment area of upto 1.6 ha. A composite check dam of earth and brick masonry is necessary for catchment areas larger than 1.6 ha. The first structure is located at the confluence of two or more gullies. For long gullies, more such structures are built either at 1.2 m vertical interval or 120 m horizontal interval.

Contour Bunding

This measure involves construction of horizontal lines of small earthen or boulder bunds across the sloping land surface.

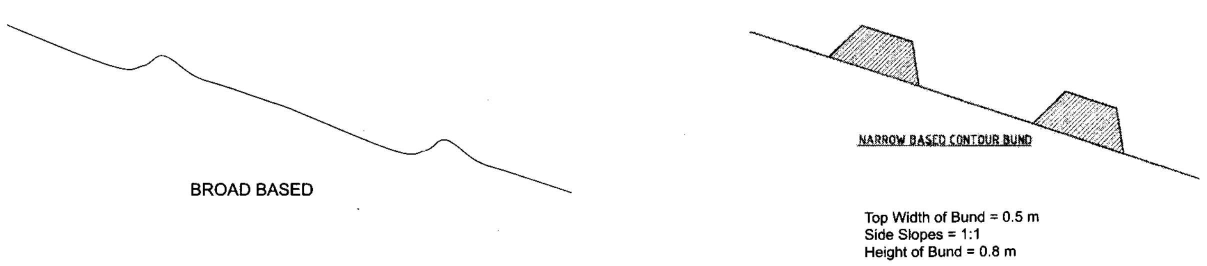


Figure 7.5 : Contour Bunding

The term contour bunding used in India is same as "level terraces" and "ridge type terraces". The bunds act as barriers to the flow of water and at the same time impound water to build up soil moisture storage. The spacing of bunds is so arranged that the flowing water is intercepted before it attains the erosive velocity. The vertical interval between the two bunds is determined by the following formula:

$$V = 0.3 \left(\frac{S}{3} + 2\right)$$

Where,

S = Degree of slope in percent

V = Vertical interval between two bunds

The spacing is increased by 25% in highly permeable soils and decreased by 15 percent in poorly permeable soils. It is always desirable to remove local ridges and depressions before building contour bunds. If levelling is not economical, a deviation of 10 cm for crossing the ridges and 20 cm for crossing the depressions.

For narrow bunds the top width is 50 cm, height is 80 cm and side slopes of 1:1. Cross sectional area in sq.m of broad based contour bunding with different height and side slope, is recommended as given in Table 7.3.

Table 7.3 : Recommended Side Slope for different Heights of Bund

Height of bund (m)	Side Slope				
	4:1	5:1	6:1	7:1	8:1
0.30	0.36	0.45	0.54	0.61	0.72
0.40	0.64	0.84	0.96	1.12	1.28
0.50	1.00	1.25	1.50	1.75	2.00

The design of cross-section of contour bund, which can store runoff excess from 24 hrs rainstorm, can be done with the help of the following equation.

$$h = \frac{Re \times VI}{50}$$

Where,

h = Depth of impounding in m near the bund

Re = 24 hours rainfall excess in cm

VI = Vertical interval in m

Using the above equation, height of impounding required for 10 years frequency (or any other frequency) can be obtained which will not cause any spill over. To the depth of impounding 'h', the free board of 25 to 30% may be added.

Stream Bank Protection

Eroding stream banks not only damage adjoining agricultural lands but also contribute large quantities of sediment load to the river systems. Under the watershed management programme, bank protection of only small/ minor streams are included. However, works of this nature should only be taken up if the benefits justify the cost of construction.

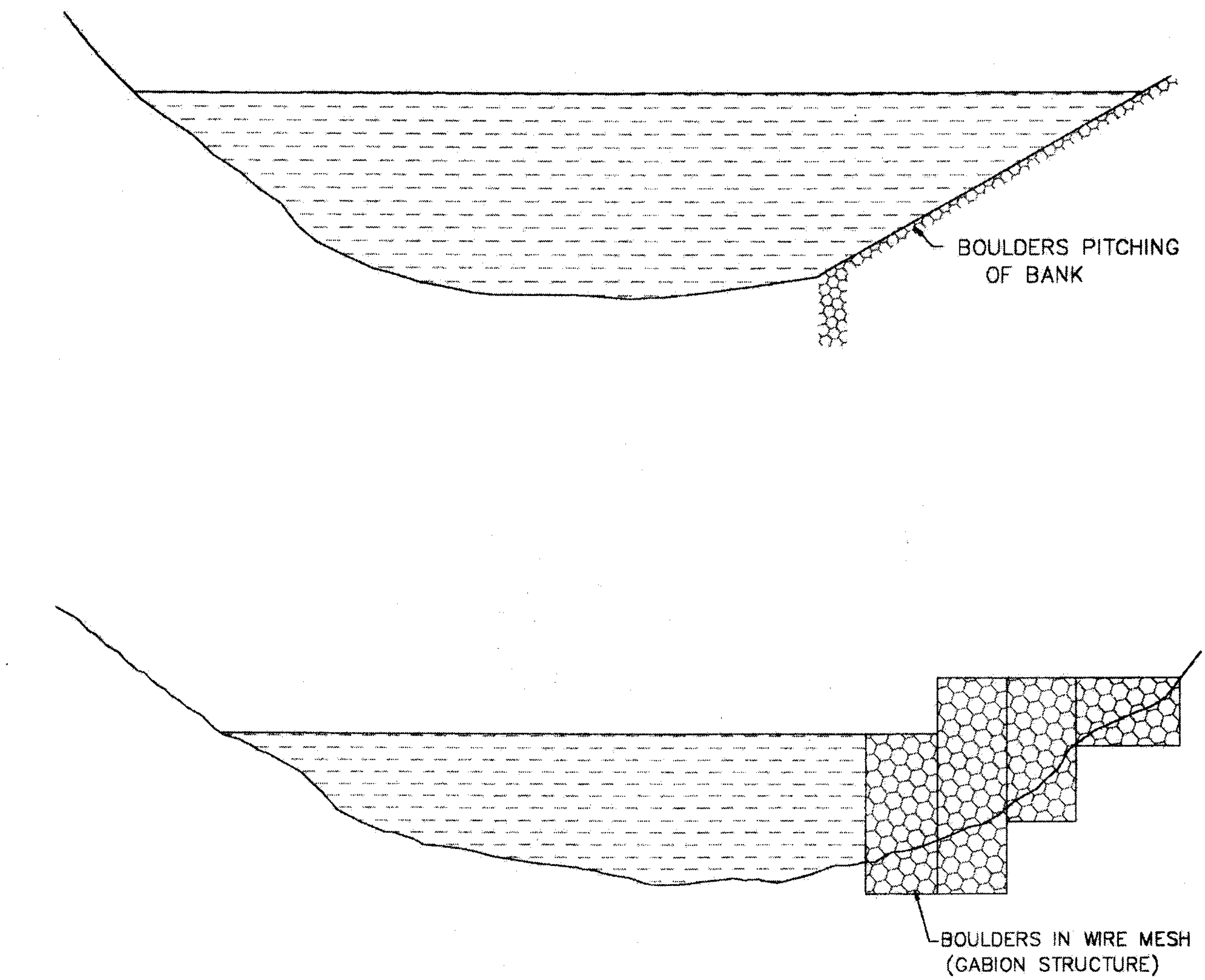


Figure 7.6 : Stream Bank Protection

The works usually involved are in the nature of boulder pitching on banks of about 20-30 cm thickness after dressing the bank to a stable slope. Where the flow velocity of the stream is high (1.5 m/sec or more) gabion structures should be built at the toe of the bank with foundation firmly embedded in the streambed and bank.

Farm Ponds

There is very little qualitative difference between a pond/ tank, which usually serves the population of a village, and farm pond, which serves an individual agricultural field. Farms ponds greatly vary in size depending upon the rainfall. In high rainfall areas of Orissa, for example, these have only a few metres of length and width and are built across the flow path of natural drainage channels. Surplus water from one pond spills over to a lower pond. In some cases a series of farm ponds are built on one single stream. Each pond caters to the irrigation needs of one farm and also augments ground water recharge.

In any watershed management programme farm ponds are an important component. Farm ponds are useful in storing water for irrigation. They also retard sediment and flood flows to the downstream river system. In relatively flatter terrain with good soil cover, a farm pond has an earth section with usually 3:1 side slopes on waterside and 2:1 side slopes on the downstream face (A uniform side slope of 2½:1 on both sides can be adopted at some sites). The sides are sodded. A natural depression nearby may be used as an earthen spillway with minimum channel section construction. A pipe drop inlet spillway and an irrigation outlet are also provided. A key trench is dug to give a good bondage between the original ground and the filled earth. Storm riprap against wave action may be required in some cases. The pond crest usually serves as a farm road (provide 4.25 m roadway for motorable roads).

A good pond site should possess the following traits:

(i) The site for the earthen bund should be narrow gorge with a fan shaped valley above so that a small amount of earthwork gives a large capacity.

(ii) The drainage area above the pond should be large enough to fill the pond in 2 or 3 spells of good rainfall.

(iii) The pond should be located where it could serve a major purpose: e.g. for irrigation, it should be above the irrigated fields and for sediment control it should intercept the flow from the most erodible parts of the catchment.

(iv) Junction of two drainage channels or large natural depressions should be preferred.

(v) The land surface should not have excessive seepage losses unless it is meant to serve as a percolation tank for ground water recharge.

Planning and design aspects of farm ponds are dealt with more or less in accordance with those for ponds/tanks as discussed in Chapter-6.

CHAPTER - 8

Recommended Water Harvesting and Watershed Management Works

8.0 AGRO-CLIMATIC ZONES

Based on the requirements of agricultural development, the country has been demarcated into 15 agro-climatic regions. However, for promoting rainwater harvesting with particular reference to augmenting drinking water availability in rural areas, these regions have been slightly modified and an additional region viz. "Himalayan foot hills" has been added. Broad features of these 16 regions and the recommended water harvesting measures for each region are discussed in the following paras.

8.1 HUMID NORTH-WESTERN HIMALAYAS

This region comprises hilly areas of Jammu & Kashmir, Himachal Pradesh and Uttaranchal. This cold region has skeletal soils, podsolic soils, mountain meadow soils and hilly brown soils. The terrain is highly undulating with steep slopes. The soils are generally silty loam and are prone to erosion. Landslides are common in denuded hill slopes especially where there are excessive human settlements with good network of roads and hill tracks. Water harvesting measures recommended for the region are:

(i) Roof water harvesting
(ii) Diversion of perennial springs and streams water in storage structures
(iii) Village ponds
(iv) Collection from hill slopes

8.2 HIMALAYAN FOOT HILLS

The region is characterized by slope-wash material comprising loose soil deposits underlain by boulders and pebbles. These deposits generally have moderate to high percolation rates where the soil cover is thin. In topographic lows the thick soil cover provide scope for dug ponds with fairly good water retention capacity.

Often the ground water gradient is steep which is conducive to quick drainage of ground water into nearby streams. The region covers foothill areas of Jammu & Kashmir, Himachal Pradesh, Punjab and Uttaranchal in the west and parts of West Bengal, Assam and Arunachal Pradesh in the east. The recommended structures are:

(i) Collection from hill slopes

(ii) Village ponds

(iii) Contour trenching

8.3 HUMID HIGH RAINFALL NORTH-EASTERN ZONE

The region is characterized by complex geological formations with rocks either exposed on surface or under moderately thick soil cover. The soils are generally fragile and prone to severe erosion. The region covers large areas of Sikkim, Darjeeling hills, Arunachal Pradesh, Meghalaya, Nagaland, Manipur, Tripura, Mizoram, Assam, and Jalpaiguri and Cooch Behar districts of West Bengal. These are high rainfall areas with high surface runoff. In some areas because of adverse topography and hydrogeological conditions, ground water development is not techno-economically viable while in some others the habitations do not have convenient access to the potential ground water sources, which are usually found in topographic lows like stream beds and intermontane valleys. The recommended measures are:

(i) Roof top harvesting

(ii) Diversion of perennial springs and streams in storage structures (tanks)

8.4 HUMID ASSAM-BENGAL PLAINS

The region covers parts of the lower Gangetic plains comprising alluvium with diverse mix of sand, silt and clay. The main topographic features of the region are the fluvial plains, and lower and upper alluvial terraces. The fluvial plains are characterized by abandoned river channels, ox-bow lakes and the land surface carved by numerous perennial and seasonal streams. Though the region receives good rainfall, there are often drought like situations due to long gaps between successive spells of rainfall especially in areas drained by small seasonal streams. The natural drainage channels and streams flowing through the alluvial terraces severely erode their banks. Because of excessive agricultural activity coupled with unscientific land management the topsoil is prone to erosion.

The ground water usually has excessive iron and mica. Excessive arsenic is found in about 1,000 habitations in West Bengal. However, ground water development in the region especially in Assam is constrained by, interalia, lack of reliable power supply. The recommended water harvesting measures are:

(i) Tanks

(ii) Check dams/ Anicuts

(iii) Gully plugging

(iv) Contour bunding

8.5 SUB-HUMID AND HUMID SUTLEJ-GANGA ALLUVIAL ZONE

The region covers parts of Punjab, Haryana, Uttar Pradesh and Bihar and is served by middle reaches of the Sutlej basin and the lower and middle reaches of the Ganga basin. The eastern part of the region covering plains of Bihar and eastern Uttar Pradesh receives good rainfall but due to its uneven distribution in space and time, some areas face sub-humid conditions and even drought like conditions in the years of below-normal rainfall. The southern part of the Sutlej basin has sub-humid climate.

During the last 5 decades the region has seen large-scale development of ground water for irrigation. This has resulted in lowering of ground water table in many areas. The problem of drinking water supply is, however, mainly because of non-sustainability of the water sources for various socio-economic reasons. The recommended water harvesting measures for the region are:

(i) Ponds
(ii) Check dams
(iii) Gully plugging
(iv) Contour bunding

8.6 NORTH-WESTERN SEMI-ARID AND ARID ZONE

This zone consists of western Rajasthan, which is characterized by hot sandy desert, erratic rainfall, high evaporation, absence of any perennial rivers and scanty vegetation. Because of low rainfall and high evaporation the natural ground water recharge is negligible. The ground water table in most places is at considerable depth. Potable ground water at reasonable depths is found at a few locations.

Agriculture in the area, except the command of the Indira Gandhi Nahar Pariyojna (IGNP) is rainfed. There is extensive ground water exploitation for drinking water supply in rural areas. The rainwater harvesting measures recommended for this zone are:

(i) Nadi/ Talab
(ii) Tanka
(iii) Khadin
(iv) Percolation tanks
(v) Anicuts
(vi) Gully plugging
(vii) Contour bunding

8.7 CENTRAL SEMI-ARID VINDHYAN ZONE

This zone comprises southeastern districts of Rajasthan, southern districts of Uttar Pradesh and central parts of Madhya Pradesh. The area has diverse topography with ravines in some parts of Narmada Valley and hills in others. Nearly one third of the land is not suitable for cultivation. Irrigation and cropping intensities are low. While the rainfall in areas lying in Madhya Pradesh is fairly good being of the order of 900 mm, it is as low as 350 mm in the areas falling in Rajasthan and Uttar Pradesh. Because of the predominantly hilly terrain the monsoon runoff is high which causes extensive soil loss from hill slopes and erosion of riverbanks. Ground water movement from higher levels to lower levels is significant which is evident from the depletion of water levels in wells and hand pumps especially those along stream banks. The water harvesting and watershed development measures recommended are:

(i) Ponds
(ii) Check dams
(iii) Contour bunding
(iv) Gully plugging
(v) Sub-surface dykes

8.8 HIGH RAINFALL HIGH RUNOFF CHHOTANAGPUR PLATEAU

This area is characterized by soils of medium to shallow depths and undulating topography. Because of steep slopes, high rainfall intensities and long rainy spells the surface runoff is high which causes extensive soil loss due to rill and gully formations and stream bank erosion. The problem is further compounded by unscientific agricultural practices. The region covers the entire Jharkhand state and adjoining hilly areas of Bihar, West Bengal and Orissa. Because of adverse topography and pattern of human settlements in the hilly terrain potential ground water sources are not within convenient reach of all the rural population. Improvement of watersheds and local rainwater collection and storage are considered necessary to improve water availability. The recommended water harvesting practices, therefore, are:

(i) Tanks/ Ponds

(ii) Check dams/ Anicuts

(iii) Gully plugging

(iv) Contour bunding

8.9 MALWA PLATEAU & NARMADA BASIN

The region forms a major part of peninsular India with an annual rainfall of about 900 mm. The predominant soil type is deep black soil. Because of low permeability of soil natural ground water recharge is mainly through fissures and joints in exposed rocky strata and through streambeds. The water harvesting methods recommended for the region are:

(i) Ponds

(ii) Check dams

(iii) Sub-surface dams

8.10 SOUTH-CENTRAL DECCAN PLATEAU ZONE

The region covering parts of Andhra Pradesh, Tamil Nadu, Karnataka and Maharashtra is typically semi-arid. The region is characterized by highly diverse geological setting with predominance of hard basaltic rocks and variable rainfall. Ground water occurs under varying conditions in shallow and deep aquifers. Surface strata and soil types are by and large conducive to natural ground water recharge. The recommended water harvesting structures are:

(i) Ponds

(ii) Check dams

(iii) Percolation tanks

(iv) Bandhara

(v) Gully plugging

(vi) Sub-surface dams

(vii) Contour bunding

8.11 CHHATTISGARH PLATEAU ZONE

The region comprises Chhattisgarh state and southwestern Orissa hills. The geological and geomorphological characteristics of the region are more or less similar to those in South-Central Deccan Plateau Zone. Even though rainfall in the region is relatively higher, the recommended structures are the same as those for the South-Central Deccan Plateau Zone.

8.12 SOUTH-EASTERN BROWN/ RED SOIL ZONE

The region covers Pachamalai and Kadavur hills and pediplain areas of Tamil Nadu and Veligond hills and part of the plains (excluding the 4-5 km wide coastal belt) of Andhra Pradesh. The rainfall in the region varies from about 818 mm in Perambalur district of Tamil Nadu to 1,148 mm in Nellore district of Andhra Pradesh. Runoff coefficient varies from 6.64 to 10.67 percent in plains and from 20 to 45 percent in plateau and foothill areas.

The recommended water harvesting structures for the region are the traditional ponds/ tanks. Besides percolation tanks and sub-surface dams are suggested in the vicinity of drinking water sources like dug wells, hand pumps and tube wells.

8.13 SOUTHERN VARIABLE RAINFALL, MIXED SOIL ZONE

The region covers southern parts of Maharashtra and west-central parts of Tamil Nadu. It has a highly undulating and dissected landform with an elaborate natural drainage system. Distribution of rainfall is highly uneven. The land surface is diverse in composition, the main features being sandy or younger alluvial plains and rocky gravel pediments. The soils are friable and prone to erosion, which results in excessive gully formation. The recommend water harvesting and watershed development measures are:

(i) Ponds/ Tanks/ Kunta

(ii) Nadi

(iii) Check dams

(iv) Percolation tanks

(v) Sub-surface dams

(vi) Gully plugging

8.14 SOUTHERN BI-MODAL RAINFALL ZONE

The region covers the southern most parts of Kerela, Karnataka and Tamil Nadu. The prominent physiographic features are the southern plateau and hills, east coast plains and hills and west coast plains and hills. The recommended water harvesting and watershed development measures are:

(i) Ponds/ Tanks

(ii) Percolation tanks

(iii) Check dams

(iv) Gully plugging

(v) Contour bunding

8.15 EASTERN COROMANDAL

The region covers the entire coastal belt of Orissa, Andhra Pradesh and West Bengal. The recommended measures for water harvesting, ground water recharge and watershed development are:

(i) Ponds/ Tanks/ Kunta

(ii) Nadi

(iii) Check dams

(iv) Percolation tanks

(v) Sub-surface dams

(vi) Gully plugging

8.16 WESTERN MALABAR

The region covers the western Malabar area of Kerela and coastal areas of southern Karnataka. The recommended measures for water harvesting, ground water recharge and watershed development are:

(i) Ponds/ Tanks/ Kunta

(ii) Check dams

(iii) K.T. Weirs

(iv) Bandhara

(v) Percolation tanks

(vi) Sub-surface dams

(vii) Contour bunding

CHAPTER - 9

Artificial Ground Water Recharge

9.0 WHY ARTIFICIAL RECHARGE

Average annual water resources in our river basins are estimated as 1,869 billion cubic metres (BCM) of which utilizable resources are of the order of 1,086 BCM. Out of this, 690 BCM is available as surface water and the remaining 396 BCM as ground water. The source of all this water is rain or snow. The huge ground water storage of 396 BCM is the result of rain and snowmelt water percolating through various layers of soil and rocks. However, the amount of percolation varies greatly from region to region and within the same region from place to place depending upon the amount and pattern of rainfall (i.e. number and duration of rainy days, rainfall amount and intensity), characteristics of soils and rocks (i.e. porosity, cracks and loose joints in rocks etc.), the nature of terrain (i.e. hills, plateaus, plains, valleys etc.), and other climatic factors like temperature and humidity. As a result, availability of water from sub-surface storages varies considerably from place to place.

In most low rainfall areas of the country the availability of utilizable surface water is so low that people have to depend largely on ground water for agriculture and domestic use. Excessive ground water pumping in these areas, especially in some of the 91 drought prone districts in 13 states, has resulted in alarming lowering of the ground water levels. The problem has been further compounded due to large-scale urbanization and growth of mega cities, which has drastically reduced open lands for natural recharge. In hard rock areas there are large variations in ground water availability even from village to village.

In order to improve the ground water situation it is necessary to artificially recharge the depleted ground water aquifers. The available techniques are easy, cost-effective and sustainable in the long term. Many of these can be adopted by the individuals and village communities with locally available materials and manpower.

9.1 ADVANTAGES OF ARTIFICIAL RECHARGE

Following are the main advantages of artificially recharging the ground water aquifers.

- No large storage structures needed to store water. Structures required are small and cost-effective
- Enhance the dependable yield of wells and hand pumps
- Negligible losses as compared to losses in surface storages

- Improved water quality due to dilution of harmful chemicals/ salts
- No adverse effects like inundation of large surface areas and loss of crops
- No displacement of local population
- Reduction in cost of energy for lifting water especially where rise in ground water level is substantial
- Utilizes the surplus surface runoff which otherwise drains off

9.2 IDENTIFICATION OF AREAS FOR RECHARGE

The first step in planning a recharge scheme is to demarcate the area of recharge. Such an area should, as far as possible, be a micro-watershed (2,000-4,000 ha) or a mini-watershed (40-50 ha). However, localized schemes can also be taken up for the benefit of a single hamlet or a village. In either case the demarcation of area should be based on the following broad criteria:

- Where ground water levels are declining due to over-exploitation
- Where substantial part of the aquifer has already been desaturated i.e. regeneration of water in wells and hand pumps is slow after some water has been drawn
- Where availability of water from wells and hand pumps is inadequate during the lean months
- Where ground water quality is poor and there is no alternative source of water

9.3 SOURCES OF WATER FOR RECHARGE

Before undertaking a recharge scheme, it is important to first assess the availability of adequate water for recharge. Following are the main sources, which need to be identified and assessed for adequacy:

- Precipitation (rainfall) over the demarcated area
- Large roof areas from where rainwater can be collected and diverted for recharge
- Canals from large reservoirs from which water can be made available for recharge
- Natural streams from which surplus water can be diverted for recharge, without violating the rights of other users
- Properly treated municipal and industrial wastewaters. This water should be used only after ascertaining its quality

"In situ" precipitation is available at every location but may or may not be adequate for the recharge purposes. In such cases water from other sources may be transmitted to the recharge site. Assessment of the available sources of water would require consideration of the following factors:

- Available quantity of water
- Time for which the water would be available
- Quality of water and the pretreatment required
- Conveyance system required to bring the water to the recharge site

9.4 INFILTRATION CAPACITY OF SOIL

Infiltration capacity of soil is an important factor that governs the rate of saturation of the vadose zone and thereby the efficacy or otherwise of a recharge scheme. Infiltration capacity of different soil types are done by field-tests by State Agriculture Departments and/ or the Land Use Survey Organizations. This data/ information together with maps showing infiltration rates is usually available in their departmental reports published periodically and are available with the District Agriculture Officer. At the district level, this information is available in the departmental reports of the Central and State Ground Water Boards.

9.5 AQUIFER SUITABILITY

This depends mainly on storage coefficient, availability of storage space and permeability. Very high permeability results in loss of recharged water due to sub-surface drainage where as low permeability reduces recharge rate. In order to have good recharge rate and to retain the recharged water for sufficient period for its use during lean period, moderate permeability is needed. Older alluvium, buried channels, alluvial fans, dune sands, glacial outwash etc. are the favourable places for recharge. In hard rock areas, fractured, weathered and cavernous rocks are capable of allowing high intake of water. The basaltic rocks i.e. those formed by lava flows, usually have large local pockets, which can take recharge water.

9.6 HYDRO-METEOROLOGICAL STUDIES

These studies are undertaken to understand the rainfall pattern and evaporation losses and thereby to determine the amount of water that would be available from a given catchment and the size of storages to be built. The main factors to be considered are:

- Minimum annual rainfall during the previous 10 years
- Number of rainy spells in a rainy season and duration of each spell
- Amount of rainfall in each rainy spell
- Rainfall intensity (maximum) 3 hourly, 6 hourly etc. as may be relevant for a region. As a general guide, the one, which causes significant runoff and local flooding, should be adopted.

This information/ data is usually readily available in District Statistical Reports published by the District Statistical Organisation. However, the most important source is the India Meteorological Department. For the purpose of rainwater harvesting only readily available secondary data is adequate. The alternative sources of this data are the reports of major, medium or minor irrigation projects, which have been recently completed in the region or are under construction or are planned.

9.7 HYDROGEOLOGICAL STUDIES

A detailed hydrogeological study of the project area and also the regional picture of hydrogeological setting is necessary to know precisely the promising locations for recharge and the type of structures to be built for the purpose. The aspects to be considered for a recharge scheme are:

(a) Detailed information and maps showing

- Hydrogeological units demarcated on the basis of their water bearing capabilities at both shallow and deeper levels
- Ground water contours to determine the form of the water table and hydraulic connection of ground water with rivers, canals etc.
- Depth to water table (Maximum, Minimum and Mean)
- Amplitude of water level fluctuations

- Piezometric head in deeper aquifers and their variation with time
- Ground water potential of different hydrogeological units and the level of ground water development
- Chemical quality of water in different aquifers

This information is usually available in district-wise ground water reports prepared by the Central Ground Water Board and/ or the State Ground Water Board.

(b) Information from local open wells

Artificial recharge schemes are site-specific and even the replication of the proven techniques are to be based on the local hydrogeological and hydrological conditions. However, following information from local wells needs to be taken into consideration in planning such schemes:

- The unsaturated thickness of rock formations occurring beyond 3 metres below ground level should be considered to assess the requirement of water to build up the sub-surface storage. The ground water recharge process should aim at saturating this entire unsaturated zone (also know as vadose zone)
- The upper 3 m of the unsaturated zone should not be considered for recharging since it may cause adverse environmental impacts like water logging, soil salinity etc.
- The post-monsoon depth to water level represents a situation of minimum thickness of vadose zone available for recharge. This should be considered vis-à-vis the available surplus runoff in the area

9.8 GEOPHYSICAL STUDIES

These studies are expensive and time consuming and require high levels of skill and sophisticated equipment. These are, therefore, economically viable for large ground water development projects and are not suitable for small artificial recharge schemes at local/ village level.

The main purpose of applying geophysical methods for the selection of appropriate site for artificial recharge studies is to assess the unknown sub-surface hydrogeological conditions economically, adequately and unambiguously. Generally the prime task is to compliment the exploratory programme. Mostly it is employed to narrow down the target zone, pinpoint the probable site for artificial recharge structure and its proper design.

Nevertheless, the application of geophysical methods is to bring out a comparative picture of the sub-surface litho environment, surface manifestation of such structures and correlate them with the hydrogeological setting. Besides defining the sub-surface structure and lithology, it can identify the brackish/ fresh ground water interface, contaminated zone (saline) and the area prone to seawater intrusion.

Using certain common geophysical methods, it is possible to model the

- Stratification of aquifer system and spatial variability of hydraulic conductivity of the characteristic zone, suitable for artificial recharge
- Negative or non-productive zones of low hydraulic conductivity in unsaturated and saturated zones
- Vertical hydraulic conductivity discontinuities, such as dyke and fault zone
- Moisture movement and infiltration capacity of the unsaturated zone
- Direction of ground water flow under natural/ artificial recharge processes

- Salinity ingress, trend and short duration depth salinity changes in the aquifers due to varied abstraction or recharge

The application of proper techniques, plan of survey and suitable instruments can yield better understandable results, but, of indirect nature.

9.9 QUALITY OF SOURCE WATER

(a) Chemicals and Salts

Problems which arise as a result of recharge to ground water are mainly related to the quality of raw waters that are available for recharge and which generally require some sort of treatment before being used in recharge installations. They are also related to the changes in the soil structure and the biological phenomena, which take place when infiltration begins, thereby causing environmental concerns. The chemical and bacteriological analysis of source water and that of ground water is therefore essential.

(b) Sediment Load

A major requirement for waters that are to be used in recharge projects is that they be silt-free. Silt may be defined as the content of undissolved solid matter, usually measured in mg/l, which settles in stagnant water or in flowing water with velocities, which do not exceed 0.1 m/hr.

9.10 PREVENTION OF CLOGGING OF SOIL PORES

This is one of the important considerations in planning an artificial recharge scheme. The usual methods to minimize the clogging are:

- Periodical removing of the mud-cake and dicing or scraping of the surface layer
- Installation of a filter on the surface, the permeability of which is lower than that of the natural strata (the filter must be removed and renewed periodically)
- Addition of organic matter or chemicals to the uppermost layer
- Cultivation of certain plant-covers, notably certain kinds of grass
- Providing inverted filter consisting of fine sand, coarse sand and gravel at the bottom of infiltration pits/ trenches are very effective

Clogging by biological activity depends upon the mineralogical and organic composition of the water and basin floor and upon the grain-size and permeability of the floor. The only feasible method of treatment developed so far consists in thoroughly drying the ground under the basin.

9.11 METHODS OF ARTIFICIAL RECHARGE

These can be broadly classified as:

(a) Direct Recharge

- Spreading Method
  - Spreading within channel
  - Spreading stream water through a network of ditches and furrows

- Ponding over large area
  - (a) Along stream channel viz. Check Dams/ Nala Bunds
  - (b) Vast open terrain of a drainage basin viz. Percolation Tanks
  - (c) Modification of village tanks as recharge structures.
- Recharge Shafts
  - Vertical Shafts
  - Lateral Shafts
- Injection Wells

(b) Induced Recharge

- Improved Land and Watershed Management
  - Contour Bunding
  - Contour Trenching
  - Bench Terracing
  - Gully Plugging

9.11.1 Channel Spreading

This involves constructing small 'L' shaped bunds within a stream channel so that water moves along a longer path thereby improving natural recharge as shown in Figure 9.1.

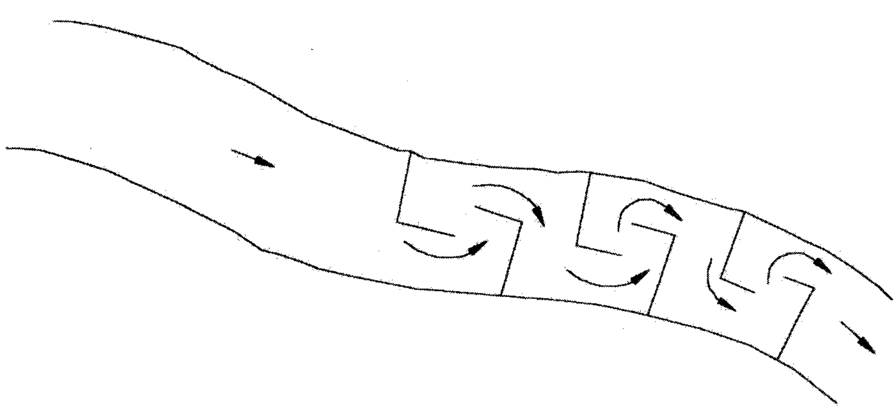


Figure 9.1 : Channel Spreading

This method is useful where a small flowing channel flows through a relatively wide valley. However this is not useful where rivers/ streams are prone to flash floods and the bunds (levees) may be destroyed.

9.11.2 Ditch and Furrow Method

In areas with irregular topography, shallow, flat-bottomed and closely spaced ditches or furrows provide maximum water contact area for recharge water from source stream or canal. This technique requires less soil preparation than the recharge basins and is less sensitive to silting. Figure 9.2 shows a typical plan or series of ditches originating from a supply ditch and trending down the topographic slope towards the stream. Generally three patterns of ditch and furrow system are adopted.

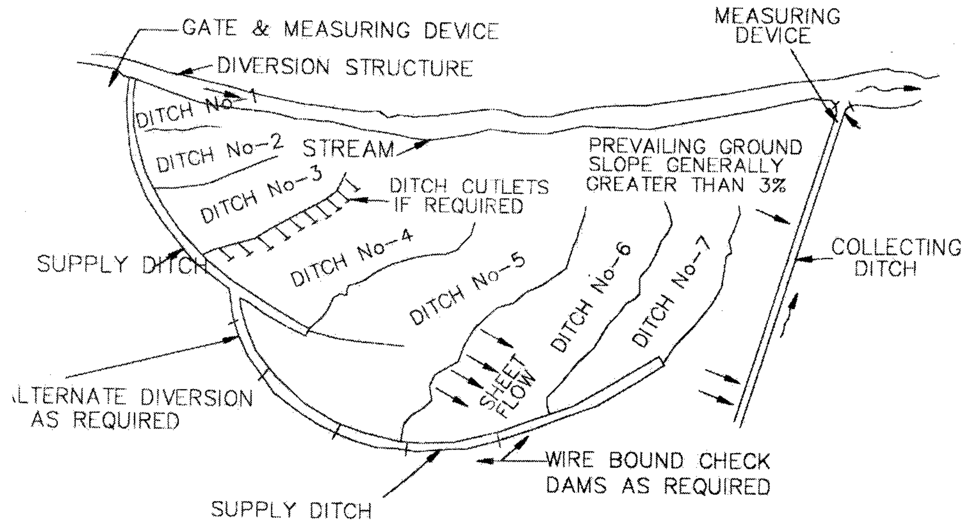


Figure 9.2 : Ditch and Furrow Method

(a) Lateral Ditch Pattern

The water from stream is diverted to the feeder canal/ ditch from which smaller ditches are made at right angles. The rate of flow of water from the feeder canal to these ditches is controlled by gate valves. The furrow depth is kept according to the topography and also with the aim that maximum wetted surface is available and uniform velocity can be maintained. The excess water is routed to the main stream through a return canal along with residual silt.

(b) Dendritic Pattern

The water from stream is diverted from the main canal to a series of small ditches spread in a dendritic pattern. The bifurcation of ditches continues until practically all the water is infiltrated in the ground.

(c) Contour Pattern

The ditches are excavated following the ground surface contour of the area. When the ditch comes closer to the stream a switchback is made and thus the ditch is made to meander back and forth repeatedly. At a lowest point downstream, the ditch joins the main stream, thus returning the excess water to it.

Site Characteristics and Design Guidelines

(i) Although this method is adaptable to irregular terrain, the water contact area seldom exceeds 10 percent of the total recharge area.

(ii) Ditches should have slope to maintain flow velocity and minimum deposition of sediments.

(iii) Ditches should be shallow, flat-bottomed, and closely spaced to obtain maximum water contact area. Width of 0.3 to 1.8 m is typical.

(iv) A collecting ditch to convey the excess water back to the mainstream channel should be provided.

Ditch and furrow method is usually costly since it requires high level of supervision and maintenance.

9.11.3 Check Dams/Nala Bunds

As discussed in Chapter-6, these provide not only channel storage but also augment ground water recharge.

9.10.4 Percolation Tanks (PTs)/Spreading Basins

As discussed in Chapter-6, these are the most prevalent structures in India to recharge the ground water reservoir both in alluvial as well as hard rock formations. The efficacy and feasibility of these structures is more in hard rock formation where the rocks are highly fractured and weathered. In the States of Maharashtra, Andhra Pradesh, Madhya Pradesh, Karnataka and Gujarat, the percolation tanks have been constructed in basaltic lava flows and crystalline rocks. The percolation tanks are however also feasible in mountain fronts occupied by talus scree deposits. These are found to be very effective in Satpura Mountain front area in Maharashtra. The percolation tanks can also be constructed in the Bhabar zone. Percolation tanks with wells and shafts are also constructed to recharge deeper aquifers where shallow or superficial formations are highly impermeable or clayey.

9.11.5 Modification of Village Tanks as Recharge Structures

The existing village tanks, which are often silted up or damaged, can be modified to serve as recharge structure. In general no "Cut Off Trench" (COT) and Waste Weir is provided for village tanks. A village tanks can be converted into a recharge structure by desilting its bed and providing a COT on the upstream end of the bund. Several such tanks are available which can be modified for enhancing ground water recharge. Some of the tanks in Maharashtra and Karnataka have been converted.

9.11.6 Recharge of Dug Wells and Hand Pumps

In alluvial as well as hard rock areas, there are thousands of dug wells, which have either gone dry, or the water levels have declined considerably. These dug wells can be used as structures to recharge the ground water reservoir (Figure 9.3). Storm water, tank water, canal water etc. can be diverted into these structures to directly recharge the dried aquifer. By doing so the soil moisture losses during the normal process of artificial recharge, are reduced. The recharge water is guided through a pipe to the bottom of well, below the water level to avoid scouring of bottom and entrapment of air bubbles in the aquifer. The quality of source water including the silt content should be such that the quality of ground water reservoir is not deteriorated. Schematic diagrams of dug well recharge are given in Figure 9.3.

In urban and rural areas, the roof top rainwater can be conserved and used for recharge of ground water. This approach requires connecting the outlet pipe from rooftop to divert the water to either existing wells/ tubewells/ borewells or specially designed wells. The urban housing complexes or institutional buildings having large roof areas can be utilised for harvesting roof top rainwater for recharge purposes (Figure 9.3).

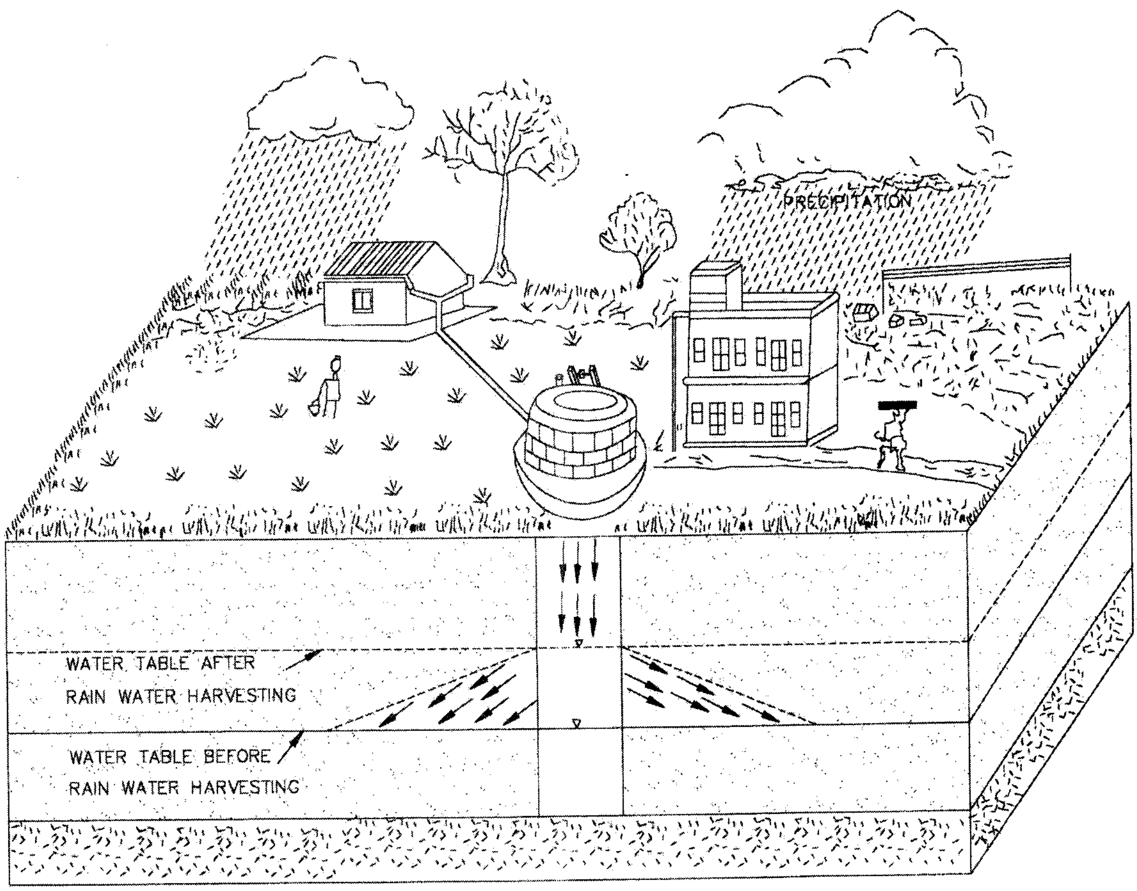


Figure 9.3 : Recharge of Dug Wells through Roof Top Rain Water Harvesting

9.11.7 Recharge Shaft

These are the most efficient and cost effective structures to recharge the aquifer directly. These can be constructed in areas where source of water is available either for some time or perennially. Following are the site characteristics and design guidelines:

(i) To be dug manually if the strata is of non-caving nature.

(ii) If the strata is caving, proper permeable lining in the form of open work, boulder lining should be provided.

(iii) The diameter of shaft should normally be more than 2 m to accommodate more water and to avoid eddies in the well.

(iv) In the areas where source water is having silt, the shaft should be filled with boulder, gravel and sand to form an inverted filter. The upper-most sandy layer has to be removed and cleaned periodically. A filter should also be provided before the source water enters the shaft.

(v) When water is put into the recharge shaft directly through pipes, air bubbles are also sucked into the shaft through the pipe, which can choke the aquifer. The injection pipe should therefore be lowered below the water level.

The main advantages of this technique are as follows:

- It does not require acquisition of large piece of land as in case of percolation tanks.
- There are practically no losses of water in the form of soil moisture and evaporation, which normally occur when the source water has to traverse the vadose zone.
- Disused or even operational dugwells can be converted into recharge shafts, which does not involve additional investment for recharge structure.
- Technology and design of the recharge shaft is simple and can be applied even where base flow is available for a limited period.
- The recharge is fast and immediately delivers the benefit. In highly permeable formations, the recharge shafts are comparable to percolation tanks.

The recharge shafts can be constructed in two different ways viz. vertical and lateral. The details of each are given in the following paragraphs.

9.11.8 Vertical Recharge Shaft

The vertical recharge shaft can be provided with or without injection well at the bottom of the shaft.

(a) Without Injection well

- Ideally suited for deep water levels (up to 15 m bgl).
- Presence of clay is encountered within 15 m.
- Effective in the areas of less vertical natural recharge.
- Copious water available can be effectively recharged.
- Effective with silt water also (using inverted filter consisting of layers of sand, gravel and boulder).
- Depth and diameter depends upon the depth of aquifer and volume of water to be recharged.
- The rate of recharge depends on the aquifer material and silt content in the water.
- The rate of recharge with inverted filter ranges from 7-14 lps for 2-3 m diameter.

This type of shaft has been constructed at the following places and is shown in Figure 9.4.

- Brahm Sarovar, Kurukshetra district, Haryana - silt free water
- Dhuri drain, Sangrur district, Punjab - surface runoff with heavy silt
- Dhuri link drain, Sangrur district, Punjab - surface runoff with heavy silt
- President Estate, New Delhi - roof top and surface runoff
- Nurmahal block, Jalandhar district, Punjab
- Kirmich and Samastipur, Kurukshetra district - surface water from depression

(b) With Injection Well

In this technique an injection well of 100-150 mm diameter is constructed at the bottom of the shaft piercing through the layers of impermeable horizon to the potential aquifers to be reached about 3 to l5 m below the water level (Figure 9.5).

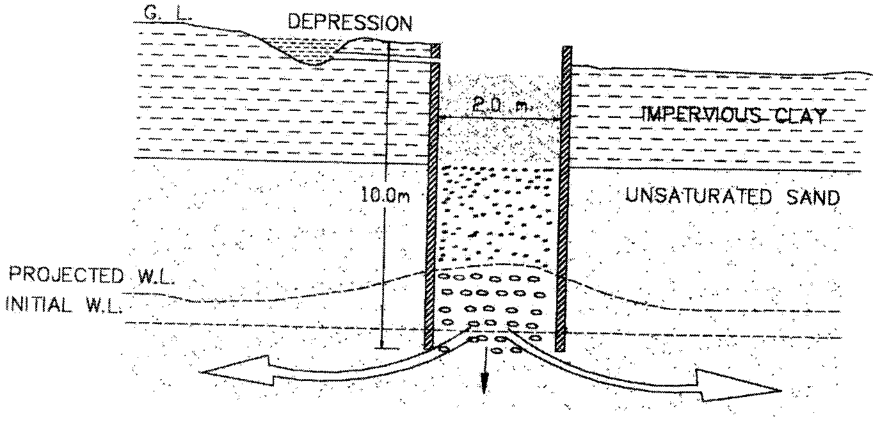


Figure 9.4 : Vertical Recharge Shaft without Injection Well

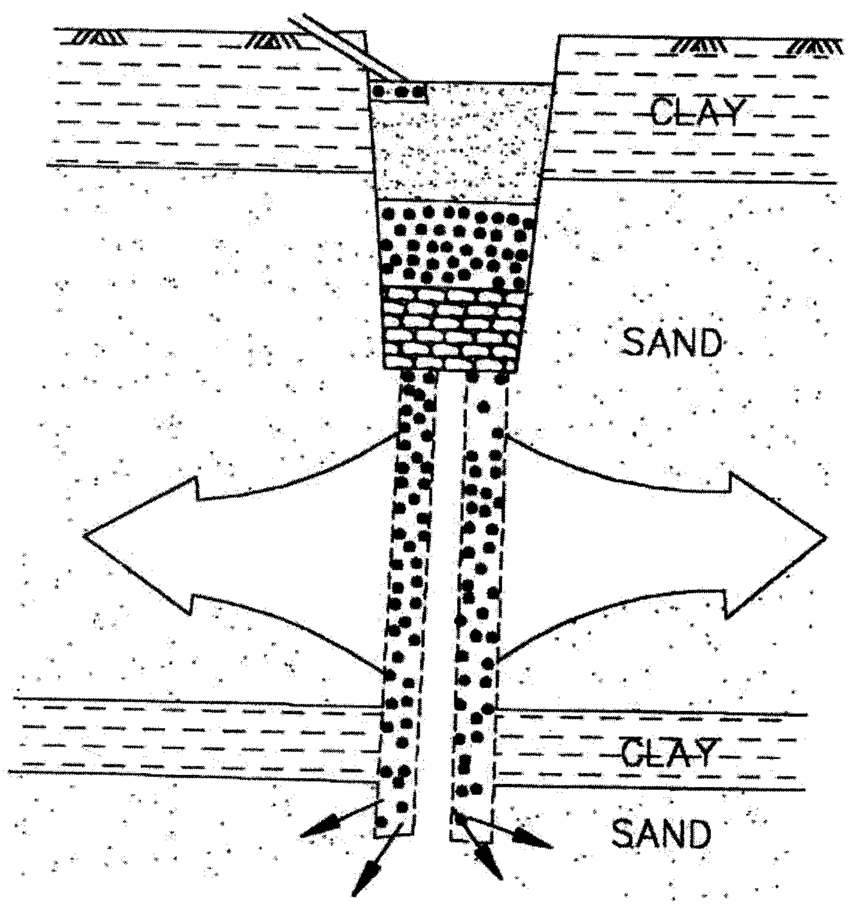


Figure 9.5 : Vertical Recharge Shaft with Injection Well

- Ideally suitable for very deep water level (more than 15 m)
- Aquifer is overlain by impervious thick clay beds
- Injection well can be with or without assembly
- The injection well with assembly should have screen in the potential aquifer at least 3-5 m below the water level
- The injection well without assembly is filled with gravel to provide hydraulic continuity so that water is directly recharged into the aquifer
- The injection well without assembly is very cost effective
- Depending upon volume of water to be injected, number of injection wells, can be increased to enhance the recharge rate
- The efficiency is very high and rate of recharge goes even up to 15 lps at certain places

These structures have been constructed at following places:

(i) Injection Well Without Assembly
   - Dhuri drain, Sangrur district, Punjab
   - Issru, Khanna block, Ludhiana district, Punjab
   - Lodi Garden, New Delhi
   - Dhaneta, Samana block, Patiala district, Punjab

(ii) Injection Well With Assembly
   - Dhuri drain, Sangrur district, Punjab
   - Dhuri link drain, Sangrur district, Punjab
   - Kalasinghian, Jalandhar district, Punjab

9.11.9 Lateral Recharge Shaft

- Ideally suited for areas where permeable sandy horizon is within 3 m below ground level and continues upto the water level – under unconfined conditions (Figure 9.6)
- Copious water available can be easily recharged due to large storage and recharge potential
- Silt water can be easily recharged
- 2 to 3 m wide and 2 to 3 m deep trench is excavated, length of which depends on the volume of water to be handled
- With and without injection well (Details of structures already described in Section 9.11.8 above)

This structure has been constructed at following places:

- Dhuri drain, Sangrur district, Punjab - 300 m (with 6 injection wells)
- Dhuri link drain, Sangrur district, Punjab - 250 m (with 3 injection wells)
- Garhi Kangran, Baghpat district, U.P. - 15 m (with 2 injection wells)
- Shram Shakti Bhawan, New Delhi - 15 m (3 lateral shafts with 2 injection well in each)
- Dhaneta, Samana block, Patiala district, Punjab - 4 lateral shafts with injection wells

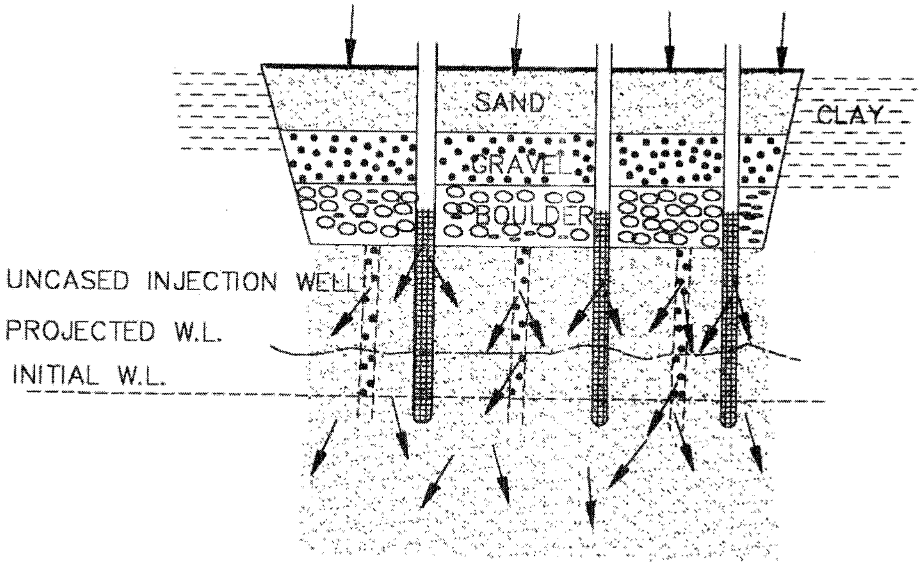


Figure 9.6 : Lateral Recharge Shaft

- D.C. Office Complex, Faridabad, Haryana - with injection wells
- Lodhi Garden, New Delhi - with injection wells

9.11.10 Artificial Recharge Through Injection Wells (Direct Recharge)

Injection wells are structures similar to a tube well but with the purpose of augmenting the ground water storage of a confined aquifer by pumping in treated surface water under pressure (Figure 9.7). The injection wells are advantageous when land is scarce.

Injection Method

Water is led directly into the depleted aquifers by providing a conduit access, such as tube well or shaft or connector wells. Recharge by injection is the only method for artificial recharge of confined aquifers or deep-seated aquifers with poorly permeable overburden. The recharge is instantaneous and there are no transit and evaporation losses. Injection method is also very effective in case of highly fractured hard rocks and karstic limestones but very high permeabilities are not suitable, as they do not allow the water to be retained for long periods for use during dry season. However, it is necessary to ensure purity of the source water as well as its compatibility with aquifer to prevent frequent clogging of injection structures, by bacterial growth, chemical precipitation or deposition of silt. Dual-purpose injection wells i.e. injection cum pumping wells are more efficient. Connector injection well where saturated shallow aquifer and over-exploited confined aquifers are tapped in a single well, allows freefall of water from shallow aquifer into the deeper aquifer, thereby reducing cost of injection. Injection method is also used as a "Pressure Barrier Technique" to arrest or reverse saline water ingression.

The selection of site for these structures depends upon the configuration of the confined aquifers, hydraulic gradient and location of source of surplus surface water. It is always better to construct it closer to source to save cost of water conveyance.

This technique was successfully adopted at temple town of Bhadrachallam in Andhra Pradesh during 1987 to provide safe drinking water to about 2 to 3 lakh pilgrims on the festival of Shriramanawami. The ground water aquifer had meagre reserve and had to be necessarily replenished through induced recharge from Godavari river. The surface water could not be directly pumped to the distribution system due to turbidity and bacteriological contaminations. A water supply scheme was successfully executed by construction of 30 filter point wells of 90 cm diameter which yielded about 60 cum/ha of potable water, mainly the induced recharge from river with phreatic alluvial aquifer acting as filtering medium. Hydraulically, the effectiveness of induction of water in injection well is determined by:

- Pumping rate
- Permeability of aquifer
- Distance from stream
- Natural ground water gradient
- Type of well

In alluvial areas injection well can be provided for recharging a single aquifer or multiple aquifers. An injection pipe with opening against the aquifer to be recharged may be sufficient. However, in case of number of permeable zones separated by impervious rocks, a properly designed injection well with inlet pipe against each aquifer to be recharged need to be constructed. The injection wells as a means of artificial recharge are comparatively costlier and require specialised techniques of tubewell construction. Proper operation and maintenance are necessary to project the recharge well from clogging.

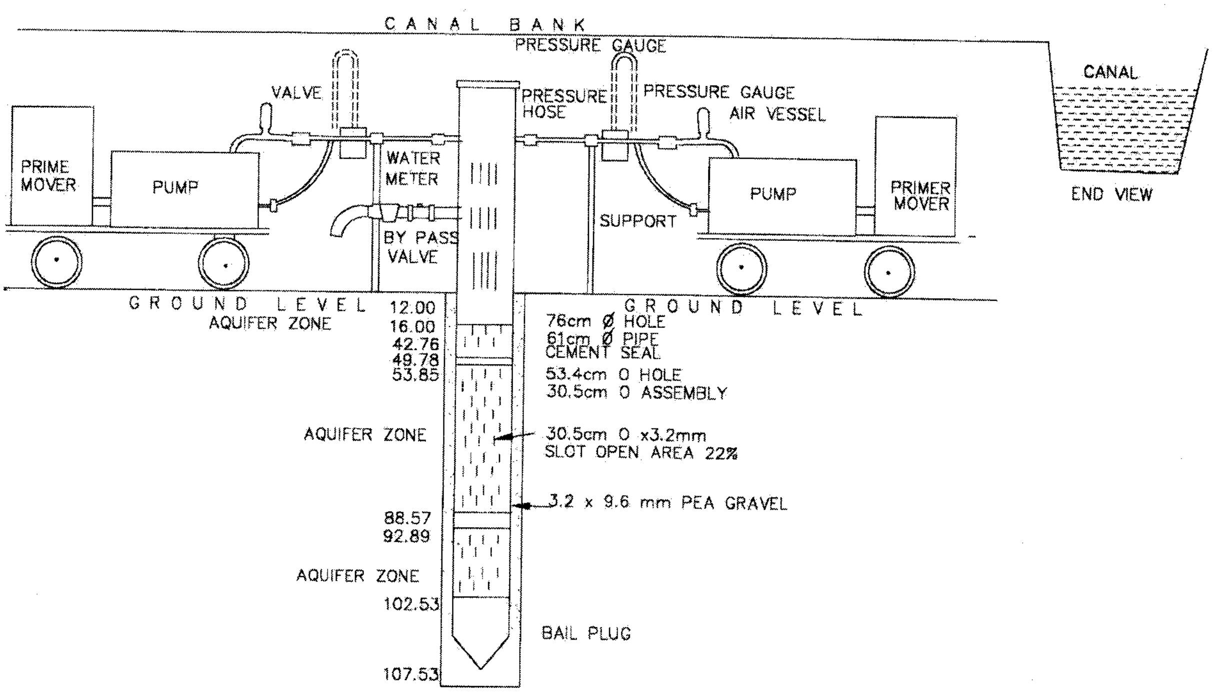
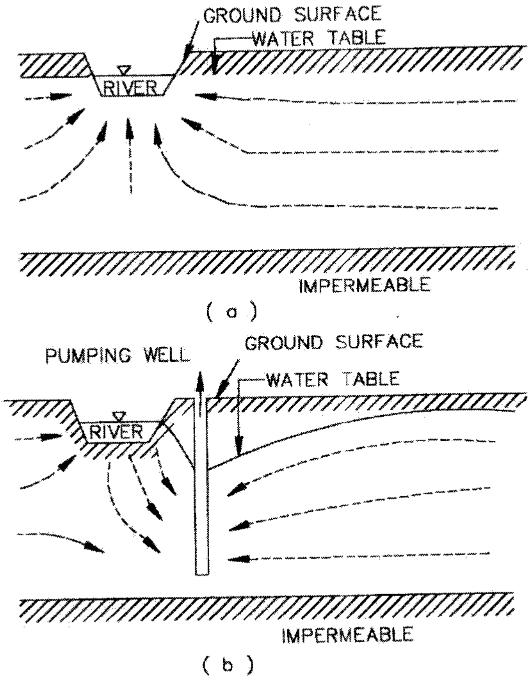


Figure 9.7 : Artificial Recharge through Injection Well

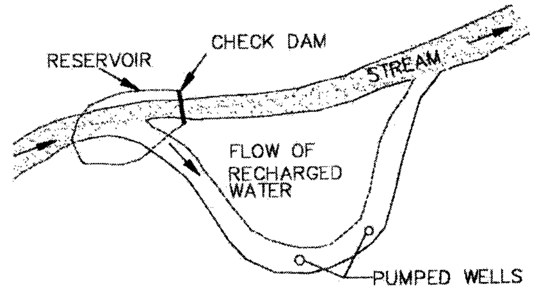
9.11.11 Induced Recharge

It is an indirect method of artificial recharge involving pumping from aquifer, hydraulically connected with surface water, to induce recharge to the ground water reservoir. When the cone of depression intercepts river recharge boundary a hydraulic connection gets established with surface source, which starts providing part of the pumpage yield. In such methods, there is actually no artificial build up of ground water storage but only passage of surface water to the pump through an aquifer. In this sense, it is more a pumpage augmentation rather than artificial recharge measure (Figure 9.8).



INDUCED RECHARGE RESULTING FROM A WELL PUMPING NEAR A RIVER

(a) NATURAL FLOW PATTERN
(b) FLOW PATTERN WITH PUMPING WELL



ARTIFCIAL RECHARGE OF BURRIED CHANNEL

Figure 9.8 : Induced Recharge

In hard rock areas the abandoned channels often provide good sites for induced recharge. Check weir in stream channel, at location up stream of the channel bifurcation, can help in high infiltration from surface reservoir to the abandoned channel when heavy pumping is carried out in wells located in the buried channel.

The greatest advantage of this method is that under favourable hydrogeological situations the quality of surface water generally improves due to its path through the aquifer material before it is discharged from the pumping well.

For obtaining very large water supplies from riverbed, lakebed deposits or waterlogged areas, collector wells are constructed. In India such wells have been installed in Yamuna bed at Delhi and other places in Gujarat, Tamil Nadu and Orissa. The large discharges and lower lift heads make these wells economical even if initial capital cost is higher as compared to tube well.

In areas where the phreatic aquifer adjacent to the river is of limited thickness, horizontal wells may be more appropriate than vertical wells. Collector well with horizontal laterals and infiltration galleries can get more induced recharge from the stream collector wells. Constructed in seasonal nala beds these can be effective as induced recharge structures for short periods only.

Site Characteristics and Design Guidelines

A collection well is a large diameter (4 to 8 m) well from which laterals are driven/ drilled near the bottom at one or two levels into permeable strata. The central well is a vertical concrete cassion in pre-cast rings, (wall thickness 0.45 m) sunk upto the bottom of aquifer horizon. The bottom of cassion is sealed by thick concrete plugs. Slotted steel pipes, 9 mm thick, 15 to 50 cm in diameter having open area above 15% and a tapered leading are driven laterally through portholes at appropriate places in the cassion. The successive slotted pipes are welded and driven using special hydraulic jacks installed at the bottom of the cassion. The number of laterals is usually less than 16, thus permitting minimum angle of 22°30", between two laterals. The maximum length of lateral reported is 132 m and the total length of laterals from 120 to 900 m depending upon requirement of yield.

The laterals are developed by flushing and if entrance velocity of water is kept less than 6-9 mm/sec, these do not get filled by sand. The effective radius of a collector well is 75 to 85% of the individual lateral length.

9.11.12 Improved Land And Watershed Management

Improved land and watershed management techniques viz. contour bunding, contour trenching, bench terracing, gully plugging etc. are discussed in Chapter-7.

CHAPTER - 10

Water Harvesting and Recharging in Hard Rock Areas

10.0 CONCEPTUAL FRAME WORK

From a technical stand point, though hard rock areas occupy greater part of our country, but very little knowledge exists about the "vadose zone", that spans the region between ground surface and fluctuating water table. There is no much reliable information about unsaturated zone that exists over hard rock formations. As a matter of fact one would need a regional as well as large scale maps of weathering crust over hard rocks which are normally not available though sporadic pieces of information do exist through reports of survey organisations.

It is, therefore, essential to have a quantitative knowledge of the dynamics of water storage & water release mechanism from vadose zone (unsaturated zone) that is considered important in the formulation and implementation of artificial recharge works in water shortage and drought prone hard rock regions in the country.

It would be necessary therefore for any one to know first the nature, movement and occurrence of ground water in hard rocks. Some salient characteristics of occurrence of ground water in hard rock are listed below:

Features of Occurrence of Ground Water in Hard Rocks are:

(i) Ground water reservoir (aquifer) in hard rocks are dominantly shallow

(ii) The bulk of the ground water is stored in the zone of weathering (Vadose zone)

(iii) Fractures and joints in hard rock occur as conduits for rapid transport of water as they do not provide large space for storage of ground water

(iv) The width of fractures & lineaments and weak planes narrows as depth increases

(v) Fairly limited aquifer water yield by wells and borewells in comparison to alluvial and sedimentary rock aquifer wells

(vi) Unpredictable ground water occurrence over short distances

(vii) Poor water quality in certain areas

10.1 VADOSE ZONE IN HARD ROCKS

The principle ground water reservoir in hard rocks therefore consists of two parts viz

(i) "Vadose zone" or unsaturated zone that lie between ground surface and water table; and

(ii) The phreatic or unconfined zone that lie below the water table

In view of the above idealization, about the shallow nature of occurrence of ground water, the ground water system is controlled by individual, zero order and 1st order watersheds though water movement is also expected to occur between 1st order & 2nd order basins. What is important therefore is to know the flow patterns in ground water at local levels in relation to dyke rocks and outcrop ridges. The deeper ground water below water table in zone of fractures lack substantial storage unless it is connected with thick vadose zone above or else is connected to a surface water source.

Exclusively from the issue of ground water storage, the "vadose zone" in hard rocks is extremely important, because the pore spaces in this domain undergo resaturation during infiltration and recharge and undergo desaturation under conditions of evaporation and drainage. The volume of saturation involved in the process of change in saturation in vadose zone (zone of weathering) is far large than the changes in volume of water involved in the elastic storage of water below the water table. It therefore may be noted, that the dynamic resource in ground water reservoir in the hard rock areas is governed by the "vadose zone" through which water levels fluctuate.

It is, therefore, imperative for any rechargeable scheme to have first hand information obtained/required about the water saturation and permeability of the vadose zone/weathering zone before undertaking execution of ground water recharging works. This information is very much rare in its availability. It may also be mentioned that available storage in weathered zone in hard rocks is very much linked to baseflow fluctuations in local streams.

10.2 WATER HARVESTING IN HARD ROCK REGION

The hard rocks such as basalts, granite, quartzites, limestones etc. occupy nearly 65% of the total geographical area of the country. The basaltic hard rocks form plateau region whereas granite rocks form hill ranges as inselbergs. The aquifer in hard rocks are characterized by low permeability and low specific yield. In hard rocks the framework of fracture system in which groundwater occurs is highly variable and aquifers are of heterogeneous nature.

(a) Plateau Basalt

Basaltic rocks of Deccan occupy the most extensive tract of Western Peninsula covering large parts of the states of Maharashtra, Gujarat, Madhya Pradesh and Andhra Pradesh. Deccan basalts popularly known as Deccan Traps consists of vast pile of bedded lava flows. These lava flow beds have two district horizons, the lower one are massive and the upper are vesicular basalts. The massive part of basaltic rocks is hard and compact whereas the vesicular part is characterized by vesicles as cavities filled with secondary minerals. The massive traps are fractured and jointed at places. The weathering and fracturation of massive and vesicular basalts are favourable zones for surface and sub-surface storage.

Before embarking upon a purposeful ground water recharging programme it is imperative to understand in greater depth the vadose zone that exists between the ground surface and the fluctuating ground water levels.

By and large the hard rock areas have very limited yield by individual wells with variation in well discharge over short distances and poor quality of ground water in some areas.

(b) Deccan Basalt Plateau

The Deccan basalt rocks have plateau like topography in West Central India. This cover about 5 lakh sq km area. These rock formations comprise many lava-flow rock beds which range in thickness from a few meters 9 to about 100 m. The plateau-like relief have two basic rock layers:

1.	Angadaloided upper rock layer	:	Vesicular with bedded joints
2.	Compact lower rock layer	:	Upper part with columnar & vertical joints & lower parts as massive & compact

The individual lava-flow beds are separated at places by clay zone called "Redbole horizon" which is a marker horizon that impedes the vertical infiltration of water.

A diagrammatic section through Plateau basalts having lava-flow beds is shown in fig-10.1, 10.1(a) and10.1(b)

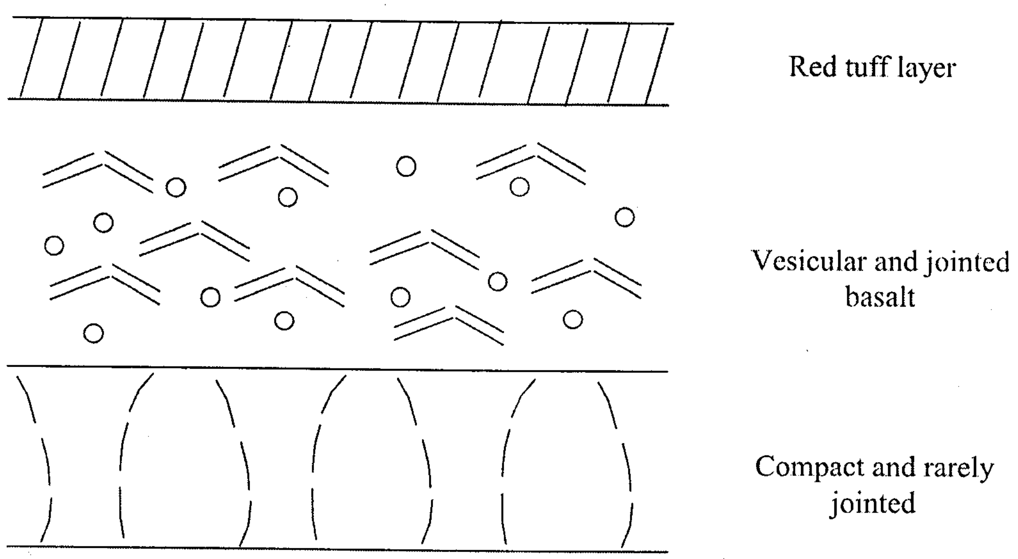


Figure 10.1 - Basalt lava beds

Normally a basalt plateau section has repetitive sequence of alternating vesicular and compact basalt lava-flows that are horizontal bedded flows.

(c) Weathering and Fracturation of Hard Rocks:

The fractures are only the conduit for refill and water transport rather than serving as space for storage of ground water. Therefore the vadose zone is only important as it is related to issue of storage of ground water. The fractures tend to close at depth and 100 m is approximately is the optimum depth within which potential aquifer water supplies are obtainable. Thus it is only the vadose zone which undergoes resaturation during infiltration of rain water or through other source of recharging water. This zone undergoes desaturation under drainage and evaporation. The vadose / weathered zone is important since the fracture porosity of hard rock is as small as 1% and therefore fracture zone alone is not considered productive zone unless it is connected with recharge boundary. Therefore weathered horizons play a dominant role for consideration of

Figure 10.1(a) Example of the compact lower layer of a lava sequence showing sub-vertical jointing

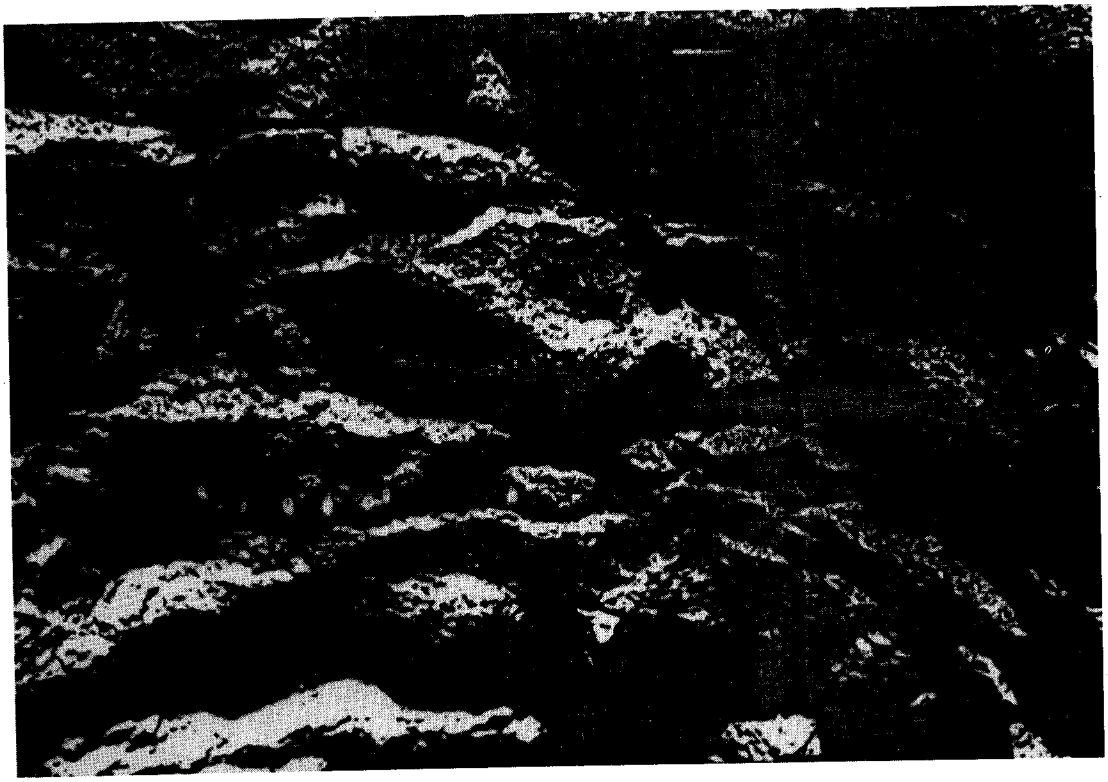


Figure 10.1(b) Example of the amygdaliodal upper layer of a lava sequence showing sheet jointing

water circulation and recharge. The cracks in the weathered zones are often filled with concretionary material as Kankar. The recharge capability of basaltic rocks is greatly influenced by the overlaying thickness, texture and structures of the soil and their location with reference to topography and geomorphology of landscape units.

The feature of low permeability of Basalts, their multilayered occurrence, fractured and jointed natures, vesicular character besides topographic and other geological features are to be normally considered in the formulation and construction of recharging schemes in Plateau forming basaltic rock terrain.

Broad hydraulic features for consideration with regard to water harvesting and ground water recharging in Basaltic rock regions are given in table. The success of a recharge scheme will depend on a combination of various topographic and hydrologic situations. The following factors should receive consideration in the formulation of a water harvesting & recharge scheme.

Table : Topographic - Hydrogeological framework

Hydrologic Considerations	The weathered, fractured and vesicular basalts constitute most favourable hydraulic zones which need to be delineated on large scale maps.
Topography of Watershed area	The piedmont slopes constitutes the best topographic geologic environment followed by valley floors. Highly dissected slopes and plateau tops are less favourable.
Hydraulic conductivity of basaltic layers	The weathered, jointed and vesicular portions of basaltic rocks have high permeability and shall constitute favourable places in comparison to massive basalts that are less suitable for recharge and percolation.
Ground Water table and fluctuation in levels	The position of water table & its value of annual fluctuation
Thickness of Soil cover and infiltration rates.	Granular soil cover will have high infiltration rate in comparison to clay / black cotton soil that would impede infiltration and deep percolation.
Rate of Recharge	In favourable zones, fractured and vesicular basalts are expected to attain a recharge of 10 – 15% whereas in non-favourable zones, underlain by massive basalts the rates may be 2 to 3%.

Accordingly the topographic and geologic considerations that shall govern suitability of recharging works in Plateau forming Basaltic rock region are outlined below:

Topography	**Areas / Region**	**Feasible Method**
Plateau Area	Western Ghats	Pits, ponds and shafts
Highly dissected plateau slopes (gradients of 1 in 10 and more)	Narrow areas flanking hill ranges and ghats	Recharge shafts feasible locally.
Moderately dissected plateau, foot hills and piedmont region (gradients 1 in 10 to 1 in 100)	Areas between interbasin divides plateau and valley floors.	Recharge trenches, Nala bunds, contour bunds, percolation tanks and ground water dams.
Low lying valley areas (gradients of 1 in 100 to 1 in 500)	Valley floor of rivers (eg. Godavari, Bhima, Nira, Krishna etc. and their tributaries)	Water spreading basins and ground water dams (conservation structures)

(d) Granite Hard Rocks

The weathered zone on granitic-gneissic rocks have primary porosity and permeability. The jointed and fractured character of such rocks exhibit secondary permeability determined by the fracture density and fractures frequency as well as infiltration numbers, which are the product of these to factors. The weathering process serves to enlarge the fracture and joint openings. The topography, depth of weathering and degree of fracturation and jointing have large influence on the occurrence and infiltration and recharging capabilities of such hard rocks.

The Water-table representing top of reservoirs generally lies in disintegrated rock materials. In the lower part of the ground water aquifers, the water occurs in the interconnecting fractures by seeping through overlaying weathered material. A layer of residual soil and weathered rock lies in the fresh and massive rock in most places. The thickness of soil and weathered rock ranges from few meters to as much as 30 meters.

The watertable in such rock-terrain have a hill and valley relation that more or less confirm with surface topography although the watertable may be somewhat flatter. In such a terrain over hard rocks, a river could be the surface expression of water table in a valley but beneath a hill the watertable may be 10 to 25 meters below ground surface. The natural movement of ground water is relatively short and is almost everywhere restricted to the zone underlying the topographic slope extending from a divide to adjacent stream. Thus a good understanding of landscape units is prerequisite to understand mechanism of recharge over granite hard rocks. The aerial photos and remote sensing imagery provide imaginative overview in the identification of features and selection of areas for construction of appropriate recharging structures.

The fracture-trace mapping and satellite lineament mapping and the mapping of zones of weathering have great role in the delineation of potential sites for recharging of groundwater. The another factor which is of great relevance to the recharge mechanism in hard rock is the time and space distribution of storage. The shallow storage takes place in weathered hard rocks that occur at shallow depth. The deep storage is the state of ground water in aquifer whereas storage at or near the land surface comprises interception or detention storage on the upper part of vadose zone. The storage at the surface is in the form of ponds. A satellite based area of fracture over granite gneissic hard rock around Bangalore is shown in figure-10.2. It can be seen that the ponds have alignment along topographic depressions caused by rock fracture alignments.

From above mentioned facts it is considered essential pre-requisite to conceptualise a topographic – hydrogeologic framework of a hard rock region before identifying and evaluating sites for ground water recharging and water harvesting. A generalized geologic cross-section of such a terrain shall show a phenomenon of local flow system which has its recharge area at "topographic high" in hills occupied by hard rocks and its discharge area in "topographic lows" occupied by a stream. As a rule the regional flow shall have its recharge at the basin divide and it discharge areas at the valley bottom.

The geomorphic, tectonic and geologic considerations for the sustainability of a Recharge Scheme over crystalline hard rocks are outlined below:

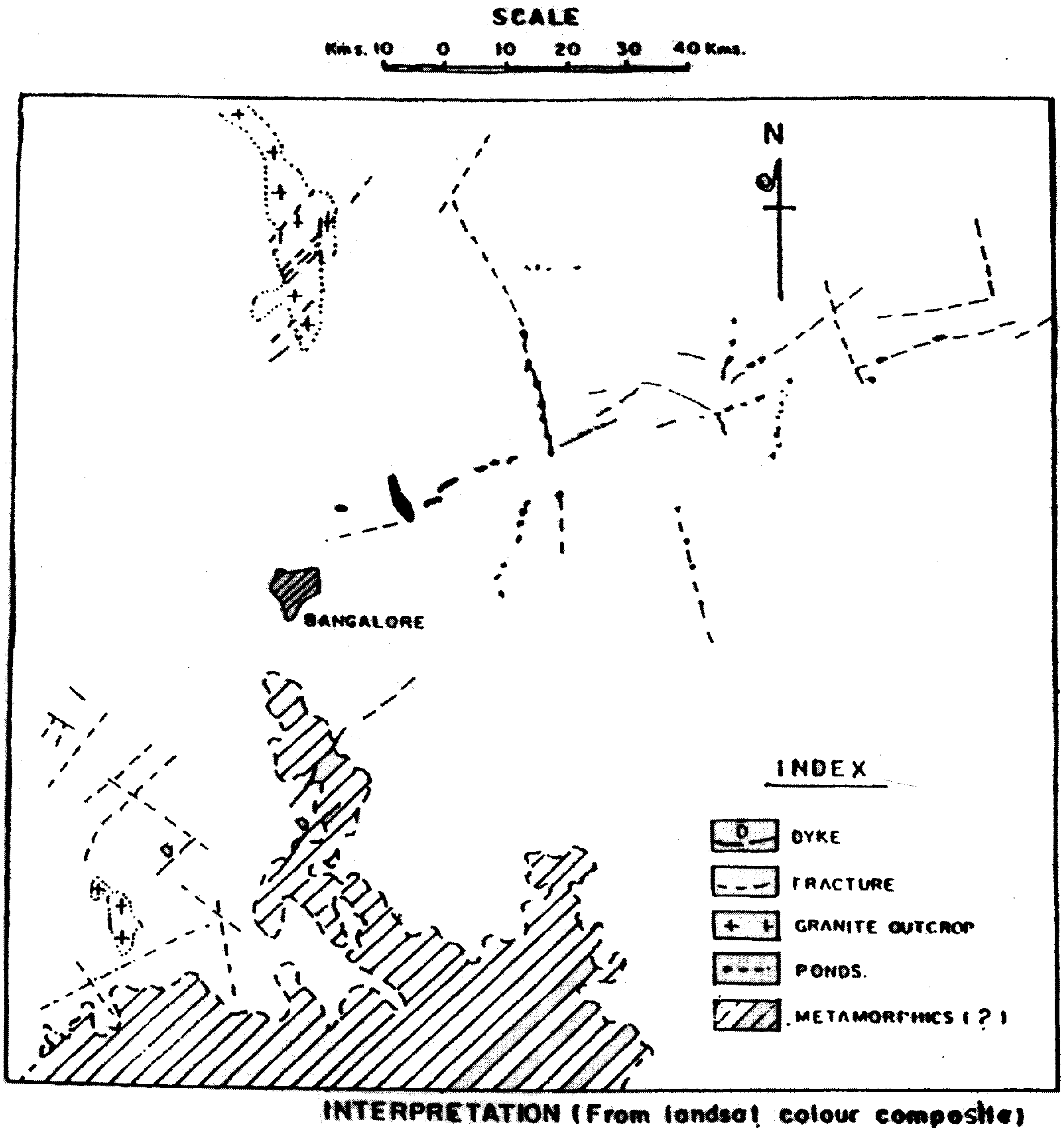


Figure 10.2 : Structural Map of Hard Rock area around Bangalore

S.No.	Geomorphic Conditions	Method Feasible for Recharging Hard Rocks
1.	Piedmont surface (a gently slopping plain with shallow weathered hard rock)	Percolation tanks and sub-surface dyke.
2.	Burried piedmont on undulating plain having deep weathered hard rocks	Infiltration dams and percolation ponds.
3.	Tectonic Features; folds & faults	Recharge methods feasible; zones of direct infiltration
4.	Lineaments and fractures intersection in topographic low areas / valleys	Sub-surface dams and percolation tanks.
5.	Area between dykes as vertical geological barriers	Check dams / percolation tanks.

10.3 GIS OVERLAYS ANALYSIS

A geographic information System (GIS) may be used as it is an automatic method to evaluate the potential of an area for recharging ground water especially over hard rock regions since most information of use is derived from high resolution satellite imaging and aerial photo interpretation. This method enables ranking the potential of an area on the basis of "Recharge Favourability Score" by using statistical relationship among factors that are assumed to be related to ground water recharge. The recharge favourability score should be evaluated as per table given below:

Factors No.	Recharge Favourability Score	Map Scale	Source of Data
A	**Topographic Factors**		
1.	% Slope or weighted average slope.	1:25,000	Digital Terrain Model
2.	Soil factors/land surface altitude.	1:25,000	Topographic maps
3.	Weighted average soil permeability or infiltration	1:20,000	Soil Maps
B	**Geologic Factors**		
4	Lineament intersection	1:25,000	Satellite images; LISS III & PAN
	Fracture trace intersection	1:50,000	Satellite images
5.	Fracture density/Fracture frequency and infiltration numbers	1 to 2 m resolution data	High resolution Satellite data; LISS III, PAN & IKONOS imagery
C	**Geomorphological Factors**		
6	Ridge & Valley	1:25,000	Enhanced Satellite images e.g. ETM + images
	Piedmont surface buried pediment, zones of weathering	1:50,000/1:25,000	Air photos/Satellite images

Factors No.	Recharge Favourability Score	Map Scale	Source of Data
D	**Hydrologic Factors**		
7	Existing surface water ponds/ tanks	11:25,000/1:50,000	Satellite images, LISS III & PAN IKONOS Images
8	Perennial character of streams, gaining and losing reaches in stream courses	High resolution images	Images / Maps / Photos
E	**Factors of Saturated thickness of weathered zones**	High resolution images	Satellite imagery

It is recommended to use invariably, the following remote sensing broad criteria while deciding to locate sites for recharging ground water over hard rock terrain.

1.	Detailed Geomorphological Mapping	Mapping and delineating of weathered zones and assigning of depth classes.
2.	Mapping of Fractures and lineaments	Identification of open and close fractures through digital enhancement that control stream segments.
3.	Compiling the drainage network	Joint – trellis drainage Fault – trellis drainage
4.	Mapping Dyke rocks and their orientation	As vertical geological barriers / permeability zones.
5.	Correlation of data with Aeromagnetic map of the area if available	Aero-magnetic anomalies and correlation with lineaments and faults
6.	GIS overlay Analysis	Production of area / zone maps of varying recharging possibilities.

CHAPTER - 11

Ground Water Recharge of Coastal Areas

11.0 INTRODUCTION

The coastal areas have very fragile resource base that effects the economy, agricultural and other activities. The basic problem that concerns water is that due to saline intrusion and migration of sea water landwards, the sweet water of fresh water aquifers is turned into saline water in coastal-deltaic plain areas. This phenomenon causes reduction in drinking & irrigation water supplies of usable quality.

The following are the main reasons responsible for salinity ingress of ground water aquifers:

1. Excessive and heavy withdrawals of ground water from Coastal Plain Aquifers
2. Sea water ingress
3. Tidal water ingress
4. Relatively less recharge
5. Poor land and water management

There are many measures like agriculture water management, recharging measures and salinity control measures that are needed to be done in improving water availability and water quality of coastal aquifers. In this manual only recharging and salinity control techniques have been discussed.

Whereas, the recharging methods for coastal aquifer system would include, check dams, recharge ponds/ tanks, spreading channels and recharge wells, the salinity control measures that cannot be separated from recharge techniques in coastal areas would include extraction barriers, fresh water barriers, static barriers and tidal regulators.

In case of heavy ground water withdrawal the artificial recharge is to be done by creating storage of fresh water and maintaining of head in aquifers to accelerate infiltration and also by increasing detention – storage time of surface runoff through afforestation and other vegetative measures. The recharging is to be done through recharge tank, check dam, injection wells & water spreading channels/basins as storage methods. The tidal regulators shall prevent upland movement of sea water, while sub-surface ingress can be prevented by creating fresh water heads for balancing sea water head. This can be done through injection well barriers.

11.1 SEAWATER INTRUSION

The situation of over-extraction of ground water in coastal aquifers cause problem of seawater intrusion. The method that is used to control sea water intrusion is to use recharge well barriers through a line of injection tubewells driven parallel to the coast. This mechanism establishes a pressure ridge which pushes the saline front seawards.

A schematic diagram through a confined aquifer system in coastal plain areas and injection well barrier measure for control of sea water intrusion is shown in figure 11.1.

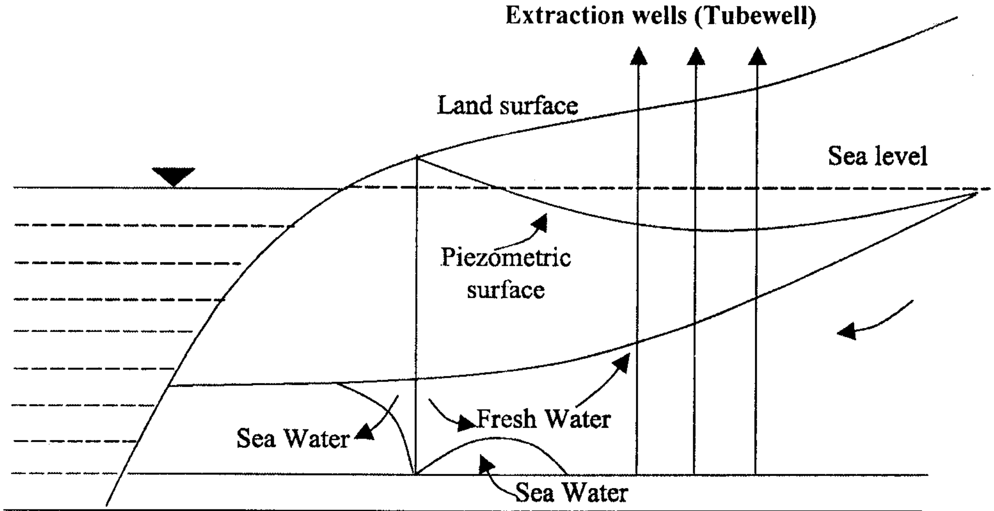


Figure 11.1 : Schematic Diagram of Injection Well Barrier in Confined Aquifer in a Coastal Plain

11.2 RECHARGE OF COASTAL PLAIN AQUIFERS

Various methods are in use world wide for the control of coastal sea water intrusion. In our country very sporadic work has been done as for example in Tamil Nadu (Chennai) and along Saurashtra Coast in Gujarat state (Mangrol-Chorwad-Veraval area).

Methods that can be employed for control of sea water ingress into aquifers are listed and described below:

(a) Artificial recharge

(b) Modification of ground water pumping and extraction pattern

(c) Injection barrier

(d) Sub-surface barrier

(e) Tidal regulators

(a) Artificial recharge

The efforts here should be to raise the levels of ground water table through appropriate method. The area where unconfined ground water occurs along coastal plain, a surface water spreading method alone should be tried whereas for confined aquifer area, the well recharging method should be employed.

(b) Modification of ground water Extraction pattern

The pumping pattern disturbs the hydraulic gradient whereby it causes landward migration of sea water. It therefore necessitates that the location of pumping wells be changed/shifted. Such wells are required to be dispersed inland to re-establish the ground water flow gradient seawards. Simultaneously it would also suppose to reduce the quantity of pumped water from such wells to produce positive and sweet water effect in fresh water aquifer.

(c) Injection barrier

The intention in this case is to recharge confined aquifer through injection well method whereby water is injected into deep confined aquifer at predetermined pressure through a battery/or line of recharging wells along the coast. The water injected thus under pressure would form pressure ridge along the coast whereby the water shall flow seaward. This would however need very high quality water which if not available nearby should be imported for well injection recharge. A large number of such wells are needed, the number depending up the requirement of a desirable pressure ridge to push ground water seaward.

(d) Sub-surface barrier

In this method, impermeable sub-surface barrier is constructed parallel to the coast but through the extent of fresh water aquifer. This barrier will combat & prevent the inflow to aquifer of sea water. Local method such as clay, asphalt, cement, bentonite etc. can be used to construct barriers.

(e) Tidal regulators

Tidal regulators are required to be constructed to control the discharge of sweet water of river/stream into the sea. Such structures shall have provision to store fresh water for injection and also arrest flow of saline water into river. This will provision fresh water on the other side saline water area along the crest & shall also raise water table in the vicinity of structures.

Ground water monitoring around such recharging and salinity ingress structures is always necessary to keep watch on availability of fresh water/ground water as well as ground water build up for agricultural and drinking water needs.

For check dams & tanks/ponds, tidal regulators, it is advisable to collect detailed information about hydrology, run-off, reservoir level, likely submergence area, command area, geology, geography, soil, drainage network etc. before a suitable design is proposed. A checklist of for such structures in the form of a field format is given below:

CHECK DAM

I. Hydrology

- (i) Catchment area
- (ii) Analysis of run off/rainfall data
- (iii) Estimated design flood
- (iv) Out flow

II. Reservoir

- (i) Bed level
- (ii) HFL/FSL (estimates)
- (iii) Capacity

III. Earthen Bund

(i) Upstream/dam shown slops

(ii) Anticipated length & width of dam

(iii) Weir parameters estimates

IV. Regulators

(i) Type

(ii) Discharge

(iii) Size of gate (initially estimated)

TIDAL REGULATORS

A. Hydrology

(i) Tidal catchment area

(ii) Effective catchment

(iii) Rainfall

(iv) Run-off

(v) E.T. losses

B. Reservoir

(i) Anticipated FRL

(ii) Anticipated HFL

(iii) Anticipated gum Capacity at FRL

(iv) Estimates of possible reservoir losses

(v) Expected gross area under submergence

C. Weir

(i) Type of weir

(ii) Possible location

(iii) R.L. of crest

(iv) Length (estimated)

(v) Possible/estimated flood height over crest

D. Dam

(i) Type of earth dam

(ii) Expected max-length of dam

(iii) Upstream/down stream slope

11.3 EXAMPLE FOR COASTAL AREAS

(a) Saurashtra Coast Gujarat

Due to heavy withdrawals of ground water from coastal plain area of Mangrol-Chorwad-Veraval in coastal Saurashtra, ground water depletion has caused sea water to move inland into fresh water aquifer. Experiments were done under a UNDP assisted CGWB recharge project in which Govt. of Gujarat also participated. As per experiments, the injection well recharge and water spreading methods were employed as means to cause recharge to ground water and to accordingly attempt to control salinity ingress into aquifers. Experiment was conducted to show that while during recharging through pit & shaft methods, a recharge of 192 and 2600 m^3 per day respectively was caused by two methods. It is also shown that tidal regulators in creeks cause stoppage of sea water ingress and forming of lakes behind dams to cause infiltration of water & also ponding in the form of water available as storage for irrigation.

(b) Chennai Coastal Area

The Minjur coastal area in the north of Chennai has been affected by sea water ingress due to excessive lowering of ground water levels caused of heavy withdrawals of ground water. The salinity ingress was observed as much as 8 to 9 km inland from the coast. Experiments pushed the saline water front seaward through check dams & injection barriers under a UNDP assisted - State Govt project of Tamil Nadu.

11.4 PREVENTION OF SALINE INTRUSION IN COASTAL AQUIFERS

Sub–Surface Barrier

Given below is an example of a sub-surface barrier constructed along the coast and through the vertical extent of aquifer which effectively prevents sea water inflow into the aquifer (Fig. 11.2). This example is from USA. The material used in construction of barrier includes sheet piling, clay, asphalt and cement grout or plastics etc.

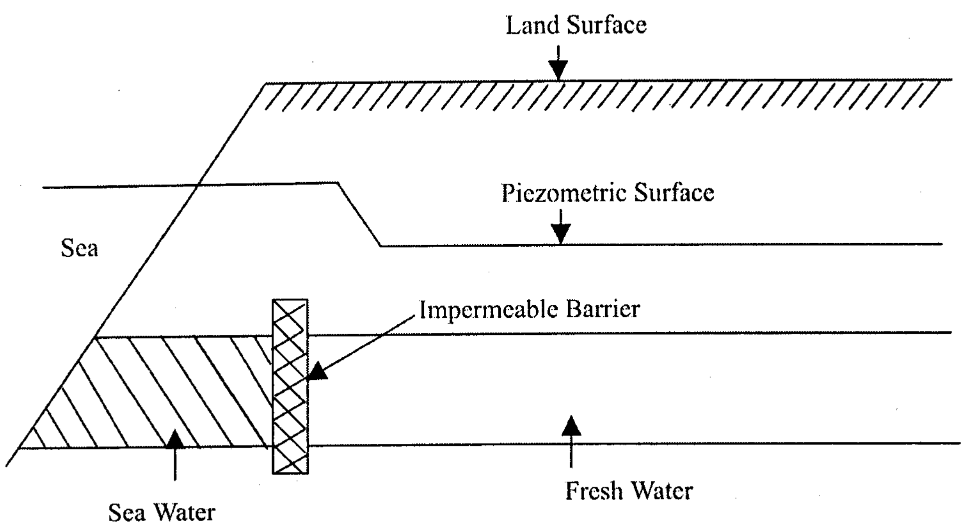


Figure 11.2 : Control of Sea Water Intrusion by an Impermeable Sub-Surface Barrier Along the Coast.

CHAPTER - 12

Training Needs and Support for Water Harvesting Initiatives

12.0 GENERAL

Though traditionally water harvesting is in practice in our country since ages, the renewed interest in water harvesting and recharging is because of fast depleting and polluting water resource. There is growing awareness about the conservation and wise use of water. This has now necessitated that people from various cross section and levels shall be suitably trained in methods, procedures and practices of water harvesting. The approach to such training programme shall be one of a scientific approach with much focus on innovative technologies of water conservation, harvesting and augmentation. Special training is needed to be provided in the preparation of projects, designs and construction of water harvesting systems including usage of local and low cost materials in the building and construction of such harvesting and recharge systems that shall have public acceptability at local & required level.

At national level the CGWB a Central agency and at State level, a State Ground Water Board as well as WALMIS/NGRI have capacity to undertake and impart training in watershed management, water harvesting, and conservation and recharging works.

It would be desirable that Institutions who are already engaged in watershed training programme may exclusively be made responsible to cater to the watershed management training needs in the region of their location. The CGWB/CWC can together provide training in water harvesting and water recharging including design aspects of harvesting and recharging systems at their academy/institute. Since the training needs shall be of gigantic scale, training can also be imparted by WALMIS/NGRI / Universities to meet the local specific training needs of a block or a panchayat.

These organizations shall prepare training modules with the help of consultants / NGO's having sufficient proficiency in the subject discipline which can be approved for adoption by Drinking Water Mission in the Department of Drinking Water Supply (MORD). The technical guidelines for specific theme areas under various agro – climatic and hydrologic environment can be prepared by CGWB and CWC who are the repository of groundwater and surface water and related data for whole of the country at their Data Bank site

As a matter of fact Department of Drinking Water Supply (MORD) should initiate action for preparing training modules for the local areas / regions with representatives from State Departments of Water Resources, Rural Development, Panchayat Raj and Agriculture Departments.

12.1 TRAINING MODALITIES

The end result of training & education of field level persons, farmers, Water User Groups and Associations is to enable them making a wise & efficient use of surface water & ground water through water conservation.

The modules can be:

- Hand-outs with simple material with sketches and design of water harvesting system in regional languages
- Case studies / success stories including demonstration material
- Approach to training through participatory mechanism

These can be single figure stimuli about the need of person to be trained as it is intended that every body should have education & knowledge of water source & water conservation measures as each drop saved would mean energy saved & humanity served well.

The training activities and training material will provide a long-term utility to the water harvesting and recharging practices. A series of training modules therefore would need to be prepared on following:

(i) Basic criteria for site selection for water harvesting

(ii) Design aspect of Rainwater Harvesting and Groundwater Recharging System

(iii) Synergies between Govt. organizations & NGO's / VO's and Media personnel and women groups including Self Help Groups (SHGs).

(iv) Material and cost estimate for different Harvesting Systems

(v) Traditional Harvesting System vis-a vis piped water supply system.

The training modules shall be adopted into packages which will consist of CD-ROM, overheads and short booklets etc and used widely via inter-governmental organizations and through websites etc. The Regional and web-based networks of website will help to perpetuate training and education work of many interested groups. Training material shall also be distributed to key-users, school and college students and teachers and researchers and others.

The training programme shall be both for technical personnel and managerial level personnel including training of village water & sanitation committee members, volunteers and woman groups.

CHAPTER - 13

Implementation, Monitoring and Evaluation of Water Harvesting Structures

13.0 GENERAL

The post-implementation monitoring and evaluation of water harvesting and recharging structures lies in determining the efficiency of water harvesting systems and the benefits accrued to community in the areas as a result of such harvesting and recharge of works and programmes. The overall monitoring and evaluation criteria is listed below:

1. Monitoring the rise in ground water levels caused by changes in surface and ground water storages.
2. Area benefited and population served by additional availability of surface and ground water through harvesting and water augmentation measures.
3. Monitoring the changes / improvements in water quality caused by recharged water.
4. Periodic operation and maintenance of water harvesting and recharging structures such as desilting and safeguarding of catchment areas against possible pollution and degradation activities.
5. Making people aware of the benefits and outcome of implementation measures and efforts made in sectoral reform programme leading to water conservation and augmentation measures.
6. Monitoring and evaluation system shall be both a inbuilt system of schemes execution as well as concurrent system through independent consultants and or agencies with long experience in implementing Rainwater Harvesting and Ground water recharging works.
7. Harvesting Technology chosen should be appropriate for local area and culture and thoroughly assessed both before and after implementation and corrections made where necessary with peoples involvement.
8. Implementation should best be done by Watershed Conservation Approach through specially set up various levels of watershed committee's for all levels of water management including initial planning and design of harvesting and recharging structures, as well as construction, supervision, decision making, operation and maintenance, monitoring and evaluation of systems designed and constructed.

13.1 IMPLEMENTATION

Implementation shall be on following lines:

1. Build upon participatory process within each Zila Parishad / Panchayat to engage civil society, government, NGO's and user groups.

2. The CGWB, CWC, SGWB's and other institutions be invited to contribute advice on scientific and technical issues including issue of designs of water harvesting and recharging systems, while it may also be required to register experienced NGO's and VOS groups to contribute at local levels in system constructions. The two process could work parallel and in tendom.

3. GPs under RRIs can be entrusted with implementation work with technical support of independent experts whose roaster will be available with MORD.

4. It would be desirable to establish a National Network consisting of Organisation, Institutions involved in execution, monitoring, impact assessment of water harvesting and Recharging System. The interaction with academic institutions and NGO's can be initiated and rationalised on area specific needs. The Department of Drinking Water Supply may be the focal institution for coordinating national and regional level networks. A working group for developing designs/ standards needs to be constituted.

   The above excercise over a time frame would promote a fully decentralised implementation mechanism at Block & Panchayat level once the training and experience is fully gained.

13.2 COMMUNITY / PRI / NGO BASED IMPLEMENTATION STRATEGY

Major portion of development in groundwater is through private initiative with assistance from financial institutions. The water harvesting and recharging of ground water cannot be taken up by individuals except where it happens to be a roof top water harvesting work of a small roof catchments. The water harvesting and artificial recharging of groundwater would require group action by committees, societies, farmers with financial assistance from Govt. and Financial institutions.

Whereas the harvesting and recharging work may be executed and implemented by local committee / Gram panchayat in cooperation with experienced NGO's / Consultants, the technical inputs is to be provided by CGWB / SGWB / CWC/Local institutions.

Broad areas of activities of CGWB/CWC for example in promoting groundwater conservation and augmentation technologies through recharging should be: -

1. Preparation of detailed National Perspective Plan and its periodic revision.

2. Preparation of detailed Regional Perspective Plans and Master Plans to assist the State agencies including periodic revision of such plans.

3. Preparation of National Guidelines/areawise problems specific guidelines and Manuals for use by State Govt. / NGO's etc.

4. Bringing out Annual Review of efforts on ground water recharging and water harvesting through success stories.

The strategy for participatory implementation and monitoring, by and large, would have following components:

1. Generation of mass awareness about water conservation for augmentation through NGOs/VWSCs.
2. formulation of women groups/Self Help Groups, micro watershed management committees etc.
3. imparting of training through central/state ground water agencies and rural/agriculture universities/ water technology centres/Local institutions.
4. preparation of area specific modules for training in local languages for distribution to group & individuals.
5. strengthening of Panchayat Raj Institutions for adopting water harvesting & conservation measures.

APPENDIX - I

REFERENCE TABLES AND DESIGN EXAMPLE OF ROOF TOP HARVESTING

Table A-1.1 : Water Availability for a given Roof Top Area and Rainfall

Roof Top Area (sq.m)	Rainfall (mm)												
	100	200	300	400	500	600	800	1000	1200	1400	1600	1800	2000
	Harvested Water from Roof Top (cum)												
20	1.6	3.2	4.8	6.4	8	9.6	12.8	16	19.2	22.4	25.6	28.8	32
30	2.4	4.8	7.2	9.6	12	14.4	19.2	24	28.8	33.6	38.4	43.2	48
40	3.2	6.4	9.6	12.8	16	19.2	25.6	32	38.4	44.8	51.2	57.6	64
50	4	8	12	16	20	24	32	40	48	56	64	72	80
60	4.8	9.6	14.4	19.2	24	28.8	38.4	48	57.6	67.2	76.8	86.4	96
70	5.6	11.2	16.8	22.4	28	33.6	44.8	56	67.2	78.4	89.6	100.8	112
80	6.4	12.8	19.2	25.6	32	38.4	51.2	64	76.8	89.6	102.4	115.2	128
90	7.2	14.4	21.6	28.8	36	43.2	57.6	72	86.4	100.8	115.2	129.6	144
100	8	16	24	32	40	48	64	80	96	112	128	144	160
150	12	24	36	48	60	72	96	120	144	168	192	216	240
200	16	32	48	64	80	96	128	160	192	224	256	288	320
250	20	40	60	80	100	120	160	200	240	280	320	360	400
300	24	48	72	96	120	144	192	240	288	336	384	432	480
400	32	34	96	128	160	192	256	320	384	448	512	576	640
500	40	80	120	160	200	240	320	400	480	560	640	720	800
1000	80	160	240	320	400	480	640	800	960	1120	1280	1440	1600
2000	160	320	480	640	800	960	1280	1600	1920	2240	2560	2880	3200
3000	240	480	720	960	1200	1440	1920	2400	2880	3360	3840	4320	4800

(i) Figures above — For single household

(ii) Figures above but below — For 2 to 5 households depending upon water scarcity (to be stored in one or two tanks)

(iii) Figures above but below — (a) For village community to be stored in two or more tanks (b) Recharge of wells and tubewells

(iv) Figures below — (a) Village community tank suitable for recharge of wells and tubewells (b) Large surface storages in the absence of natural catchment i.e. hill tops/ ridges

Table A-1.2 : Diameter of Gutter and Width of G.I. Sheet

Rainfall Intensity(I) (in mm/hr)		10	15	20	25	30	35	40	45	50	60	70	80	90	100
Roof Top Area (A) (sq.m)		Diameter (D) of Channel and Width (W) of G.I. Sheet (in mm)													
10	D	20	23	26	28	30	32	33	35	36	39	41	43	45	47
	W	51	56	60	64	67	70	72	74	77	81	84	88	91	93
20	D	26	30	33	36	39	41	43	45	47	50	53	56	58	61
	W	60	67	72	77	81	84	88	91	93	99	103	108	112	115
30	D	30	35	39	42	45	48	50	52	54	58	62	65	68	71
	W	67	74	81	86	91	95	99	102	106	112	117	122	127	131
40	D	33	39	43	47	50	53	56	58	61	65	69	72	76	79
	W	72	81	88	93	99	103	108	112	115	122	128	134	139	144
50	D	36	42	47	51	54	58	61	63	66	71	75	79	82	86
	W	77	86	93	100	106	111	115	120	124	131	138	144	149	154
60	D	39	45	50	54	58	62	65	68	71	76	80	84	88	92
	W	81	91	99	106	112	117	122	127	131	139	146	152	158	164
70	D	41	48	53	58	62	65	69	72	75	80	85	89	93	97
	W	84	95	103	111	117	123	128	133	138	146	153	160	167	172
80	D	43	50	56	61	65	69	72	76	79	84	89	94	98	102
	W	88	99	108	115	122	128	134	139	144	152	160	167	174	180
90	D	45	52	58	63	68	72	76	79	82	88	93	98	102	107
	W	91	102	112	120	127	133	139	144	149	158	167	174	181	188
100	D	47	54	61	66	71	75	79	82	86	92	97	102	107	111
	W	93	106	115	124	131	138	144	149	154	164	172	180	188	194
150	D	54	63	71	77	82	87	92	96	100	107	113	119	124	129
	W	106	120	131	141	149	157	164	170	176	188	197	207	215	223
200	D	61	71	79	86	92	97	102	107	111	119	126	132	138	144
	W	115	131	144	154	164	172	180	188	194	207	218	228	237	246
250	D	66	77	86	93	100	105	111	116	121	129	137	144	150	156
	W	124	141	154	166	176	186	194	202	209	223	235	246	256	266
300	D	71	82	92	100	107	113	119	124	129	138	146	154	161	167
	W	131	149	164	176	188	197	207	215	223	237	250	262	273	283
400	D	79	92	102	111	119	126	132	138	144	154	163	172	179	186
	W	144	164	180	194	207	218	228	237	246	262	276	290	302	313
500	D	86	100	111	121	129	137	144	150	156	167	177	186	195	203
	W	154	176	194	209	223	235	246	256	266	283	299	313	326	339
1000	D	111	129	144	156	167	177	186	195	203	217	230	242	253	263
	W	194	223	246	266	283	299	313	326	339	361	381	400	417	433
2000	D	144	167	186	203	217	230	242	253	263	282	298	314	328	341
	W	246	283	313	339	361	381	400	417	433	462	489	513	535	556
3000	D	167	195	217	236	253	268	282	294	306	328	347	365	382	397
	W	283	326	361	391	417	441	462	482	501	535	566	594	620	644

Provide minimum Diameter of channel - 100 mm and Width of sheet - 176 mm

Diameter to be limited to - 300 mm and Width of sheet - 510 mm

Table A-1.3 : Size of Storage Tank
(Depth of live storage above the outlet pipe = 1.4 m)

Tank Capacity(in cum)	Diameter of Tank (in m)
1.60	1.21
2.40	1.48
3.20	1.71
4.00	1.91
4.80	2.09
5.60	2.26
6.40	2.41
7.20	2.56
8.00	2.70
9.60	2.95
11.20	3.19
12.00	3.30
12.80	3.41
14.40	3.62
16.00	3.81
16.80	3.91
19.20	4.18
20.00	4.26

Note: For rural areas the diameter of tank may be limited to 3 m. The tank would be adequate to meet the drinking water requirements of a family of 5 members for 6 months. For large storage two or more tanks may be provided instead of a single large tank.

DESIGN EXAMPLE

A house has a slopping roof of G.I. sheet with an area of 50 sq.m. The owner of the house has a family of 5 members. Design a roof water harvesting system. The 10 year rainfall for the areas is as follows :

Year 1	320 mm
Year 2	360 mm
Year 3	311 mm
Year 4	290 mm
Year 5	330 mm
Year 6	280 mm
Year 7	335 mm
Year 8	380 mm
Year 9	355 mm
Year 10	340 mm

The maximum rainfall intensity is 10 mm/hour. The lower edge of the roof is 3 m above the ground.

Arranging the rainfall in descending order: 380, 360, 355, 340, 335, 330, 320, 311, 290, 280

The first figure if 380 mm is equalled or exceeded only once in 10 years. Therefore, its expected return period is 1 in 10 years. This is rare. On the other hand the last figure of 280 mm is equalled or exceeded in all the 10 years. Thus is the most reliable figure. So lets us design the system for this figure.

From Table 1, for the roof area of 50 sq.m and rainfall of 280 mm, the available water

= 11.2 cum = 11,200 litres.

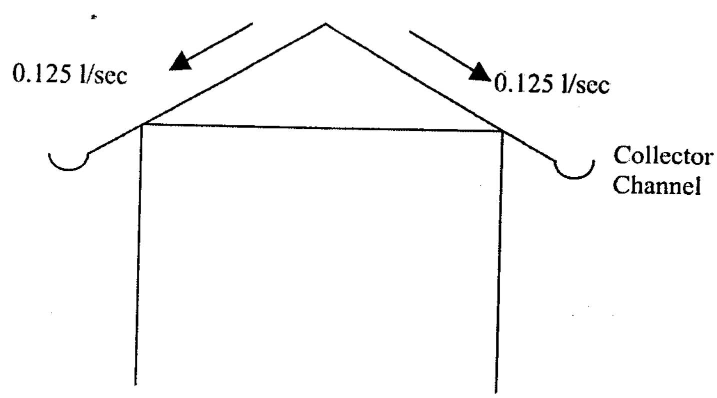
Allowing a consumption of 10 lpcd this water should be sufficient for 224 days or atleast 7 months. In rural areas houses are of low height. So let us limit the height of the tank to 1.6 m with water storage upto 1.4 m height.

A tank of 3.2 m dia and 1.4 m height should be adequate. However provide an extra 0.2 m height to allow for fixing overflow pipe and dead storage below the outlet (tap). Provide a tank size of 3.2 m dia and 1.6 m height.

Size of Collector Channel (Gutter)

During heavy rains i.e. with maximum intensity of 10 mm/hr the runoff coefficient may be taken as 0.9 i.e. assuming a net loss of 10% of rainfall. Maximum rate of runoff from the roof on either side (ignoring the concentration time for runoff i.e. instant generation of runoff is considered)

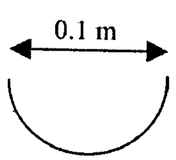
$$= \left[\frac{10.0}{1000} \times \frac{50 \times 0.9}{2 \times 3600}\right] = 0.000125 \text{ cum/sec} = 0.125 \text{ litres/sec}$$



Provide a minimum slope of the collector channel of 5 cm in a length of 10 m i.e. 1 in 200

Trial - I

Providing a collector channel of 0.1 m diameter



$$\text{Area, } A = \frac{1}{2}\pi\frac{D^2}{4} = \frac{1}{2} \times \pi \times \frac{0.01}{4} = 0.003925 \text{ sq.m}$$

Perimeter, $P = \frac{\pi D}{2} = 3.14 \times \frac{0.1}{2} = 0.157$ m

Hydraulic Mean Depth, $R = \frac{0.003925}{0.157} = 0.025$ m

Providing a slope of 1 in 200 for the collector channel,

Velocity of flow, $v = \frac{1}{0.025} (.025)^{2/3} \sqrt{\frac{1}{200}}$

$= \frac{1}{0.025} \times 0.0855 \times \frac{1}{14.14} = 0.24$ m/sec

Discharge, q = A × v = 0.003925 × 0.24
= 0.000942 cumecs
against the design discharge of 0.000125 cumecs

The channel is too oversized.

Trial - II

Let us try a channel of 0.05 m diameter

Area, $A = \frac{1}{2} \pi \times \frac{(0.05)^2}{4} = 0.00098$ sq.m

Perimeter, $P = \pi \times \frac{0.05}{2} = 0.0785$ m

Hydraulic Mean Depth, $R = \frac{0.00098}{0.0785} = 0.0125$ m

Velocity, $v = \frac{1}{0.025} \times (0.0125)^{2/3} \times \frac{1}{14.14} = 0.152$ m/sec

Discharge, q = A × v = 0.00098 × 0.152 = 0.000148 cumecs
O.K.

The channel may be made of plain G.I. sheet. Width of the G.I. sheet required for channel

= P = 0.0785 m = 78.5 mm

Providing 25 mm extra for fixing with rafters/ purlins

Total width required = 78.5 + 25 = 103.5 mm
say 104 mm

Design of Base for the Tank

Total weight of water = 11.2 × 1 = 11.2 Tonnes

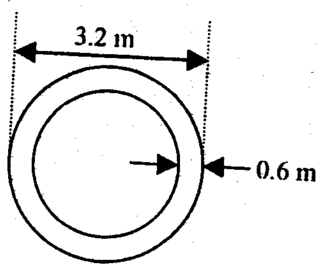
Dead weight of tank & cover (L.S.) = 0.3 Tonnes

Total = 11.5 Tonnes

Assuming bearing capacity of soil = 10 Tonne/sq.m

$\therefore$ Area of foundation = $\frac{11.5}{10}$ = 1.15 sq.m

Providing a minimum width of 0.6 m for foundation



$$\text{Total area of foundation} = \pi \times \frac{(3.2)^2}{4} - \pi \times \frac{(3.2-1.2)^2}{4}]$$

$$= \frac{\pi}{4}\,[(3.2)^2 - (3.2) - (1.2) + 2 \times 1.2 \times 3.2]$$

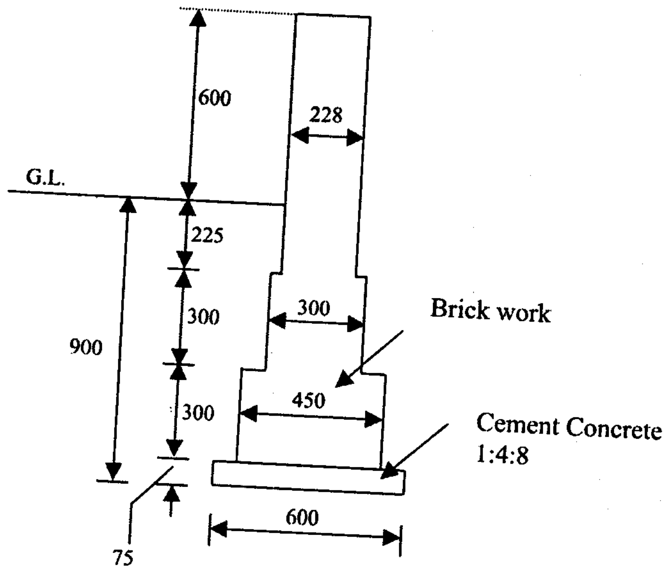
$$= \frac{\pi}{4} \times (6.24) = 4.9 \text{ sq.m}$$

Foundation is safe.

Provide 0.6 m wide circulator foundation in cement concrete 1:4:8, 75 mm thick.

Depth of foundation – 900 mm below ground level.

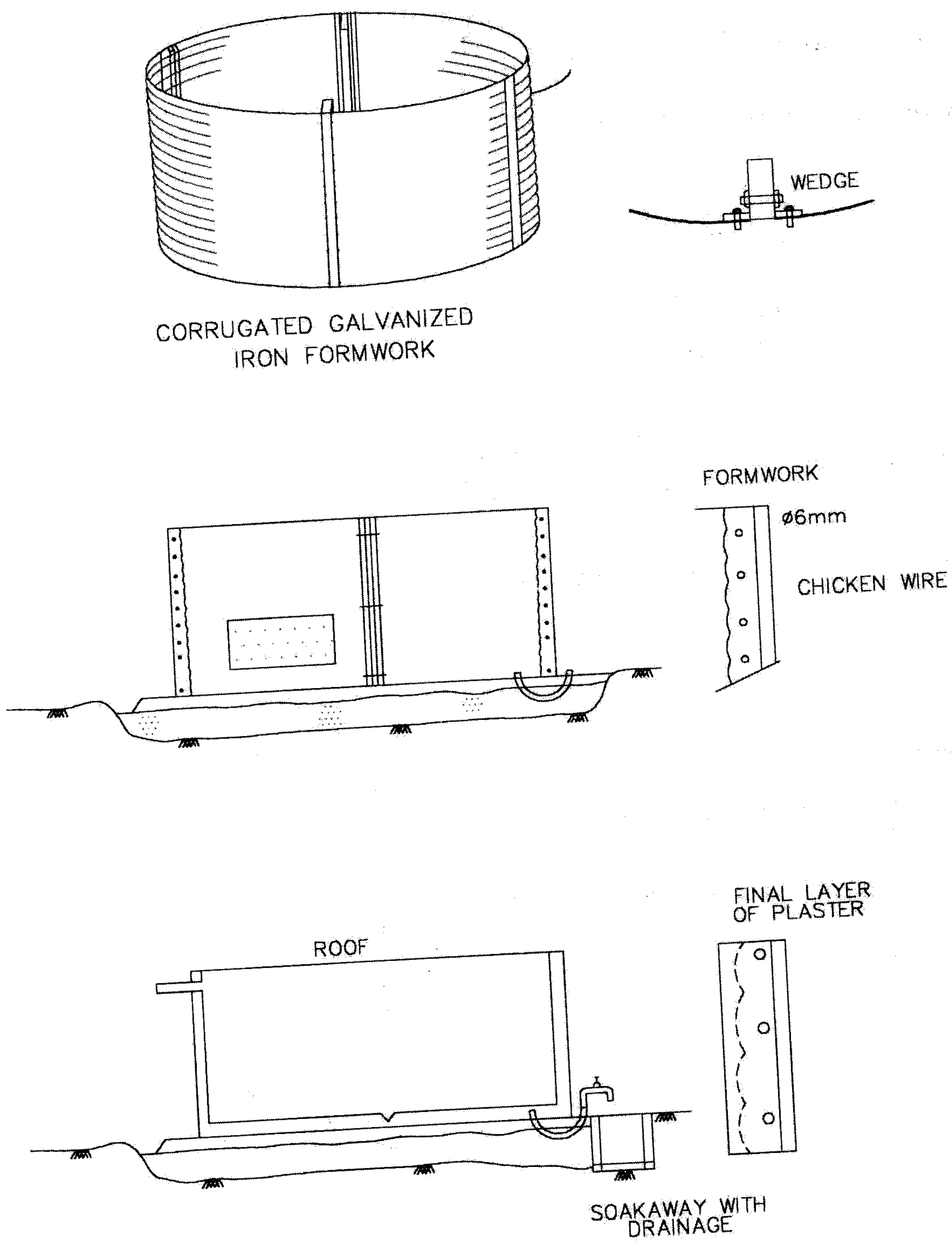
Brick work in foundation to be provided in width of 450 mm to 228 mm in steps as shown in figure below :



APPENDIX - II

CONSTRUCTION, MATERIAL AND DESIGN OF FERROCEMENT TANK

Figure A-2.1 : Construction of Small Ferrocement Standing Tanks



MATERIALS NEEDED FOR FERROCEMENT TANK CONSTRUCTION

Cement

Three types of cement are available in the Indian Market and all the three can be used for ferrocement tank construction:

1. Ordinary Portland Cement (O.P.C.) may be used in normal conditions.
2. Portland Puzolona Cement (P.P.C.) may be used in normal conditions but after checking the mortar setting.
3. High-early-strength Cement (quick setting cement) may be used in cold climatic zones and also in places where early setting and strength gaining is desired.

Sand

Sand from local sources may be checked/ tested and depending upon its properties, can be selected to meet the requirement in terms of silt contents, freedom from chemical pollution and trading. Medium coarse sand with grading may be used for ferrocement jobs.

In order to find strength of mortar for designing, the tank mortar specimens may be made from these local sands. The ratio of cement : sand is 1:2 to 1:3 by volume, and water : cement ratio is 1:3 0.45 by weight (Recommended WC is 0.4) but 0.45 may be used to allow for the variation in the degree of control in the field. The desirable strengths of the mortar are as follows :

Tensile strength at 28 days : (direct tension test ASTM, C190)	17-30 kg/cm^2
Compressive strength at 28 days : (2" cube)	200 kg/cm^2

Wire Mesh

The most common wire meshes used for ferrocement are hexagonal wire mesh, square welded mesh and woven square mesh. Use of woven square mesh is preferred for F.C. Water Tanks.

Chemical Admixtures

Selected grade of poresealing compound and plasticizer may be added to the mortar to be used for construction of F.C. Tanks.

Table A-2.1 : Description and Properties of Hexagonal & Square Woven Wire Meshes

- Ultimate Strength — 8740 kg/cm^2
- Yield Strength — 2100 kg/cm^2
- Modulus of elasticity — 93.75 x 10^4 kg/cm^2

Mesh (mm)	Size (inch)	Wire diameter commonly available (mm)	Roll size generally available
19	(3/4)	0.5 to 1.2	0.91 to 1.2m x 45.7 m (3 to 4 x 150) for hexagonal mesh
10	(3/8)	0.5 to 1.2	0.75 to 1.5m x 15 to 30 m (2.5 x 100) for square woven mesh
12.5	(1/2)	0.5 to 1.2	—

For water tank construction without the aid of a formwork, the tank reinforcement must be strong enough to hold the weight of mortar applied on it and must also be stiff enough to prevent slumping of motor during plastering. Hence the square woven mesh of grid size 12.5 mm (0.91 ´ 30.5 m roll size) has been chosen because to its stiffness when compared to hexagonal mesh and cost advantage when compared to welded wire meshes.

Tank Dimensions	$12m^3$ Unit	$15m^3$ Unit
Diameter	2.5 m	2.5m
Area (in plan) of tank	4.90 m^2	4.90 m^2
Height	2.50 m	3.11 m
Wall Thickness	30 mm	30 mm
Actual Volume of container	12.27 m^3	15.19 m^3
Capacity for water storage	12 m^3	15 m^3

The maximum hoop stresses obtained from an analysis of fixes and hinged types connections between the wall and the base are 6.64 kg/cm^2 and 7.18 kg/cm^2 respectively. The maximum bending moment at the base of the wall is 34.20 kg-cm/cm width, which creates a maximum fibre stress of 12.83 kg/cm^2, if the wall is not reinforced.

DESIGN

The stresses occurring in the tank are small and do not exceed event the tensile strength of unreinforced mortar (17 kg/cm^2) hence, in this case, the design of the tank is controlled partly by construction techniques and the sizes of materials available. For ease in construction, the tank reinforcement chosen of 6 mm skeletal steel rods sandwiched between two layers of 12.5 mm squares, woven 20g (0.9 mm) wire G.I. mesh should be used. The distance between the mesh layers should be 13 to 15 mm.

A single tank can be constructed in four days. Construction can be carried out by unskilled labour if good finishing, plastering is not required. Water tightness of the tank is excellent. A waterline or a seepage loss, which is normally visible in a concrete tank when it is first filled with water, does not exist. Villagers may at first be sceptical because of the thickness of the walls of the tank but these reactions, however, will change when the tank shows its remarkable strength.

Casting of Roof for Tanks

Ferrocement roofs for water tanks are also precast over masonry moulds in one piece or in 4 to 6 pieces depending upon size and height of the tank. Jointing method for roof segments is the same as for wall segment. If the roof is in pieces, the pieces are erected, placed in position at the top and supported temporarily. The laps of reinforcement for joints are fixed up and the joints are filled with mortar. Two types of joints between wall and roof can be adopted.

1. The edge cast around the roof is placed in collar provided at the top of the wall (assembled with segments) and the mortar is filled in the wall roof paint.
2. The roof/ roof segment edge beam covers the wall top edge, like a cover

Various stages of construction of Roofing Units for Ferrocement tanks have been shown in Figure A-2.2.

Do's and Don'ts for Ferrocement Tanks

Do's

1. Use the best quality material for constructing the tank.
2. Take all care to see that there are no lose pockets or honey-combed areas in the surface of wall or

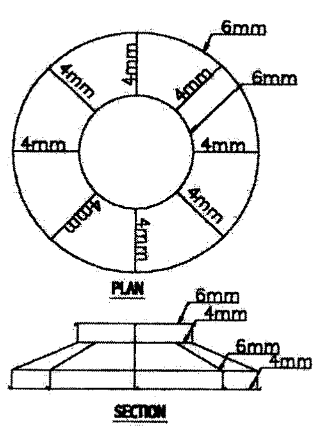
base of ferrocement tank. If such a defect is detected, repair it by chipping mortar on inside and outside surfaces (exposing the wire mesh in that area) and replastering.

3. Cure F.C. tanks for a minimum of 10 days.
4. Clean the tank from inside atleast twice a year.
5. Keep the top of the tank clean to avoid entry of waste material in the tank.
6. Construct the tank at higher point so that drainage of water is proper or construct a soaking pit and connect it to the tank by a drain.
7. Take all care during mortar application and ensure that the mortar enters behind the seat rods and wires provided as skeletal steel and into the wire mesh layer reinforcement. Ensure that the cover over outer and inner mesh layer is not less than 3 mm.

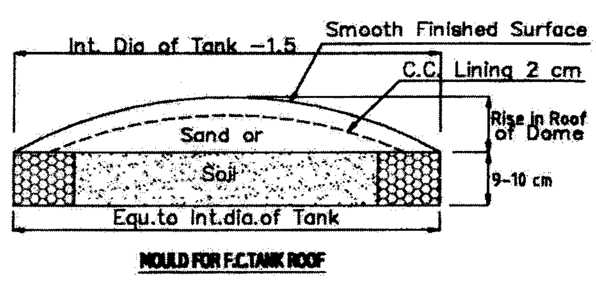
Don'ts

1. Do not allow animals to come near the tank.
2. Do not allow children to climb over the tank.
3. Do not use corrected steel or mesh for construction of the tank.
4. Do not use old stocks of cement for tank construction.
5. Sand to be used should be graded and clean sand having silt contents within 3 percent of the volume. Extra fine or coarse sand must not be used.
6. Do not allow water fittings fixed in the tank to leak, it will not only waste water but may also prove a base for algae growth on fitting joints or surface of the tank and lead to development of bacteria colonies in these.
7. Do not use chemically polluted water on mixing the mortar or curing of ferrocement tank.
8. Do not paint drinking water tank without confirmation of specifications laid down by the Indian Standard Specifications 158 (I.S.–158).

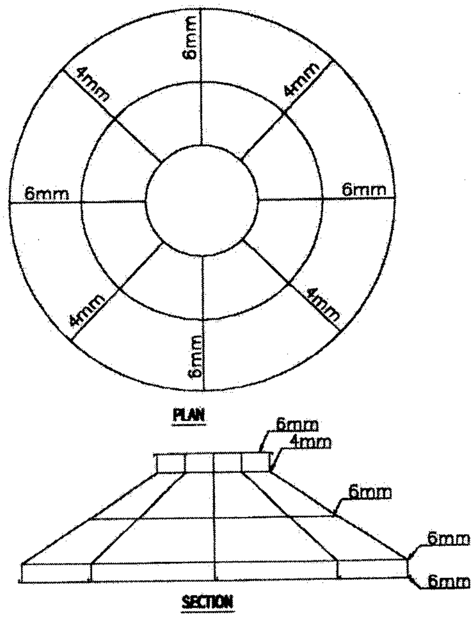
Figure A-2.2 : Mould and Reinforcement Cage for Roof of Ferrocement Water Tanks

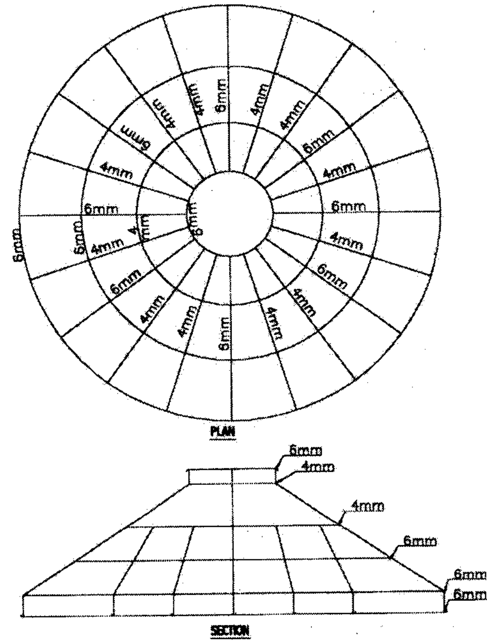


Reinforcement Cage for 60, 65, 75 & 90 cm Diameter F.C. Tanks



Rise of Roof Dome							
Dia of Tank (cm)	65	75/80	90	120	160	200	300
Rise in Roof Dome, (cm)	10	10	10	12	18	20	25





- Reinforcement Cage for Roof of F.C. Tanksof 120, 130, 140 & 160 cm Diameter
- Wire Mesh Reinforcement 1 Layer of 22G´½"´½" G.I. Woven Mesh on inside & outside surfaces

- Reinforcement Cage for Roof of F.C. Tanks of Diameters upto 2.25 m
- Wire Mesh 2-22G´½"´½" G.I. Woven Mesh one on each side

Casting Matrix -	Cement	– 1 Part
	Medium Coarse Graded Sand	– 2 Part
	Water	– 0.4 Parts
	Poresealing Compound	– 0.5 Percent of Cement
	Plasticizer	– 0.5 Percent of Cement

APPENDIX - III

TABLES AND DESIGN EXAMPLE FOR TANKA/PERCOLATION TANK

Table A-3.1 : Yield from 1 hectare of Natural (Untreated) Catchment

Total Monsoon rainfall in mm	Good Catchment		Average Catchment		Bad Catchment	
	Percentage of Utilisable rain water	Utilisable rain water (cum)	Percentage of utilisable rain water	Utilisable rain water (cum)	Percentage of utilisable rain water	Utilisable rain water (cum)
20	0.080	0.16	0.06	0.12	0.04	0.08
40	0.130	0.52	0.0975	0.39	0.065	0.26
60	0.245	1.47	0.1735	1.10	0.1225	0.73
80	0.410	3.28	0.3075	2.56	0.205	1.64
100	0.700	7.00	0.525	5.25	0.350	3.50
120	0.900	10.80	0.675	8.10	0.450	5.40
140	1.1225	17.15	0.91875	12.86	0.6125	8.57
160	1.625	26.00	1.21875	19.50	0.8125	13.00
180	2.120	31.86	1.5900	28.62	1.060	19.08
200	2.700	54.00	2.025	40.50	1.350	27.00
220	3.260	71.72	2.445	53.79	1.630	35.86
240	3.810	91.44	2.8575	68.58	1.905	47.52
260	4.450	115.70	3.3375	86.77	2.225	57.85
280	5.190	145.32	3.3925	108.99	2.595	72.66
300	5.900	177.00	4.425	132.75	2.95	88.50
320	6.720	215.04	5.040	161.26	3.36	107.52
340	7.750	257.38	5.6775	193.03	3.785	128.69
360	8.550	307.80	6.4125	230.85	4.275	153.90
380	9.450	369.10	7.0876	276.82	4.725	184.55
400	10.250	410.00	7.6875	307.50	5.125	205.00
420	11.050	464.10	8.2875	348.07	5.525	232.05
440	12.000	528.00	9.000	396.00	6.00	264.00
460	12.950	595.70	9.7125	446.77	6.475	297.86
480	13.900	667.20	10.425	500.40	6.950	333.60
500	14.700	735.00	11.025	551.25	7.350	367.50
520	15.500	806.00	11.625	604.50	7.750	403.00
540	16.360	882.90	12.2625	662.17	8.175	441.45
560	17.200	963.20	12.900	772.40	8.600	481.60
580	18.000	1040.00	13.500	780.00	9.000	520.00
600	19.000	1140.00	14.250	855.00	9.500	570.00

Good catchment: Hills or plains with little cultivation and moderately absorbent soil.

Average catchment: Flat partly cultivated stiff gravely/ sandy absorbent soil.

Bad catchment: Flat and cultivated sandy soils.

Table A-3.2 : Runoff from Treated Catchments (30 m dia) for rainfall range 130 mm to 317 mm

Sl. No.	Treatment	Percentage of utilisable rain water	Utilisable rain water (cum)
1	Bentonite 20% mixed	51-87	46.80-194.84
2	Cement 8% mixed with soil 1.25 cm thick	23-41	21.12-91.82
3	Mud Plaster (Local) 1.25 cm thick	38-67	34.90-150.00
4	Lime Concrete 5 cm thick	48-74	44.00-165.73
5	Sodium carbonate spray @ 1 kg/ 10 sq.m over 1.25 cm thick compacted tank silt	63-92	57.86-206.00
6	Mud Plaster - with mixture of mud, wheat husk (Bhusa) and Jantha Emulsion (a kind of asphalt) - (95:3:2)	49-79	45.00-176.92
7	Well dressed and compacted without treatment	30-57	27.55-127.65

Note: For a given rainfall the utilisable rainwater can be suitably interpolated.

DESIGN EXAMPLE

Assuming that the average annual monsoon rainfall for a village is 220 mm and the natural catchment is flat, partly cultivated, with stiff sandy absorbent soil. Land is available only for one community Tanka with a catchment of 2 ha.

From Table A-3.1, it is seen that the catchment is "Average".

For 220 mm of rainfall the available rainwater = 2 x 68.58
= 137.16 cum

Assuming that we decide to treat a circular area of 30 m diameter around the Tanka with lime concrete.

From Table A-3.2, the utilisable rainwater from the treated catchment (by interpolation) = 102.58 cum.

Therefore, total amount of water from natural and treated catchment = 137.16 + 102.58
= 239.74 cum

The site is therefore suitable for a standard community Tanka of 200 cum capacity.

APPENDIX - IV

DESIGN EXAMPLE OF PERCOLATION TANK

TYPICAL DESIGN OF PERCOLATION TANK

Data

Catchment Area = 1.4 sq.km (0.549 sq.miles)
Nature of Catchment = Good
Average annual rainfall = 786 mm
65 percent dependable rainfall = 717 mm

Capacity Table for Tank

R.L. (m)	Capacity (MCM)
97.00	0.0070
97.50	0.0090
98.00	0.0105
98.50	0.0116
99.00	0.0120
99.50	0.0131
100.00	0.0139
100.50	0.0142

Yield from Catchment

From Strange's Table
Yield/sq. km for 717 mm rainfall = 0.187 MCM
Yield from the catchment = 0.187 ´ 1.4 = 0.262 MCM

Assumptions

(i) Number of fillings per year = 2
(ii) Utilisation of yield per filling = 5 percent

Design of Tank

Capacity of percolation tank = 0.05 ´ 0.262 = 0.0131 MCM
Total utilisation of yield per year = 2 ´ 0.0131 = 0.0262 MCM
Full Tank Level for capacity of 0.0131 MCM = 99.50 m
Crest level of spillway = 99.50 m
Providing 0.5 m head over the spillway crest
Maximum water level in tank = 100.00 m
Providing free board of 0.5 m above M.W.L.
Top of bund = 100.50 m

Design Flood

Where a formula applicable to a given situation is available viz. Dicken's or Ryve's formula. Assuming that following Dicken's formula is available. This gives flood discharge of 25 years frequency

$Q = 1000\ A^{3/4}$

Where,

Q = Flood discharge in cusecs

A = Catchment area in sq.miles

$Q = 1000 \times (0.549)^{3/4}$

$= 1000 \times 0.638$

= 638.00 cusecs

= 18.09 cumecs

Length of Spillway

Head over spillway crest = 0.5 m

For weir discharge per m length, $q = 1.84\ (h)^{3/2}$

$$\text{Length of spillway} = \frac{Q}{1.84\,(h)^{3/2}}$$

$$= \frac{18.09}{1.84 \times (0.5)^{3/2}}$$

= 27.82

Say 28 m

Design of Surplus Course

Area of flow = (28+0.5) 0.50 = 14.25 sq.m

Bed slope = 1 in 750

$P = 28 + (2 \times 1.118 \times 0.50) = 29.118$ m
Say 29.12 m

$$R = \frac{14.25}{29.12}$$

= 0.4894 m

$R^{2/3} = (0.4894)^{2/3}$

= 0.621

$$\text{Velocity} = \frac{1}{n} \times R^{2/3} S^{1/2}$$

$$= \frac{1}{0.025} \times 0.621 \times \frac{1}{(750)^{1/2}}$$

= 0.907 m/sec

Discharge = 14.25 ´ 0.907

= 12.92 cumecs as against 12.66 cumecs

Hence safe

Depth of foundation

Design flood discharge, Q = 18.09 cumecs

$$\text{Normal Scour depth, } R = 1.35 \left(\frac{q^2}{f}\right)^{1/3}$$

$$q = \frac{18.09}{28} = 0.646$$

Assuming, f = 1

$$R = 1.35 \left(\frac{0.646^2}{1}\right)^{1/3}$$

= 1.00 m

Scour depth = 1.5 R

= 1.5 × 1.00

= 1.5 m

Maximum scour level = 100.00 – 1.50

= 98.50

Height of body wall = 0.90 m

Thickness of foundation concrete = 0.15 m

Foundation level = 99.50 - 0.90 - 0.15

= 98.45 O.K.

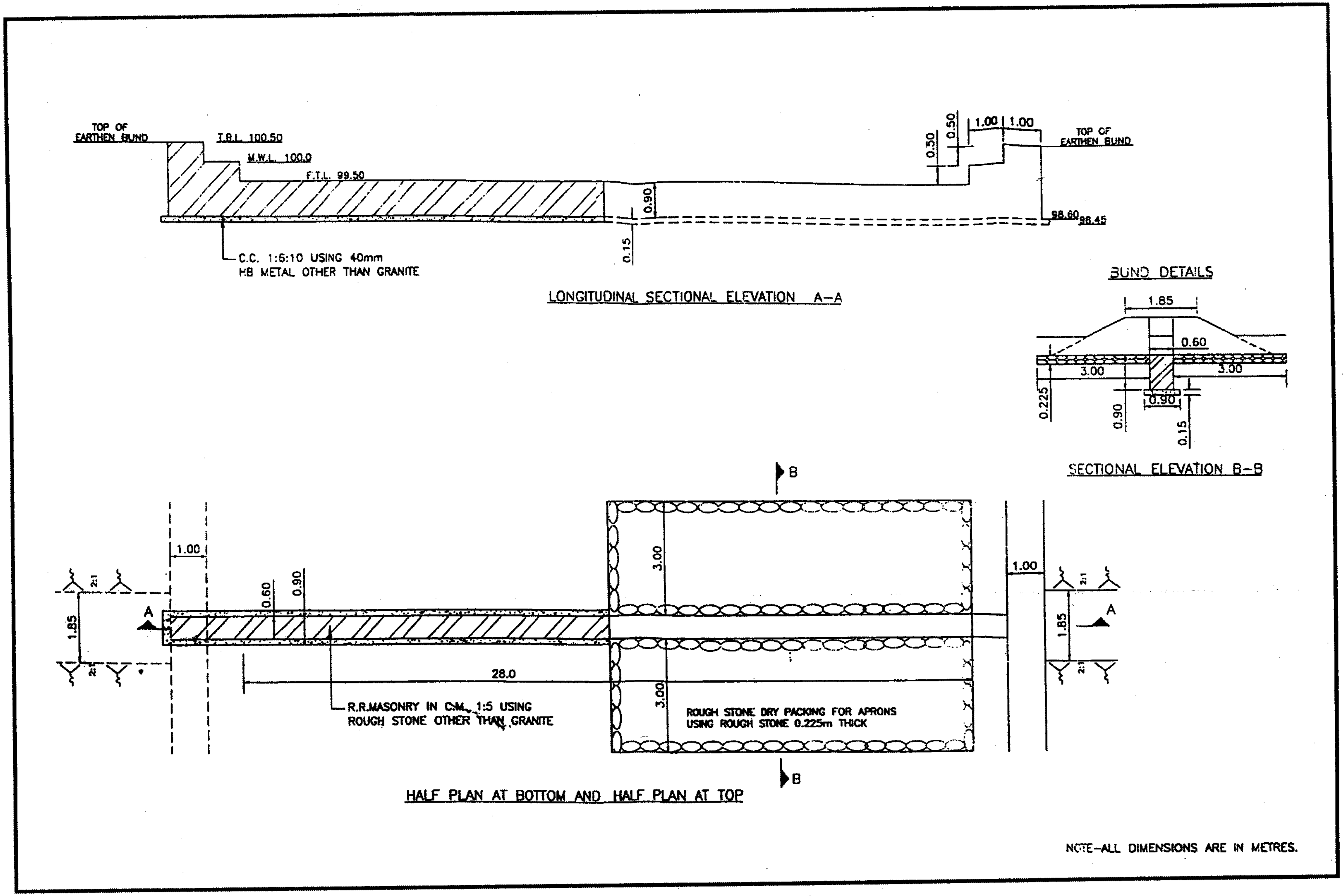
Earthen Bund

Top width = 1.85 m

Side slopes : Taking into consideration the nature of soil and local practice, side slopes of 2:1 are proposed on both sides of the bund.

The sample drawings for Percolation Tank are shown in Figure A-4.1.

Figure A-4.1 : PLAN SHOWING WASTE WEIR OF PERCOLATION TANK



APPENDIX -V

DESIGN EXAMPLE OF CHECK DAM

TYPICAL DESIGN OF CHECK DAM

Data

Catchment area = 15.68 sq. km (6.127 sq. miles)
Nature of Catchment = Good
Average annual rainfall = 825 mm
65 percent dependable rainfall = 717 mm

Gauge-Discharge Table

Discharge	Water Level
50	89.98
60	91.59
70	93.21
80	94.83
90	96.45
110	99.69
115	100.50

Yield from Catchment

From Strange's Table

Yield/sq. km for 717 mm rainfall is 26.08 percent of rainfall = 0.187 MCM

Yield from the catchment = 15.68×0.187
= 2.93 MCM

Design Flood

Where a formula applicable to a given situation is available viz. Dicken's or Ryve's formula. Assuming that following Dicken's formula is available

$Q = 1000\ A^{3/4}$

$Q = 1000\ (6.127)^{3/4}$

= 3894 cusecs

= 110.37 cumecs

Design of Sharp Crested Weir

Discharge, $Q = 1.84\ (L - KnH)\ H^{3/2}$

Where,

L = Length of weir

K = Coefficient of end contraction (adopted 0.1)

n = Number of end contractions (in this case = 2)

H = Total head over spillway crest

Q = Discharge

Providing a total head (including velocity head of 0.05) = 1.05 m

$110.37 = 1.84\,(L - 0.1 \times 2 \times 1.05)\,1.05^{3/2}$

$= 1.84\,(L - 0.21) \times 1.076$

L = 55.95 m
Say 56 m

Discharge intensity, $q = \dfrac{110.37}{56}$

$= 1.97$ cumecs

Normal Scour depth, $R = 1.35\,(\dfrac{q^2}{f})^{1/3}$

$= 1.35\,(\dfrac{1.97^2}{f})^{1/3}$

Assuming, f = 1

R = 2.12 m below the maximum flood level

Computed flood level at weir site corresponding to the design discharge of 110.37 cumecs is 99.75 m

Keeping the crest level = 99.00 m

Maximum water level = 99.00 + 1.05
= 100.05 m

Thus, there will be a net flood lift of (100.05 – 99.75) i.e. 0.3 m at the weir site

Depth of downstream cutoff = 1.5 R
= 1.5 × 2.12
= 3.18 m

Desired R.L. of cut off = 100.05 - 3.18 = 96.87 m

Average bed level of deep channel is 97.30 m

Providing a minimum depth of 1 m for cutoff

Actual R.L. of cutoff = 97.30 - 1.00
= 96.30 (against the desired level of 96.87)

Design of Weir Floor

Design flood = 110.37 cumecs

Length of weir = 56 m

Height of weir above the bed = 99.00 - 97.30
= 1.7 m

Bottom width of weir = 1.6 m

Total maximum head, H = 1.7 m

Total creep length required, L = C ´ H

Adopting C = 4

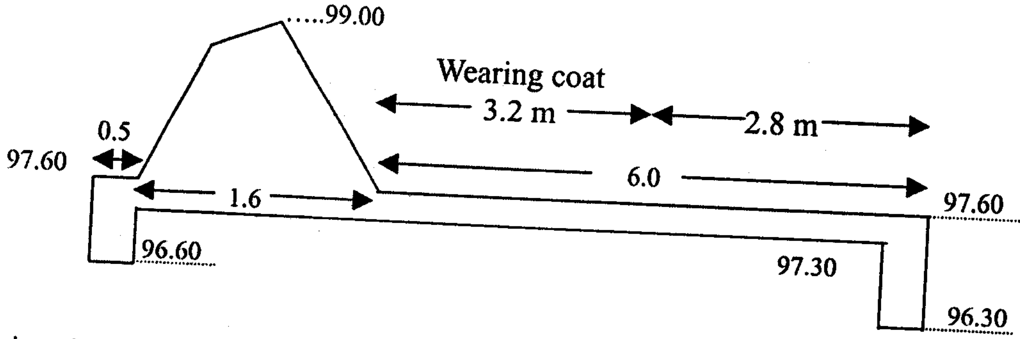
L = 4 × 1.7
= 7.22 m
Say 7.25 m

Length of downstream floor, $L_d = 2.21\ C \sqrt{\left(\frac{H}{13}\right)}$

$= 2.21 \times 4 \sqrt{\left(\frac{1.7}{13}\right)}$

= 3.19 m

Say 3.20 m



Provide a length of 6.0 m and provide wearing coat for 3.20 m.

Bottom level of downstream cutoff = 96.30

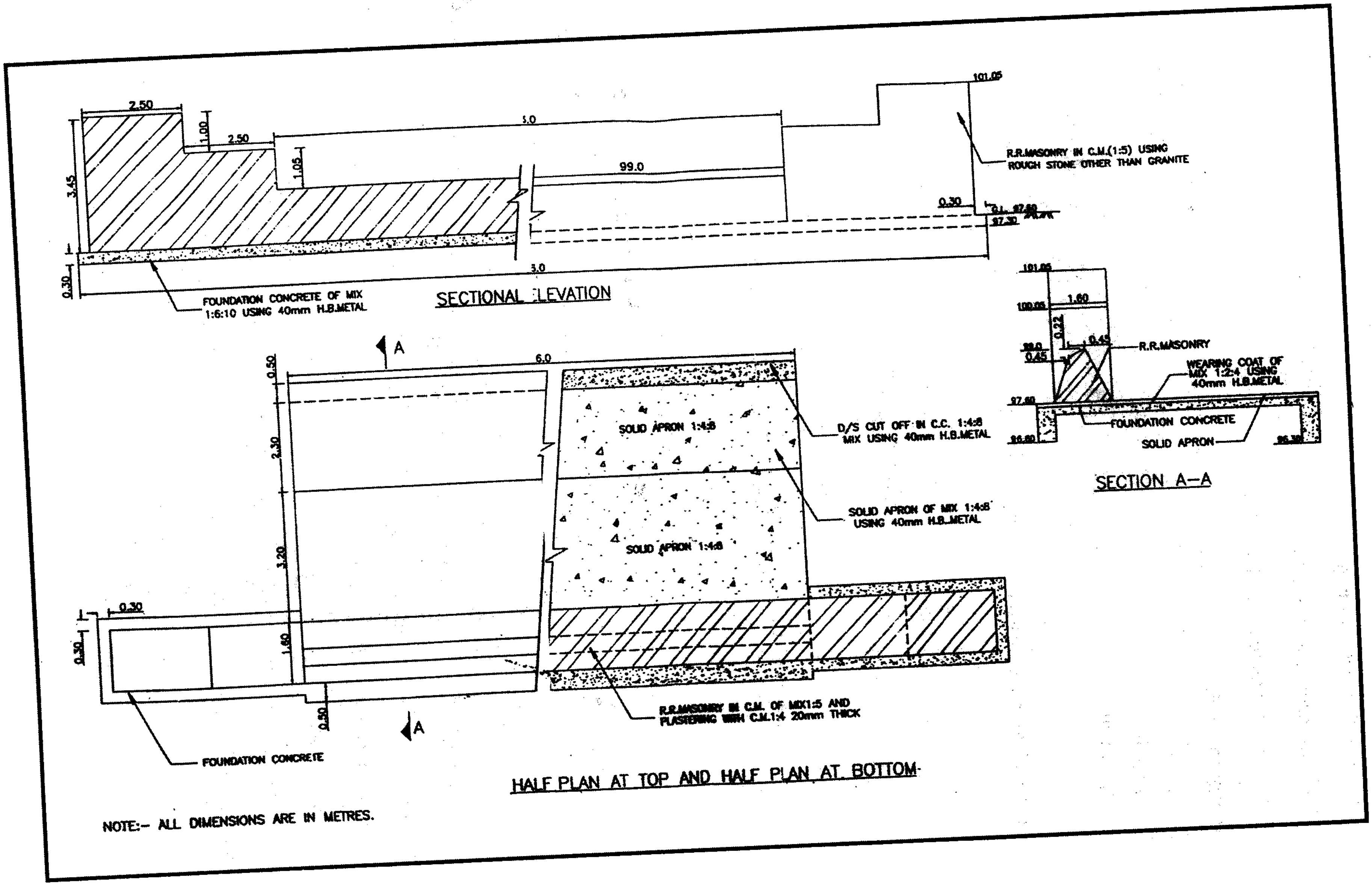
Assuming bottom level of U/S cut off = 96.60

Provide floor thickness = 0.3 m

Actual creep length = 1.0 + 0.5 + 1.6 + 3.2 + 2.8 + 1.3 = 10.4 m against 7.25 m required. Hence O.k.

The sample drawings for Check Dam are shown in Figure A-5.1.

Figure A-5.1 : PLAN SHOWING CHECK DAM



APPENDIX -VI

TABLE FOR COMPUTATION OF STORAGE VOLUME OF POND/TANK

Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Channel Width, B = 1 m						
		Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 4	1	50	63	75	125	250	375	500
	2	360	450	540	900	1800	2700	3600
	3	1170	1463	1755	2925	5850	8775	11700
	4	2720	3400	4080	6800	13600	20400	27200
	5	5250	6563	7875	13125	26250	39375	52500
	6	9000	11250	13500	22500	45000	67500	90000
	7	14210	17763	21315	35525	71050	106575	142100
	8	21120	26400	31680	52800	105600	158400	211200
n = 5	1	60	75	90	150	300	450	600
	2	440	550	660	1100	2200	3300	4400
	3	1440	1800	2160	3600	7200	10800	14400
	4	3360	4200	5040	8400	16800	25200	33600
	5	6500	8125	9750	16250	32500	48750	65000
	6	11160	13950	16740	27900	55800	83700	111600
	7	17640	22050	26460	44100	88200	132300	176400
	8	26240	32800	39360	65600	131200	196800	262400
n = 6	1	70	88	105	175	350	525	700
	2	520	650	780	1300	2600	3900	5200
	3	1710	2138	2565	4275	8550	12825	17100
	4	4000	5000	6000	10000	20000	30000	40000
	5	7750	9688	11625	19375	38750	58125	77500
	6	13320	16650	19980	33300	66600	99900	133200
	7	21070	26338	31605	52675	105350	158025	210700
	8	31360	39200	47040	78400	156800	235200	313600
n = 7	1	80	100	120	200	400	600	800
	2	600	750	900	1500	3000	4500	6000
	3	1980	2475	2970	4950	9900	14850	19800
	4	4640	5800	6960	11600	23200	34800	46400
	5	9000	11250	13500	22500	45000	67500	90000
	6	15480	19350	23220	38700	77400	116100	154800
	7	24500	30625	36750	61250	122500	183750	245000
	8	36480	45600	54720	91200	182400	273600	364800

Channel Width, B = 1 m								
		Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
Bank Slope (n : 1)	Maximum Depth of Water, D (m)	S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 10	1	110	138	165	275	550	825	1100
	2	840	1050	1260	2100	4200	6300	8400
	3	2790	3488	4185	6975	13950	20925	27900
	4	6560	8200	9840	16400	32800	49200	65600
	5	12750	15938	19125	31875	63750	95625	127500
	6	21960	27450	32940	54900	109800	164700	219600
	7	34790	43488	52185	86975	173950	260925	347900
	8	51840	64800	77760	129600	259200	388800	518400
n = 15	1	160	200	240	400	800	1200	1600
	2	1240	1550	1860	3100	6200	9300	12400
	3	4140	5175	6210	10350	20700	31050	41400
	4	9760	12200	14640	24400	48800	73200	97600
	5	19000	23750	28500	47500	95000	142500	190000
	6	32760	40950	49140	81900	163800	245700	327600
	7	51940	64925	77910	129850	259700	389550	519400
	8	77440	96800	116160	193600	387200	580800	774400
n = 20	1	210	263	315	525	1050	1575	2100
	2	1640	2050	2460	4100	8200	12300	16400
	3	5490	6863	8235	13725	27450	41175	54900
	4	12960	16200	19440	32400	64800	97200	129600
	5	25250	31563	37875	63125	126250	189375	252500
	6	43560	54450	65340	108900	217800	326700	435600
	7	69090	86363	103635	172725	345450	518175	690900
	8	103040	128800	154560	257600	515200	772800	1030400
n = 25	1	260	325	390	650	1300	1950	2600
	2	2040	2550	3060	5100	10200	15300	20400
	3	6840	8550	10260	17100	34200	51300	68400
	4	16160	20200	24240	40400	80800	121200	161600
	5	31500	39375	47250	78750	157500	236250	315000
	6	54360	67950	81540	135900	271800	407700	543600
	7	86240	107800	129360	215600	431200	646800	862400
	8	128640	160800	192960	321600	643200	964800	1286400
n = 30	1	310	388	465	775	1550	2325	3100
	2	2440	3050	3660	6100	12200	18300	24400
	3	8190	10238	12285	20475	40950	61425	81900
	4	19360	24200	29040	48400	96800	145200	193600
	5	37750	47188	56625	94375	188750	283125	377500
	6	65160	81450	97740	162900	325800	488700	651600
	7	103390	129238	155085	258475	516950	775425	1033900
	8	154240	192800	231360	385600	771200	1156800	1542400

		Channel Width, B = 2 m						
Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 4	1	60	75	90	150	300	450	600
	2	400	500	600	1000	2000	3000	4000
	3	1260	1575	1890	3150	6300	9450	12600
	4	2880	3600	4320	7200	14400	21600	28800
	5	5500	6875	8250	13750	27500	41250	55000
	6	9360	11700	14040	23400	46800	70200	93600
	7	14700	18375	22050	36750	73500	110250	147000
	8	21760	27200	32640	54400	108800	163200	217600
n = 5	1	70	88	105	175	350	525	700
	2	480	600	720	1200	2400	3600	4800
	3	1530	1913	2295	3825	7650	11475	15300
	4	3520	4400	5280	8800	17600	26400	35200
	5	6750	8438	10125	16875	33750	50625	67500
	6	11520	14400	17280	28800	57600	86400	115200
	7	18130	22663	27195	45325	90650	135975	181300
	8	26880	33600	40320	67200	134400	201600	268800
n = 6	1	80	100	120	200	400	600	800
	2	560	700	840	1400	2800	4200	5600
	3	1800	2250	2700	4500	9000	13500	18000
	4	4160	5200	6240	10400	20800	31200	41600
	5	8000	10000	12000	20000	40000	60000	80000
	6	13680	17100	20520	34200	68400	102600	136800
	7	21560	26950	32340	53900	107800	161700	215600
	8	32000	40000	48000	80000	160000	240000	320000
n = 7	1	90	113	135	225	450	675	900
	2	640	800	960	1600	3200	4800	6400
	3	2070	2588	3105	5175	10350	15525	20700
	4	4800	6000	7200	12000	24000	36000	48000
	5	9250	11563	13875	23125	46250	69375	92500
	6	15840	19800	23760	39600	79200	118800	158400
	7	24990	31238	37485	62475	124950	187425	249900
	8	37120	46400	55680	92800	185600	278400	371200
n = 10	1	120	150	180	300	600	900	1200
	2	880	1100	1320	2200	4400	6600	8800
	3	2880	3600	4320	7200	14400	21600	28800
	4	6720	8400	10080	16800	33600	50400	67200
	5	13000	16250	19500	32500	65000	97500	130000
	6	22320	27900	33480	55800	111600	167400	223200
	7	35280	44100	52920	88200	176400	264600	352800
	8	52480	65600	78720	131200	262400	393600	524800

Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Channel Width, B = 2 m						
		Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 15	1	170	213	255	425	850	1275	1700
	2	1280	1600	1920	3200	6400	9600	12800
	3	4230	5288	6345	10575	21150	31725	42300
	4	9920	12400	14880	24800	49600	74400	99200
	5	19250	24063	28875	48125	96250	144375	192500
	6	33120	41400	49680	82800	165600	248400	331200
	7	52430	65538	78645	131075	262150	393225	524300
	8	78080	97600	117120	195200	390400	585600	780800
n = 20	1	220	275	330	550	1100	1650	2200
	2	1680	2100	2520	4200	8400	12600	16800
	3	5580	6975	8370	13950	27900	41850	55800
	4	13120	16400	19680	32800	65600	98400	131200
	5	25500	31875	38250	63750	127500	191250	255000
	6	43920	54900	65880	109800	219600	329400	439200
	7	69580	86975	104370	173950	347900	521850	695800
	8	103680	129600	155520	259200	518400	777600	1036800
n = 25	1	270	338	405	675	1350	2025	2700
	2	2080	2600	3120	5200	10400	15600	20800
	3	6930	8663	10395	17325	34650	51975	69300
	4	16320	20400	24480	40800	81600	122400	163200
	5	31750	39688	47625	79375	158750	238125	317500
	6	54720	68400	82080	136800	273600	410400	547200
	7	86730	108413	130095	216825	433650	650475	867300
	8	129280	161600	193920	323200	646400	969600	1292800
n = 30	1	320	400	480	800	1600	2400	3200
	2	2480	3100	3720	6200	12400	18600	24800
	3	8280	10350	12420	20700	41400	62100	82800
	4	19520	24400	29280	48800	97600	146400	195200
	5	38000	47500	57000	95000	190000	285000	380000
	6	65520	81900	98280	163800	327600	491400	655200
	7	103880	129850	155820	259700	519400	779100	1038800
	8	154880	193600	232320	387200	774400	1161600	1548800

		Channel Width, B = 3 m						
Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 4	1	70	88	105	175	350	525	700
	2	440	550	660	1100	2200	3300	4400
	3	1350	1688	2025	3375	6750	10125	13500
	4	3040	3800	4560	7600	15200	22800	30400
	5	5750	7188	8625	14375	28750	43125	57500
	6	9720	12150	14580	24300	48600	72900	97200
	7	15190	18988	22785	37975	75950	113925	151900
	8	22400	28000	33600	56000	112000	168000	224000
n = 5	1	80	100	120	200	400	600	800
	2	520	650	780	1300	2600	3900	5200
	3	1620	2025	2430	4050	8100	12150	16200
	4	3680	4600	5520	9200	18400	27600	36800
	5	7000	8750	10500	17500	35000	52500	70000
	6	11880	14850	17820	29700	59400	89100	118800
	7	18620	23275	27930	46550	93100	139650	186200
	8	27520	34400	41280	68800	137600	206400	275200
n = 6	1	90	113	135	225	450	675	900
	2	600	750	900	1500	3000	4500	6000
	3	1890	2363	2835	4725	9450	14175	18900
	4	4320	5400	6480	10800	21600	32400	43200
	5	8250	10313	12375	20625	41250	61875	82500
	6	14040	17550	21060	35100	70200	105300	140400
	7	22050	27563	33075	55125	110250	165375	220500
	8	32640	40800	48960	81600	163200	244800	326400
n = 7	1	100	125	150	250	500	750	1000
	2	680	850	1020	1700	3400	5100	6800
	3	2160	2700	3240	5400	10800	16200	21600
	4	4960	6200	7440	12400	24800	37200	49600
	5	9500	11875	14250	23750	47500	71250	95000
	6	16200	20250	24300	40500	81000	121500	162000
	7	25480	31850	38220	63700	127400	191100	254800
	8	37760	47200	56640	94400	188800	283200	377600
n = 10	1	130	163	195	325	650	975	1300
	2	920	1150	1380	2300	4600	6900	9200
	3	2970	3713	4455	7425	14850	22275	29700
	4	6880	8600	10320	17200	34400	51600	68800
	5	13250	16563	19875	33125	66250	99375	132500
	6	22680	28350	34020	56700	113400	170100	226800
	7	35770	44713	53655	89425	178850	268275	357700
	8	53120	66400	79680	132800	265600	398400	531200

Channel Width, B = 3 m								
Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 15	1	180	225	270	450	900	1350	1800
	2	1320	1650	1980	3300	6600	9900	13200
	3	4320	5400	6480	10800	21600	32400	43200
	4	10080	12600	15120	25200	50400	75600	100800
	5	19500	24375	29250	48750	97500	146250	195000
	6	33480	41850	50220	83700	167400	251100	334800
	7	52920	66150	79380	132300	264600	396900	529200
	8	78720	98400	118080	196800	393600	590400	787200
n = 20	1	230	288	345	575	1150	1725	2300
	2	1720	2150	2580	4300	8600	12900	17200
	3	5670	7088	8505	14175	28350	42525	56700
	4	13280	16600	19920	33200	66400	99600	132800
	5	25750	32188	38625	64375	128750	193125	257500
	6	44280	55350	66420	110700	221400	332100	442800
	7	70070	87588	105105	175175	350350	525525	700700
	8	104320	130400	156480	260800	521600	782400	1043200
n = 25	1	280	350	420	700	1400	2100	2800
	2	2120	2650	3180	5300	10600	15900	21200
	3	7020	8775	10530	17550	35100	52650	70200
	4	16480	20600	24720	41200	82400	123600	164800
	5	32000	40000	48000	80000	160000	240000	320000
	6	55080	68850	82620	137700	275400	413100	550800
	7	87220	109025	130830	218050	436100	654150	872200
	8	129920	162400	194880	324800	649600	974400	1299200
n = 30	1	330	413	495	825	1650	2475	3300
	2	2520	3150	3780	6300	12600	18900	25200
	3	8370	10463	12555	20925	41850	62775	83700
	4	19680	24600	29520	49200	98400	147600	196800
	5	38250	47813	57375	95625	191250	286875	382500
	6	65880	82350	98820	164700	329400	494100	658800
	7	104370	130463	156555	260925	521850	782775	1043700
	8	155520	194400	233280	388800	777600	1166400	1555200

Channel Width, B = 4 m								
Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Storage Volume, V (cum) Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 4	1	80	100	120	200	400	600	800
	2	480	600	720	1200	2400	3600	4800
	3	1440	1800	2160	3600	7200	10800	14400
	4	3200	4000	4800	8000	16000	24000	32000
	5	6000	7500	9000	15000	30000	45000	60000
	6	10080	12600	15120	25200	50400	75600	100800
	7	15680	19600	23520	39200	78400	117600	156800
	8	23040	28800	34560	57600	115200	172800	230400
n = 5	1	90	113	135	225	450	675	900
	2	560	700	840	1400	2800	4200	5600
	3	1710	2138	2565	4275	8550	12825	17100
	4	3840	4800	5760	9600	19200	28800	38400
	5	7250	9063	10875	18125	36250	54375	72500
	6	12240	15300	18360	30600	61200	91800	122400
	7	19110	23888	28665	47775	95550	143325	191100
	8	28160	35200	42240	70400	140800	211200	281600
n = 6	1	100	125	150	250	500	750	1000
	2	640	800	960	1600	3200	4800	6400
	3	1980	2475	2970	4950	9900	14850	19800
	4	4480	5600	6720	11200	22400	33600	44800
	5	8500	10625	12750	21250	42500	63750	85000
	6	14400	18000	21600	36000	72000	108000	144000
	7	22540	28175	33810	56350	112700	169050	225400
	8	33280	41600	49920	83200	166400	249600	332800
n = 7	1	110	138	165	275	550	825	1100
	2	720	900	1080	1800	3600	5400	7200
	3	2250	2813	3375	5625	11250	16875	22500
	4	5120	6400	7680	12800	25600	38400	51200
	5	9750	12188	14625	24375	48750	73125	97500
	6	16560	20700	24840	41400	82800	124200	165600
	7	25970	32463	38955	64925	129850	194775	259700
	8	38400	48000	57600	96000	192000	288000	384000
n = 10	1	140	175	210	350	700	1050	1400
	2	960	1200	1440	2400	4800	7200	9600
	3	3060	3825	4590	7650	15300	22950	30600
	4	7040	8800	10560	17600	35200	52800	70400
	5	13500	16875	20250	33750	67500	101250	135000
	6	23040	28800	34560	57600	115200	172800	230400
	7	36260	45325	54390	90650	181300	271950	362600
	8	53760	67200	80640	134400	268800	403200	537600

Channel Width, B = 4 m								
Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Storage Volume, V (cum) Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 15	1	190	238	285	475	950	1425	1900
	2	1360	1700	2040	3400	6800	10200	13600
	3	4410	5513	6615	11025	22050	33075	44100
	4	10240	12800	15360	25600	51200	76800	102400
	5	19750	24688	29625	49375	98750	148125	197500
	6	33840	42300	50760	84600	169200	253800	338400
	7	53410	66763	80115	133525	267050	400575	534100
	8	79360	99200	119040	198400	396800	595200	793600
n = 20	1	240	300	360	600	1200	1800	2400
	2	1760	2200	2640	4400	8800	13200	17600
	3	5760	7200	8640	14400	28800	43200	57600
	4	13440	16800	20160	33600	67200	100800	134400
	5	26000	32500	39000	65000	130000	195000	260000
	6	44640	55800	66960	111600	223200	334800	446400
	7	70560	88200	105840	176400	352800	529200	705600
	8	104960	131200	157440	262400	524800	787200	1049600
n = 25	1	290	363	435	725	1450	2175	2900
	2	2160	2700	3240	5400	10800	16200	21600
	3	7110	8888	10665	17775	35550	53325	71100
	4	16640	20800	24960	41600	83200	124800	166400
	5	32250	40313	48375	80625	161250	241875	322500
	6	55440	69300	83160	138600	277200	415800	554400
	7	87710	109638	131565	219275	438550	657825	877100
	8	130560	163200	195840	326400	652800	979200	1305600
n = 30	1	340	425	510	850	1700	2550	3400
	2	2560	3200	3840	6400	12800	19200	25600
	3	8460	10575	12690	21150	42300	63450	84600
	4	19840	24800	29760	49600	99200	148800	198400
	5	38500	48125	57750	96250	192500	288750	385000
	6	66240	82800	99360	165600	331200	496800	662400
	7	104860	131075	157290	262150	524300	786450	1048600
	8	156160	195200	234240	390400	780800	1171200	1561600

Channel Width, B = 5 m								
Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 4	1	90	113	135	225	450	675	900
	2	520	650	780	1300	2600	3900	5200
	3	1530	1913	2295	3825	7650	11475	15300
	4	3360	4200	5040	8400	16800	25200	33600
	5	6250	7813	9375	15625	31250	46875	62500
	6	10440	13050	15660	26100	52200	78300	104400
	7	16170	20213	24255	40425	80850	121275	161700
	8	23680	29600	35520	59200	118400	177600	236800
n = 5	1	100	125	150	250	500	750	1000
	2	600	750	900	1500	3000	4500	6000
	3	1800	2250	2700	4500	9000	13500	18000
	4	4000	5000	6000	10000	20000	30000	40000
	5	7500	9375	11250	18750	37500	56250	75000
	6	12600	15750	18900	31500	63000	94500	126000
	7	19600	24500	29400	49000	98000	147000	196000
	8	28800	36000	43200	72000	144000	216000	288000
n = 6	1	110	138	165	275	550	825	1100
	2	680	850	1020	1700	3400	5100	6800
	3	2070	2588	3105	5175	10350	15525	20700
	4	4640	5800	6960	11600	23200	34800	46400
	5	8750	10938	13125	21875	43750	65625	87500
	6	14760	18450	22140	36900	73800	110700	147600
	7	23030	28788	34545	57575	115150	172725	230300
	8	33920	42400	50880	84800	169600	254400	339200
n = 7	1	120	150	180	300	600	900	1200
	2	760	950	1140	1900	3800	5700	7600
	3	2340	2925	3510	5850	11700	17550	23400
	4	5280	6600	7920	13200	26400	39600	52800
	5	10000	12500	15000	25000	50000	75000	100000
	6	16920	21150	25380	42300	84600	126900	169200
	7	26460	33075	39690	66150	132300	198450	264600
	8	39040	48800	58560	97600	195200	292800	390400
n = 10	1	150	188	225	375	750	1125	1500
	2	1000	1250	1500	2500	5000	7500	10000
	3	3150	3938	4725	7875	15750	23625	31500
	4	7200	9000	10800	18000	36000	54000	72000
	5	13750	17188	20625	34375	68750	103125	137500
	6	23400	29250	35100	58500	117000	175500	234000
	7	36750	45938	55125	91875	183750	275625	367500
	8	54400	68000	81600	136000	272000	408000	544000

Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Channel Width, B = 5 m						
		Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 15	1	200	250	300	500	1000	1500	2000
	2	1400	1750	2100	3500	7000	10500	14000
	3	4500	5625	6750	11250	22500	33750	45000
	4	10400	13000	15600	26000	52000	78000	104000
	5	20000	25000	30000	50000	100000	150000	200000
	6	34200	42750	51300	85500	171000	256500	342000
	7	53900	67375	80850	134750	269500	404250	539000
	8	80000	100000	120000	200000	400000	600000	800000
n = 20	1	250	313	375	625	1250	1875	2500
	2	1800	2250	2700	4500	9000	13500	18000
	3	5850	7313	8775	14625	29250	43875	58500
	4	13600	17000	20400	34000	68000	102000	136000
	5	26250	32813	39375	65625	131250	196875	262500
	6	45000	56250	67500	112500	225000	337500	450000
	7	71050	88813	106575	177625	355250	532875	710500
	8	105600	132000	158400	264000	528000	792000	1056000
n = 25	1	300	375	450	750	1500	2250	3000
	2	2200	2750	3300	5500	11000	16500	22000
	3	7200	9000	10800	18000	36000	54000	72000
	4	16800	21000	25200	42000	84000	126000	168000
	5	32500	40625	48750	81250	162500	243750	325000
	6	55800	69750	83700	139500	279000	418500	558000
	7	88200	110250	132300	220500	441000	661500	882000
	8	131200	164000	196800	328000	656000	984000	1312000
n = 30	1	350	438	525	875	1750	2625	3500
	2	2600	3250	3900	6500	13000	19500	26000
	3	8550	10688	12825	21375	42750	64125	85500
	4	20000	25000	30000	50000	100000	150000	200000
	5	38750	48438	58125	96875	193750	290625	387500
	6	66600	83250	99900	166500	333000	499500	666000
	7	105350	131688	158025	263375	526750	790125	1053500
	8	156800	196000	235200	392000	784000	1176000	1568000

Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Channel Width, B = 10 m						
		Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 4	1	140	175	210	350	700	1050	1400
	2	720	900	1080	1800	3600	5400	7200
	3	1980	2475	2970	4950	9900	14850	19800
	4	4160	5200	6240	10400	20800	31200	41600
	5	7500	9375	11250	18750	37500	56250	75000
	6	12240	15300	18360	30600	61200	91800	122400
	7	18620	23275	27930	46550	93100	139650	186200
	8	26880	33600	40320	67200	134400	201600	268800
n = 5	1	150	188	225	375	750	1125	1500
	2	800	1000	1200	2000	4000	6000	8000
	3	2250	2813	3375	5625	11250	16875	22500
	4	4800	6000	7200	12000	24000	36000	48000
	5	8750	10938	13125	21875	43750	65625	87500
	6	14400	18000	21600	36000	72000	108000	144000
	7	22050	27563	33075	55125	110250	165375	220500
	8	32000	40000	48000	80000	160000	240000	320000
n = 6	1	160	200	240	400	800	1200	1600
	2	880	1100	1320	2200	4400	6600	8800
	3	2520	3150	3780	6300	12600	18900	25200
	4	5440	6800	8160	13600	27200	40800	54400
	5	10000	12500	15000	25000	50000	75000	100000
	6	16560	20700	24840	41400	82800	124200	165600
	7	25480	31850	38220	63700	127400	191100	254800
	8	37120	46400	55680	92800	185600	278400	371200
n = 7	1	170	213	255	425	850	1275	1700
	2	960	1200	1440	2400	4800	7200	9600
	3	2790	3488	4185	6975	13950	20925	27900
	4	6080	7600	9120	15200	30400	45600	60800
	5	11250	14063	16875	28125	56250	84375	112500
	6	18720	23400	28080	46800	93600	140400	187200
	7	28910	36138	43365	72275	144550	216825	289100
	8	42240	52800	63360	105600	211200	316800	422400
n = 10	1	200	250	300	500	1000	1500	2000
	2	1200	1500	1800	3000	6000	9000	12000
	3	3600	4500	5400	9000	18000	27000	36000
	4	8000	10000	12000	20000	40000	60000	80000
	5	15000	18750	22500	37500	75000	112500	150000
	6	25200	31500	37800	63000	126000	189000	252000
	7	39200	49000	58800	98000	196000	294000	392000
	8	57600	72000	86400	144000	288000	432000	576000

Channel Width, B = 10 m								
Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 15	1	250	313	375	625	1250	1875	2500
	2	1600	2000	2400	4000	8000	12000	16000
	3	4950	6188	7425	12375	24750	37125	49500
	4	11200	14000	16800	28000	56000	84000	112000
	5	21250	26563	31875	53125	106250	159375	212500
	6	36000	45000	54000	90000	180000	270000	360000
	7	56350	70438	84525	140875	281750	422625	563500
	8	83200	104000	124800	208000	416000	624000	832000
n = 20	1	300	375	450	750	1500	2250	3000
	2	2000	2500	3000	5000	10000	15000	20000
	3	6300	7875	9450	15750	31500	47250	63000
	4	14400	18000	21600	36000	72000	108000	144000
	5	27500	34375	41250	68750	137500	206250	275000
	6	46800	58500	70200	117000	234000	351000	468000
	7	73500	91875	110250	183750	367500	551250	735000
	8	108800	136000	163200	272000	544000	816000	1088000
n = 25	1	270	338	405	675	1350	2025	2700
	2	2080	2600	3120	5200	10400	15600	20800
	3	6930	8663	10395	17325	34650	51975	69300
	4	16320	20400	24480	40800	81600	122400	163200
	5	31750	39688	47625	79375	158750	238125	317500
	6	54720	68400	82080	136800	273600	410400	547200
	7	86730	108413	130095	216825	433650	650475	867300
	8	129280	161600	193920	323200	646400	969600	1292800
n = 30	1	400	500	600	1000	2000	3000	4000
	2	2800	3500	4200	7000	14000	21000	28000
	3	9000	11250	13500	22500	45000	67500	90000
	4	20800	26000	31200	52000	104000	156000	208000
	5	40000	50000	60000	100000	200000	300000	400000
	6	68400	85500	102600	171000	342000	513000	684000
	7	107800	134750	161700	269500	539000	808500	1078000
	8	160000	200000	240000	400000	800000	1200000	1600000

Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Channel Width, B = 15 m						
		Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 4	1	190	238	285	475	950	1425	1900
	2	920	1150	1380	2300	4600	6900	9200
	3	2430	3038	3645	6075	12150	18225	24300
	4	4960	6200	7440	12400	24800	37200	49600
	5	8750	10938	13125	21875	43750	65625	87500
	6	14040	17550	21060	35100	70200	105300	140400
	7	21070	26338	31605	52675	105350	158025	210700
	8	30080	37600	45120	75200	150400	225600	300800
n = 5	1	200	250	300	500	1000	1500	2000
	2	1000	1250	1500	2500	5000	7500	10000
	3	2700	3375	4050	6750	13500	20250	27000
	4	5600	7000	8400	14000	28000	42000	56000
	5	10000	12500	15000	25000	50000	75000	100000
	6	16200	20250	24300	40500	81000	121500	162000
	7	24500	30625	36750	61250	122500	183750	245000
	8	35200	44000	52800	88000	176000	264000	352000
n = 6	1	210	263	315	525	1050	1575	2100
	2	1080	1350	1620	2700	5400	8100	10800
	3	2970	3713	4455	7425	14850	22275	29700
	4	6240	7800	9360	15600	31200	46800	62400
	5	11250	14063	16875	28125	56250	84375	112500
	6	18360	22950	27540	45900	91800	137700	183600
	7	27930	34913	41895	69825	139650	209475	279300
	8	40320	50400	60480	100800	201600	302400	403200
n = 7	1	220	275	330	550	1100	1650	2200
	2	1160	1450	1740	2900	5800	8700	11600
	3	3240	4050	4860	8100	16200	24300	32400
	4	6880	8600	10320	17200	34400	51600	68800
	5	12500	15625	18750	31250	62500	93750	125000
	6	20520	25650	30780	51300	102600	153900	205200
	7	31360	39200	47040	78400	156800	235200	313600
	8	45440	56800	68160	113600	227200	340800	454400
n = 10	1	250	313	375	625	1250	1875	2500
	2	1400	1750	2100	3500	7000	10500	14000
	3	4050	5063	6075	10125	20250	30375	40500
	4	8800	11000	13200	22000	44000	66000	88000
	5	16250	20313	24375	40625	81250	121875	162500
	6	27000	33750	40500	67500	135000	202500	270000
	7	41650	52063	62475	104125	208250	312375	416500
	8	60800	76000	91200	152000	304000	456000	608000

Channel Width, B = 15 m								
Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 15	1	300	375	450	750	1500	2250	3000
	2	1800	2250	2700	4500	9000	13500	18000
	3	5400	6750	8100	13500	27000	40500	54000
	4	12000	15000	18000	30000	60000	90000	120000
	5	22500	28125	33750	56250	112500	168750	225000
	6	37800	47250	56700	94500	189000	283500	378000
	7	58800	73500	88200	147000	294000	441000	588000
	8	86400	108000	129600	216000	432000	648000	864000
n = 20	1	350	438	525	875	1750	2625	3500
	2	2200	2750	3300	5500	11000	16500	22000
	3	6750	8438	10125	16875	33750	50625	67500
	4	15200	19000	22800	38000	76000	114000	152000
	5	28750	35938	43125	71875	143750	215625	287500
	6	48600	60750	72900	121500	243000	364500	486000
	7	75950	94938	113925	189875	379750	569625	759500
	8	112000	140000	168000	280000	560000	840000	1120000
n = 25	1	400	500	600	1000	2000	3000	4000
	2	2600	3250	3900	6500	13000	19500	26000
	3	8100	10125	12150	20250	40500	60750	81000
	4	18400	23000	27600	46000	92000	138000	184000
	5	35000	43750	52500	87500	175000	262500	350000
	6	59400	74250	89100	148500	297000	445500	594000
	7	93100	116375	139650	232750	465500	698250	931000
	8	137600	172000	206400	344000	688000	1032000	1376000
n = 30	1	450	563	675	1125	2250	3375	4500
	2	3000	3750	4500	7500	15000	22500	30000
	3	9450	11813	14175	23625	47250	70875	94500
	4	21600	27000	32400	54000	108000	162000	216000
	5	41250	51563	61875	103125	206250	309375	412500
	6	70200	87750	105300	175500	351000	526500	702000
	7	110250	137813	165375	275625	551250	826875	1102500
	8	163200	204000	244800	408000	816000	1224000	1632000

		Channel Width, B = 20 m						
Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 4	1	240	300	360	600	1200	1800	2400
	2	1120	1400	1680	2800	5600	8400	11200
	3	2880	3600	4320	7200	14400	21600	28800
	4	5760	7200	8640	14400	28800	43200	57600
	5	10000	12500	15000	25000	50000	75000	100000
	6	15840	19800	23760	39600	79200	118800	158400
	7	23520	29400	35280	58800	117600	176400	235200
	8	33280	41600	49920	83200	166400	249600	332800
n = 5	1	250	313	375	625	1250	1875	2500
	2	1200	1500	1800	3000	6000	9000	12000
	3	3150	3938	4725	7875	15750	23625	31500
	4	6400	8000	9600	16000	32000	48000	64000
	5	11250	14063	16875	28125	56250	84375	112500
	6	18000	22500	27000	45000	90000	135000	180000
	7	26950	33688	40425	67375	134750	202125	269500
	8	38400	48000	57600	96000	192000	288000	384000
n = 6	1	260	325	390	650	1300	1950	2600
	2	1280	1600	1920	3200	6400	9600	12800
	3	3420	4275	5130	8550	17100	25650	34200
	4	7040	8800	10560	17600	35200	52800	70400
	5	12500	15625	18750	31250	62500	93750	125000
	6	20160	25200	30240	50400	100800	151200	201600
	7	30380	37975	45570	75950	151900	227850	303800
	8	43520	54400	65280	108800	217600	326400	435200
n = 7	1	270	338	405	675	1350	2025	2700
	2	1360	1700	2040	3400	6800	10200	13600
	3	3690	4613	5535	9225	18450	27675	36900
	4	7680	9600	11520	19200	38400	57600	76800
	5	13750	17188	20625	34375	68750	103125	137500
	6	22320	27900	33480	55800	111600	167400	223200
	7	33810	42263	50715	84525	169050	253575	338100
	8	48640	60800	72960	121600	243200	364800	486400
n = 10	1	300	375	450	750	1500	2250	3000
	2	1600	2000	2400	4000	8000	12000	16000
	3	4500	5625	6750	11250	22500	33750	45000
	4	9600	12000	14400	24000	48000	72000	96000
	5	17500	21875	26250	43750	87500	131250	175000
	6	28800	36000	43200	72000	144000	216000	288000
	7	44100	55125	66150	110250	220500	330750	441000
	8	64000	80000	96000	160000	320000	480000	640000

Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Channel Width, B = 20 m						
		Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 15	1	350	438	525	875	1750	2625	3500
	2	2000	2500	3000	5000	10000	15000	20000
	3	5850	7313	8775	14625	29250	43875	58500
	4	12800	16000	19200	32000	64000	96000	128000
	5	23750	29688	35625	59375	118750	178125	237500
	6	39600	49500	59400	99000	198000	297000	396000
	7	61250	76563	91875	153125	306250	459375	612500
	8	89600	112000	134400	224000	448000	672000	896000
n = 20	1	400	500	600	1000	2000	3000	4000
	2	2400	3000	3600	6000	12000	18000	24000
	3	7200	9000	10800	18000	36000	54000	72000
	4	16000	20000	24000	40000	80000	120000	160000
	5	30000	37500	45000	75000	150000	225000	300000
	6	50400	63000	75600	126000	252000	378000	504000
	7	78400	98000	117600	196000	392000	588000	784000
	8	115200	144000	172800	288000	576000	864000	1152000
n = 25	1	450	563	675	1125	2250	3375	4500
	2	2800	3500	4200	7000	14000	21000	28000
	3	8550	10688	12825	21375	42750	64125	85500
	4	19200	24000	28800	48000	96000	144000	192000
	5	36250	45313	54375	90625	181250	271875	362500
	6	61200	76500	91800	153000	306000	459000	612000
	7	95550	119438	143325	238875	477750	716625	955500
	8	140800	176000	211200	352000	704000	1056000	1408000
n = 30	1	500	625	750	1250	2500	3750	5000
	2	3200	4000	4800	8000	16000	24000	32000
	3	9900	12375	14850	24750	49500	74250	99000
	4	22400	28000	33600	56000	112000	168000	224000
	5	42500	53125	63750	106250	212500	318750	425000
	6	72000	90000	108000	180000	360000	540000	720000
	7	112700	140875	169050	281750	563500	845250	1127000
	8	166400	208000	249600	416000	832000	1248000	1664000

Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Channel Width, B = 25 m						
		Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 4	1	290	363	435	725	1450	2175	2900
	2	1320	1650	1980	3300	6600	9900	13200
	3	3330	4163	4995	8325	16650	24975	33300
	4	6560	8200	9840	16400	32800	49200	65600
	5	11250	14063	16875	28125	56250	84375	112500
	6	17640	22050	26460	44100	88200	132300	176400
	7	25970	32463	38955	64925	129850	194775	259700
	8	36480	45600	54720	91200	182400	273600	364800
n = 5	1	300	375	450	750	1500	2250	3000
	2	1400	1750	2100	3500	7000	10500	14000
	3	3600	4500	5400	9000	18000	27000	36000
	4	7200	9000	10800	18000	36000	54000	72000
	5	12500	15625	18750	31250	62500	93750	125000
	6	19800	24750	29700	49500	99000	148500	198000
	7	29400	36750	44100	73500	147000	220500	294000
	8	41600	52000	62400	104000	208000	312000	416000
n = 6	1	310	388	465	775	1550	2325	3100
	2	1480	1850	2220	3700	7400	11100	14800
	3	3870	4838	5805	9675	19350	29025	38700
	4	7840	9800	11760	19600	39200	58800	78400
	5	13750	17188	20625	34375	68750	103125	137500
	6	21960	27450	32940	54900	109800	164700	219600
	7	32830	41038	49245	82075	164150	246225	328300
	8	46720	58400	70080	116800	233600	350400	467200
n = 7	1	320	400	480	800	1600	2400	3200
	2	1560	1950	2340	3900	7800	11700	15600
	3	4140	5175	6210	10350	20700	31050	41400
	4	8480	10600	12720	21200	42400	63600	84800
	5	15000	18750	22500	37500	75000	112500	150000
	6	24120	30150	36180	60300	120600	180900	241200
	7	36260	45325	54390	90650	181300	271950	362600
	8	51840	64800	77760	129600	259200	388800	518400
n = 10	1	350	438	525	875	1750	2625	3500
	2	1800	2250	2700	4500	9000	13500	18000
	3	4950	6188	7425	12375	24750	37125	49500
	4	10400	13000	15600	26000	52000	78000	104000
	5	18750	23438	28125	46875	93750	140625	187500
	6	30600	38250	45900	76500	153000	229500	306000
	7	46550	58188	69825	116375	232750	349125	465500
	8	67200	84000	100800	168000	336000	504000	672000

Channel Width, B = 25 m								
Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 15	1	400	500	600	1000	2000	3000	4000
	2	2200	2750	3300	5500	11000	16500	22000
	3	6300	7875	9450	15750	31500	47250	63000
	4	13600	17000	20400	34000	68000	102000	136000
	5	25000	31250	37500	62500	125000	187500	250000
	6	41400	51750	62100	103500	207000	310500	414000
	7	63700	79625	95550	159250	318500	477750	637000
	8	92800	116000	139200	232000	464000	696000	928000
n = 20	1	450	563	675	1125	2250	3375	4500
	2	2600	3250	3900	6500	13000	19500	26000
	3	7650	9563	11475	19125	38250	57375	76500
	4	16800	21000	25200	42000	84000	126000	168000
	5	31250	39063	46875	78125	156250	234375	312500
	6	52200	65250	78300	130500	261000	391500	522000
	7	80850	101063	121275	202125	404250	606375	808500
	8	118400	148000	177600	296000	592000	888000	1184000
n = 25	1	500	625	750	1250	2500	3750	5000
	2	3000	3750	4500	7500	15000	22500	30000
	3	9000	11250	13500	22500	45000	67500	90000
	4	20000	25000	30000	50000	100000	150000	200000
	5	37500	46875	56250	93750	187500	281250	375000
	6	63000	78750	94500	157500	315000	472500	630000
	7	98000	122500	147000	245000	490000	735000	980000
	8	144000	180000	216000	360000	720000	1080000	1440000
n = 30	1	550	688	825	1375	2750	4125	5500
	2	3400	4250	5100	8500	17000	25500	34000
	3	10350	12938	15525	25875	51750	77625	103500
	4	23200	29000	34800	58000	116000	174000	232000
	5	43750	54688	65625	109375	218750	328125	437500
	6	73800	92250	110700	184500	369000	553500	738000
	7	115150	143938	172725	287875	575750	863625	1151500
	8	169600	212000	254400	424000	848000	1272000	1696000

Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Channel Width, B = 30 m						
		Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 4	1	340	425	510	850	1700	2550	3400
	2	1520	1900	2280	3800	7600	11400	15200
	3	3780	4725	5670	9450	18900	28350	37800
	4	7360	9200	11040	18400	36800	55200	73600
	5	12500	15625	18750	31250	62500	93750	125000
	6	19440	24300	29160	48600	97200	145800	194400
	7	28420	35525	42630	71050	142100	213150	284200
	8	39680	49600	59520	99200	198400	297600	396800
n = 5	1	350	438	525	875	1750	2625	3500
	2	1600	2000	2400	4000	8000	12000	16000
	3	4050	5063	6075	10125	20250	30375	40500
	4	8000	10000	12000	20000	40000	60000	80000
	5	13750	17188	20625	34375	68750	103125	137500
	6	21600	27000	32400	54000	108000	162000	216000
	7	31850	39813	47775	79625	159250	238875	318500
	8	44800	56000	67200	112000	224000	336000	448000
n = 6	1	360	450	540	900	1800	2700	3600
	2	1680	2100	2520	4200	8400	12600	16800
	3	4320	5400	6480	10800	21600	32400	43200
	4	8640	10800	12960	21600	43200	64800	86400
	5	15000	18750	22500	37500	75000	112500	150000
	6	23760	29700	35640	59400	118800	178200	237600
	7	35280	44100	52920	88200	176400	264600	352800
	8	49920	62400	74880	124800	249600	374400	499200
n = 7	1	370	463	555	925	1850	2775	3700
	2	1760	2200	2640	4400	8800	13200	17600
	3	4590	5738	6885	11475	22950	34425	45900
	4	9280	11600	13920	23200	46400	69600	92800
	5	16250	20313	24375	40625	81250	121875	162500
	6	25920	32400	38880	64800	129600	194400	259200
	7	38710	48388	58065	96775	193550	290325	387100
	8	55040	68800	82560	137600	275200	412800	550400
n = 10	1	400	500	600	1000	2000	3000	4000
	2	2000	2500	3000	5000	10000	15000	20000
	3	5400	6750	8100	13500	27000	40500	54000
	4	11200	14000	16800	28000	56000	84000	112000
	5	20000	25000	30000	50000	100000	150000	200000
	6	32400	40500	48600	81000	162000	243000	324000
	7	49000	61250	73500	122500	245000	367500	490000
	8	70400	88000	105600	176000	352000	528000	704000

Channel Width, B = 30 m								
Bank Slope (n : 1)	Maximum Depth of Water, D (m)	Storage Volume, V (cum)						
		Bed Slope of Stream (S : 1)						
		S = 20	S = 25	S = 30	S = 50	S = 100	S = 150	S = 200
n = 15	1	450	563	675	1125	2250	3375	4500
	2	2400	3000	3600	6000	12000	18000	24000
	3	6750	8438	10125	16875	33750	50625	67500
	4	14400	18000	21600	36000	72000	108000	144000
	5	26250	32813	39375	65625	131250	196875	262500
	6	43200	54000	64800	108000	216000	324000	432000
	7	66150	82688	99225	165375	330750	496125	661500
	8	96000	120000	144000	240000	480000	720000	960000
n = 20	1	500	625	750	1250	2500	3750	5000
	2	2800	3500	4200	7000	14000	21000	28000
	3	8100	10125	12150	20250	40500	60750	81000
	4	17600	22000	26400	44000	88000	132000	176000
	5	32500	40625	48750	81250	162500	243750	325000
	6	54000	67500	81000	135000	270000	405000	540000
	7	83300	104125	124950	208250	416500	624750	833000
	8	121600	152000	182400	304000	608000	912000	1216000
n = 25	1	550	688	825	1375	2750	4125	5500
	2	3200	4000	4800	8000	16000	24000	32000
	3	9450	11813	14175	23625	47250	70875	94500
	4	20800	26000	31200	52000	104000	156000	208000
	5	38750	48438	58125	96875	193750	290625	387500
	6	64800	81000	97200	162000	324000	486000	648000
	7	100450	125563	150675	251125	502250	753375	1004500
	8	147200	184000	220800	368000	736000	1104000	1472000
n = 30	1	600	750	900	1500	3000	4500	6000
	2	3600	4500	5400	9000	18000	27000	36000
	3	10800	13500	16200	27000	54000	81000	108000
	4	24000	30000	36000	60000	120000	180000	240000
	5	45000	56250	67500	112500	225000	337500	450000
	6	75600	94500	113400	189000	378000	567000	756000
	7	117600	147000	176400	294000	588000	882000	1176000
	8	172800	216000	259200	432000	864000	1296000	1728000

APPENDIX -VII

TABLE FOR DIAMETER OF PIPE SPILLWAY (mm)

V/RA	K	Peak Inflow, Q (cumecs)													
		0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.20	0.30	0.40	0.50
0.00107	0.01	67	86	100	112	122	130	138	145	152	158	205	238	265	289
0.00105	0.02	86	112	130	145	158	169	179	188	197	205	265	309	344	374
0.00103	0.03	100	130	152	169	184	197	208	219	229	238	309	360	401	436
0.00102	0.04	112	145	169	188	205	219	232	244	255	265	344	401	446	485
0.00100	0.05	122	158	184	205	223	238	252	265	277	289	374	436	485	528
0.00098	0.06	130	169	197	219	238	255	270	284	297	309	401	467	520	565
0.00097	0.07	138	179	208	232	252	270	286	301	315	327	425	494	551	599
0.00095	0.08	145	188	219	244	265	284	301	317	331	344	446	520	579	629
0.00094	0.09	152	197	229	255	277	297	315	331	346	360	467	543	605	658
0.00092	0.10	158	205	238	265	289	309	327	344	360	374	485	565	629	684
0.00085	0.15	184	238	277	309	336	360	381	401	419	436	565	658	733	797
0.00083	0.16	188	244	284	317	344	369	391	411	429	446	579	674	751	816
0.00082	0.17	193	250	291	324	352	377	399	420	439	457	592	689	768	835
0.00080	0.18	197	255	297	331	360	385	408	429	448	467	605	704	785	853
0.00079	0.19	201	260	303	338	367	393	417	438	458	476	617	719	801	871
0.00078	0.20	205	265	309	344	374	401	425	446	467	485	629	733	816	888
0.00076	0.21	208	270	315	351	381	408	432	455	475	494	641	746	831	904
0.00075	0.22	212	275	320	357	388	415	440	463	484	503	652	759	846	920
0.00073	0.23	216	280	326	363	394	422	447	470	492	511	663	772	860	935
0.00072	0.24	219	284	331	369	401	429	455	478	500	520	674	785	874	950
0.00071	0.25	223	289	336	374	407	436	462	485	507	528	684	797	888	965
0.00069	0.26	226	293	341	380	413	442	468	493	515	536	695	809	901	979
0.00068	0.27	229	297	346	385	419	448	475	500	522	543	704	820	913	993
0.00067	0.28	232	301	351	391	425	455	482	506	529	551	714	831	926	1007
0.00065	0.29	235	305	355	396	430	461	488	513	536	558	724	842	938	1020
0.00064	0.30	238	309	360	401	436	467	494	520	543	565	733	853	950	1033
0.00058	0.35	252	327	381	425	462	494	524	551	575	599	776	904	1007	1095
0.00052	0.40	265	344	401	446	485	520	551	579	605	629	816	950	1059	1151
0.00047	0.45	277	360	419	467	507	543	575	605	632	658	853	993	1106	1203
0.00042	0.50	289	374	436	485	528	565	599	629	658	684	888	1033	1151	1251

Note: V = Available storage (Cubic meter/sec.)
R = Run off in mm
K = Drainage area in hectares

APPENDIX -VIII

SURVEY OF BUND SITE

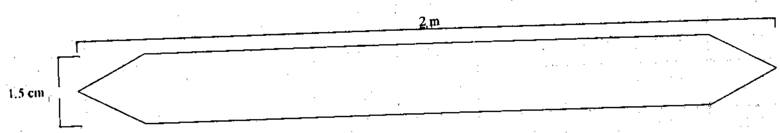
Ideally a contour survey should be done with a Dumpy level or a Total Station so that cross –section and longitudinal section of the drainage channel at the bund site may be drawn as also the area-capacity table or curve for the pond. However, a rough survey can also be done if the planning and construction is to be done by the village community or an NGO who do not have the requisite technical skills or resources for elaborate contour survey. The procedure is discussed in the following paras :

Equipment/ Tools Required

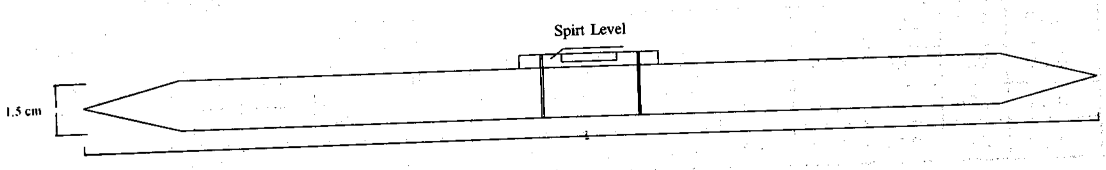
The equipment/ tools required are rudimentary and can be obtained/ made locally.

(i) Two straight wooden stakes each 2 metres long, 5 cm wide and 1.5 cm thick,

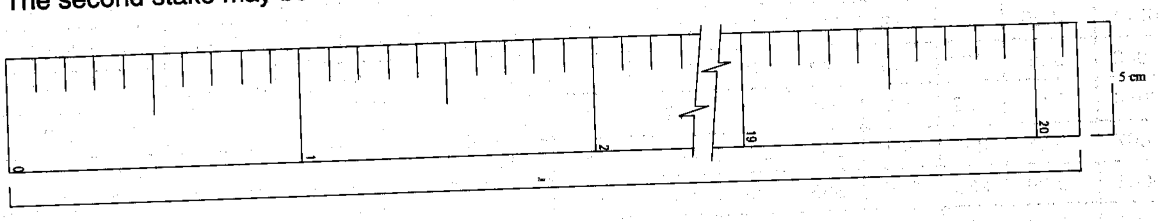
(a) Both ends of one stake may be sharpened as shown below :



(b) A mason's level (spirit Level) may be securely tied in the middle of this stake as shown below



(ii) The second stake may be marked along the length in centimeters and millimeters as shown below :



(iii) Measuring Tapes

(a) Carpenter's steel tape 1.5 or 2.00 m long

(b) Metallic tape – 30 metres long

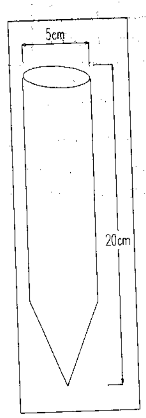
(iv) Bamboo Poles – 3 No. each 3 m long (For ranging purposes)

(v) Wooden Pegs – about 10-15 No.

Length – 20 cm

Diameter – 5 cm

Pointed at one end



(vi) Paint and brush for marking

(vii) Lime/ Chalk powder

Procedure for Survey

(A) Bund Alignment

Bund Alignment is first decided approximately by visual observation and judgement and is marked with the wooden pegs firmly driven into the ground with suitable markings. Where the surface is rocky, marking is done with paint and brush. The alignment is then suitably adjusted by ranging with the three bamboo poles. In case of curved alignment, the curve is made smooth by adjusting the location of pegs/ paint marks. The alignment is then firmly marked with lime/ chalk power.

The alignment is marked upto high banks on either side upto a level about 1 meter above the expected top of the bund or about 25 metres beyond the bund on either side depending upto the land slope.

As far as possible the bund alignment should be perpendicular to the main drainage channel or the direction of high monsoon flow.

(B) Demarcation of Main Drainage Channel

In situations where the main drainage has no defined channel, it is necessary to demarcate it based on the local knowledge.

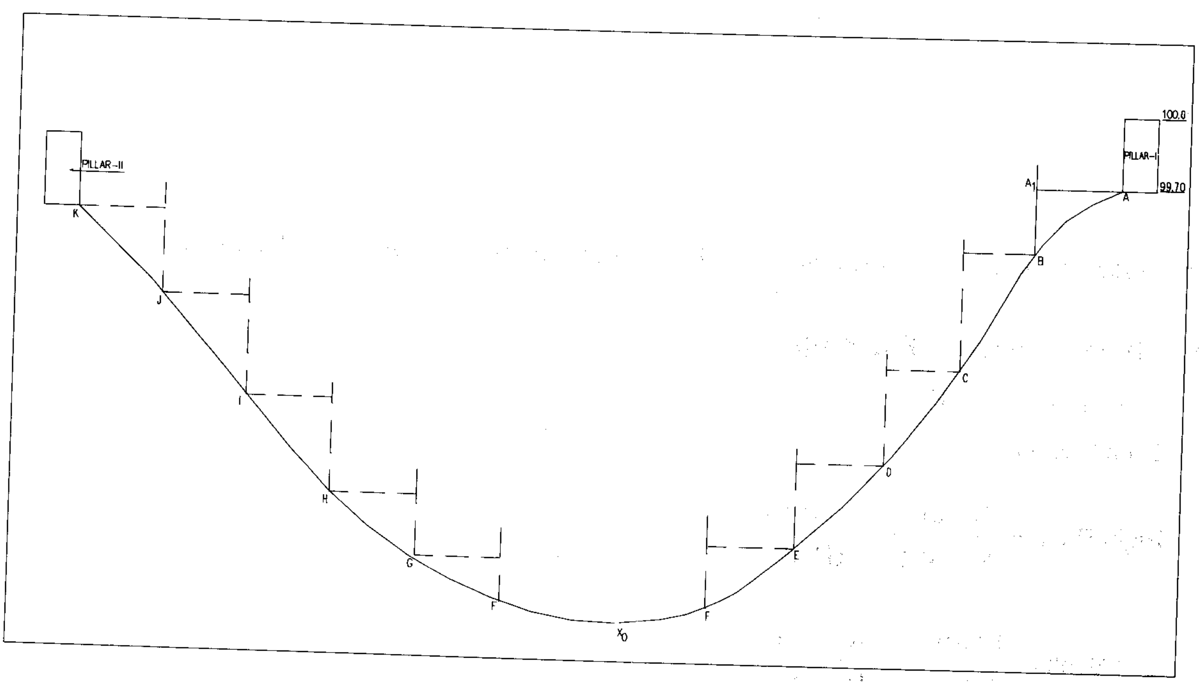
(C) Longitudinal Section of Bund Alignment

A small masonry pillar is built at each end of the bund alignment. The top of one of the pillars is assigned an arbitrary level (say 100.00 m) since this is the starting point its reduced distance is assigned the value 0.00.

Measure the height of the pillar above the ground (say 0.3 m) and deduct this from 100.00 to get the ground level at point A. Thus the position of point A is defined as follows :

RD = 0.00

RL = 100.00 - 0.30 = 99.70



By using the two wooden stakes measure the fall in level between point A and Point B. The first stake with spirit level is held horizontally with one end placed at A. The second stake with graduation is held vertically at point B such that its graduated face just touches the other end of the horizontal stake. Thus the position of point B with respect to the known position of point A is worked out as follows :

AA_1 = 2 m (Length of the stake)

Assuming A_1B = 0.45 m (Read from Vertical stake)

RL of B = 99.70 – 0.45 = 99.25m

RD of B = 0.00 + AA_1

= 0.00 + 2.00 = 2.00

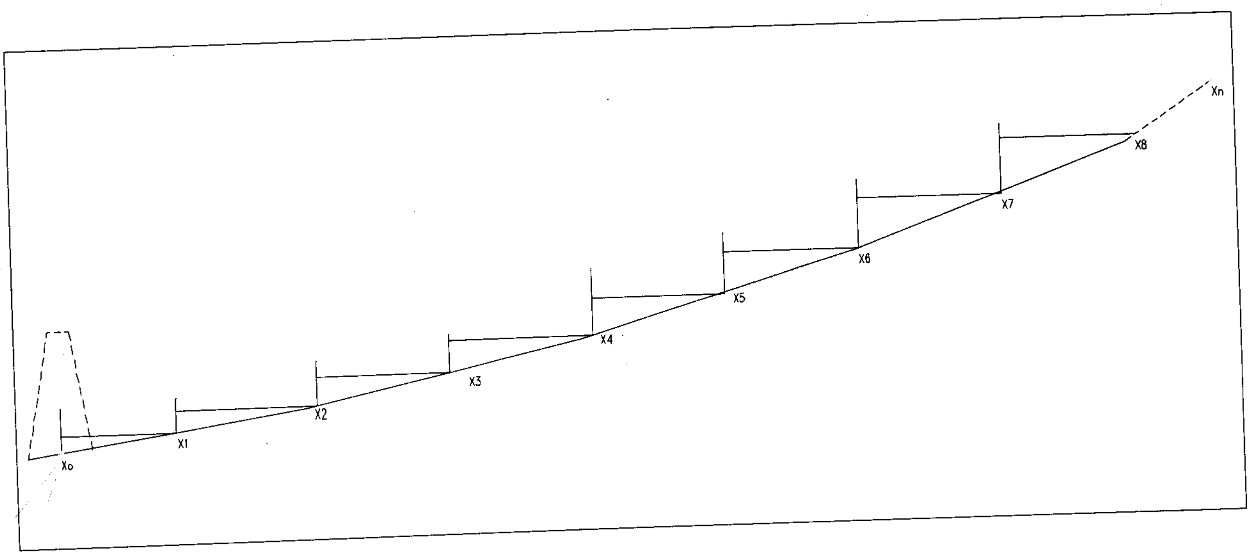
Similarly, the positions of points C, D and E are found using the same STEP METHOD in succession.

If E and F are the two points in the bed of the channel and there is no appreciable difference in their levels, then only the horizontal distance between E and F is measured with the tape.

The "Step Method" is then repeated in succession to determine the position of points G, H, I, J and K. By adding the height of Pillar II to the level of point K, the level of the top of Pillar II is determined.

(D) Longitudinal Section of the Channel

Assuming that X_0 is a point in the middle of the channel (between E and F) the longitudinal section of the channel from X_0 to X_n is similarly determined by STEP METHOD.



This survey should be continued upto about 1 to 2 m above the expected top of the bund.

(E) Data for Project Planning

(i) Channel Width = EF

(ii) Bank Slopes :

$$\text{Right Bank} = \frac{\text{RL of A} - \text{RL of E}}{\text{RD of E} - \text{RD of A}}$$

$$\text{Left Bank} = \frac{\text{RL of K} - \text{RL of F}}{\text{RD of K} - \text{RD of F}}$$

(iii) $$\text{Bed Slope of Channel} = \frac{\text{RL of } X_n - \text{RL of } X_0}{\text{RD of } X_n - \text{RD of } X_0}$$