NABARD Knowledge Series - 1

# INTRODUCTION TO WATER RESOURCES

P. K. Chatterjee
Kolkata

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नाबार्ड ज्ञान श्रृंखला - 1
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# जल संसाधनों का परिचय
# INTRODUCTION TO WATER RESOURCES

पी.के. चटर्जी
P.K. CHATTERJEE

आर्थिक विश्लेषण और अनुसंधान विभाग
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# CONTENTS

# प्रस्तावना

हाल के वर्षों में विभिन्न क्षेत्रों में प्रतिस्पर्धा और बढ़ रहे जल की मांग के कारण जल संसाधन पर दबाव बढ़ा है । जल संसाधन भंडार की घट रही गुणवत्ता और मात्रा, दोनों को देखते हुए अक्सर कहा जाता है कि भविष्य में पानी के लिए युद्ध लड़ा जाएगा, जो एक भविष्यवाणी लगता है । दुनिया में भूजल संसाधन पर सबसे ज्यादा दबाव है, इस लिए हमे देश में वैकल्पिक जल प्रबंधन के बारे में सोचना होगा ।

जैसा कि हम सभी जानते हैं, जल संसाधन के विवेकपूर्ण उपयोग के लिए दोहन की सीमा और तकनीकी विकल्पों को समझने हेतु जल संसाधन की तकनीकी पहलुओं को जानना आवश्यक है । यह प्रकाशन वर्तमान संदर्भ में इस तरह की जरूरत को पूरा करता है । मैं जल संसाधनों से संबंधित विभिन्न तकनीकी पहलुओं के संकलन हेतु श्री पी के चटर्जी, मुख्य महाप्रबंधक (सेवानिवृत्त), नाबार्ड के प्रयासों की सराहना करता हूँ ।

नाबार्ड ने नॉलेज सीरीज में प्रथम अंक के रूप में इस पुस्तिका को प्रकाशित करने के लिए चुना है । मैं इस श्रृंखला की शुरुआत के लिए आर्थिक विश्लेषण और अनुसंधान विभाग (डियर) को बधाई देता हूँ और कामना करता हूँ कि नीति निर्माताओं, शोधकर्ताओं, प्रैक्टिश्नरों और बैंकरों के बीच ज्ञान का प्रसार करने के लिए इस प्रकार के और भी प्रकाशन प्रकाशित किए जाएंगे ।

**एच आर दवे**
**उप प्रबंध निदेशक**

# FOREWORD

Water resources have increasingly come under pressure of late due to competing and ever increasing demands from different sectors. What is often said that future wars will be fought for water, seems prophetic, given the depleting water resource endowment both in quality and quantity. That the groundwater resource in the country is the most stressed in the world, drives us to think of alternatives to water management.

As we all know, understanding of technical aspects of water resources is essential to appreciate the limits to exploitation and technological options for judicious use of the resource. This publication caters to such need in the present context. I appreciate the efforts of Shri P.K.Chatterjee, Chief General Manager (Retd.), NABARD in compiling the different technical aspects relating to water resources.

NABARD has chosen to publish this booklet as the maiden issue in the Knowledge Series. I congratulate the Department of Economic Analysis and Research (DEAR) for initiating this series and wish that more of such publications should come to disseminate knowledge across policy makers, researchers, practitioners and bankers.

**H.R. Dave**
**Deputy Managing Director**

# INTRODUCTION

The subject of hydrology deals with the entire domain of water and is a multidisciplinary subject. It studies the occurrence of water, both at surface and groundwater, its circulation, its movement affecting the human lives, plants, fishes, its depletion and replenishment, etc. Quality of water, both surface and groundwater, affects the environment. With the advancement of civilization, water utilization in various fields have progressed rapidly like in the field of agriculture, industries, energies (hydel projects), housing compendium, etc. In fact there is no area where water use is not involved. Multiplicity of water use has developed into various sciences and technologies like Irrigation Engineering, Public Health Engineering , Industrial Engineering with various facets of water supply.

Notwithstanding such importance of this scarce natural resource, water has been very badly managed throughout the world so much so that with the advancement of science and increase in population, there will be acute shortage of water within the next few decades. This may lead to international dispute on sharing of water and ultimately lead to devastating war. Arid and semi-arid regions of the earth are already suffering but the measures taken with the help of modern technologies are not adequate to mitigate the hardship. Even an advanced country like Israel will face the water crisis beyond 2020. While many advanced countries having adequate resources have resorted to desalinization of sea water, but such technology may be beyond the reach of poor nations. Coupled with the problem of water shortage, contamination of water is emerging as a major problem and water borne diseases have become a major health hazard. Awareness regarding water conservation, prevention of pollution and contamination measures to keep our rivers clean is very poor. The need for recycling of water for further use is generally overlooked. Water is a visible resource, no doubt, but many people may not know how do they occur in nature and how water can be used beneficially for the human kind, how they get contaminated.

Storage of water on earth is $1387.71 \times 10^{15} m^3$ out of which 97.2% occurs in ocean. Fresh water resources on the earth is $37.526 \times 1010^{15} m^3$ including groundwater (Gilbert M Masters, 1995).

Hydrologic cycle is an important process fixing the water resources on the earth. Precipitation is a major source of fresh water. A brief outline has been given in the book about precipitation, its measurement, surface and sub-surface run off  base flow and stream flow on earth.

Rivers and stream which are visible throughout the earth, its origin and how river water can be beneficially used for mankind by its storage are also discussed briefly along with measurement of stream flow which is essential for the engineers to embark on any project. Description of few major dams are also given for general information.

Flood is an annual phenomenon in areas of excess rainfall and causes enormous hardship and losses to human kind. A chapter has been devoted on flood and its protection works.

Groundwater is one of the most important component of hydrologic cycle. Use of groundwater is known from the ancient times. With the advancement of science and technology groundwater is withdrawn even from a depth of 2 km where there is dearth of water. This is a natural storage being replenished every year from rainfall and is popular as a most dependable drinking water source. It is estimated that half of world population use groundwater for drinking water purposes. It is also a major source of irrigation and in the Indo-Gangetic plains of Uttar Pradesh, Bihar, West Bengal groundwater irrigation covers more than 50% of irrigated area.

Understanding of groundwater science is essential for planning its utilization so that there is no over-exploitation of groundwater creating grave danger, particularly in the alluvial terrain. A chapter is devoted for understanding the occurrence of groundwater, various methods of its utilization, it quality etc. Flow of groundwater broadly follows Darcy's law, provided the movement is laminar and the medium of flow is homogenous. In most cases the aquifer or the porous medium through which the water flows are heterogenous in character. Flows through such natural conditions are complex in nature and various mathematical equations are evolved to suit the site conditions. Withdrawal of groundwater from depth are made by various methods : Dug wells, Tube wells, Bore wells etc. depending upon local hydrological conditions. Various methods of construction are deployed for open or dug wells, tube wells in various hydrological situations including hard rock areas, shallow tubewells, deep tubewells. Suitable pumpsets like centrifugal, vertical turbine, submersible pumpsets are fitted with such groundwater structures to draw required water.

Pollution of water is a grave societal problem affecting health and hygiene and also restricting availability of good quality water. With the advancement of science and technology, contaminated and polluted water can be purified and used. Recycling of waste water is an important area today. Demands of water is increasing day by day in the field of domestic, industry and agriculture. The need for the day is judicious use of water and a holistsic approach for water resource management.

The book discusses these aspects briefly and may be helpful for the beginners or people interested on the subject.

# आभार

लेखक भूविज्ञान में एमएससी है, भारतीय भूवैज्ञानिक सर्वेक्षण और केन्द्रीय भूजल बोर्ड में जल-भूविज्ञान (हाइड्रोज्योलोजी) के विशेषज्ञ रहे हैं । बाद में उन्होंने भारतीय रिज़र्व बैंक के कृषि ऋण विभाग की सेवा में आ गये जो 1982 में राष्ट्रीय कृषि और ग्रामीण विकास (नाबार्ड) बन गया । लेखक ने नाबार्ड में रहते हुए कृषि क्षेत्र मे जल संसाधनों के उपयोग के विभिन्न पहलुओं को समझने के लिए मिले अवसर के प्रति आभार व्यक्त किया । इस संदर्भ में, मैं वर्तमान अध्यक्ष श्री हर्ष भनवाला के प्रति अपनी गहरी कृतज्ञता व्यक्त करता हूँ जिन्होंने मेरे इस छोटे प्रयास को प्रकाशन के लायक समझा । लेखक, डॉ. ए के चटर्जी एफएनएई, अध्यक्ष, कॉनमैट टेक्नोलॉजीज प्राइवेट लिमिटेड एसीसी के पूर्ण कालिक पूर्व कार्यकारी निदेशक द्वारा इसे मूर्त रुप देने के लिए दिये गए प्रोत्साहन हेतु आभार प्रकट करता है । श्री पी के बसु, सेवानिवृत्त सचिव और पश्चिम बंगाल सरकार के मुख्य अभियंता ने सतह जल अध्याय को पढ़ कर इस पुस्तक को पूरा करने के लिए मुझे प्रोत्साहित किया । मैं उनके प्रति आभार व्यक्त करता हूँ । प्रो. अनिल कुमार घोष, कलकत्ता विश्वविद्यालय के अवकाश प्राप्त प्रोफेसर के प्रति भी धन्यवाद ज्ञापित करता हूँ । जिन्होंने पांडुलिपि को पढ़ने में अपना बहुमूल्य दिया समय और आवश्यक मार्गदर्शन प्रदान किया । मैं डॉ हिमांशु कुलकर्णी, संस्थापक ट्रस्टी और कार्यकारी निदेशक, एडवांस सेंटर फॉर वाटर रिसौर्स डेवलपमेंट ॲण्ड मैनेजमेंट, पुणे द्वारा समालोचनात्मक समीक्षा और पुस्तक में सकारात्मक सुधार के लिए सुझाव के लिए हार्दिक आभार व्यक्त करता हूँ । अंत में, लेखक पांडुलिपि को अनेक बार टाइप करने और इसे आकर्षक बनाने में श्री किशोर दत्ता के परिश्रम के लिए आभारी है ।

# ACKNOWLEDGEMENT

The author is M.Sc. in Geology having specialized in hydrogeology in Geological Survey of India and Central Groundwater Board. He later joined the Agricultural Credit Department of Reserve Bank of India which became National Bank for Agriculture and Rural Development (NABARD) in 1982. The author took this opportunity to express his gratitude to NABARD who had given him the exposure to various aspects of water resources utilization in the agriculture sector. In this context, I cannot but express my deep gratitude to the present Chairman, Shri Harsh Bhanwala, who thought it fit for publication of this small venture of mine. The author gratefully acknowledges the incentive provided by Dr. A.K.Chatterjee FNAE, Chairman, Conmat Technologies Private Limited and formerly a Whole time Executive Director of ACC for making this book a reality. Shri P.K. Basu, Retired Secretary and Chief Engineer of Govt. of West Bengal had gone through the surface water chapter and encouraged me to complete the book. I thankfully acknowledge him. Thanks are also due to Prof. Anil Kumar Ghosh, Emeritus Professor of Calcutta University took his valuable time to go through the manuscript and provided necessary guidance. I convey my sincere gratitude to Dr. Himanshu Kulkarni, Founder Trustee and Executive Director, Advanced Centre for Water Resources Development and Management, Pune, for critical review and positive suggestion for improvement of the book. Not but the least, the author is indebted to Shri Kishore Dutta for taking pains to type the manuscript a number of times and make it presentable.

# CHAPTER - I

# WATER RESOURCES

## INTRODUCTION

Water the most prolific visible natural resource is covering about 70% of the earth's total surface area. Existence of water on the earth differentiates our planet from other planets, because without water no life can exist. More than 97% of water occurs as saline water in oceans, and the balance water is available in various forms like glaciers, rivers and streams, groundwater etc. The table indicates the distribution of water on earth :

**Table 1.1 : Stocks of water on earth**

| Location | Amount ($10^{15}$ $m^3$) | Percentage of world supply |
|---|---|---|
| Oceans | 1350 | 97.2 |
| Icecaps and Glaciers | 29 | 2.09 |
| Groundwater within 1 km | 4.2 | 0.30 |
| Groundwater below 1 km | 4.2 | 0.30 |
| Fresh water lakes | 0.125 | 0.009 |
| Saline lakes and inland seas | 0.104 | 0.007 |
| Soil water | 0.067 | 0.005 |
| Atmosphere | 0.013 | 0.009 |
| Water in living bi mass | 0.003 | 0.002 |
| Average in stream channels | 0.001 | 0.00007 |
| **Source : Harde (1985) in Gilbert M Masters (1995)** | | |

It may be observed from the table that only a negligible part of the total water resources that are available in streams and rivers which influence the human civilization from the time immemorial. Only a limited groundwater resources are withdrawn from a depth less than 1 km. Major part of water resources occur in oceans as saline water.

## Hydrologic cycle

Earth's water resource is constant, though it can change forms i.e. from water to ice and to moisture. Oceans contain saline water and is not usable by human excepting in areas like cooling etc. Fresh water from the ocean surface is evaporated consuming a huge quantity of solar energy leaving the salt in the ocean. Evaporation is thus a very important physical process which balances the hydrologic cycle. Transpiration is a process which allows water to be lost in the atmosphere by absorbing solar energy. The combined process is known as evapotranspiration. Precipitation that occurs on the land surface is very important for living organism, parts of which is lost by evapotranspiration, while the balance is subjected to surface run off that sustains the streams and rivers which ultimately joins the ocean. A part of surface run off seeps underground to form the groundwater reservoir. It is worthwhile to note that the total energy used for the combination of evapotransportation requires an enormous amount of energy, equivalent to roughly 4000 times the rate at which humankind utilizes energy resources.

Figure 1.1 is a simplified diagram of 'Hydrologic Cycle" illustrating the natural process of precipitation, evaporation, evapotranspiration, run-off.

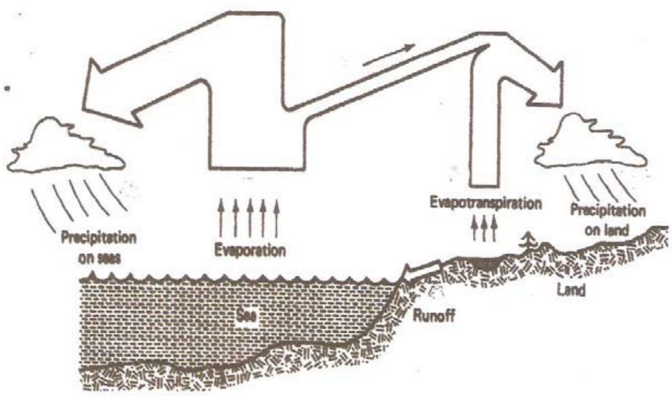



**Fig. 1.1 : Hydrologic cycle**

Thus 'Hydrologic Cycle' has the following components (1) Evaporation and Transpiration (E), (2) Precipitation, and (3) Run-off.

## 1. Evaporation and Transpiration (E) :

Evaporation is the amount of water that evaporates from the surface of oceans, rivers, streams, lakes and all other water bodies like reservoirs of dams etc. and also from atmosphere. Transpiration is the process by which water is lost from the leaves of plants. The combined process is known as Evapotranspiration (E) and is a component of Water Budget.

## 2. Precipitation (P) :

Precipitation is the amount of moisture that fall on the surface of the earth and can be classified as :

| | | | |
|---|---|---|---|
| (a) | Liquid precipitation | : | Rainfall |
| (b) | Frozen precipitation | : | i) Snow |
| | | | ii) Hail |
| | | | iii) Sleet |
| | | | iv) Freezing rain |

## 3. Run-off (R) :

Part of the precipitation that falls on the earth's surface is lost due to evaporation from the surface, soil and vegetation and by transpiration. The balance part of precipitation is the 'run-off' which travels to the rivers, streams, lakes and ultimately join the oceans. Part of run off also flows as sub-surface run off which also joins the rivers or oceans depending upon the geology of the area. Part of the sub-surface flow infiltrates further down and joins the groundwater which also flows towards rivers and ultimately oceans.

The hydrologic cycle, thus, may be expressed as :
Precipitation (P) = Evaporation (E) + Run-off (R).
This is the fundamental equation of water budget.

**Precipitation :**

Water vapour forms due to evaporation and transpiration rise above the surface and joins the atmosphere. Vapour thus formed behaves like a gas and follows the general laws of gas like Charle's and Boyle's law. As the vapour goes up and up, the temperature goes down. The fall in temperature is not due to heat transfer or in other words there is no loss of heat to the surrounding air and the process is known as adiabetic. The drop in temperature is entirely due to expansion and it is estimated that for every Km of ascent of air, the temperature drop is about $10^0$C. As the evaporation continues, the vapour that rises joins the already evaporated vapour and a stage is reached when the space cannot accommodate further vapour and any addition of vapour will get condensed on the surfaces. The condensed vapour may take any of the forms like mist, rain, hail, snow, sleet etc. The evaporated water, thus, comes back to the earth's surface in the form of mist, rain, hail etc. Rainfall is the most important component that falls on the earth as precipitation, while the other forms like mist, snow, hail etc. are negligible.

It is well known that some amount of water or moisture is always present in the air and its presence in the air is expressed in terms of humidity. Thus -

**Absolute humidity** at a given temperature = Mass of moisture present in unit volume of air at the given temperature.

Relative humidity is defined as the ratio of the actual vapour pressure to the saturation vapour pressure at the same temperature. Thus -

Relative humidity (R.H.) =

Actual vapour press at a given temperature (ea)
Saturation vapour pressure at the same temperature (es)

Relative Humidity thus gives an idea of the extent to which the air is saturated.

**Causes of Precipitation**

The science of Meterology deals with the causes of precipitation, its prediction etc. We shall discuss briefly the causes of precipitation, weather conditions which is again influenced by atmospheric vapour pressure (presence of moisture), temperature etc.

The upward movement of evaporated air mass causes cooling which ultimately condenses and forms clouds or fog. Clouds or fog consists of small ice particles and droplets of water. As has been discussed when the available space is saturated with such ice particles and water droplets, precipitation occurs. Formation of clouds is, thus, a pre requisite for precipitation. There are different types of clouds formation of which depends upon the upward motion of the air mass.

(1) **Stratiform clouds :** Prolonged wide spread slow ascent of air in the low pressure area gives rises to stratified layers of cloud and is known as stratiform clouds and is responsible for cyclonic precipitation.

(2) When the air mass consisting of large bubbles starts upward motion abruptly and violently and meets warmer air mass, heap type of clouds are formed, commonly known as cumuliform clouds. Such clouds cause corrective precipitation.

(3) When air is forced to ascend hill or a mountain barrier, typical orographic clouds are formed and lead to orographic precipitation.

Forms of cloud are mainly classified into (a) Stratiform (b) Cumuliform and (c) Fibrous.

Formation of clouds and its heights are dependent at different geographical regions : (1) Tropical or equatorial region, (ii) temperate latitude regions, (iii) polar regions. Clouds can also be classified depending upon its altitude as shown in the Table :

**Table 1.2 :Formation of clouds at different levels**

| Type of cloud (Basic group) | Level of occurrence in different regions | | |
|---|---|---|---|
| | Tropical regions | Middle latitude regions | Polar regions |
| High clouds | 6 – 18 km | 5 – 12 km | 3 – 8 km |
| Medium clouds | 2 – 8 km | 2 - 7 km | 2 – 4 km |
| Low clouds | 0 – 2 km | 0 – 2 km | 0 – 2 km |
| Vertically developing clouds | a) base 0.5-2 km<br>b) tops 18-20 km | 0.5 – 2 km<br>10 – 12 km | 0.5 – 2 km<br>5 – 8 km |

Source : S.K. Garg (1988)

Formation of clouds can now-a-days be easily detected by means of RADAR and Weather Satellites and weather can be predicted more or less accurately.

### Measurement of Rainfall

Accurate measurement of rainfall is very important for all hydrological studies. Amount of rainfall and precipitation varies over space and time. Total amount of rainfall that falls on the earth surface is measured in terms of vertical height from the horizontal surface with the conception that how much water can be accumulated from the rainfall that falls in a given area. Measuring device thus consists of accumulation of rainfall in measuring containers, known as Rainfall gauges. Rainfall gauges are of two types (i) Non-recording type and (2) Recording type.

**Non-recording rain gauges :** Non-recording rain gauges are most widely used in India. Indian Metereological Department has installed large number of such rain gauges throughout the country. These type of rain gauges are known as non-recording type because they do not record, but only collect the rainfall, which is then measured by means of graduated cylinders and is expressed in depth, i.e. mm, cm depth. Various models have been designed for non-recording rain gauges like Symon's type, which is now replaced by standard rain gauges by IMD.

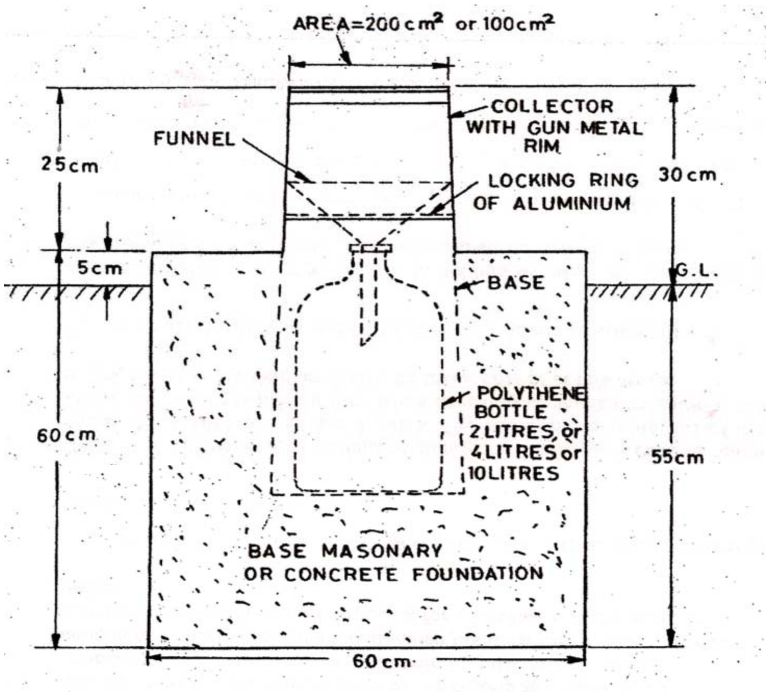



**Fig. 1.2 : Standard non-recording Rain-gauge of Indian Meteorological Department** (After S.K. Garg, 1988)

**Standard rain gauges :** Standard rain gauge consists of a collector, with a gun metal rim, a base and a polythene bottle (Fig. 1.2). Both the collector and the base are made up of fibre glass reinforced polythene. The collector with a deep set funnel having an aperture of either 100 or 200 sq.cm. are interchangeable depending upon the area and expected rainfall. There are also two bases, the smaller and the other larger and are also inter changeable, the smaller one being used for all sizes of rain gauges except the largest. The polythene bottles have three capacities i.e. 2 litres, 4 litres and 10 litres. By interchanging the collector, base and the polythene bottles depending upon the rainfall pattern, rain gauges as set up in our country can measure the rainfall more or less accurately, subjected to corrections due to wind speed, direction of rainfall etc. Data from these gauges are collected manually by a person who visits the site at 8.30 am daily for recording 24 hours rainfall.

**Recording types** of rain gauges records in a sheet of paper directly the amount of rainfall over a period of time, generally of very short duration. Types of recording rain gauges are :

i) Weighing bucket rain-gauge.
ii) Tipping bucket rain-gauge.
iii) Float type rain-gauge.

**Snow fall and Snow melt**

Snowfall is the next important component of precipitation. Snow fall occurs at high altitude and is seasonal. In India, heavy show falls occur in the upper reaches of the Himalayan rivers, such as Ganga, Yamuna, Brahmaputra during December, January and February. The snow melts during summer season and sustains the perennial river flow in the major rivers.

Snow fall can be measured either for individual snow fall or for seasonal snow fall. Snow gauges are used for measurement of both types of snow fall by measuring the depth of snow, actually collected on a level platform or by measuring the depth of the snow, caught in a shield gauge vessel, after leveling the accumulated snow. Unlike rainfall, the amount of snow fall may vary within a very short distance. One of the methods adopted is snow survey which is carried out in a pre-determined snow courses in a particular season or weekly or daily basis. The measurement of snowfall is necessary for anticipating the stream flow during dry seasons. There are few empirial formulae for determining the snow melt, of which mention may be made of U.S. Army Corps of engineer's equation. According to this equation : (Source : S.K. Garg, 1988)

(a) For open sites : $M_{24} = 0.03\ (9\ Tm + 40)$; and
$M_{24} = 0.02\ (Tmax + 25)$

Where $M_{24}$ = daily (24 hrs) spring time snow melt
$Tm$ = Mean daily temperature in $^0C$
$Tmax$ = Maximum daily temperature $^0C$

(b) For forested sites :

$M_{24} = 0.025\ (9\ Tm)$; and
$= 0.02\ (9\ Tmax - 50)$

According Light's equation, the suggested monthly values of 12-h snow melt in clear weather within latitute 400 to 480 (after Wilson as in Garg, 1988) is as below :

| Month | Snow melt occurring in half day In clear weather in cm |
|---|---|
| March | 0.89 |
| April | 1.07 |
| May | 1.22 |
| June | 1.35 |

(Source : S.K. Garg, 1988)

**Rain-gauge Net Work :**

Rain fall varies from place to place even in the same basin. For all hydrological studies, it is essential to understand the rainfall pattern and average rainfall in a basin or over large terrain. A number of rain gauge stations need to be installed, i.e. net work of rain gauge stations in such a fashion so as to be representative of the area. Selection of rain gauge stations needs to be carefully chosen, depending upon the purpose of the study. The World Meteorological Organisation has given the following guidelines for minimum density of rain gauges in a catchment area :

(1) For flat regions of temperate Mediterranean and Tropical Zones : One station per 600-900 sq.km. For countries with limited funds, population or other factors such as communication, the density may be reduced to one station per 600-3000 sq.km.

(2) For Mountainous regions of temperate Mediterranean and Tropical Zones : One station per 100-250 sq.km. For countries with problems as mentioned above, the density may be reduced to one station per 250-1000 sq.km.

(3) For arid and polar zones : The minimum density may be one station per 1500 - 10,000 sq.km. depending upon the feasibility.

In India, there are more than 5000 rain gauge stations spread over a vast area of 31.5 lakh sq.km. The High Level Committee on floods set up by Government of India recommends to set up at least one rain gauge station per 500 sq.km.

**Average or Mean Rainfall and Normal Rainfall**

Rainfall data are collected over a 24 hours period and is known as daily rainfall. Total rainfall recorded in a station for one year period is known as annual rainfall. Annual rainfall in an area varies year to year and for hydrological investigation long term records are required. The average of long term records of annual rainfall provides us annual average annual rainfall of the area. In India more than 100 year records are available. The term normal annual rainfall indicates average of long term records of 50 years or 100 years data when available. In India average of 35 years annual rainfall is known as normal rainfall. In an area annual rainfall may be in excess or deficient than the normal rainfall.

**Average Rainfall in a Drainage Basin**

In a drainage basin, there are more than one rain gauge station. The number of rain gauge stations will be higher in a larger basin than a smaller basin. Ideally the number of rain gauge stations required for determining the average rainfall is as under : (Source : S.K. Garg, 1988)

Area of the basin in sq. km. No. of raingauge station

| Area of the basin in sq.km. | No. of raingauge station |
|---|---|
| 0 - 80 | 1 |
| 80 - 160 | 2 |
| 160 – 320 | 3 |
| 320 – 560 | 4 |
| 560 – 800 | 5 |
| 800 - 1200 | 6 |

Following procedure are adopted for estimating the average annual rainfall :

**(1) Arithmetical Mean Method**

This is the simplest way to determine the average annual rainfall in a basin of size, having 'r' number of rain gauge stations, i.e.

$$P = \frac{P_1 + P_2 + P_3 \ldots\ldots P_n}{r}$$

When P = Average annual rainfall, r = no. of rain gauge stations
$P_1, P_2, P_3 \ldots. P_n$ = Rain fall in different rain gauge stations

This number is more or less satisfactory when the density of rain gauges are high and the rain fall variations from station to station is not high. This method, however, has serious drawback as it does not take into account the weightage of area of different rain gauge stations.

### (2) Thiessen's Polygon method

This method (Fig. 1.3) takes into account the weightage of area of influence of each rain gauge stations. Adjacent stations are joined by straight lines, thus dividing the entire area into a series of triangles. Perpendicular bisectors are erected on each of these lines, thus forming a series of polygons, each containing one and only one rainfall station. The rainfall recorded at a station is assigned the value to the polygon within which the station is located. Thus, if P is the mean rainfall of the basin of area A, then

$$P = \frac{A_1 P_1 + A_2 P_2 + A_3 P_3 \text{------} A_n P_n}{A}$$

When $P_1$, $P_2$, $P_3$ etc. represents rainfalls at the respective stations, whose surrounding polygons have the areas $A_1$, $A_2$, $A_3$ etc.

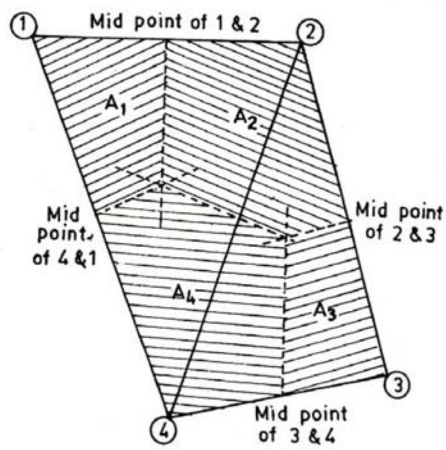



**Fig. 1.3 : Theissen's Polygon Method (After Punnia et al, 1992)**

### (3) The Isohyetal Method (Fig. 1.4)

Isohyets are the contours of equal rainfall. Values of annual rainfall are recorded in a map of basin of respective rain gauge stations and then contours are drawn based on the judgement of equal rainfall. The areas between two isohyets are estimated either by planimeter or by tracing on a graph paper. Let the areas be $A_1$, $A_2$, $A_3$ etc. Corresponding to the rain gauge stations of $P_1$, $P_2$, $P_3$ etc. Then the average or mean rainfall is given by :

$$P = \frac{P_1 A_1 + P_2 A_2 + P_3 A_3 \text{--------} P_n A_n}{A_1 + A_2 + A_3 \text{------} A_n}$$

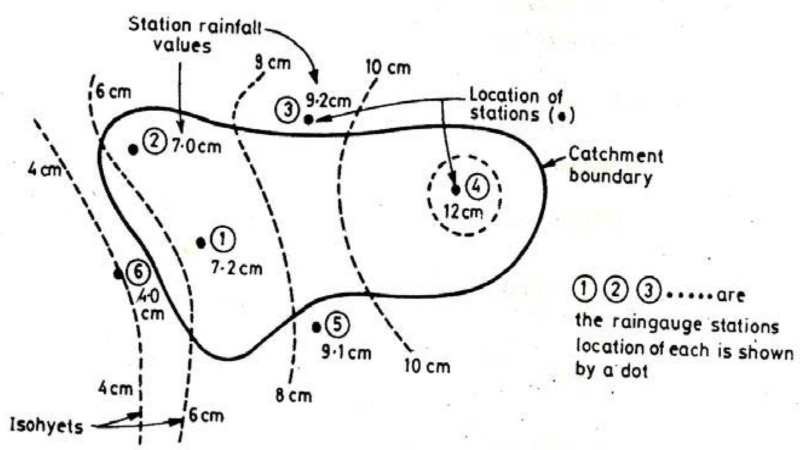



**Fig. 1.4 : Isohyetal method for computing average rainfall (After Punmia et al, 1992)**

### Rainfall - Run off

When rainfall occurs over an area, it falls on the earth's surface after being intercepted by trees, habitations, buildings, etc. and flows overland, generally towards the nearby rivers or streams. If during the passage it encounters small depressions, the area is first filled up and hardly contributes to the direct run-off, but very significant for groundwater recharge or the contribution of rainfall to the groundwater body. Movement of overland flow is also influenced by the soil type over which surface run-off is moving towards the streams. If the soil type is very pervious or having high infiltration capacity water will move downwards to reach groundwater body or the water-table below which the entire soil depth is saturated with water. The area intervened between the land surface and the water table, is the unsaturated zone and water in this moves laterally towards the stream and is known as sub-surface flow and is a part of run-off.

The rainfall in a catchment area is disposed off in the following manner:

1) Basin recharge
2) Direct run off
3) Precipitation down to groundwater
4) Evaporation

**1. Basin recharge :**

Basin recharge has the following components :

i) Rain intercepted by leaves of the trees and stems of vegetation.

ii) Water held up in topographic (surface) depressions, known as depression storage.

iii) Soil moisture as capillary water in the pore spaces of the soil. The maximum rate at which the soil in a given condition can absorb water is known as infiltration capacity of the soil.

Effective rainfall or excess rainfall is the amount that falls on the ground is of interest to the agriculturist and irrigation engineers. This can be expressed as :

Effective Rainfall or Excess Rainfall = Rainfall - Interception - Depression storage - infiltration.

The sum total of interception and depression storage is called initial loss or basin loss. In case of heavy rainfall the basin loss is insignificant and is considered to be included in infiltration, i.e. Effective or Excess rainfall = Rainfall - infiltration.

## 2. Direct Run-off

Run-off that reaches directly or through stream is called direct run off or stream discharge. It has two components :

i) Water that flows directly over the ground surface, called True Surface run-off.

ii) When the soil is permeable, water infiltrates part of which flow laterally and joins the adjacent stream, through sub-surface run-off.

iii) Some amount of rainfall also adds to run-off.

## 3. Percolation down to groundwater

Rainfall that infiltrates downward vertically joins the groundwater body (Fig. 1.5) recharges groundwater, as a result of which water table rises. When the stream water level is lower than the adjacent water level groundwater will flow into the stream. Such streams are known as effluent streams. Groundwater inflow to the stream is known as baseflow. In dry period, many perennial streams are fed by base flow.

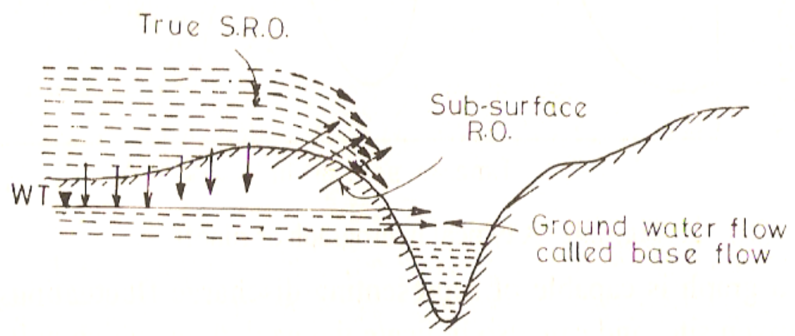



**Fig. 1.5 : Constituents of Surface runoff and of runoff (Source : Garg, 1988)**

## 4. Evaporation

Part of rainfall water received on the surface or intercepted by plants and leaves or in depressions or from the water surfaces of streams is lost due to evaporation and transpiration. It has already been discussed about the role played by evapotranspiration in the hydrologic cycle.

Evaporation losses will depend upon several factors, like area of water surface, depth of water in the water body, humidity, wind velocity, temperature, atmospheric pressure and quality of water.

### Factors Affecting Run Off

When rainfall occurs on the earth's surface its disposal in run off depends upon several factors such as :

1) Intensity of rainfall and characteristics of precipitation,
2) Topography,
3) Size and shape of the catchment area,
4) Geology of the area,
5) Meterological characteristics,
6) Character of the catchment surface,
7) Storage characteristics.

Rainfall can be of very short duration or it can be continuous over a period of time. More is the rainfall, more will be run-off. For short duration rain or drizzles, most of rain water may be evaporated or infiltrates into the soil. Nearness of nalas or streams or drainage channels also influences run off. In case of fan shaped catchment or watershed, most of drainage channels join the main stream at a time, thus inducing greater runoff. Topography greatly influences run-off. In case of hills, rainwater reaches the main stream with greater velocity than those occurring in flat areas. This is again influenced by the geological terrain. In hard rock areas with steep gradient of hillocks, run-off is greater. Even in flat lands covered by hard rocks run-off is higher. In flat alluvial terrain water percolates through the soil, thus reducing the surface run-off. If the surface area is cultivated, or away from any drainage channel run off will be less. Meteorological conditions also controls run-off. A frozen surface or stream gives rise to more run off. Rise in temperature induces more evaporation and thus run off is reduced. Wind direction of the storm in the direction of streams give higher run off. If there are artificial storage like dam and weirs, run-off will be reduced.

**Measurement of Run-off :**

Measurement of run-off is very important for the Irrigation Engineers for designing the dams, weirs and other water holding structures. There are several methods which are adopted by the Engineers, but details of the methodologies are beyond the scope of this book. In brief, methods adopted are:

a) Run-off formulae and tables.
b) By infiltration method.
c) By Unit Hydrograph.
d) Rational Method.

**Run Off Formulae and Tables :**

One of the most common method used by using the formulae for small areas

$R = K \times P$

Where R = run-off in cm
P = rainfall in cm.
K = run-off co-efficient.

Run-off co-efficient depends on various factors like the urban area, vegetative area, farm lands etc. Various values of K, which are commonly used, are shown in the Table 1.3. (After S.K. Garg, 1988)

**Table1.3 : Values of run-off co-efficient**

| Type of area | Value of K | | |
|---|---|---|---|
| | Flat land 0 to -5% slope | Rolling land 5% to 10% slope | Hilly land 10% to 30% slope |
| Urban areas | | | |
| 30% area impervious (paved) | 0.40 | 0.50 | -- |
| 50% area impervious (paved) | 0.55 | 0.65 | -- |
| 70% area impervious (paved) | 0.65 | 0.80 | -- |
| Single family residence in urban areas | 0.30 | -- | -- |
| Cultivated area | | | |
| Open sandy loam | 0.30 | 0.40 | 0.52 |
| Clay and silt loan | 0.50 | 0.60 | 0.72 |
| Tight clay | 0.60 | 0.70 | 0.82 |
| Pastures | | | |
| Open sandy loam | 0.10 | 0.16 | 0.22 |
| Clay and silt loan | 0.30 | 0.36 | 0.42 |
| Tight clay | 0.40 | 0.55 | 0.60 |
| Wooden land or Forested Areas | | | |
| Open sandy loam | 0.10 | 0.25 | 0.30 |
| Clay and silt loan | 0.30 | 0.35 | 0.50 |
| Tight clay | 0.40 | 0.50 | 0.60 |

# CHAPTER - II

## RIVERS, STORAGE AND DISTRIBUTION OF SURFACE WATER

Rainfall and snow melt are the main sources of water. Water that flows over the surface and is visible is commonly known as Surface Water. Water that seeps underground is known as groundwater. Surface water flows through definite channels, i.e. rivers, streams etc. Flow of rivers has influenced the human habitation and its propriety in a way that no natural resources can compare. In general, most of the rivers originate from the hills. Innumerable streams which are fed by water from the catchment joins the main river. These small streams or rivers are termed tributaries to the main river. The area from where these innumerable streams or rivulets originate is the catchment area of the main river. The main river while flowing may part with some of its discharge through small streams during its passage from the hills to oceans are known as distributaries.

Rivers are classified as (a) Hill Rivers and (b) Rivers in the plains.

**Hill Rivers :** These rivers have got two stages during this journey : (a) Incised or Rocky River State and (b) Boulders Rivers State.

(a) Incised or Rocky River State (Upper reaches) : In this type, the flow channel is generally formed by the process of degradation. The sediment transported in this reach is often different from the river bed material, since most of it comes from the catchment due to denudation and soil erosion. These river reaches are highly steep with swift flow, and forming rapids along their courses. The beds and banks of such rivers are less susceptible to erosion.

(b) Boulder River State (Upper reaches) : The river bed in these reaches consists of a mixture of boulders, gravels, shingles and alluvial sand deposits created by itself. Still these river reaches differ considerably from those carrying sand and silt and flowing through plains. In the later stage, the river flows through deep well defined beds and wider flood plains and develop zig-zag courses. On the other hand, in the boulder stage, the river flows through wide shallow beds and interlaced channels and develops a straighter course. During floods, the boulders, shingles and gravels are transported downstream but as the flood subsides, the materials get deposited in heaps. The water, then, unable to shift these heaps, go round them and channel often wanders in new direction, attacking the banks and consequently widening the bed.

**Rivers in the alluvial plains**

From the hills, the rivers flowing through a definite channel tends to have a fairly flat and level bottoms, but very few rivers remain straight for a long distance and follow a zig zag path called meanders. These are actually complex formations curved out by lateral movements of the river flow. A single bend has a concave outer bank where the current is faster and erosion predominates, and a convex inner bank, where the slower water deposits more alluvium. As the river flows there could be successive meanders. Sometimes meander will curve so much that it becomes a complete loop, cutting off the meander core and resulting in the formation of an  oxbow lake.

All the rivers are characterized by several dynamic components like current, type of flow and its discharge, erosion, transportation of materials and deposition. Although erosion, transportation and deposition all occur simultaneously, rivers are often described by their dominant process. A river that is aggrading is carrying a load greater than its capacity and therefore depositing alluvium to its channel. By contrast, a degrading river is one that is piling up alluvium and thus eroding the channel. A river that is in dynamic equilibrium between erosional and depositional forces is called graded or stable. No river is stable throughout its profile although the tendency of the river flow is to attain the stage of equilibrium. In general, the rivers in the upper reaches are mostly degrading whereas in the low land reaches they are aggrading type.

Near the oceans where the rivers release all the transported materials are very flat, often take the shape of delta, fans out through number of distributaries. This is the deltaic part of the river. This is extremely dynamic, almost opposite to the dendritic pattern in the catchment area of the river where it originates and land forming. There are adequate examples of new land being formed in the Sunderban areas of Indian sub-continent. In contrast to deltaic formations estuaries develop where the rivers carry less sediment to the ocean which has steep slopes, strong ocean current and strong tidal effects.

Briefly this is the tale of journey of a river from the hills to the oceans through flood plains. In fact flood plains are essential component of a river system. During its journey it faces the advent of civilization, development of urban areas. Flood, which is a natural phenomenon occurs in most of the rivers carrying volumes of silt and nutrients adjacent to the river i.e. in the flood plains. Floods are sometimes devastating causing enormous loss to the habitants. Dams are constructed in many rivers to thwart the problem of flood. Moreover, river water that reaches the ocean forms part of the hydrologic cycle, but is lost for the beneficial use of mankind. Dams also help in storing some amount of flow of water and are used for irrigation, generate hydroelectricity, drinking water supply, etc.

## DAMS

Water that falls on the surface as precipitation or as snow melt ultimately finds its way through streams and nalas to the oceans, thus making it impossible for human use, either for irrigation, industries, power generation and for drinking purposes. Humanity from time immemorial is trying to hold the flowing water by artificial means for its own use. Advancement of science has made it possible to hold the flowing water for various uses. The dam is such an artificial hydraulic structure to hold the water by obstructing the flow of water through rivers, resulting in raising water levels on its upstream side. As a result, a reservoir is formed in the upstream side submerging large areas on its side. Consequently, the flow in the downstream side is greatly reduced.

Dams are often classified according to its uses or purpose. Storage dams as the name signifies store water in the upstream side of the river by making suitable obstruction structure. Gravity dam is an example. Such storage dams may be constructed by a wide variety of materials like stone, concrete, earth, rockfill etc. A barrage or a weir is classified under diversion dam does not submerge any area by pool of water, but the water level in the upstream side is slightly raised to direct water through canals.

Dams are also classified according to hydraulic design. Spill way is a overflow dam when the crest of the dam is kept at lower elevation than the High Flood Level. In case of non-overflow dam the top of the dam is kept at higher elevation than the maximum High Flood Level.

**Classification according to use**

**Storage diversion and detention dams**

Storage dam, as the name signifies, store water in the upstream side of the river by making a suitable obstruction structure. Such storage dam may be constructed by a wide variety of materials like stone, concrete, earth, rockfill etc.

The dam so constructed across the river raises the water level on the upstream side causing a huge pool of water behind the dam, known as reservoir, which is filled up during the rainy season to the desired level as per the requirement of the project, i.e. irrigation water supply, power, multipurpose etc. The submerged area of the reservoir depends on the local topography and the height of the dam. On the contrary, a barrage or a weir which is classified under diversion dam does not submerge any area by pool of water, but the water level in the upstream side is slightly raised to divert water through canals. If the major part or the entire ponding of water is achieved by a raised crest and a small or nil part is diverted, it is known as weir. If, however, the water is raised by means of installing gates, which can be used for controlled release of water, the structure is known as barrage. Farakka Barrage is an example of diversion of water by raising the water level of the Ganga through Farakka Feeder Canal. Detention dams are widely used, particularly in the dry areas, to hold the water during rainy seasons. Such detention dams also recharges groundwater which can be used by constructing wells around the detention dams. They are common in water shed development projects.

**Various Types of Dams**

Modern day engineers classify the dams into eight different types :

1) Earth Dams
2) Rockfill Dams

3) Gravity dam
4) Buttress or hollow masonry gravity dam
5) Timber Dams
6) Steel Dams
7) Arch Dams
8) Rubber Dams

**Earth Dam and Rockfill Dam**

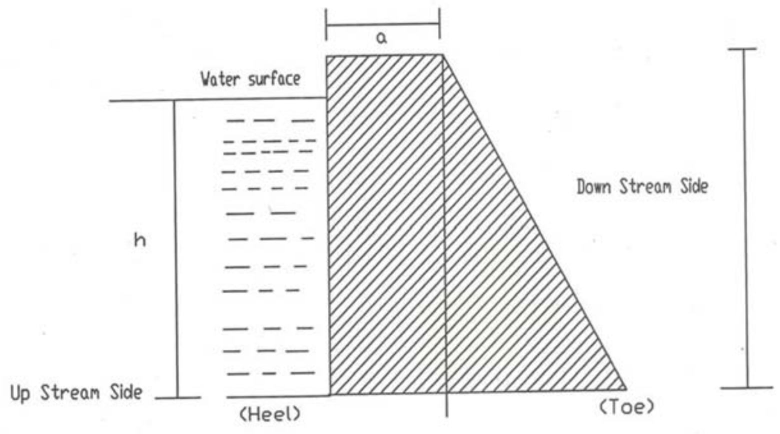
Earthen Dam is constructed out of local soil even by local labour. The dam essentially consists of a compact core (generally impermeable soil/clay), with designed side slopes. They can be constructed on any type of foundation.

The rockfill dam is an embankment which is constructed with different sizes of rocks and boulders. The upstream needs to be blocked by impervious membrance to make it water tight. In a combined earth and rockfill dam, the rockfill on the upstream side is laid by hydraulic rockfill and no derrick is required. The impervious membrance is also not required (Fig. 2.3).

Cost of both earthen dam and rockfill dam is cheaper and may not need any skilled labour. They need, however, good maintenance. They are also vulnerable to flood damage.

**Gravity Dam**

A gravity dam may be defined as a dam of having sufficient weight to resist the external forces like water pressure, uplift pressure, silt pressure etc. which tend to destabilize the structure by exerting its own weight i.e. gravity forces and the mass of the dam. Gravity dams are mostly constructed by concrete or masonry. Masonry gravity dams have limited height, but the concrete dam may be raised to any height, provided suitable foundations are made. Most of the modern dams are of gravity type. Such type of dams can be constructed at any site having strong foundation even in the steep gorges of the rivers, are stable and needs less area than the earthen dams. Concrete spillways can also be constructed along such dams. However, such dam sites require sound foundation, particularly on hard rocks.




**Q - Top of the Dam** **h - Height of water Column** **H - Height of the Dam**

**Fig. 2.1. Section of a Gravity Dam**

## Forces Acting on Gravity Dam

Te various external forces acting on a gravity dam may be :

1) Water Pressure
2) Uplift Pressure
3) Pressure due to earthquake forces
4) Silt Pressure
5) Wave Pressure
6) Ice Pressure
7) Weight of the dam

While designing a gravity dam these factors are taken into consideration.

## Buttress Dam

A buttress dam divides the space to be dammed by a number of buttresses or piers. The adjacent piers are held by means of horizontal arches or flat slabs. Buttress dams need less concrete and its height can be increased subsequently in time of need.

## Steel Dam

Steel dams are constructed with framework of steel, but now-a-days they are used only for construction of coffer dams, usually reinforced with timber or earthfill, during construction of major permanent dams.

## Timber Dams

Timber dams are temporary in nature and are constructed locally to meet the requirements of small population. These are frameworks of timber struts and beams, with timber plank facing to resist the water pressure.

## Arch Dam

Arch Dams are constructed in areas where the dams need to be constructed with narrow width and extremely high height. The dam is curved in plan and carries at major part of its water load horizontally by arch actions.

## Rubber Dams

The concept of flexible dams comes with the invention of inflatable rubber dams. A rubber dam is built on permanent base flushing with the bed of the river or stream on which the dam is located.

It is a permanent structure comprising of a sheet of rubber-coated fabric (rubber body) which is fixed to reinforced concrete foundation using clamp plates and bolts. The rubber is inflated by pumping air or water inside the rubber body until the design height or pressure is reached. It is deflated by allowing air or water to escape.

Central Water Commission (1994) has classified Dam according to storage capacity and height as shown below :

Size classification (Based on storage and height)
(As cited by George C. Varughese, 2007)

| **Category** | **Storage in Hectare Metres** | **Height in Metres** |
|---|---|---|
| Minor | < 125 and > 6 | < 12 and > 8 |
| Medium | > 125 and < 6250 | > 23 and < 30 |
| Major | > 6250 | > 30 |
| Taking into account only those dams with height > 15 metres, Indian has 2342 large | | |

## Impact of Dams

Dams are a source of water storage and conservation. However, there are controversies regarding the scale of such dams, large, medium or minor, which need to be constructed keeping in view of its societal and environmental impact. With over 5000 minor, medium and major dams already operational, both positive and negative impacts have been observed from their construction, operation and maintenance.

### Positive Impact

By and large Indian agriculture has been a major beneficiary of dams on all scales. Estimates indicate that the large and medium dams have contributed to approximately 25 per cent increase in agricultural production. Minor dams scattered throughout the country have contributed to 15 per cent increase in agricultural production.

Multipurpose river valley projects have also contributed to about 20 per cent power generation in the country, besides flood control, recreation and water supply for domestic and industrial needs.

### Negative Impacts

#### Disruption ands displacement of affected communities

Large dams on an average affects about a million people, having tremendous upheaval in the lives, mostly tribal. In addition live stocks are affected, agricultural lands are submerged and lost, affect the existing heritage structure by submergence, spread of disease.

#### Disturbance of ecosystems and loss of biodiversity

This includes :

Loss of forests and wild life habitat, loss or endangering of flora species, disturbance of aquatic and riparian life, changes in the river morphology and quality of water and changes in the groundwater regime.

Notwithstanding such negative impacts, construction of dams, whether major, medium or minor, will continue for storage of water and our food security. However, appraisal for construction of new projects of dams are made carefully, keeping in view the negative impacts so that minimum areas are affected. Relief and Rehabilitation measures are also taken up by the implementing agencies.

**Selection of site for a dam**

Investigation on selection of suitable dam site is very important for appropriate design of the dam. Major factors affecting the selection of dam sites are topography, geology, availability of materials, required land for reservoir, spillway locations, the economic impact on the local inhabitants, catchment areas etc.

Study of the detailed topography is of vital importance for deciding the type of dam. A narrow U-shaped valley suggests suitability of concrete overflow dam, whereas a V-shaped valley would suggest an arch dam, provided the top width of the valley is less than one fourth of its height with separate spillway site. A low rolling topography will suggest construction of an earthen dam.

Geology decides the foundation of the dam. In solid hard rocks like granite, gneiss etc. any types of dams can be constructed. The hard rocks should, however, be devoid of fractures, fissures, faults etc. Separate treatment like grouting etc. may be required when fracture and fissures can not be avoided at the site. Boulder formations are suitable for earth dam, rockfill dam or low concrete gravity dam with appropriate methods to prevent under seepage. Silt or fine sand have the problem of settlement, seepage and toe-erosion. In clay formation, only earth dams are suitable, but gravity dams or rockfill dams are unsuitable.

Availability of construction materials is an important factor for selection of dam sites. For example concrete gravity dams require sand, gravel and crushed stone. Availability of materials in nearby area will reduce the cost of transportation which becomes prohibitive if long distance transportation is required.

Spillway discharges heavy flood water during monsoon season and is an essential part of a dam. While selecting the dam site, choice of spill section will decide about the type of dam. Generally in concrete gravity dam a separate spillway is constructed.

In case of requirement of large spillway section, overflow concrete gravity dam is to be constructed. If the discharge from the spillway is small and suitable location for spillway site is available it needs to be selected along the major river section with concrete overflows section in the middle of the main dam.

**Distribution of Water**

Distribution of surface water is mainly from the river or storage like dams and effected by irrigation canals.

Main uses of water are for :

1) Irrigation
2) Industry
3) Water supply for drinking water.

**Irrigation Canals**

Canals are artificially excavated channels designed to carry water of required discharge from any river or head works of dams. Such canals are classified according to the discharge as under :

a) Main canal
b) Branch canal
c) Major distributary
d) Minor distributary
e) Water course
f) Field channel

## Main canal

Main canal is the one which carries water directly from the river or diversion head work. Branch canals are situated on either side of the main canal and distributes water to the major distributary which carries discharge ranging from ¼ to 5 cumecs. Minor distributaries receive water from either branch canals or major distributary and carry water of about ¼ cumecs. Water courses carries water from the minors for irrigating farmers field. Field channels carry water of smaller discharge from the water course to the farmers field.

## Canal Alignment

Alignment of canal is very important for distribution of water effectively and economically. The alignment of the canal should be such as to ensure (i) the most economical way of distributing the water to the land, (ii) as high a command as possible, and (iii) minimum number of cross drainage works (Fig3.1).

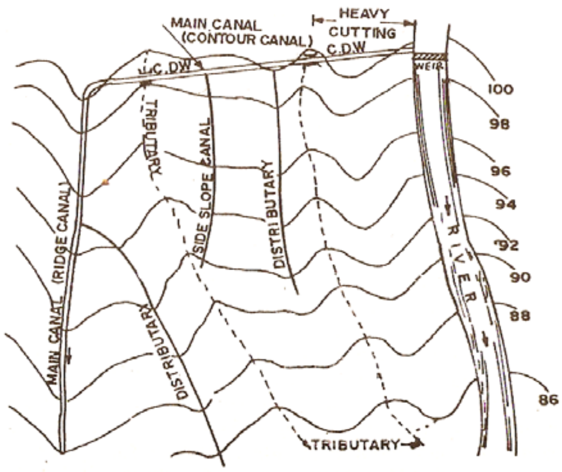



**Fig. 3.1 : Canal Alignment**
(After Punmia et al, 1992)

According to alignment, the channels may be :

(1) Ridge canal
(2) Contour canal
(3) Side slope canal

Ridge canal is designed in a command when the high contours join in a straight alignment can distribute water on both sides of the canal. On the contrary, a contour canal follows in parallel a contour line and as a result water can be distributed only one side of the canal. In practice, both the types have field problems and in a ridge canal, it could be necessary to keep the alignment straight because the water shed or high contours may turn in a loop abruptly. In such cases, economics of the canal construction is considered so that major part of the command area can be covered. Side slope canals runs at right angles to the contours and roughly parallel to the natural drainage of the country.

Design of Irrigation channels is a special subject dealt by the Irrigation Engineers. The design aspects take into account the required discharge through the canals, the area of cross-sections, the silt factor and the required slope, the soil characteristics, seepage from the canals. Seepage losses constitutes a major portion of losses from the canals and excessive losses may lead to water logging. The Central Water Power Commission recommends the following values of losses :

| **Soil type** | **Transmission loss (cumec/ million sq.m. of wetted perimeter)** |
|---|---|
| Rock 0.91 | |
| Black cotton soil | 1.83 |
| Alluvial soil | 2.74 |
| Weather rock or gravel | 3.00 |
| Sometimes losses are expressesed as percentage of total discharge : | |
| Main canal and branches | 15% to 20% |
| Distribution and minors | 6% to 7% |
| Water courses | 17% to 22% |

**Lining of canal**

With a view to prevent excessive losses the canals are lined with cement-concrete or materials which prevent seepage. Most common types of lining are :

1) Cement concrete lining
2) Brick lining

3) Pre-cast concrete lining
4) Soil cement lining
5) Pre-fabricated light membrane lining

Concrete lining is very costly and used only on exceptional circumstances keeping in view of the economic viability.

**Piped Water Distribution System**

Canal water distribution system is basically meant for irrigation system, particularly major and medium irrigation projects and may in certain cases for minor irrigation projects. Major irrigation projects have command area of more than 10,000 ha; Medium Irrigation Projects have command area between 2000 ha and 10000 ha; Minor irrigation projects have command area of 2000 ha. and below. While major and medium irrigation projects can hardly think of using piped distribution system because of high discharge and high cost involved, in many Minor irrigation projects, piped water distribution system is used. Piped water distribution is also used for the industry and also for water supply for drinking water purposes.

**Classification of Piped water distribution**
**Cement Concrete Pipes**

Cement concrete pipes (with or without reinforcement) are used in many areas for distribution of water as they have many advantages over other materials like metal pipes or asbestos pipes, as if properly used they are not susceptible to rusting or incrustation. However, such pipes can not be laid in highly alkaline or saline soils. Highly acidic or alkaline water or water with wild hardness or having sediments are also not suitable. These types of pipes are cheaper and durable.

**RCC Pipes**

Unreinforced pipes are not generally used for diameters above 450mm. Reinforced concrete pipes are made with steel fabric or wire cages in single or double layers inside and outside for gripping the concrete. Such pipes are used where the pressure is low and seldom exceeds 50m. A surge pipe or vacuum chamber is used near the pumpset to prevent sudden shock when the pump is stopped.

The following is the classification of Cement Concrete Pipes according to IS : 458 [Khanna, 1995].

| Class | Description | Conditions where normally used |
|---|---|---|
| NP 1 | Unreinforced concrete, non-pressure pipes | For drainage and irrigation use, above ground or in shallow trenches. For culverts carrying heavy traffic. |
| NP 2 | RC, heavy duty, non-pressure pipes | For culverts carrying light traffic. |
| NP3 | | For culverts carrying heavy traffic. |
| NP4 | | For culverts carrying very heavy traffic, such as railway loadings. |
| P 1 | RC pressure pipes tested to a hydrostatic pressure of 2.0 kg/ sq.cm. (20m head) | For use on gravity mains, the actual working pressure not exceeding 2/3 of the test pressure. |
| P 2 | RC pressure pipes tested to a hydrostatic pressure of 4.0 kg/ sq.cm. (40m head) | For use on pumping mains, actual working pressure not exceeding ½ of the test pressure. |
| P 3 | RC pressure pipes tested to a hydrostatic pressure of 6.0 kg/ sq.cm (60m head) | For use on pumping mains, actual working pressure not exceeding ½ of the test pressure. |

**Source : Khanna's Hand Book of Civil Engineering (1995)**

### Cast Iron Pipes (C1 pipes)

Cast iron pipes are extensively used for water mains because of its durability, good strength, low cost of maintenance. They can be used upto a maximum working pressure of 130 metres of vertical head and upto 1000 mm of diameter, above which steel pipes or RC pipes are used. Disadvantages of cast iron pipes are heavy weight, high transportation cost, high cost of laying and jointing. Cast iron pipes are also subjected to corrosion when hard water flows through them due to calcareous incrustation causing obstruction during flow causing loss in discharge. Life of cast iron pipes may be more than 200 years, but when laid in chemically impregnated soils the life may be less than 30 years.

### Steel Pipes

Steel pipes are used when long distribution mains are required to be laid on the surface. Steel pipes are light in weight, thickness of the pipe is smaller than those of MS / RC pipes. Can withstand high working pressure (above 7 kg/sq cm). Steel pipes are generally used in areas requiring diam. higher than 600 mm. Steel pipes are susceptible to attack by acids and alkalis, even present in traces in water.

### Galvanised Iron Pipes(GI)

Galvanised Pipes of steel or wrought iron are widely used for distribution system and are good materials for conveyance of hard water. With soft active waters such pipes deteriorate rapidly and should not be used. Galvanised / wrought iron pipes and fittings are used where exposed to corrosive conditions such as, the presence of sea water or salty water. GI pipes are manufactured in diam. of 8mm to 100mm.

### Asbestos Pipe

Asbestos - cement Pipes are manufactured with asbestos and cement and are used for distribution of water. These pipes perform better in areas of corrosive soils, or alkalis or acidic water without much corrosion. Diam of such pipes may be 8mm to 600mm. Disadvantages of the pipes are reported danger of health as the water may contain asbestos cement fibres which may cause lungs disease.

### Polythene and Polyvinyl (PVC) Pipes

Polythene pipes are very flexible and can be laid without problem. Friction losses through the pipes are very low and discharge through the pipes are smooth. PVC pipes are not flexible and differ the thickness and weight depending upon the quality of the pipe. Rigid PVC pipes are light to handle, resistant to corrosion, available in long lengths. They are also economical.

### Classification of Polythene Pipes

Plastic pipes are classified as 2.5, 4,6 and 10.

### Test pressures and Allowable Working Pressures

| Class of pipe | Test Pressure | | Allowable Working Pressure | |
|---|---|---|---|---|
| | Kg/Sq.cm. | Head in meters | Kg/Sq.cm. | Head in meters |
| 2.5 | 3.75 | 37.5 | 1.875 | 18.75 |
| 4 | 6 | 60 | 3.0 | 30 |
| 6 | 9 | 90 | 4.5 | 45 |
| 10 | 15 | 150 | 7.5 | 75 |

**Source : Khanna's Hand Book of Civil Engineering, 1995**

Pipe diameter (outer) are available between 63 to 250mm is standard length of 3, 5 and 6 meters.

# CHAPTER - III

# MEASUREMENT OF FLOW OF WATER

Measurement of discharge of flowing water through rivers and canals and also from tubewells is essential to design any irrigation/water supply structures to cater to the need of required water. There are several methods to determine the discharge of flowing water for both surface water and groundwater.

**Measurement of surface water :**

Stream flow or surface water flow is the discharges that flow in a particular section of the stream/canal at a particular time. There are several methods to determine the discharge of flowing water in a river or streamflow or canals. These are :

1. Area velocity method
2. Weir method
3. Chemical method
4. Stage discharge curve method
5. Meter flume method

1) **Area Velocity Method**

The discharge can be calculated from the simple formula :

Q (Discharge) = Area x velocity

The equation thus shows that we must know the velocity of the flowing water and cross-section area of the steams/rivers/canals to find out the discharge.

**Determination of the velocity**

Velocity of a river/stream/canal varies both vertically and laterally in a given cross section, it is being minimum at the centre. There are several methods to determine the velocity as under :

1) Surface floats
2) Sub-surface floats
3) Twin floats
4) Velocity rod or floats
5) Current meter
6) Pilot tube

Surface float and current meter methods are widely used.

**Surface float method**

Light materials which float on water are floated at a known distance and time taken to traverse the distance by the float is noted. The velocity of the float is calculated :

$$V = \frac{\text{Distance travelled by float}}{\text{Time taken}}$$

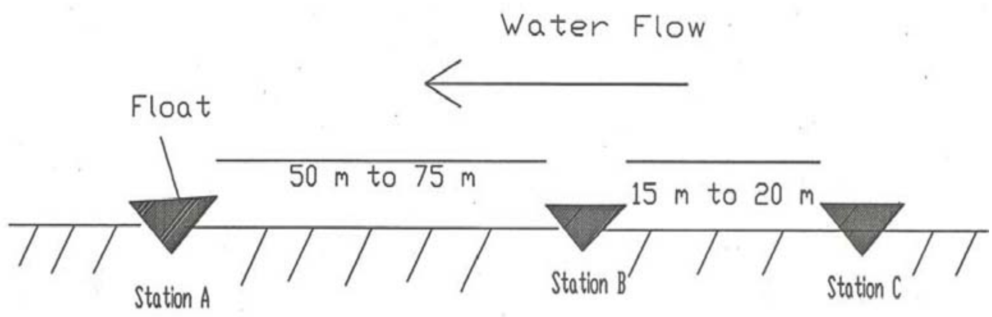



**Fig. 3.1. Surface Float method for measurement of flow of water**

The floats are either 'cone' or made up of tight hollow wooden blocks and are painted. Small flags can be used for identification. Two wire ropes are stretched across the width of the channel. The first station is on the downstream and the second station is on the upstream. The distance between the two station (test length) is between 50m to 75m for the large channels. For lined small channels this length may be kept at 15m to 20m. A third station is maintained upstream about 15m to 20m away from the 2nd station to observe the float for the steady flow of the float. Strong wind velocity and turbulence in the stream should be avoided. Surface velocity thus obtained is multiplied by an appropriate co-efficient, varying from 0.80 to 0.75 to obtain the mean velocity.

***Current meter***

Current meter is the best method to measure the velocity of stream flow or canal flow. There are various types of current meters and may be classified into :

i) Conical cup type current meters such as Price Current meter.

ii) Hellicoidal vanes type current-meter such as Haskell Current Meter and Amsler Current Meter.

Conical type of current meter such as Price Current meter is most popular and widely used.

**Price's Current Meter**

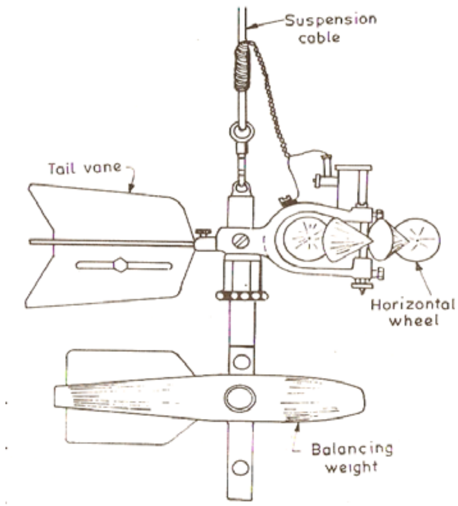



**Fig. 3.2 : Price's current meter**
(After Garg, 1998)

Price's current meter consists of a horizontal wheel carrying a series of cups that rotate on a vertical axis. The cups point towards the current, fifty percent of the cups having convex side towards the current and the balance fifty percent behave as concave towards the current. There is a tailvane and a weight-suspended at the bottom to balance and keep the meter steady (Fig. 3.2). When the current meter is suspended in water, the velocity of the flow causes the wheel to rotate. Since the velocity causes the rotation, velocity can be measured directly, provided the rotation of the current meter is rated (or calibrated ?). Rating formula is generally in the form of :

$V = (a + bN)$

Where V is the velocity of flow in m/sec.

N = No. of revolutions made by the wheel per second,

A & b are constants given by the manufacturer.

The water meter is lowered from a boat (or a rope in case of shallow depth) at the centre, keeping a depth of 0.6y from the free surface where y is the depth of the stream/canal to determine the mean velocity. Such experiments are conducted for each strip of the width which are compartmentalized in various strips because of the variation of the velocity both vertically and laterally in each strip. Average of all the readings gives the mean velocity.

**Measurement of the Area of flow :**

Cross-sectional areas of the streams or canals are divided into several vertical strips like $A_1$, $A_2$ etc. (Fig. 3.3). The depth of each of the vertical strips are determined by a rope tied with weight so as to touch the bottom. In case of deeper rivers, sounding method is used to determine the depth. Thus if $A_1$, $A_2$ etc. are areas of cross-sections of the stream and $V_1$, $V_2$ are velocities (as determined by the methods already discussed), then the discharge (Q) of the stream is :

$$\begin{aligned} Q &= A_1V_1 + A_2V_2 + A_3V_3 - - - \\ &= \Sigma AV \end{aligned}$$

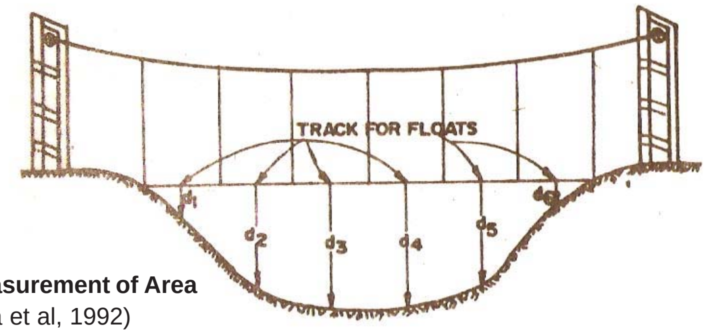



**Fig. 3.3 : Measurement of Area**
(After Punmia et al, 1992)

### Measurement of Discharge

Weir Method

V-notch is the most popular method for measuring the discharge through a flowing channel, which should be smooth and free from any disturbances. The notches are cut from thin metal plates and water is allowed to flow over the crest. This method can be used when the head is more than 6cm and maximum discharge is within 1.25 cumecs. The discharge Q for the V notch is calculated from the following equation : (Source : K.R.Karanth, 2004)

$$Q = \frac{8}{15} \, Cd. \sqrt{2g}.^{\tan} Ø/2. \, H^{5/2}$$

Where H = Head over the notch sill
Ø = angle of the notch at the centre
g = Acceleration due to gravity
= 9.8` m/sec$^2$
cd = Effective discharge co-efficent, the values of which depend on the shape of the crest.

For $90^0$ triangular (V notch), the equation becomes :

$$Q = \frac{8}{15} \, Cd. \sqrt{2g}. \tan.45^0. \, H^{5/2}$$

$$= 2.36 \text{ cd. } H^{5/2}$$

Often calibrated V-notches are used in the field to read directly the discharge.

**Stage Discharge Curve :**

Discharge of a river/stream varies at different seasons and at different locations of the same river. Discharges are calculated at a particular point, the control point, by area velocity method for different seasons. A gauge is installed at the centre point or near the bank for medium or large rivers and is calibrated with reference to mean sea level. A graph is then prepared with discharge as abscissa and corresponding gauge reading as ordinate. This graph is known as rated graph with known discharge and gauge reading. Subsequently, only by reading the gauge, discharge can be determined from the graph. For preparation of rated curve statistical data need to be collected. Fig. 3.4 shows a stage discharge curve.

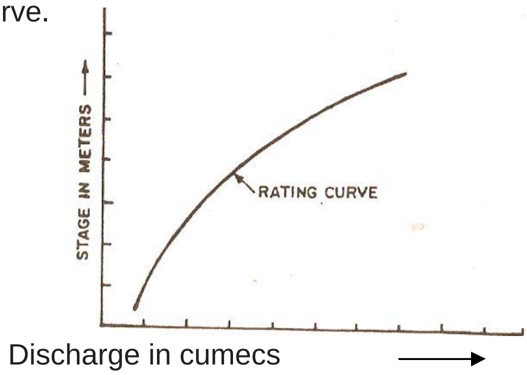



**Fig. 3.4 : Stage Discharge Curve**
(After Punmia et al, 1992)

**Measurement of discharge from Tubewells :**

Discharge from the tubewell is measured by (a) Orifice Method and (b) by V-notch Method.

**Orifice Method :**

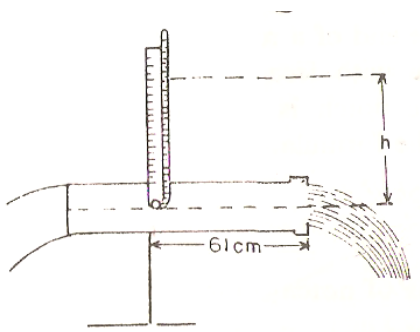



**Fig. 3.5 : Orifice Weir Method**
(After Karanth, 2004)

In orifice method, an orifice is fitted with the known diam of the delivery pipe. There is an attachment of manometer. Water from the delivery pipe exerts pressure during discharge which is reflected on the head of the manometer. The manometer is calibrated with different head in the column. Discharge can be directly read by knowing the head in the manometer. Needless to add that the head will be different for different diameter of the delivery pipe.

**V-notch Method :**

Discharge from the tubewell is allowed to fall on a stilling basin which has V-notch on the outlet side of the chamber. Discharge can be directly read from the calibrated V-notch.

When working in the field, there may not be any accessory like V - notch etc. to measure the discharge from a tubewell. There is one simple field method which can approximately give the value of discharges from a tubewell. The method is shown in the figure 3.6.

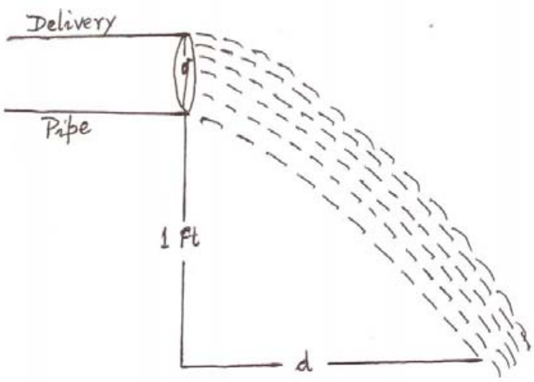



**Fig. 3.6 : Field Method of measurement of discharge**

From a discharging tubewell of known diam. of the delivery pipe, an imaginary line of 1 ft. or 12" is drawn from the delivery pipe. The distance 'd' is measured from the point at which the imaginary line falls on the G.L.(Fall) to the point where discharging water touches the G.L. The distance 'd' and radius 'r' of the delivery pipe is expressed in inches. Then -

$Q = \pi r^2 x\ d$ in gpm (us)

Example : 'd' = 36 inches
'r' = 1.5 inches

Then Q $= \pi r^2 x\ d$ gpm (us)
= 3.14 x 1.5 x 1.5 x 36 gpm (us)
= 254.34 gpm (us)
= 15,260 gallons per hour (us)
= 12,200 gallons per hour (Imperial

This method is really an extension of the Jet method (Karanth, KR, 2004). A fairly accurate determination of flow from full open horizontal or inclined pipes can be made by measuring the distance, parallel to the pipe, traveled by the trajectory of water for a vertical fall of 30 cm. and using the value in conjunction with that of diameter of the pipe in the formula. [Karanth, KR. 2004]

Q = 0.017 CP
Where Q = flow of water, in m3/s
C = Constant
P = distance traveled by the trajectory for a 30cm vertical drop from the discharging pipe.

# CHAPTER - IV

# WATER RESOURCES AND MAJOR DAMS IN INDIA

**Water Resources of India**

The National Commission on Agriculture (1976) assessed the total annual replenishable water resources to be of about 400 m.ha.m.or 4000 BCM. Recent publication of Government of India (Ref. www.cwc.nic.in/main.webpages/statistics.html) indicates the following figures on water resources of India :

1) Average Annual Precipitation : 4000 BCM
2) Average precipitation during Monsoon (June - Sept.) 3000 BCM
3) Natural Run off : 1986.5 BCM
4) Estimated utilized surface water resources : 690 BCM
5) Total utilizable groundwater resources : 433 BCM
6) Total annual utilizable water resources : 1123 BCM
7) Per capita water availability : 1720.29 Cu m.

**Indian River System**

**Rivers**

Rivers in India may be classified as (i) Himalayan rivers, (ii) Peninsular rivers (iii) Coastal rivers (iv) rivers of inland drainage basin.

The Himalayan rivers are perennial as they are snow-fed and have reasonable flow throughout the year. During the monsoon the Himalayas receive heavy rainfall and the rivers discharge the maximum quantity of water causing frequent floods. The Peninsular rivers are generally rainfed and therefore fluctuate in volume. The coastal streams, specially in the west coast, are short in length and have limited catchment area. Most of them flow during monsoon season, but gradually loose discharge and are non-perennial.

The streams of the inland drainage basin of Western Rajasthan are few and far between. Most of them are of an ephemeral character. They drain towards the individual basins of salt lakes like the Sambhar or are lost in the sand. The Luni is the only river of this category that drains into the Rann of Kutch.

The Ganga sub-basin, a part of the Ganga- Brahmaputra-Meghna basin, is the largest in India receiving water from an area, which is one quarter of the total area of the country. Its boundaries are well defined by the Himalayas in the north and Vindyayans in the south. The Ganga flows through Uttaranchal, UP, Bihar, West Bengal in India and enters Bangladesh. It has two main headwaters in the Himalayas - Bhagirathi and Alakananda, the former rising from the Gangotri glacier at Gomukh and the latter from the Alkapuri glacier. The Ganga is joined by a number of the Himalayan rivers including Yamuna, Ghagra, Gomti, Gandak and Kosi. Among important rivers flowing north from Central India into the Yamuna/Ganga are the Chambal, Betwa and Son.

The Brahmaputra and the Barak flowing east to west in the north-eastern region are international rivers and have immense water resources potential.

The Godavari in the Southern Peninsula is the second largest river basin covering 10% of the area of India. Next to it is the Krishna basin in the region, while Mahanadi is the third largest basin. The basin of the Narmada in the uplands of the Deccan flowing to the Arabian sea and of the Kaveri in the south falling into the Bay of Bengal are about the same size, but have different character.

### Basin-Wise Water Resources

Notwithstanding such vast water resources, many of the country suffer from acute water storage. In fact, 2/3rd of our country is drought prone. The uneven distribution of rain, both in space and time, diverse geographical terrain, extreme climatic conditions from snow clad mountains to the deserts of Rajasthan, have all contributed to uneven distribution of water resources.

India has 12 river basins with drainage area exceeding 20000 sq.km. These are:

| | | | |
|---|---|---|---|
| 1. | Indus | 7. | Pennar |
| 2. | Ganga-Brahmaputra-Meghna | 8. | Cauveri |
| 3. | Brahmani-Baitarani | 9. | Tapi |
| 4. | Mahanadi | 10. | Narmada |
| 5. | Godavari | 11. | Mahi |
| 6. | Krishna | 12. | Sabarmati |

Subarnarekha basin having a drainage area of 19296 sq km is also an important river basin. The remaining river basins can be conveniently clubbed together into seven river system clusters for purpose of planning and management. Therefore in all, India comprises of basic twenty river basin units from the point of water resource management.

It is observed from Table 4.1 that average annual run off per capita in Brahmaputra basin is highest at 21000 m3 and very low in west flowing rivers of Kutch and Saurashtra, being only 165 $m^3$. East flowing rivers between Pennar and Kanyakumari is also very low 487 m3 only. The figures are based on 1986 census and the current figures will be even lower.

**Table 4.1 : Water availability Per Capita and Per hectare of Culturable Area in the River Basins of India (Pumia et al, 1992)**

| Sl. No | River Basins | Drain-age Area ($Km^2$) | Average annual run off ($Mm^3$) | Popula-tion (1986) (Million) | Cultur-able area (Th.ha) | Average annual runoff per capita ($M^3$) | Average annual runoff per ha.of culturable area ($M^3$) |
|---|---|---|---|---|---|---|---|
| 1 | Indus | 321289 | 73305 | 36.58 | 96 | 2015 | 7600 |
| 2 | Ganga-Brahmaputra Meghna | | | | | | |
| | a. Ganga | 861404 | 525023 | 301.37 | 60161 | 1742 | 8727 |
| | b. Brahmaputra | 194413 | 537240 | 25.51 | 12146 | 21060 | 44232 |
| | c. Barak & others | 78150 | 59800 | 8.00 | 1114 | 7475 | 5368 |
| 3 | Subarnarekha | 10206 | 10794 | 7.94 | 1898 | 1359 | 5687 |
| 4 | Brahamani Baitarani | 51822 | 36227 | 10.35 | 3201 | 3500 | 11317 |
| 5 | Mahanadi | 141589 | 66879 | 24.45 | 7994 | 2735 | 8366 |
| 6 | Godavari | 312812 | 118982 | 4734.00 | 18931 | 2513 | 6285 |
| 7 | Krishna | 258948 | 67790 | 47.09 | 20299 | 1440 | 3339 |
| 8 | Perrier | 55213 | 6858 | 8.91 | 3551 | 770 | 1931 |
| 9 | East flowing rivers between Mahanadi and Perrier | 74354 | 16948 | 13.41 | 4328 | 1264 | 3916 |
| 10 | Cauvery | 87900 | 121358 | 27.46 | 5797 | 778 | 3784 |
| 11 | East flowing rivers between Perrier and Kanyakumari | 100139 | 17725 | 36.39 | 6876 | 487 | 2678 |
| 12 | West flowing rivers from Tadri to Kanyakumari | 112117 | 198854 | 53.70 | 6279 | 3703 | 3170 |
| 13 | West flowing from Tapi to Tadri | — | — | — | | | — |
| 14 | Tapi | 65145 | 18389 | 11.75 | 4536 | 1565 | 4054 |
| 15 | Narmada | 98796 | 41273 | 14.92 | 5901 | 2766 | 6994 |
| 16 | Mahi | 34842 | 11829 | 7.13 | 2210 | 1659 | 5352 |
| 17 | Sabarmati | 21674 | 4079 | 6.60 | 1548 | 618 | 2635 |
| 18 | West flowing rivers of Kutch and Saurashtra | 321851 | 5098 | 30.84 | 23447 | 163 | 217 |
| 19 | Area of inland drainage in Rajasthan desert | — | — | — | — | — | — |
| 20 | Minor rivers draining to Bangladesh and Burma | — | 31000 | — | — | — | — |

## Major Dams in India

Following are the major dams in India :

### 1. BHAKRA DAM

Bhakra Dam is one of the earliest multipurpose project in independent India. The work was started in 1948 and completed in 1963. Situated in Bhakra, Bilaspur district in Himachal Padesh over Sutlej river has an area of 56,976 km$^2$. Water in the catchment is received from both rainfall (70 cm) and snow (239 cm).

The dam is one of the tallest gravity dam in the world having maximum height of 226 m, even higher than the Hoover dam, USA (221 m). Besides irrigation, the Dam has a Hydro Power Unit having an installed capacity of 1204 MW.

## 2. KOYNA DAM

Koyna dam is a gravity dam and is constructed over the river Koyna in Satara district of Maharashtra and generates Hydro power. The catchment area is 891 $km^2$ and the installed capacity is 135 MW. The construction was started in 1956 and completed in 1961. Maximum height of the dam is 103m and length at the top of the dam is 808m. Design flood discharge is 7854 $m^3$/sec.

## 3. NAGARJUNA SAGAR DAM

Nagarjuna Sagar Dam is earth-cum-gravity dam and is located near Nandikonda village, Nalgonda district, Andhra Pradesh. It is a combined irrigation and hydro power project, constructed across Krishna river and the constructed work started in 1957 and completed in 1974. The catchment area of the project is 215,192 $km^2$ and the average annual rainfall is 890 mm. Maximum height above the lowest point of foundation is 125m. The length is 3145m at earthen dam non-overflow side, 978m in non-overflow masonary side and spillway length is 472m. Maximum discharge capacity is 53,450$m^3$/sec.

## 4. GANDHI SAGAR DAM

Gandhi Sagar Dam is an irrigation and hydropower project constructed across river Chambal in Mandasaur district of Madhya Pradesh. Average rainfall in the area is 86 cm. and the project has a catchment area of 23,140 sq.km. The dam is masonry one having maximum height of 64m and spillway length is 254m and non-overflow length of 260m. The design flood discharge of 21,240 $m^3$/sec. There are 5 nos. generating units having 23 MW each.

## 5. RIHAND DAM

Rihand Dam is a straight concrete gravity dam located in Pipri, Mirzapur district, UP. This is a hydropower project having an installed capacity of 300 MW. The dam is 91m high and more than 900m in length.

## 6. HIRAKUD DAM

Hirakud Dam is a multipurpose (irrigation, power and flood control) composite (earth, masonry and concrete) project having a height of 59m and is about 5 km in length. It is located at Hirakud, Sambalpur district, Orissa. This is a composit dam and the construction work started just after independence in 1948 and completed in 1957.

Other important dams are :

a) Lower Bhavani Dam - Tettupallyam, Tamil Nadu on river Bhavani

b) Krishnaraja Sagar Dam - Karnataka, on river Cauvery

c) Ukai Dam - Sonagarh, Gujarat across Tapti

d) Thein Dam - Gurudaspur district, Punjab across river Ravi

e) Tehri Dam - Tehri district, U P

f) Ramganga Dam - Bijnor, UP across Ramganga

g) Mahi Bajaj Sagar Dam - Banswara district, Rajasthan across Mahi river

h) Ujjani Dam - Sholapur district, Maharashtra across Bhima river

i) Tungabhadra Dam - Hospet, Karnataka

j) Dantiwada Dam - Banaskatha district, Gujrat

# CHAPTER - V

# FLOODS

Flood is almost an annual phenomenon in India in time of excess rainfall and causes enormous hardship to the people in the affected areas. Besides habitation and buildings, it also causes loss of crops. The nature of floods varies from place to place depending upon the topography, the nature of natural drainage or river systems. While flash flood occurs in the hilly areas due to sudden increase in run off in the catchment areas due to excessive rains, water in the plains overtops or breaches the embankment along the rivers inundating the adjacent areas.

Estimation of maximum rate of run off or flood discharge is, therefore, utmost importance for planning to prevent recurrence of flood in the flood affected areas by creating suitable structures, such as embankments, spurs or gryones etc.

The estimation of peak flow or flood can be made by one of the following methods:

(a) physical inspection of past records
(b) flood discharge formulae
(c) flood frequency studies
(d) unit hydrographs

a) Past records of floods can be detected in the old structures like monuments, temples etc. near the river bank. The Site Engineers or Survey parties contact the local old people from the villages and enquire about the maximum level of water that occurred during the past years, may be 30 - 35 years ago, and correlate with the markings left by the flood on the old monuments or even trees. This level is taken as the High Flood Level. The survey party then prepares the cross sections across the rivers and along the rivers in both downstream and upstream sides are made. Width of the river, water flow areas, wetted perimeter and hydraulic mean depth are calculated from the cross-sections. The longitudinal slope is assumed to be the same as the hydraulic slope in the past, and the mean velocity can be calculated from suitable hydraulic formula like Chezy's formula. Past Flood discharge can now be calculated by multiplying the velocity with the probable water section the past.

b) Flood discharge formulae :

There is a number of mathematical formula used to estimate the flood discharge depending upon the areas, availability of data, etc. The basic form of such formulae is : (Source : S.K. Garg, 1988)

Q = CAn, where
Q = flood discharge
A = catchment area
n = flood index
C = flood co-efficient.

Both C and n depend upon various factors such as (i) size, shape and location of the catchment (2) topography of the catchment and (3) intensity and duration of the rainfall, and distribution pattern over the basin.

Many of such formulae are derived by the study of drainage areas. For example, Dicken's formula states :

Qp = C A3/4
Where Qp = High flood or peak discharge in cumecs.
A = A constant depending upon the various factors affecting flood discharge.

Values of 'C' adopted by Dicken's is given in the following table (Table 5.1):

**Table 5.1 : Zonal values of 'C' for Dicken's; Formula in Indian conditions (After S.K. Garg, 1988)**

| Region | Value of 'C' in Dicken's formula |
|---|---|
| Northern India | 11.5 |
| Central India Provinces | 14 to 19.5 |
| Western Ghats | 22 to 26 |

There are other formulas like Ryve's formula, Inglish Formula, Nawab Jung Bahadur formula, Boston Society of Civil Engineers formula, modified Myer formula, Jarvis formula etc. - all derived based on 'C' and 'A'. Amongst them Nawab Jung Bahadur formula are used extensively for small catchment areas of Maharashtra.

Nawab Jung Bahadur formula = This formula has been derived for Hyderabad Deccan catchment and states that [S.K. Garg, 1988].

$Qp = C.\ A_1^{[0.93 - (1/14) \log A_1]}$ in cumecs, where

C = 48 to 60

$A_1$ = Area in square km.

The rational formulae uses both rainfall intensity and drainage area and states that :

Qp = 1/36 (K.pc.A), where

K = The percentage of rainfall that becomes surface run off, called run off co-efficient.

PC = Critical rainfall intensity in cm/hr. generally taken as the average rate during the time of concentration Te and can be determined from the Intensity - duration curve for the given frequency flood.

A = Catchment Area in ha.

**Statistical Methods or Flood Frequency Methods or Probability Methods:**

Statistical methods are useful stools to predict floods when long term data on stream flow and rainfall data are available. The stream flows vary from year after year and the sequence of such stream flow are recorded and a probable prediction can be made based on such available records. These probability methods are more or less reliable when long term records say 100 years, are available, but may not be precise for short period of data. Flood frequency or chance floods denote the likelihood or occurrence of flood. For example a 1% flood frequency indicates the possibility of flood once in 100 years. A 20% flood frequency there is likelihood of flood 20 times in 100 years.

**Unit Hydrograph Method for estimating Flood Discharge**

Hydrograph is a graphical representation of stream flow variation with time at a particular point of stream. When a storm occurs there is an increase in the discharge of the stream which varies with time. Initially there is an increase in the discharge in the stream and is reflected in the rising limb of the discharge curve. Hydrograph when plotted against time some valuable information can be derived in respect of total run off due to the storm and recharge to groundwater.

The unit Hydrograph follows the above principle to decipher the flood discharge. A unit hydrograph is a hydrograph representing unit (1 cm or 1 inch) run off from rainfall of some unit duration and specific aerial distribution. Unit duration refers to the duration of a run off producing rainfall excess, that results in a unit hydrograph or in other words a hydrograph depicting a duration of one unit, say, 3 hours, results in producing an excess rainfall of unit (1 cm or 1 inch). The unit duration may vary from basin to basin or in different catchment areas, depending upon its size.

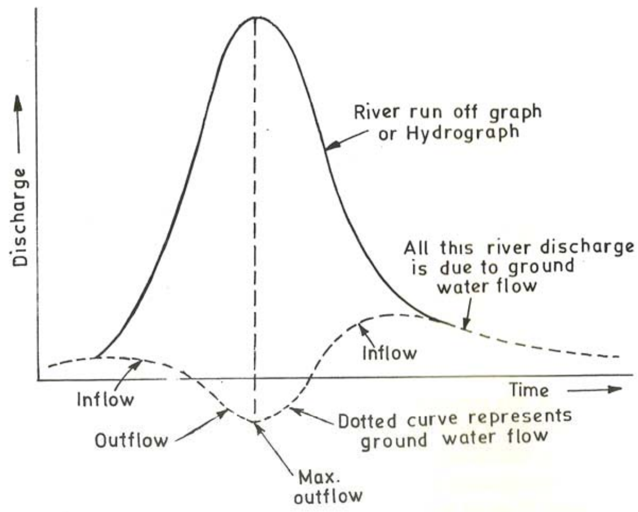



**Fig. 5.1 : Effect of ground water flow on river discharge**
**(Source : S.K.Garg, 1988)**

Application of unit hydrograph for estimating the flood discharge, however, are based on certain assumption, namely,

1) Distribution of effective rainfall throughout the drainage area over a specific time is uniform.
2) The effective rainfall is uniformly distributed throughout the whole area of the drainage basin.
3) The base or time duration of the hydrograph of direct run-off due to an effective rainfall of unit duration is constant.
4) For a given drainage basin the hydrograph of run-off due to a given period of rainfall reflects all the physical characteristics of the basin.
5) The ordinates of direct run-off and common base time are directly proportional to the total amount of direct run-off represented by each hydrograph.

**Flood Protection Work**

As has already been mentioned, when the river water overtops the banks and the adjacent areas which may be cities, industrial areas or agricultural lands are submerged, causing enormous damage to the country. On the other hand there are some beneficial effects of flood - it carries enormous amount of silt and nutrients covering the adjacent flood affected areas.

Flood protection works will depend upon the nature of the river, social and economic impact etc. For example in certain areas there may not be any habitation or agricultural land. Protecting such barren areas at a cost may not be required. On the contrary, there are areas where there may be enormous crop loss or damage to the property, roads, bridges etc. Such areas need to be protected from the vagaries of flood.

Depending upon the river characteristics and the local problems, the following methods are used for flood protection works :

1) Marginal embankments or levees
2) Pitching of banks and provision of launching aprons
3) Groyens or spurs

## 1. Marginal embankments or levees :

Marginal embankments are like earthen dams constructed along the rivers and therefore have considerable length depending upon the vulnerability of the river section. Embankments have side slopes on both river side and land side. The embankment walls are constructed suitably so as to prevent flood water spreading into the nearby land. The top of the embankment may have width varying between 2.5m and 10m and it is kept at least 1m above High Flood Level i.e. free board. The gradient of the slope of embankment on the river side is about 3.1 with stone pitching over filter layers. The weight of the stone should be such as not to be carried out by the high velocity of the river water during flood. The slopes on the land side should take care of the hydraulic gradient or seepage gradient which should be at least 1m below the top surface of the embankment and should be kept within the embankment. There are more than 30,000 km of embankment in India for flood protection work.

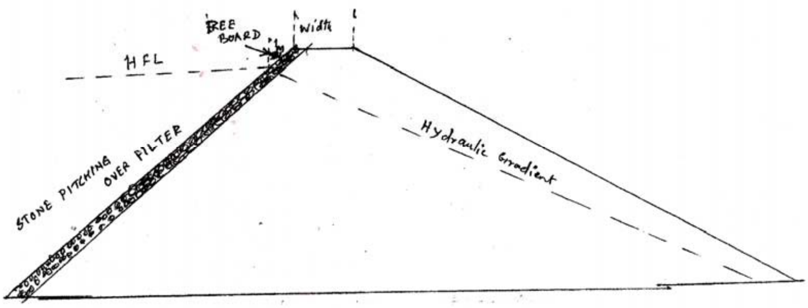



**Fig. 6.2 : Typical Section of levees or embankments**

## 2. Pitching of banks and provision of launching aprons

River banks are often protected, at least in the vulnerable sections which are prone to erosion by the strong river current particularly during the monsoons or by the tidal waves, by stone pitching or by concrete blocks or by brick lining. In some less susceptible areas growing of vegetable covers are also adopted. Banks are made stable by providing a slope of 1 : 1 or 2 : 1 depending upon the material of the bank. They are then pitched to make them strong enough to resist erosion. Scouring action of the river bed often spoils the pitched portion in the river bed making the entire pitched section ineffective. To avert such situation a launching apron was laid over the pitching slope from the toe of the bank into the river so as to prevent scour at the toe and consequent damage to the pitching.

The thickness of the stone pitching is calculated from the formulae [Source : S.K. Garg, 1993].

t = 0.06 x ½, when
t = thickness of the stone pitching in metre
Q = Discharge in cumecs.

Scour depth can be calculated from Lacy's formula which is :

$$R = 0.47 \left( \frac{Q}{f} \right)$$

Where Q = discharge in cumecs and
f = silt factor

The total scour below HFL is taken as xR where x varies between 1.25 to 2.25 depending upon the location of the pitched portion. A typical section of launching apron is shown below :

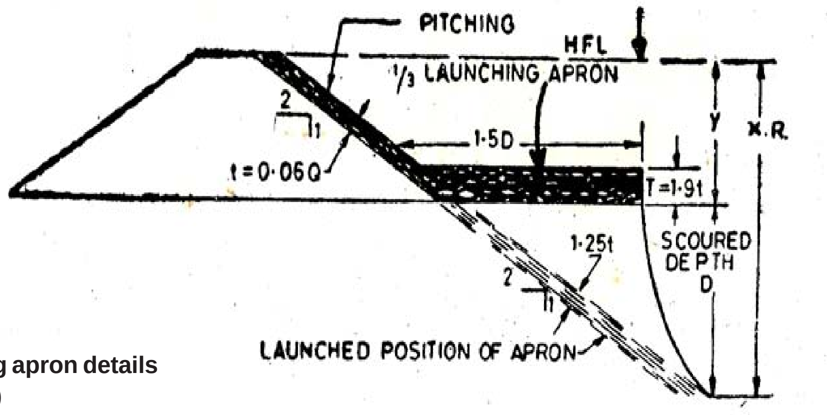



**Fig. 5.3 Launching apron details (After Garg, 1998)**

### 3. Gryones or spurs

Sometimes the banks of the rivers are damaged by the velocity of river flow, often resulting in overtopping and flooding the adjacent lands. Gryones or spurs are constructed from the banks transverse to the flow of the river to prevent direct attack by the river flow which is deflected away by the gryones. The nose of the gryones, below the river bed is subjected to the enormous force by the flowing river and the needs to be constructed strong to withstand such pressure. When the gryones are directed slightly to the upstream side, they are called repelling gryones. However when the length of such gryones are small, they are called deflecting gryones instead of repelling gryones. When the gryones direct slightly towards downstream side, they are called as attracting gryones.

### 4. Guide Banks

Guide banks are constructed parallel to the river with a view to reduce the width of the river and channelise the flow so as not to change the direction of flow as in meandering rivers to protect the engineering structures like weirs, bridges over the river. The guide banks are generally provided in pairs, symmetrical in plan and may either be kept parallel or diverge slightly upstream of works, depending upon local conditions. General layout of guide banks, plan and sections are shown in Figure 6.4.

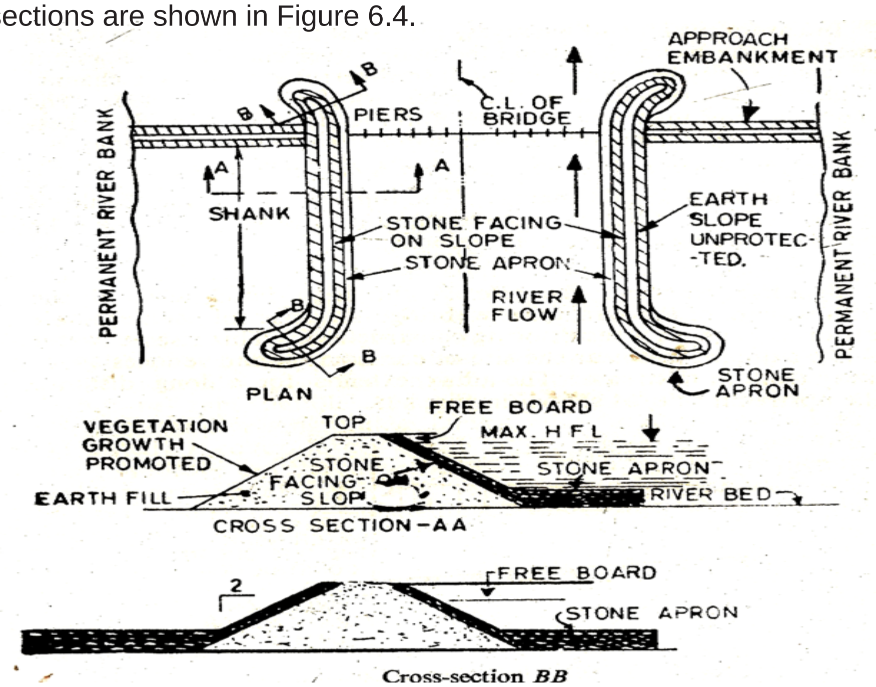



**Fig. 5.4. Guide Bank details**

(After Garg, 1998)

# CHAPTER - VI

# GROUNDWATER RESOURCES

Groundwater hydrology may be defined as the science of the occurrence, distribution and movement of water below the surface of the earth (Todd, 1959). We refer frequently to "geohydrology" and "hydrogeology" to connote the same as defined above. Hydrogeology, however, gives more emphasis on geology, while "geohydrology" gives more importance to hydrology. The subject essentially is an earth science and encompasses within its domain geology, mathematics, fluid mechanics, soil science, meteorology, oceanography, chemistry etc. When we think on a broader perspective including utilization and applied aspects, we are to include civil, mechanical, agricultural and electrical engineering in its domain. Civil Engineers, Agricultural Engineers and Geologists are the generally professional groundwater scientists.

**What is Groundwater ?**

Literally, it means water that occurs below the ground surface. Surface water infiltrates into underground through suitable geological formations and its vertical flow continues until it reaches the zone of saturation, below which the entire permeable geological formation is saturated with water i.e. all the interstices are filled with water under hydrostatic pressure. The zone above the zone of saturation is the zone of aeration where the interstices of soil particles are filled with water and air. The upper surface of the imaginary line between the zone of saturation and the zone of aeration is known as water table. The pressure on the water table is the atmospheric pressure. In certain geologic conditions, the upper surface of the zone of saturation may be an impermeable layer and the pressure on the saturated zone may be more than the atmospheric pressure and a well or a tube piercing this zone may experience the rushing out of water through a tube to the surface (artesian condition). The upper surface of this pressure zone is known as "piezometric surface". Water occurring in the zone of saturation is "groundwater" commonly used by us. Groundwater occurring under atmospheric condition is known to be water table condition or under unconfined condition and ground water occurring under the pressure of impermeable layer is said to be occurring under 'confined condition'. For example groundwater in Kolkata is occurring under confined condition while groundwater in Nadia District, West Bengal occurs under water table condition. The zone of aeration, or the suspended zone (vedose water) is very important for agriculture. This zone is commonly divided into three zones, i.e. soil water zone, intermediate zone and the capillary zone. In certain cases, due to addition of excess water in the saturated zone, water-table may rise upto the roots of the plants in the soil water zone, affecting the productivity. Such situations are not uncommon in the command of major irrigation projects like Sarda Sahyak Canal Command in U.P., Indira Gandhi Nahar Yojana in Rajasthan etc. This phenomenon is known as water-logging.

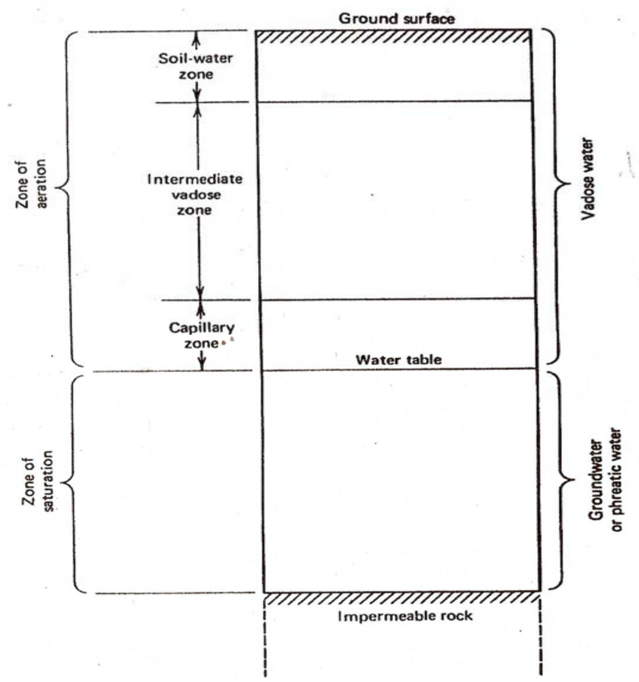



**Fig. 6.1 : Divisions of subsurface water**
(After Todd, 1995)

Figure 6.1 explains the vertical movement of water in a soil or permeable stratum . When water fall on the surface a small part is first absorbed in the top thin layer so as to replenish the soil moisture deficiency. This process of vertical movement in the soil zone is known as infiltration. Amount of water absorbed in such situation will depend upon the soil characteristics, largely, its grain size, shape and sorting of the particles, which determine the void space in the soil. Such void space may be different for different areas and therefore have the different capacities to absorb water. The maximum rate at which a soil in any given condition is capable of absorbing water is called infiltration capacity.

**Field capacity of soil :** Immediately after rainfall water infiltrates down to reach the water table zone, but some amount of water is retained on the surface of the soil grains due to molecular attraction. This water, known as pellicular water, can not be removed easily. Expressed in terms of depth of water as it is spread over the basin, this is known as field capacity of the soil and is of importance to agriculture. A portion of the pellicular water is absorbed by the vegetative root and is known as available moisture. The remaining unavailable water is known as hygroscopic water. The plants can extract water from the soil till it reach wilting point of the plant beyond which the plants wilt permanently. In other words the available moisture is the moisture between the field capacity (upper limit) and the wilting point (lower limit).

In the zone above water table the vertical flow of water is significant even though there is a horizontal flow known as sub-surface flow. When the vertical inflow enters the water table or in the saturated zone horizontal flow becomes important. In this zone groundwater flows from higher gradient to lower gradient till it reaches the outfall area i.e. stream, rivers or oceans. The amount of water that flow out from a particular basin to rivers etc. is replenished every year by rainfall and other sources and is known as annual replenishable groundwater recharge. Annual replenishable groundwater is withdrawn every year for various purposes, mainly for irrigation. Such replenishable groundwater is also known as dynamic groundwater resource. When groundwater is withdrawn more than the dynamic resource, gradual water table recession is observed and the area is known to be over developed. In case of thick zone of groundwater saturation only the upper zone is susceptible to change in water table due to either withdrawal or replenishment, but the zone below this dynamic flow zone is not affected by such drawal or replenishment and is known as static groundwater resource.

Dynamic water resources are of recent origin and is a part of the hydrologic cycle. In contrast, there are water resource at depth which are not part of the hydrologic cycle and may be quite ancient. Such water is known as 'connate' or 'fossil' water and is highly mineralized. Magmatic water is derived from magma. Such water, when occurs at great depth is known as 'plutonic water' and in a comparatively shallow depth is known as 'juvenile water'. Metamorphic water is water that is or has been associated with rocks during metamorphism.

**Aquifers :** Occurrence of groundwater is influenced by the medium or rock types i.e.soils, alluvium, sedimentary, igneous or metamorphic rocks through which it moves. An aquifer is a saturated permeable formation which can yield and store water freely and consists of unconsolidated sand, gravel etc. Aquifer or water bearing formations are a really extensive may be underlain or overlain by an impermeable layer stratigraphically. When the permeable formation or aquifer is overlain and underlain by impermeable bed, the aquifer is said to be occurring under confined conditions. A saturated formation but impermeable does not yield appreciable quantities or water to wells is known as 'acquiclude'. On the contrary, a relatively imperable formation which neither transmit water nor store water is known as aquifuge. Aquitard is a saturated but poorly permeable formation which does not freely yield water, but can store water and transmit water to the adjacent aquifer formation. Sandy clay, for instance is aquitard.

Aquifers are classified into unconfined or water table aquifer and confined aquifer. In an unconfined aquifer the water bearing strata are directly exposed to the top soil from where it receives water and forms the zone of saturation, the upper, the upper surface of which is known as water table and that is why it is sometimes referred to as water table aquifer. Water table aquifer generally follows the topography of the land surface and water flows from higher elevation to lower elevation. Water table maps can be prepared by noting the water level elevation with respect to a fixed datum which is generally the sea level. Based on the elevation with respect to the mean sea level of an area contours are drawn showing the flow direction of groundwater. In a thick saturated zone, there may be localised zone where the water table may be different than the regional water table because of presence of a local impermeable bed hindering vertical flow of water and thus creating an independent saturated zone. This localized water table is known as perched water table.

Confined aquifers, also known as artesian or pressure aquifers, occur where groundwater is confined under pressure greater than atmospheric pressure by overlying relatively impermeable strata. In such cases when a well penetrates upto the confining bed, water level will rise above the bottom of the impermeable bed. Fig. 6.2 depicts the actual disposition of confined and unconfined aquifers. It will be seen therefrom that the pressure exerted on the confining bed is equivalent to the water table of the recharge zone of the confining aquifer and may be far away from the area where the well is dug. The pressure level or pizeometric surface as it is called for confined aquifers may be higher than the water table of the area. When the pizeometric surface goes above the given level, 'autoflow' or 'artesian' conditions occur.

## Perched Water Table

In a thick saturated zone, there may be localized zone where the water table may be different than the regional water table because of presence of a local impermeable bed hindering vertical flow of groundwater and thus creating an independent saturated zone. Such localized water table is known as perched water table (Fig. 7.2)

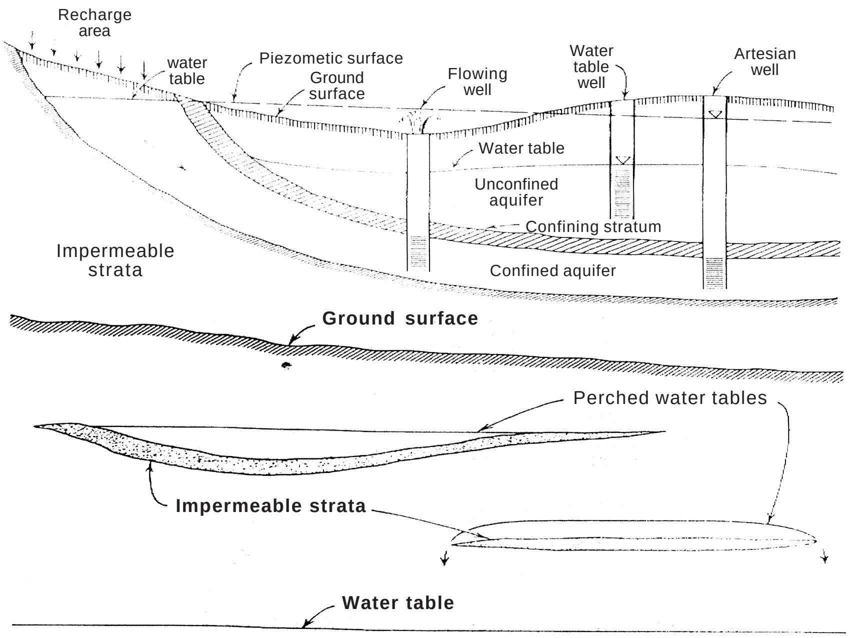



**Fig. 6.2. Confined and unconfined aquifers**
(After Karanth, 2004)

**Porosity :**

Porosity is the property of the rocks and soil to contain interstitial pore spaces. Some rocks are dense and devoid of interstices while some are quite porous and can absorb water readily. Such water holding capacities of the rocks and soils are dependent on the geologic formations, shape, size, arrangement, interconnection and extensiveness of the voids in which water can accumulate and move. For example sandy formations in alluvium can absorb water freely and can move, while in solid granite it can neither absorb water or there is any free movement of water. Porosity is expressed as a percentage of the void volume in a given volume of rock/soil. If ? is the porosity, then porosity or

$$\alpha = \frac{100\ W}{V}$$

Where W = volume of water required to fill or saturate all the pore space, and V is the total volume of rock or soil.

Porosity can be of primary or secondary depending upon the formation of void spaces. In unconsolidated sedimentary formations like alluvium deposits, porosity is primary. Secondary porosities develop in consolidated sedimentary, igneous and metamorphic formations due to availability of joints, fissures, faults etc. which were the results of earlier geological processes of stress and strain in the rock formations.

**Table 6.1 : Some representative values of porosity (after Morrison and Johnson as in Todd 1995)**

| Material | Porosity Percent | Material | Porosity Percent |
|---|---|---|---|
| Gravel } Coarse | 28 | Loess | 49 |
| repacked } Medium | 32 | Peat | 92 |
| samples } Fine | 34 | Schist | 38 |
| Sand, Coarse | 39 | Siltstone | 35 |
| Sand, Medium | 39 | Claystone | 43 |
| Sand, Fine | 43 | Shale | 6 |
| Silt | 46 | Till, predominantly silt | 34 |
| Clay | 42 | Till, predominantly sand | 31 |
| Sandstone, Fine grained | 33 | Tuff | 41 |
| Sandstone, Medium grained | 37 | Basalt | 17 |
| Limestone | 30 | Gabbro, Weathered | 43 |
| Dolomite | 26 | Granite, Weathered | 45 |
| Dune, sand | 45 | | |

The topmost layer on the surface is the soil (other than the exposed rocks) which plays an important role in groundwater recharge from rainfall. snowfall etc. Soils are classified according to the particle size as shown in the table :

**Table 6.2 : Soil classification based on particle size (Todd, 2004)**

| Material | Particle size, mm |
|---|---|
| Clay | 0.004 |
| Silt | 0.004 - 0.062 |
| Very fine sand | 0.062 - 0.125 |
| Medium sand | 0.25 - 0.50 |
| Coarse sand | 0.50 - 1.00 |
| Very coarse sand | 1.0 - 2.0 |
| Very fine gravel | 2.0 - 4.0 |
| Medium gravel | 4.0 - 8.0 |
| Coarse gravel | 16.0 - 32.0 |
| Very coarse gravel | 32.0 - 64.0 |

Grain size analysis can be performed by mechanical analysis of sieves having different mesh sizes. ISI standard sieves in the following mesh sizes are generally adequate for groundwater studies :

25, 20, 16, 10, 6.3, 4, 2, 1 milli metre and
710, 600, 425, 300, 125, 90, 75, 63 and 45 microns ($^1/1000$ mm).

Results of the sieve analysis are plotted in a cumulative curve as shown in Figure 6.3. From the cumulative curve the following analysis can be performed which are of importance to groundwater analysis :

1$^{st}$ Quartile (d75) : Size of sieve which separates 25 percent of coarser materials from the rest.

Median (d 50) : Size of sieve which separates the materials into two equal halves.

3rd quartile (d 25) : Size of sieve which separates 75 percent of coarser material.

Screen size : Size of sieve which separates 40 percent of coarser materials.

Effective size (d10) = Size of sieve which separates 90 percent of coarser materials.

Sorting co-efficient = $\sqrt{d75 / d25}$

Uniformity Co-efficient = d 60 / d10

The above statistical information are helpful in respect of aquifer materials to be tapped during construction of well.

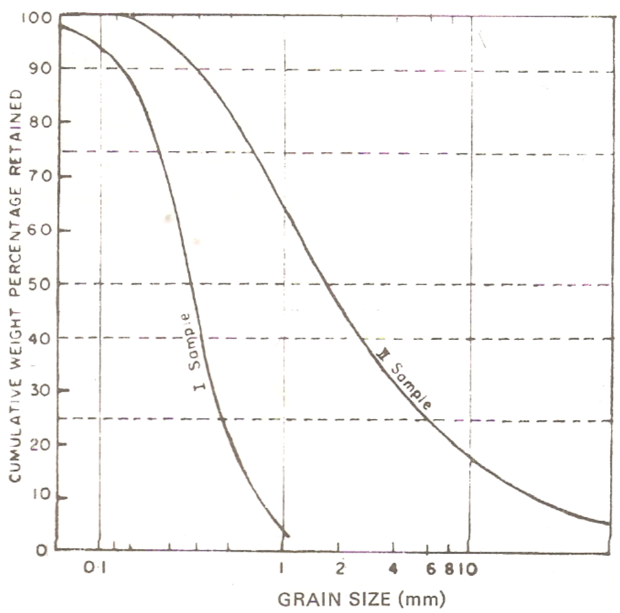



**Fig. 6.3. Cumulative Curve of grain size distribution**
(After Karanth, 2004)

## Water table fluctuation

Groundwater table which represents the upper surface of water level in the zone of saturation is susceptible to change in the atmospheric pressure, but signification variation occurs due to withdrawal or pumpage and also due to groundwater recharge from rainfall and other sources of recharge like irrigation etc. Thus in short the fluctuation of water table is a measure of storage of the aquifer and the change in storage over an area "A" can be measured by knowing the value of the specific yield i.e.

Change in storage = Area x Fluctuation of the water table x Sp. Yield value.

Seasonal variation of the water table can be computed by knowing the pre-monsoon and post monsoon water table records. Rise in the water table indicates addition in storage; lowering of water table on the other hand indicates withdrawal from the storage. Long term water-table data reveal the status of groundwater situation in an area. In case there is a continuous withdrawal of groundwater which exceeds the annual recharge in the area, long term records depicted in a hydrograph will reveal gradual recession of water table. There may be several other natural or artificial causes like evapo-transpiration, earthquake, tidal effects, movement of the ground due to railways etc., which may be small, but significant. Water-table recorders on selected observation wells reveal daily (even hourly), weekly, monthly fluctuation of the water-table.

## Fluctuation of the Piezometric Surface

Fluctuation of the water-table aquifer in the recharge area of the confined aquifer due to rainfall or pumpage causes fluctuation of the pizometric surface in the confined bed. Since a small amount of storage is released from the confined aquifer, heavy pumpage will cause a significant lowering of poezometric surface. Heavy withdrawal from the confining aquifer is thus warranted because of large decline of the piezometric head which may cause land subsidence.

Minor fluctuation of the piezometric surface also occurs because of atmospheric pressure, tides, passing of trains etc.

**Specific Yield :**

Groundwater fills all of the interstices in the saturated zone, hence the porosity is a direct measure of the water contained per unit volume. Not all of this water may be removed from the ground by drainage or pumping from a well, however, as molecular and surface tension forces will hold a portion of the water in place. Thus, retained water is that held in place against gravity. The specific retention of a rock or soil is the ratio expressed as a percentage of the volume of water it will retain after saturation against the force of gravity to its own volume. If Sr is the specific retention, then

$$Sr = \frac{100Wr}{V}$$

Where Wr = volume occupied by retained water, and V = Gross volume of the rock or soil.

The water on the other hand, which can be drained is expressed as the specific yield, Sy. It can be defined as the ratio expressed as a percentage of the volume of water which after being saturated, can be drained by gravity to its own volume.

Therefore,

$$Sr = \frac{100Wy}{V}$$

Where Wy is the volume of water drained. Because Wr + Wy = W, it is apparent that :

$$I\,I = Sr + Sy.$$

Thus, specific yield is a fraction of the productivity of an aquifer. Values depend upon grain size, shape and distribution of pores, and compaction of the stratum.

Representative value of specific yield is given in the following table :

**Table 6.3 : Representative value of specific yield (after John son as in Todd, 1995)**

| Material | Specific yield percent |
|---|---|
| Gravel, coarse | 23 |
| Gravel, medium, | 24 |
| Gravel, fine | 25 |
| Sand, coarse | 27 |
| Sand, medium | 28 |
| Sand, fine | 23 |
| Silt | 8 |
| Clay | 3 |
| Sandstone, fine grained | 21 |
| Sandstone, medium grained | 27 |
| Limestone | 14 |
| Dune sand | 38 |
| Loess | 18 |
| Peat | 44 |
| Schist | 26 |
| Siltstone | 12 |
| Till, predominantly silt | 6 |
| Till, predominantly sand | 16 |
| Till predominantly gravel | 16 |
| Tuff | 21 |

**Storage Co-efficient :**

In confined aquifers changes in the pressure (i.e. Pumping of well) produce only small changes in the storage volume. The water yielding capacity of a confined aquifer can be expressed in terms of its storage co-efficient.

Storage coefficient is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in the component of head normal to that surface. In most confined aquifers, values fall in the range of 0.00005 to 0.005, indicating that large pressure changes over extensive areas are required to produce substantial water yields.

Storage co-efficient for an unconfined aquifer corresponds to its specific yield.

**Movement of Groundwater and Darcy's law :**

Groundwater in the upper layers is dynamic and moves from high potential (or higher head) to lower potential (low head) through the porous medium of sand. Darcy has shown that the flow of water through sand follows the property of laminar flow and the rate of flow through the porous medium of sand is proportional to the head loss and inversely proportional to the length of the flow path. This is known as Darcy's law and is an established tool in the study of hydraulics. Commonly Darcy's law can be expressed as : [Source : Karanch, 2004]

$$Q = \frac{K(h^1 - h^2)\,A}{l}$$

Where Q = Discharge in $m^3$/day

K = Hydraulic conductivity in $m^3$/day/$m^2$ or (m / day)

h1 - h2 = Head loss in meters over a distance of l, also in meter, in the flow direction.

A = Cross sectional area of the porous medium through flow occurs, in square metres, measured at right angles to the direction of flow.

Sometimes negative (-) sign is used on the right hand side to show the flow of water from high head to low head.

The expression Q/A represents velocity, but the velocity of groundwater through the porous medium is very sluggish. Moreover, the water through the sand/ aquifers flow depending upon the pore size, grain distribution of sand etc. and the expression Q/A for the aquifer is generally known as Darcy's velocity i.e.

$$V = \frac{Q}{A} = -K \frac{dh}{dl}$$

Darcy's law is valid in case of laminar flow. When the flow is turbulent, Reynold's number, NR, or dimensionless number is used to show the turbulence. It is observed that Darcy's law is valid when NR < 1, and in certain cases do not deviate much even if when NR = 10

**Permeability & Transmissivity :**

Permeability, expressed as a co-efficient, was defined by Meinzer (1923, in Todd, 1955) as the rate of flow of water in gallons per day through a cross sectional area of one square foot under a hydraulic gradient of one foot per foot at a temperature of 600 F. When permeability is determined in the field, adjustment to the standard temperature is not made. Permeability is then understood to be a field co-efficient at the prevailing temperature of water. In recent years, the term hydraulic conductivity is being widely used in preference to co-efficient of permeability. Permeability has got the units of velocity i.e. m/day.

**Transmissivity**

The overall capacity of an aquifer to transmit groundwater is dependent on the thickness and hydraulic conductivities of the component parts of the aquifer. (Theis (1935) (as in Todd) introduced the term co-efficient of transmissibility, which was expressed as the rate of flow of water at the prevailing water temperature, in gallons per day, though a vertical strip of the aquifer under the hydraulic gradient of 100 per cent. Currently, in wide usage is the term transmissivity which is the rate at which water of the prevailing kinematics viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Lohman et al. 1972, as in Todd, 1955). From transmissivity (T), average hydraulic conductivity (K) is obtained :

K = T/b [when b = thickness of the aquifer]

From these parameters, groundwater flow under a uniform hydraulic gradient through a confined aquifer of constant thickness may be given as :-

| | | | |
|---|---|---|---|
| | Q | = | TIL |
| Where | Q | = | Groundwater flow in m3 / day |
| | T | = | Transmissitivity (Kb) in m2 / day |
| | L | = | Length of the aquifer along the equipotential linc, in metres, through which the discharge occurs. |
| | I | = | Hydraulic gradient |

**Occurrence of ground water -**
**Role of Geology - Hydrogeological set up**

Occurrence and movement of ground water is controlled by the geology of the area. In contrast to the common three types of rocks, i.e. metamorphic, igneous and sedimentary, hydrogeologists prefer to classify geological formations as consolidated, semi-consolidated and unconsoli-dated formations. Consolidated rocks are metamorphic, igneous and hard sedimentaries rocks and groundwater occurs in joints, fractures, and weathered residuum. This formation does not hold large quantities of water and are not good aquifers. Semi-consolidated formations are sedimentary rocks like sandstone, shale, limestones etc. Sandstone can yield moderate quantity of water, while Karstic limestones can be good aquifers. Unconsolidated formations, mostly of recent origin, are good repository of groundwater and form the major aquifers. Geological history like migration of river beds in space and time has formed buried channels and are good locations for tapping aquifers. Other important deposits are fluvial deposits in plain lands, inter montane valley deposits. Deposits at the foothills of the Himalayas are known as 'bhabar' deposits.

Geological or hydrogeological and topographical set up influences the accumulation of groundwater deposits. While in hills, major part of rainfall passes away as run-off, in the plains and intermontane' valley deposits, groundwater occurs in plenty. In hard rock areas, the outcrop area is not good locales of groundwater reserve, while weathered rocks can hold copious amount of water. Weathered granite, weathered vesicular lava, laterites have good water holding capacities. In short, unless you know the geological set up of the area, you cannot plan to explore the area for groundwater development.

**OCCURRENCE OF GROUNDWATER IN INDIA**

Groundwater in India occurs depending upon the hydrological set up. Hydrologically the country can be divided into the following three important zones:-

1) Bhabar and Piedmont in the foot hills of the Himalayas.
2) Indo-Gangetic Alluvial plains which is the main repository of groundwater.
3) The Peninsular shield area which is occupied mainly by the hard rocks.

Rainfall is the primary source of groundwater and varies widely in the country ranging from 11000 mm in Cherrapunji in the north-east to 4000 mm to 5000 mm in the western coast to as low as 100 - 200 mm in Rajasthan desert. Since percolation of groundwater depends up the porosity of rock formations, occurrence of groundwater can also be classified based on rock types :

1) Occurrence of groundwater in unconsolidated and semi-consolidated formations i.e. in alluvium and sedimentary rocks.
2) Occurrence of groundwater in the consolidated formations i.e. in hard rocks.

## WATER BEARING FORMATIONS

Availability of groundwater is largely dependent upon the types of geological formations in an area. For this purpose the geological formations in India can be divided into the following 3 main categories :

a. Unconsolidated Formations
b. Semi-consolidated Formations
c. Consolidated Formations

### a. Unconsolidated Formations

Unconsolidated formations are also sometimes termed as alluvial formations. These are formed as a result of deposition of sediment in water over a period of time. An alluvial plain is generally flat or gently sloping. Its lithology consists of alternate layers of water yielding formations comprising of sand., gravel and pebbles which are interbedded with varying thickness of non-water yielding clay formations. Alluvial formations are found in areas given below :

i. Alluvial plains of Himalayan rivers viz. Indus, Ganges and Brahmaputra including their tributaries.
ii. Alluvial valley fills of river in Central India viz., Narmada, Tapi, Purna and Godavari.
iii. Alluvial plains of East and West Coast and Plains of Gujarat.

These unconsolidated formations hold about 50 to 60% of the total usable groundwater resources in India and cover about one-third of the total land area. The Gangetic basin is the biggest groundwater reservoir in the world and is estimated to hold over 26 million ha m of gross yearly replenishable groundwater resources. Major part of this storage can be utilized continuously from year to year unlike oil which is a non-renewable resource. Unconsolidated formations are found to occur in major parts of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal. To a lesser extent these are found in the deltaic region of southern rivers like Mahanadi, Godavari and Krishna and in the alluvial plains of Gujarat.

The total area of these formations available for recharge is estimated at 8,50,000 ssq.km. The approximate state-wise break-up is given in Table 6.4.

**Table 6.4. Water Bearing formations in India ('000 Sq km) (NABARD, 1989)**

| **State** | **Total** | **Un-consolidated** | **Semi-consolidated** | **Consolidated** |
|---|---|---|---|---|
| Andhra Pradesh | 276.81 | 25.0 | 12.5 | 170.0 |
| Assam | 99.61 | 50.0 | -- | -- |
| Bihar | 173.88 | 75.0 | 5.0 | 55.0 |
| Gujarat | 195.98 | 85.0 | 7.0 | 50.0 |
| Haryana | 44.22 | 40.0 | -- | 0.5 |
| Himachal Pradesh | 55.67 | 1.5 | -- | -- |
| Jammu and Kashmir | 22.22 | 5.0 | -- | -- |
| Karnataka | 191.77 | 4.0 | 3.5 | 140.0 |
| Kerala | 38.86 | 7.5 | -- | 22.5 |
| Madhya Pradesh | 442.841 | 25.0 | 4.0 | 300.0 |
| Maharashtra | 307.762 | 15.0 | 5.0 | 215.0 |
| Orissa | 155.78 | 25.0 | 4.0 | 90.0 |
| Punjab | 50.36 | 60.0 | 0.5 | -- |
| Rajasthan | 342.21 | 175.0 | 10.0 | 70.0 |
| Tamil Nadu | 130.07 | 25.0 | 2.5 | 75.0 |
| Uttar Pradesh | 294.41 | 170.0 | -- | 25.0 |
| West Bengal | 87.85 | 62.0 | 1.0 | 5.0 |
| | **Total** | **850.0** | **55.0** | **1218.0** |

### b. Semi-Consolidated Formations

These formations are second in importance from the point of view of groundwater availability. Areas covered by sedimentary rocks like sandstone and also limestone having cavernous and solutions channels belong to these formations. Total area occupied by these formations is estimated to be around 55,000 sq.km (excluding hilly, forested and uncultivable land) (Table 6.5). Sandstone formations of Rajasthan and Gujarat, Gondwana formations and Cuddapah formations in West Bengal, Orissa, Bihar, Andhra Pradesh, Madhya Pradesh are examples. The different parts of the country where these formations are encountered are given below :

**Table 6.5. Total area covered by semi-consolidated formations (After NABARD, 1989)**

| Location | Formation Type |
|---|---|
| Western Rajasthan | Lathi sandstones |
| Madhya Pradesh | Punchmari sandstones |
| Maharashtra | Kamthi sandstones |
| West Coast | |
| Gujarat | Bhuj and Himmatnagar sandstone |
| Kerala | Quilon - Varkala sandstones |
| East Coast | |
| Tamil Nadu - Pondicherry | Cuddalore sandstone |
| Andhra Pradesh | Rajamundri sandstone |
| Orissa | Talcher sandstone |
| Bihar | Barakar sandstone |
| West Bengal | Raniganj sandstone |

### c. Consolidated Formations

Consolidated formations or the area covered by hard rocks constitutes about 2/3rd area of India. The entire peninsular area is covered by such formations consisting of granites, schists, gneiss, basalt etc. Total area covered by such rocks is estimated at 12,18,000 sq.km.

Groundwater occurs in hard rock areas in weathered residuum, fractures, faults, vesicular lavas etc. Depth of weathered residuum varies from place to place and may be as deep as 50m. Dugwells are constructed in such areas to extract groundwater. However, in suitable locations borewells are also constructed.

Statewise distribution of consolidated formations is indicated below :

**Table 6.6. Statewise distribution of consolidated formations (NABARD, 1989)**

| **Lithology** | **Statewise distribution** |
|---|---|
| Vidhyans & Cuddapahs quartzites etc. | Madhya Pradesh, Andhra Pradesh and Rajasthan |
| Deccan Trap basalts | Maharashtra, Madhya Pradesh, Andhra Pradesh, Gujarat and Karnataka |
| Granites, Gneisses and Schists, etc. | Tamil Nadu, Andhra Pradesh, Karnataka, Madhya Pradesh, South Bihar, Rajasthan, Maharashtra, Assam, West Ben gal and southern parts of Uttar Pradesh. |

## EXPLORATION OF GROUNDWATER

Groundwater exploration or investigation can be described under two heads : (1) Surface investigation of groundwater and (2) Subsurface exploration of groundwater.

### 1. Surface Investigation

The fundamental of surface investigation is to have a geological map of the area and plan for geophysical survey. Although several methods can be enumerated under geophysical heading, only the electrical resistivity and seismic refraction methods have been proved to be useful for groundwater investigation. Under surface investigation, photo interpretation of satellite maps can also be mentioned.

**Electrical Resistivity Method**

The electrical resistivity of a rock formation limits the amount of current passing through the formation when an electrical potential is applied. Resistivity of rock formations vary over a wide range, depending upon the material, density, porosity, pore size and shape, water content and quality, and temperature. There are no fixed limits for resistivities of various rocks; igneous and metamorphic rocks yield values in the range 102 to 104 ohm-m. In relatively porous formations, the resistivity is controlled more by water content and quality within the formation than by the rock resistivity. The interpretation of the resistivity curves needs experience and expertise which can be developed after working for few years in different areas.

**Seismic Refraction Method**

The seismic refraction method involves the creation of a small shock at the earths surface either by the impact of a heavy instrument or by exploding a small dynamic charge and measuring the time required for the resulting sound, or shock wave to travel known distances. Seismic waves follow the same laws of propagation as light rays and may be reflected or refracted at any interface where a velocity change occurs. Seismic reflection methods provide information on geologic structure thousands of feet below the surface, whereas seismic refraction methods - of interest in groundwater studies - cover only a few hundred feet. The travel time of a wave depends upon the media through which it is passing; velocities are greatest in solid igneous rocky and least in unconsolidated materials.

**Air Photo Interpretation**

Proper interpretation of aerial photographs of a region can provide information on the terrain characteristics, vegetation, land form use, drainage pattern, alluvial planes, even buried channels. Groundwater maps prepared from such observations can predict areas of most and least promising for ground water supplies. Such maps aid in selecting test drilling sites, reduce costs of groundwater investigations and assist in locating industrial plants requiring large water supplies.

## 2. Subsurface of Groundwater

Availability of aquifer and its characteristics can be ascertained by exploratory tubewell. Small diameter holes are drilled by means of direct rotary rig to ensure collection of samples of geologic formations. If thick good aquifer materials are obtained, the small hole can be reamed to a bigger diameter production well. The exploratory tubewell is suitably developed by air-compressor and ascertained the yield by using pumps of varying r.p.m. Chemical quality, draw down at a given discharge is also recorded. Such an exercise is needed for future well development in the area. However, if the test well fails to encounter any good aquifer the well is abandoned.

### Resistivity Logging

Within an uncased well, current and potential electodes can be lowered to measure electrical resistivities of the surrounding media and to obtain a trace of their variation with depth. The result is a resistivity (or electric) log. Such a log is affected by fluid within a well, by well diameter, by the character of surrounding strata, and by groundwater. Electrical logging is very useful in delineating fresh water aquifer from saline aquifers and in coastal or salinity affected areas, this method must be applied before screening the well to be used as production well.

### Aquifer performance - Tests

Aquifer parameters such as transmissivity, storage coefficient are determined by Aquifer Performance Test (APT) in the field condition. This need a pumping well with one or more observation wells to study the effect of pumping on water-table or piezometric surfaces. Darcy's law is utilized for arriving at different equations to determine the aquifer parameters such as transmissibility, storage co-efficient etc. in the field in different conditions of water flow such as steady flow under confined conditions, unsteady flow and non-equilibrium conditions etc. The basic assumptions in applying the mathematical equations are:

1) The aquifer is isotropic and homogenous.
2) The aquifer has infinite areal extent.

3) The discharge well penetrates and receives water from the entire thickness of the aquifer.
4) The transmissivity is constant at all times and at all places.
5) The well has an infinitesimal diameter.
6) Water removed from storage is discharged instantaneously with decline in the head.

When a well is pumped, water is removed from the aquifer surrounding the well, and the water table or piezometric surface, depending on the aquifer, is lowered. The drawdown at a given point is a distance the water table is lowered (Figure 6.4). The drawdown curve, plotted based on observation well installed away from the pumped well, shows variation or drawdown with distance from the pumped well.

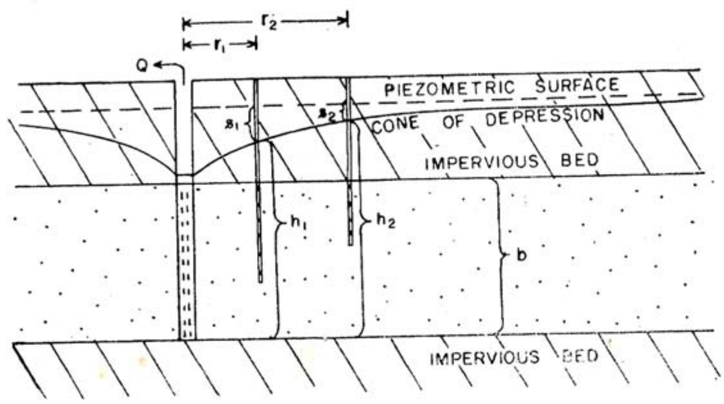



**Fig. 6.4 : Cross section of confined aquifer and piezometric surface (After Karanth, 2004)**

### Determination of 'T' for confined aquifer
### Steady state and constant discharge :

When a pumped well penetrates the entire thickness of a confined aquifer, Theim's equations applied to determine the value of 'T'. Two observation wells are installed at a distance of r1 and r2 and the well is pumped at a constant rate until the drawdown reached a steady state. The values of drawdowns are measured at regular intervals and are recorded. The values of drawdowns are generally not taken from the pumped well because of well loss etc. 'T' can be calculated from the following equations:

$$T = \frac{2.30\,Q}{2\pi\,(S1 - S2)} \quad \log \frac{r_2}{r_1}$$

T = Transmissivity in $m^2$/day

Q = Well discharge in $m^3$/day

$r_1$ and $r_2$ = Distance of two piezometers from the pumped well, in m.

$S_1$ and $S_2$= Steady state drawdowns, in m, in the piezometers located at a distance of $r_2$ and $r_1$.

Semi Confined Aquifers - Constank discharges

In field conditions, in many cases aquifers are in semiconfined state because of leakage from the overlying impervious body. In such cases, Hantush and Jacob equation (as in Todd, 1995) is used. The equation is given below :

$$S = \frac{Q}{4\pi T} \quad W(u, r/L)$$

Where u = $r^2S/4Tt$

$$L = \frac{\sqrt{T}}{K^1/b^1}$$

s = Drawdown in m

r = Distance from pumped well to observation well, in m.

Q = Discharge in $m^3$ / day

t = Time since pumping started, in days.

T = Coefficient of transmissivity, in $m^2$ / day.

S = Storage co-efficient, fraction.

$K^1$ = Hydraulic conductivity of aquitard in m/day

$b^1$ = Saturated thickness of aquitard.

W (u, r/L) is the well function, values of which are given by Hantush for practical field situations and the table indicating different values are given in the Text Book.

Different sets of equations are available for different disposition of aquifers or field situation i.e. unconfined aquifers, confined aquifer, partially penetrating wells, leaky aquifers, steady or unsteady sate etc. Computer softwares are now a days used to avoid rigorous mathematical calculations.

**Assessment of Groundwater**

Groundwater can be compared to liquid mineral like petroleum. While petroleum occurs at suitable geological structures and is not renewable, groundwater occurs in groundwater basins as a vast natural underground reservoir which is replenished annually. Thus, a petroleum reserve can be exhausted by continuous withdrawal, a balance between withdrawal and replenishment can be maintained, provided groundwater is used judiciously, keeping the withdrawal within 'safe yield' of the basin. The safe yield of a groundwater basin can be defined as the amount of water which can be withdrawn from it without producing an undesired result. Any draft (groundwater withdrawal) in excess of safe yield is overdraft. Overdraft can cause reduced water-supply, deteriorate the quality of groundwater (as in some parts of Kolkata), economics of groundwater withdrawal, legal and social problems affecting water rights.

### Water Balance Equation

Groundwater is a component of 'Hydrologic Cycle' - a natural cycle which controls the entire water resources based on the law of conservation of matter. In its simplest form it can be represented as :-

[Surface inflow + Sub-surface inflow + Precipitation + Imported water + Decrease in surface storage + Decrease in Groundwater storage] = [Surface outflow + Sub-surface outflow + consumptive use + Exported water + Increase in surface storage + Increase in groundwater storage].

In this form, the equation includes all waters - surface and sub-surface - entering and leaving a basin.

The groundwater balance of a basin or an area, for an inventory period, may be expressed in the form of an equation :

Groundwater inflow - Groundwater outflow = Change in Groundwater storage.

In an expanded form, to include most usual sources of recharge and discharge, the equation can be written in the form :-

$$S_{gw} = W_p + W_r + W_i + W_{as} + GW_i - GW_b - GW_e - GW_{et} - GW_e - GW_0 \pm GW_n.$$

Where,

| | | |
|---|---|---|
| $S_{GW}$ | = | Volume change in groundwater storage |
| $W_p$ | = | recharge from precipitation infiltration |
| $W_r$ | = | recharge from stream lakes and other natural water bodies |
| $W_i$ | = | recharge by canals, distributaries and other irrigation works |
| $W_{as}$ | = | recharge from surface water applied for irrigation |
| $GW_i$ | = | Groundwater inflow |
| $GW_b$ | = | Groundwater discharge to streams and springs |
| $GW_e$ | = | Evaporation loss of groundwater from capillary fringe |
| $GW_{et}$ | = | Evapotranspiration loss of groundwater from phrentophytic Vegetation |
| $GW_e$ | = | Groundwater extraction by pumping and flowing wells |
| $GW_o$ | = | Groundwater outflow |
| GWn | = | Other items, if any |

The equation is valid for a basin where it is possible to determine the parameters.

**Indian Seanario**

Prior to 1970s, the subject of groundwater was sidelined. Geological Survey of India and Exploratory Tubewell Organisations were the only two organizations engaged in groundwater studies. The entry of World Bank for financing agricultural projects saw a quantum jump of groundwater utilization for minor irrigation. Heavy duty tubewells and shallow tubewells were sunk in large numbers. The Government of India was, however, not ready with basin wise ground water assessment. In the initial years, only empirical methods of rainfall recharge was used. With a view to control and keep track of the rapid development, Government of India at the advice of the World Bank, opened State Groundwater Organisations in most of the states. Besides, guidelines were framed to calculate groundwater recharge and groundwater draft. The guidelines were framed by a Committee constituted by the Government of India with representative from State Governments and National Bank for Agriculture and Rural Development. These committees, known as Groundwater

Estimation Committee, upgrade the data base from time to time. The National Water Policy also recommended utilization of only dynamic groundwater resource (annually replenishable) as against static groundwater resource stored in alluvial groundwater basins through centuries. Salient features of the Committees recommendation :-

1. Groundwater assessment are made on "block" basis ("Mondal" basis in Andhra Pradesh). "Block" is an administrative unit and as such, scientifically not correct. However, this system helps the planner for allocation of fund etc.

2. Detail guidelines are given for calculation of groundwater recharge and draft i.e. Rainfall method when data are not available, water table fluctuation method, rainfall characteristic and normalization factor, recharge from canals, floods etc. Groundwater draft from various ground water structures, like tubewells, dugwells etc. are mentioned.

3. 15% of gross groundwater recharge is kept reserved for industry and domestic use.

4. Based on stage of utilization of groundwater, blocks are classified as "over-exploited", "critical" and "safe". Over-exploited blocks are those which have already utilized 85% utilizable groundwater recharge. "critical" blocks where utilization is between 70% to 85% - "safe" blocks are those where utilization is less than 70%.

5. No fund allocation are made, where the block is declared as "over-exploited" for construction of any groundwater structures.

**Quality of Groundwater**

Quality of groundwater is to be ascertained by chemical, physical and bacteriological analysis of the groundwater samples. The quality required of a groundwater supply depends upon its purpose, thus the needs for drinking water, industrial water and irrigation water vary widely. Accordingly prescribed quality of groundwater for irrigation, drinking water and industry are different.

**Chemical Quality**

All groundwater contain salts carried in solution. The kinds and concentration of salts depend upon the environment, movement, and source of ground water. Ordinarily higher proportions of dissolved constituents are found in groundwater than in Surface Waters because of the greater exposure to soluble materials in geologic strata. Soluble salts found in groundwater percolating through soils by soluble products of soil weathering, and of erosion by rainfall and flowing water. Soluble fertilizers also add to groundwater.

Concentration of different chemical constituents are generally expressed in parts per million (ppm) per litre. Total dissolved solids are measured by electrical conductance (EC) of groundwater samples and are expressed in milliomhos/cm.

Physical characteristics are expressed in colour, turbidity etc.
Bacteriological studies indicate presence of chloroform bacteria.
Quality Standards followed for irrigation, drinking water and industrial purposes are shown separately.

The classification of water for irrigation use according to various criteria is given below :- (Source : NABARD, 1989)

**Table 6.7 : Classification of Irrigation water**

| Constituent | Water Classification | | |
|---|---|---|---|
| | **Class I** | **Class II** | **Class III** |
| Total dissolved solids | 0 - 700 ppm | 700 - 2000 ppm | Above 2000 ppm |
| Chloride | 0- 150 ppm | 150 - 500 ppm | Above 500 ppm |
| Boon | 0 - 0.5 ppm | 0.5 - 2.5 ppm | Above 2.5 ppm |
| Percentage Alkalies | Under 60% | 60 - 75% | Above 75% |

Class I Water is regarded as entirely safe for irrigation under ordinary soil and climate conditions, even for sensitive crops.

Class II Water is regarded as intermediate which may be safe for certain crops but may be slightly harmful for other type of crops.

Class III Water is generally not safe for irrigation except under certain type of soil conditions and for salt tolerant crops.

### Drinking Water Standard

### Physical Characteristics :

| Characteristics | Upper limit |
|---|---|
| Turbidity | 100 ppm (silica scale) |
| Colour | 20 (Std cobalt scale) |
| Taste | Not objectionable |
| Odour | Not objectionable |

These limits are mandatory for filtered water supplies, for others, their application is subject to reasonable judgement and discretion based on local conditions.

**Table 6.8 : Chemical Characteristics of Drinking Water - (Source : Todd, 1995)**

| Constituent | Upper limit, ppm |
|---|---|
| Lead (Pb) | 0-1 |
| Fluoride (F) | 1 - 5 |
| Arsenic (As) | 0.05 |
| Selenium (Se) | 0.05 |
| Hexavalent Chrimium | 0.05 |
| Copper (Cu) | 3.00 |
| Iron (Fe) Manganese (Mn) together | 0.30 |
| Magnesium (Mg) | 125 |
| Zinc (Zn) | 15 |
| Chloride (Cl) | 250 |
| Sulfate (SO4) | 250 |
| Phenol | 0.001 |
| Total solids, desirable | 500.0 |
| Total solids, permitted | 1000.0 |

The limits for the first five constituents are mandatory; the others are recommended. The standards as specified by WHO and BIS (Indian Standard) are indicated under Chapter VII (Table 7.1). Suggested Water Quality Tolerance for the Industries are given in Table 6.9.

**Table 6.9 : Suggested Water Quality Tolerance for Industrial Uses**
(Allowable limits in ppm)

| Industry or use | Turbidity | Color | Odor and Taste | Iron as Fe1 | Manganese as Mn | Total Solids | Hardness as CaCO3 | Alkalinity as CaCO3 | Hydrogen Sulfite | Health | pH | Other Requirements |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Air conditioning** | -- | -- | Low | 0.5 | 0.5 | -- | -- | -- | 1.0 | -- | -- | No corrosiveness or lime formation |
| **Baking** | 10 | 10 | Low | 0.2 | 0.2 | -- | -- | -- | 0.2 | Potable | -- | |
| **Pressure 0-150 pai** | 20 | 80 | | | | 3000 -500 | 80 | -- | 5 | -- | 8.01 | No corrosiveness or scale formation $ |
| **Pressure 150-250 pai** | 10 | 40 | | | | 2500 -500 | 40 | -- | 3 | -- | 8.41 | No corrosiveness or scale formation $ |
| **Pressure 250-400 pai** | 5 | 5 | | | | 1500-100 | 10 | -- | 0 | -- | 9.01 | No corrosiveness or scale formation $ |
| **Pressure >400 pai** | 1 | 2 | | | | 50 | 2 | -- | 0 | -- | 9.01 | No corrosiveness or scale formation $ |
| **Brewing and Distilling** | | | | | | | | | | | | |
| **Light Beer, gin** | 10 | -- | Low | 0.1 | 0.1 | 500 | -- | 25 | 0.2 | Potable | 6.5 – 7.0 | NaCl 275 |
| **Dark beer, whiskey Canning** | 10 | -- | Low | 0.1 | 0.1 | 1000 | -- | 150 | 0.2 | Potable | 7.01 | NaCl275 |
| **Legumes** | 10 | -- | Low | 0.2 | 0.2 | -- | 25-75 | -- | 1.0 | Potable | -- | |
| **General** | 10 | -- | Low | 0.2 | 0.2 | -- | -- | -- | 1.0 | Potable | -- | |
| **Carbonated Beverages** | 2 | 10 | Low | 0.2 | 0.2 | 850 | 250 | 50-100 | 0.2 | Potable | -- | Organic matter infinitesimal; |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | oxygen consumed 1.51 |
| **Confectionery** | -- | -- | Low | 0.2 | 0.2 | 100 | -- | -- | 0.2 | Potable | 7.0 | |
| **Cooling** | 50 | -- | -- | 0.5 | 0.5 | -- | 50 | -- | 5 | -- | - | No corrosiveness or slime formation |
| **Food, general** | 10 | -- | Low | 0.2 | 0.2 | -- | -- | -- | -- | Potable | -- | |
| **Ice** | 5 | 5 | Low | 0.2 | 0.2 | 1300 | -- | -- | -- | Potable | -- | $SiO_2$ 10 |
| **Laundering** | -- | -- | -- | 0.2 | 0.2 | -- | 50 | -- | -- | -- | -- | |
| | | | | | | | | | | | | |
| **Paper and Pulp** | | | | | | | | | | | | |
| **Ground wood** | 50 | 20 | -- | 1.0 | 0.3 | -- | 180 | -- | -- | -- | -- | No grit or corrosiveness |
| **Kraft pulp** | 25 | 15 | -- | 0.2 | 0.1 | 300 | 100 | -- | -- | -- | -- | |
| **Soda & sulfite pulp** | 15 | 10 | -- | 0.1 | 0.03 | 200 | 100 | -- | -- | -- | -- | |
| **High-grade light papers** | 3 | 3 | -- | 0.1 | 0.03 | 200 | 30 | -- | -- | -- | -- | No slime formation |
| **Rayon (Viscose)** | | | | | | | | | | | | |
| **Pulp production** | 3 | 3 | -- | 0.03 | 0.03 | 100 | 9 | 30 | -- | -- | -- | OH 8, $Al_2O_3$8, $SiO_2$, 25, Cu 5, |
| **Manufacture** | 0.3 | -- | -- | 0.0 | 0.0 | -- | 33 | -- | -- | -- | 7.8 - 8.3 | |
| **Steel manufacture$** | -- | -- | -- | -- | -- | -- | 50 | -- | -- | -- | 6.9 – 7.0 | Temperature 75$^0$F, Cl 175, suspended matter 25, minimum organic content and corrosiveness |
| **Steel manufacture$** | -- | -- | -- | 0.1 | -- | -- | -- | -- | -- | -- | -- | Ca20, Mg10, $SO_4$20, $Cl_{20,}$ |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | $HCO_4$ 100 |
| **Synthetic rubber $** | -- | -- | -- | -- | -- | -- | 50 | -- | -- | -- | -- | Oxygen consumed 3.0, minimum organic content and corrosiveness |
| **Tanning** | 20 | 10-100 | -- | 0.2 | 0.2 | -- | 50-135 | 135 | -- | -- | -- | OH 8 |
| **Textiles** | | | | | | | | | | | | |
| **General** | 5 | 20 | -- | 0.25 | 0.25 | -- | -- | -- | -- | -- | -- | |
| **Dyeing** | 3 | 3-20 | -- | 0.25 | 0.25 | 200 | -- | -- | -- | -- | -- | Constant composition – residual alumina <0.5 |

*Data from Reference and unless otherwise specified
! Limit applied both iron alone and the sum of iron and manganese.
! Minimum value
$ Other limits fixed for oxygen consumed, dissolved oxygen, $Na_2SO_4$/ $Na_2CO_2$ ratio, $Al_2O_3$, $SiO_2$, $HCO_2$, $CO_2$ and OH

**Utilisation of Groundwater**

Groundwater is used from ancient times as a source of water supply. The source, however, gained tremendous popularity from 1960 onwards in India because of its easy availability in the vast Indo-gangetic plains, particularly with the advent of hybrid seeds in agriculture which essentially needs irrigation. Government of India increased its fund allocation for development of groundwater for crating development of groundwater for creating minor irrigation potential in all the states from VI Plan onwards. It is estimated that more than 70 m.ha. land can be irrigated by groundwater alone. In West Bengal, more than 60% of irrigated area is covered by groundwater projects. This spurt in groundwater development introduced new technologies, different types of Rig Machines for drilling etc. helps in establishing industries using groundwater as a main source of water supply.

Groundwater as a source of water supply has many advantages over surface water source like :-

a) It is natural reservoir where water is stored and can be used when required;
b) Loss through evaporation is minimal;
c) It can withstand vagaries of nature;
d) Chemical quality remains more or less constant;
e) It does not need an elaborate processing unit;
f) The project is cost effective, it can be installed where water is required.

The disadvantage are :

a) We cannot see the resource
b) We do not know when the water is overdrawn, unlike our bank account. When we overdraw from the bank account, immediately our accounts becomes red. When overdraft occurs in groundwater supply, no red water comes out. However, with proper management, groundwater project can run year after year without problem.

Utilisation of groundwater needs a suitable groundwater structures and a lifting device.

**Groundwater Structures :**

Design of groundwater structure will require knowledge of the geology of the area. Following are the different types of groundwater structures :

**A. Hard Rock / Consolidated rocks :**

a) Dug wells
b) Dug-cum-borewells
c) Bore wells

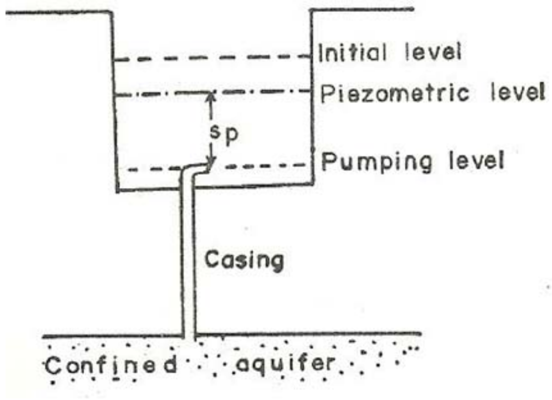
**a) Dug wells or open wells :**

Dug wells are excavated as pits or holes to reach the water table for extraction of ground water. These are the most ancient methods of drawal of groundwater and are recorded in all ancient civilization. Dug wells are mostly circular and varies in diameter from 1 meters to 10 meters Depth also ranges from a few meters to as much 100 meters depending upon the hydrogeological condition. Depth of the well should be decided in such a manner so that at least 0.8 meters water column exists during summer months to enable the foot valve of the pump to operate in case of mechanized lifting devices. There are records of rectangular shaped dug wells also, but circular design is preferred for stability. For the ease of construction for deep dugwells, telescopic diameter are also constructed.

In the hard rocks, the weathered zone is curbed by masonary or concrete rings. The hard rocks portion may remain naked. The masonary or concrete rings must have weep holes for ease of entry of water from the side.

**b) Dug-cum-bore wells :**

In many areas a borewell is drilled at the bottom of a dug well to increase the well yield. Groundwater in the fractured zone percolates through inclined fracture planes and create a confining layer and when the drilled hole at the bottom of the dugwell touches this layer, water will rush in  to the bottom of the dugwell thus increasing the well yield.




**Dug-cum-bored well**

**c) Borewells :**

**Borewells**

In hard rock area, conventional tubewells are not feasible. In 1980s, exploratory works were conducted in the shield areas of South India, particularly in Coimbatore, where water was detected at depth. Borewells were installed in such areas and with the use of small submersible pumps, significant discharge was obtained. In dugwells, continuous pumping is not possible, as the wells go dry after pumping for, say 1 hour. In case of borewells, continuous pumping is possible.

Borewells are 150 mm to 200 mm diameter bores, which have casing at the top (to prevent collapse of the hole in the weathered zone), but naked at the bottom. No filter or strainer is used at the bottom. Water is lifted by means of submersible pump. 2000 gph to 10000 gph water is available from such borewells. With the success of borewells as irrigation wells, irrigating about 2 ha area, a large number of borewells were sunk during the last two decades in Andhra Pradesh, Karnataka, Tamil Nadu. Orissa has also taken a decision to go for such wells on a moderate scale.

Experience of sinking large number of borewells in hard rock areas is not very encouraging. It is observed that in the borewell well field, water levels in the dugewells are continuously going down. Moreover, many borewells have already stopped functioning after being operated for few (2 to 5) years.

Borewells are welcome innovation in groundwater technology for meeting the domestic water supply. Most of the households in Andhra and Karnataka towns have provision of borwells. UNICEF / Govt. of India have installed large number of drinking water borewells operated by Special hand pumps (Mark-II, Mark-III) capable of drawing water from depth.

**B. Semi-consolidated / Sedimentary rocks**

In semi-consolidated rocks, dug wells are constructed. In favourable conditions. Tubewells are also feasible, particularly in sandstone and limestone areas.

**Tubewells**

Tubewells are the most prominent groundwater structures for drawal of groundwater. A tubewells has following important components :

1. Casing pipe
2. Housing pipe
3. Slotted pipe or filter
4. Bail plug
5. Lifting device - pumpsets

In normal nomenclature, we say deep tubewell and shallow tubewell, as if to indicate the depth and deeper the well, better is the discharge. It is really not true. Discharge depends upon availability of good aquifer. Tubewells are best defined in terms of prime mover and pumpset used for discharge. A shallow tubewell is a well which can be run by a prime mover upto 5 hp. Such tubewells are of low diameter upto 100 mm (4"). They do not have housing pipe. In contrast tubewells fitted with higher horsepower prime mover, generally 15 HP to 25 HP are heavy duty tubewells. The diameter of such tubewells are also higher, 200 mm and above. Casing pipe is the main tubewell pipe. Housing pipe is placed above the casing pipe and is so named because it houses the prime mover. Slotted pipe or filter is placed against the aquifer. Bail plug is placed at the bottom where sand from aquifer may accumulate.

## Utilization of Tubewells

### Shallow Tubewells

Utilization of tubewells will depend upon the need for which the tubewells are constructed. Most of the tubewells in India are used for irrigation, be it shallow tubewells or deep tubewells.

Shallow tubewells are constructed by individual farmers to irrigate their own command which is about 4 ha. having a prime mover varying from 3 to 5 hp. The prime movers are either diesel operatd or electrical operated. Discharge from such tubewell are about 10,000 gallons per hour which fall directly on a stilling basin from where water is diverted through irrigation channels, mostly 'kutcha' though lined channels are constructed by few farmers to avoid seepage losses. Diesel pumpsets can be carried by the individual farmers from one place to another and is convenient for the farmers having scattered land holdings. Electrical pumpsets on the other hand can not be removed from its place of installation. A pumphouse is a must for electrical pumpsets. They are normally preferred by the farmers because of cost effectiveness, but depends on he availability of power connection, permission from the State Electricity Boards. Taking power connection from a distant pole is costly and a cluster of tubewell with electrical pumpset was introduced early so that the distance between two tubewells was approximately 660 ft. or about 200m. In this case also irrigation water is conveyed by 'kutcha channels'.

Shallow tubewells are sometimes known as 'filter points' as in Uttar Pradesh where shallow tubewells are described as low duty tubewells with a pumphouse. In other places like Assam 'Bamboo tubewells" are in vougue where the casing pipe is of bamboo fitted with a specially designed bamboo filters. Life of such tubewells are often questioned because of fluctuation of the water table causing bamboo to rot. There are local variations of design as well when the top part may be replaced by GI pipe. In some parts of Tripura, autoflows exist where a small bamboo pipe, say about 6 meter long are inserted in the hole to get continuous flow of water.

### Pumpset Selection for Shallow Tubewells

The Selection of the proper pumpset to suit the agroclimatic conditions in an area is of prime importance. Field studies by various organizations have indicated that as of 1982 about 96% of the pumpsets installed in the field were defective in one way or the other. Therefore, maximum emphasis is to be laid on proper selection of pumpsets. NABARD carried out extensive studies on the efficiency of agricultural pumpset in 1980's and came out with certain guidelines which are narrated below :

### Pumpsets

An agricultural pumpset consists of the following components :

1. Pump
2. Prime Mover - Diesel Engine or Electric Motor
3. Suction Pipe / Delivery Pipes
4. Foot Valve
5. Other accessories like base plate, power panel, etc.

During selection of a pumpset all the above components should match each other. Given below are the important aspects that may be kept in view at the time of pumpset selection.

### Selection of Pump

The main points that are to be considered while selecting a pump are given below:

i. Discharge to be pumped
ii. Total Head
iii. Pump Efficiency
iv. Seasonal variation of Groundwater Level

At a given site and for a given command of the well the discharge that is required to be pumped out for a given cropping pattern is known. The head over which water is to be lifted from the well to the discharge point on the delivery side is also known. When a pump is operated the water level in the well falls down. This is known as Drawdown in the case of wells in alluvial formation. For wells in hard rock areas part of the water column is dewatered during the 4 to 6 hour operation of the pump. Therefore, in these cases the drawdown can be taken to be equal to half the dewatered water depth in the well.

For lifting groundwater from shallow wells mostly centrifugal pumps operating at about 1500 RPM are used. The selection criteria given below is applicable to the above type of pumps only.

**Suction limit of Centrifugal Pump**

The total head over which a pump is required to lift water comprises of suction head, the delivery head, the head loss due to friction in suction and delivery pipes and the velocity head. However, at the well site only the suction and delivery heads are measurable and are known. The other parameters have to be evaluated or furnished in the form of a matrix. The suction or delivery head is always referred to from the centerline of the pump known as axis. In the case of centrifugal pumps, the suction head is very important as beyond a certain value of static suction head the working of the pump may be adversely affected.

**Suction Head**

(i) It is known that the atmospheric pressure at sea level is about 10 metres of water head. For pumps operating above sea level the reduction is about 1.15 metres for every 1,000 metes altitude. It has, however, been observed in practice that if the total suction lift is greater than 6 to 7 meters, cavitations take place and the pump stops working. If the suction limit exceeds 9 meters centrifugal pumps are not suitable for use and in that case either vertical turbine pumps or submersible pumps should be used.

The practical limit of 6 to 7 meters of total suction head can be attributed to the various components as below. The maximum practical suction lift can be computed by the following equation. [NABARD, 1989]

$$Hs = Ha - Hf - Cs - NPSH - Fs$$

Where Hs = Max. practical suction lift in meters

Ha = Atmosphere pressure at water surface (10.33m at sea level)

Hf = Friction losses in pipe, foot valve etc. on suction side

Cs = Saturated vapour pressure of water in meters

NPSH= Net positive suction head of pump including losses at impeller and Velocity head in metres

Fs = Safety factor taken as 0.6m

Thus, in the equation, the practical limit at sea level can be estimated considering certain known factors like Hf as 5% of practical suction lift, Cs at a temp of 28$^{o}$C (Avg) is 0.42m and the available NPSH at 4m for good quality pumps. Thus say,

$$Hs = 10.33 - 0.05\ Hs - 0.42 - 4 - 0.6$$

$$\text{Therefore, } 1.05\ Hs = 10.33 - 5.02$$

$$Hs = \frac{5.31}{1.05} = 5m$$

If a pump installed at an altitude of more than 500m above mean sea level allowance be made at a rate of one meter pressure drop for every 1000m increase in altitude.

**Net Positive Suction Head (NPSH)**

Out from a manufacturing stage a pump needs as its inherent requirement a certain minimum suction head known as the Net Positive Suction Head. This is a function of the rate of pumping and design of the pump and has to be supplied by the manufacturers. The value of net positive suction head should be given by the manufacturer for a discharge at duty point where the efficiency is maximum. A comparatively low value of net positive suction head for the same value of head, discharge and RPM for different make of pumps indicates that a pump with the lowest net positive suction head is better as it can operate at greater suction head. From the above equation it would be seen that the static suction head (Hs) can be increased if the head loss due to friction, velocity head (Hv) and net positive suction head (NPSH) are low.

### Static Suction Head

As a thumb rule, the frictional losses in a centrifugal pumpset level in the well and the centerline of the pump. Evidently, its value should be less than 6 meters which is the practical limit of total head in a centrifugal pump.

As a thumb rule the frictional losses in a centrifugal pumpset are about 8% of the total head. It is also known that for good quality pumps the NPSH requirement is of the order of 10% of the head at first stage of the pump. Velocity on suction side is restricted to a maximum of 1.5 metres per second which gives a velocity head of 0.077 metres. Thus, in the equation for total head the following values can be substituted.

$$6 = Hs + Hf + Hv + NPSH$$

Where $Hf = 8\%$ of Hs,

$NPSH = 10\%$ of Hs

$Hv = 0.077$ metes or

$$H = \frac{5.923}{1.18} = 5 \text{ meters}$$

Thus, as a thumb rule the static suction head for a centrifugal pump should not exceed 4.5 to 5 metres. Otherwise cavitation may start and the working of the pump may become inefficient.

### Guidelines for selection of Centrifugal Pumps

The following are the main guidelines for selection of centrifugal pumps:- [NABARD, 1989]

1. The Horse power (HP) required for a pump can be calculated from the following formula :

$$HP = \frac{Q \times H}{75 \times e}$$

Where Q = Discharge in litres per second

H = Total head (including friction losses), in meters

E = Efficiency of the pump, in fraction.

2. The pump should be so selected as to have a maximum efficiency at the operating head likely to be obtained during major part of the year.

3. For the site condition of head and discharge the centrifugal pump should have the following minimum efficiency in the HP range given below :

**Table 6.9 : Minimum required efficiency of puymp [NABARD, 1989]**

| HP of the Pump | Minimum required efficiency(%) |
|---|---|
| Upto 2 | 50 |
| 2 to 4 | 55 |
| 4 to 10 | 60 |

4. On practical considerations the vertical distance between the lowered water level when the pump is working and the centerline of the pump should not be more than 4.5 m excluding friction losses.

5. The pump should have ISI Certification mark.

6. The pump which has a maximum efficiency for the head and discharge required at site should be selected from a group of ISI marked pumps available locally. This criteria should override other considerations.

7. Only those pumps for which genuine spare parts are readily available should be preferred.

8. Only those pumps for which after sales service is easily and effectively available should be preferred.

9. The pumps which have reputation of giving efficient and trouble free service should be preferred.

It is now mandatory that it should conform the specification laid under IS10804 : 1986.

## Selection of Electric Motor

The following are the main guidelines for selection of an electric motor :

1. The HP of the pump should also be the power output of the electric motor which is called HP of the motor. However, on practical considerations, the HP of the motor is always kept slightly more than what is theoretically required for the pump. Increase in motor HP over that of the pump should be provided at 20% extra over its HP.

2. The efficiency of the motor, as declared by the manufacturer, should not be less than the values given below :

**Table 6.10 :Minimum Efficiency of electric Motor (NABARD, 1989)**

| HP of Motor | Minimum Efficiency(%) |
|---|---|
| 2 | 3 |
| 2 | 74 |
| 3 | 77 |
| 5 and above | 80 |

The motor should have ISI Certification Mark.

3. Motors conforming to IS : 7538 are to be preferred over other types of ISI certified motors. Such motors can withstand voltage variation of + 6% to -15% of the rated voltage. This fairly covers the range of voltage fluctuation in rural power supply systems.

4. The motor which has a maximum efficiency for a given HP should be selected from a group of ISI marked motors. This criteria should override cost considerations.

5. Motors for which spare parts are easily available should be preferred.

6. Motors for which after sales service is easily available should be preferred.

7. Motors which have a reputation for giving efficient and trouble free service should be preferred.

8. An electric motor should always be provided with a starter and a capacitor matching the motor. In general, for motors below 3 HP a 1 KVAR capacitor should be used and for motors between 3 to 5 HP, a 2 KVAR rating capacitor should be used.

9. Although the HP of the motor should be calculated according to the requirements of discharge and head at site, the following table gives the recommended HP of the motor for different head and discharge ranges.

It is now mandatory that it should conform the specification laid under IS10804 : 1986.

**Table 6.11 : Matrix for HP of Motor for Various Head and Discharge Ranges**
(Source : NABARD, 1989)

| Discharge | | Total Head including Friction Losses Depression (m) | | | | |
|---|---|---|---|---|---|---|
| | | 8 | 10 | 12 | 14 | 16 |
| Lps | Igph | Required HP of Motor | | | | |
| 2.8 | 2,200 | 0.75 | 1.25 | 1.5 | 2.0 | 2.0 |
| 5.6 | 4,400 | 2.00 | 3.00 | 3.0 | 3.0 | 3.0 |
| 8.4 | 6,600 | 3.00 | 3.00 | 4.0 | 4.0 | 5.0 |
| 11.2 | 9,020 | 3.00 | 4.00 | 5.0 | 5.0 | 7.5 |
| 14.2 | 11,220 | 4.00 | 5.00 | 5.0 | 7.5 | 7.5 |

**Selection of Diesel Engine [NABARD, 1989]**

The performance of a diesel engine is judged by its fuel consumption for a specified unit of work and the period of its trouble free service. The fuel consumption of a diesel engine is expressed in terms of Special Fuel Consumption (SFC). The SFC is specified in terms of rate of diesel oil consumed in grams per hose power (HP) per hour running of the engine. It is also expressed in terms of rate of diesel oil consumed in gram per Kwh running of the engine. For converting weight into volume the specific gravity of diesel can be taken as 0.835. Majority of the engines used in agricultural pumpsets are in the horse power range of 3 to 5 at 1500 rpm. According to IS:1001 - 1981 the maximum specific fuel consumption of diesel engine used for agricultural operations are given below.

**Horse Power and Fuel Consumption**

Before selecting a diesel engine, the requirements of discharge (O) and head (H) over which he pump is required to operate are known. Also known is the efficiency of the pump. Thus the horse power of the engine can be calculated by the following equation.

$$\text{HP of engine} = \frac{\text{Q X H}}{\text{75 X Pump Efficiency (in \%)}}$$

Where Q is the discharge in lps and H the head in metres.

The HP of the selected engine should be 20% extra over the theoretically calculated Hp.

$$\text{P} = \frac{\text{1.2 X Q X H}}{\text{75 X Pump Efficiency}}$$

From the performance curve of the engine the SFC at this HP can be read for the operating rpm. The SFC of the selected engine should not be more than 198 grams/hp/hour. Knowing the annual running hours of an engine the consumption of diesel oil can be estimated from the following formula :

$$\text{Annual Fuel Consumption in litres} = \frac{\text{SFC X BHP X Hours Run/Year}}{\text{0.835 (Sp. Gr. Of fuel) x 100}}$$

**Selection of Diesel Engine**

The main considerations that should be kept in view while selecting a diesel engine are given below :

1. The HP of the diesel engine should be 20% more than the HP of the pump which it is required to run.

2. The specific fuel consumption (SFC) of the selected diesel engine should be as low as possible and it should not exceed 198 grams per hp per hour. The specific fuel consumption is specified in terms of the diesel oil consumed in grams per HP for one hour operation of the engine.

3. The diesel engine should have ISI Certification Mark.

4. The lubricating oil consumption of the diesel engine should be about 1 per cent by volume of diesel oil consumed by it. Engines having low lubricating oil consumption should be preferred.

5. Engines for which spare parts are easily available should be preferred.

6. Engines for which after sales service is easily available should be preferred.

7. Engines which have a reputation of giving efficient and long term trouble free service should be preferred.

It is now mandatory that it should conform the specification laid under IS10804 : 1986.

**Selection of Suction and Delivery Pipes**

Guidelines for selection of suction and delivery pipes were earlier based on IS:9694(Part I)-1980. These have now been revised by ISI vide their standard for a Complete Pumping System IS:10804 - 1986. The salient points of the same are given below.

1. Installation of a centrifugal pump should be such hat it is not required to operate beyond a maximum total suction head of 6m. If a pump is required to operate at an elevation higher than the sea level, the suction limit should be reduced by 1.5m for every 100m altitude above sea level.

2. The size of suction and delivery pipes should be equal and should be such that the Frictional Head Loss (hf) do not exceed 10% of the total equivalent length of the piping system upto the delivery point. Based upon this standard, Matrix for selection of agricultural pumpsets for various discharges and operating head is given in tables 4.1 & 4.2 foe Electric and Diesel pumpsets respectively.

**Selection of Foot Valve**

The size of foot valve is generally defined by the diameter of suction pipe to which it is attached.

i. ISI marked foot valves should be used.
ii. Size of the foot valve should be equal to the size of suction pipe and it should have a low coefficient of friction.

**Utilization of Deep Tubewells**

The heavy duty deep tubewells are designed to yield discharge of 1.5 cusecs to 2 cusecs i.e. 150 m3/hr to 200m3/hr and are fitted with vertical turbine or submersible pumpsets of 15 to 20 HP. Distribution of irrigation water to the farmers field on an equitable manner is a major concern for the planners. In the earlier days lined open channels were constructed to irrigate the farmers field. These were, however, beset with the problems of (a) less water to the tail enders due to transmission and evaporation losses and (b) very often they were broken while transporting crops by means of carts (c) miscreants were causing damage to the lined channels for diverting water to their own fields. To overcome such problems underground pipelines of 200mm diameter were laid with overground spouts which were irrigating about 8 ha per spout. In such cases also the tailenders suffer due to higher frictional losses with reduced discharge. The underground RCC pipes were replaced by cheaper PVC pipes which had less frictional losses, but this did not solve the problem of lesser discharge in the tail ends, because the pipes were laid in an open system. Over the years underground PVC pipes were laid in a closed system, so that the pressure at any point remains the same assuring same discharge at each spout point. This necessitates construction of an overhead tank where the water is pumped directly from the deep tubewells. The height of the overhead tank is such as to cover entire command area by gravitational forces. The norm for the length of the conveyance pipe 50m/ha command area of a deep tubewell will vary depending upon the crop pattern and discharge from the tubewells. In general command area is designed for Rabi season and varies between 40 ha to 50 ha.

### Casing Pipe

The diameter of the casing pipe depends upon the required discharge and local conditions. In general GI pipes and MS pipes are used. As indicated earlier, in localized areas, bamboo casing pipes are also used. but they are restricted for low discharge, PVC pipes for small discharge tubewells or shallow tubewells are common. PVC pipes are available as 4 kg, 8 kg, 16 kg classes, but 4 kg or 8 kg pipes are not suitable for hydrostatic pressure. Similarly for GI pipes, Class A, B, C are available depending upon the thickness and quality of the materials. GI pipes are used in shallow tubewells. Diameter of shallow tubewells vary from 40mm (hand tubewells) to 199mm depending upon the discharge. MS pipes are invariably used for heavy duty or deep tubewells having diameter of 200mm to 300mm. Sometimes fibre glass pipes are used to prevent corrosion particularly in the saline belt.

### Housing Pipe

Housing pipe is so called because it houses the pump assembly and is at the upper part of the tubewell. Housing pipes are essential for the heavy duty or deep tubewells, but in shallow tubewells they are not required, particularly when fitted with centrifugal pumpsets. In case the water table is deeper than the suction limit of the centrifugal pumpsets, shallow tubewells need a housing pipe, say 150mm pipe against the casing or blank pipe of 100mm to enable installation of submersible pumpsets. Essentially, the diameter of the housing pipe will depend upon the bowl diameter of the pumpsets to be installed, be it vertical turbine or submersible. The length of the housing pipe will depend upon the pumping level of the tubewell. The pumping level should not go beyond the housing pipe depth to prevent cavitation. The length of the housing pipe may be decided based on the groundwater condition and the anticipated discharge. Accordingly, length of the housing pipe = Depth of the static water level + maximum anticipated draw down for the operational discharge + seasonal water level fluctuation + water level decline due to drought + additional draw down due to reduced well efficiency in course of time + interference effect + pump intake.

**Slotted pipe or Filter or Screens**

Slotted pipes or Filters of Screens are placed against the aquifers to be tapped. Important parameters for the slotted pipes or filters are its length, opening size and open area. Length of the screens will depend upon the required discharge, thickness of the aquifer, draw down. Thickness of the screen may be calculated as : [Karanth, 2004]

$$\text{Thickness of screen size} = \frac{\text{Discharge}}{\text{Yield factor} \times \text{draw down}}$$

$$\text{When yield factor} = \frac{\text{Specific capacity of the well}}{\text{Thickness of the aquifer}}$$

Screen opening size will depend upon the aquifer material. In general the size of the opening is such as to retain 30 to 60 per cent of the aquifer materials (d70 to d40 size), enabling finer particles to be removed and the retained particles creates a natural strainer wall increasing the permeability around the well. In a heterogenous aquifer the screen size may be increased so as to retain 30 to 40 percent of the materials (d70 to d40 size), but increasing the size more may increase the entrance velocity thereby allowing more materials to pass through the screen affecting life of the well. Screen open area should be such as to keep the entrance velocity as an optimum value which may vary depending upon the quality of the aquifer. An approximate value of 3 cm/sec of entrance velocity is considered safe while designing the well screen. Screen open area may vary from 8 to 10 percent of the well screen.

Slotted MS pipes are normally used for well construction for economic consideration. However, when groundwater is corrosive it is better to use screens of stainless steel, monet (70% nickel, 30% copper), PVC, everdue (96%, 3% silicon, 1%# manganese). This well increase the screen life.

In shallow tubewells various types of screen materials are used : agricultural strainer (GI pipe with iron wiremesh), coir filter, bamboo filter, PVC filter etc.).

**Cavity Boring**

Cavity boring is neither a tubewell nor a dugwell. These are constructed in areas where the upper layer is an impermeable layer overlying an aquifer bed below. A hole is pierced through the impermeable layer to tap the aquifer below. A high powered pump, say 7.5 hp is used to develop the aquifer, when the cavity is formed. Initially, sand will be pumped out creating a cavity below the impermeable layer. When there will be no more sand pumping , pumping of 7.5 hp pumpset is stopped. A tube or a blank pipe is then inserted to the cavity without any strainer. Cavity boring is now fitted with 5 hp pumpsets and are operated mainly for irrigating about 2 ha to 3 ha area. Life of such cavity boring is rather short due to collapse of the cavity due to excessive pumping.

**Construction of tubewell**

Methods of construction of tubewell will depend upon the nature of geological formations, requirements of discharge from the tubewells. Hand tubewells having diametwere of 3 cm to 4 cm and depth upto 15 metre to 20 metre for domestic water supply are constructed in an unconsolidated formations by auger drilling method, while deep tubewell having diameter of 20 cm to 350 cm are constructed by heavy drilling rigs which can pierce through more than 500 metres. Principle of drilling is either rotary or percussion. Shallow tubewells which are sunk in large numbers in the alluvial terrain in India follow jet method whereby a high velocity jet of water are forced from a drill bit to cut a hole in the consolidated sediments. Percussion and rotary actions are imparted to the bit by raising and dropping and by turning the jetting pipe. An outer casing is inserted to prevent caving in and for circulation of the drilling mud.

Drilling Rigs are deployed in construction of heavy duty or deep tubewells having diameter varying from 30 cm to 50 cm. Depth of drilling may be 100m to 500m or more.

There are three major types of Drilling Rig Machines depending upon the method of drilling :

1) Percussion or Cable Tool Method
2) Hydraulic Rotary Method which may be direct circulation or reverse circulation.
3) Down-the-hole or DTH method.

The first two methods are used for mainly unconsolidated formations. Percussion methods are used when the unconsolidated sediments are mixed with pebbles or boulders. In case of hydraulic direct rotary method the rate of drilling is slow, but good for exploratory drilling because it provides good formation sampling. Hydraulic reverse rotary methods are faster and good for production wells in already proven well fields. DTH method is used for hard rock areas, mainly for the construction of bore wells.

The annular space between the tubewell and the drilled diameter are filled up with suitable gravel. Gravels should be well rounded, homogenous having uniformity co-efficient less than 2.5. A gravel packing increases the well stability, prevents finer particles to enter through the screen, reduces the entrance velocity thus increasing the well effectiveness and increases the effective well diameter.

After the gravel packing the well is developed for making water sand free (less than 20 ppm). Various methods are used for well development like over pumping, surging, use of compressed air, back washing, high velocity jetting and treating with chemicals.

**Spacing of Wells**

Well spacing is a very important factor in planning development of groundwater resources in an area. There are two important aspects of spacing. One is the technical and the other economical aspect. Under the technical requirements spacing between two adjacent wells should be such that simultaneous pumping of the two do not adversely affect the discharge of either of them. In pumped wells there is an area around the well underneath which aquifers feed the water requirements of a well. Thus, a cone of influence is formed around a pumped well which becomes devoid of groundwater and provides the necessary differential head to make water move into the well. The maximum spread of this cone of influence is at the groundwater level and the distance up to its maximum spread from the center of the well is known as the radius of Influence.

The radius of influence of a pumped well mainly depends upon the properties of aquifer, discharge being pumped from the well and duration of pumpage. It is greater for alluvial formations compared to hard rock areas. For a given set of conditions the radius of influence of a well can be reasonably estimated by pump tests.

To determine the radius of influence of a well and hence the requirements of spacing on technical grounds, pump tests for a minimum period of 12 hours duration for shallow tubewells tapping the top unconfined aquifers are necessary. This period of pumping tests adequately covers the duration of continuous running of any such well during an year. In case of dug wells, the value of radius of influence to evaluate spacing may be determined by carrying out short duration pump tests for a minimum period of 3 hours duration. It is desirable to carry out longer duration pump tests on these wells because their pumpage period sometimes extends to even 6 hours.

Thus, the spacing of different type of groundwater pumpage works should be based upon the following studies.

1. The spacing should be 2 times the radius of influence estimated on the basis of pump tests for various types of pumpage works.

2. The spacing should be such that the pumpage works are economically viable. This implies that if a particular type of groundwater pumpage unit can irrigate a certain area, another unit should not be put in its irrigated

command so as to avoid over capitalization on minor irrigation structures. Based upon the present irrigated area concept the economic viability of the various type of minor irrigation works require the following minimum spacings.

**Minimum Spacings Between Pumpage Works (Economic Aspects only) (Source : NABARD, 1989)**

| Type of Unit | Irrigated Area (ha) | Spacing (m) Sq.plot | Spacing (m) Circular | Recommended spacing (m) plot |
|---|---|---|---|---|
| 2 | 3 | 4 | 5 | 6 |
| Alluvial Areas | | | | |
| 1. Dug well | 1 | 100 | 112 | 100 |
| 2. Dug well with pumpset | 2 | 140 | 160 | 150 |
| 3. Shallow tubewell | 3 | 170 | 200 | 180 |
| 4. Deep tubewell | 40 | 625 | 700 | 650 |
| Consolidated Rocks | | | | |
| 1. Dug well with pumpset | 2 | 140 | 160 | 150 |
| 2. Medium Duty Tubewell | 8 | 300 | 300 | 280 |

Different districts/talukas/blocks have different hydrological, agro-climatic and economic conditions and would require different spacings. From technical point of view the spacing can only be evaluated by actually carrying out pump tests in the field but the adopted spacing in an area should be higher of the two as obtained by pump test results or as justified on economic considerations. It is, therefore, suggested that the State Groundwater Organization should carry out pump tests selecting similar geohydrological areas and then extend the programme to cover each block.

### Density and Other Criteria for Spacing

Sometimes the density concept for spacing is also advocated. Under this concept a fixed number of wells are cleared in an area so that a particular level of density of wells viz. their number per unit area is required to be maintained.

This criteria has little relevance in so far as the concept of well interference and spacing is considered. This is on account of the fact that keeping a certain well density, spacing between one pair of adjacent wells can be variable. The other approximate method for evaluating well spacing viz. The one based on water requirement of crops, command area of a well, cropping intensity and groundwater recharge in an area need not be applied. Pump tests give the best and most reliable values for spacing subject to their governance by economic considerations.

**Normal Rainfall Criteria for Spacing**

In certain blocks the State Groundwater Directorate may not be in a position to carry out pump tests for deciding the spacing of wells. In such cases normal rainfall in an area can be taken as a basis for deciding this spacing. The well spacing for different type of minor irrigation works based upon the normal rainfall concept is recommended as below : [NABARD, 1989]

| | **Annual Normal Rainfall (mm)** | | | |
|---|---|---|---|---|
| | **Upto 500** | **500 - 1000** | **1000 - 1500** | **Over 1500** |
| **Hard Rock Areas** | Well Spacing in m | | | |
| Dug wells | 180 | 150 | 110 | 100 |
| Dug wells with pumpset | 250 | 200 | 150 | 100 |
| **Alluvial Areas** | | | | |
| Shallow tubewells | 275 | 225 | 175 | 150 |
| Deep tubewells | 1000 | 800 | 600 | 500 |
| Tubewells in Sedimentary Rocks | | | | |
| Medium Tubewells | 700 | 700 | 700 | 700 |

(Source : NABARD, 1989)

The above spacing should be modified as soon as the pump tests are completed in an area.

# CHAPTER - VII

# ENVIRONMENT AND WATER POLLUTION

Water and environment almost go hand in hand. Polluted water invariably affects the environment and a polluted environment always pollutes water. It is necessary to understand the role played by some frequently occurring elements on earth's surface which have direct bearing on the pollution of environment. Carbon and nitrogen are two such elements, the cycles of which is related to earth is given below :

After hydrogen (H), helium (He), oxygen (O) and carbon (c) is the most abundant elements in the universe. Tens of billions of tons of carbon are recycled every year by natural processes. Diagram illustrate exchange of carbon between vegetation and soil, water and plants. Here's how it works in plants :

- Plants absorb carbon dioxide ($CO_2$). Through the action of photosynthesis, plants harvest the carbon contained in this molecule to produce sugar for foods.

- Excess sugars are stored as cellulose in the plants cell walls, forming stems and stalks.

- Much of the carbon stays captive for the life of the plant. When the plant dies, decomposition releases all the plants nutrients into the soil.

- Carbon returns to the soil and is free to be taken up again by other organisms.

Carbon is stored and released not only in plants but in atmosphere, forests, soils, oceans and fuels as well. The action of burning wood or coal, for example, releases carbon into the atmosphere. Ideally this would not be a problem, because the excess carbon - in the form of carbon dioxide - would be captured by the world's forests. Deforestation and increases in carbon dioxide emissions from the burning of fossil fuels and manufacturing of cement from limestone have led to an excess of carbon dioxide in the atmosphere, a situation recognized as the chief culprit behind global warming.

**Nitrogen Cycle :** Earth's atmosphere is made up of 80 per cent nitrogen gas. Humans and other animals need nitrogen to produce healthy cells. Plants need the element as well. But living organisms cannot always use nitrogen in its natural form. So nature has developed ways to alter nitrogen so it can be more readily absorbed by living things.

- Soil bacteria harvest nitrogen out of the air and convert it to nitrates, a chemical form that is more readily absorbed by plants.
- During storms, lightening causes nitrogen to bond with rain water, and it falls to the earth in nitrate form.

Water is an universal solvent. While flowing over the surface or enters groundwater body, it carries dissolved materials along with it. While in some areas it carries useful materials, it also carries in dissolved state toxic materials harmful to the environment and human habitation. The problem becomes acute when discharge of effluents from the factories fall in nearby streams without treatment. The problem is accentuated by the absence of proper sanitation in rural areas. It is estimated that only 20% waste water in Class I and 2% waste water in Class II cities are treated, a little more than 3% of rural population has proper sanitary services and 115 million people do not have any toilets, more than 40% of large and medium scale industries and over 2 million small scale industries pollute water.

**Water Pollutants**

**Oxygen - Demanding wastes :**

The amount of dissolved oxygen (DO) in water ranges from 8 to 15 mg/l depending upon the temperature and salinity of water. Dissolved oxygen is required for aquatic life like fishes and varies from 5 - 8 mg/l. For species like carp requirement may be as low as 3 mg/l. However, below this level all aquatic life will die.

Oxygen demanding wastes like biodegradable organic substances contaminated in municipal wastes or effluents from certain industries like food processing and paper industries reduce the dissolved oxygen in water threatening the aquatic life.

**Biological Oxygen Demand (BOD) :**

Bio-degradable organic matter when contaminated with surface water (rivers, stream, ponds, lakes etc.) existing micro organisms feed on such matters breaking into simple organic and inorganic substances. In an aerobic environment that is, in the presence of oxygen, the organic and inorganic substance produced are non-objectionable stable products like sulfate, carbon-dioxide ($CO_2$), orthophosphate ($PO_4$) etc., but in case of anaerobic condition, compounds like methane, hydrogen sulphide etc. are produced. Thus it is always preferable to have aerobic condition for biodegradable effluents. The amount of oxygen required by micro-organism to oxidize organic wastes is know as Biological Oxygen Demand i.e. BOD and is generally expressed as milligram of oxygen required in one litre (mg/litre) or equivalent $g/m^3$.

**Chemical Oxygen Demand (COD) :**

This is the amount of oxygen required to chemically oxidize the wastes.

COD is an important component in waste water before the entire process of treatment is taken up and is determined in the laboratory. Since the entire process of oxidation may require a very long time, may be few weeks, COD is determined for a period of 5-day period for all practical purposes.

The theoretical oxygen demand is the amount of oxygen required to completely oxidize a particular organic substance, as calculated from stoichiometric equation. This calculation provides for chemical oxygen demand for a single pollutant having a known chemical formula. The result will be always higher than the measured BOD because actual biodegradation does not oxidize all the carbon to $CO_2$. Chemical oxygen test, however, is quicker and can be achieved within few hours. COD test may be conducted at certain urgent situation to know the ultimate BOD.

**Nitrification :**

Protein is essential for life and nitrogen is an essential element of protein. When a living thing dies, the decomposition stakes place and the complex nitrogenous molecules is converted to ammonia by bacteria and fungi. In an aerobic conditions, nitrite bacteria (Nitrosomonas) convert ammonia to nitrite and nitrite bacteria (Nitrobacter) convert nitrate to nitrite. This process is called nitrification. Thus :

$$2\ NH_3 + 3O_2 \xrightarrow[\text{Nitrobacter}]{\text{Nitrosomonas}} 2\ NO_2 + 2H^+ + 2H_2O$$

$$2\ NO_2 + O_2 \longrightarrow 2\ NO_3$$

Thus nitrification process also demands some oxygen and is known as Nitrogenous Oxygen Demand (NBOD) as against Carbonaceous Oxygen Demand (CBOD). Nitrogen demand of oxygen by the decomposed organic substances may be necessary, may be after more than 8 days, thus do not interfere with the five day determination of BOD or BODS. The total concentration of nitrogen and ammonia in waste water is known as total Kjeldahl nitrogen or TKN. Generally ultimate NBOD = 4.6 X TKN.

**Pathogens**

Pathogens are disease producing organisms that grow and multiply within the host i.e. waste water, like (i) bacteria which produce cholera, bacillary dysentery, typhoid etc., (ii) Viruses which causes hepatitis, (iii) protozoa, causing dysentery, giardiasis etc., (iv) indirectly it can cause malaria, skin diseases etc, schistosomiasis through water contact.

**Nutrients :**

Chemicals such as Carbon, nitrogen, phosphorus, sulphur, calcium, iron, potassium, manganese, boron and cobalt are essential for growth of living things and are termed nutrients. Such nutrients when present help growth of aquatic plants such as hyacinth and are pollutants because excessive growth of aquatic plants in drinking water source, or water used for recreational purposes. Nutrient enrichment can help growth of algae in abundance and when the algae die and decompose removes oxygen and BOD level may go down below the sustainable level of the aquatic life. Phosphorus and nitrogen required in small quantities for aquatic growth and are known as limiting nutrient. Municipal wastes contain nitrogen and phosphorus. If they can be removed by treatment of municipal wastes, aquatic growth can be prevented.

**Salts :**

Water normally accumulates salts or dissolved solid when it flows through soils and rocks. The cations are generally sodium, calcium, magnesium etc. and anious are chloride, sulfate, bicarbonate etc. Thus, total dissolved solids are indicators of salinity in different types of water. For example fresh water has less than 1500 mg/l of TDS (total dissolved solids), brackish water may have TDS up to 5000 mg/l and saline water are those with concentration above 5000 mg/l of TDS. Sea water contain 30,000 - 34,000 mg/l TDS.

There are recommended values of salinity and other chemical constituents for different uses like drinking water, irrigation, industrial purposes. Tables show the recommended standards for drinking water and irrigation water.

**Table 7.1 : Standards for physical and chemical quality of drinking water :**

| Quality | W H O International Standards, 1971 | | Indian Standards Institution, 1983 | |
|---|---|---|---|---|
| | Highest desirable | Maximum permissible | Highest desirable | Maximum permissible |
| 1 | 2 | 3 | 4 | 5 |
| ***Physical*** | | | | |
| Turbidity (JTU units) | 5 | 25 | 10 | 25 |
| Colour, Hazen-units (on platinum cobalt scale) | 5 | 50 | 5 | 50 |
| Taste and odour | Unobjectionable | -- | -- | Unobjectionable |
| ***Chemical*** | | | | |
| pH | 7.0-8.5 | 6.5-9.2 | 6.5-8.5 | 6.5-9.2 |
| Total dissolved solids (mg/l) | 500 | 1500 | 500 | 1500 |
| Total hardness as $CaCO_8$ (mg/l) | 100 | 500 | 300 | 600 |
| Calcium (mg/l) | 75 | 200 | 75 | 200 |
| Magnesium (mg/l) | <30 if $SO_4$ is 250mg/l up to 150 mg/l if $SO_4$ is less than 250 mg/l | 150 | 30 | 100 |
| Iron (as Fe) (mg/l) | 0.05 | 1.5 | 0.3 | 1.0 |
| 1 | 2 | 3 | 4 | 5 |
| Manganese (as Mn) (mg/l) | 0.1 | 1.0 | 0.1 | 0.5 |
| Copper (as Cu)(mg/l) | 0.05 | 1.5 | 0.05 | 1.5 |
| Zinc (as Zn) (mg/l) | 5.0 | 15.0 | 5.0 | 15.0 |
| Chloride (mg/l) | 200 | 600 | 250 | 1000 |
| Sulphate (mg/l) | 200 | 400 | 150 | Upto 400 if Mg does not exceed 30 mg/l |
| Phenolic substances (as phenol) (mg/l) | 0.001 | 0.002 | 0.001 | 0.002 |
| Fluorides (mg/l) | 0.6-0.9 | 0.8-1.78 | 0.6-1.2 | 1.5 |
| Nitrates (mg/l) | - | 45 & | 45 | No relaxation |
| ***Toxic constituents*** | | | | |
| *Arsenic (mg/l) | - | 0.05 | 0.05 | -do- |
| *Mercury (mg/l) | - | 0.001 | 0.001 | -do- |
| *Cadmium (mg/l) | - | 0.01 | 0.01 | -do- |
| *Chromium (hexavalent) (mg/l) | - | - | 0.05 | -do- |
| *Cynide (as CN) (mg/l) | - | 0.05 | 0.05 | -do- |
| *Lead (mg/l) | - | 0.1 | 0.1 | -do- |
| *Selenium (mg/l) | - | 0.01 | 0.01 | -do- |
| ***Radioactivity*** | | | | |
| Gross alfa-emitters ($P^{c}_{i}$/l) | - | 3 | - | - |
| Gross beta emitters ($P^{c}_{i}$/l | - | 30 | - | - |

Cols 2-3 : World Health Organisation, 1971, International Standards for Drinking Water.

Cols 4-5 : Indian Standards Institution, 1983 - Indian Standard Specification for Drinking Water, IS 10500.

$ : The limit applicable should be determined by a consideration of the annual average of maximum daily air temperatures. The upper limits vary from 0.8 mg/l for a temperature of 26.30 to 32.60 C to 1.7 mg/l for a temperature range of 10 to 120 C.

& : In areas where the nitrate concentration is known to be in excess of the stated concentration, the public should be warned of the potential danger of using the water for infant feeding.

* : The concentrations listed under columns 3 and 5, against toxic constituents, are mandatory upper limits and should not be exceeded.

**Heavy Metals :**

In chemical terminology there is no specific mention about metals which are heavy or light. In general we define heavy metals having specific gravity between 4 to 5 and are generally toxic. Such heavy metals include aluminium, arsenic, beryllium, bismuth, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, strontium, thallium, tin, titanium and zinc. Chromium and nickel, though essential component of our food nutrients, may show adverse effect if taken in excess.

Some heavy metals are inhaled and many of them are ingested. Metal salts of lead, tin and cadmium are poorly absorbed, but salts of arsenic and thallium are completely absorbed. Toxic metals are generally filtered through our kidney containing vast complex excretory units called nephrons and chemicals that are toxic to the kidneys are known as nephrotoxins, like cadmium, lead and mercury.

**Thermal Pollution :**

Thermal pollution is caused by the release of hot water into nearby lake/ponds. Enormous amount of cool water is required for the cooling of condensers in steam-electrically heated thermal plant. Cool water is thereby heated and when released increase the temperature of the surface water lake/pond. While some of the marine life like fish can survive or even promote its growth within certain limits, while other may die.

**Pesticides :**

Pesticides are used to kill/destroy some organisms like insecticides, herbicides, rodenticides and fungicides that are considered to hindrance to human lives. For example, when malaria became epidemic through mosquitos, DDT or dichlorodiphenyltrichroethane, was used to kill mosquitos and save human lives from the deadly disease like malaria. When it was proved though DDT helps in removing malaria it affects food chain of human and it was banned ultimately. Synthetic organic insecticides are of three types : Organochlorines, organophosphates and carbamates.

Other than DDT other organochlorines are methoxychlor, chlordane, heptachlor, asdrin, dieldrin, endrin, ensosulphur and kepone.

Oxygenophosphates like parathion, malathion, diasion, TEPP (tetraethyl pyrophosphate) and dimethoate are effective against wide range of insects and are not persistent like DDT to effect the food chain. However, they are very toxic and must be carefully handled to avoid skin rash, tendency of vomiting and convulsion if inhaled.

**Volatile Organic Compounds (VOC) :**

Volatile organic compounds or VOCs are used for industrial uses or even for domestic uses like detergents and because of its volatility, may be found in traces in surface water, but while flowing underground their concentration may increase many times and may be very harmful as they are suspected to carcinogens or mutagens.

VOCs are toxic and their presence in drinking water may be very harmful. Vinyl chlorine is most toxic and are generally used in polyvinyl chloride resins. Triochloroethelene (TCE) is a solvent that was commonly used for cleaning electronic parts, as a medium of heat transfer and in the production of chlorofluro carbons. Carbon tetrachloride, used for household cleaning and is very toxic if ingested, only a few millimeter can cause death.

### Water Treatment Systems for Drinking Water

Water treatment system for drinking water will depend upon the source of water. Surface water treatment system seldom needs softening of hard water whereas ground water invariably require softening, since the hardness level is often more than 1000 mg/l. A simple surface water treatment system consists of the following :

1. Screening : to remove large floating and suspended solids.
2. Mixing : The water with some chemicals so that small particles may coagulate the suspended solids which may settle.
3. Flocculation : is the process when water mixes gently with the floculant.
4. Sedimentation : When the velocity of flow is reduced, the flocs settles down as sediment.
5. Sludge processing is the process whereby the settled solids and liquids are dewatered and disposed of.
6. Disinfection of the liquid is then effected to make water free of harmful objects for drinking.
7. Softening process is used when the source is ground water to remove hardness of water.

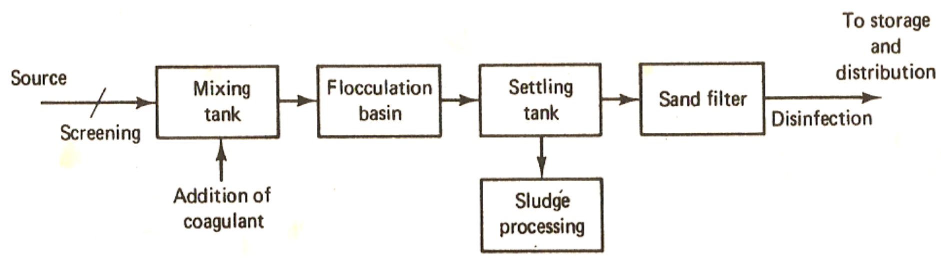



**Fig.7.1 : Schematic flow of a typical water treatment plant for surface water (After Gilbert, 1955)**

**Coagulation and Flocculation :**

Coagulation is a chemical process by which small dispersed colloidal particles (size range 0.001 - 1 μm) adhere to each other. Most common coagulant is alum [$Al_2$ $(SO4)_3$. $18H_2O$), though $Fecl_3$, FeSO4 and other coagulants like polyelectrolytes can also be used.

Coagulants are mixed in raw water in a chamber where there are rapidly rotating paddles to mix the chemicals. Such rapid mixing may need about a minute. This water is then passed into another chamber where gentle agitation allows floc formation. This process may need about an hour.

**Sedimentation and filtration :**

After flocculation, the velocity of the water is greatly reduced in the sedimentation basin or classifier. The sedimentation tank is a large circular or rectangular concrete tank where the water may be retained from 1 to 10 hours for settling the solids to the bottom. The solids are regularly removed by mechanical means or scrappers as sludge, by temporarily shutting the operation. The effluent from the tank is then filtered through rapid sand filter which consists of sieved sand on the top of graded gravels. The pore space between the grains of sand are greater than floc-particles to be removed. Adsorption, continued flocculation and sedimentation also takes place during flow of water through the sedimentation bed. When the pore spaces are entirely clogged, the operation is shut and the clogging is cleaned by forcing water backwards through the sand for 10 to 15 minutes.

**Disinfection :**

During the operation of flocculation, coagulation and sedimentation the water becomes clear and all but few bacteria are removed. Disinfection process, generally known as chlorination, uses chlorine gas ($Cl_2$), Sodium hypochlorite $(NaOCl)_2$. Though chlorination is effective against bacteria, its effectiveness on viruses like giardia lambia is doubtful. In case of presence of suspect giardia it is necessary to operate the complete system from flocculation, sedimentation and disinfection.

**Wastewater Treatment :**

Waste water derived from the municipalities are mostly water, say 99.9 per cent while the remaining may be from industrial facilities in the cities. The composition of such waste water may vary from cities to cities and various chemical reaction may occur during the flow of water. Gilbert (1995) cited the typical range of compositions of untreated domestic waste water as given below :

**Range of composition of untreated domestic waste water (After Gilbert, 1955)**

| Constituent | Abbreviation | Concentration (mg / L) |
|---|---|---|
| 5-day biochemical oxygen demand | BOD5 | 100 - 300 |
| Chemical oxygen demand | COD | 250 - 1000 |
| Total dissolved solids | TDS | 200 - 1000 |
| Suspended solids | SS | 100 - 350 |
| Total Kjeldahl nitrogen | TKN | 20 - 80 |
| Total Phosphorous as P | TP | 5 - 20 |

Total dissolved solids is sum of TDS and SS. The suspended solids having a pore size of 1 - 2/μm can be removed only by membrane filter.

Wastewater treatment can be processed in different stage like primary, secondary and advanced treatment depending upon the requirement. Primary treatment consists of (a) screening (b) grilling in grit chamber (c) setting tank or sedimentation basis or clarifier (d) sludge treatment and (e) disinfection.

Screening are parallel steel bars placed about 2 - 7 cm apart, which is again screened by a small wire mesh. Communiter then breaks the bigger particles into smaller pieces and allows them to pass to grit chamber where the heavy particles settle down. Heavy particles thus settled are disposed of and the water enter the next chamber or sedimentation basin where water is kept for 2 to 3 hours without any flow. Suspended solids then settles down. The sludge from the bottom is then removed. Primary process removes about 50 - 65 per cent suspended solids and 25 - 35 per cent BOD. Water is then chlorinated in the next chamber to destroy bacteria.

**Secondary (Biological) Treatment :**

Secondary treatment is required for removal of BOD because primary treatment can not remove BOD completely. Biological treatment takes advantage of micro organism to convert wastes into stabilized, low energy compound. Secondary treatment like trickling, filter and activated sludge process are used after primary treatment of water. Oxidation ponds method can be used directly to the raw sewage water.

**Trickling Filters & Rotating Biological Contractor :**

In trickle filter system, a rotating arm sprinkles waste water (after primary treatment) over a rock or gravel bed, the pore spaces which are filled with biological slime containing bacteria or algaes fungi, worms, snails, insects which helps in removal of BOD. In case of rotating disc which consists of about 3 - 5m diameter plastic discs which rotates around a horizontal axis. The biomers films that grows on the surface of the disc which moves out of water and air as the disc rotates. While submerged in water the organism is adsorbed and while out absorbs oxygen.

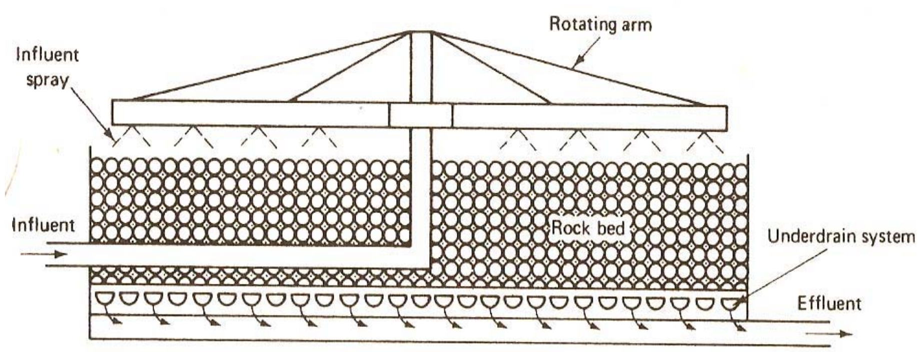



**Fig. 7.2 : Sketch of the cross section of a trickling filter (After Gilbert, 1955)**

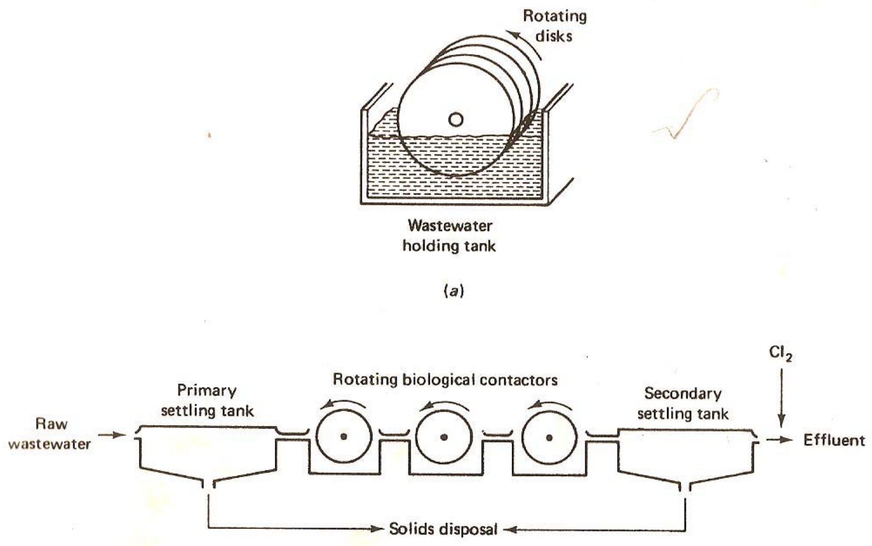



**Fig. 7.3 : Rotating biological contactor cross section and treatment system (a) RBC cross section; (b) RBC treatment system**
**(After Gilbert, 1955)**

## Sludge Tratement :

Sludge treatment is a very important step in the waste water treatment process, at least from the environmental point of view. Sludge may be as high as 2% of volume of water treated and huge amount of sludge is removed from the waste water treatment plants. Since sludge contains mostly organic compounds, they are treated in an anaerobic condition in two stages (a) to convert organic compounds to organic acids by using acid forming bacteria and (b) to methane by using methane forming bacteria. The second process is very sensitive to change of pH which is caused by organic acids produced and when the pH comes down around 2, the product needs to be treated with huge amount of lime. Methane gas produced during the second stage of operation is collected and used as a source of energy. Stabilised wastes contain mostly water and are dewatered in a pond by evaporation and seepage. The wastes after drying may be used as land fill.

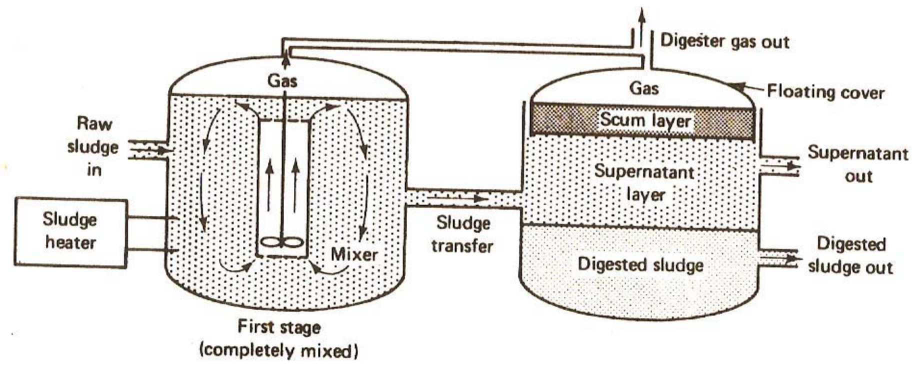



**Fig. 7.4 : Schematic diagram of a two-stage anaerobic digester (After Gilbert, 1955)**

## Oxidation Ponds :

Oxidation Ponds are simple ponds having 1m - 2m deep where partially treated or raw water are exposed to aerobic conditions for reaction with micro organisms. However, in case of deeper ponds, anaerobic condition may prevail where the organic wastes reacts with anaerobic bacteria and releases $CO_2$, methane etc. as shown in Figure. Oxidation Ponds requires large areas depending upon the volume of raw water and may be used in areas where adequate land is available.

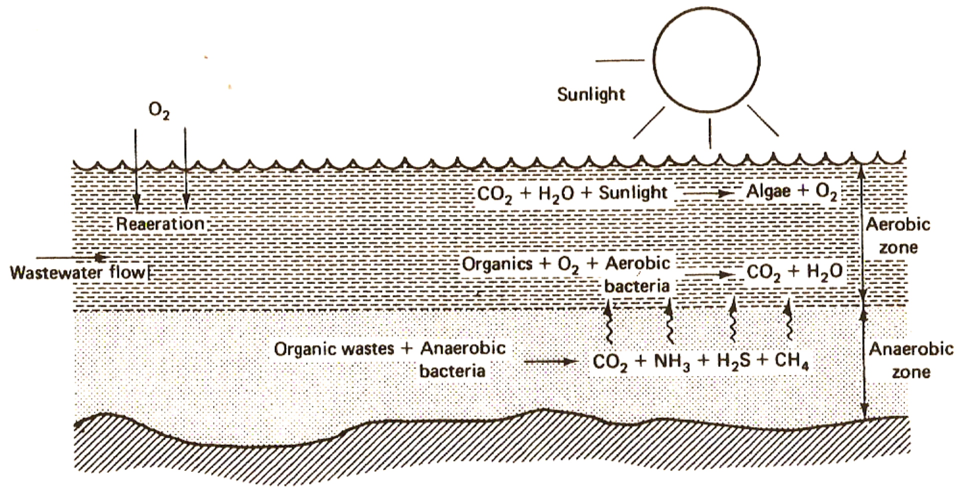



**Fig. 7.5 : Schematic diagram of an oxidation pond (After Gilbert, 1955)**

## Advanced Wastewater Treatment :

Advanced wastewater treatment is required to remove hazardous Nitrogen and Phosphorous. Most of the widely used processes in the present day are Reverse Osmosis (RO), Ion Exchange and Redox method, they are discussed in brief :

### Reverse Osmosis (RO) :

Reverse osmosis devices use pressure to force contaminated water against a semi permeable membrane, which acts as a filter, allowing the water to be pushed through its pores, but restricting the passage of larger molecules that are removed.

### Ion Exchange :

Ion exchange is a device wherein toxic ions in the waste water can be removed by using a special resin which reacts with toxic ion in the solution like heavy metals and are removed.

### Reduction - Oxidation (Redox) :

Redox signifies a chemical process whereby reduction and oxidation takes place in the same reaction. For example hexavalent chromium which is toxic can be converted to trivalent chromium following the way when sulphur dioxide ($SO_2$) is used as a reducing agent. This process is used for chromium plating.

$$3SO_2 + 3H_2O \rightarrow 3H_2SO_3$$
$$2CrO_3 + 3H_2SO_3 \rightarrow Cr_2(SO_4)_3 + 3H_2O$$

Wastes that include chromium (hexavalent), mercury, lead, silver can be removed by redox method. Most organics, cynamides, bezene, phenol, arsenic, iron and manganese can also be removed from the waste water.

# CHAPTER - VIII

# SECTORAL DEMAND OF WATER AND CHALLENGES AHEAD

No other natural resources were as badly managed as water in the last few decades, at least in Indian context. Water is a scarce natural resource and critical input for the survival of mankind, nay, the entire global system. Though 70% of the planet is covered by water, more than 97% occurs in oceans and seas and only 0.3% is available as fresh water for human consumption. This availability also varies in both space and time. It is estimated that total utilisable water resources in India are 1123 BCM or 112 M ha m out of which surface water resource is 690 BCM or 69 M ha m and that of groundwater resource is 433 BCM or 43.3 N ha m. Average per capita availability is 1720 $m^3$. Due to uneven distribution of water resources in the 20 river basins, the per capita availability is already 500 - 1000 $m^3$ or less in a few basins showing water stress. The situation may become critical in the coming decades with growth in population and water demand. When the water availability falls below 1000 $m^3$/capita/year scarcity conditions develop and below 500 $m^3$/capita/year water shortage becomes primary constraint to life.

Requirement of water is the basic need for the following sectors :

1. Irrigation/Agriculture
2. Domestic
3. Industry
4. Power
5. Inland Water supply
6. Environment & Animal Husbandry
7. Evaporation from the reservoir

Irrigation consumes more than 80% of water and is a major concern for the government. Consumption of water for domestic and industry will increase with the development and increase in the population.

Table indicates an estimate of requirement of water at year 2020, 2025 and 2050 at different sectors keeping 1997-98 as base year.[Source : Basu, P.K., 2004]

**Table 8.1 : Requirement of water in different sectors (In Km3)**

| Sectors | 1997-98 | 2010 | | 2025 | | 2050 | |
|---|---|---|---|---|---|---|---|
| | As per recorded use | Min. | Max | Min. | Max | Min. | Max. |
| Irrigation | 524 | 543 | 557 | 561 | 611 | 628 | 807 |
| Domestic | 30 | 42 | 43 | 55 | 62 | 90 | 111 |
| Industry | 30 | 37 | 37 | 67 | 67 | 81 | 81 |
| Power | 9 | 18 | 19 | 31 | 33 | 63 | 70 |
| Inland Water ways | -- | 7 | 7 | 10 | 10 | 15 | 15 |
| Environment & Conservation of natural habitats | -- | 5 | 5 | 10 | 10 | 20 | 20 |
| Evaporation from the Reservoirs | 36 | 42 | 42 | 50 | 50 | 76 | 76 |

It will be observed from the above able that maximum water requirement in 2050 will be 1180 Km3 or 118 M ha m as against the total availability of 112 M ha m. Thus there will be shortage in the water in 2050, keeping in view the development space. With a view to mitigate this we need to conserve water, resort to waste water management and recycling water.

## Conservation of Water

In India, one of the major problems in Irrigation sector is underutilization of most of the irrigation systems entailing loss of water through seepage, over irrigation etc. Government of India and State Governments are all aware of this problem and aiming to bridge the gap by introduction of Farmers participation, CADA etc. Rotational system of irrigation or 'wara bandi' is also introduced for better management of irrigation system. Consumptive use of surface and groundwater is another step where either surface or groundwater to be used in the same command area. Ideally, during dry period or when surface water can not be released, groundwater can be used. Use of sprinkler, micro-sprinklers, drip irrigation system conserve precious water. Artificial recharge can be introduced with suitable structure for capturing excess surface water from irrigation, rainfall run-off etc. Construction of weirs/ sub-surface dams in suitable locations is helpful for rainwater harvesting in drought prone areas to increase surface water potential and artificial recharge. The country is endowed with large numbers of traditional water harvesting structures. Unfortunately, most of then are dilapidated, silted, or encroached due to breakdown of the traditional community-based management systems and neglect by the state water engineering department, mostly because of the lack of fund. Revival of these traditional water harvesting structures coupled with contemporary watershed management systems (including large scale afforestation and regeneration of nearly 30% of the degraded lands of the country, small structures like check dams, gully plugs can significantly enhance the surface water retention and storage capacity and also recharge groundwater aquifers of the country.

**Recycling of Waste Water**

With the advancement of industrialization the demand of water for industry is increasing day by day. In most industries it is essentially used as input and mass and heat transfer media. However, the industries consume a small amount of water and the major part is discharged as effluent. Different industries consume different quantities of water. Thermal power, textiles, pulp and paper and iron and steel industries are highly water intensive, whereas cement, copper, zinc, plastics etc. require little water. In addition, ever growing population needs water for domestic purposes including drinking, sanitation, washing etc. According to Central Pollution Control Board (CPCB), major Indian industries consumes 40 billion cubic meters and discharges about 30.7 billion cubic meters. Thus the overall utilization of fresh water is only 0.77 indicating that major part of fresh water is discharged as waste water. A simple country-wise analysis will reveal that the Indian industries give little importance to the re-use of waste water. [Source : Google search].

**Table 8.2 : Use of Industrial Water**

| Country | Industrial water use (billion cubic metres) | Industrial productivity (million/US $) | Industrial water productivity (US $/$m^3$) |
|---|---|---|---|
| Argentina | 2.6 | 77171.0 | 30.0 |
| Brazil | 9.9 | 231442.0 | 23.4 |
| India | 15.0 | 113041.0 | 7.5 |
| Korea, Rep | 2.6 | 249268.0 | 95.6 |
| Norway | 1.4 | 47599.0 | 35.0 |
| Sweeden | 0.8 | 74703.0 | 92.2 |
| Thailand | 1.3 | 64800.0 | 48.9 |
| UK | 0.7 | 330097.0 | |

Indian industries are gradually waking up from the slumber and some of the major industries like Tata Group, etc, are trying to reuse the waste water as much as possible and some of the plants have 98% efficiency on water use. There are, however, thousands of medium and small industries who leave the waste water after primary treatment to the nearby streams/rivers thereby not only wasting water, they are polluting the ecology and environment also. According to the Centre for Science and Environment (CSE) (ref. : website www.cseindia.org), average water consumption in Indian industries and globally best countries are given below :

**Table 8.3 : Average water consumption in the industries**

| Sector | Average water consumption in Indian industry | Globally best |
|---|---|---|
| Thermal Plant | On an average 80$m^3$ / mwh | Less than 10$m^3$/mwh |
| Textiles | 200 – 250$m^3$ / tonne cloth | Less than 100$m^3$/tones cotton cloth |
| Pulp & Paper | Wood based mills :<br>150 – 200$m^3$/tonne<br>Waster paper based mills :<br>75 – 100$m^3$/tonne | |
| Integrated Iron and Steel Plant | 10 – 80$m^3$/tonne of finished product | 5-10$m^3$/tonne of finished product |
| Distilleries | 75 – 200$m^3$/tonne alcohol product | N.A. |
| Fertilizer Industries | a) Nitrogen fertilizer plant -:<br>5-20$m^3$/tonne<br>b) Straight phosphatic plant :<br>1.4 – 2.0$m^3$/tonne<br>c) Complex fertilizer :<br>0.2 – 5.4$m^3$/tonne | An effluent discharge of less than 1.5$m^3$/tonne of product as $P_2O_5$ |

Iron and Steel industries in India are one of the best in recycling of raw water. Once the source of water is identified, raw water is pumped into an Intake well. The dimension of the Intake well is designed as per the water requirement of the plant. From the Intake well water is pumped to Central Influent Water Treatment Plant (IWTP), which is designed to supply the following four qualities of water required for operation :

a) Filtered water
b) Demineralised water
c) Soft water
d) Drinking water

Different quantities of water is pumped into different plants for operation. Effluents from different plants are collected in the Central Effluent Water Treatment Plant (EWTP). The EWTP is designed to treat the following types of waste water generated within the Steel Plant.

1. Inorganic effluents including cooling tower blow down effluents from various unit operations.

2. Waste water collected from steel melting shop, Hot strip mill section.

3. Oily waster water.

4. Organic waste water from Coke oven plant.

5. Waste Water from influent water treatment plant.

6. Sanitary waste from Canteen and Toilets of office complexes.

7. Waste water collected from different sections like, machine shops, laboratories, medical facilities.

The treated waste water from the effluent treatment plant will cater to the following :

a. Recycled water for process use within the steel plant.
b. Recycled water for Landscaping and Raw material handling.
c. Treated water for disposal to meet disposal quality standards.

The entire system is designed in such a way so as to utilize 98% of raw water.

Many of the industries are gradually shifting towards recycling of raw water. Unfortunately majority medium and small scale industries are lagging behind. They are even discharging waste water even without proper treatment.

All major hotels in India are recycling water. Housing compendium are also trying to utilize waste water at least for toilets and cloth washing. In the long run all major housing compendiums will be required the recycle waste water, even for drinking water like advanced countries.

**Competing Water Users :**

On a global scale, average water use is 69% in Agriculture, 23% in Industry, 8% in domestic sectors, but in African countries 88% of water is used for Agriculture alone. In India, agriculture consumes nearly 85%, the balance being used for industrial and domestic sectors. In advanced European countries, need in the industrial sector is 54%, agriculture 33% and domestic 13%. Besides agriculture, competing users of water are vastly growing rural population, emerging big cities with housing compendium, hydel power generation, river flushing and navigation, emerging industrial revolution in the developing countries. Water demand and its management will thus be critical in the present century.

**Major Challenging Issues :**

Major challenging issues in the next decades are :-

a) Water crisis Vs. Increased Demand
b) Water pricing mechanism and social impact.

c) Sharing of water on national and international water bodies.
d) Social and Environmental consideration.
e) Legal framework.

**Agriculture Sector :**

Agriculture sector consumes greater part of water demand for agriculture production and poverty alleviation. Effect of irrigation in alleviating poverty and improving the quality of life is apparent in Indian sub-continent. The north-western part of Punjab and Haryana where irrigation system is well developed have better standard of living than rest of India. Strangely, India has got the largest network of irrigation, but very poorly managed. Problems of over irrigation near the headwork causing water logging and salination and non-availability of water in the tail ends continue to cause anxiety to the planners. Managing the created water resources in the major/medium irrigation projects is a state subject which perennially suffer from lack of maintenance fund. The result is silting up of the existing canal system and reservoirs. Participatory Irrigation Management (PIM) is, thus, a necessary.

Deficient water management is a widespread problem and it is estimated more than 10 million ha. of irrigated land are performing below potential. Water management practices in such vast areas can substantially increase the agricultural productivity. Coupled with proper agricultural practices, water management in the farmers' field can maximize production. In 1970s Government of India established Command Area Development Authority (CADA). There are 53 CADAs covering 131 command areas representing a total command of 18.5 million ha. for constructing micro network of irrigation field channels in the farmers' field. It also coordinates with the Agriculture Department for management of irrigation water depending upon the crops. Operation and maintenance of this huge network requires enormous fund. Moreover, irrigation engineers are not always good managers of irrigated agriculture. Awareness amongst farmers and their participation in the irrigation management (PIM) proves meaningful. Transfer of irrigation management is also a concept and introduced successfully by Government of West Bengal, India for tubewell irrigation.

Experts feel that there is a need to create more storage facilities in India. In fact per capita storage in India is much less than that of China. Construction of major dams creates social problem. Moreover, most of the accessible sites are already used unless the pricing mechanism are settled, construction of major dams may lead to economic burden.

Watershed development program, mostly in association with NGO's have yielded benefit in rainfed areas. There is increase in groundwater recharge, construction of wells becomes feasible. Rainwater harvesting in the semi-arid regions of India as well as in African countries are now become an integral part of water management.

In the Indo-Gangetic plains in U.P., Bihar and West Bengal, groundwater irrigation is most popular and covers more than 50% of irrigated area. Water Management practices in the tubewell command is easier than in surface flow irrigation schemes. Piped distribution system from heavy duty tubewells was a matter of detailed experimentation by the State Governments under World Bank assisted projects and the problems of tailenders were solved to a great extent. Piped distribution system from distributaries of surface flow schemes are being experimented in India. Introduction of drip and sprinkler irrigation systems in Maharashtra, Andhra Pradesh, Karnataka, Haryana on a large scale has effected water management and also increased food production. Government of India's strategy to reduce the water demand from 85% to less than 68% over the years, keeping the space of development of irrigation and agriculture productivity need careful scrutiny in each area for diagnostic and prognostic programme, creation of low cost infrastructure and upgrading the managerial efficiency.

**Industrial Sector :**

The demand for industrial sector will increase throughout the globe. Steel and allied industries, paper industry are water intensive. Reuse of recycled waste water in most of the industries is a compulsion because of scarcity of water. While major industrial houses reuse more than 90% of recycled water, smaller industries release the water in nearby streams/rivers causing environmental problem. In Israel, waste water is used compulsorily for agriculture. In USA, EPA does not allow release of waste water not properly treated. Most of the industries in the advanced countries reuse the industrial effluents.

**Domestic Sector :**

The majority of our rural population, potable domestic water is a daily problem. Women folks carry water from long distances and waste time for domestic water supply. During the last century, only 25% of the rural population in Africa are served adequate potable water, while for urban population in Africa 70% got the benefit of potable water. In India, 200 million people do not have access to safe drinking water and 200 million man days are lost every year. Availability of water and its quality in the domestic sector particularly in the rural area is a serious issue. Wastage of flowing water in kitchen, toilets etc. in countries like India is a daily affairs, but in advanced countries toilet and domestic wastes are recycled. In Japan, waterless toilets have emerged.

**Water Pricing / Cost Recovery :**

Water was earlier treated as an unlimited resource and providing water for social cause, be it for irrigation or drinking, is the responsibility of the Government. Industries used to draw water with or without permission from the source for its use. Water charges, even if levied, were so meager that collection of water charges was costlier for the revenue Departments. The scenario has drastically changed now. Cost of infrastructure, its operation and maintenance, in all sectors have become enormous and unless water charges are enhanced no Governments can afford to bear the burden indefinitely. Water pricing policy has been discussed in all the countries and appropriate legislatures framed. Israel, for example, enforced water pricing as a tool for integrated water resource management. Water pricing policy is a sensitive issue for all Governments because of its immediate impact on the people. Conceptually at least, water pricing could effect :-

- Water allocation between competing uses
- Water conservation
- Generation of additional revenue which could be used to operate and maintain water systems, and even repay part of all investment costs.
- Cropping pattern
- Income distribution
- Efficiency of water management, and
- Overall environmental impacts.

In India charging economic water rates is a distance dream. The Vaidyanathan Committee (1992) recommended recovery of O & M cost and part of capital cost in irrigation sector. This could not be achieved. Pricing and cost recovery is a crucial instrument to water management in the present century. This, however, needs a paradigm shift in its approach to socio-political scenario of the developing countries. Water is considered to be a subsidized commodity and recovery of cost for its use will be a big political challenge.

**Sharing of water on national and international water bodies**

There are 41 countries (20 in Africa) where at least 80 percent of the total area lies within international basins, Estimates show out of 214 river and lake basins, about 75% are shared by two countries, nine basins are shared by six or more countries. Table 8.4 shows major international river and lake basins having catchment area in excess of 1,00,000 $Km^2$.

**Table 8.4 : Major international river and lake basins having (catchment area in excess of 1,00,000 $Km^2$)**

| Region | Number of countries sharing basin | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| **Africa** | 3 | 2 | 6 | - | 2 | 1 | - | 3 | - | 17 |
| **America** | 10 | 2 | - | 1 | - | 1 | - | - | - | 14 |
| **Asia** | 7 | 5 | 2 | - | 2 | - | - | - | - | 16 |
| **Europe** | - | 2 | - | 1 | - | 1 | - | - | 1 | 5 |
| **Total** | 20 | 11 | 8 | 2 | 4 | 3 | - | 3 | 1 | 52 |

India has international river basin boundaries with Pakistan, Bhutan, Nepal and Bangladesh. International organizations, to a great extent, stay away from the development and management of international water bodies because of political sensitiveness.

On a national scale, most of the river basins transgress adjacent state boundaries and may lead to inter state dispute. Sharing of Cauvery between Karnataka, Tamil Nadu and Kerala is an example. Similar is the case with sharing of Yamuna between Haryana and U.P. The Krishna river passes through Maharashtra, Karnataka and Tamil Nadu and has been amicably settled. So is the Subarnarekha river flows covering Jharkhand, Orissa and West Bengal or Narmada flow passing through Maharashtra, M.P. and Gujarat.

**Social and Environmental Issues :**

Effect of long term misuse of water resource is gradual, whether rise of water table due to excess irrigation/canal seepage or over development of groundwater and is often irreversible. Remedial resources like reclamation of 'user land' or 'saline' land or artificial recharge to stop groundwater over exploitation also need a very long term action, often so expensive as to warrant its continuation over a long period of time. The present century needs to address such difficult situation without causing environmental degradation. In the industrial sector, untreated effluents join the nearby streams, rivers causing health hazards. Keeping aside the small industries, only 59% of large, medium industries have effluent treat plants (ETP) in India. Situation may be worse in other developing countries including African countries. In big cities, pure potable water is available but will become scarce day by day. Most or all of the rural villages, treated piped water is not available.

Water quality management and its monitoring will be extremely important in the present century. This may need expertise, proper equipments and huge expenditure. This appears to be insignificant to-day, but to-morrow it may take a major share in annual budgets of all Governments.

**Legal Issues**

In England and Wales, river basin authorities have overriding powers over local administrative authorities. France, Germany and Canada also follow river basin management and its authorities have powers over sharing of water within the country. USA, being guided by Environmental Protection Act, the federal authority over water is restricted to consultative process including examination of environmental issues. But major inter state rivers have come under river basin planning commissions and major inter state share of water is by agreement between states recognized under law. In India, water being a state subject under the constitution, Government of India, at the apex level play an advisory role. Two acts have provided some mechanisms to tackle inter-state water issues. The River Boards Act of 1956 gives Govt. of India the authority to set up river board for any inter state dispute. Inter-state Disputes Act, 1956 empowers Govt. of India to refer the dispute to a tribunal for adjudication.

Central Pollution Control Board in India monitor the quality of water, whether in river basin, or polluting industries and formulates Minimum National Standards (MINAS) for enforcement through State Pollution Control Boards and Pollution Control Committees in Union territories. The Board also acts as an arm for Environment and Forest Protection Act, by providing data on quality of water for Environment Impact Assessment (EIA) and EMP (Environment Management Plan).

This will again be reflected in the pricing policy of water. Israel has taken conscious step not only pricing as an instrument for water management but also directs sewage water for use in agriculture.

## Conclusion

Water is all pervasive in the social fabric of mankind. Scarcity of water will affect rich and poor. Pollution does not make any difference to the social status. Irrigation, an instrument to alleviate poverty, can also be an instrument of social conflict. Water Resources Management, thus need participation of people at all level. World Water Day, celebrated at big cities may not help the poor farmer. A massive awareness at the grass root level with appropriate policy and fund can be the beginning of a new era to combat water scarcity.

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# APPENDIX

## Some Special Properties of Water

The characteristics of water which is so essential for life can be understood by its (molecular) structure. Because of the electron-pair repulsion, a water molecule has a V-shape, with oxygen at the apex and the hydrogen on the either side, which lends its distinct characteristics that it not have in any other shape. When water is heated up, the individual molecules begin to increase their motion and move in many different ways. They fly across the room faster and become of its V-shape. Water can always vibrate - and rotate - and these additional modes of motion allow water to absorb lot of heat energy without much change in temperature. This property of water is essential for human body consisting of two-thirds of water to insulate against the summer heat and cold winter.
[Smithsonian Science Series 101 - Chemistry by Denise, Kiernan and Joseph D'Agnese] - Harper Collins Publisher.

Unlike other liquids water has some special and unique physical and chemical properties which help in sustenance of life. These special properties are :

**Density :** Water is the only liquid which expands when freezes. Maximum density of water occurs at $4^0$C, below or above which water is lighter. Thus ice floats on water and we find water below the frozen lakes/oceans. Thermal stratification in lakes is the result of this special density characteristics of water rendering the aquatic life's survival in a frozen lake. Water in liquid form enters into the joints, fractures and fisoures of the rocks and during winter when water is frozen, it expands exerting pressure on the rocks, facilitating weathering process.

## Melting and Boiling Point

Boiling point of water is higher than most of the liquids and the difference in boiling point and melting points is very high, rendering it possible for water to remain in liquid state in most parts of the globe.

## Specific heat

Specific heat of water (4184 J/Kg$^0$C) is higher than most of the liquids excepting ammonia and about 5 times higher than most of common heavy solids like rock, concrete etc. Higher specific heat mans water heats up slowly and cools over longer period of time helping moderation of climate near large water bodies. Thermal fluctuation is also slow, as rapid thermal fluctuation may cause danger in sustenance of life.

## Heat of Vaporisation

Water requires unusually high heat to vaporize (2258 KJ/$K_3$). Water vapor this stores an unusually high energy as heat and transports such high energy from one place of globe to other areas, keeping our climate suitable for life.

## Water as a solvent

Water is a good solvent and dissolves more substances than any other solvents. Water this transports many nutrients to the soil for organic growth. Water also eliminates wastes from the earths surface. Water is thus always contaminated and can also carry hazardous wastes.

## Important Physical Properties of Water

| Property | SI Units | U S C S Units |
|---|---|---|
| Specific heat (at 17$^0$C) | 4.184 KJ/Kg$^0$C | 1.00 Btu/lb$^0$F |
| Latent heat of vaporisation | 2258 KJ/Kg | 972 Btu/lb |
| Heat to vaporize 17$^0$C water | 2459 KJ/Kg | 1057 Btu/lb |
| Latent heat of fusion | 333 KJ/Kg | 144 Btu/lb |
| Density at 4$^0$C | 1000.00 Kg/m3 | 62.4 lb/ft3 |
| (8 - 34 lb/gal) | | |

## Units of Measurement of Water

Water is a liquid and when in static condition is measured in volume. Thus, when it is stored in a 1 ft x 1 ft x 1 ft pot/cylinder, it is 1 cu.ft. of water in FPS system or 1 cm x 1 cm x 1 cm pot/cylinder it is 1 C.C. of water in CGS system.

However, when water is flowing or in dynamic condition, the dimension of time has to be brought in. 1 cu.ft. of water flowing in one second is 1 cu.ft./sec. or 1 CuSec or one Cubic Metre of water flowing in one second, it is one cubic metre/ sec or one cumec. In irrigation practices, if there is a standing column of water of 1 ft in one acre of area, it is known as 1 acre.ft. of water. Similarly, 1 m of standing water in one ha. Of area, it is 1 ha.m. of water. Water is also measured in gallons. British or Imperial units of gallons is slightly higher than US gallons i.e. 1 US gallon = 0.8 Imp. Gallon (approximately).

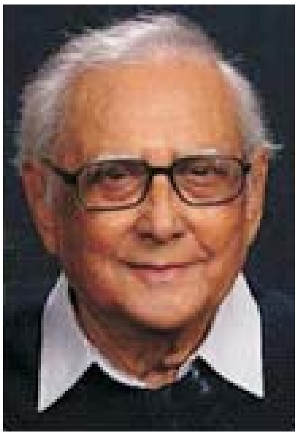
Flowing river/stream water is measured either in cusecs or cumecs. Flowing water from the delivery pipe of a tubewells (tubewell discharge) is also measured in cusecs or cumecs or in litres (1000 CC). Standing water in a reservoir or pond is measured in cu.ft. or cubic metres of kilo litres.

**Conversion :**

| | | |
|---|---|---|
| 1 cubic foot | = | 7.4805 gals (US) |
| | = | 0.02832 $m^3$ |
| | = | 28.32 litres |
| 1 Acre foot | = | 43,560 $ft^3$ |
| | = | 1233.49 $m^3$ |
| | = | 325,851 gals (US) |
| 1 gallon (US) | = | 0.134 $ft^3$ |
| | = | 0.003785 m3 |
| | = | 3.785 litres |
| 1 cubic meter | = | 8.11 x $10^{-4}$ Ac ft. |
| | = | 35.3147 ft3 |
| | = | 264.172 gal (US) |
| | = | 1000 litres |
| | = | $10^6$ $cm^3$ |

**Flow rate**

| | |
|---|---|
| 1 cubic foot per second | = 0.028316 $m^3$ / s. |
| | = 447.8 gals (US)/min (gpm) |
| 1 gallon (US) per minute | = 6.31 x $10^{-5}$ $m^3$/sec. |
| 1 million gals (US) per day | = 0.0438 $m^3$/sec. |
| 1 cubic meter per second | = 35.315 $ft^3$ / sec. (cfs) |
| | = 2118.9 f3/min (cfm) |
| | = 22.83 x $10^6$ gals/d. |
| | = 70.07 Ac.ft/d. |



## Author's Profile

Shri P.K.Chatterjee passed M.Sc in Geology from Calcutta University in 1961. After a brief stint of research in Presidency College, Kolkata, he joined Geological Servery of India as a direct recruit in class I Services of Govt of India, in 1965. During his stay in Geological Servery of India, he carried out extensive ground water investigation in most part of West Bengal. His services were transferred to Central Ground Water Board in 1972 by Govt of India. He joined on deputation from Central Groundwater Board to the Agriculture Credit Department of Reserve Bank of India who placed his service to Agriculture Refinance Corporation which became Agriculture Refinance and Development Corporation. During this period Shri Chatterjee was posted at Kolkata and made extensive studies in the eastern and north eastern states and assisted to the visiting members of the World Bank. He was also a member of the World Bank Mission for Assam Agriculture Development Project. Agriculture Refinance development corporation (ARDC) became National Bank of Agriculture and Rural Development (NABARD) by an, Act of Parliament in July 1982 and Shri Chatterjee continued in his capacity as Technical officer in the discipline of Minor Irrigation and served the Bank in Kolkata, Lucknow and Mumbai. He headed the discipline of Minor Irrigation prior to his elevation as Chief General Manager of the newly created State Project Department to administer the Rural Infrastructure Development Fund. He retired from the service of the Bank in Jan, 1997, but continued to work for the Bank as Consultant upto 2005. He joined in 2005 Conmat Technologies Private Limited as a Director. He was later elevated in the rank of Managing Director of Conmat Technologies Private Limited, a multidisciplinary consultancy organisation engaged in the Quality Control of building materials, geological investigation, preparation of mining plan and water resources development investigation.

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