ENVS 435: Watershed Management

Unit 3: Water Yield and Quality; Conservation Irrigation

INSTR: R. M. Bajracharya
Water sources & availability

- Only 3% of all the water on earth is usable fresh water.
- Of this the effectively available fresh water is considerably less (<1%).
- **Sources of water for human use include:**
  - Rivers & streams
  - Lakes & ponds
  - Ground water (from aquifers)
  - Springs & wells (vadose or shallow ground water)
- **The availability or distribution of water in nature is uneven over space and time!**
  - Humid/per-humid vs. arid/semi-arid (desert) regions
  - Seasonal (bi-modal, uni-modal) vs. year-round rainfall (tropical rain forests)
Global annual water cycle

Figures in km$^3 \times 10^3$

A: Continental rainfall
B: Continental evaporation
C: Water from ocean to land
D: Rainfall over ocean
E: Evaporation from ocean
F: Flow from continent to ocean

Source: Gleick, 1993

Global availability of water

<table>
<thead>
<tr>
<th>Location</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt water (in oceans)</td>
<td>97.0</td>
</tr>
<tr>
<td>Fresh water</td>
<td>3.0</td>
</tr>
<tr>
<td>Groundwater</td>
<td>1.7</td>
</tr>
<tr>
<td>River and lakes</td>
<td>0.0072</td>
</tr>
<tr>
<td>Ice caps and glaciers</td>
<td>1.74</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>0.001</td>
</tr>
<tr>
<td>Nepal's rivers</td>
<td>0.000016</td>
</tr>
</tbody>
</table>

Sources: Gleick, 1993 and Pani Ko Artha Rajniti, 1997
Water use constructions

Kulekhani Dam

Water intake

Kosi Barrage

Kamala Weir
Global water issues

- ~3800 km³ of fresh water withdrawn annually
- This is double the volume extracted 50y ago.
- Growing population & increasing economic activity increase demands for water & water-related services.
- World population projected to peak between 7.3 and 10.7 billion by around 2050.
- World economic activity grew ~five-fold since 1950 at a rate of about 4% per year.
- Regional balance is shifting with increasing growth in Asia over the past 25 years.
- In 1990 more than 1 billion people had access to less than 50 L of water per day.
- Avg. per capita water consumption in rural Nepal ranges from 30 L (hills) to 55 L (Terai).
Water consumption & distribution

Fig. 1.1. Proportion of water use for various purposes in different countries

Figure 1.2: Annual fresh water withdrawals per capita average (1987-95)

Figure 1.3: Distribution of the world’s water

Uses of Water

- **Industrial uses:**
  - Steel & other metal production
  - Energy production (hydropower, nuclear)
  - Paper & textiles industries
  - Automobile & other heavy industries

- **Commercial uses:**
  - Food & beverage production; catering
  - Construction (urban, rural buildings, roads, etc.)
  - Laboratories, offices, institutions, etc.
  - Agricultural production (irrigation, livestock)

- **Domestic uses:**
  - Drinking & cooking
  - Washing & bathing
  - Sanitation
  - Lawn, garden, etc.

### Water Use Amount (m³)

<table>
<thead>
<tr>
<th>Water Use</th>
<th>Amount (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per capita daily (urban)</td>
<td>0.1</td>
</tr>
<tr>
<td>Per capita daily (rural)</td>
<td>0.04</td>
</tr>
<tr>
<td>To produce 1 tonne steel</td>
<td>261</td>
</tr>
<tr>
<td>To produce 1 tonne Al</td>
<td>410</td>
</tr>
<tr>
<td>To produce 1 tonne paper</td>
<td>543</td>
</tr>
<tr>
<td>To produce 1 automobile</td>
<td>138</td>
</tr>
</tbody>
</table>
Various means of accessing ground water

- Hand pump
- Mark-IV pump
- Rower hand pump
- Shallow well
- Tube-well drilling
Diversion and distribution of water

“Sancho” for flow control

Aquaduct

Water storage tank – ferro-cement

Water lift (manual)

Water lift (animal)
A rural water collection and distribution system
Water Quality – Definition/Introduction

• Water quality refers to the physical, chemical and biological characteristics of water with reference to a particular use.

• Water quality requirements depend on:
  – Purpose for which the water is to be used
  – Source and supply of the water
  – Geophysical and climatic factors

• Quality of water for the following purposes:
  – Consumption (food, drink, etc.) = requires high quality water, mainly free from contamination by pathogens, heavy metals and toxic compounds.
  – Irrigation (agriculture) = low to medium quality water, but should be free of toxic compounds and some heavy metals.
  – Industrial use = generally medium to high quality depending on the process.
  – Hydropower generation = low quality water will suffice, but best if sediment load is minimized.
Water Quality

• Quality of water deteriorates due to contamination by natural and human factors

• **Sources of contamination:**
  – Point source pollution (fixed or known outlet/source)
  – Non-point source pollution (originate from broad areas, pollution transport is highly variable, hence difficult to control or regulate)

• **Point sources include:**
  – Factories, industries, dump-sites, land-fills, etc.

• **Sources of Non-point pollution:**
  – Urban
  – Rural
  – Forest & land management
Urban sources of non-point pollution

- **Atmospheric deposition**
  - Long range contaminant transport (trans-boundary)
  - Local atmospheric inputs from industry

- **Transportation**
  - Combustion by-products (CO, CO$_2$, SO$_x$, NO$_x$)
  - Corrosive materials (lead-acid batteries, etc.)
  - Wearing of tires & brakes
  - Leakage of oil & grease

- **Illegal dumping of chemicals, dyes, paints, etc.**

- **Household use, gardening/lawn maintenance**
  - Chemical fertilizers
  - Pesticides
  - Rodent and insect repellants

- **Accidental chemical spills**
Rural sources of non-point pollution

- **Atmospheric deposition**
  - Acid rain from industrial and urban areas
  - Long range transported contaminants

- **Transportation**
  - Highway traffic
  - Local agricultural traffic & gravel roads (dust)

- **Agriculture**
  - Chemical fertilizers and manures (excess nutrients)
  - Pesticides (toxic chemicals, organochlorine/phosphates)
  - Sediment (eroded & stream transported)
  - Dust (wind blown & deposited)

- **Septic systems, open defecation & grazing**
  - Microbial contamination (pathogens in manure, sewage, etc.)
  - Excess nutrients
Forest and land management as sources of non-point pollution

- Tree harvesting; land clearing; tillage; etc.
- Sediments due to soil erosion
- Nutrient leaching due to vegetation removal

- Planting of trees, crops or other harvestable plants
- Nutrients from fertilizers
- Pesticides for weed, insect and disease control

- Infrastructure development – road, bridge, dam, building construction
- Sediment from exposed soil and bank cutting/filling

- Fighting of forest or grassland fires
- Fire retardant chemicals
Physical characteristics of water

• The main physical water quality characteristics generally measured include:
  – Temperature
  – Colour
  – Taste and odour
  – Turbidity
  – Dissolved solids

• These characteristics are influenced both by human induced as well as natural factors and processes.

• Some of these parameters are of major concern for health (human or ecosystem) reasons, while others are more of concern for aesthetic reasons.
Temperature of water

• **Causes of change:**
  – Impoundment & release of epi- or hypo-limnetic water
  – Removal of shade (stream bank or side vegetation)
  – Logging or tree-felling in the watershed
  – Diversion of water for irrigation (& return of irrig. water)
  – Discharge of water into stream from industrial facilities
  – Nuclear and thermal power plant discharges
  – Ground water withdrawal
  – Climate change (more CO₂ in atmosphere)

• **Effects on aquatic life:**
  – High summer temperature can be lethal to fish
  – Accelerated embryo development and earlier emergence in spring.
  – Inhibition of migration of fish
  – Increased susceptibility to diseases
  – Higher respiration rate and reduced metabolic efficiency
Thermal pollution

• Solubility of oxygen in water is inversely related to temperature.

<table>
<thead>
<tr>
<th>Water Temp. (°C)</th>
<th>Dissolved oxygen (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>12.8</td>
</tr>
<tr>
<td>10</td>
<td>11.3</td>
</tr>
<tr>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td>25</td>
<td>8.2</td>
</tr>
</tbody>
</table>

• Potential change in daily temperature due to removal of stream bank vegetation could be estimated as:

\[ \Delta T = 0.000267 \times \frac{A \times R_n}{Q} \]

where:

- \( \Delta T \) is temperature in °F (max potential daily due to exposure to direct solar radiation)
- \( T \) is temperature in °F
- \( A \) is surface area of stream newly exposed (sq. ft)
- \( Q \) is stream discharge in cfs
- \( R_n \) is net solar radiation per minute upon newly exposed stream surface (BTU/ft²)

Brown (1980)
Physical characteristics cont’d…

- **Water colour** – primarily a water quality concern for aesthetic reasons
  - Does not necessarily indicate poor water quality
  - Generally due to dissolved organic matter or suspended materials

- **Taste & Odour** – are merely human perceptions of water quality
  - Due to presence of iron, minerals, organic content, etc.

- **Turbidity** – measure of light transmitting property of water expressed as NTU (Nephelometric Turbidity Unit)
  - Important for both aesthetic and health reasons
  - Due to the presence of suspended or colloidal material (either organic or mineral in nature)

- **Dissolved solids** – residue remaining after evaporation at 105 °C
  - Mineral or organic substances
Physical characteristics of stream and river water.

<table>
<thead>
<tr>
<th>Water quality parameter</th>
<th>Typical value</th>
<th>Observed ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>Variable</td>
<td>0-30</td>
</tr>
<tr>
<td>Colour (colour units)</td>
<td>1 – 10</td>
<td>0-500</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td></td>
<td>0-3</td>
</tr>
<tr>
<td>Sp. Conductance at 25 °C (µS/cm)</td>
<td>70</td>
<td>40-1500</td>
</tr>
<tr>
<td>Total dissolve solids (mg/l)</td>
<td>73-89</td>
<td>5-317</td>
</tr>
<tr>
<td>Suspended solids (mg/l)</td>
<td>10-110</td>
<td>0.3-50000</td>
</tr>
<tr>
<td>Total Solids (mg/l)</td>
<td></td>
<td>20-1000</td>
</tr>
</tbody>
</table>

SOURCE: McCutcheon (1993); Livingstone (1963); Hem (1971)
The main chemical parameters used in assessing chemical quality of water include:

- Inorganic constituents
- Organic compounds
- Acids
- Dissolved oxygen
- Chemical oxygen demand, and
- Biological oxygen demand

Major cations of common occurrence in water include:

- Ca, Mg, Na, and K

Principle anions commonly found in water are:

- \( \text{HCO}_3^- \), \( \text{Cl}^- \), \( \text{SO}_4^{2-} \), \( \text{F}^- \), \( \text{CO}_3^{2-} \), \( \text{PO}_4^{3-} \) and \( \text{NO}_3^- \)
1. Inorganic constituents (contaminants)

- Nutrient elements and compounds are the main inorganic contaminants in surface water.
- Those of most concern: N and P (macro-nutrients); Fe, Mn, and Mo (micro-nutrients)

Effect of nutrient enrichment in surface waters (eutrophication – critical under ice)

<table>
<thead>
<tr>
<th>Lake and river classification</th>
<th>Oligotrophic</th>
<th>Mesotrophic</th>
<th>Eutrophic (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total P</td>
<td>1-5</td>
<td>5-15</td>
<td>15-100</td>
</tr>
<tr>
<td>Total N</td>
<td>1-250</td>
<td>200-500</td>
<td>500-1500</td>
</tr>
<tr>
<td>Chlorophyll-a</td>
<td>0.3-3</td>
<td>3-15</td>
<td>10-500</td>
</tr>
</tbody>
</table>

Limiting nutrient concept

(P is usually limiting in lakes and N in estuaries)
Inorganic constituents cont’d.

<table>
<thead>
<tr>
<th>Water quality of streams and rivers (N &amp; P forms &amp; amounts, mg/l)</th>
<th>Typical nutrient concentrations in rivers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total N</strong></td>
<td><strong>Cations:</strong></td>
</tr>
<tr>
<td>0.1-10</td>
<td><strong>(mg/l)</strong></td>
</tr>
<tr>
<td><strong>Organic N</strong></td>
<td><strong>Ca^{2+}</strong></td>
</tr>
<tr>
<td>0.1-9</td>
<td>15</td>
</tr>
<tr>
<td><strong>Ammonia</strong></td>
<td><strong>Mg^{2+}</strong></td>
</tr>
<tr>
<td>0.01-10</td>
<td>4.1</td>
</tr>
<tr>
<td><strong>Nitrite</strong></td>
<td><strong>Na^{+}</strong></td>
</tr>
<tr>
<td>0.01-0.05</td>
<td>6.3</td>
</tr>
<tr>
<td><strong>Nitrate</strong></td>
<td><strong>K^{+}</strong></td>
</tr>
<tr>
<td>0.23</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>Nitrogen gas</strong></td>
<td><strong>Anions</strong></td>
</tr>
<tr>
<td>0-18.4</td>
<td></td>
</tr>
<tr>
<td><strong>Total P</strong></td>
<td><strong>HCO_3^-</strong></td>
</tr>
<tr>
<td>0.02-6</td>
<td>58.4</td>
</tr>
<tr>
<td><strong>Orthophosphate</strong></td>
<td><strong>SO_4^{2-}</strong></td>
</tr>
<tr>
<td>0.01-0.5</td>
<td>11.2</td>
</tr>
<tr>
<td></td>
<td><strong>Cl^-</strong></td>
</tr>
<tr>
<td></td>
<td>7.8</td>
</tr>
<tr>
<td></td>
<td><strong>NO_3^-</strong></td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Source: L.W. Mais (1996) Adapted from Livingstone (1963)
## Typical composition of untreated domestic wastewater

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Weak (all mg/L except settleable solids)</th>
<th>Medium (all mg/L except settleable solids)</th>
<th>Strong (all mg/L except settleable solids)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity (as CaCO₃)ᵃ</td>
<td>50</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>BOD₃ (as O₂)</td>
<td>100</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>Chlorideᵃ</td>
<td>30</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>COD (as O₂)</td>
<td>250</td>
<td>500</td>
<td>1,000</td>
</tr>
<tr>
<td>Suspended solids (SS)</td>
<td>100</td>
<td>200</td>
<td>350</td>
</tr>
<tr>
<td>Settleable solids, mL/L</td>
<td>5</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Total dissolved solids (TDS)</td>
<td>200</td>
<td>500</td>
<td>1,000</td>
</tr>
<tr>
<td>Total Kjeldahl nitrogen (TKN) (as N)</td>
<td>20</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>Total organic carbon (TOC) (as C)</td>
<td>75</td>
<td>150</td>
<td>300</td>
</tr>
<tr>
<td>Total phosphorus (as P)</td>
<td>5</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>

ᵃTo be added to amount in domestic water supply. Chloride is exclusive of contribution from water-softener backwash.
2. Organic Contaminants

- 114 organic pollutants are recognized by EPA (US)
- Of these some hazardous chlorinated compounds are:
  - Chloroform, Chloronapthalene, Chlorophenol, DDT, Dieldrin, etc.
- Example of other organic compounds are:
  - Toluene, Nitrophenol, Naphthalene, Benzene, etc.

<table>
<thead>
<tr>
<th>Process/substance</th>
<th>No. of types of OCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organics &amp; plastics</td>
<td>105</td>
</tr>
<tr>
<td>Pesticides</td>
<td>80</td>
</tr>
<tr>
<td>Non-ferrous metals</td>
<td>66</td>
</tr>
<tr>
<td>Iron &amp; steel</td>
<td>64</td>
</tr>
<tr>
<td>Sewage tmt. Works</td>
<td>61</td>
</tr>
<tr>
<td>Petroleum refining</td>
<td>59</td>
</tr>
<tr>
<td>Mechanical products</td>
<td>58</td>
</tr>
<tr>
<td>Auto &amp; laundry works</td>
<td>56</td>
</tr>
<tr>
<td>Electrical works</td>
<td>51</td>
</tr>
<tr>
<td>Pharmaceuticals</td>
<td>49</td>
</tr>
</tbody>
</table>
3. Acids – sources & transformation

Sources & formation:

• Automobile exhaust
• Industrial processes (fumes & gaseous emissions)

Atmosphere

\[ \text{NH}_3 + \text{H}^+ \rightarrow \text{NH}_4^+ \]
\[ \text{NO}_x \rightarrow \text{HNO}_3 \rightarrow \text{H}^+ + \text{NO}_3^- \]
\[ \text{SO}_2 \rightarrow \text{H}_2\text{SO}_4 \rightarrow 2\text{H}^+ + \text{SO}_4^{2-} \]

Dry deposits

\[ \text{NO}_x, \text{SO}_2 \]

Wet deposits

\[ \text{SO}_4, \text{NO}_3, \text{NH}_4, \text{H}^+ \]

Land/soil/surface & ground waters

• Industrial wastes (liquid & solid)
• Urban & commercial wastes & dump sites
4. Dissolved Oxygen

- Dissolved O\textsubscript{2} is highly variable and fluctuates rapidly in time and space.
- It is a function of temperature and aeration of flowing water (turbulence).
- DO is an indication of pollutant loads (as indicated by oxygen requirements) and includes measurements of BOD and COD.
- Solubility of O\textsubscript{2} in water can be estimated from the equation by Churchill et al. (1962):
  \[ O_s = 14.652 - 0.41022T + 0.007991T^2 - 0.000078T^3 \]
  Where,
  - \( O_s \) is the solubility of oxygen in mg/l, and
  - \( T \) is the temperature of water (ºC)
5. Chemical oxygen demand (COD)

• COD is a measure of the pollutant load as reflected by the amount of a strong oxidizing agent ($K_2Cr_2O_7$) required to degrade (oxidize) the pollutant.

• The COD test the strong oxidizing agent (chromic acid) is mixed with the water sample and boiled. The difference in oxidizing agent at the beginning and end of the test is used to calculate the COD.

• Does not require knowledge of the composition of chemical substances in the water.

• COD is generally higher than BOD because more compounds can be oxidized chemically than biologically.

• Not well suited to natural waters
6. Biochemical oxygen demand (BOD)

- BOD is an index of the oxygen consumed by microorganisms that decompose biodegradable substances (nutrients, sewage, organic materials) in water.
- Bacterial growth proceeds exponentially in the degradation and active decomposition zones.
- Corresponding decomposition of carbonaceous and nitrogenous organic materials in the stream as reflected by oxygen levels.
### BOD values for different conditions

<table>
<thead>
<tr>
<th>CONDITION</th>
<th>BOD (mg/l)</th>
<th>5-day</th>
<th>90-day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean, undisturbed natural stream</td>
<td>&lt; 4</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Pulp &amp; paper processing effluent</td>
<td>20 - 20000</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Untreated sewage effluent</td>
<td>100-400</td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>Logging residues (twigs, leave, needles)</td>
<td>36-80</td>
<td>115-287</td>
<td></td>
</tr>
</tbody>
</table>

**Typical BOD curve**

- **Carbonaceous oxygen demand**
- **Nitrogenous oxygen demand**
Oxygen sag in stream due to waste decomposition by microorganisms
Microbiological characteristics of water

- Categories of microorganisms found in natural waters & examples of those of public health concern:
  - Bacteria: E. coli, V. cholerae, Salmonella spp., M. tuberculosis
  - Fungi: Sphaerotilus spp.
  - Algae: green, red, yellow-green algae, diatoms
  - Protozoa: Paramecium, Giardia lambia, E. hystolitica, P. vivax
  - Worms: Trichinella, Ascaris, Filaria, Schistosomes, Necator
  - Crustaceans: Potamon, Gammarus
  - Viruses: Hepatitis A, Enterovirus
Conservation Irrigation

• **What is Irrigation?**
  - In areas where natural rainfall is insufficient – in time and space-the crops are supplied with additional water through artificial means to secure potential crop yields. This process is called irrigation.

• **What is Conservation Irrigation?**
  - The objective of conservation irrigation is to optimize agricultural production with available irrigation water without adversely affecting the quality of environment and production resources.
There are four major river systems in Nepal.
- The rainfall distribution is uneven, nearly 90.4% concentration is in wet season (June to October).
- In winter 9.6% precipitation occurs by westerly wind.
- The average rainfall is around 1700 mm.
- The low flow is for nine months and is just enough to meet the evapo-transpiration need of Nepal (1000mm).
- Damming is effective in East-West trend of the river. Whereas for run-of-the-river type of hydro-electricity generation the North-South trend is suitable.
- The sediment load of Nepalese rivers is heavy (24 * 10^6 m^3 per year).
Ground water, aquifers and wells

- Artesian and non-Artesian wells
- Deep well
- Shallow well
- Artesian well
- Drawdown
- Confined aquifer
- Upper and lower confining layers
- Impervious bedrock
- Perched water table
- Main water table
- Impervious layer
- Confining/impervious layer
- Soil
- Ground surface
Soil moisture and ground water

- Zone of aeration
  - Ground surface
  - Soil moisture (soil water zone)
  - Partially-filled pores (intermediate zone)
  - Capillary fringe

- Zone of saturation
  - Suspended water
  - Ground water
  - Water under pressure
  - Bedrock
Two phases of conservation irrigation:

1. Water development for irrigation, and
2. Utilization of irrigation water for agricultural production

Phase 2 is governed by three subsystems:

- Soil-water relations
- Soil-plant relations
- Plant-water relations, i.e.,
- Soil–water–plant relations
Indices of Plant–Water Stress

4.1 Relative Leaf–Water Content (RLWC)

\[ RLWC = \text{Fresh weight} - \text{Oven dry weight} \]
\[ = \text{Fully turgid weight} - \text{Oven dry weight} \]

4.2 Leaf-Water Potential (LWP) or Xylem Water Potential

\[ \text{LWP} = \text{matric potential} (m) + \text{pressure potential} (p) + \text{osmotic potential} (o) \]

Or

\[ \text{LWP} = p + o \]

4.3 Leaf Diffusion Resistance (LDR)

LDR increases with a decrease in RLWC
Water Use Efficiency (WUE)

- WUE is defined as the ratio of produce per unit area to the water used by the crop.
  \[ WUE = \frac{\text{Biomass (kg)}}{\text{area (m}^2\text{)}} \times \frac{1}{\text{Water used (m)}} = \text{kg.m}^{-3} \]
- WUE is also defined as the ratio of biomass per unit area to transpiration (T) loss from the crop.
  \[ WUE = \frac{\text{Biomass (kg)/area (m}^2\text{)}}{\text{T (m)}} = \text{kg.m}^{-3} \]

WUE is also defined as biomass (B) or grain (G) yield in terms of evapotranspiration (ET) or (T) on daily or seasonal basis.

WUE signifies WUE based on biomass per unit T on daily basis.
Management of Irrigation Water

- **Sources of irrigation**
  - Diversions (streams, rivers)
  - Dams (reservoirs/storage; multipurpose)
  - Weirs (V-notch, rectangular, types)
  - Barrages (broad/shallow, lowland rivers)

- **Transportation of Surface Water**
  - Channel systems
### Canal types and system characteristics

**Seepage losses**
- **High**
- **Low**

#### Evaporation losses occur – depend on envir. conds. (temp., wind, etc.)

**Table:**

<table>
<thead>
<tr>
<th>System characteristics</th>
<th>Main canal (%)</th>
<th>Distributary (%)</th>
<th>Field water courses (%)</th>
<th>Total conveyance losses (%)</th>
<th>Conveyance efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire system unlined</td>
<td>15</td>
<td>7</td>
<td>22</td>
<td>44</td>
<td>56</td>
</tr>
<tr>
<td>Only canal lined</td>
<td>4</td>
<td>7</td>
<td>25</td>
<td>36</td>
<td>64</td>
</tr>
<tr>
<td>Canal and distributaries lined</td>
<td>4</td>
<td>2</td>
<td>26</td>
<td>32</td>
<td>68</td>
</tr>
<tr>
<td>Whole system lined</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>12</td>
<td>88</td>
</tr>
</tbody>
</table>

*Source: Agrawal and Khanna (1983)*
Outlet and pumps

- **Two general types of outlets:**
  - Direct type (gate – raised or lowered), size depending upon land area to be irrigated
  - Siphon type (using pipe over the canal ridge)

- **Water discharge in irrigation canals require energy:**
  - Gravity flow involves down-slope flow from rivers, streams or springs
  - Artesian wells – flow against gravity under pressure from aquifer
  - Pumping is used to distribute water to elevated areas from wells or streams/rivers (lifting).

- **Pumps may be:** diesel, electric, solar, wind or animal powered
Irrigation methods fall under four categories:

- **Surface Methods (ditches/canals & flooding)**
  - Check Basin Method
  - Border Strip Method
  - Furrow Method

- **Overhead Application Methods**
  - Sprinkler irrigation (numerous types)
  - Boom irrigation (automated & manual types)

- **Drip Irrigation (micro-irrigation)**
  - Surface drip
  - Sub-surface drip

- **Sub-irrigation – sub-surface water level control (essentially controlled drainage)**
Methods of Irrigation

- Sprinkler irrigation
- Boom irrigation
- Canal/furrow irrigation
- Flood irrigation (ponding of water)
- Drip irrigation
SURFACE WATER DISTRIBUTION METHODS

Supply ditch (canal)

Cross ridges

basins

Lateral canals

Check basin method

Contour check basin

Supply canal

Basin

Contour ridges

Turnout

Check gate

Supply canal

Lateral rings

Ring method (orchard)
Water distribution methods (surface) for agriculture

Fig. 19.1 Surface methods of applying water to field crops. (Redrawn from SCS, 1947.)

Fig. 19.5 Methods of distribution of water from (a) low-pressure underground pipe, (b) multiple-outlet risers, and (c) portable gated pipe. (Adapted from SCS and USBR, 1959)

Fig. 19.3 Devices for distribution of water from irrigation ditches into fields. (a) Spile or lath box. (b) Border takeout. (c) Siphons. (Adapted from SCS and USBR, 1959)
Water application methods

Irrigation Methods

Surface
- Border
  - Straight
  - Contour
- Check basin
- Furrow
  - Rectangular
  - Contour
  - Ring

Sub-surface
- Deep furrow
  - Straight
  - Contour
  - Level
  - Graded
- Corrugation

Sprinkler
- Rotating head
- Perforated pipe
  - (stationary)

Drip
- Surface
- Sub-surface
Scheduling of irrigation to Crops

▪ **Plentiful water**
  - Soil-Water Regime (soil depth, soil type, depth to water table, water-holding capacity)
  - Meteorological Parameters (Mean monthly/annual rainfall, rainfall distribution pattern, PET)
  - Plant Indices (crop type, density, LAI, spacing)

▪ **Limited Water Supplies**
  - Water harvesting (farm ponds, reservoirs, ground water harvesting, tanks)
  - Storage & conservation of water (tanks, ponds, soil surface roughness, ridge/furrows, ditches)
  - Minimal applications (drip; also called micro-irrigation)
Special Purpose Irrigation

Special Purpose Irrigation – sometimes irrigation is done for purposes other than merely watering crops, these include:

- Drainage: controlled removal of water from the soil surface or profile.
- Leaching: deliberate flushing of the soil profile with water to reduce the concentration of certain chemical constituents (salts – sodium, magnesium, calcium, etc.)
- Maintenance of water table at or below the rooting zone
Adverse Effects of Irrigation

Occasionally, irrigation may also have adverse effects on the crop directly, or indirectly through its effects on the soil:

- **Irrigation with poor quality water:**
  - Water contaminated with toxic compounds
  - Water with high concentration of salts
  - Water of low pH (acidic conditions)

- **Maintenance of a high water table through sub-irrigation or controlled drainage may:**
  - Lead to poor aeration of the root zone for crops
  - Accumulation of salts due to upward water movement (capillary action).

- **Erosion and slope failure due to over-saturation or canal/ditch breakage.**