Water Sources
(Improved and Unimproved)
and
Water Supply Planning

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Photo: Donna Coveney
Water on Earth – the Hydrologic Cycle

- Condensation
- Advection
- Condensation
- Sublimation
- Ice and Snow
- Melt Runoff
- Ocean
- Runoff
- Transpiration
- Evaporation
- Soil Moisture
- Lake
- Infiltration
- Groundwater
- Groundwater Flow

Figure by MIT OpenCourseWare.
# Water on Earth

<table>
<thead>
<tr>
<th>Water Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seawater</td>
<td>96.5%</td>
</tr>
<tr>
<td>Ice and Snow</td>
<td>1.76%</td>
</tr>
<tr>
<td>Atmospheric Water</td>
<td>0.001%</td>
</tr>
<tr>
<td><strong>Sub-Total</strong></td>
<td><strong>98.26%</strong></td>
</tr>
<tr>
<td>Freshwater Available</td>
<td>1.74%</td>
</tr>
<tr>
<td>Groundwater</td>
<td>1.7%</td>
</tr>
<tr>
<td>Lakes</td>
<td>0.013%</td>
</tr>
<tr>
<td>Rivers</td>
<td>0.002%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

(Shiklomanov, I, 1993)
Fresh water lakes and rivers (also known as “surface waters”)

- Fresh water lakes and rivers, which are the main sources of human water consumption, contain just 0.01% of Earth's total water (about 90,000 km³ of water)
## Average Renewal Time for Various Water Resources

<table>
<thead>
<tr>
<th>Water Resource</th>
<th>Renewal Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric Water</td>
<td>8 days</td>
</tr>
<tr>
<td>River Water</td>
<td>16 days</td>
</tr>
<tr>
<td>Soil Water</td>
<td>1 year</td>
</tr>
<tr>
<td>Wetlands Water</td>
<td>5 years</td>
</tr>
<tr>
<td>Lake Water</td>
<td>17 years</td>
</tr>
<tr>
<td>Groundwater</td>
<td>1,400 years</td>
</tr>
</tbody>
</table>

(Clarke, R. 1993)
Reliable Run-off

• Surface waters supplied by run-off are further limited because more than two-thirds of all run-off is due to torrential rains, floods, or from precipitation on uninhabited land. Thus the amount of reliable run-off available globally is only 9,000 km³/year
## Surface Water Run-off

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount (km³/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Run-off from Land Surface (polar zones excluded)</td>
<td>40,000</td>
</tr>
<tr>
<td>Unreliable Run-off due to torrential rains, floods, etc. = 2/3rds of World Run-off</td>
<td>26,000</td>
</tr>
<tr>
<td>Reliable on Uninhabited Land</td>
<td>5,000</td>
</tr>
<tr>
<td>Reliable Run-off</td>
<td>9,000</td>
</tr>
</tbody>
</table>

(Clarke, R. 1993)
Sources of Drinking Water

- **Major Sources**
  - Rainwater
  - Surface Water
  - Groundwater

- **Minor Sources**
  - Seawater
  - Saline water
  - Dew
  - Fog
Rainwater
Pristine Surface Waters
Pristine Ground Water
Surface Water – Stream (Kenya)
Surface Water-Rivers (Nepal)
Surface water is frequently contaminated by human and animal waste in many parts of the developing world.
Groundwater

- Usually free from pathogens
  - Filtered by soil
  - Contamination due to poorly sited latrines or poor well construction
  - Susceptible to contamination in karst areas
- May contain metals (Fe, Mn) or hydrogen sulfide (H$_2$S)
- Yields in some areas may be too low for practical use
- May be too deep to use economically
- May not be available everywhere
- Usually need pumps (exception – artesian flow)
- Well construction can be difficult, dangerous, expensive
Water is recharged to the ground-water system by percolation of water from precipitation and then flows to the stream through the ground-water system. (USGS, 2006)
Water pumped from the ground-water system causes the water table to lower and alters the direction of ground-water movement. Some water that flowed to the stream no longer does so and some water may be drawn in from the stream into the ground-water system thereby reducing the amount of streamflow. (USGS, 2006)
Contaminants introduced at the land surface may infiltrate to the water table and flow towards a point of discharge, either the well or the stream. (Not shown, but also important, is the potential movement of contaminants from the stream into the ground-water system, or naturally occurring toxins, such as arsenic or fluoride. (USGS, 2006)
Pollution of Wells

- Groundwater is polluted
  - Well too close to pit latrines, soakaways, refuse dumps
  - Karst geology
- Seepage from surface
  - Slope ground away from well
  - Grout well and install concrete apron
  - Divert water away from well to soakaway (>10 m away from well)

Figure by MIT OpenCourseWare.
Pollution of Wells

• Vessels for drawing water
  – Contaminate water after contact with ground
  – Design so buckets and ropes can’t touch ground
  – Permanently attach buckets and ropes to prevent removal
  – Use collapsible buckets
Pollution of Wells

• Rubbish thrown down well
  – Keep children and irresponsible people away from well
  – Guard or attendant may be necessary

• Surface water
  – May wash or be splashed into well
  – Ground surface around well may be sunken
  – Build headwall around well or cover
  – Divert surface runoff from well

• Spilt water
  – Water splashes on people’s feet and back into well
  – Can spread Guinea worm
Unimproved Water Supplies
(as defined by the WHO-UNICEF Joint Monitoring Programme)

• Unprotected well;
• Unprotected spring;
• Vended water (includes bottled and bagged water)
• Tanker Truck water
• All surface waters
Unprotected Well – Hand Dug Well

- Hand dug well
  - Most common
  - Low capital costs, but labor-intensive
  - Dangerous to construct without proper skills
  - 1.5-2.0 m diameter, 10-30 m deep
  - Pump not a feature of an “unprotected” dug well
Unprotected Well - Nicaragua

(San Francisco Libre, Nicaragua)
Unprotected Well - Kenya

(Nyanza Province, Kenya)
Unprotected Well - Burma
Zimbabwe - Finishing handdug well
Unprotected Spring
Vended Bottled (or Bagged) Water
Vended Tanker Truck Water
Vended Water
Surface Water – Stream - Nepal
Improved Water Supplies
(as defined by the WHO-UNICEF Joint Monitoring Programme)

- Public standpipe
- Borehole (drilled well)
- Protected dug well
- Protected spring
- Rainwater harvesting
- Household connection
  - Outside the home
  - Inside the home
Public Standpipe

(Photo: Monique Mikhail)
Public Standpipe
Drilled Well Types

• Driven tube well
  – Perforated tube with well point driven into ground with hammers, pile drivers, etc.
  – 5-10 cm diameter, 15-20 m deep
  – Pump required due to small diameter
  – Generally last ~5 years as well points clog or rust

• Bored tube well
  – Dug with auger (hand or mechanical)
  – Soil must be cohesive or can use casing
  – Pack area around well screen with gravel to improve recharge
  – 10-25 cm diameter, 20-40 m deep
  – Pump required due to small diameter

Figures by MIT OpenCourseWare.
Well Types

• Jetted tube well
  – Tube jetting into soft material
  – Soil removed from hole as sediment-laden water flows out top
  – 10-25 cm diameter, up to several hundred m deep
  – Pump required due to small diameter
  – Usually cased

• Bore hole wells
  – Require mechanical drilling rig
  – Rotary-type drills most common
  – 15-30 cm diameter, can be drilled deep as required
  – Pump required due to small diameter
  – Usually cased unless in bedrock

Figures by MIT OpenCourseWare.
(Jetted) Tubewell - Nepal
A “Protected” Well

A well equipped with:

• Handpump;
• Concrete Platform;
• Drainage Channel;
Still, “protected wells” can have problems:

- Broken apron;
- Broken handpump;
- Use of dirty water to prime the well;
- Flooding during monsoon;
- Improper siting;
- Poor drainage

(Photos: Yongxuan Gong, MIT, 2003)
Machine-drilled Borehole Construction
Deep Well with Lift Pump
Deep Borehole Well with Lift Pump
Deep Borehole Well with Lift Pump
Hand Pumps

• Shallow well pumps
  – Pumping mechanism above ground
  – Water pulled up by suction
  – Limited to vertical distance of 7-8 m

• Deep well pumps
  – Pumping mechanism in well
  – Water pushed up by piston
  – Entire mechanism must be pulled out for maintenance (3-5 times per year)
  – Can raise water from great depths
Handpumps

• Moving the water
  – Piston
    • Suction
    • Positive displacement
  – Helical rotor - progressing cavity
  – Diaphragm

• Moving the pump rod
  – Traditional
  – Direct action – shallow wells
Figure by MIT OpenCourseWare.
Handpump Improvements

• Reduce corrosion
  – Stainless steel or plastic (PVC) rods and mains
  – Brass, plastic, and/or rubber for valves and pistons

• Reduce production costs and spare parts required
  – Identical designs for piston and foot valves
  – Identical body for piston and foot valve housing
  – Direct action handles
  – Identical bearings for rod hanger and handle
Handpump Improvements

• Easier maintenance
  – Requires few tools
  – Bearings easy to replace
  – Open-top cylinder design
  – Special rod joints

• VLOM pumps
  – Village Level Operation and Maintenance
  – Centralized maintenance a problem – must be done at village level
Characteristics of a Good Hand Pump

- Simple and as easy to repair as possible
- Easy to maintain – low maintenance requirements
- Local country manufacture, if possible
- Reliable and as low cost as possible
- Resistant to abuse, vandalism, theft of parts
- Easy for women and children to use
- Produces water at reasonable rates
- Suitable for local geologic conditions (corrosion, sufficient suction head, etc.)
- Clearly illustrated installation and maintenance instructions
- Basic tool and maintenance kit
Alternate Pump Power Sources

- **Wind**
  - High maintenance
  - Storage required
  - Include standby hand pump

- **Solar**
  - High maintenance
  - Storage for cloudy days and night use
  - Local manufacture may not be possible
  - Standby hand pump necessary
Alternate Pump Power Sources

• Diesel/Gasoline engines
  – Required for high output pumps
  – High maintenance requirement
  – High initial and operating cost

• Electric motors
  – Moderate maintenance requirements
  – Suitable for high or low output wells
  – High initial cost
  – Dependent on local power supply
Dug Well Improvements

• Headwalls (about 1 m high) and drainage aprons
  – Prevents surface runoff and spilt water from entering well
  – Drainage apron should convey water to soakaway
  – Most important improvement

• Windlass, pulleys, rollers
  – Helps people pull up bucket without dragging it along inside of well
  – May help keep rope and bucket off ground

• Well cover
  – Water tight to prevent pollution entering open top

• Pump or permanent bucket anchored to the well.

• Proper Siting
  – least 60 m (preferably uphill) from any source of pollution (latrines, rubbish dumps)

• Shock chlorination of well
  – Continuously or periodically
  – May cause taste problems – drive users away
Unimproved and Improved Dug Well

Conventional

Improved
Improved Dug Well
An improved dug well goes from this --->>>

to this --->>>
Improved dug well in Sierra Leone
Protected Springs
Protected Springs

- Good quality water
- Usually do not require pump
- Focus on collecting and protecting water
- Important characteristics
  - Spring box of brick, masonry or concrete to collect water and protect from contamination
  - Permeable back wall to allow water seepage into box
  - Graded gravel or sand over eye to prevent piping and erosion
  - Lockable cover
  - Screened outlet and overflow pipes
  - Do not disturb impermeable base of spring
Protected Springs

• Important characteristics, continued
  – Top of spring box > 300 mm above ground level
  – Compact clay around exterior of spring box
  – Divert upslope surface runoff using ditch and bund
  – Fence off spring box with stones, wooden fence, or thorny vegetation
  – Allow for sediment accumulation – place outlet pipe 100 mm above bottom of box
  – Install bottom drain with valve for sediment removal and spring box cleaning
Spring Box Design

- **Hinge detail**
- **Lockable cover**
- **Soil**
- **Puddled clay**
- **Gravel**
- **Eye of spring**
- **Overflow**
- **To tank or to collection point**
- **Impervious layer**
- **Mosquito screen**
- **Open stone wall**
- **Screen**

Figure by MIT OpenCourseWare.
Spring Box Design

- **PLAN**
  - Bund planted with hedge
  - Overflow pipe
  - Drainage ditch for surface water
  - Slit trap
  - Springs
  - To storage

- **SECTION**
  - Minimum 8m
  - Bund planted with hedge
  - Protective ditch
  - Water bearing layer
  - Spring box
  - Slit trap
  - Overflow pipe
  - Erosion protection
  - To storage tank

Figure by MIT OpenCourseWare.
Rainwater Harvesting

Advantages:
• Household access;
• Free of chemical contamination (e.g. arsenic, fluoride etc.);
• Limited susceptibility to microbiological pollution.
• Good technology in floods.

Disadvantages:
• Seasonality;
• Relatively expensive;
• People unaccustomed to it.
Piped Water System
Household Connection

Outside the Home

Inside the Home