11.479J / 1.851J Water and Sanitation Infrastructure in Developing Countries
Spring 2007

Water Sources

(Improved and Unimproved)

and

Water Supply Planning

Susan Murcott

Week 4 - MIT 11.479 J / 1.851J

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Photo: Donna Coveney

Water on Earth – the Hydrologic Cycle

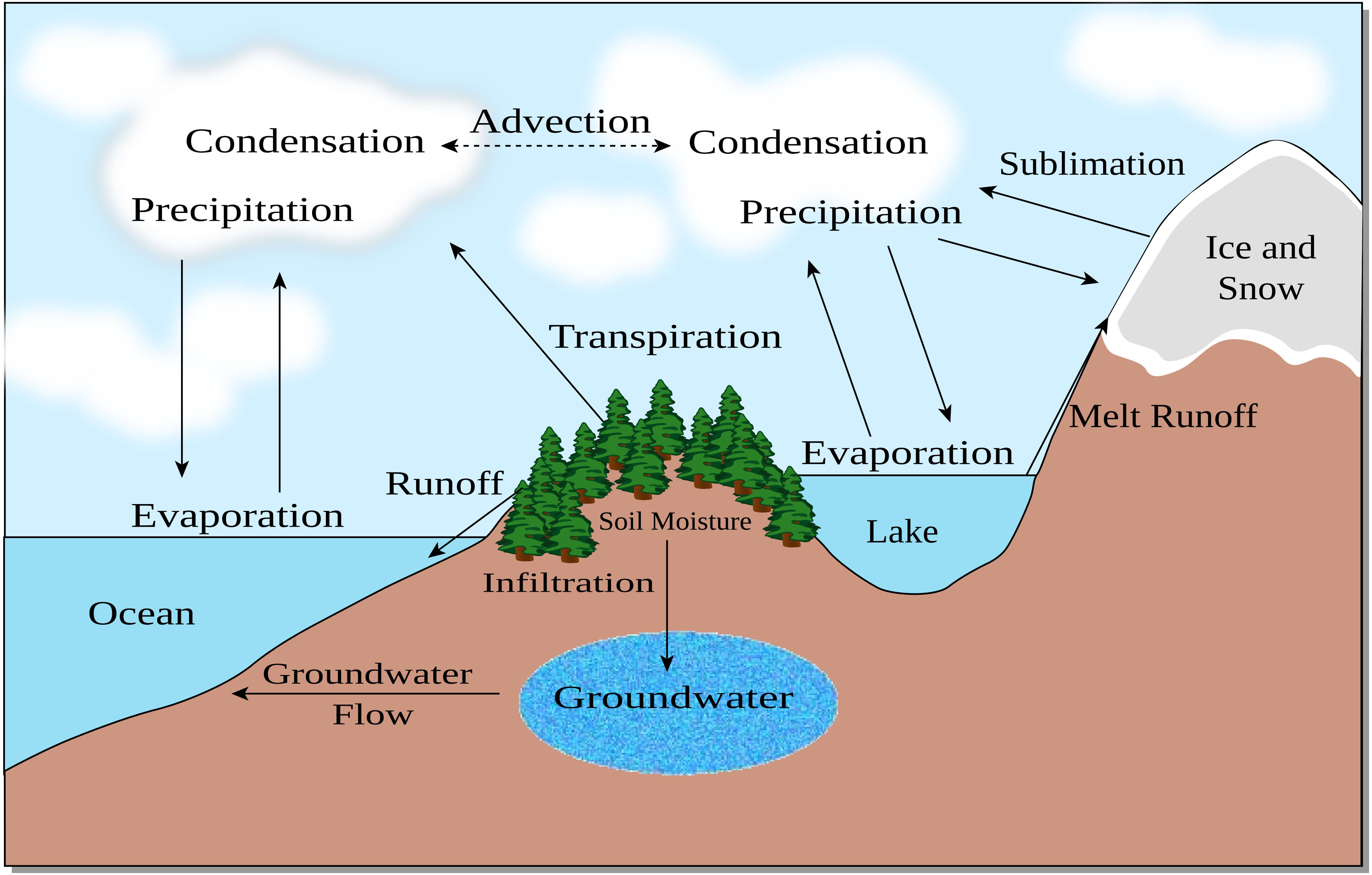


Figure by MIT OpenCourseWare.

Water on Earth

Seawater	96.5%
Ice and Snow	1.76%
Atmospheric Water	0.001%
Sub-Total	**98.26%**
Freshwater Available	1.74%
Groundwater	1.7%
Lakes	0.013%
Rivers	0.002%
Total	**100%**

(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

Atmospheric Water	8 days
River Water	16 days
Soil Water	1 year
Wetlands Water	5 years
Lake Water	17 years
Groundwater	1,400 years

(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 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

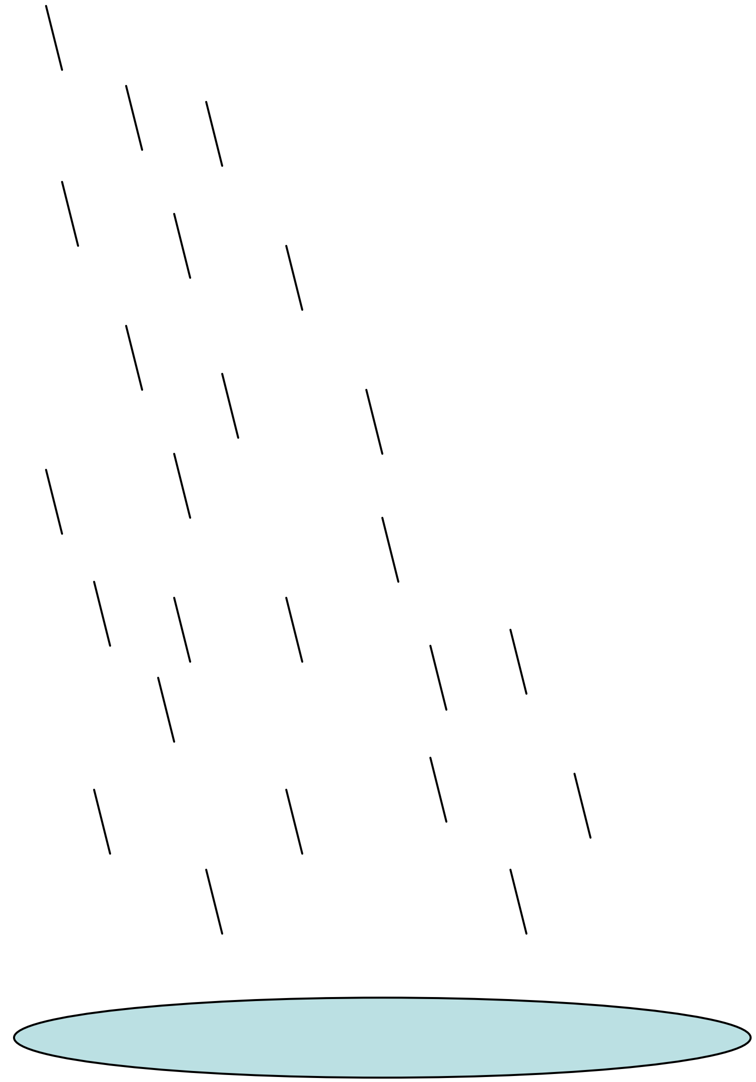
	km3/year
World Run-off from Land Surface (polar zones excluded)	40,000
Unreliable Run-off due to torrential rains, floods, etc. = 2/3rds of World Run-off)	26,000
Reliable on Uninhabited Land	5,000
Reliable Run-off	9,000

(Clarke, R. 1993)

Sources of Drinking Water

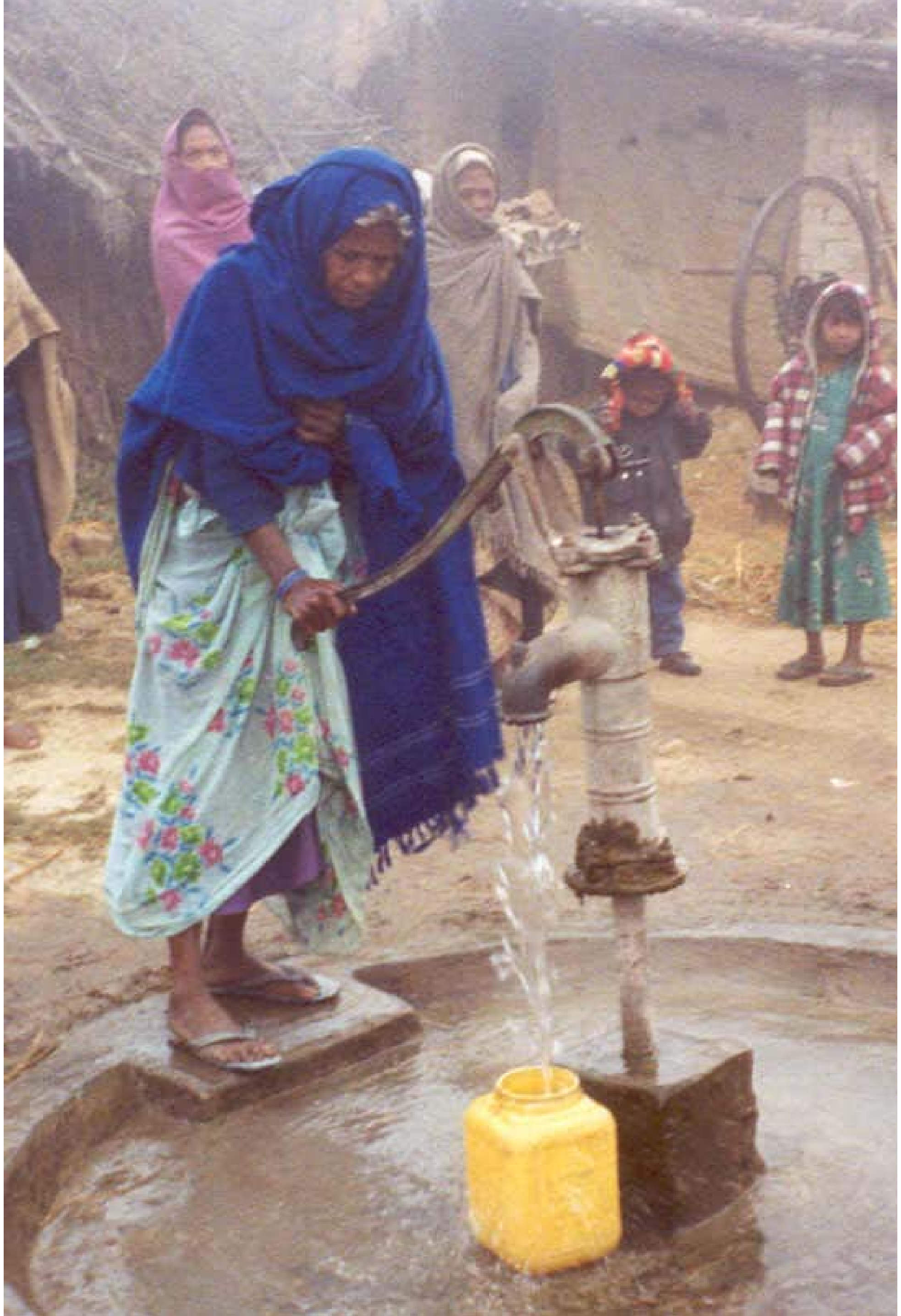
- <u>Major Sources</u>
  - Rainwater
  - Surface Water
  - Groundwater
- <u>Minor Sources</u>
  - Seawater
  - Saline water
  - Dew
  - Fog

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.

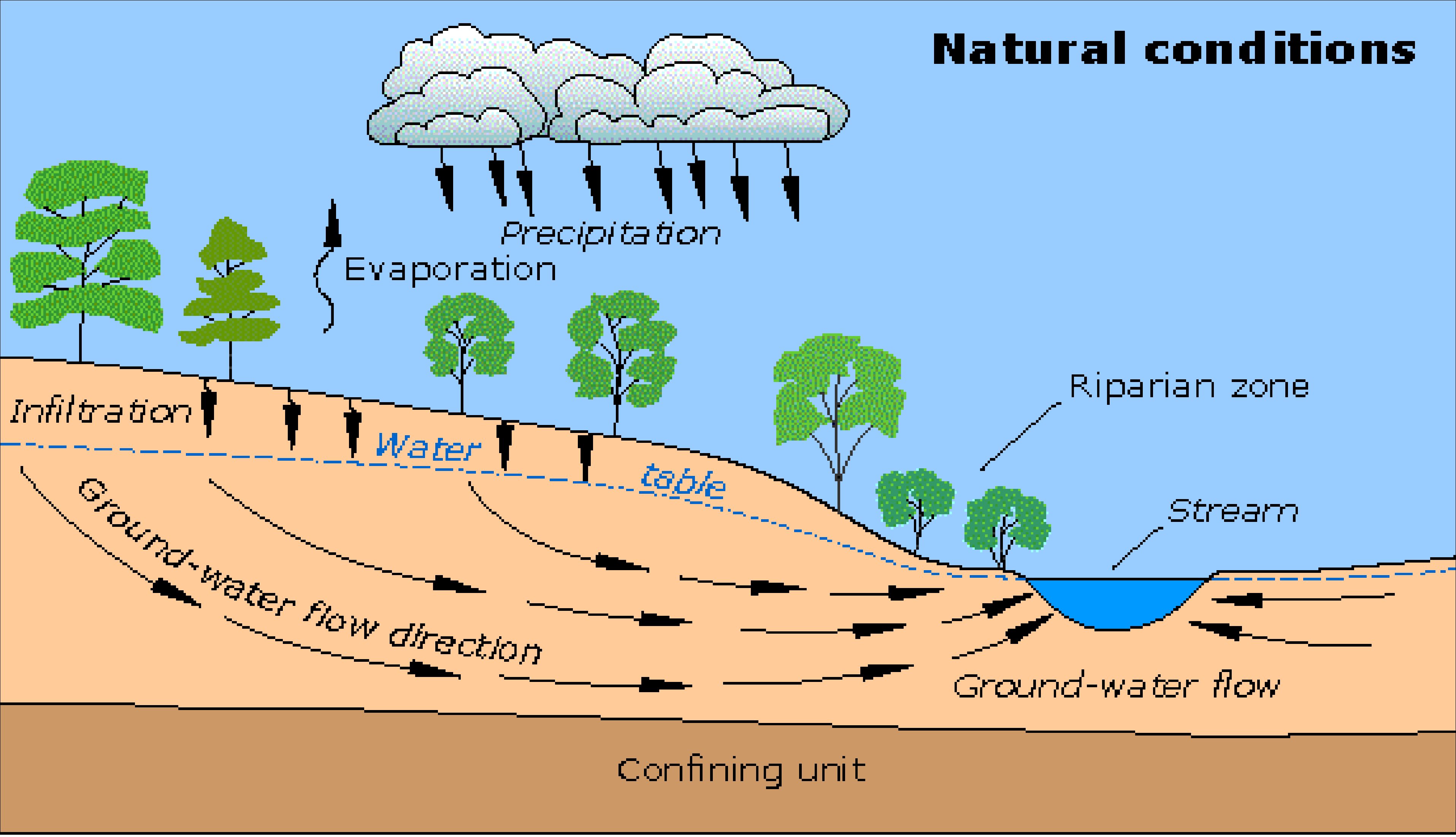
Feces

and

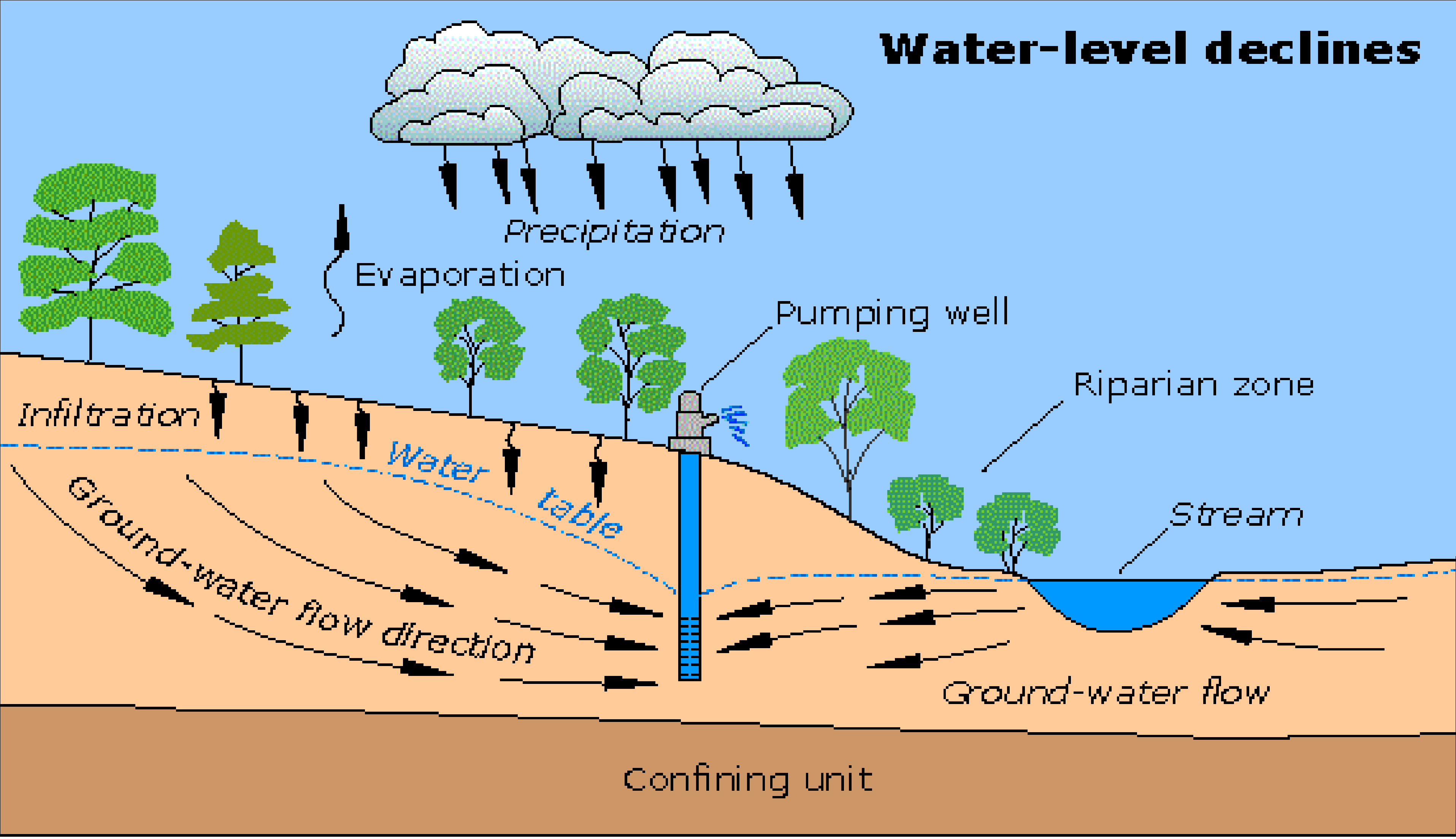
Trash

Groundwater

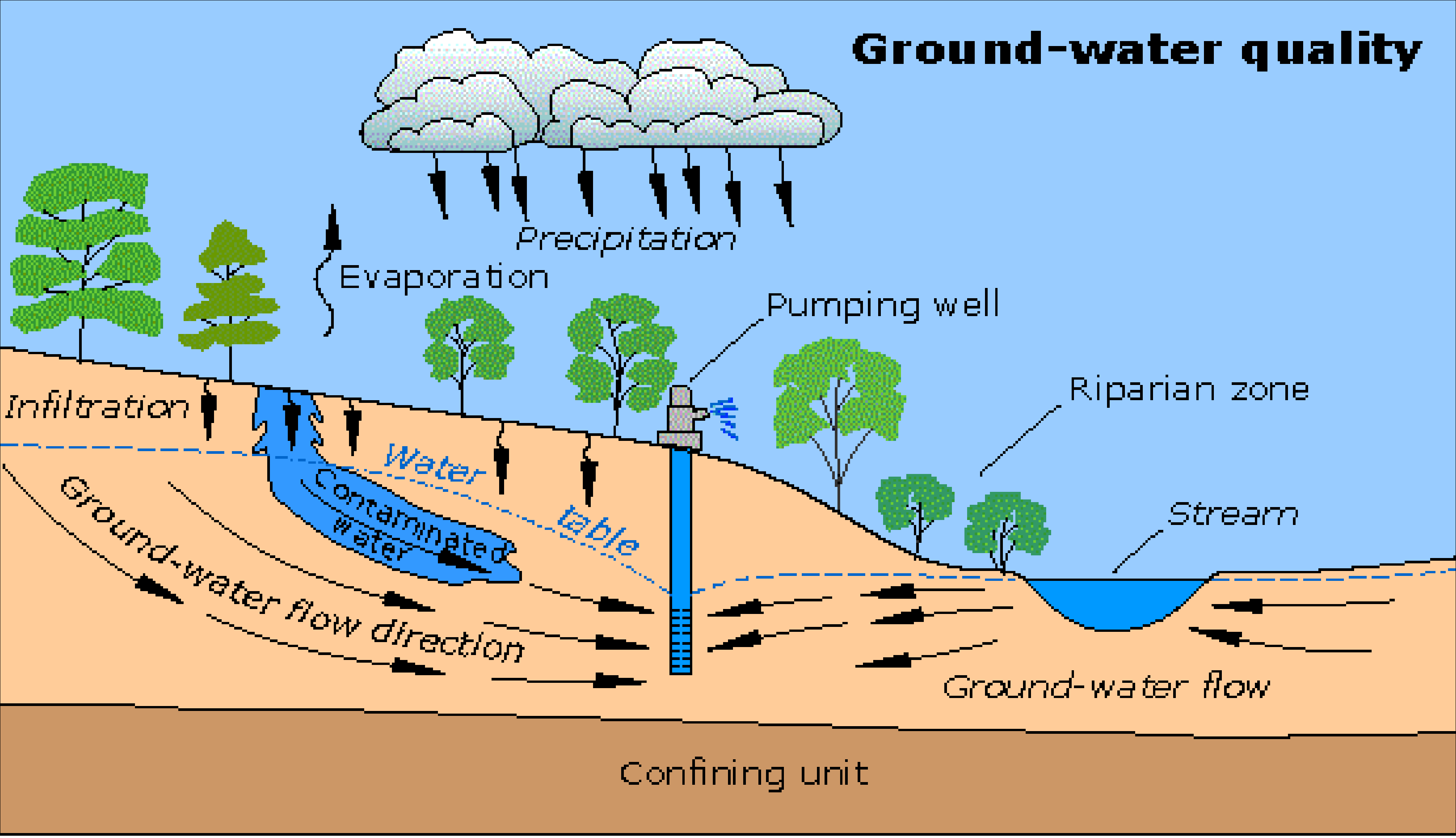
- Usually free from pathogens
  - Filtered by soil
  - Contamination due to poorly sited latrines or poor well construction
  - Susceptible to contamination in karst areas
- May contain metals (Fe, Mn) or hydrogen sulfide (H_2S)
- Yields in some areas may be too low for practical use
- May be too deep 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)



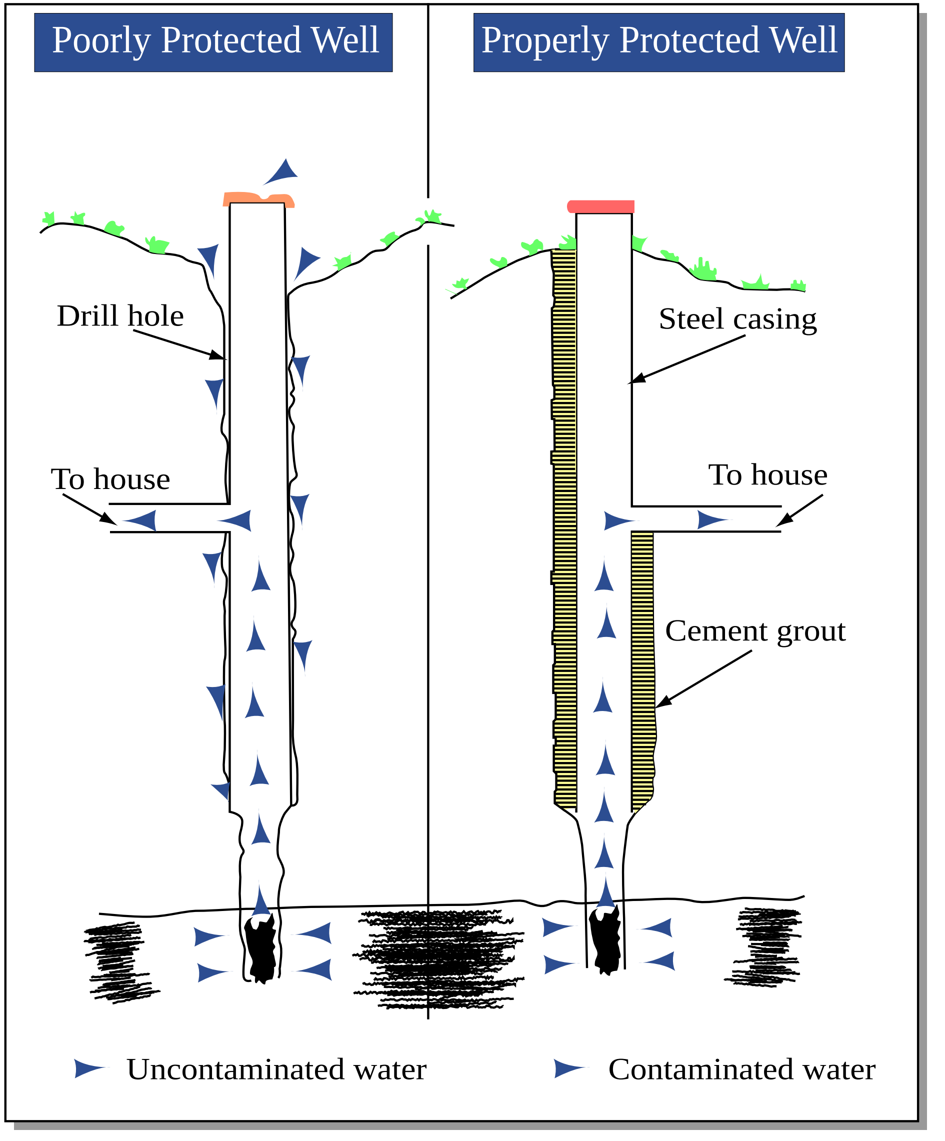
Water pumped from the ground-water system causes the water table to lower and alters the direction of ground-water movement. Some water that flowed to the stream no longer does so and some water may be drawn in from the stream into the ground-water system thereby reducing the amount of streamflow. (USGS, 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)



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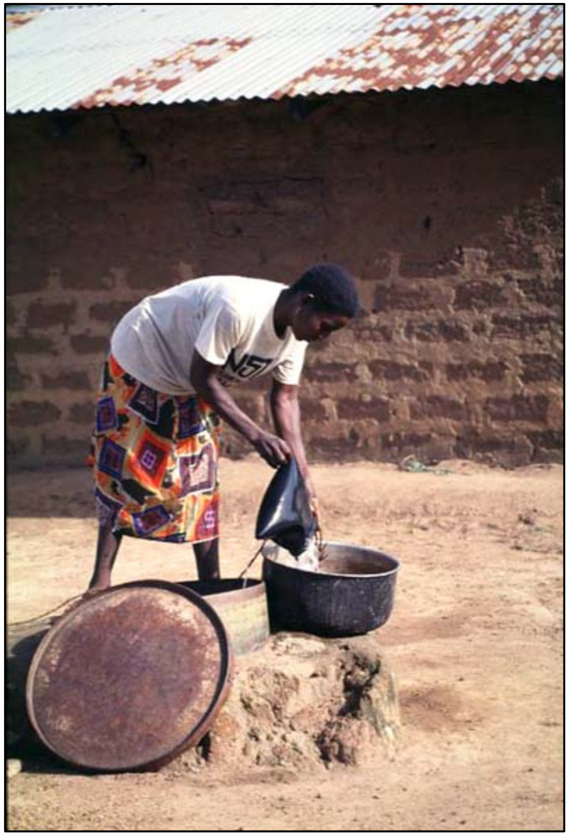
Pollution of Wells

- 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 - Ghana

Surface Water – Stream - Nepal

Improved Water Supplies

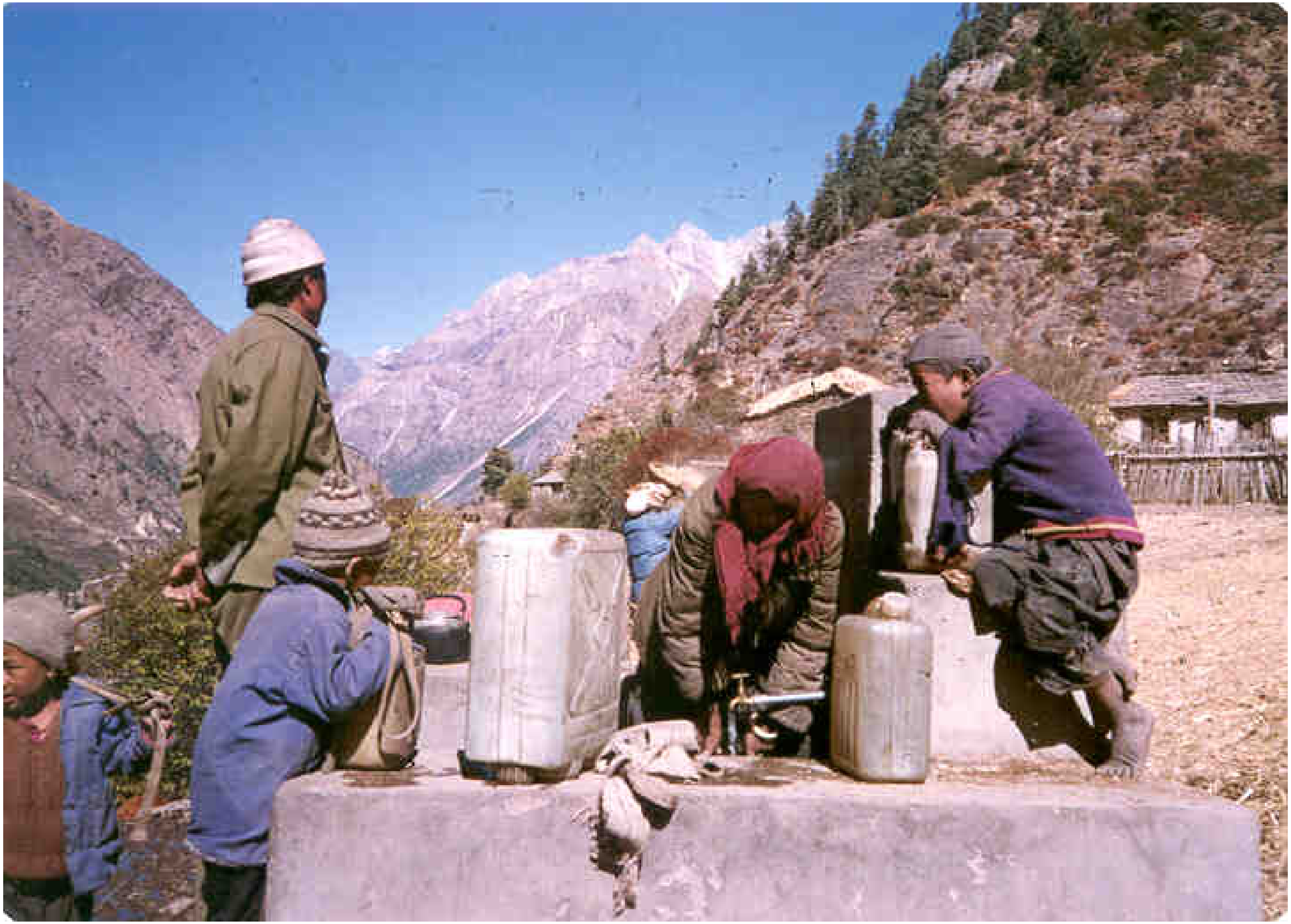
(as defined by the WHO-UNICEF Joint Monitoring Programme)

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

Public Standpipe

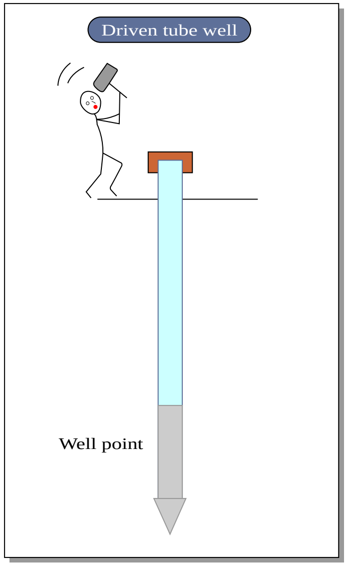
(Photo: Monique Mikhail)

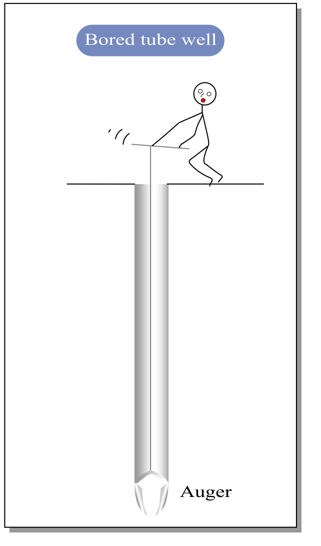
Public Standpipe



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





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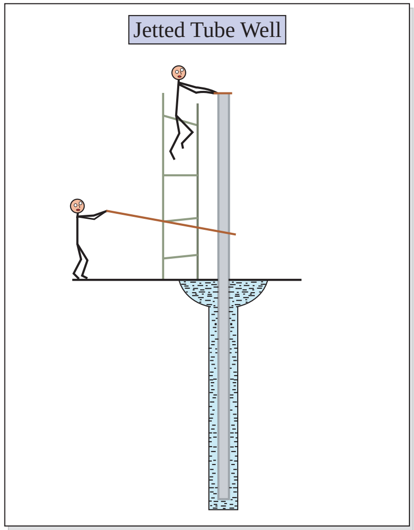
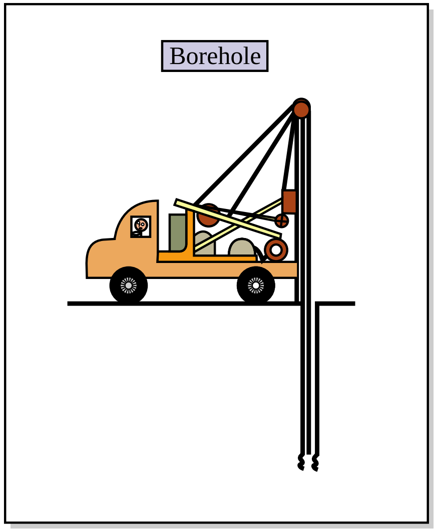
Well Types



- 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

Broken apron

Broken handpump

(Photos: Yongxuan Gong,MIT, 2003)

Machine-drilled Borehole Construction

Deep Well with Lift Pump

Deep Borehole Well with Lift Pump

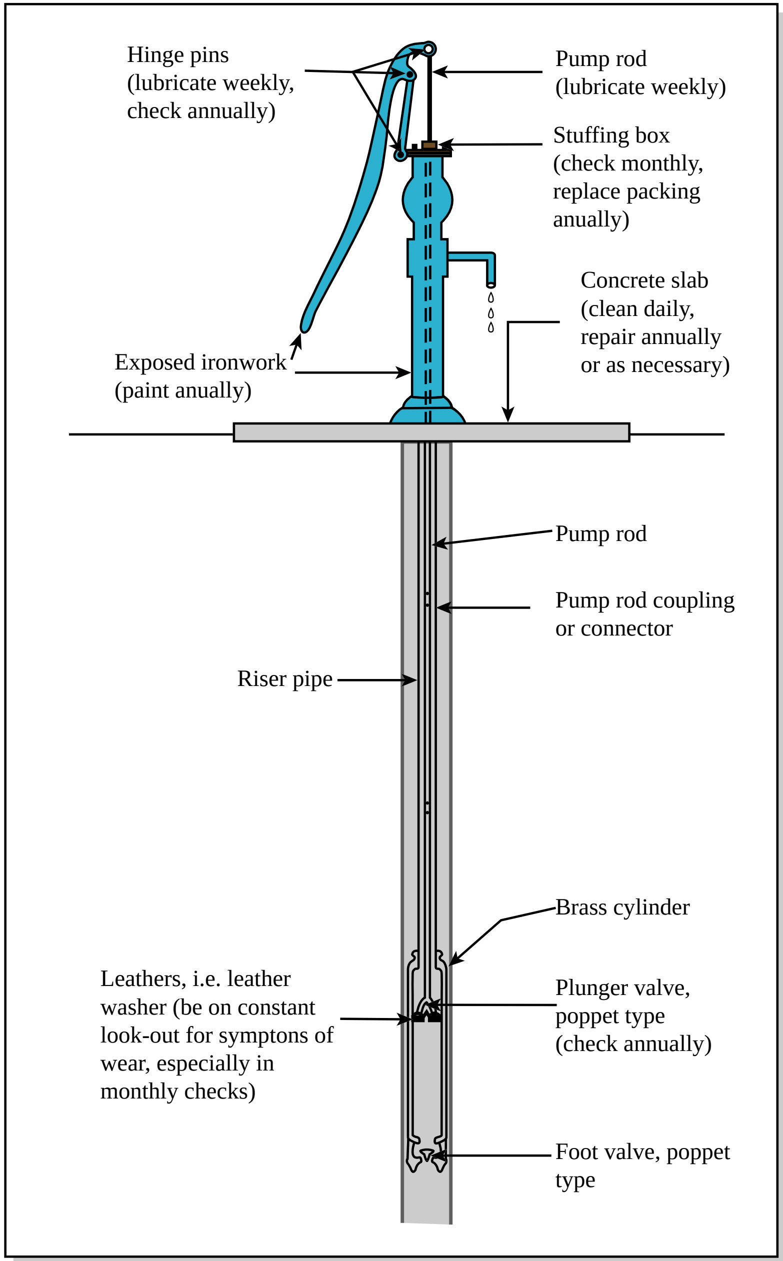
Deep Borehole Well with Lift Pump

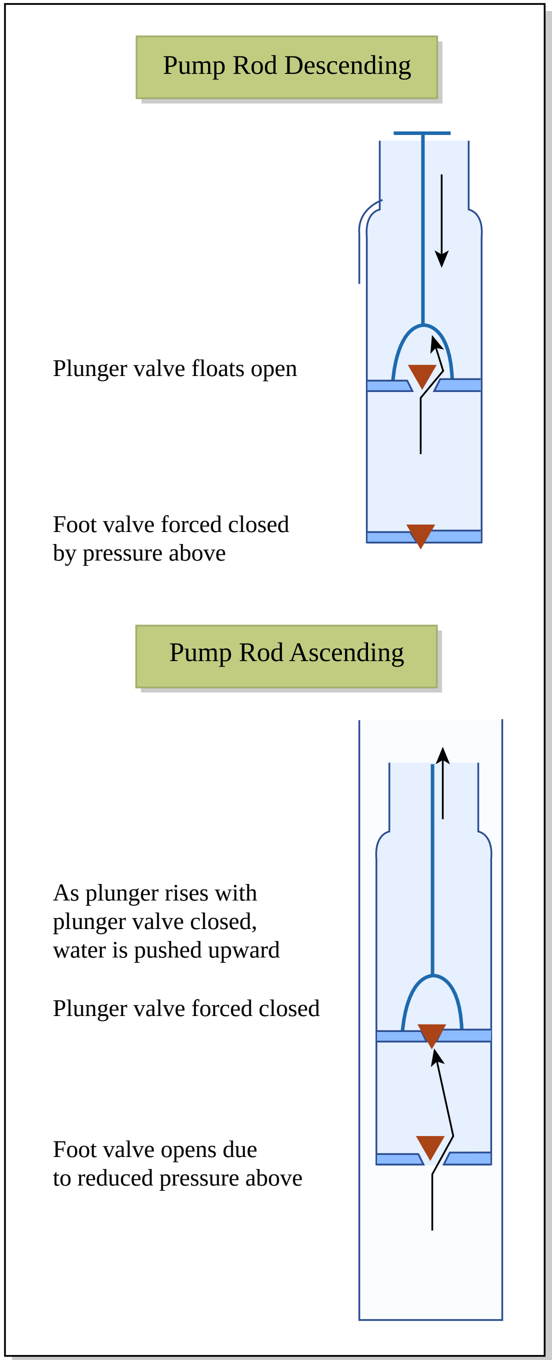
Hand Pumps

- 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





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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

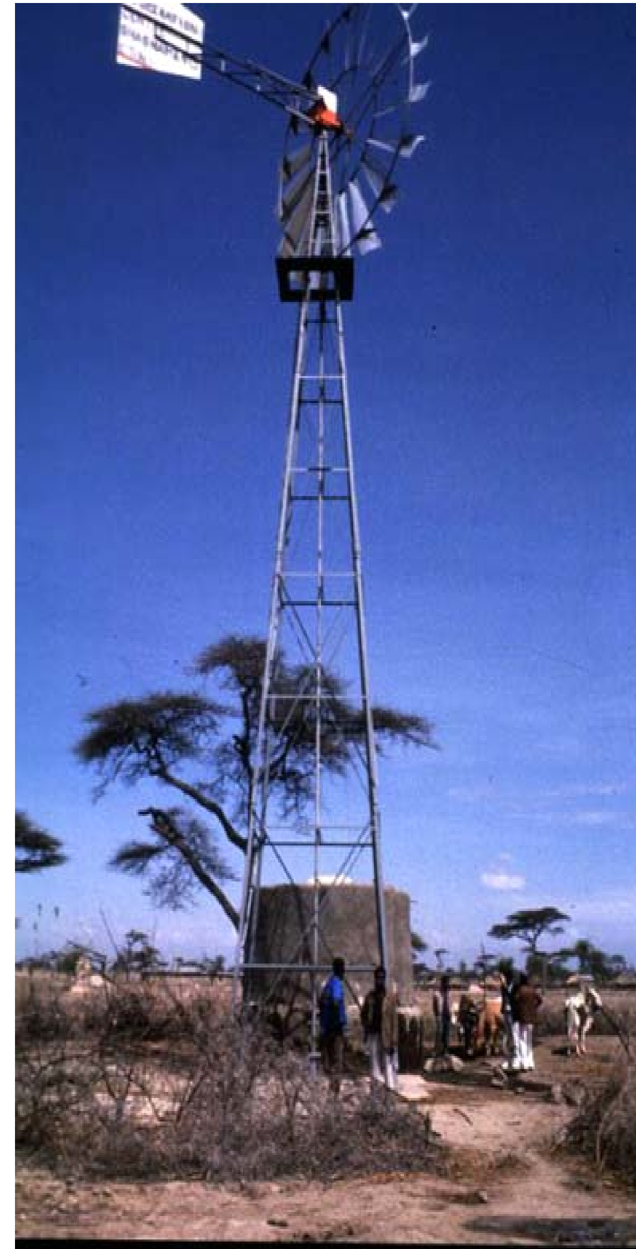
- Easier maintenance
  - Requires few tools
  - Bearings easy to replace
  - Open-top cylinder design
  - Special rod joints
- VLOM pumps
  - Village Level Operation and Maintenance
  - Centralized maintenance a problem – must be done at village level

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



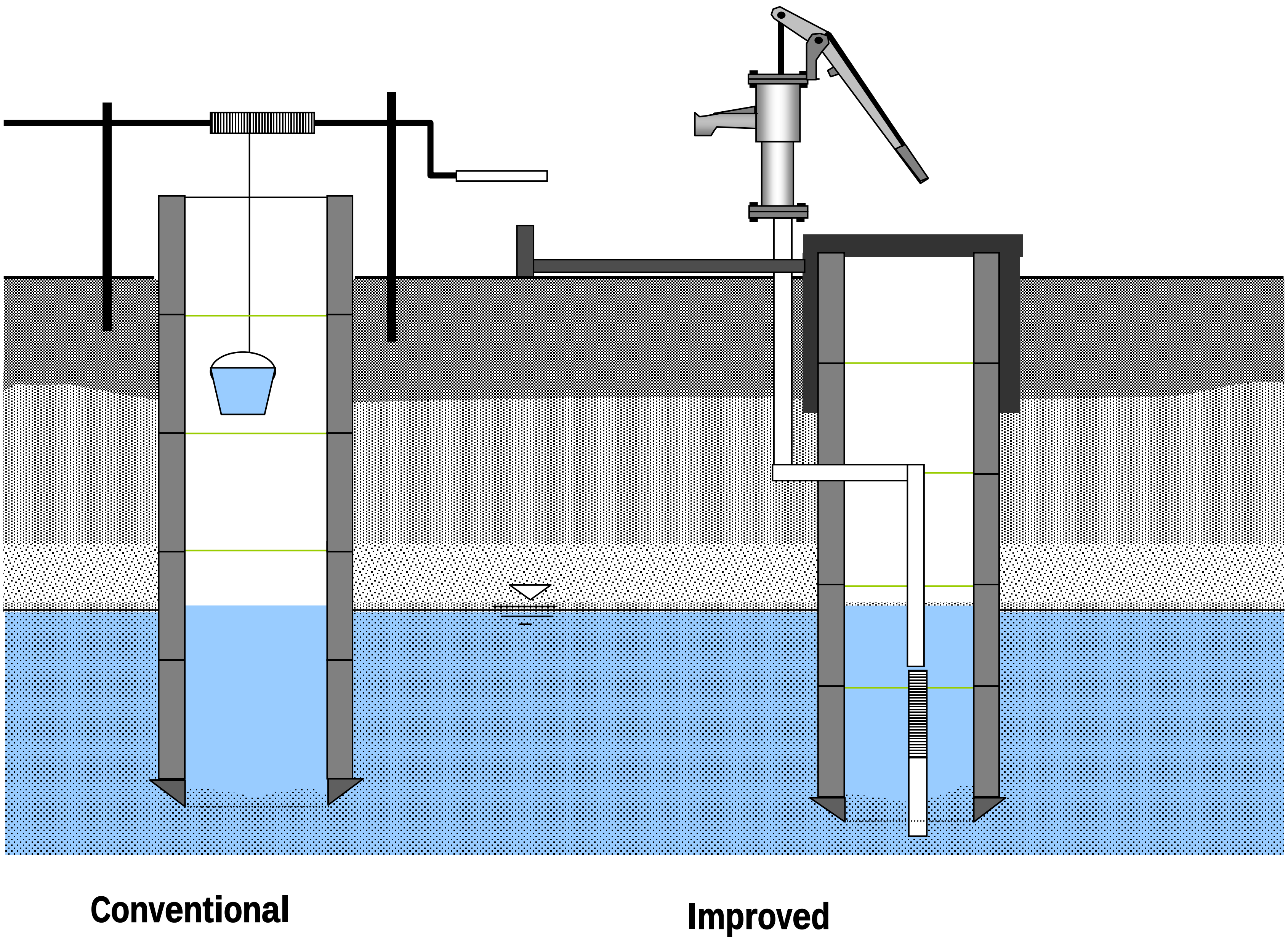
Alternate Pump Power Sources

- 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



Improved Dug Well

An improved dug well goes from this --->>>

to this --->>>

Improved dug well in Sierra Leone

Protected Springs

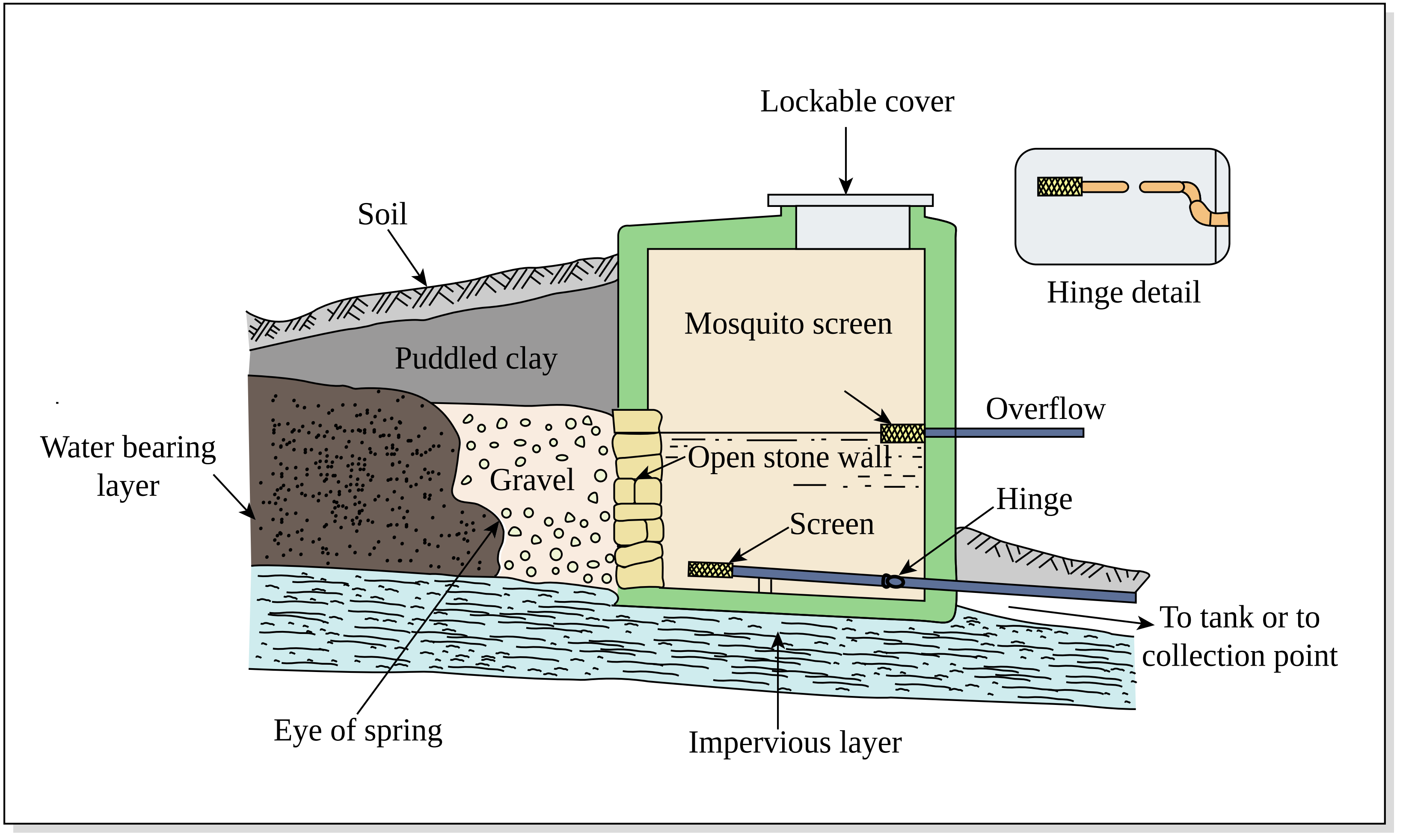
Protected Springs

- 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



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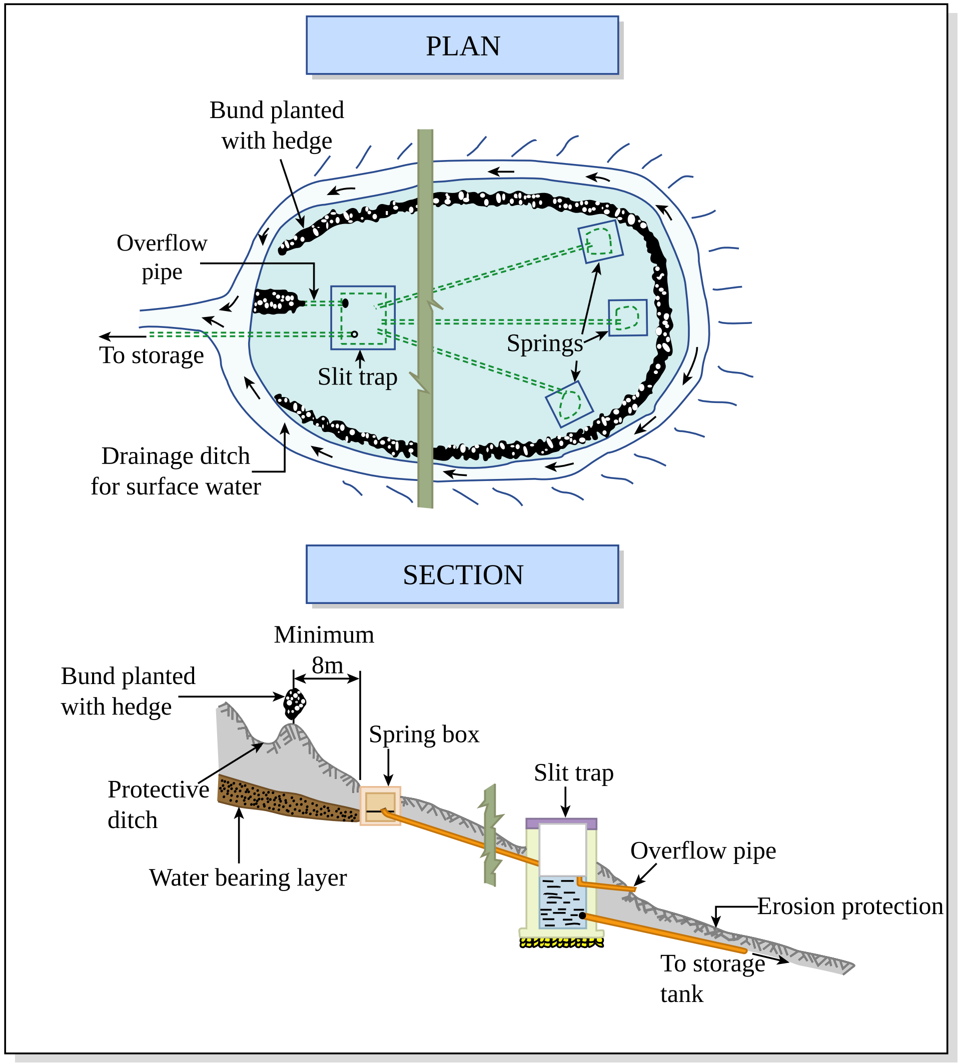
Spring Box Design



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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