Water Sources

(Improved and Unimproved)

and

Water Supply Planning

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Week 4 - MIT 11.479 J / 1.851J

March 5, 2007

Photo: Donna Coveney

Water on Earth – the Hydrologic Cycle

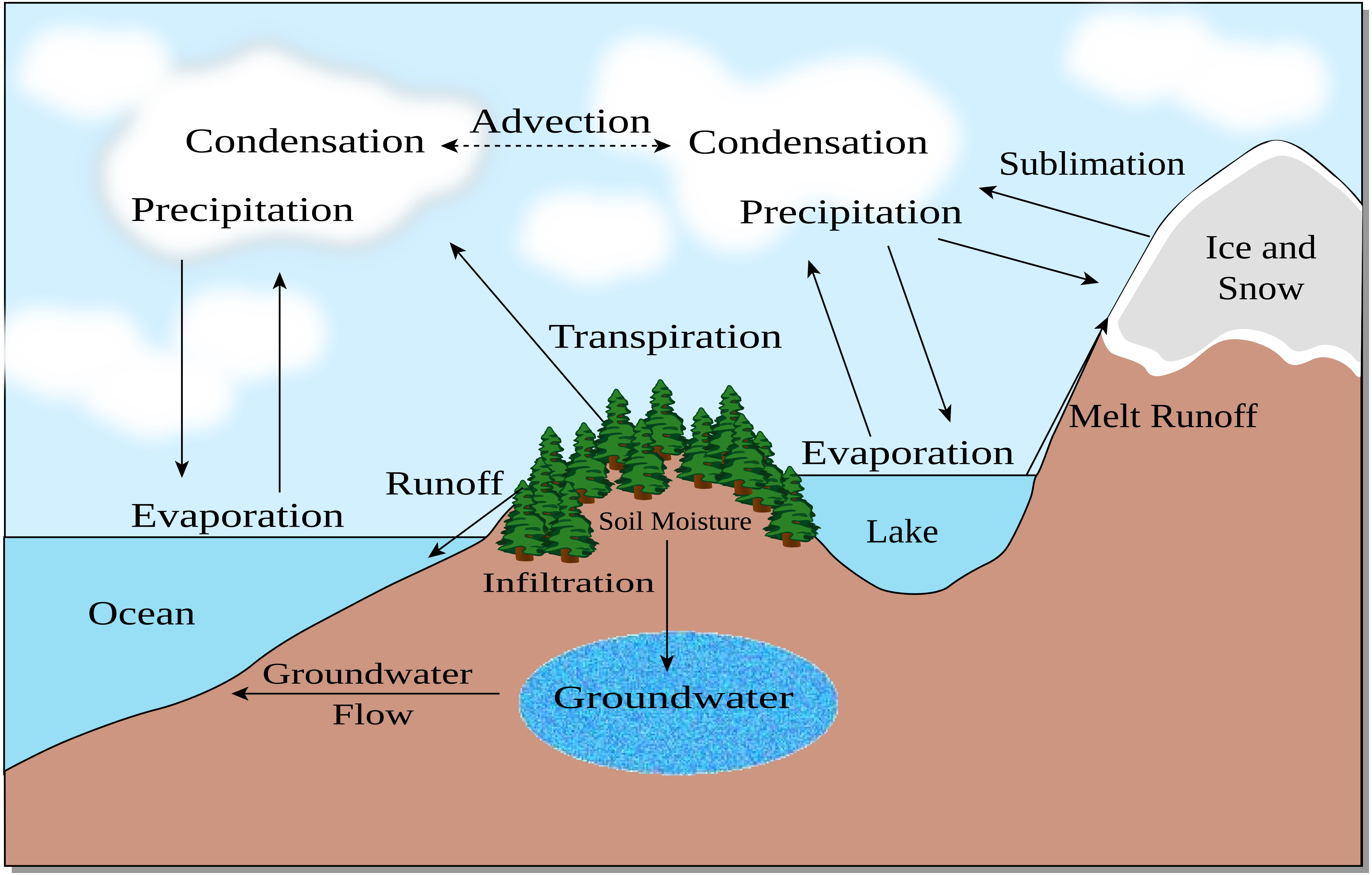


Figure by MIT OCW.

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

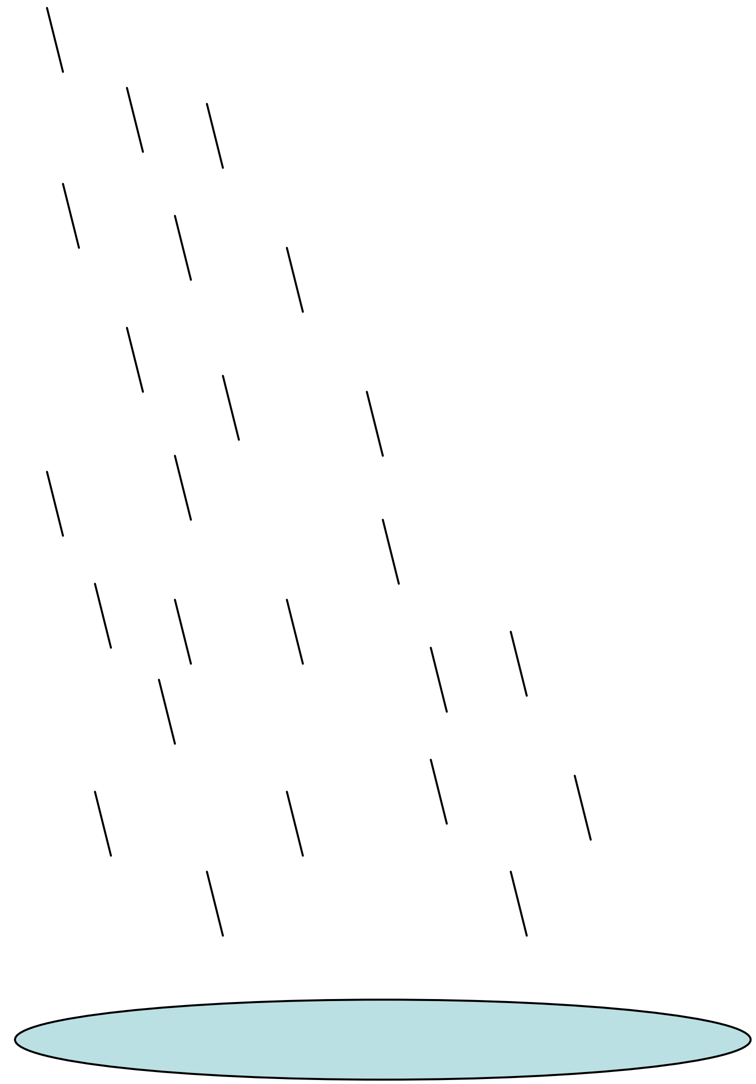
	km3/year
World Run-off from Land Surface (polar zones excluded)	40,000
Unreliable Run-off due to torrential rains, floods, etc. = 2/3rds of World Run-off)	26,000
Reliable on Uninhabited Land	5,000
Reliable Run-off	9,000

(Clarke, R. 1993)

Sources of Drinking Water

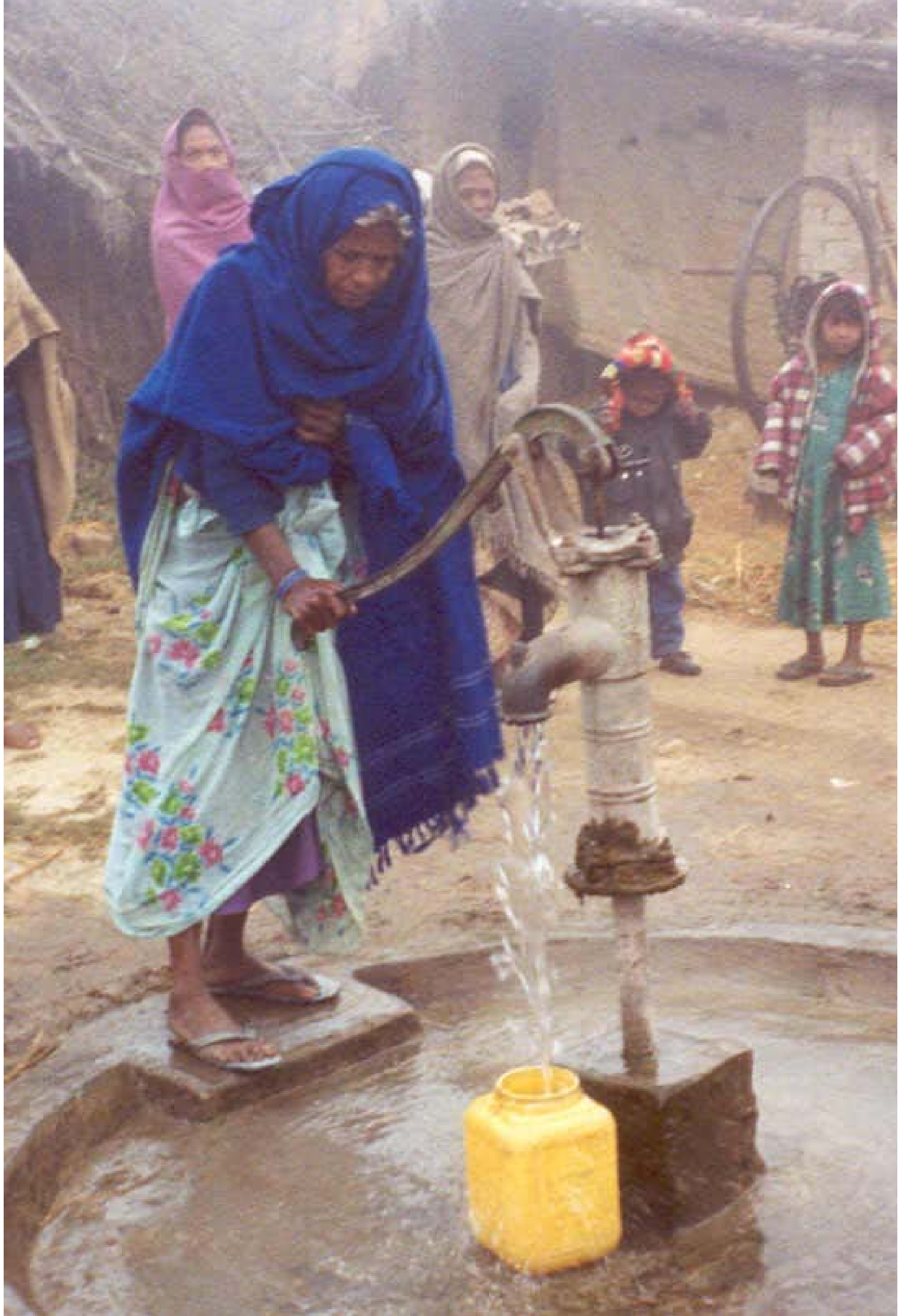
- <u>Major Sources</u>
  - Rainwater
  - Surface Water
  - Groundwater
- <u>Minor Sources</u>
  - Seawater
  - Saline water
  - Dew
  - Fog

Rainwater



Pristine Surface Waters

Pristine Ground Water



Surface Water – Stream (Kenya)

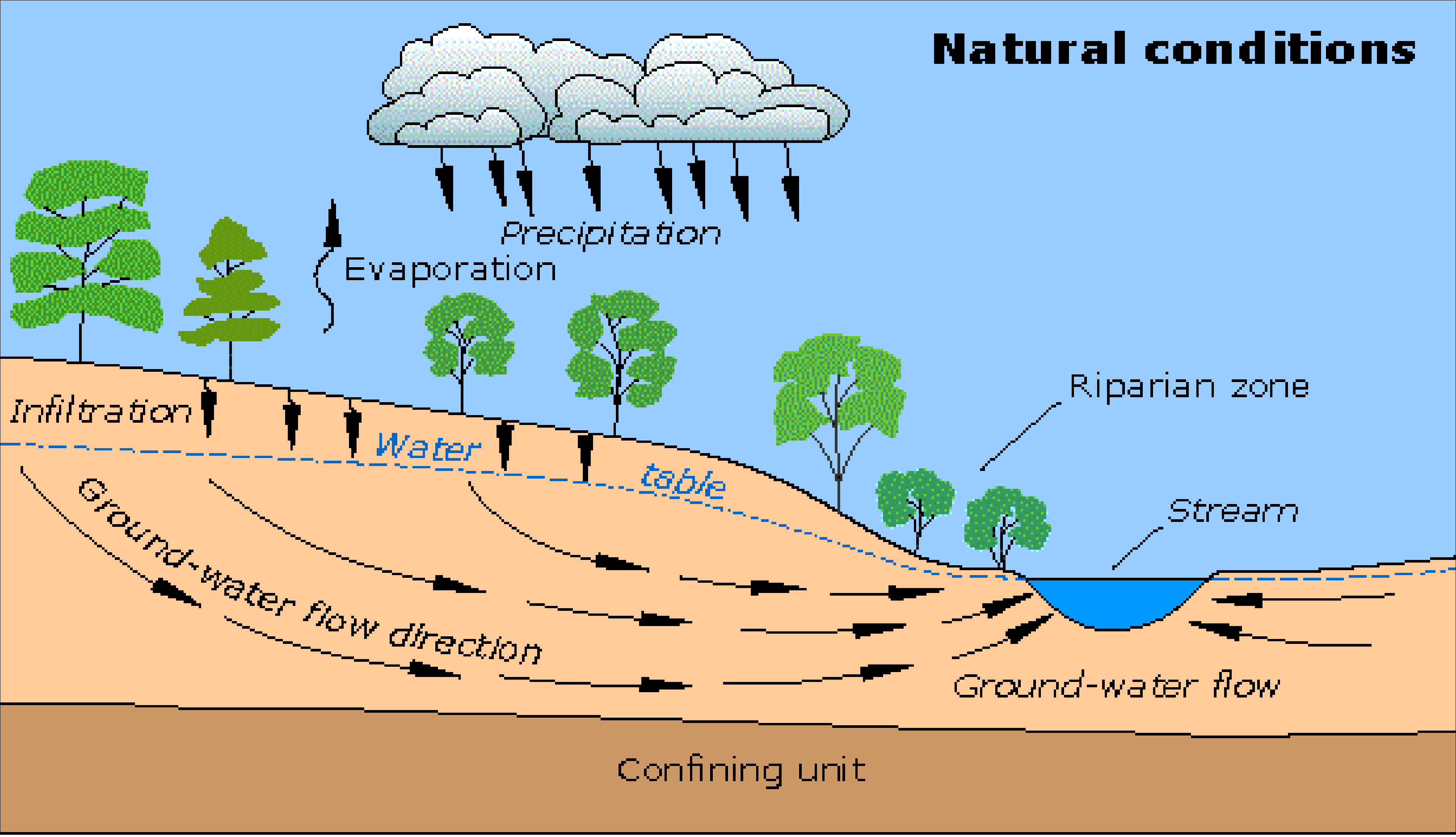
Surface Water-Rivers (Nepal)

Surface water is frequently contaminated by human and animal waste in many parts of the developing world.

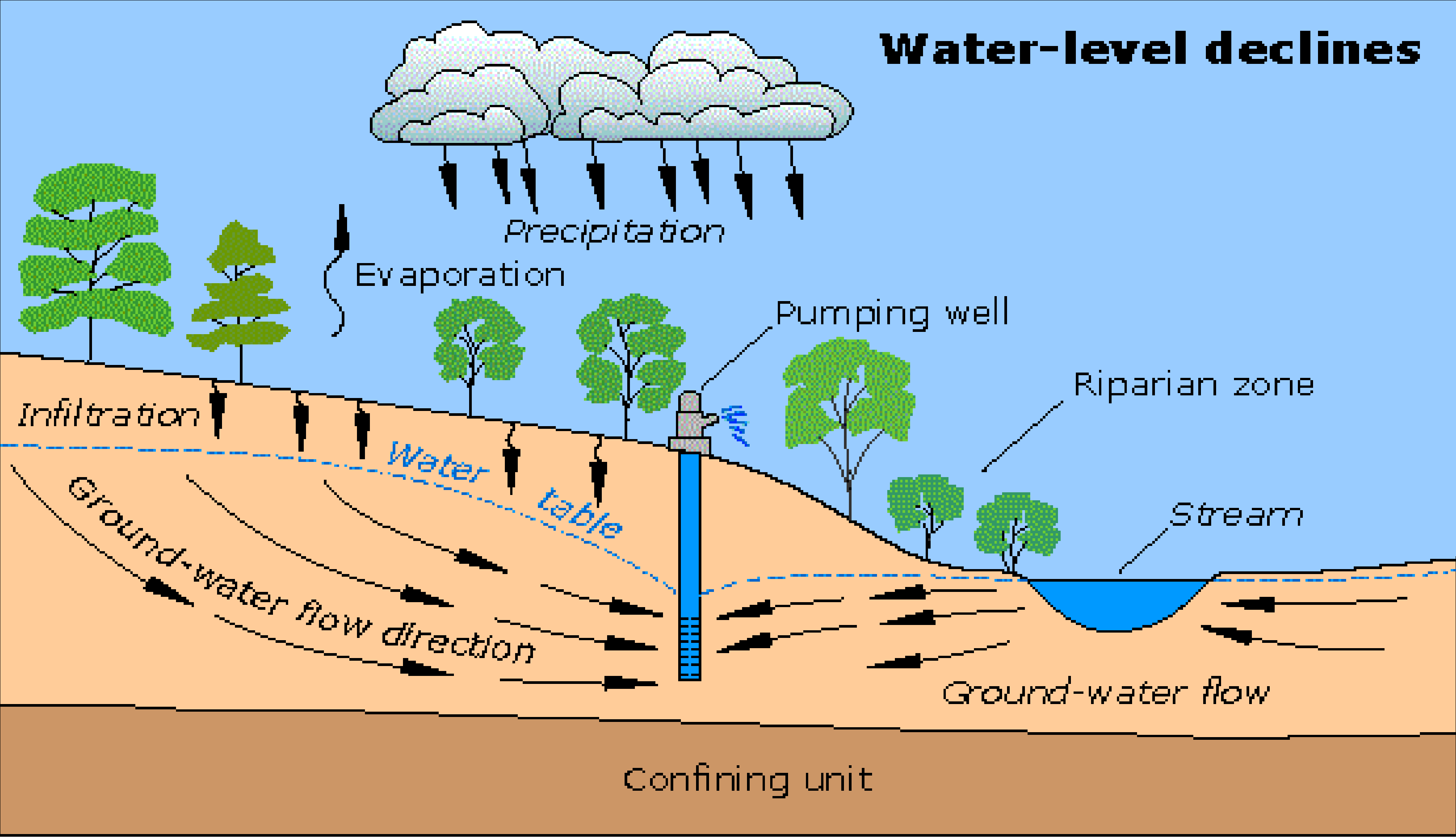
Feces and Trash

Groundwater

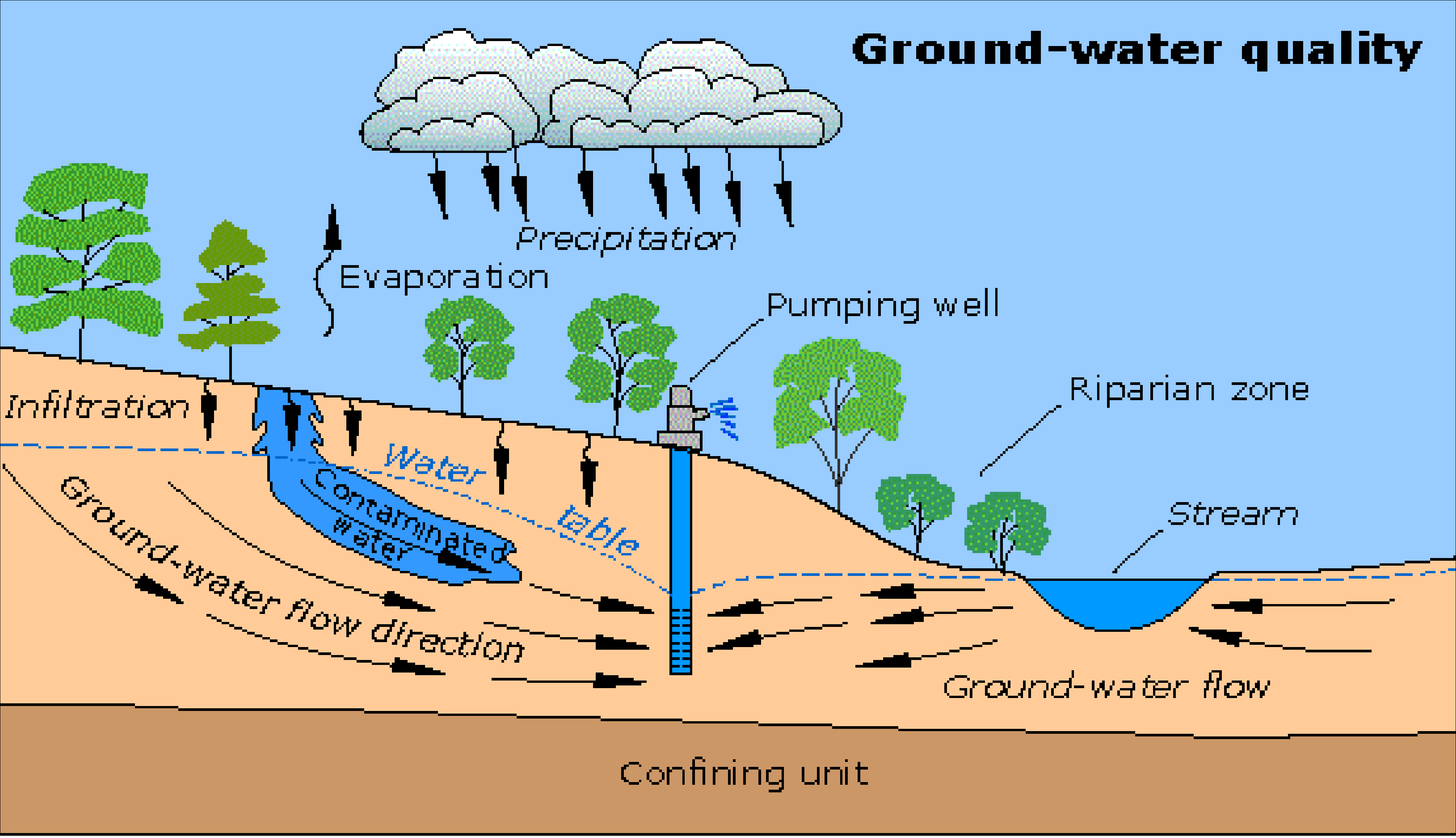
- Usually free from pathogens
  - Filtered by soil
  - Contamination due to poorly sited latrines or poor well construction
  - Susceptible to contamination in karst areas
- May contain metals (Fe, Mn) or hydrogen sulfide (H_2S)
- Yields in some areas may be too low for practical use
- May be too deep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

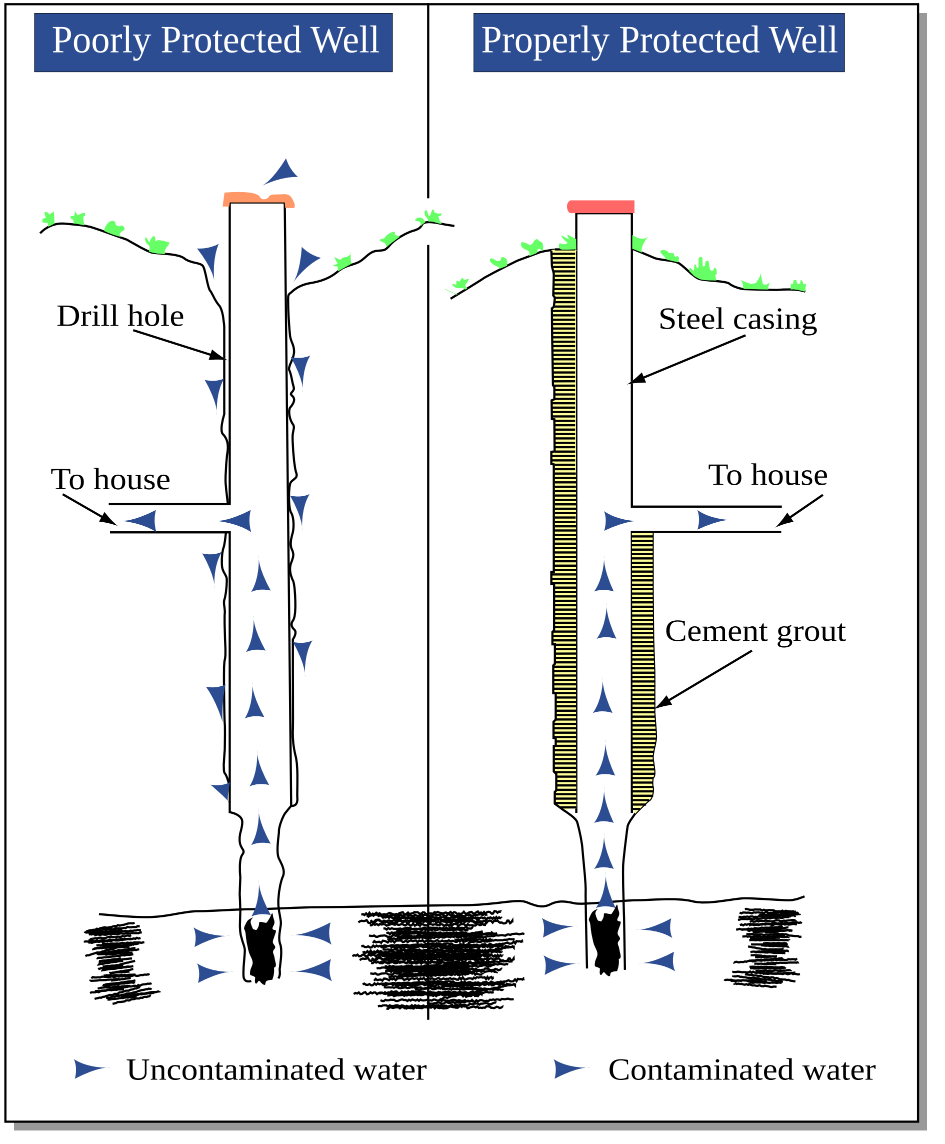
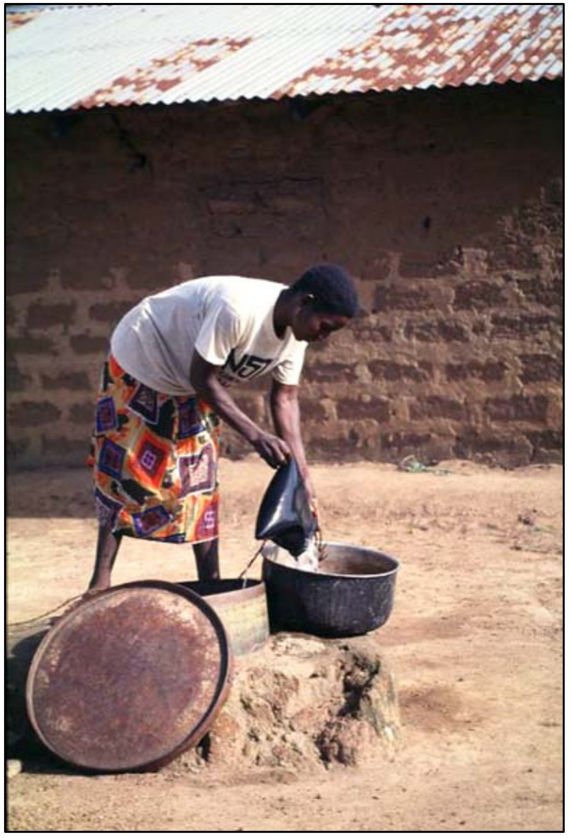


Figure by MIT OCW.

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 - 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

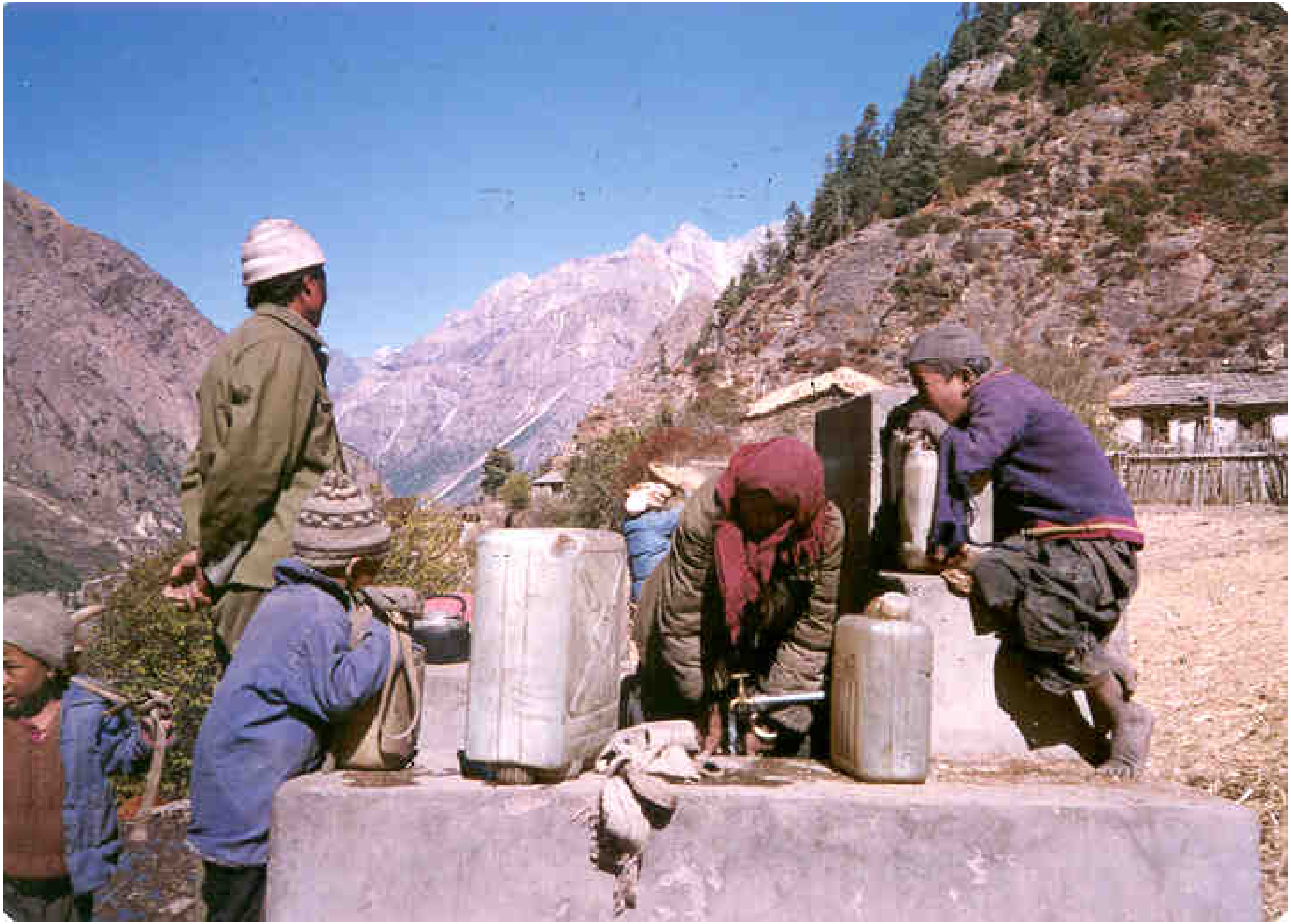
(as defined by the WHO-UNICEF Joint Monitoring Programme)

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

Public Standpipe

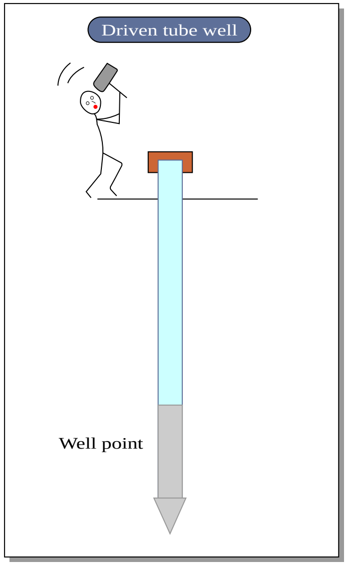
(Photo: Monique Mikhail)

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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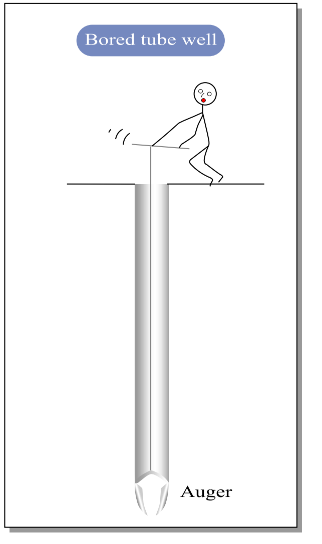
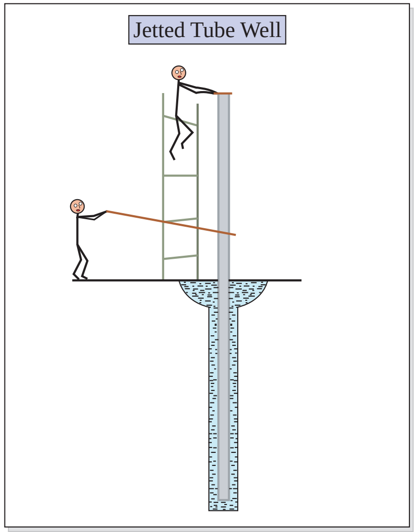


Figure by MIT OCW.

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



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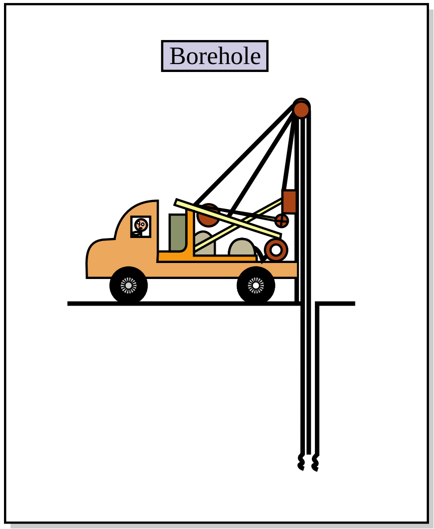


Figure by MIT OCW.

(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

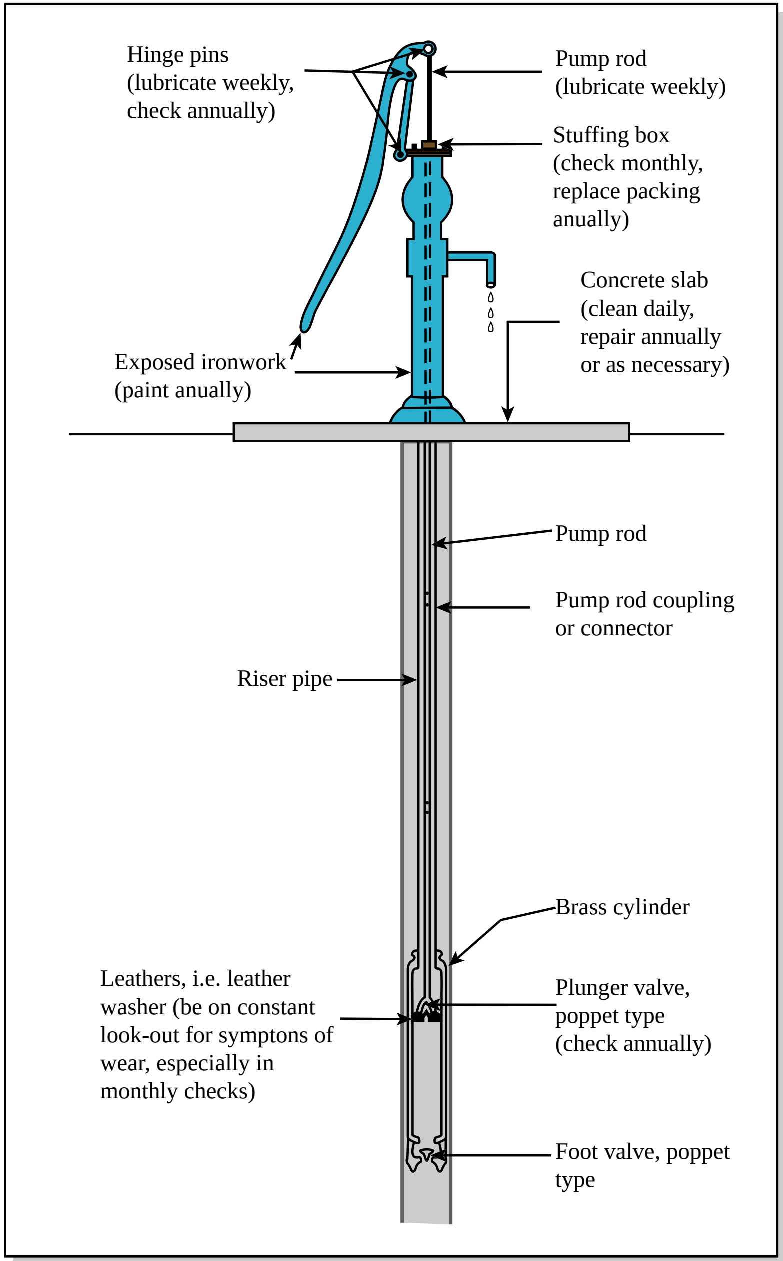
Deep Borehole Well with Lift Pump

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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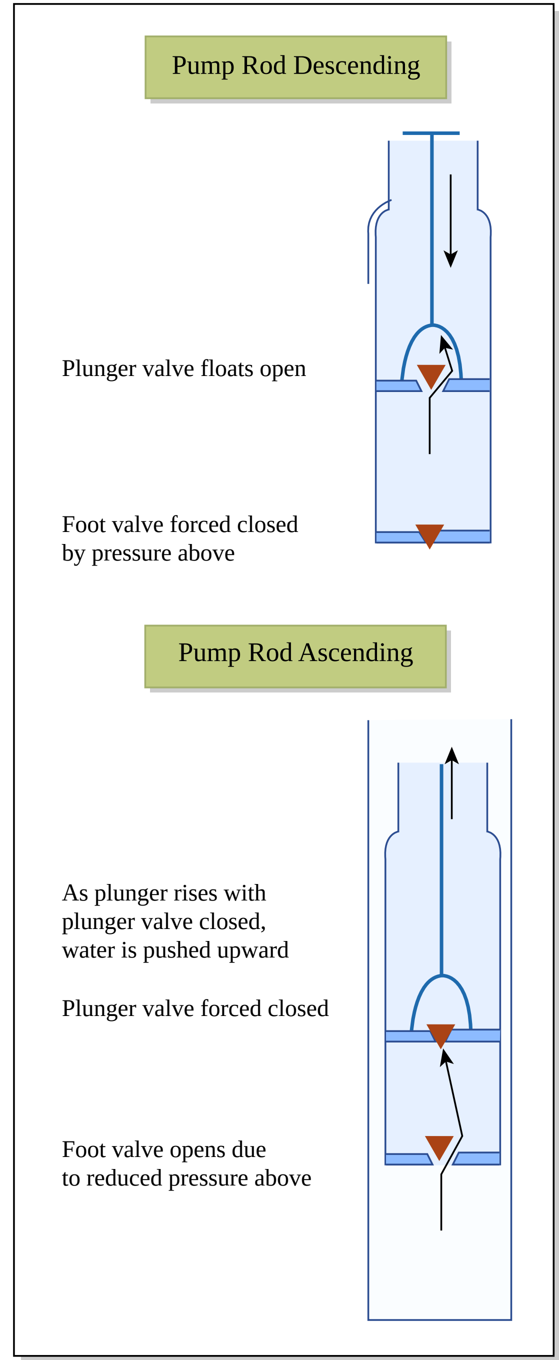


Figure by MIT OCW.

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

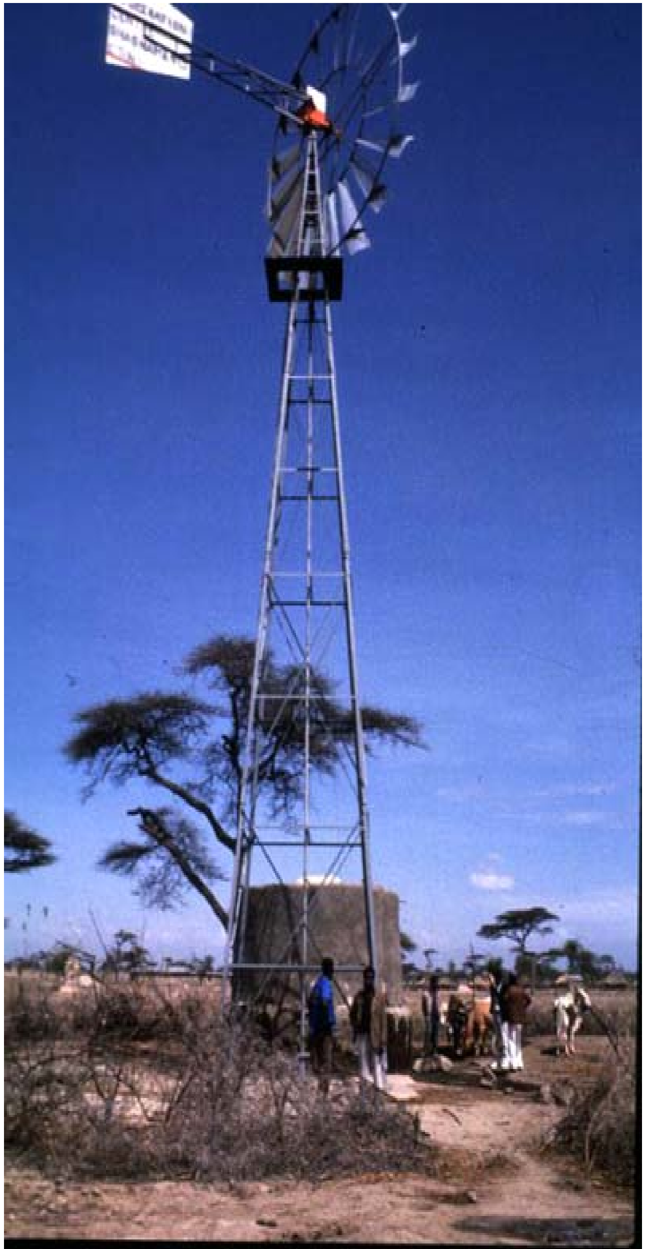
- Easier maintenance
  - Requires few tools
  - Bearings easy to replace
  - Open-top cylinder design
  - Special rod joints
- VLOM pumps
  - Village Level Operation and Maintenance
  - Centralized maintenance a problem – must be done at village level

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



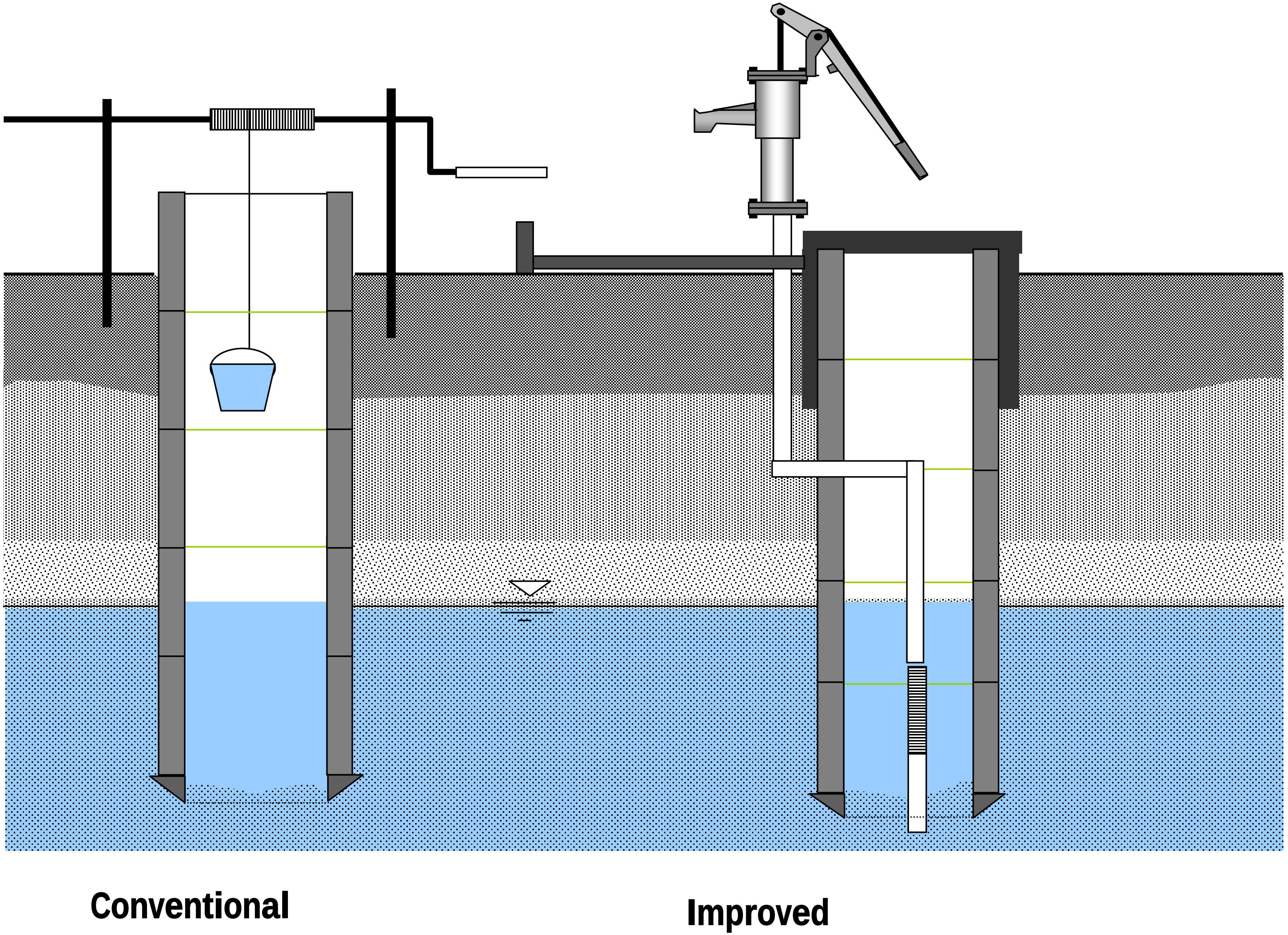
Alternate Pump Power Sources

- 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

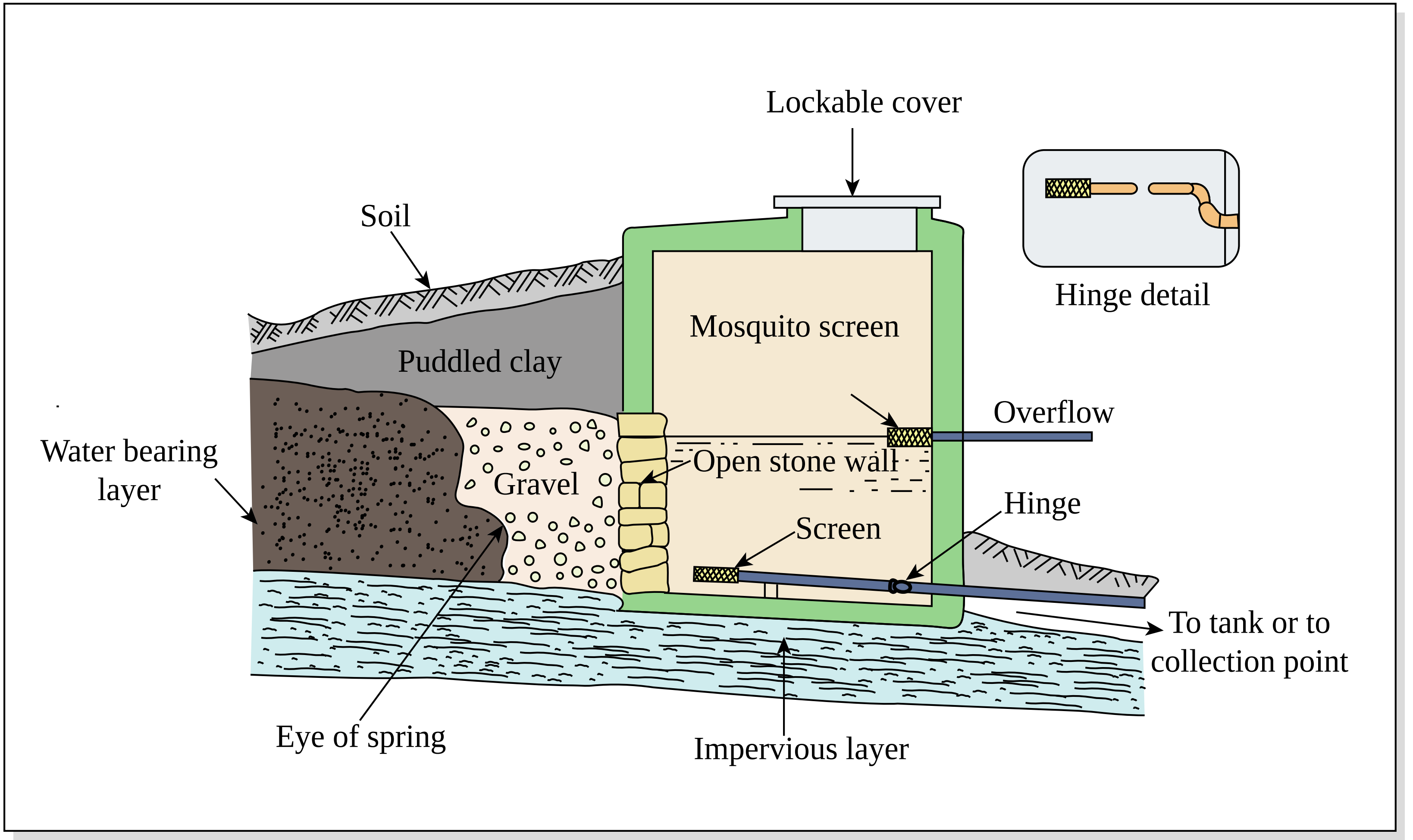
Protected Springs

- 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

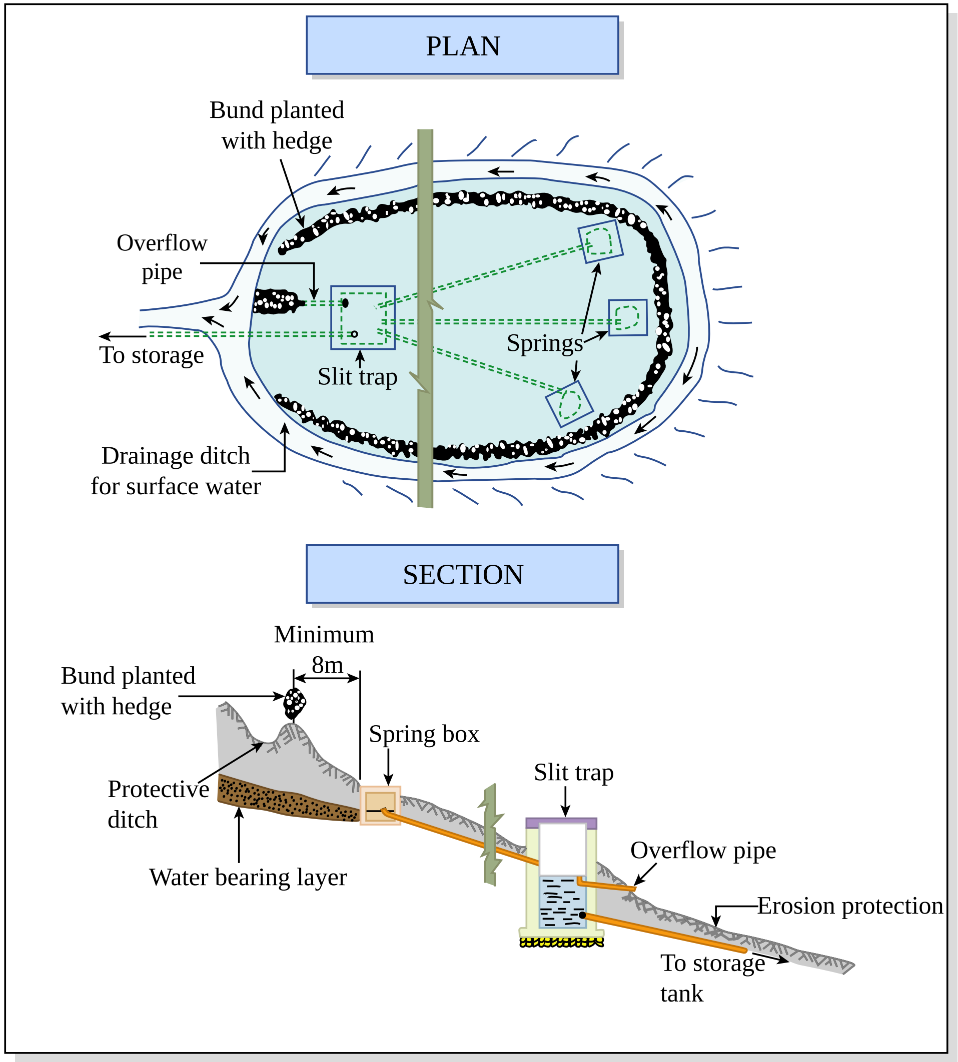


Figure by MIT OCW.

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

Steps in Water and Sanitation Planning

- Problem Identification
- Organize Community Participation & Support
- Set Objectives
- Collect Data
- Formulate Alternatives
- Choose Best Method
- Develop Detailed Plan
- Build the System
- Operate and Maintain
- Monitor and Evaluate

Problem Identification

- Current water source is unacceptable, if:
  - Water Quality is bad;
  - Water Quantity is insufficient;
  - Inaccessible Water Source
  - Unreliable Water Source

- Water Quality is measured by laboratory or field testing, but oftentimes, this is difficult, so…
- Surveys…

Types of Surveys

- “Sanitary” Surveys (water/sanitation/hygiene)
- Infrastructure Survey
- Epidemiological Surveys
  - Prospective and Retrospective Cohort Surveys
  - Cross-Sectional Surveys (snapshot in time);
  - Longitudinal ecologic surveys (on-going surveillance over many years)
- Willingness-to-Pay Surveys (aka “Contingent Valuation”)
- Focus Groups
- Example: Batey1, Dominican Republic

Batey – Dominican Republic

Batey, DR

Batey 1 Water Tower

Aquaduct

Community Participation and Support

- A successful program must include a plan for community support
- 3 ways to gain community support:
  - Promotion
  - Community involvement (community appraisal, user groups, mapping)
  - Training in O&M

Can you think of other ways?

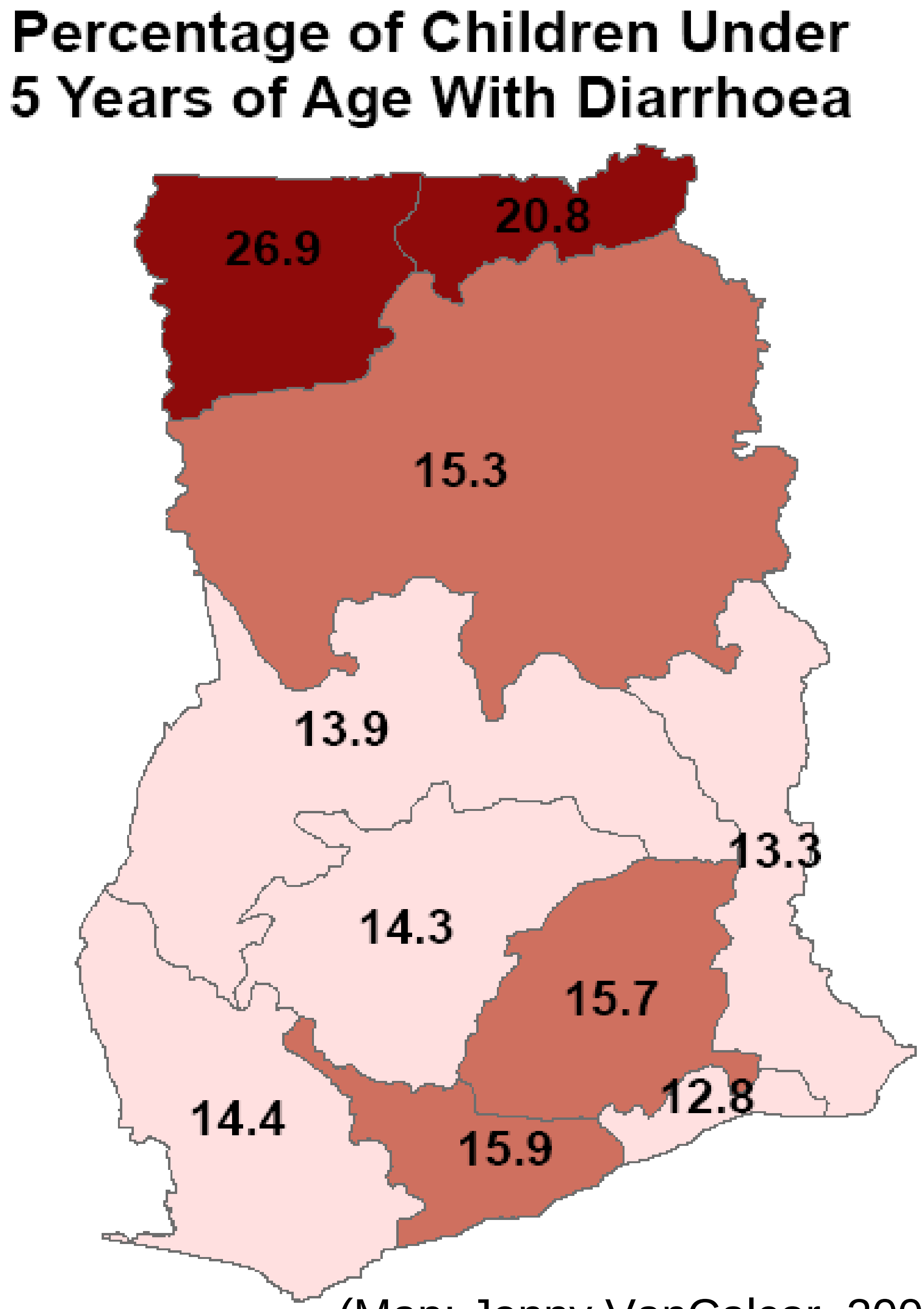
Data Collection

- Population statistics
- Rainfall
- Environmental data
- Mapping
  - Community Mapping / Community Appraisal
  - GIS Mapping
- Community's development history
- Community resources
- Culture and customs

- http://www.scn.org/ip/cds/cmp/modules/par-par.htm

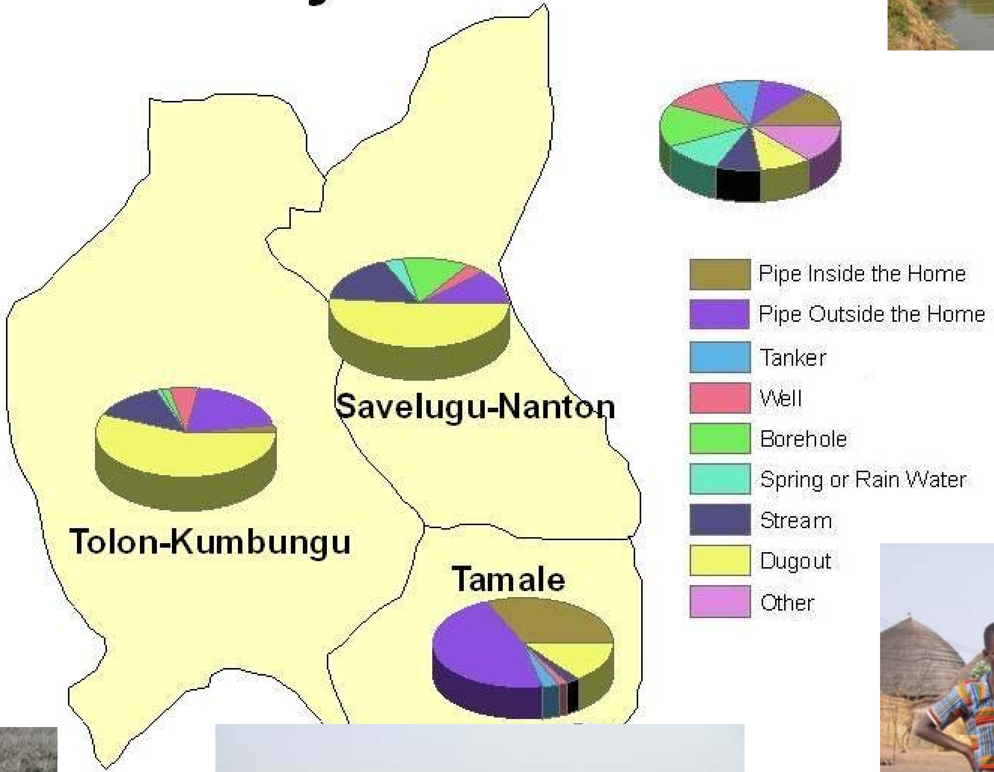
GIS
& Data
Mapping
–

Diarrhea
in
Northern
Region
Ghana



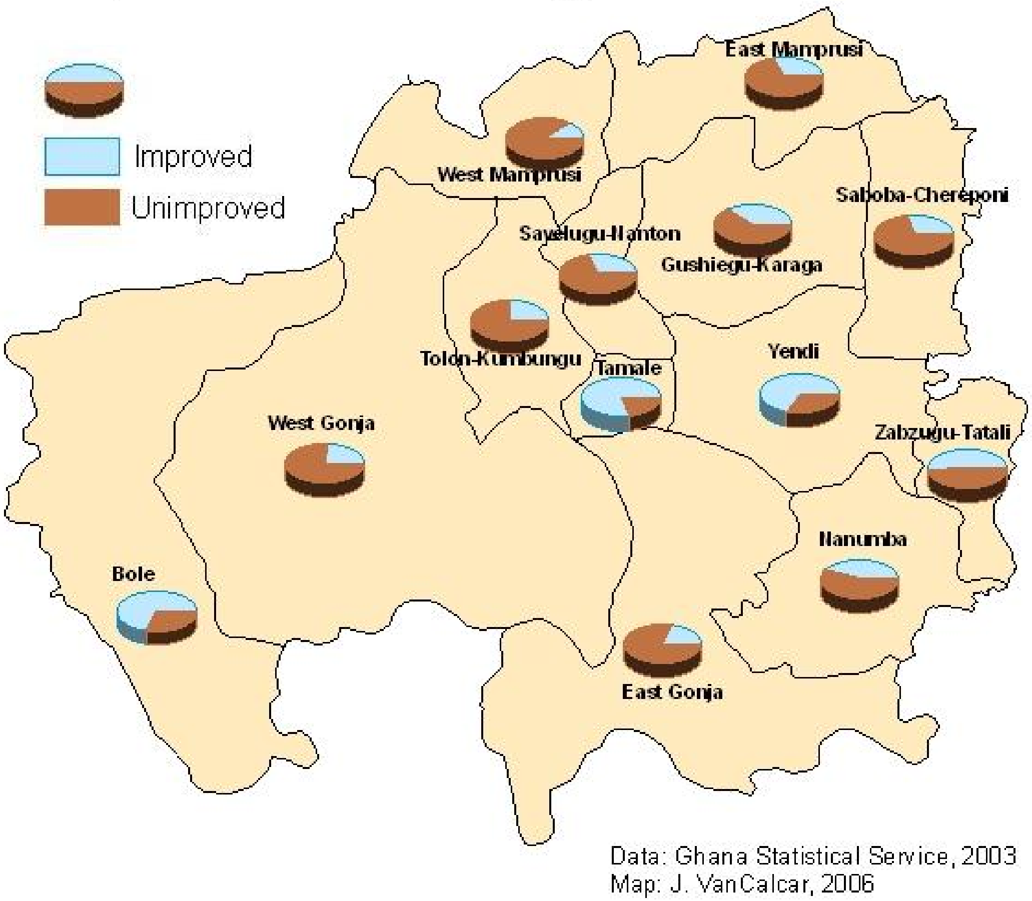
(Map: Jenny VanCalcor, 2006)

Types of Water Sources Used by Households



Statistical Serv
alcar, 2006

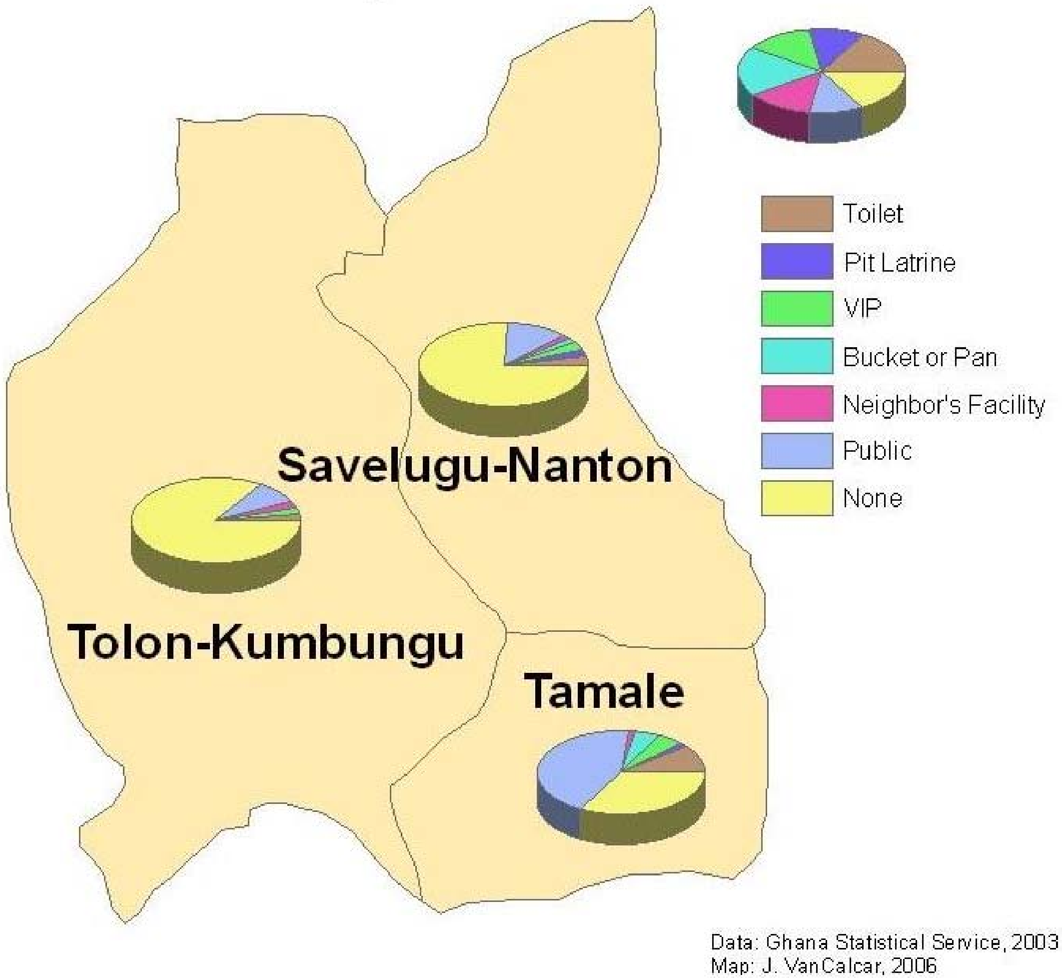
Percentage Use of Improved and Unimproved Drinking Water Sources



- Improved Sources
  - Boreholes
  - Household connection
  - Public standpipe
  - Rainwater harvesting
  - Protected Springs and dug wells
- Unimproved Sources
  - All surface water sources
  - Unprotected dug wells and spring
  - Tanker trucks
  - Vendor water

1 million out of 1.8 million people in the Northern Region are currently using an unimproved source

Types of Sanitation Facilities Used by Households



Latrine is the process of being built

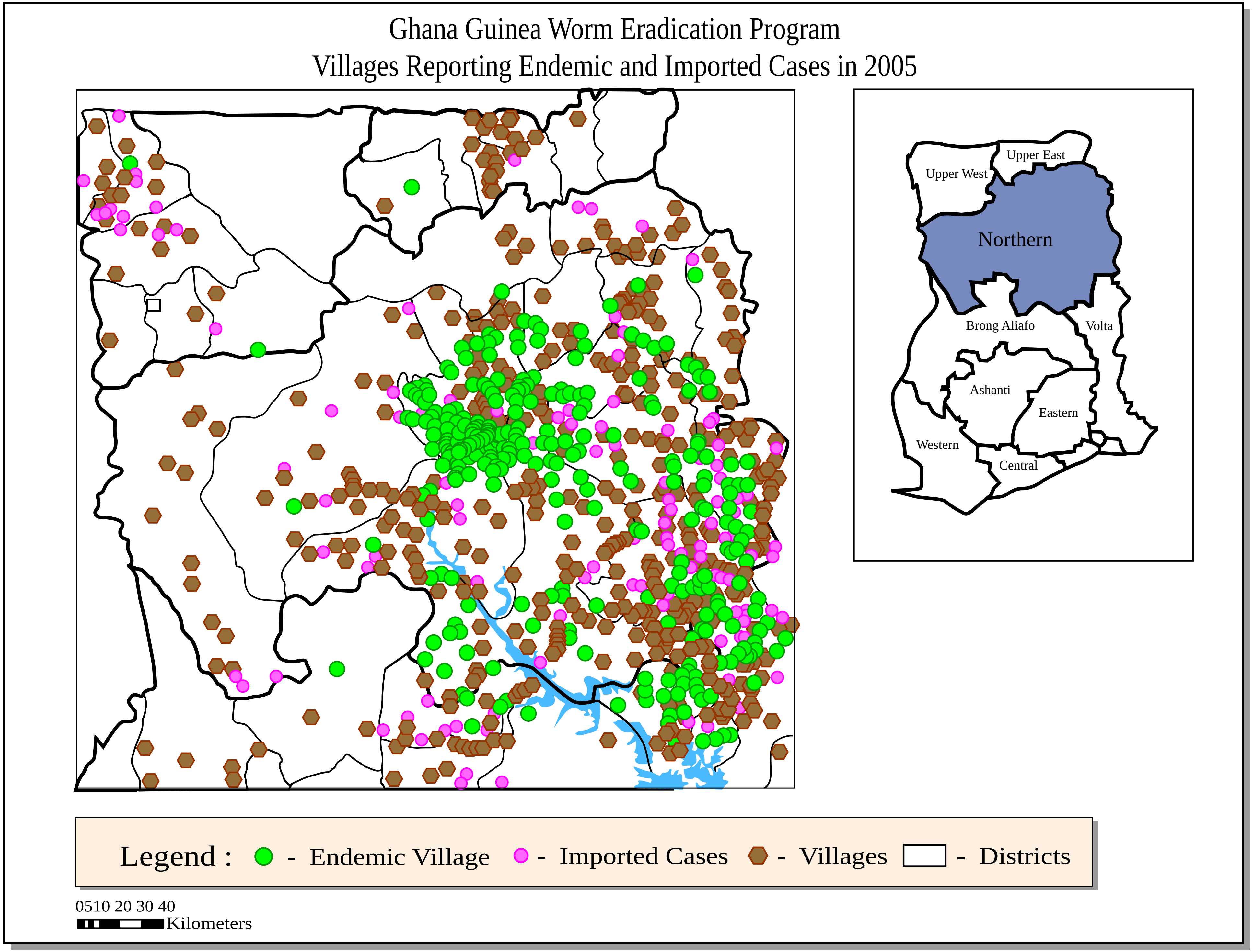


Figure by MIT OCW.

Set Alternatives

OR

OR

OR…?

Choose the Best Alternative

- **Question: What are some considerations (decision criteria) you might use to choose the best alternative?**

Choose the Best Alternative

- Water supply characteristics (will it meet demand now? In 10 years?)
- Social acceptability – community’s needs
- Health factors
- Economic factors- willingness to pay
- Institutional context
- Accessibility
- Other… What do you think…?

Develop the Plan

- **Question: What should be in the plan?**

What's in the Plan?

- Proposed System
- Costs
- Sources of Finance
- Implementation Schedule
- Plan for Construction and Sources of Materials
- Energy Requirements
- Environmental Impacts
- Social Impacts
- Operation and Maintenance Requirements
- Other?

Monitor and Evaluate the System

- User Acceptance
- Water Quality
- Water Quantity
- Accessibility
- Reliability
- Proper Operation and Maintenance
- Financial sustainabilty
- Sustainable Yield
- Systems Thinking: Relationship to:
  - Sanitation
  - Hygiene interventions
  - Other?

Some Factors Affecting Planning

- Geographic Location, Environment & Climate
- Urban vs. Rural – Population Growth and Density
- Settlement Patterns
- Domestic Water Use, Agriculture Water Use
- Culture

Geographic Location, Environment and Climate

Tropical Climates Hinder:

- Agricultural development
  - Year-long insect problems
  - Locusts are endemic in many regions
  - Tsetses flies prevent use of animals for plowing
- Mineral resource development
  - Deep, highly weathered soils
  - Extraction is expensive, special equipment
- Human productivity
  - Disease and malnutrition
  - High temperature and humidity

Tropical Land Degradation

- Commodity crops
- Change from shifting cultivation
- Progressive problems
  - Poor agricultural practices reduce nutrients and organic matter
  - Vegetation and organic material are removed for fuel and fodder
  - Lack of vegetative cover causes erosion
  - Irrigation increases salinity content of soils
  - People abandon degraded land and move to other areas

Environmental Factors - Rainfall

- Not uniformly distributed throughout the year
- Distinct wet and dry seasons
- Excessive precipitation and storms during the wet season often destroy crops
- Droughts common

Annual Rainfall Distribution

Map removed due to
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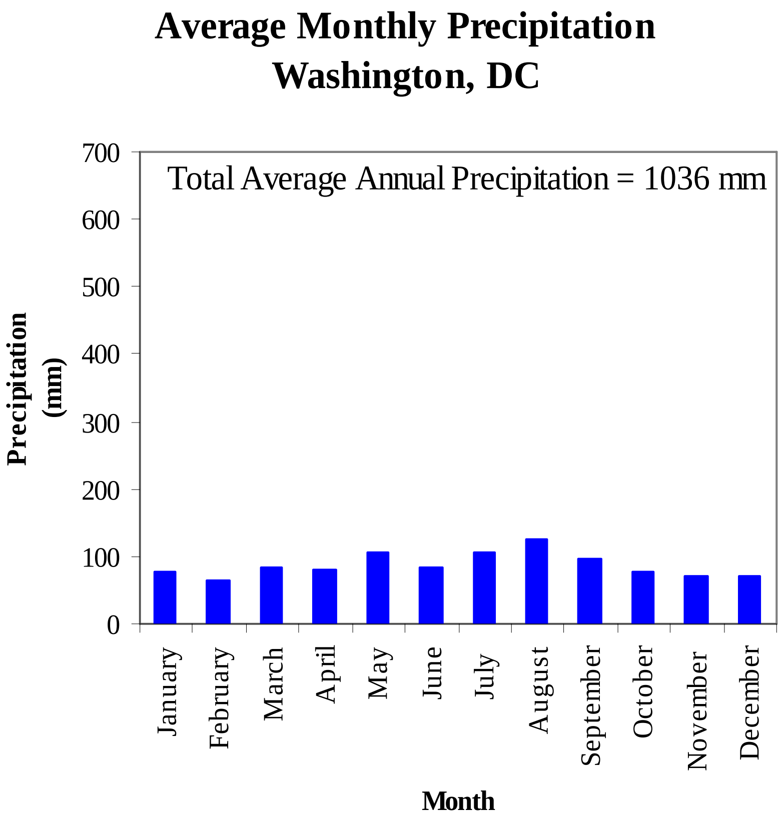

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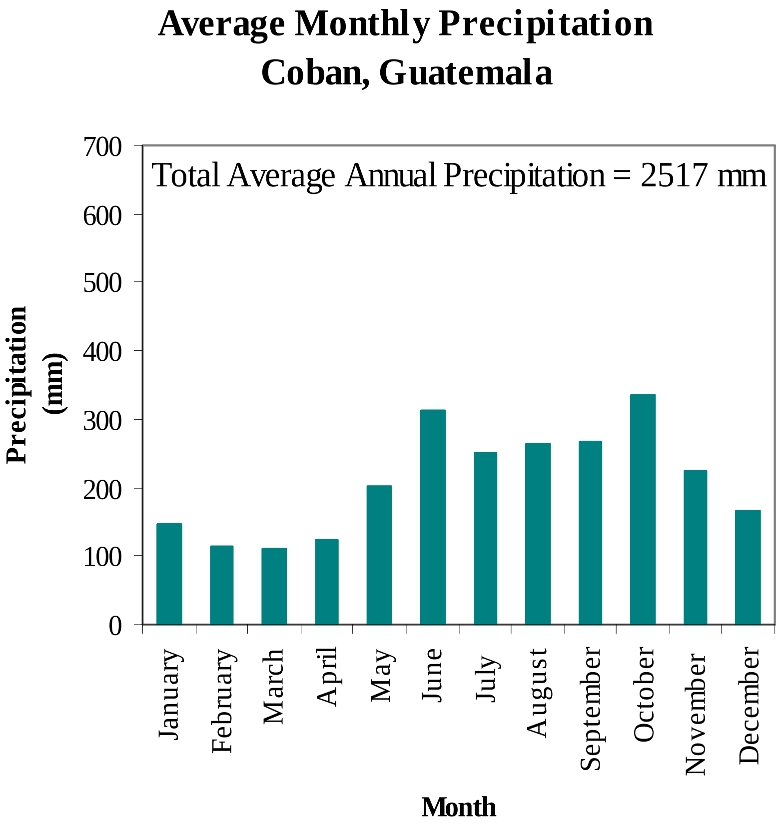

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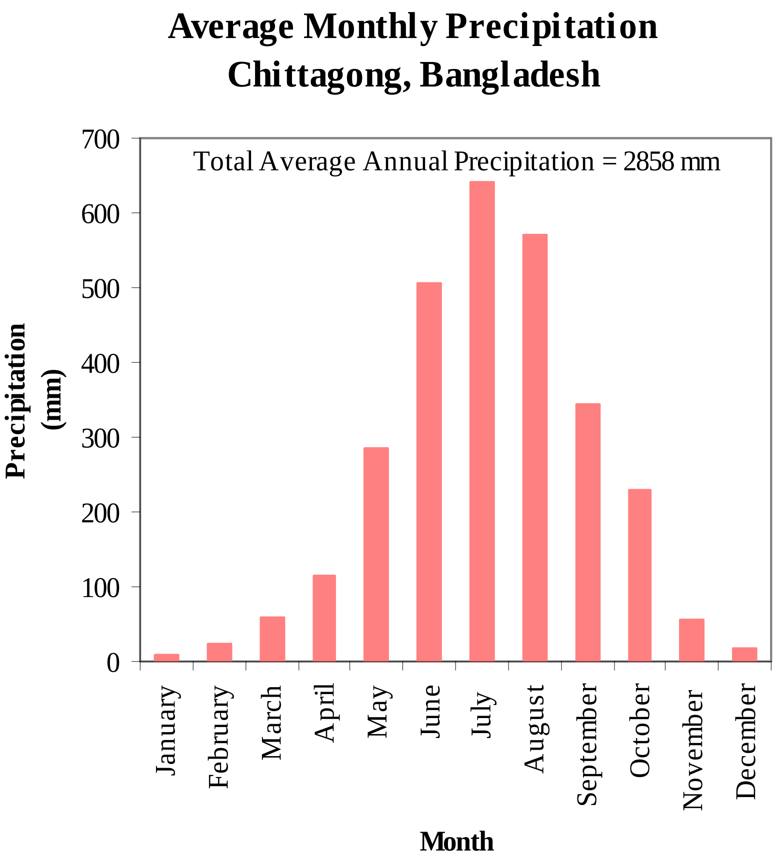

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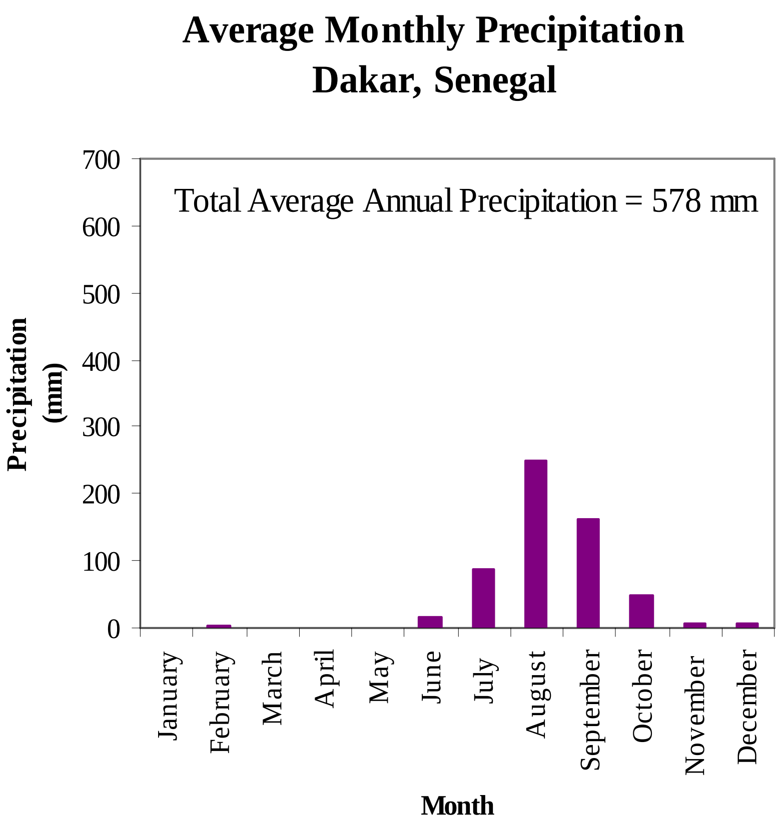


Environmental Factors - Heat

- No freezing temperatures in the tropics
  - Plant and animal pests and diseases reproduce throughout the year
  - Intense ecological competition
  - Quick turnover of soil organic matter
- UV radiation destroys plastics, rubber, and synthetics
- Heat and humidity cause corrosion of machinery

Environmental Factors - Soils

- Tropical soils are highly weathered
  - Low organic matter
  - Low nutrient contents
- Laterites (high iron clays)
  - Harden when exposed to sun and air
  - Used to build roads
- Alluvial and volcanic soils are the exception – rich and fertile

Community and Cultural Factors

Communities in Northern Region Ghana

Non-Traditional

Traditional

(Photos: Rachel Peletz, 2006)

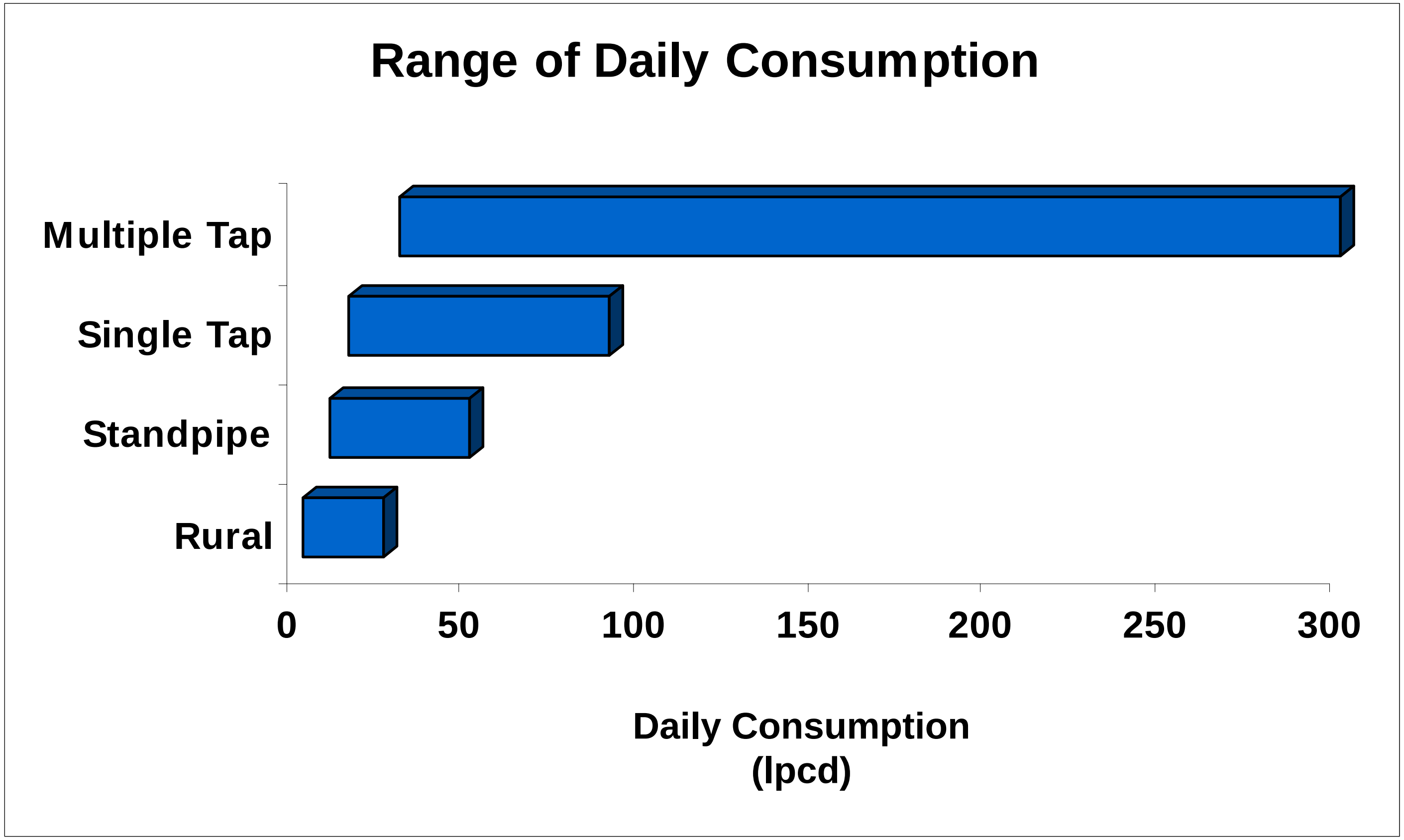
Patterns of Domestic Water Use

- Volume of water used depends on income
- Only the wealthy have large amounts of safe water
- In rural areas, water is often carried from a source outside the home
  - Performed by women and children
  - Requires time and energy
  - Opportunity cost for agriculture and other productive activities
- People may use different sources for different uses

Patterns of Domestic Water Use

- Domestic water uses
  - Bathing
  - Cooking
  - Dishwashing
  - Drinking
- Other water uses
  - Clothes washing (often done at water source)
  - Gardening
  - Livestock

Patterns of Domestic Water Use



Patterns of Domestic Water Use

Water Source	**Consumption (lpcd)**
Rural springs, streams, etc.	2-25
Standpipes in cities/villages	10-50
Single tap in the home	15-90
Multiple taps in the home	30-300
United States	375-600

Patterns of Domestic Water Use

- Factors influencing water use and consumption
  - Cost – money, time, and energy
    - How much women and children can carry
    - Distance to source
    - Time spent in line
    - Effort to pump or haul water from well
  - Woman's perception of quality – based on aesthetics
  - Family size and family power structure
    - The larger the family, the lower the amount available per person
    - How much water the husband uses for bathing
  - Social norms
    - Is clothes washing usually done at source?
    - Socializing

Patterns of Domestic Water Use

- Factors influencing water use and consumption
  - Technology – are pumps functional?
  - Reliability of the water source
  - Time of year (rainy or dry season)
  - Competing uses
- Other considerations
  - Women do most of the carrying, but men make most of the decisions
    - Location of house
    - Community improvements
    - How income is spent
  - Women are the ones most affected by community water projects, but they have little public voice

Patterns of Domestic Water Use

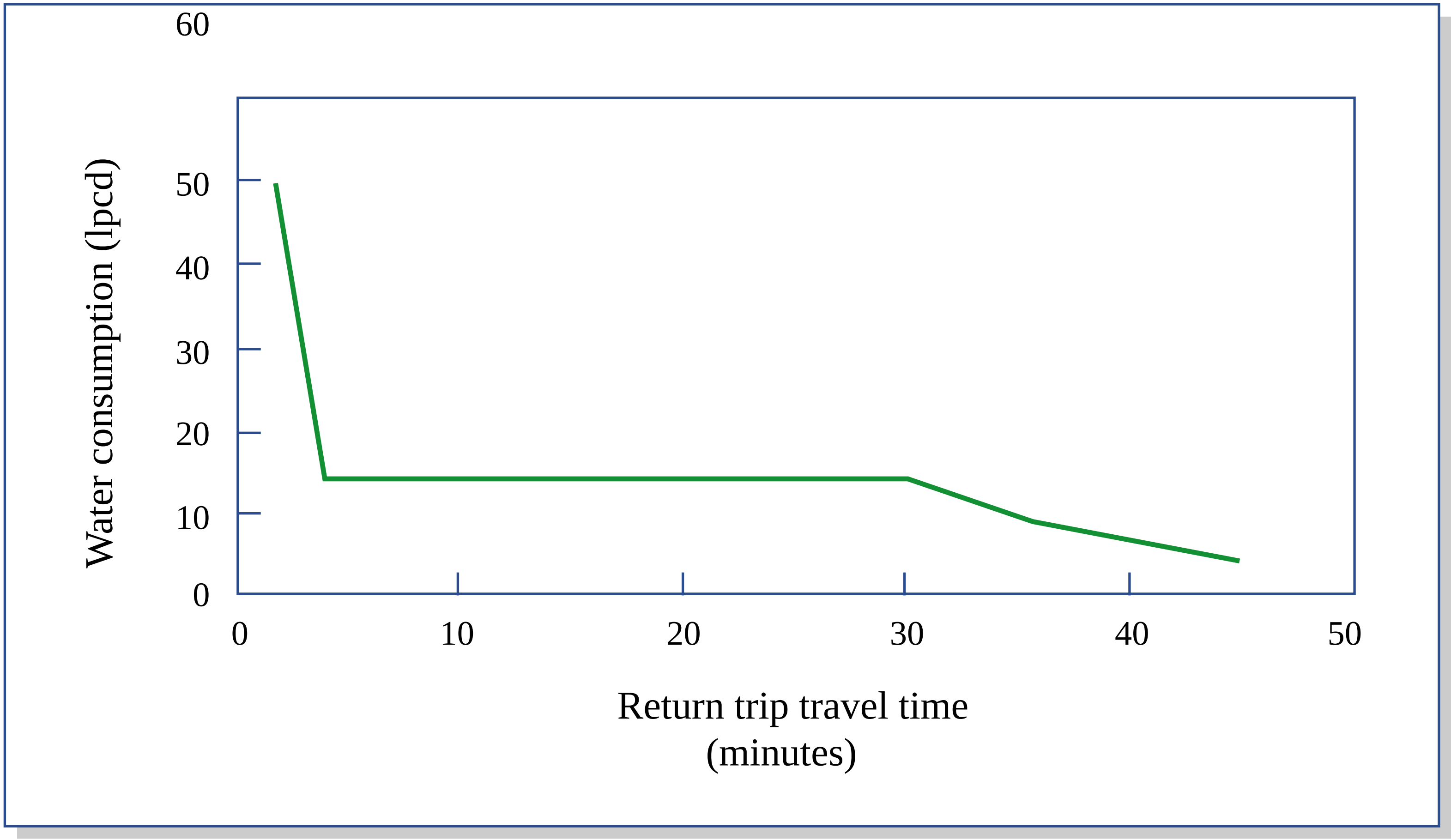


Figure by MIT OCW.

Domestic Water Use

- 20 m3/person/year represents a global average.

- But water consumption varies widely
- Oman = 7 m3/person/year
- Japan = 90 m3/person/year
- USA = 200 m3/person/year

Global Water Use by Sector

	m3/person/yr	km3/yr	%
Domestic*	20	100	3
Industrial		200	5
Cooling		225	6
Livestock		40	1
Sub-Total		**565**	**15**
Agriculture		3,300	85
Total		**3,865**	**100**

(Clarke, R, 1993 and Vovich, M.I. 1977)

Global Water Use

- Irrigation = 70%
- Industry/Commercial = 20%
- Domestic = 10%

(Brown, L. 2003)

- Today, 2B people (1/3 human population) depend on groundwater for their water needs.

Water Systems Planning

- Case studies
  - Tanzania
    - Increased number of standpipes (increased access)
    - Consumption increased only 2 lpcd
    - Access was apparently reasonable prior to the project
  - Thailand
    - Designed system assuming 50-80 lpcd
    - Actual consumption
      - Standpipes: 9.6-36.8 lpcd
      - House connections: 24.4-65 lpcd
    - System was over designed, scarce resources were wasted
    - Could have provided water to more people for same cost

Water Systems Planning

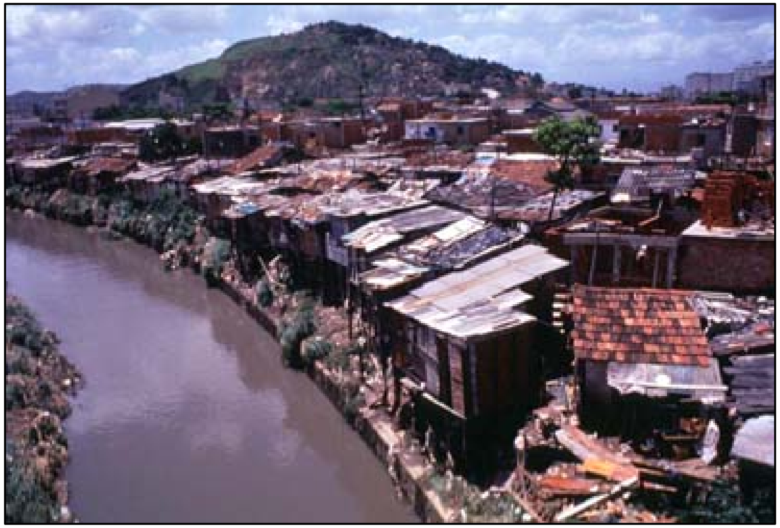
- Recommended design figures
  - Standpipes: 25 lpcd
  - House connections: 50 lpcd
- Plan for losses – leakage, illegal connections
- Planning for future growth
  - Should consider future growth and increased demand
  - Overestimating demand will waste limited capital funds
  - Try to make projects expandable, extendable, improveable

Water Systems Planning

- Planning for future growth
  - Providing excess capacity now may be more economical than adding it in the future – economies of scale
  - Industrialized countries – design to meet demand for next 20 years
  - Developing countries
    - Design for next 5-10 years
    - Funds may not be available for longer periods
    - Do not want to tie up valuable resources that could be used elsewhere

Settlement Patterns

- Urban peripheries
- Rural clustered
- Rural scattered



Settlement Patterns – Urban Peripheries

- Usually unplanned housing layouts
- Includes both rural poor and urban poor (different views)
- High unemployment
- Water supply and sanitation is inadequate
- Public health is usually precarious
- Urban dwellers generally use more water than rural people
- Places for washing clothes and dishes or bathing may not be available
- Disposal of sullage (graywater) may be a significant problem

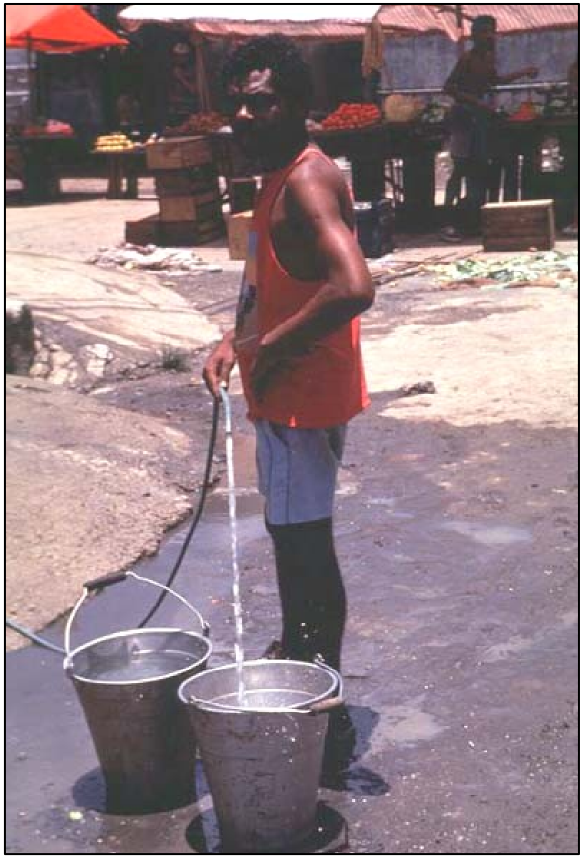
Settlement Patterns – Urban Peripheries

- Standpipes
  - May require a guard to prevent wastage, vandalism, and contamination by wastewater
  - Single standpipes often serve 500-3000 families – long lines
  - Better figures are 50-100 families per pump
  - Overuse of hand pumps cause frequent pump failures
  - Inconvenience and unreliability may result in people using less desirable sources
  - Need to consider demand and maintenance during planning process

Shantytown outside Rio de Janeiro

Settlement Patterns – Urban Peripheries

- Vendors
  - Sell water from tank with a hose, or from tins from a cart
  - Women may not want to be out on urban streets
  - May be of dubious quality
  - Costly




SAVELUGU/NANTON DISTRICT ASSEMBLY

Public Vendors - Cameroon

Public Water Vendor

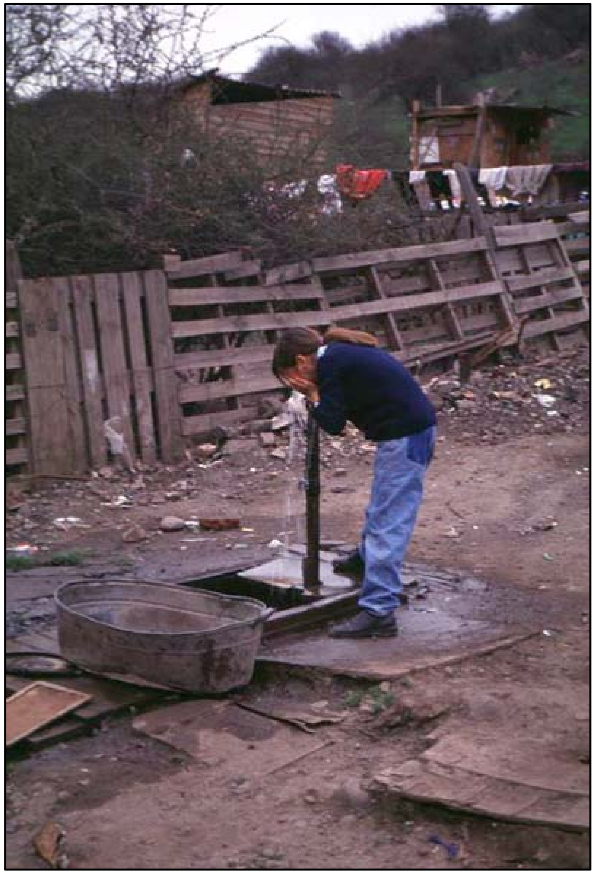
Kibera, Kenya

Settlement Patterns – Urban Peripheries

Source	Health Hazard	Cost
Taps	Low	High
Standpipes	Medium	Medium
Vendors	High	High
Surface	High	Low
Underground	High	Low
Rain-barrels	High	Low

Settlement Patterns – Rural Clustered

- Villages ranging from 50 to 5000 people
- Develop around a reliable source
- Have reasonable access to water
- Consumption does not change much until water is piped to homes



India

Nigeria

Settlement Patterns – Rural Clustered

Source	**Health Hazard**	**Cost**
Taps	Low	High
Standpipes	Low	Medium
Vendors	High	High
Surface	High	Low/High
Underground	High/Low	Low/High
Rain-barrels	Medium	Low

Settlement Patterns – Rural Scattered

- Considering women's role
  - Time spent carrying water is time lost from other activities
  - 80% of women participate in agriculture
  - In Africa, women produce approximately 80% of the food consumed by their families
  - Women collect and gather 80% of fuel supplies
  - Women perform 50% of house repairs
  - Women participate in 33% of house construction
  - Women do 100% of the cooking, cleaning, washing, and child care
  - Women receive a disproportionately smaller share of food, leisure time, and health care than men

Settlement Patterns – Rural Scattered

- Hauling water consumes a considerable portion of women's time
- Women may carry up to 40 liters (40 kg – 88 lbs) per trip and may make several trips per day
- Men use more water for bathing since they don't carry the water
- Water stored in the home in 200-300 liter containers – not much storage
- Sullage often used for watering animals or irrigation – reduces water to be hauled

Settlement Patterns – Rural Scattered

Source	Health Hazard	Cost
Surface	High	Low/High
Underground	Low	Low/High
Rain-barrels	Low	Low

Carrying Water, Northern Region, Ghana

Kenya – Waiting for water

Kenya – Women-run water vending

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