A Lecture on

Groundwater Treatment Systems: Domestic and industrial Hazards

Faculty Development Programme on 09/09/08

IRDT Kanpur

by

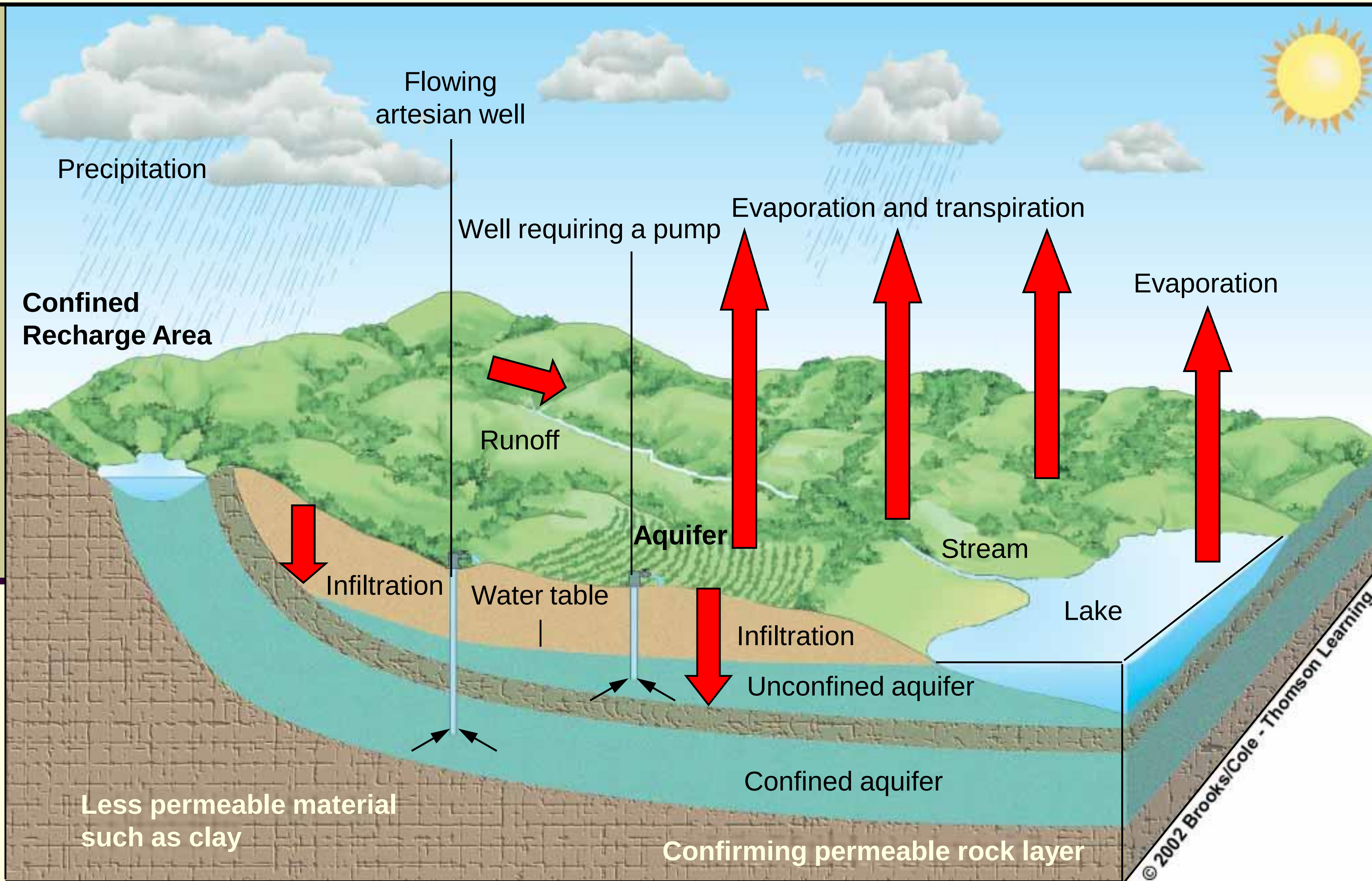
Dr. Deepesh Singh

Department of Civil Engineering, H.B.T.I., Kanpur

What is groundwater?

- Water from rain, melting snow, streams, and lakes infiltrates into the earth.
- Water which is stored underground in permeable rocks.

Ground Water



Water Cycle including Groundwater

Aquifers

Use of Water Resources

- **Humans use about 54% of reliable runoff**
- **Agriculture**
- **Industry**
- **Domestic**
- **Power plants**

Water Resources

- Over the last century
  - Human population has increased 3x
  - Global water withdrawal has increased 7x
  - Per capita water withdrawal has increased 4x
  - About one-sixth of the world's people don't have easy access to safe water
  - Most water resources are owned by governments and are managed as publicly owned resources

Problems with Using Groundwater

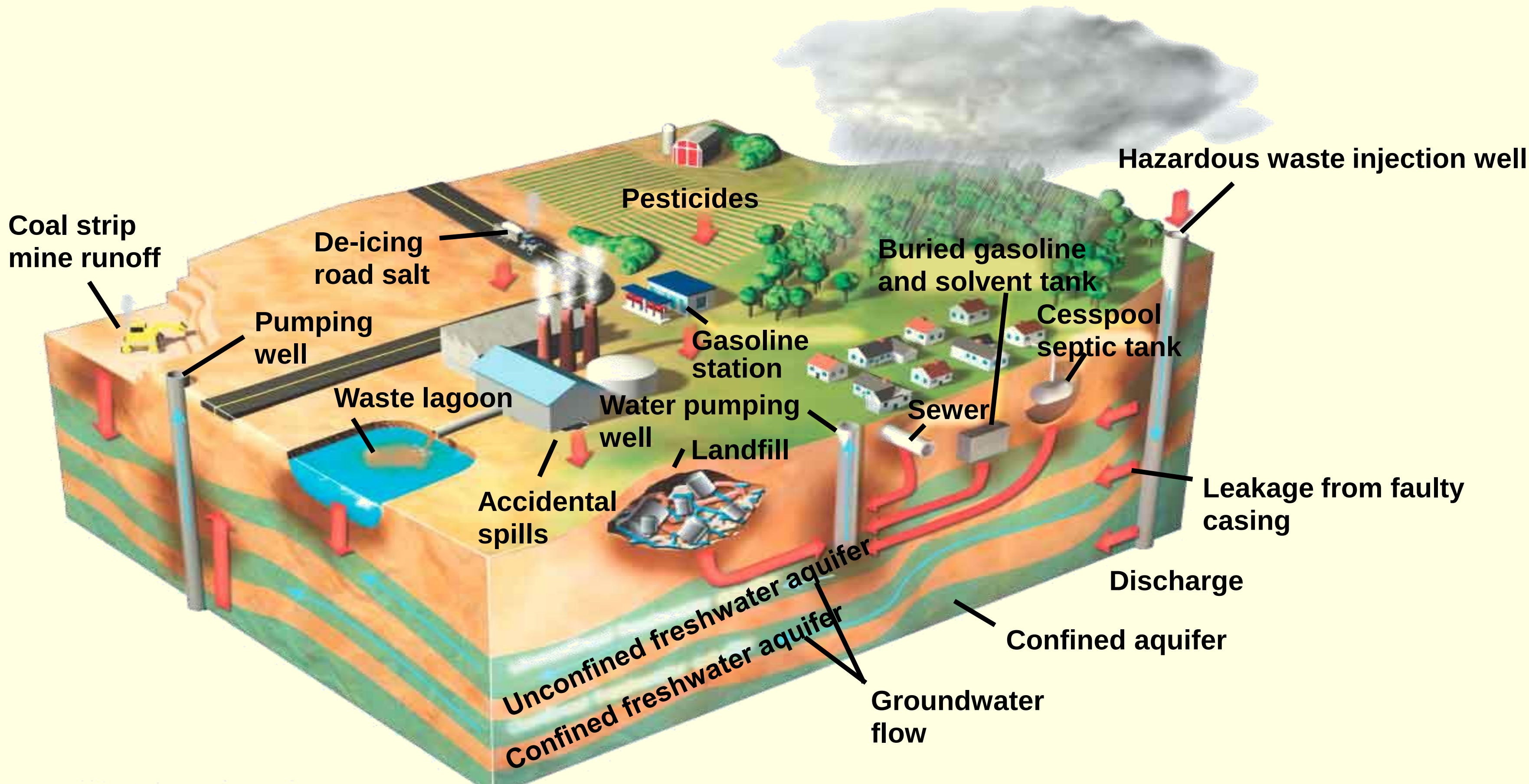
- **Water table lowering**
- **Depletion**
- **Subsidence**
- **Saltwater intrusion**

Chemical contamination

- **Reduced stream flows**

Groundwater Pollution: Causes

- Low flow rates
- Low oxygen
- Few bacteria
- Cold temperatures



How contamination spreads..

Environment Canada

How contamination spreads..

Groundwater Pollution

- Why care about ground water pollution?
  - Most abundant freshwater source
  - Growing dependency on GW
  - ~ 50% of people in world depend on GW for drinking water
  - Triggers other environmental problems, subsidence, saltwater intrusion, etc.

Groundwater Pollution

- **GW pollution hazard impact depends on:**
  - Amount of contaminant discharged
  - Chemical concentration or toxicity
  - Degree and duration of exposure of people or other organisms to the pollution

Groundwater Pollution

- **GW pollution vs. SW pollution**
  - Residence time difference
  - Environmental conditions: Inflow, flow rate, Dissolved oxygen, sunlight
  - Harder to track pollution sources
  - More difficult and expensive to clean up
  - May pose long-term risks

Groundwater Pollution

- **Saltwater intrusion**

  - More than half of the world’s population lives in or near the coastal zones

  - GW pollution from saltwater intrusion is not a local isolated problem

  - Causes major water supply problems in costal regions of India

Groundwater Pollution

- **Saltwater intrusion mechanism**
  - Water table is inclined oceanward
  - Wedge of saltwater is inclined land ward
  - Overpumping of GW
  - Severe drawdown of GW causes saltwater intrusion

Kinds of Water Pollution

- Inorganic Pollutants
- Organic Pollutants
- Biologic Pollutants

Inorganic Pollutants

- Examples:
  - Pb in gasoline
  - Radionuclides
  - Phosphorus, nitrogen (Great Lakes)
  - Other heavy metals

Inorganic Pollutants

- 3 groups
  - 1) Produce no health effects until a threshold concentration is exceeded—e.g., NO_3 –ook at , 50mg/liter; at higher levels: methaemoglobinaemia
  - 2) No threshold—e.g.—genotoxic substances: some natural and synthetic organic compounds, microorganic compunds, some pesticides, arsenic
  - 3) Essential to diets: F, I, —absence causes problems, but too much also causes problems

Inorganic Trace Contaminants

- Mercury—methyl Hg and dimethyl Hg in fish—probably most significant path to humans—Minamata Bay, Japan, 1950’s
- Rhine River drains 185,000 sq km—heavily polluted by 1970’s
- Lead—toxicity has been known for a long time
  - 1859 book
  - Tetraethyl lead—anti-knowck additive for gas, 1930-1966

Phosphates and Nitrates

- Phosphates—mostly a result of sewage outflow and phosphate detergents
  - Additional phosphate grows excess algae…oxygen depletion, Lake Erie…1972 phosphate management plant…$7.6 billion
- Nitrates—sewage and fertilizers

GW Treatment (1)

- **Pretreatment studies**
  - Identify contaminants and their characteristics of transport behavior
  - Identify the characteristics of aquifer geology (factors controlling GW flow—physical dimensions, structure)
  - Determine the hydrologic characteristics of polluted aquifer(s)—flow direction, flow rates, discharge and recharge conditions
  - Select possible treatment strategies and methods

GW Treatment (2)

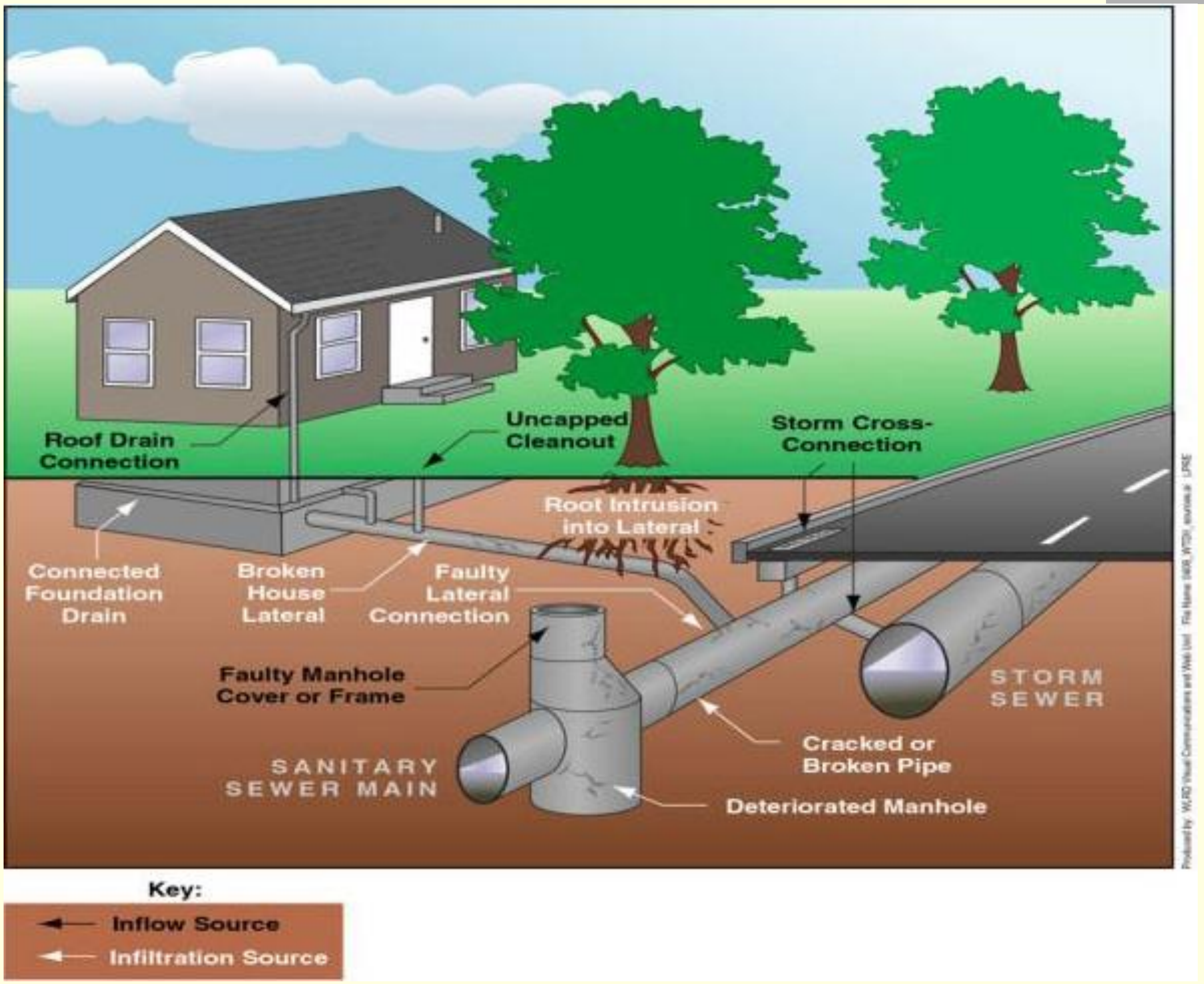
TABLE 12.2 Methods of Treating Groundwater and Vadose-Zone Water

Extraction Wells	Vapor Extraction	Bioremediation	Permeable Treatment Bed
Pumping out contaminated water and treatment by filtration, oxidation, air stripping (volatilization of contaminant in an air column), or biological processes	Use of vapor-extraction well and then treatment	Injection of nutrients and oxygen to encourage growth of organisms that degrade the contaminant in the groundwater	Use of contact treatment as contaminated water plume moves through a treatment bed in the path of groundwater movement; neutralization of the contaminant by chemical, physical, or biological processes

Waste Water Treatment

- Law: Used waste water must be treated
- Break the potential vicious cycle of waste water entering the general water cycle
- Tier treatment and reuse system
  - Septic system—rural residential areas
  - Water treatment plant for towns and urban cities
  - Innovated ways for recycling and reclaiming waste water
  - New technologies for innovative waste water treatment

Domestic Pollution



Domestic Wastewater Treatment

- Water Availability

  If little or no piped water is available, the volume of wastes generated will be minimal, and excreta and other household wastes can be disposed of in household systems

Domestic Wastewater Treatment

- Collection System

  includes septic tanks as well as community sewers

Domestic Wastewater Treatment

- Housing or Population Density

For dispersed rural homes, central sewage collection facilities are not economical due to the high cost of piping wastewater to the central treatment facility.

Domestic Wastewater Treatment

- Availability of Skilled Labour and management

The complexity of a treatment technology that a community can expect to operate and maintain successfully is determined by the local availability of skilled labour

Domestic Wastewater Treatment

- Land Availability

  Where land is abundant, low cost natural treatment systems are usually appropriate

Domestic Wastewater Treatment

- Receiving Water Requirements

  Water quality requirements for the effluent receiving water or effluent reuse significantly affect treatment requirements

Domestic Wastewater Treatment

- Hydrogeologic Conditions and Climate

For subsurface treatment or disposal processes, soil permeability and the seasonal high water table should be known

Domestic Wastewater Treatment

- Social Considerations

Residents' knowledge, attitude, opinions, and prejudices about waste disposal can determine whether a treatment technology will work in a particular culture

Domestic Wastewater Treatment

- Effluent Volume

Low and medium effluent volumes can be discharged below the ground if local soil conditions are suitable

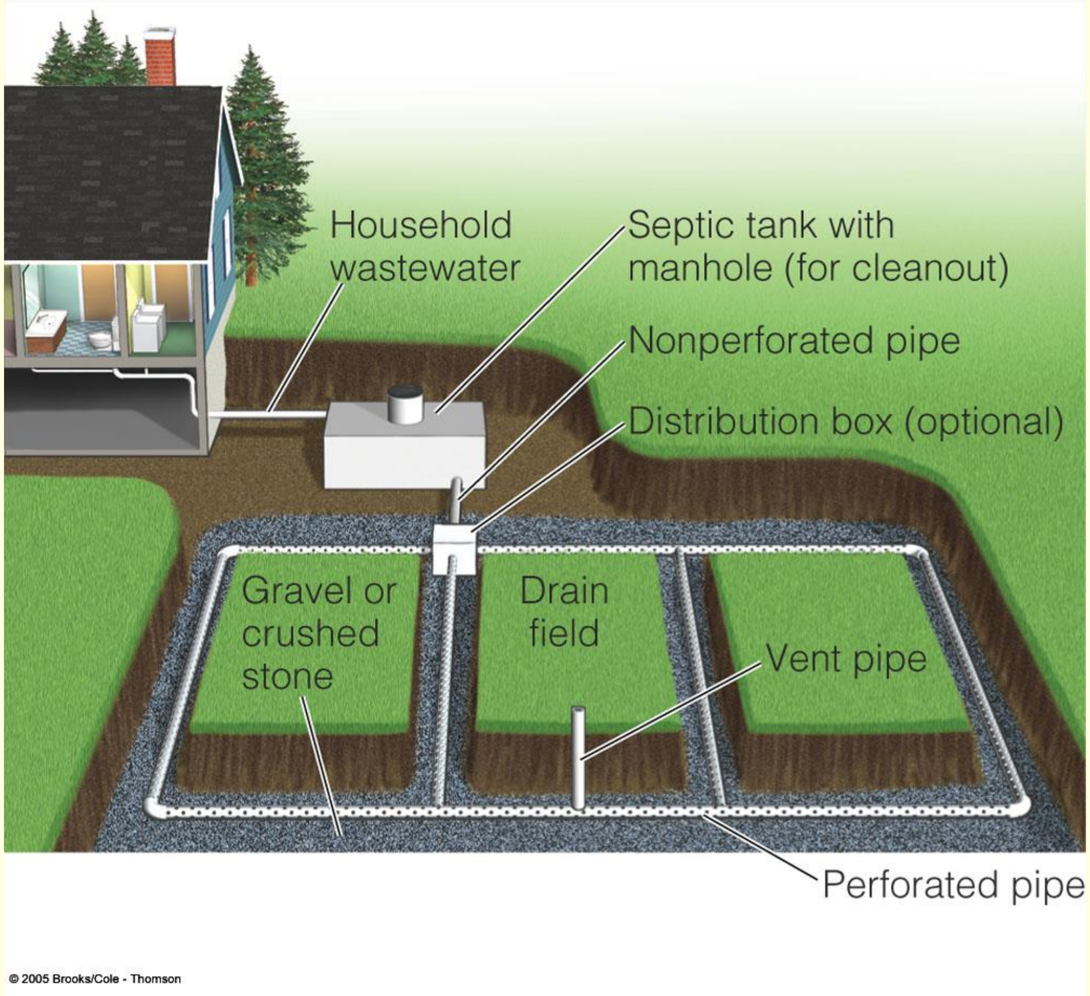
Domestic Wastewater Treatment

- Opportunities for Reuse

Wastewater can be used for street washing, cooling water, other industrial uses, irrigation of feed or fodder crops, landscaping irrigation, separate toilet water flushing systems, or in indirect or direct potable reuse.

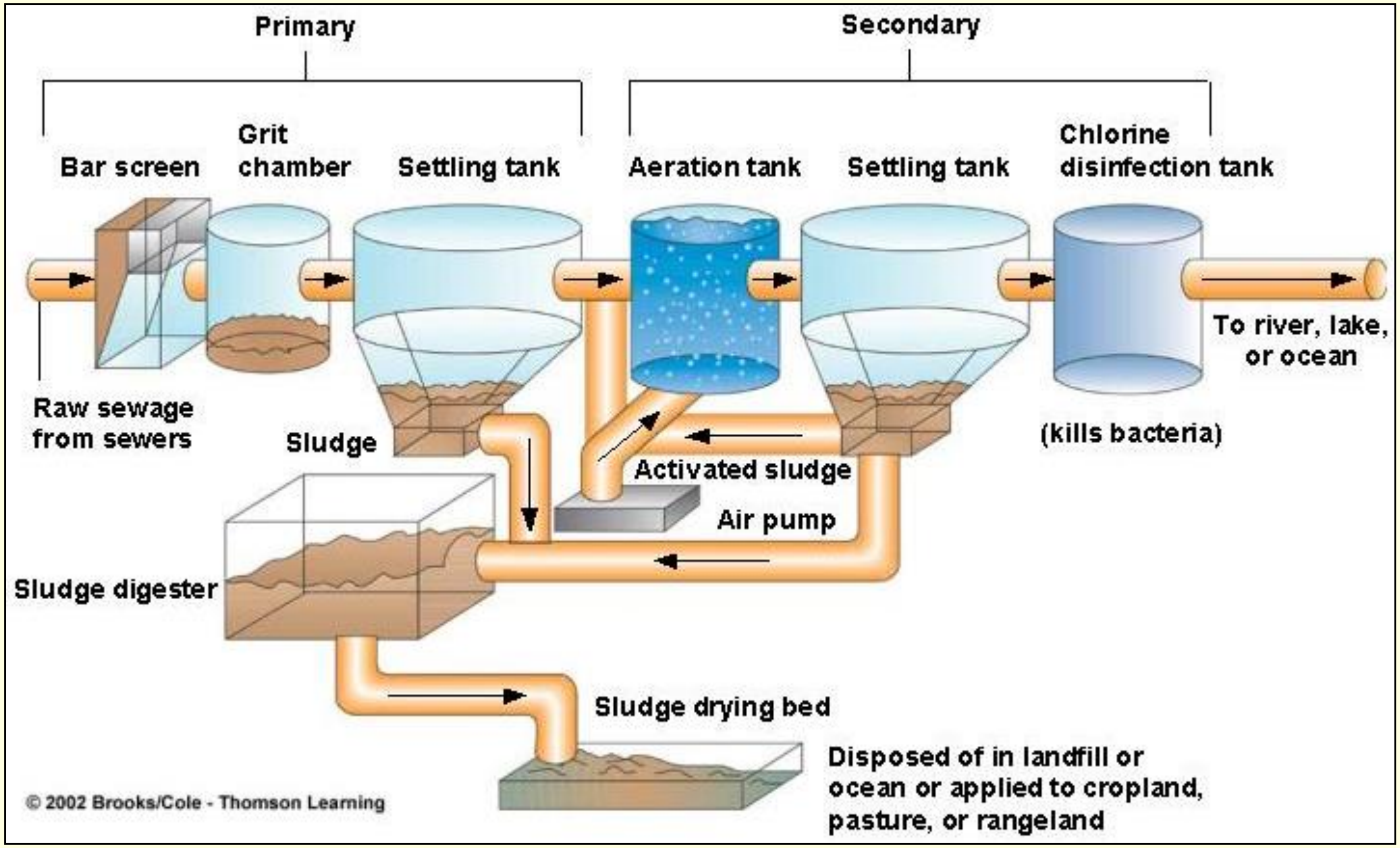
Technological Approach: Septic Systems

- **Require suitable soils and maintenance**



Sewage Treatment

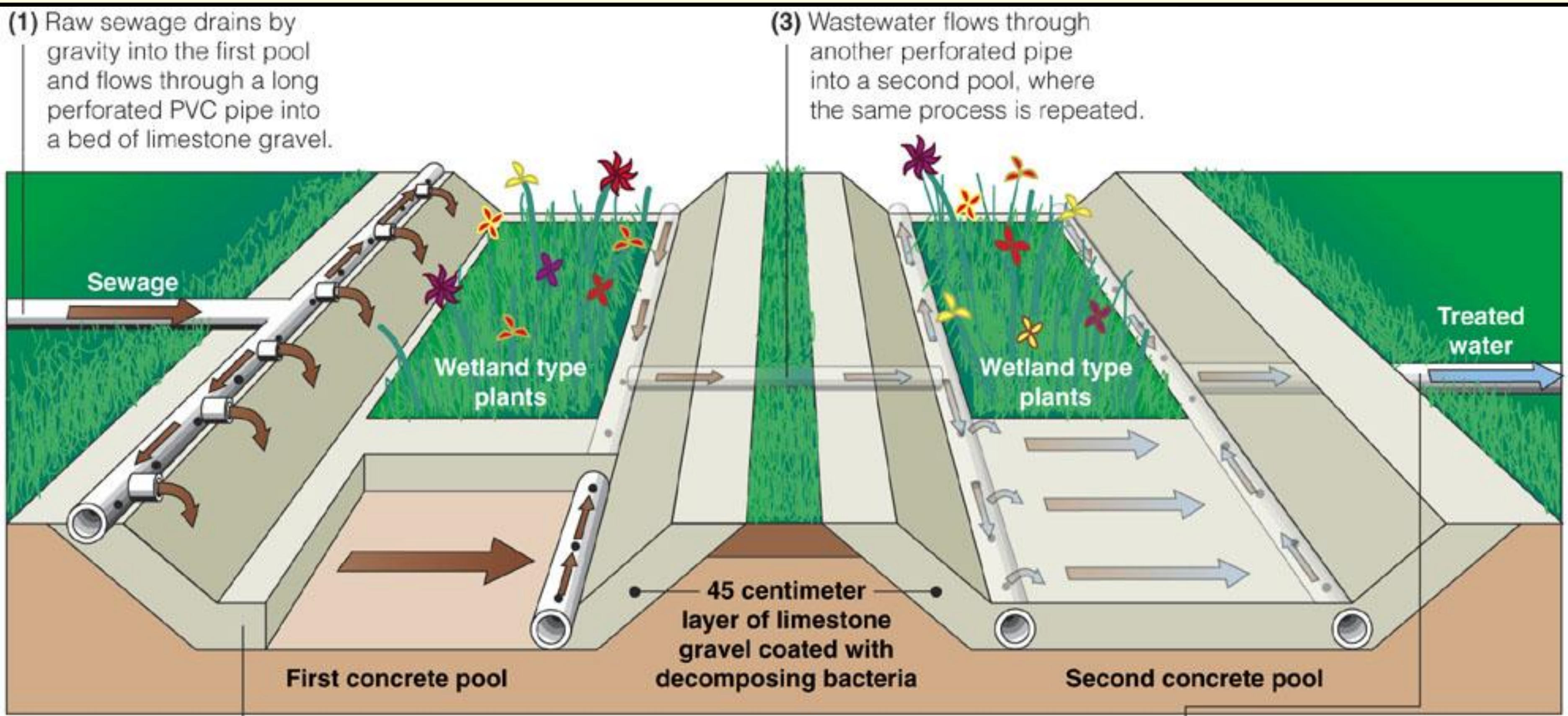
- **Physical and biological treatment**



Advanced (Tertiary) Sewage Treatment

- **Uses physical and chemical processes**
- **Removes nitrate and phosphate**
- **Expensive**
- **Not widely used**

Technological Approach: Using Wetlands to Treat Sewage



WATER QUALITY ISSUES IN INDIA

Water is Precious and scarce Resource

- Only a small fraction (about 3%) is fresh water
- India is wettest country in the world, but rainfall is highly uneven with time and space (with extremely low in Rajasthan and high in North-East)
- On an avergae there are only 40 rainy days
- Out of 4000 BCM rainfall received, about 600 BCM is put to use so far
- Water resources are over-exploited resulting in major WQ problems

Water use in India (Year 2000)

Sector	Water use in BCM	percent
Irrigation	541	85.33
Domestic	42	6.62
Industry	8	1.26
Energy	2	0.32
Other	41	6.47
Total	634	100.00

Major Water Quality Issues

Common issues of Surface and Ground water

- Pathogenic (Bacteriological) Pollution
- Salinity
- Toxicity (micro-pollutants and other industrial pollutants)

Surface Water

- Eutrophication
- Oxygen depletion
- Ecological health

Ground Water

- Fluoride
- Nitrate
- Arsenic
- Iron
- Sea water intrusion

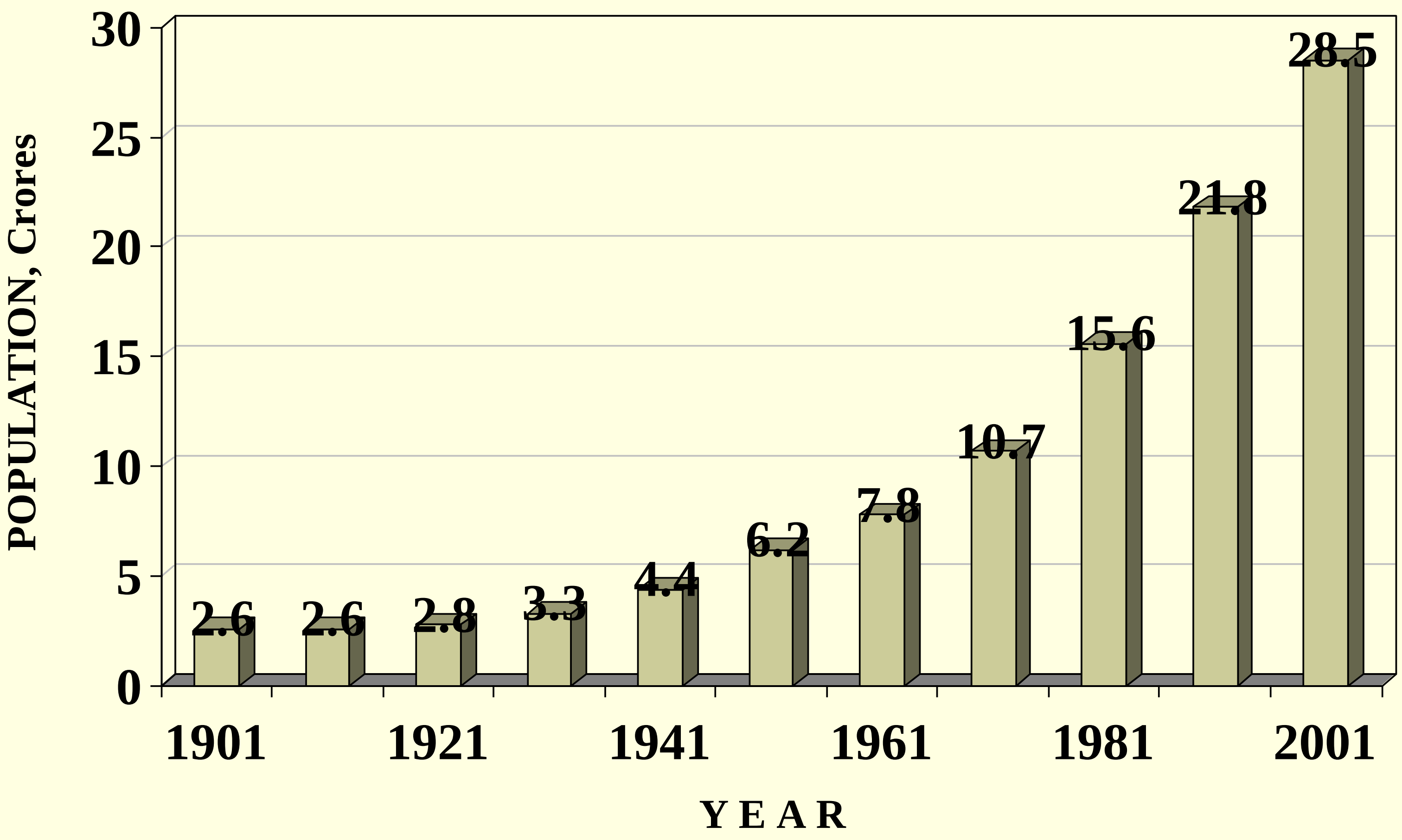
Major Factors Responsible for WQ Degradation

- **Domestic: 423 class I cities and 499 class II towns harboring population of 20 Crore generate about 26254 mld of wastewater of which only 6955 mld is treated.**
- **Industrial: About 57,000 polluting industries in India generate about 13,468 mld of wastewater out of which nearly 60% (generated from large & medium industries) is treated.**
- **Non-point sources also contribute significant pollution loads mainly in rainy season. Pesticides consumption is about 1,00,000 tonnes/year of which AP, Haryana, Punjab, TN, WB, Gujarat, UP and Maharashtra are principal consumers.**

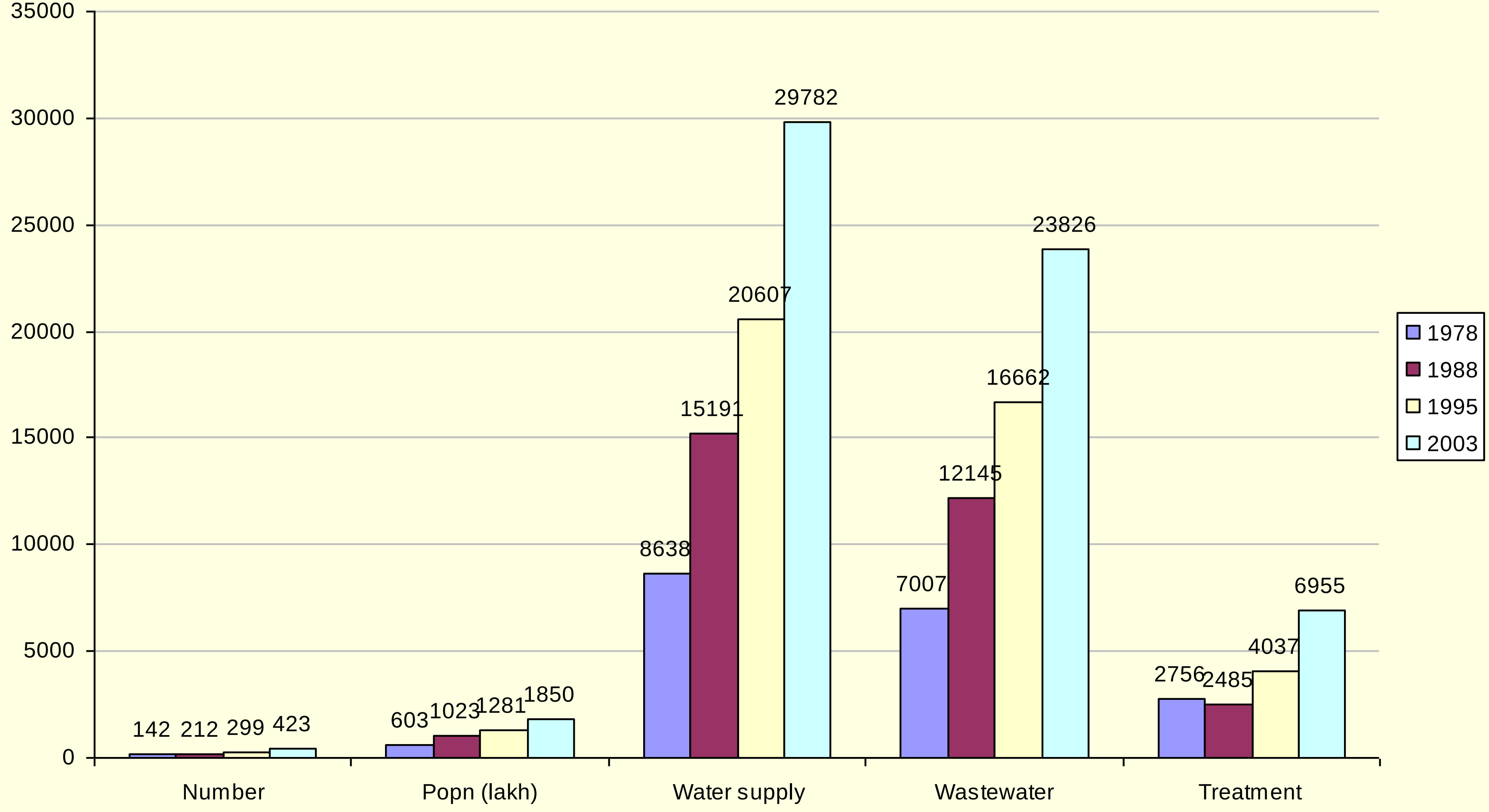
Major Factors Responsible for WQ Degradation

- **Domestic sewage is the major source of pollution in India in surface water which contribute pathogens, the main source of water borne diseases along with depletion of oxygen in water bodies.**
- **Sewage alongwith agricultural run-off and industrial effluents also contributes large amount of nutrients in surface water causing eutrophication**
- **A large part of the domestic sewage is not even collected. This results in stagnation of sewage within city, a good breeding ground for mosquitoes and contaminate the groundwater, the only source of drinking water in many cities.**

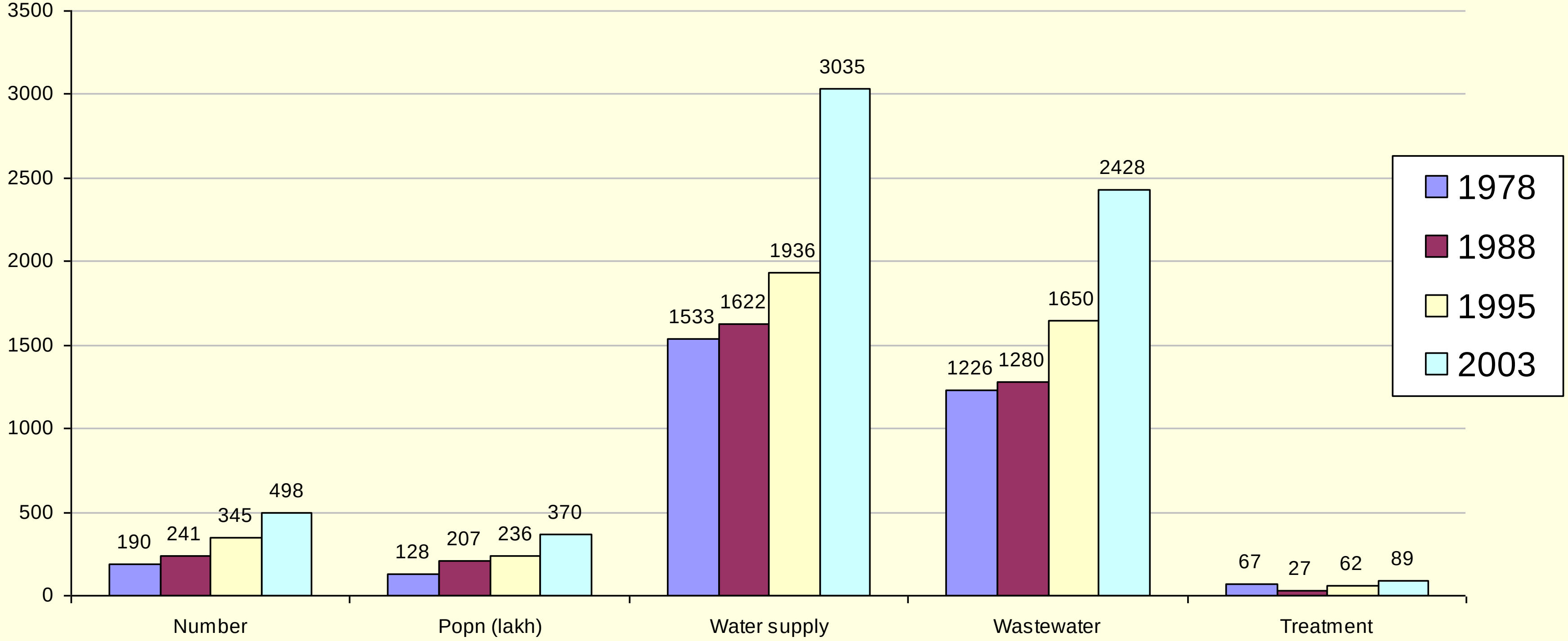
Increase in Urban Population



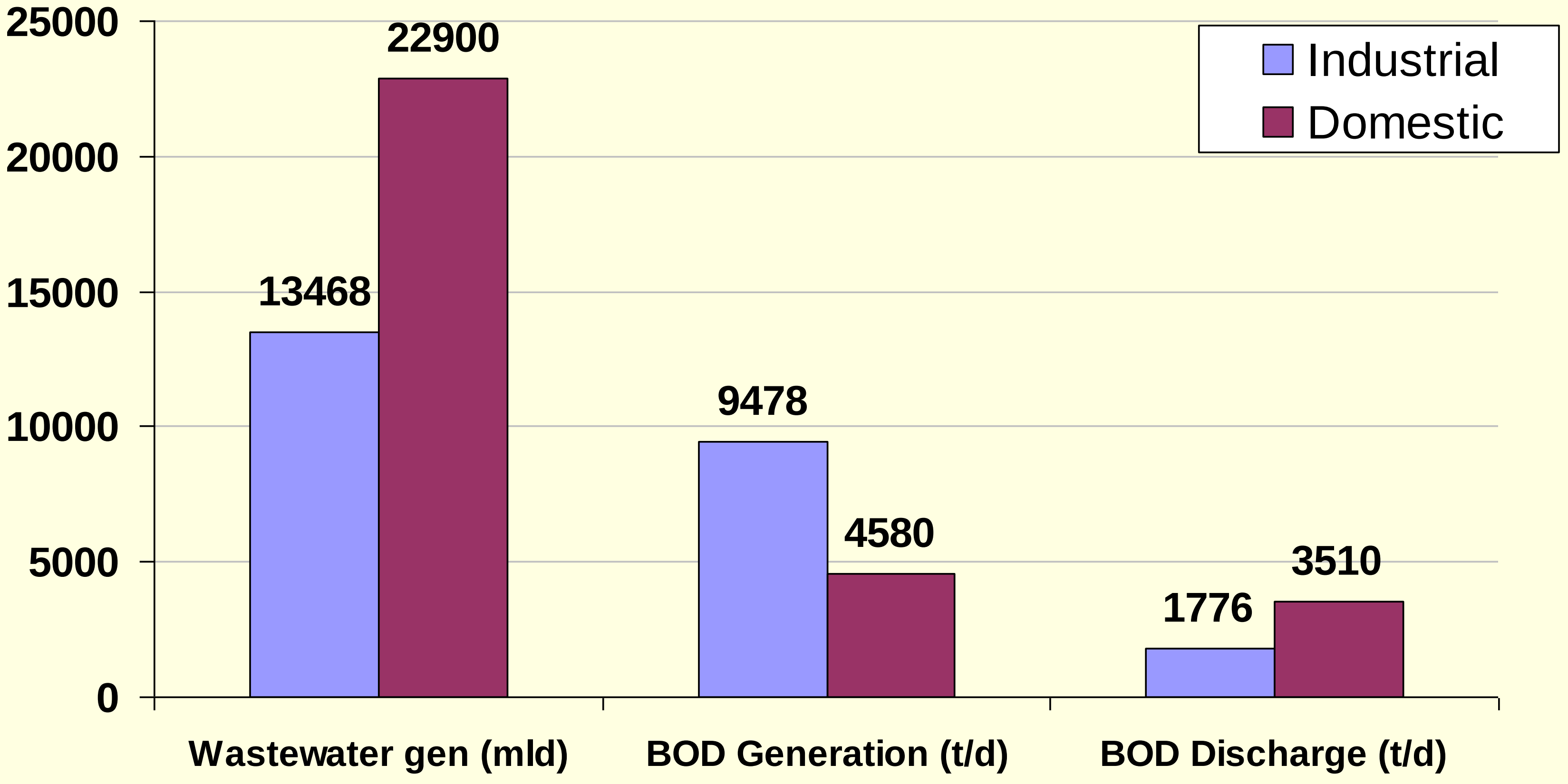
Water supply and sewage disposal status in class I cities



Water supply and wastewater generation and treatment in class II towns of India



Comparision of pollution load generation from domestic and industrial sources



Remediation

- **Techniques**
  - Source control
  - Containment
  - Pump and Treat
  - Bioremediation

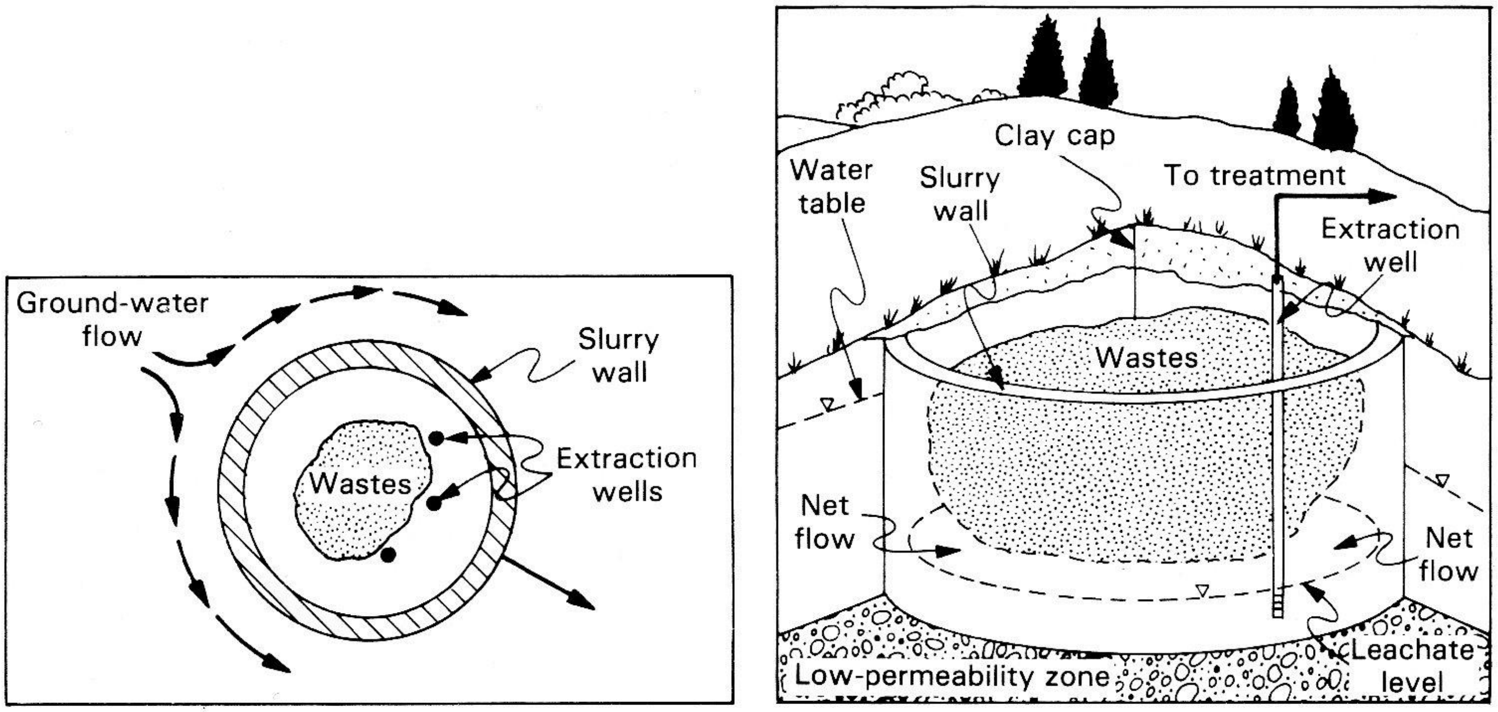
Remediation Techniques

- ***Source Control***
  - Useful if point-source of contaminant is known
  - Generally, the procedure is to find the source and remove it
  - Examples
    - Leaking underground gas tank
      - Remove bad tank and possible excavate soil below it that may have gas in residual saturation
    - Poorly constructed landfill
      - Waste can be potentially be move to more secure site
      - Liquid wastes can be funneled to a collection point and removed for treatment
    - Accidental spills
      - Area affected by spill can be excavated, removed, and treated
  - Really only useful in situations where the contaminant is small in extent or has not yet reached the water table and began to migrate
  - Important to stop contaminants before they reach water table!

Remediation Techniques

- ***Containment***
  - If contaminant has reached water table and began to migrate, source control and excavation is usually no longer feasible
  - Need to control the movement of the contaminant within the aquifer
  - ***Slurry Wall***
    - Works best in thin aquifers close to surface
    - Dig a trench all around the contaminant plume and then fill it with an ***impermeable barrier*** (typically cement)
    - New technology – '***reactive barrier***' – trench filled with coarse material and coated with reactive surface (e.g. clays, Fe-oxides)
    - Wall must be connected to impermeable formation at base of aquifer to prevent the escape of contaminants
    - Install monitoring wells, especially if wall completely surrounds the source so that contaminated water can be removed and treated
  - Only useful in certain geologic circumstances and usually during early stages of contaminant migration (i.e. before widespread dispersal and movement)

Slurry Wall

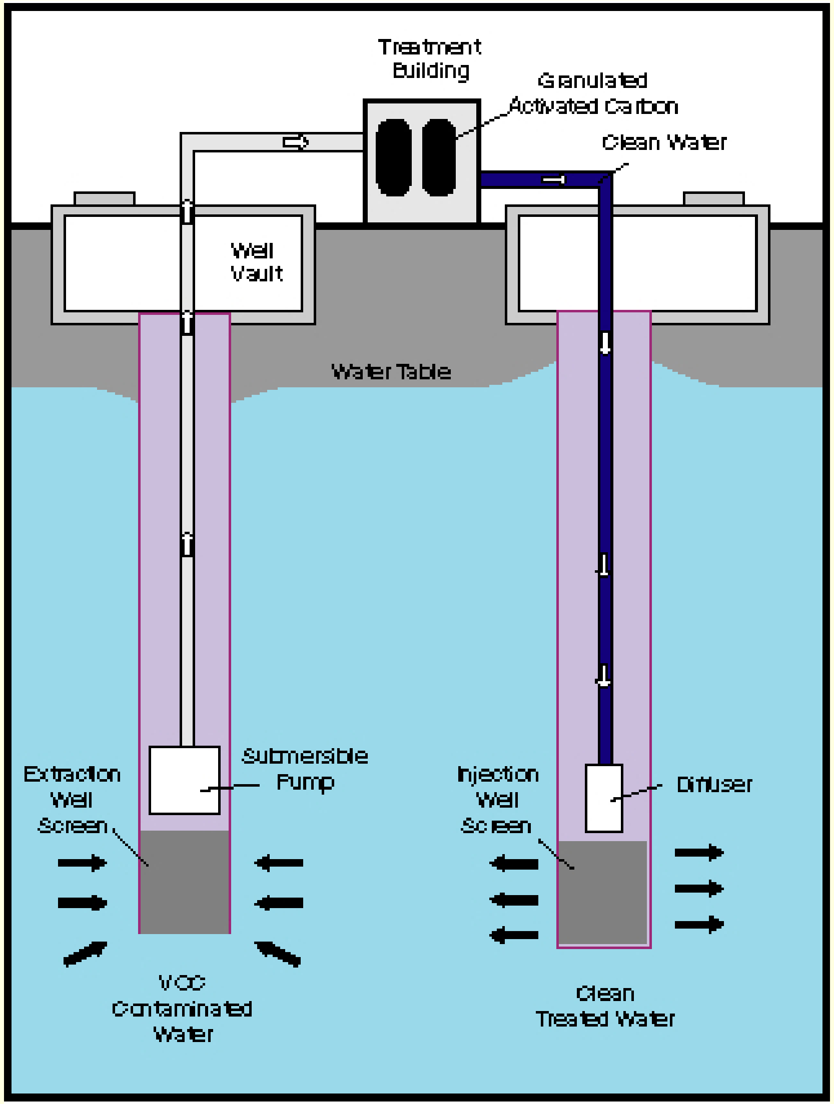


▲ FIGURE 12.39
Diagram of slurry wall used to contain a groundwater contamination plume.

Extraction, Treatment, and Reinjection (ETR)

- The most common method of treating groundwater is to extract the water, treat it at the surface, and return the treated water to the aquifer. This process also is known as "pump and treat" technology.
- Contaminated groundwater is pumped out of the aquifer through a series of *extraction wells*.
- The extracted water is then treated at the surface.

Pump and Treat



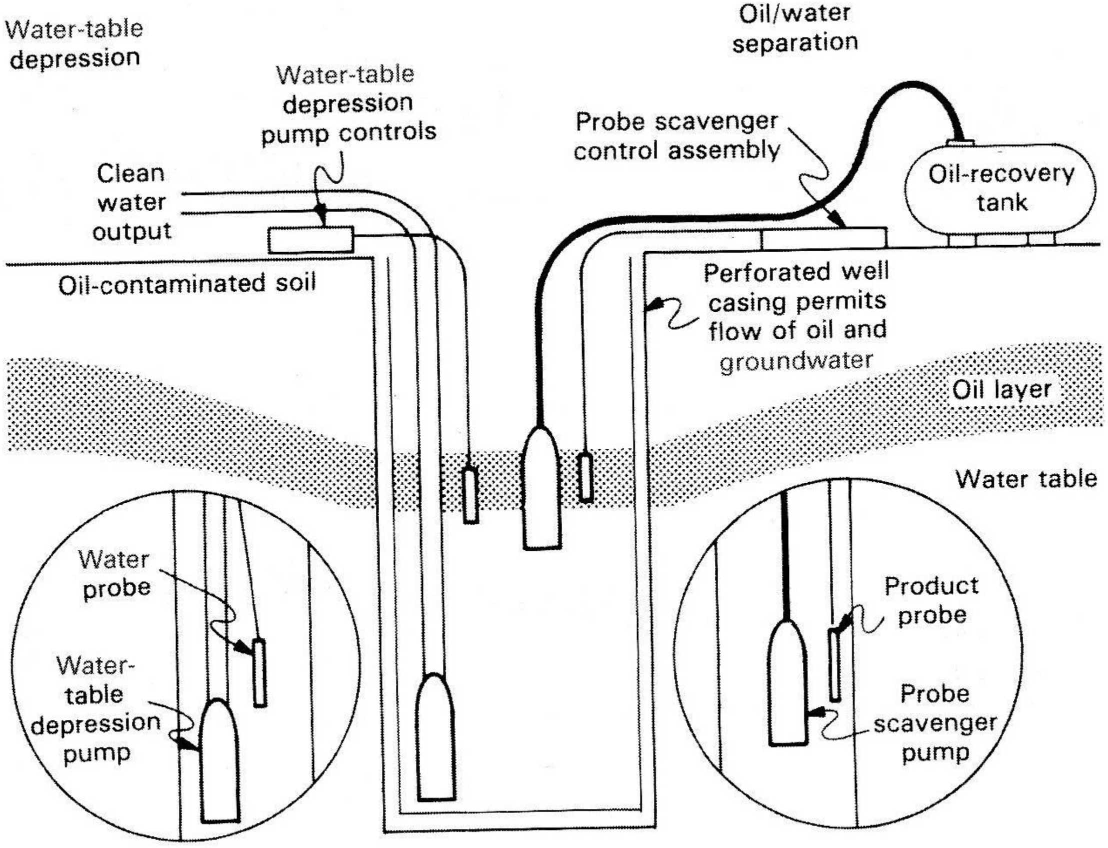
Pump and Treat

- When contaminated groundwater is pumped through a filter of carbon granules, most of the organic contaminants become trapped on the surface of the carbon.
- Eventually the carbon fills up and the carbon must be replaced. Used carbon is sent off-Cape to be recycled.
- After being tested, the treated water is pumped back into the aquifer through a series of *reinjection wells*. Reinjection wells are used to reduce the impact of the extraction wells on the groundwater hydrology, to help control plume migration, and to return treated water to the aquifer.

Pump and Treat

- Earliest used strategies for groundwater remediation
- Method
  - Use pumping from one or more wells to alter or reverse hydraulic gradient (hence control plume dispersal) – ‘cone of depression’ effect
  - 2 pump method
  - 1st pump creates a zone of depression which causes migration of the free product layer towards the well
  - 2nd pump is placed up at the water table and removes the LNAPL free product layer as it reaches the pump

Pump & Treat -Dual pump system



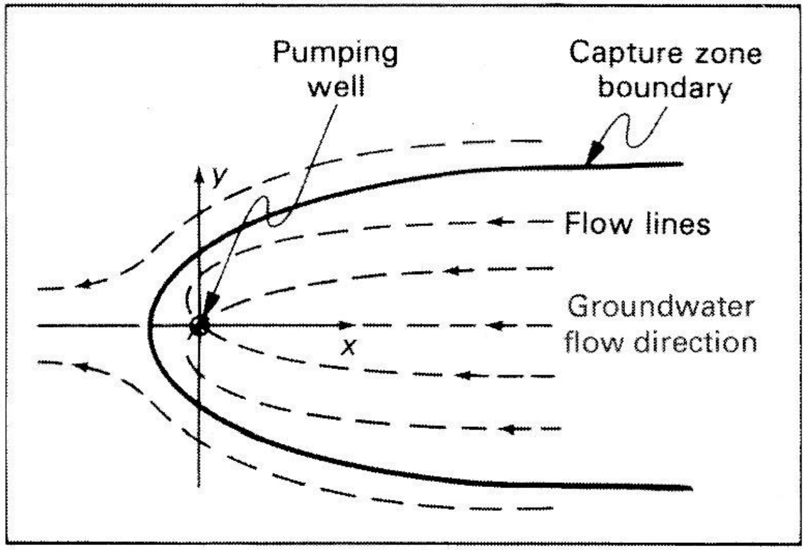
▲ FIGURE 12.40
Dual pump system used to remediate petroleum product contamination. Deeper pump creates cone of depression, causing flow of free product to well. Upper pump removes free product. *Source:* From U.S. EPA, 1989.

Pump and Treat

- ***Capture Zones***
  - Want to maximize the amount of contaminated groundwater pumped and treated and minimize the amount of uncontaminated groundwater pumped – hence delineate a 'Capture Zone'
  - (Figs. 12.41 and 12.42)
  - ***Capture zone*** - region of flow that is intercepted by a treatment well(s)
  - Important parameters to consider are ***thickness of the aquifer*** and ***rate of movement of the groundwater*** in the aquifer
    - Capture zone too small: some contaminant does not get treated
    - Capture zone too big: inefficient pumping of uncontaminated water

Capture zone

▶ FIGURE 12.41
Capture zone imposed by pumping one or more wells along the *y*-axis. All water within the boundaries flows to the well.

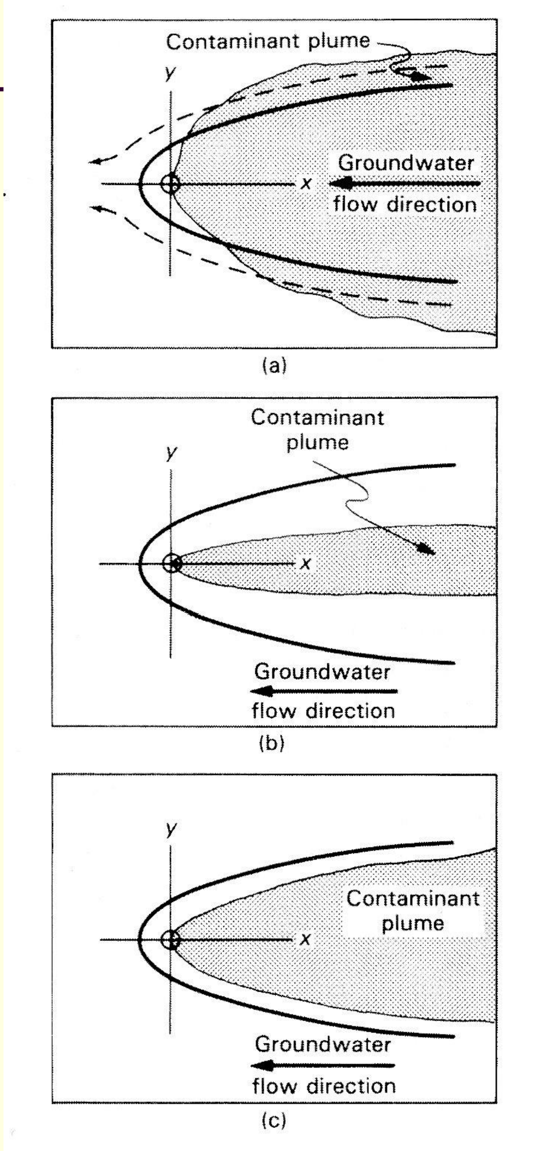


Capture zones

Too small

Too large

It’s just right…



Pump and Treat

- **Treatment Methods**
  - ***Carbon Adsorption***
    - Contaminated water passed through a canister (filter) containing granular activated carbon (GAC) filter
    - Compounds with high K_{ow} will tend to adsorb to this medium
    - Many common hazardous contaminants (such as many chlorinated solvents) have high K_{ow}
  - ***Air and Steam Stripping***
    - Contaminants with high Henry's Constant values are likely to enter a vapor phase
    - Pass air or steam through the contaminated water helps volatilize the contaminants and they can be collected or released into the atmosphere

Pump and Treat

- ***Limitations***
  - May take long time for removal of certain organic contaminants from aquifer and render groundwater to safe drinking-water standards
  - High cost
  - Long time to achieve full cleanup

Bioremediation

- Hot topic - lots of active research in this field (including at Notre Dame)
- **Main idea = let the organisms do the work for you**
  - Many microorganisms can take contaminants and break them down into non-harmful chemical species
- **Implementation**
  - Pump and treat - use microorganisms as the treatment method
  - In-situ - introduce microorganisms to the subsurface to remediate OR use the natural microbial community (***natural attenuation***)

Bioremediation

- Microorganisms usually breakdown the contaminant through oxidation reactions
  - Problem - many systems are oxygen poor or are reducing environments
  - Solution - direct injection of oxygen to the subsurface or pumping of contaminated water and oxygenating it
  - Problem - not enough nutrients and electron acceptors (i.e. oxygen)
  - Solution - pumping and spiking of the contaminated groundwater with nutrients and electron acceptors - process called ***enhanced bioremediation***
  - ***Cometabolism*** - addition of both electron donor (usually methane) and electron acceptor (oxygen) to the system in the hope that it will stimulate the growth of a microbial population which will consume **<u>contaminants present at trace-levels</u>**

Recirculating Well Technology

- *Recirculating well* technology (RWT) is a recently-developed method of treating volatile organic compounds (VOCs) in groundwater. The primary difference between RWT and ETR technology is that recirculating wells return treated water to the same well, thus minimizing impacts on the water table.
- In the recirculating well groundwater is drawn into the well near the bottom or from a selected specific zone in the groundwater. It comes into contact with air which is injected into the well, causing the VOCs to transfer from the water to the air.

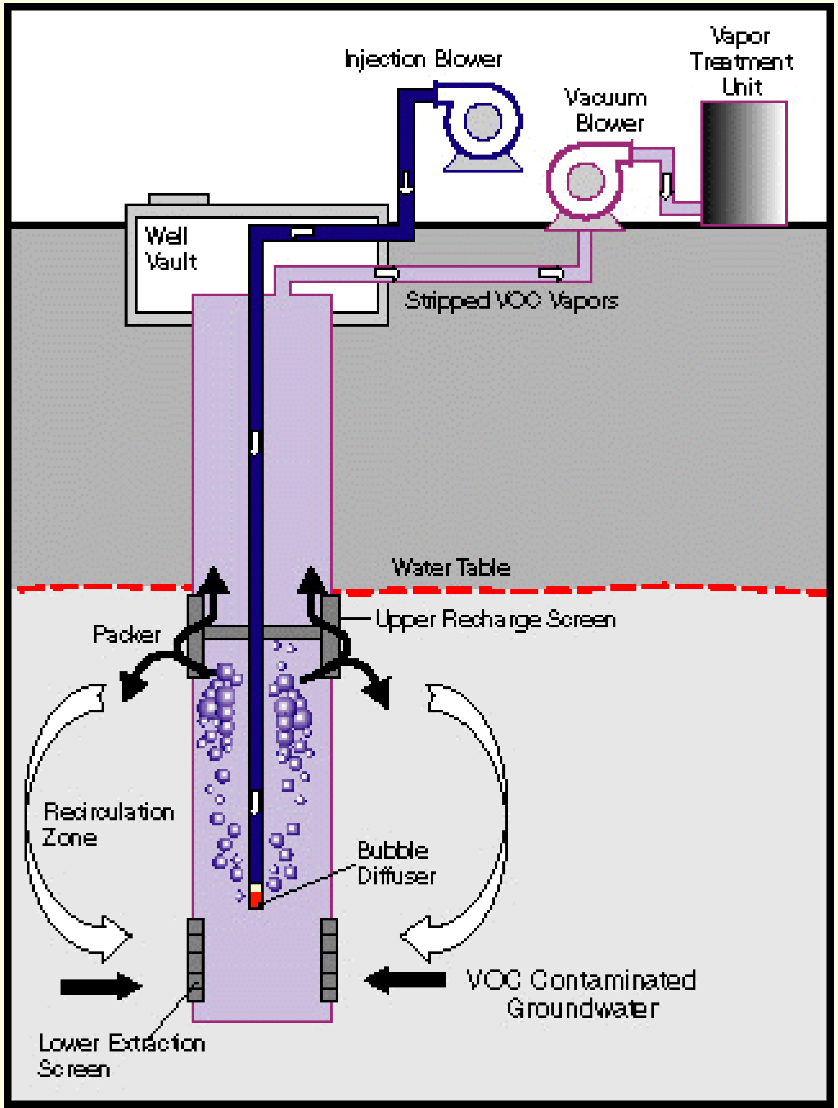
Recirculating Well Technology

- The cleaned water then is pumped back out of the well into another zone of groundwater.
- The combination of contaminated groundwater entering the well from one zone of the aquifer and clean groundwater leaving the well in another zone creates a *zone of recirculation* in the groundwater near the well.
- Contaminated water moving through the zone of recirculation is captured and treated within the well.

Recirculating Well Technology

- The air containing the VOCs is carried up the well to the surface, where it may be piped to an activated carbon treatment system.
- Activated carbon treatment removes contaminants from air just as it does from water, as described in the ETR section above.
- Depending on the design of the system, the treated air is either released to the surrounding environment or directed back into the well for additional removal of contaminants. The air stream is monitored before and after carbon treatment to ensure effective removal of VOCs.

Recirculating Well Technology



Natural Attenuation

- *Natural attenuation* refers to the strategy of allowing natural processes to reduce contaminant concentrations to acceptable levels.
- Natural attenuation involves physical, chemical and biological processes which act to reduce the mass, toxicity, and mobility of subsurface contamination.
- These processes are always occurring and in many cases may reduce risk to human health and the environment to acceptable levels.

Natural Attenuation

- There are several different physical, chemical, and biological processes that comprise natural attenuation. These include:
- *biodegradation*—breakdown of contaminants by microorganisms in the environment, often forming non-harmful byproducts like carbon dioxide and water
- *chemical stabilization*—reduction in contaminant mobility caused by chemical processes
- *dispersion*—the process of mixing that occurs when fluid flows through a porous medium
- *sorption*—attachment of compounds to geologic materials by physical or chemical attraction
- *volatilization*—transfer of a chemical from liquid to vapor; evaporation

White Karbon

- White Karbon is an alternative material to the conventional Granulated Activated Carbon (GAC) and is designed to treat a wide range of contaminants from groundwater, including petroleum and chlorinated hydrocarbons, metals, cyanides and pesticides.
- An interesting feature of White Karbon is that, unlike GAC, it is extremely efficient at removing metals, including nickel, cadmium, arsenic and hexavalent chrome. The latter substance has proved hard to remove from groundwater using other treatment methods available.

http://www.accepta.com/

Zero Valent Iron

- The current approach to in situ reduction of chlorinated hydrocarbons or heavy metals using zero-valent iron employs the construction of permeable reaction walls, or funnel and gate systems for continual passive treatment of dissolved phase contaminants.
- These types of passive treatment technologies are designed to be placed on the down-gradient side of a plume to intercept groundwater flow prior to its migration off-site. As the dissolved phase contamination flows through the permeable reaction wall, reduction of the hydrocarbons and heavy metals occurs.
- Though these types of passive treatment systems are simple to apply at shallow depths and for low concentration levels of chlorinated organics, their applicability and cost effectiveness are greatly limited at deeper depths and higher concentrations. .

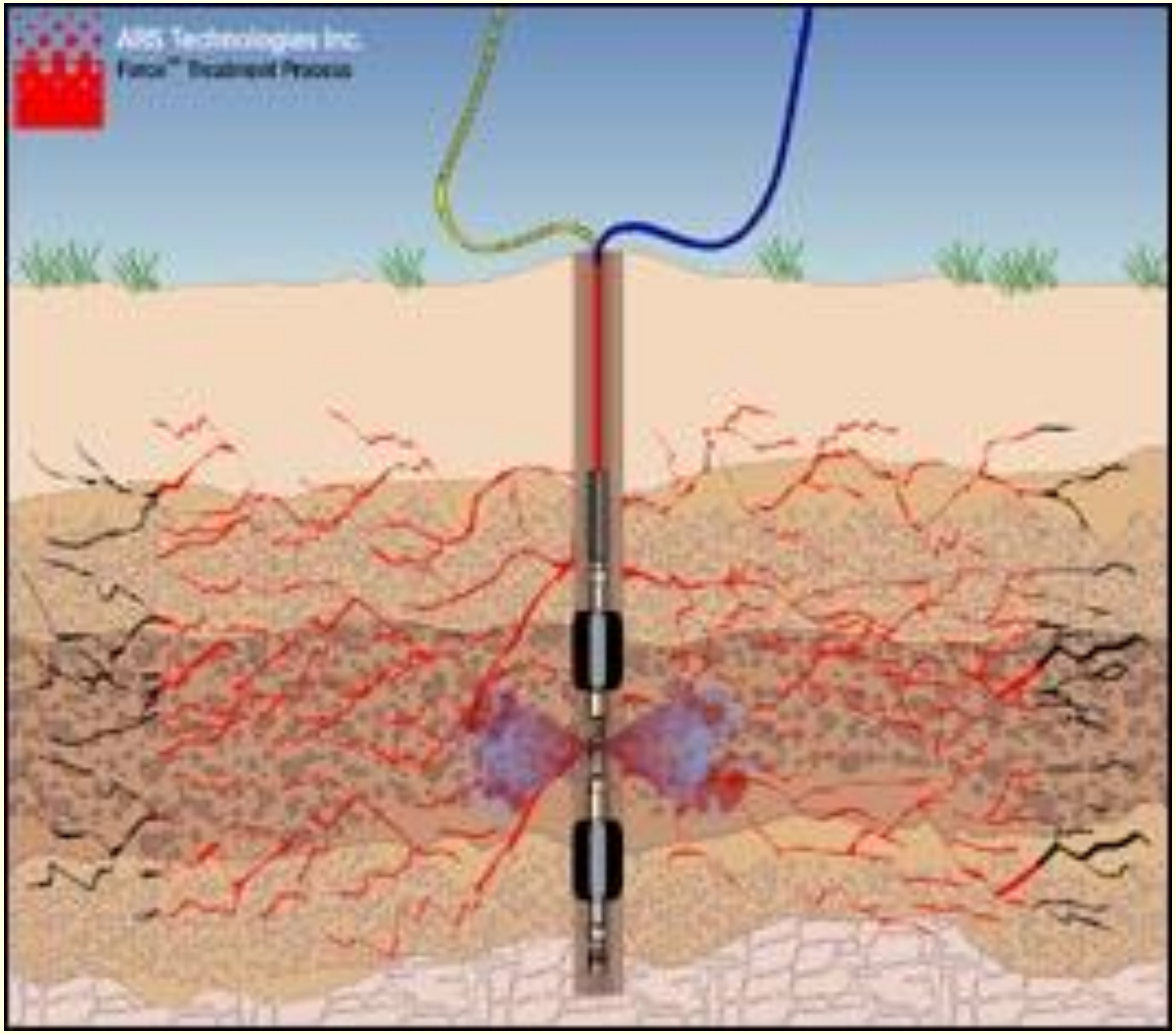
http://www.arstechnologies.com

Zero Valent Iron

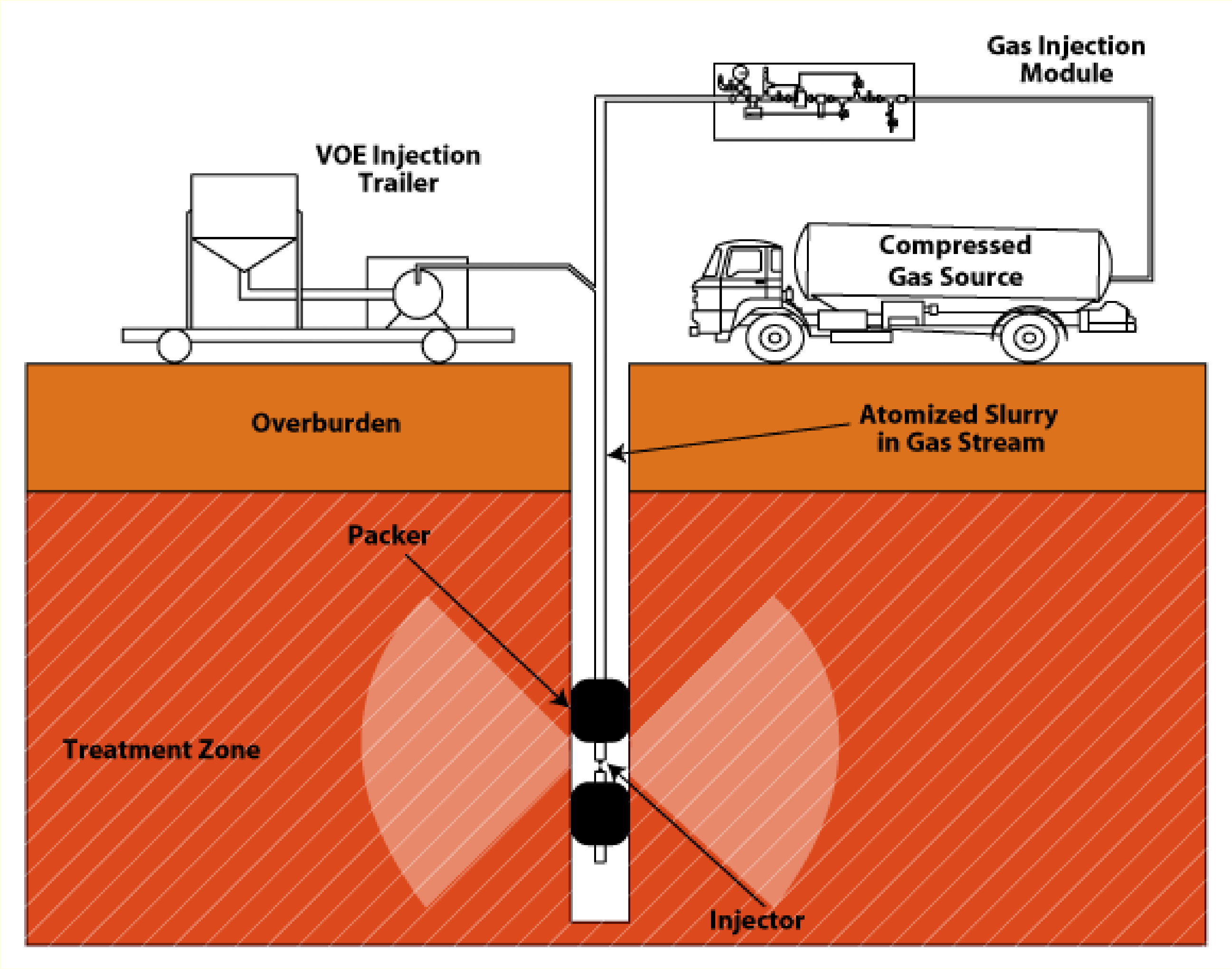
Zero Valent Iron

- The patented FEROXsm technology consists of the integration of two commercially proven processes to provide a cost-effective in situ treatment method for groundwater and soils contaminated with halogenated organic compounds, and/or leachable heavy metals.
- To apply the FEROXsm an open borehole or our direct-push injector assembly casing is used to position the downhole apparatus into the subsurface. Once in place, zero-valent iron powder is injected into the formation as a slurry or as a dry material. Nitrogen gas or compressed air is used as the carrier fluid.

Zero Valent Iron



Zero Valent Iron



THANK YOU