Environmental Engineering

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First Edition, 2012

ISBN 978-81-323-3008-0

Published by:
Research World
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
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Introduction

Environmental engineering is the application of science and engineering principles to improve the environment (air, water, and/or land resources), to provide healthy water, air, and land for human habitation and for other organisms, and to remediate polluted sites.

Environmental engineering involves waste water management and air pollution control, recycling, waste disposal, radiation protection, industrial hygiene, environmental sustainability, and public health issues as well as a knowledge of environmental engineering law. It also includes studies on the environmental impact of proposed construction projects.

Environmental engineers conduct hazardous-waste management studies to evaluate the significance of such hazards, advise on treatment and containment, and develop regulations to prevent mishaps. Environmental engineers also design municipal water supply and industrial wastewater treatment systems as well as address local and worldwide environmental issues such as the effects of acid rain, global warming, ozone depletion, water pollution and air pollution from automobile exhausts and industrial sources. At many universities, Environmental Engineering programs follow either the Department of Civil Engineering or The Department of Chemical Engineering at Engineering faculties. Environmental "civil" engineers focus on hydrology, water resources management, bioremediation, and water treatment plant design. Environmental "chemical" engineers, on the other hand, focus on environmental chemistry, advanced air and water treatment technologies and separation processes.

Additionally, engineers are more frequently obtaining specialized training in law (J.D.) and are utilizing their technical expertise in the practices of Environmental engineering law.. About four percent of environmental engineers go on to obtain Board Certification in their specialty area(s) of environmental engineering (Board Certified Environmental Engineer or BCEE).

Most jurisdictions also impose licensing and registration requirements.

Development of environmental engineering

Ever since people first recognized that their health and well-being were related to the quality of their environment, they have applied thoughtful principles to attempt to improve the quality of their environment. The ancient Harappan civilization utilized early sewers in some cities. The Romans constructed aqueducts to prevent drought and to create a clean, healthful water supply for the metropolis of Rome. In the 15th century, Bavaria created laws restricting the development and degradation of alpine country that constituted the region's water supply

The field emerged as a separate environmental discipline during the middle third of the 20th century in response to widespread public concern about water and pollution and increasingly extensive environmental quality degradation. However, its roots extend back to early efforts in public health engineering. Modern environmental engineering began in London in the mid-19th century when Joseph Bazalgette designed the first major sewerage system that reduced the incidence of waterborne diseases such as cholera. The introduction of drinking water treatment and sewage treatment in industrialized countries reduced waterborne diseases from leading causes of death to rarities.

In many cases, as societies grew, actions that were intended to achieve benefits for those societies had longer-term impacts which reduced other environmental qualities. One example is the widespread application of DDT to control agricultural pests in the years following World War II. While the agricultural benefits were outstanding and crop yields increased dramatically, thus reducing world hunger substantially, and malaria was controlled better than it ever had been, numerous species were brought to the verge of extinction due to the impact of the DDT on their reproductive cycles. The story of DDT as vividly told in Rachel Carson's "Silent Spring" is considered to be the birth of the modern environmental movement and the development of the modern field of "environmental engineering."

Conservation movements and laws restricting public actions that would harm the environment have been developed by various societies for millennia. Notable examples are the laws decreeing the construction of sewers in London and Paris in the 19th century and the creation of the U.S. national park system in the early 20th century.

Scope of Environmental Engineering

Briefly speaking, the main task of environmental engineers is to protect public health by protecting (from further degradation), preserving (the present condition of), and enhancing the environment. Also, they develop new forms of energy and ways to increase the efficiency of generating and using energy. They try to get people to convert to environmental friendly energy and products.

Environmental engineering is the application of science and engineering principles to the environment. Some consider environmental engineering to include the development of sustainable processes. There are several divisions of the field of environmental engineering.

Environmental impact assessment and mitigation

In this division, engineers and scientists use a systemic identification and evaluation process to assess the potential impacts of a proposed project , plans, programs, policies, or legislative actions upon the physical-chemical, biological, cultural, and socioeconomic components on environmental conditions. They apply scientific and engineering principles to evaluate if there are likely to be any adverse impacts to water quality, air quality, habitat quality, flora and fauna, agricultural capacity, traffic impacts, social impacts, ecological impacts, noise impacts, visual(landscape) impacts, etc. If impacts are expected, they then develop mitigation measures to limit or prevent such impacts. An example of a mitigation measure would be the creation of wetlands in a nearby location to mitigate the filling in of wetlands necessary for a road development if it is not possible to reroute the road.

The practice of environmental assessment was intitiated on January 1, 1970, the effective date of the National Environmental Policy Act (NEPA) in the United States. Since that time, more than 100 developing and developed nations either have planned specific analogous laws or have adopted procedure used elsewhere. NEPA is applicable to all federal agencies in the United States.

Water supply and treatment

Engineers and scientists work to secure water supplies for potable and agricultural use. They evaluate the water balance within a watershed and determine the available water supply, the water needed for various needs in that watershed, the seasonal cycles of water movement through the watershed and they develop systems to store, treat, and convey water for various uses. Water is treated to achieve water quality objectives for the end uses. In the case of potable water supply, water is treated to minimize the risk of infectious disease transmission, the risk of non-infectious illness, and to create a palatable water flavor. Water distribution systems are designed and built to provide adequate water pressure and flow rates to meet various end-user needs such as domestic use, fire suppression, and irrigation.

Wastewater conveyance and treatment

Water pollution

Most urban and many rural areas no longer discharge human waste directly to the land through outhouse, septic, and/or honey bucket systems, but rather deposit such waste into water and convey it from households via sewer systems. Engineers and scientists develop collection and treatment systems to carry this waste material away from where people live and produce the waste and discharge it into the environment. In developed countries, substantial resources are applied to the treatment and detoxification of this waste before it is discharged into a river, lake, or ocean system. Developing nations are striving to obtain the resources to develop such systems so that they can improve water quality in their surface waters and reduce the risk of water-borne infectious disease.

Sewage treatment plant, Australia.

There are numerous wastewater treatment technologies. A wastewater treatment train can consist of a primary clarifier system to remove solid and floating materials, a secondary treatment system consisting of an aeration basin followed by flocculation and sedimentation or an activated sludge system and a secondary clarifier, a tertiary biological nitrogen removal system, and a final disinfection process. The aeration basin/activated sludge system removes organic material by growing bacteria (activated sludge). The secondary clarifier removes the activated sludge from the water. The tertiary system, although not always included due to costs, is becoming more prevalent to remove nitrogen and phosphorus and to disinfect the water before discharge to a surface water stream or ocean outfall.

Air quality management

Engineers apply scientific and engineering principles to the design of manufacturing and combustion processes to reduce air pollutant emissions to acceptable levels. Scrubbers, electrostatic precipitators, catalytic converters, and various other processes are utilized to remove particulate matter, nitrogen oxides, sulfur oxides, volatile organic compounds (VOC), reactive organic gases (ROG) and other air pollutants from flue gases and other sources prior to allowing their emission to the atmosphere.

Scientists have developed air pollution dispersion models to evaluate the concentration of a pollutant at a receptor or the impact on overall air quality from vehicle exhausts and industrial flue gas stack emissions.

To some extent, this field overlaps the desire to decrease carbon dioxide and other greenhouse gas emissions from combustion processes.

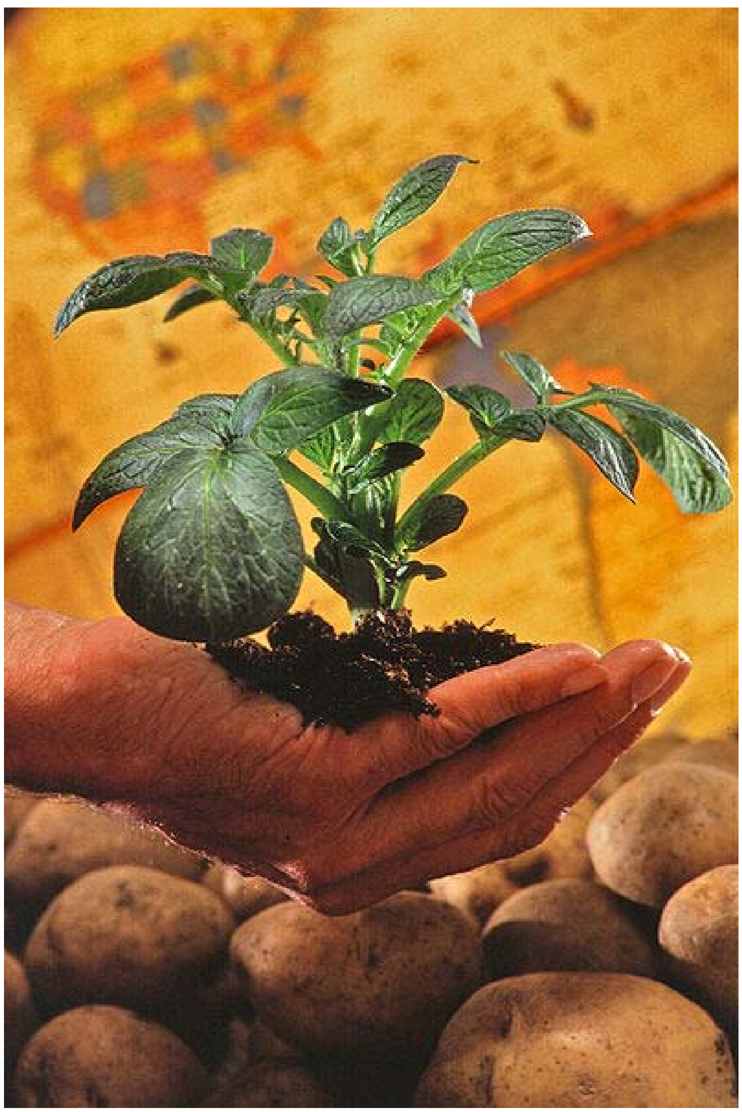
Other applications

- Environmental policy and regulation development
- Contaminated land management and site remediation
- Environment, Health and Safety
- Hazardous waste management
- Natural resource management
- Noise pollution
- Risk assessment
- Solid waste management

Chapter 1

Environmental Policy & Environmental Design

Environmental Policy



Potato plant.

Environmental policy is any [course of] action deliberately taken [or not taken] to manage human activities with a view to prevent, reduce, or mitigate harmful effects on nature and natural resources, and ensuring that man-made changes to the environment do not have harmful effects on humans.

Definition

It is useful to consider that environmental policy comprises two major terms: environment and policy. Environment primarily refers to the ecological dimension (ecosystems), but can also take account of social dimension (quality of life) and an economic dimension (resource management). Policy can be defined as a "course of action or principle adopted or proposed by a government, party, business or individual". Thus, environmental policy focuses on problems arising from human impact on the environment, which retroacts onto human society by having a (negative) impact on human values such as good health or the 'clean and green' environment.

Environmental issues generally addressed by environmental policy include (but are not limited to) air and water pollution, waste management, ecosystem management, biodiversity protection, and the protection of natural resources, wildlife and endangered species. Relatively recently, environmental policy has also attended to the communication of environmental issues.

Rationale

The rationale for governmental involvement in the environment is market failure in the form of externalities, including the free rider problem and the tragedy of the commons. An example of an externality is a factory that engages in water pollution in a river. The cost of such action is paid by society-at-large, when they must clean the water before drinking it and is external to the costs of the factory. The free rider problem is when the private marginal cost of taking action to protect the environment is greater than the private marginal benefit, but the social marginal cost is less than the social marginal benefit. The tragedy of the commons is the problem that, because no one person owns the commons, each individual has an incentive to utilize common resources as much as possible. Without governmental involvement, the commons is overused. Examples of tragedies of the common are overfishing and overgrazing.

Instruments

Environmental policy instruments are tools used by governments to implement their environmental policies. Governments may use a number of different types of instruments. For example, economic incentives and market-based instruments such as taxes and tax exemptions, tradable permits, and fees can be very effective to encourage compliance with environmental policy.

Voluntary measures, such as bilateral agreements negotiated between the government and private firms and commitments made by firms independent of government pressure, are other instruments used in environmental policy. Another instrument is the implementation of greener public purchasing programs.

Often, several instruments are combined in an instrument mix formulated to address a certain environmental problem. Since environmental issues often have many different aspects, several policy instruments may be needed to adequately address each one. Furthermore, instrument mixes may allow firms greater flexibility in finding ways to comply with government policy while reducing the uncertainty in the cost of doing so. However, instrument mixes must be carefully formulated so that the individual measures within them do not undermine each other or create a rigid and cost-ineffective compliance framework. Also, overlapping instruments lead to unnecessary administrative costs, making implementation of environmental policies more costly than necessary In order to help governments realize their environmental policy goals, the OECD Environment Directorate studies and collects data on the efficiency of the environmental instruments governments use to achieve their goals as well as their consequences for other policies.

The current reliance on a market based framework is controversial, however, with many prominent environmentalists arguing that a more radical, overarching, approach is needed than a set of specific initiatives, to deal coherently with the scale of the climate change challenge. For an example of the problems, energy efficiency measures may actually increase energy consumption in the absence of a cap on fossil fuel use, as people might drive more efficient cars further and they might sell better. Thus, for example, Aubrey Meyer calls for a 'framework based market' of contraction and convergence examples of which are ideas such as the recent Cap and Share and 'Sky Trust' proposals.

Environmental Design

Environmental design is the process of addressing surrounding environmental parameters when devising plans, programs, policies, buildings, or products. Classical prudent design may have always considered environmental factors; however, the environmental movement beginning in the 1940s has made the concept more explicit.

Environmental design can also refer to the applied arts and sciences dealing with creating the human-designed environment. These fields include architecture, geography,urban planning, landscape architecture, and interior design. Environmental design can also encompass interdisciplinary areas such as historical preservation and lighting design. In terms of a larger scope, environmental design has implications for the industrial design of products: innovative automobiles, wind-electricity generators, solar-electric equipment, and other kinds of equipment could serve as examples. Currently, the term has expanded to apply to ecological and sustainability issues.

History

The photo shows a training meeting with factory workers in a stainless steel ecodesign company from Rio de Janeiro, Brazil.

The first traceable concepts of environmental designs focused primarily on solar heating, which began in Ancient Greece around 500 BCE. At the time, most of Greece had exhausted its supply of wood for fuel, leading architects to design houses that would capture the solar energy of the sun. The Greeks understood that the position of the sun varies throughout the year. For a latitude of 40 degrees in summer the sun is high in the south, at an angle of 70 degrees at the zenith, while in winter, the sun travels a lower trajectory, with a zenith of 26 degrees. Greek houses were built with south-facing façades which received little to no sun in the summer but would receive full sun in the winter, warming the house. Additionally, the southern orientation also protected the house from the colder northern winds. This clever arrangement of buildings influenced the use of the grid pattern of ancient cities. With the North-South orientation of the houses, the streets of Greek cities mainly ran East-West.

The practice of solar architecture continued with the Romans, who similarly had deforested much of their native Italian Peninsula by the first century BCE. The Roman heliocaminus, literally 'solar furnace', functioned with the same aspects of the earlier Greek houses. The numerous public baths were oriented to the south. Roman architects added glass to windows to allow for the passage of light and to conserve interior heat as it could not escape. The Romans also used greenhouses to grow crops all year long and to cultivate the exotic plants coming from the far corners of the Empire. Pliny the Elder wrote of greenhouses that supplied the kitchen of the Emperor Tiberius during the year.

Along with the solar orientation of buildings and the use of glass as a solar heat collector, the ancients knew other ways of harnessing solar energy. The Greeks, Romans and Chinese developed curved mirrors that could concentrate the sun's rays on an object with enough intensity to make it burn in seconds. The solar reflectors were often made of silver, copper or polished brass.

Early roots of modern environmental design began in the late 19th Century with writer/designer William Morris, who rejected the use of industrialized materials and processes in wallpaper, fabrics and books his studio produced. He and others, such as John Ruskin felt that the industrial revolution would lead to harm done to nature and workers.

The narrative of Phil Cousineau's documentary film Ecological Design: Inventing the Future asserts that in the decades after World War II, "The world was forced to confront the dark shadow of science and industry." From the middle of the twentieth century, thinkers like Buckminster Fuller have acted as catalysts for a broadening and deepening of the concerns of environmental designers. Nowadays, energy efficiency, appropriate technology, organic horticulture and agriculture, land restoration, New Urbanism, and ecologically sustainable energy and waste systems are recognized considerations or options and may each find application.

By integrating renewable energy sources such as solar photovoltaic, solar thermal, and even geothermal energy into structures, it is possible to create zero emission buildings, where energy consumption is self-generating and non-polluting. It is also possible to construct "energy-plus buildings" which generate more energy than they consume, and the excess could then be sold to the grid. In the United States, the LEED Green Building Rating System rates structures on their environmental sustainability.

Examples

Examples of the environmental design process include use of roadway noise computer models in design of noise barriers and use of roadway air dispersion models in analyzing and designing urban highways. Designers consciously working within this more recent framework of philosophy and practice seek a blending of nature and technology, regarding ecology as the basis for design. Some believe that strategies of conservation, stewardship, and regeneration can be applied at all levels of scale from the individual building to the community, with benefit to the human individual and local and planetary ecosystems.

Specific examples of large scale environmental design projects include:

- Boston Transportation Planning Review

- BART - Bay Area Rapid Transit System Daly City Turnback project and airport extension.
- Metropolitan Portland, Oregon light rail system

Chapter 2

Waste Management

A blue wheelie bin in Berkshire, England

Waste management in Kathmandu (Nepal)

Waste management is the collection, transport, processing, recycling or disposal, and monitoring of waste materials. The term usually relates to materials produced by human activity, and is generally undertaken to reduce their effect on health, the environment or aesthetics. Waste management is also carried out to recover resources from it. Waste management can involve solid, liquid, gaseous or radioactive substances, with different methods and fields of expertise for each.

Waste management practices differ for developed and developing nations, for urban and rural areas, and for residential and industrial producers. Management for non-hazardous waste residential and institutional waste in metropolitan areas is usually the responsibility of local government authorities, while management for non-hazardous commercial and industrial waste is usually the responsibility of the generator.

Methods of disposal

Integrated waste management

Integrated waste management using LCA (life cycle analysis) attempts to offer the most benign options for waste management. For mixed MSW (Municipal Solid Waste) a number of broad studies have indicated that waste administration, then source separation and collection followed by reuse and recycling of the non-organic fraction and energy and compost/fertilizer production of the organic waste fraction via anaerobic digestion to be the favoured path. Non-metallic waste resources are not destroyed as with incineration, and can be reused/ recycled in a future resource depleted society.

Landfill

Landfill operation in Hawaii.

Disposing of waste in a landfill involves burying the waste, and this remains a common practice in most countries. Landfills were often established in abandoned or unused quarries, mining voids or borrow pits. A properly designed and well-managed landfill can be a hygienic and relatively inexpensive method of disposing of waste materials. Older, poorly designed or poorly managed landfills can create a number of adverse environmental impacts such as wind-blown litter, attraction of vermin, and generation of liquid leachate. Another common byproduct of landfills is gas (mostly composed of methane and carbon dioxide), which is produced as organic waste breaks down anaerobically. This gas can create odour problems, kill surface vegetation, and is a greenhouse gas.

A landfill compaction vehicle in action.

Design characteristics of a modern landfill include methods to contain leachate such as clay or plastic lining material. Deposited waste is normally compacted to increase its density and stability, and covered to prevent attracting vermin (such as mice or rats). Many landfills also have landfill gas extraction systems installed to extract the landfill gas. Gas is pumped out of the landfill using perforated pipes and flared off or burnt in a gas engine to generate electricity.

Incineration

Spittelau incineration plant in Vienna.

Incineration is a disposal method in which solid organic wastes are subjected to combustion so as to convert them into residue and gaseous products. This method is useful for disposal of residue of both solid waste management and solid residue from waste water management.This process reduces the volumes of solid waste to 20 to 30 percent of the original volume. Incineration and other high temperature waste treatment systems are sometimes described as "thermal treatment". Incinerators convert waste materials into heat, gas, steam and ash.

Incineration is carried out both on a small scale by individuals and on a large scale by industry. It is used to dispose of solid, liquid and gaseous waste. It is recognized as a practical method of disposing of certain hazardous waste materials (such as biological medical waste). Incineration is a controversial method of waste disposal, due to issues such as emission of gaseous pollutants.

Incineration is common in countries such as Japan where land is more scarce, as these facilities generally do not require as much area as landfills. Waste-to-energy (WtE) or energy-from-waste (EfW) are broad terms for facilities that burn waste in a furnace or boiler to generate heat, steam or electricity. Combustion in an incinerator is not always perfect and there have been concerns about pollutants in gaseous emissions from incinerator stacks. Particular concern has focused on some very persistent organics such as dioxins, furans, PAHs which may be created which may have serious environmental consequences.

Recycling

Steel crushed and baled for recycling

Recycling refers to the collection and reuse of waste materials such as empty beverage containers. The materials from which the items are made can be reprocessed into new products. Material for recycling may be collected separately from general waste using dedicated bins and collection vehicles, or sorted directly from mixed waste streams.

The most common consumer products recycled include aluminum such as beverage cans, copper such as wire, steel food and aerosol cans, old steel furnishings or equipment , polyethylene and PET bottles, glass bottles and jars, paperboard cartons, newspapers, magazines and light paper, and corrugated fiberboard boxes.

PVC, LDPE, PP, and PS are also recyclable. These items are usually composed of a single type of material, making them relatively easy to recycle into new products. The recycling of complex products (such as computers and electronic equipment) is more difficult, due to the additional dismantling and separation required.

Sustainability

The management of waste is a key component in a business' ability to maintaining ISO14001 accreditation. Companies are encouraged to improve their environmental efficiencies each year. One way to do this is by improving a company's waste management with a new recycling service. (such as recycling: glass, food waste, paper and cardboard, plastic bottles etc.)

Biological reprocessing

An active compost heap.

Waste materials that are organic in nature, such as plant material, food scraps, and paper products, can be recycled using biological composting and digestion processes to decompose the organic matter. The resulting organic material is then recycled as mulch or compost for agricultural or landscaping purposes. In addition, waste gas from the process (such as methane) can be captured and used for generating electricity and heat (CHP/cogeneration) maximising efficiencies. The intention of biological processing in waste management is to control and accelerate the natural process of decomposition of organic matter.

There is a large variety of composting and digestion methods and technologies varying in complexity from simple home compost heaps, to small town scale batch digesters, industrial-scale enclosed-vessel digestion of mixed domestic waste. Methods of biological decomposition are differentiated as being aerobic or anaerobic methods, though hybrids of the two methods also exist.

Anaerobic digestion of the organic fraction of MSW Municipal Solid Waste has been found to be in a number of LCA analysis studies to be more environmentally effective, than landfill, incineration or pyrolisis. The resulting biogas (methane) though must be used for cogeneration (electricity and heat preferably on or close to the site of production) and can be used with a little upgrading in gas combustion engines or turbines. With further upgrading to synthetic natural gas it can be injected into the natural gas network or further refined to hydrogen for use in stationary cogeneration fuel cells. Its use in fuel cells eliminates the pollution from products of combustion.

An example of waste management through composting is the Green Bin Program in Toronto, Canada, where Source Separated Organics (such as kitchen scraps and plant cuttings) are collected in a dedicated container and then composted.

Energy recovery

Anaerobic digestion component of Lübeck mechanical biological treatment plant in Germany, 2007

The energy content of waste products can be harnessed directly by using them as a direct combustion fuel, or indirectly by processing them into another type of fuel. Recycling through thermal treatment ranges from using waste as a fuel source for cooking or heating, to anaerobic digestion and the use of the gas fuel, to fuel for boilers to generate steam and electricity in a turbine. Pyrolysis and gasification are two related forms of thermal treatment where waste materials are heated to high temperatures with limited oxygen availability. The process usually occurs in a sealed vessel under high pressure. Pyrolysis of solid waste converts the material into solid, liquid and gas products. The liquid and gas can be burnt to produce energy or refined into other chemical products (chemical refinery). The solid residue (char) can be further refined into products such as activated carbon. Gasification and advanced Plasma arc gasification are used to convert organic materials directly into a synthetic gas (syngas) composed of carbon monoxide and hydrogen. The gas is then burnt to produce electricity and steam. An alternative to pyrolisis is high temperature and pressure supercritical water decomposition (hydrothermal monophasic oxidation).

Avoidance and reduction methods

An important method of waste management is the prevention of waste material being created, also known as waste reduction. Methods of avoidance include reuse of second-hand products, repairing broken items instead of buying new, designing products to be refillable or reusable (such as cotton instead of plastic shopping bags), encouraging consumers to avoid using disposable products (such as disposable cutlery), removing any food/liquid remains from cans, packaging, ... and designing products that use less material to achieve the same purpose (for example, lightweighting of beverage cans).

Waste handling and transport

A front-loading garbage truck in North America.

Waste collection methods vary widely among different countries and regions. Domestic waste collection services are often provided by local government authorities, or by private companies in the industry. Some areas, especially those in less developed countries, do not have a formal waste-collection system. Examples of waste handling systems include:

- In Australia, curbside collection is the method of disposal of waste. Every urban domestic household is provided with three bins: one for recyclables, another for general waste and another for garden materials - this bin is provided by the municipality if requested. Also, many households have compost bins; but this is not provided by the municipality. To encourage recycling, municipalities provide large recycle bins, which are larger than general waste bins. Municipal, commercial and industrial, construction and demolition waste is dumped at landfills and some is recycled. Household waste is segregated: recyclables sorted and made into new products, and general waste is dumped in landfill areas. According to the ABS, the recycling rate is high and is 'increasing, with 99% of households reporting that they had recycled or reused some of their waste within the past year (2003 survey), up from 85% in 1992'. This suggests that Australians are in favour of reduced or no landfilling and the recycling of waste. Of the total waste produced in 2002–03, '30% of municipal waste, 45% of commercial and industrial waste and 57% of construction and demolition waste' was recycled. Energy is produced from waste as well: some landfill gas is captured for fuel or electricity generation. Households and industries are not charged for the volume of waste they produce.

- In Europe and a few other places around the world, a few communities use a proprietary collection system known as Envac, which conveys refuse via underground conduits using a vacuum system. Other vacuum-based solutions include the MetroTaifun single-line and ring-line systems.
- In Canadian urban centres curbside collection is the most common method of disposal, whereby the city collects waste and/or recyclables and/or organics on a scheduled basis. In rural areas people often dispose of their waste by hauling it to a transfer station. Waste collected is then transported to a regional landfill.
- In Taipei, the city government charges its households and industries for the volume of rubbish they produce. Waste will only be collected by the city council if waste is disposed in government issued rubbish bags. This policy has successfully reduced the amount of waste the city produces and increased the recycling rate.
- In Israel, the Arrow Ecology company has developed the ArrowBio system, which takes trash directly from collection trucks and separates organic and inorganic materials through gravitational settling, screening, and hydro-mechanical shredding. The system is capable of sorting huge volumes of solid waste, salvaging recyclables, and turning the rest into biogas and rich agricultural compost. The system is used in California, Australia, Greece, Mexico, the United Kingdom and in Israel. For example, an ArrowBio plant that has been operational

at the Hiriya landfill site since December 2003 serves the Tel Aviv area, and processes up to 150 tons of garbage a day.

Technologies

Traditionally the waste management industry has been slow to adopt new technologies such as RFID (Radio Frequency Identification) tags, GPS and integrated software packages which enable better quality data to be collected without the use of estimation or manual data entry.

- Technologies like RFID tags are now being used to collect data on presentation rates for curb-side pick-ups which is useful when examining the usage of recycling bins or similar.
- Benefits of GPS tracking is particularly evident when considering the efficiency of ad hoc pick-ups (like skip bins or dumpsters) where the collection is done on a consumer request basis.
- Integrated software packages are useful in aggregating this data for use in optimisation of operations for waste collection operations.
- Rear vision cameras are commonly used for OH&S reasons and video recording devices are becoming more widely used, particularly concerning residential services and contaminations of the waste stream.

Waste management concepts

There are a number of concepts about waste management which vary in their usage between countries or regions. Some of the most general, widely used concepts include:

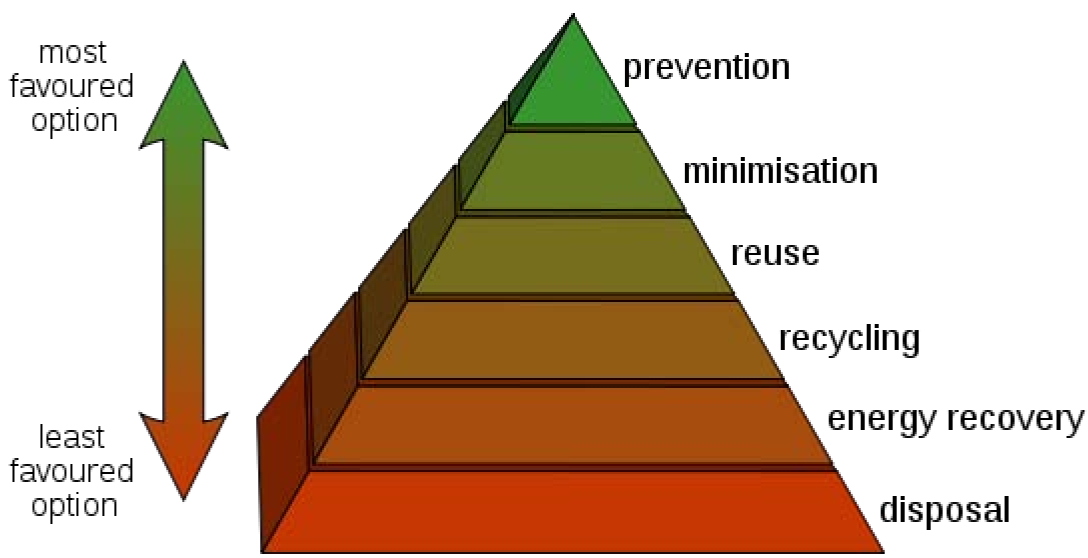


Diagram of the waste hierarchy.

- Waste hierarchy - The waste hierarchy refers to the "3 Rs" reduce, reuse and recycle, which classify waste management strategies according to their desirability in terms of waste minimization. The waste hierarchy remains the cornerstone of most waste minimization strategies. The aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste.
- Extended producer responsibility - Extended Producer Responsibility (EPR) is a strategy designed to promote the integration of all costs associated with products throughout their life cycle (including end-of-life disposal costs) into the market price of the product. Extended producer responsibility is meant to impose accountability over the entire lifecycle of products and packaging introduced to the market. This means that firms which manufacture, import and/or sell products are required to be responsible for the products after their useful life as well as during manufacture.
- Polluter pays principle - the Polluter Pays Principle is a principle where the polluting party pays for the impact caused to the environment. With respect to waste management, this generally refers to the requirement for a waste generator to pay for appropriate disposal of the waste.

Education and awareness

Education and awareness in the area of waste and waste management is increasingly important from a global perspective of resource management. The Talloires Declaration is a declaration for sustainability concerned about the unprecedented scale and speed of environmental pollution and degradation, and the depletion of natural resources. Local, regional, and global air pollution; accumulation and distribution of toxic wastes; destruction and depletion of forests, soil, and water; depletion of the ozone layer and emission of "green house" gases threaten the survival of humans and thousands of other living species, the integrity of the earth and its biodiversity, the security of nations, and the heritage of future generations. Several universities have implemented the Talloires Declaration by establishing environmental management and waste management programs, e.g. the waste management university project. University and vocational education are promoted by various organizations, e.g. WAMITAB and Chartered Institution of Wastes Management. Many supermarkets encourage customers to use their reverse vending machines to deposit used purchased containers and receive a refund from the recycling fees. Brands that manufacture such machines include Tomra and Envipco.

In 2010, CNBC aired the documentary *Trash Inc: The Secret Life of Garbage* about waste, what happens to it when it's "thrown away", and its impact on the world.

Chapter 3

Sewage Treatment

The objective of sewage treatment is to produce a disposable effluent without causing harm to the surrounding environment and prevent pollution.

Sewage treatment, or **domestic wastewater treatment**, is the process of removing contaminants from wastewater and household sewage, both runoff (effluents) and domestic. It includes physical, chemical, and biological processes to remove physical, chemical and biological contaminants. Its objective is to produce an environmentally-safe fluid waste stream (or treated effluent) and a solid waste (or treated sludge) suitable for disposal or reuse (usually as farm fertilizer). Using advanced technology it is now possible to re-use sewage effluent for drinking water, although Singapore is the only country to implement such technology on a production scale in its production of NEWater.

Origins of sewage

Sewage is created by residential, institutional, and commercial and industrial establishments and includes household waste liquid from toilets, baths, showers, kitchens, sinks and so forth that is disposed of via sewers. In many areas, sewage also includes liquid waste from industry and commerce. The separation and draining of household waste into greywater and blackwater is becoming more common in the developed world, with greywater being permitted to be used for watering plants or recycled for flushing toilets.

Sewage may include stormwater runoff. Sewerage systems capable of handling stormwater are known as combined systems. Combined sewer systems are usually avoided now because precipitation causes widely varying flows reducing sewage treatment plant efficiency. Combined sewers require much larger, more expensive, treatment facilities than sanitary sewers. Heavy storm runoff may overwhelm the sewage treatment system, causing a spill or overflow. Sanitary sewers are typically much smaller than combined sewers, and they are not designed to transport stormwater. Backups of raw sewage can occur if excessive Infiltration/Inflow is allowed into a sanitary sewer system.

Modern sewered developments tend to be provided with separate storm drain systems for rainwater. As rainfall travels over roofs and the ground, it may pick up various contaminants including soil particles and other sediment, heavy metals, organic compounds, animal waste, and oil and grease. Some jurisdictions require stormwater to receive some level of treatment before being discharged directly into waterways. Examples of treatment processes used for stormwater include retention basins, wetlands, buried vaults with various kinds of media filters, and vortex separators (to remove coarse solids).

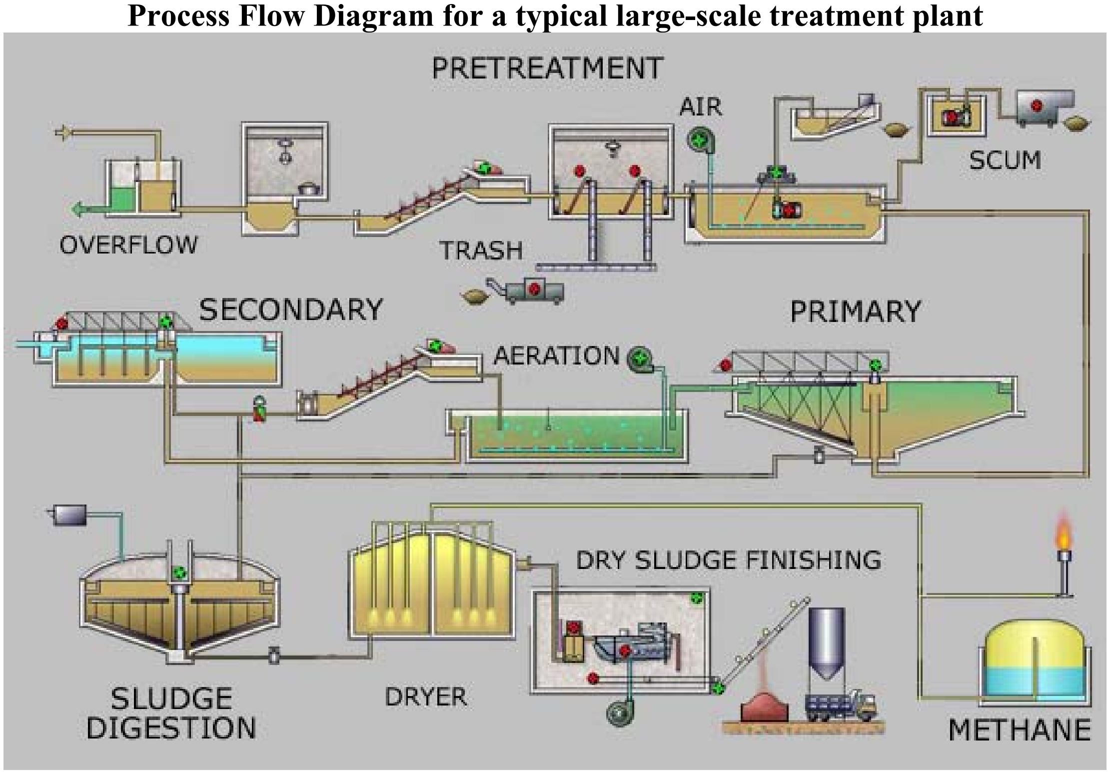
Process overview

Sewage can be treated close to where it is created, a decentralised system, (in septic tanks, biofilters or aerobic treatment systems), or be collected and transported via a network of pipes and pump stations to a municipal treatment plant, a centralised system. Sewage collection and treatment is typically subject to local, state and federal regulations and standards. Industrial sources of wastewater often require specialized treatment processes.

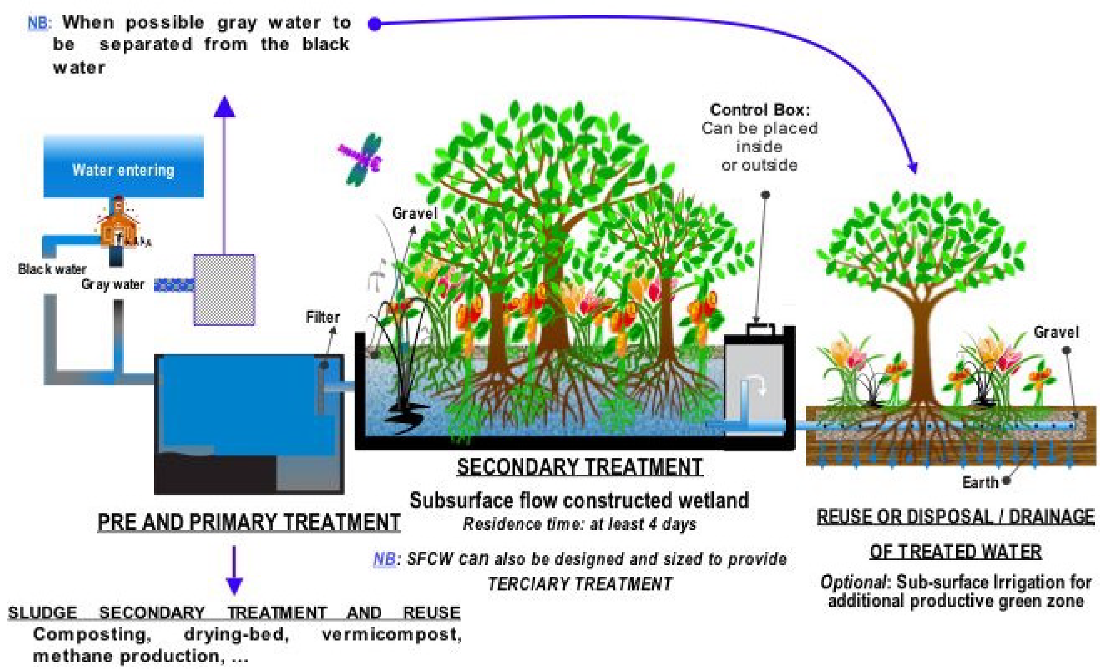
Sewage treatment generally involves three stages, called primary, secondary and tertiary treatment.

- *Primary treatment* consists of temporarily holding the sewage in a quiescent basin where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface. The settled and floating materials are removed and the remaining liquid may be discharged or subjected to secondary treatment.
- *Secondary treatment* removes dissolved and suspended biological matter. Secondary treatment is typically performed by indigenous, water-borne micro-organisms in a managed habitat. Secondary treatment may require a separation process to remove the micro-organisms from the treated water prior to discharge or tertiary treatment.
- *Tertiary treatment* is sometimes defined as anything more than primary and secondary treatment in order to allow rejection into a highly sensitive or fragile ecosystem (estuaries, low-flow rivers, coral reefs,...). Treated water is sometimes disinfected chemically or physically (for example, by lagoons and microfiltration) prior to discharge into a stream, river, bay, lagoon or wetland, or it can be used for the irrigation of a golf course, green way or park. If it is sufficiently clean, it can also be used for groundwater recharge or agricultural purposes.

Process Flow Diagram for a typical large-scale treatment plant



Process Flow Diagram for a typical treatment plant via Subsurface Flow Constructed Wetlands (SFCW)



Pre-treatment

Pre-treatment removes materials that can be easily collected from the raw waste water before they damage or clog the pumps and skimmers of primary treatment clarifiers (trash, tree limbs, leaves, etc.).

Screening

The influent sewage water is screened to remove all large objectslike cans,rags,sticks,plastic packets etc. carried in the sewage stream. This is most commonly done with an automated mechanically raked bar screen in modern plants serving large populations, whilst in smaller or less modern plants a manually cleaned screen may be used. The raking action of a mechanical bar screen is typically paced according to the accumulation on the bar screens and/or flow rate. The solids are collected and later disposed in a landfill or incinerated. Bar screens or mesh screens of varying sizes may be used to optimize solids removal. If gross solids are not removed they become entrained in pipes and moving parts of the treatment plant and can cause substantial damage and inefficiency in the process.

Grit removal

Pre-treatment may include a sand or grit channel or chamber where the velocity of the incoming wastewater is adjusted to allow the settlement of sand, grit, stones, and broken glass. These particles are removed because they may damage pumps and other equipment. For small sanitary sewer systems, the grit chambers may not be necessary, but grit removal is desirable at larger plants.

An empty sedimentation tank at the treatment plant in Merchtem, Belgium.

Fat and grease removal

In some larger plants, fat and grease is removed by passing the sewage through a small tank where skimmers collect the fat floating on the surface. Air blowers in the base of the tank may also be used to help recover the fat as a froth. In most plants however, fat and grease removal takes place in the primary settlement tank using mechanical surface skimmers.

Primary treatment

In the primary sedimentation stage, sewage flows through large tanks, commonly called "primary clarifiers" or "primary sedimentation tanks." The tanks are used to settle sludge while grease and oils rise to the surface and are skimmed off. Primary settling tanks are usually equipped with mechanically driven scrapers that continually drive the collected sludge towards a hopper in the base of the tank where it is pumped to sludge treatment facilities. Grease and oil from the floating material can sometimes be recovered for saponification.

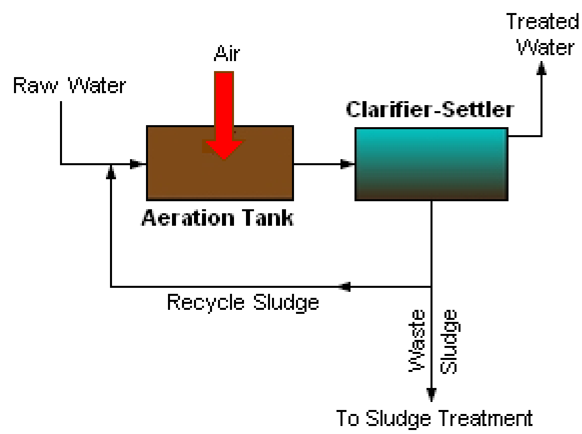
The dimensions of the tank should be designed to effect removal of a high percentage of the floatables and sludge. A typical sedimentation tank may remove from 60 to 65 percent of suspended solids, and from 30 to 35 percent of biochemical oxygen demand (BOD) from the sewage.

Secondary treatment

Secondary treatment is designed to substantially degrade the biological content of the sewage which are derived from human waste, food waste, soaps and detergent. The majority of municipal plants treat the settled sewage liquor using aerobic biological processes. To be effective, the biota require both oxygen and food to live. The bacteria and protozoa consume biodegradable soluble organic contaminants (e.g. sugars, fats, organic short-chain carbon molecules, etc.) and bind much of the less soluble fractions into floc. Secondary treatment systems are classified as *fixed-film* or *suspended-growth* systems.

- **Fixed-film** or **attached growth** systems include trickling filters and rotating biological contactors, where the biomass grows on media and the sewage passes over its surface.
- **Suspended-growth** systems include activated sludge, where the biomass is mixed with the sewage and can be operated in a smaller space than fixed-film systems that treat the same amount of water. However, fixed-film systems are more able to cope with drastic changes in the amount of biological material and can provide higher removal rates for organic material and suspended solids than suspended growth systems.

Roughing filters are intended to treat particularly strong or variable organic loads, typically industrial, to allow them to then be treated by conventional secondary treatment processes. Characteristics include filters filled with media to which wastewater is applied. They are designed to allow high hydraulic loading and a high level of aeration. On larger installations, air is forced through the media using blowers. The resultant wastewater is usually within the normal range for conventional treatment processes.



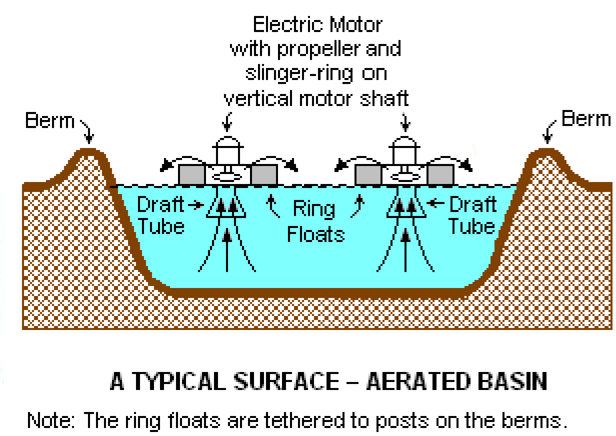
A generalized, schematic diagram of an activated sludge process.

A filter removes a small percentage of the suspended organic matter, while the majority of the organic matter undergoes a change of character, only due to the biological oxidation and nitrification taking place in the filter. With this aerobic oxidation and nitrification, the organic solids are converted into coagulated suspended mass, which is heavier and bulkier, and can settle to the bottom of a tank. The effluent of the filter is therefore passed through a sedimentation tank, called a secondary clarifier, secondary settling tank or humus tank.

Activated sludge

In general, activated sludge plants encompass a variety of mechanisms and processes that use dissolved oxygen to promote the growth of biological floc that substantially removes organic material.

The process traps particulate material and can, under ideal conditions, convert ammonia to nitrite and nitrate and ultimately to nitrogen gas.



A Typical Surface-Aerated Basin (using motor-driven floating aerators)

Surface-aerated basins (Lagoons)

Many small municipal sewage systems in the United States (1 million gal./day or less) use aerated lagoons.

Most biological oxidation processes for treating industrial wastewaters have in common the use of oxygen (or air) and microbial action. Surface-aerated basins achieve 80 to 90 percent removal of BOD with retention times of 1 to 10 days. The basins may range in depth from 1.5 to 5.0 metres and use motor-driven aerators floating on the surface of the wastewater.

In an aerated basin system, the aerators provide two functions: they transfer air into the basins required by the biological oxidation reactions, and they provide the mixing required for dispersing the air and for contacting the reactants (that is, oxygen, wastewater and microbes). Typically, the floating surface aerators are rated to deliver the amount of air equivalent to 1.8 to 2.7 kg O_2/kW·h. However, they do not provide as good mixing as is normally achieved in activated sludge systems and therefore aerated basins do not achieve the same performance level as activated sludge units.

Biological oxidation processes are sensitive to temperature and, between 0 °C and 40 °C, the rate of biological reactions increase with temperature. Most surface aerated vessels operate at between 4 °C and 32 °C.

Constructed wetlands

Constructed wetlands (can either be surface flow or subsurface flow, horizontal or vertical flow), include engineered reedbeds and belong to the family of phytorestoration and ecotechnologies; they provide a high degree of biological improvement and depending on design, act as a primary, secondary and sometimes tertiary treatment. One example is a small reedbed used to clean the drainage from the elephants' enclosure at Chester Zoo in England; numerous CWs are used to recycle the water of the city of Honfleur in France and numerous other towns in Europe, the US, Asia and Australia. They are known to be highly productive systems as they copy natural wetlands, called the "Kidneys of the earth" for their fundamental recycling capacity of the hydrological cycle in the biosphere. Robust and reliable, their treatment capacities improve as time go by, at the opposite of conventional treatment plants whose machinery age with time. They are being increasingly used, although adequate and experienced design are more fundamental than for other systems and space limitation may impede their use.

Filter beds (oxidizing beds)

In older plants and those receiving variable loadings, trickling filter beds are used where the settled sewage liquor is spread onto the surface of a bed made up of coke (carbonized coal), limestone chips or specially fabricated plastic media. Such media must have large surface areas to support the biofilms that form. The liquor is typically distributed through perforated spray arms. The distributed liquor trickles through the bed and is collected in drains at the base. These drains also provide a source of air which percolates up through the bed, keeping it aerobic. Biological films of bacteria, protozoa and fungi form on the media's surfaces and eat or otherwise reduce the organic content. This biofilm is often grazed by insect larvae, snails, and worms which help maintain an optimal thickness. Overloading of beds increases the thickness of the film leading to clogging of the filter media and ponding on the surface. Recent advances in media and process micro-biology design overcome many issues with Trickling filter designs.

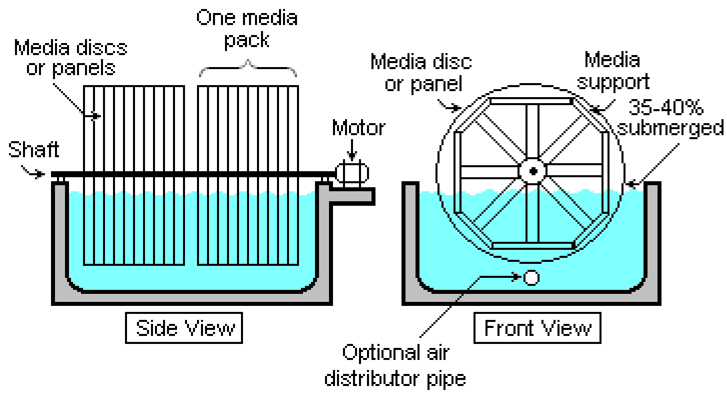
Soil Bio-Technology

A new process called Soil Bio-Technology (SBT) developed at IIT Bombay has shown tremendous improvements in process efficiency enabling total water reuse, due to extremely low operating power requirements of less than 50 joules per kg of treated water. Typically SBT systems can achieve chemical oxygen demand (COD) levels less than 10 mg/L from sewage input of COD 400 mg/L. SBT plants exhibit high reductions in COD values and bacterial counts as a result of the very high microbial densities available in the media. Unlike conventional treatment plants, SBT plants produce insignificant amounts of sludge, precluding the need for sludge disposal areas that are required by other technologies.

In the Indian context, conventional sewage treatment plants fall into systemic disrepair due to 1) high operating costs, 2) equipment corrosion due to methanogenesis and hydrogen sulphide, 3) non-reusability of treated water due to high COD (>30 mg/L) and high fecal coliform (>3000 NFU) counts, 4) lack of skilled operating personnel and 5) equipment replacement issues. Examples of such systemic failures has been documented by Sankat Mochan Foundation at the Ganges basin after a massive cleanup effort by the Indian government in 1986 by setting up sewage treatment plants under the Ganga Action Plan failed to improve river water quality.

Biological aerated filters

Biological Aerated (or Anoxic) Filter (BAF) or Biofilters combine filtration with biological carbon reduction, nitrification or denitrification. BAF usually includes a reactor filled with a filter media. The media is either in suspension or supported by a gravel layer at the foot of the filter. The dual purpose of this media is to support highly active biomass that is attached to it and to filter suspended solids. Carbon reduction and ammonia conversion occurs in aerobic mode and sometime achieved in a single reactor while nitrate conversion occurs in anoxic mode. BAF is operated either in upflow or downflow configuration depending on design specified by manufacturer.



Schematic diagram of a typical rotating biological contactor (RBC). The treated effluent clarifier/settler is not included in the diagram.

Rotating biological contactors

Rotating biological contactors (RBCs) are mechanical secondary treatment systems, which are robust and capable of withstanding surges in organic load. RBCs were first installed in Germany in 1960 and have since been developed and refined into a reliable operating unit. The rotating disks support the growth of bacteria and micro-organisms present in the sewage, which break down and stabilise organic pollutants. To be successful, micro-organisms need both oxygen to live and food to grow. Oxygen is obtained from the atmosphere as the disks rotate. As the micro-organisms grow, they build up on the media until they are sloughed off due to shear forces provided by the rotating discs in the sewage. Effluent from the RBC is then passed through final clarifiers where the micro-organisms in suspension settle as a sludge. The sludge is withdrawn from the clarifier for further treatment.

A functionally similar biological filtering system has become popular as part of home aquarium filtration and purification. The aquarium water is drawn up out of the tank and then cascaded over a freely spinning corrugated fiber-mesh wheel before passing through a media filter and back into the aquarium. The spinning mesh wheel develops a biofilm coating of microorganisms that feed on the suspended wastes in the aquarium water and are also exposed to the atmosphere as the wheel rotates. This is especially good at removing waste urea and ammonia urinated into the aquarium water by the fish and other animals.

Membrane bioreactors

Membrane bioreactors (MBR) combine activated sludge treatment with a membrane liquid-solid separation process. The membrane component uses low pressure microfiltration or ultra filtration membranes and eliminates the need for clarification and tertiary filtration. The membranes are typically immersed in the aeration tank; however, some applications utilize a separate membrane tank. One of the key benefits of an MBR system is that it effectively overcomes the limitations associated with poor settling of sludge in conventional activated sludge (CAS) processes. The technology permits bioreactor operation with considerably higher mixed liquor suspended solids (MLSS) concentration than CAS systems, which are limited by sludge settling. The process is typically operated at MLSS in the range of 8,000–12,000 mg/L, while CAS are operated in the range of 2,000–3,000 mg/L. The elevated biomass concentration in the MBR process allows for very effective removal of both soluble and particulate biodegradable materials at higher loading rates. Thus increased sludge retention times, usually exceeding 15 days, ensure complete nitrification even in extremely cold weather.

The cost of building and operating an MBR is usually higher than conventional wastewater treatment. Membrane filters can be blinded with grease or abraded by suspended grit and lack a clarifier's flexibility to pass peak flows. The technology has become increasingly popular for reliably pretreated waste streams and has gained wider acceptance where infiltration and inflow have been controlled, however, and the life-cycle costs have been steadily decreasing. The small footprint of MBR systems, and the high quality effluent produced, make them particularly useful for water reuse applications.

Secondary sedimentation

Secondary Sedimentation tank at a rural treatment plant.

The final step in the secondary treatment stage is to settle out the biological floc or filter material through a secondary clarifier and to produce sewage water containing low levels of organic material and suspended matter.

Tertiary treatment

The purpose of tertiary treatment is to provide a final treatment stage to raise the effluent quality before it is discharged to the receiving environment (sea, river, lake, ground, etc.). More than one tertiary treatment process may be used at any treatment plant. If disinfection is practiced, it is always the final process. It is also called "effluent polishing."

Filtration

Sand filtration removes much of the residual suspended matter. Filtration over activated carbon, also called *carbon adsorption,* removes residual toxins.

Lagooning

A sewage treatment plant and lagoon in Everett, Washington, United States.

Lagooning provides settlement and further biological improvement through storage in large man-made ponds or lagoons. These lagoons are highly aerobic and colonization by native macrophytes, especially reeds, is often encouraged. Small filter feeding invertebrates such as *Daphnia* and species of *Rotifera* greatly assist in treatment by removing fine particulates.

Nutrient removal

Wastewater may contain high levels of the nutrients nitrogen and phosphorus. Excessive release to the environment can lead to a build up of nutrients, called eutrophication, which can in turn encourage the overgrowth of weeds, algae, and cyanobacteria (blue-green algae). This may cause an algal bloom, a rapid growth in the population of algae. The algae numbers are unsustainable and eventually most of them die. The decomposition of the algae by bacteria uses up so much of oxygen in the water that most or all of the animals die, which creates more organic matter for the bacteria to decompose. In addition to causing deoxygenation, some algal species produce toxins that contaminate drinking water supplies. Different treatment processes are required to remove nitrogen and phosphorus.

Nitrogen removal

The removal of nitrogen is effected through the biological oxidation of nitrogen from ammonia to nitrate (nitrification), followed by denitrification, the reduction of nitrate to nitrogen gas. Nitrogen gas is released to the atmosphere and thus removed from the water.

Nitrification itself is a two-step aerobic process, each step facilitated by a different type of bacteria. The oxidation of ammonia (NH_3) to nitrite (NO_2^-) is most often facilitated by *Nitrosomonas* spp. (nitroso referring to the formation of a nitroso functional group). Nitrite oxidation to nitrate (NO_3^-), though traditionally believed to be facilitated by *Nitrobacter* spp. (nitro referring the formation of a nitro functional group), is now known to be facilitated in the environment almost exclusively by *Nitrospira* spp.

Denitrification requires anoxic conditions to encourage the appropriate biological communities to form. It is facilitated by a wide diversity of bacteria. Sand filters, lagooning and reed beds can all be used to reduce nitrogen, but the activated sludge process (if designed well) can do the job the most easily. Since denitrification is the reduction of nitrate to dinitrogen gas, an electron donor is needed. This can be, depending on the wastewater, organic matter (from faeces), sulfide, or an added donor like methanol.

Sometimes the conversion of toxic ammonia to nitrate alone is referred to as tertiary treatment.

Many sewage treatment plants use axial flow pumps to transfer the nitrified mixed liquor from the aeration zone to the anoxic zone for denitrification. These pumps are often referred to as *Internal Mixed Liquor Recycle* (IMLR) pumps. The sludge in the anoxic tanks must be mixed well (mixture of recirculated mixed liquor, return activated sludge [RAS], and raw influent) by using submersible mixers in order to achieve the desired denitrification.

Phosphorus removal

Phosphorus removal is important as it is a limiting nutrient for algae growth in many fresh water systems. It is also particularly important for water reuse systems where high phosphorus concentrations may lead to fouling of downstream equipment such as reverse osmosis.

Phosphorus can be removed biologically in a process called enhanced biological phosphorus removal. In this process, specific bacteria, called polyphosphate accumulating organisms (PAOs), are selectively enriched and accumulate large quantities of phosphorus within their cells (up to 20 percent of their mass). When the biomass enriched in these bacteria is separated from the treated water, these biosolids have a high fertilizer value.

Phosphorus removal can also be achieved by chemical precipitation, usually with salts of iron (e.g. ferric chloride), aluminum (e.g. alum), or lime. This may lead to excessive sludge production as hydroxides precipitates and the added chemicals can be expensive. Chemical phosphorus removal requires significantly smaller equipment footprint than biological removal, is easier to operate and is often more reliable than biological phosphorus removal. Another method for phosphorus removal is to use granular laterite.

Once removed, phosphorus, in the form of a phosphate-rich sludge, may be stored in a land fill or resold for use in fertilizer.

Disinfection

The purpose of disinfection in the treatment of waste water is to substantially reduce the number of microorganisms in the water to be discharged back into the environment. The effectiveness of disinfection depends on the quality of the water being treated (e.g., cloudiness, pH, etc.), the type of disinfection being used, the disinfectant dosage (concentration and time), and other environmental variables. Cloudy water will be treated less successfully, since solid matter can shield organisms, especially from ultraviolet light or if contact times are low. Generally, short contact times, low doses and high flows all militate against effective disinfection. Common methods of disinfection include ozone, chlorine, ultraviolet light, or sodium hypochlorite. Chloramine, which is used for drinking water, is not used in waste water treatment because of its persistence.

Chlorination remains the most common form of waste water disinfection in North America due to its low cost and long-term history of effectiveness. One disadvantage is that chlorination of residual organic material can generate chlorinated-organic compounds that may be carcinogenic or harmful to the environment. Residual chlorine or chloramines may also be capable of chlorinating organic material in the natural aquatic environment. Further, because residual chlorine is toxic to aquatic species, the treated effluent must also be chemically dechlorinated, adding to the complexity and cost of treatment.

Ultraviolet (UV) light can be used instead of chlorine, iodine, or other chemicals. Because no chemicals are used, the treated water has no adverse effect on organisms that later consume it, as may be the case with other methods. UV radiation causes damage to the genetic structure of bacteria, viruses, and other pathogens, making them incapable of reproduction. The key disadvantages of UV disinfection are the need for frequent lamp maintenance and replacement and the need for a highly treated effluent to ensure that the target microorganisms are not shielded from the UV radiation (i.e., any solids present in the treated effluent may protect microorganisms from the UV light). In the United Kingdom, UV light is becoming the most common means of disinfection because of the concerns about the impacts of chlorine in chlorinating residual organics in the wastewater and in chlorinating organics in the receiving water. Some sewage treatment systems in Canada and the US also use UV light for their effluent water disinfection.

Ozone (O_3) is generated by passing oxygen (O_2) through a high voltage potential resulting in a third oxygen atom becoming attached and forming O_3. Ozone is very unstable and reactive and oxidizes most organic material it comes in contact with, thereby destroying many pathogenic microorganisms. Ozone is considered to be safer than chlorine because, unlike chlorine which has to be stored on site (highly poisonous in the event of an accidental release), ozone is generated onsite as needed. Ozonation also produces fewer disinfection by-products than chlorination. A disadvantage of ozone disinfection is the high cost of the ozone generation equipment and the requirements for special operators.

Odour Control

Odours emitted by sewage treatment are typically an indication of an anaerobic or "septic" condition. Early stages of processing will tend to produce smelly gases, with hydrogen sulfide being most common in generating complaints. Large process plants in urban areas will often treat the odours with carbon reactors, a contact media with bio-slimes, small doses of chlorine, or circulating fluids to biologically capture and metabolize the obnoxious gases. Other methods of odour control exist, including addition of iron salts, hydrogen peroxide, calcium nitrate, etc. to manage hydrogen sulfide levels.

Package plants and batch reactors

To use less space, treat difficult waste and intermittent flows, a number of designs of hybrid treatment plants have been produced. Such plants often combine at least two stages of the three main treatment stages into one combined stage. In the UK, where a large number of wastewater treatment plants serve small populations, package plants are a viable alternative to building a large structure for each process stage. In the US, package plants are typically used in rural areas, highway rest stops and trailer parks.

One type of system that combines secondary treatment and settlement is the sequencing batch reactor (SBR). Typically, activated sludge is mixed with raw incoming sewage, and then mixed and aerated. The settled sludge is run off and re-aerated before a proportion is returned to the headworks. SBR plants are now being deployed in many parts of the world.

The disadvantage of the SBR process is that it requires a precise control of timing, mixing and aeration. This precision is typically achieved with computer controls linked to sensors. Such a complex, fragile system is unsuited to places where controls may be unreliable, poorly maintained, or where the power supply may be intermittent. Extended aeration package plants use separate basins for aeration and settling, and are somewhat larger than SBR plants with reduced timing sensitivity.

Package plants may be referred to as *high charged* or *low charged*. This refers to the way the biological load is processed. In high charged systems, the biological stage is presented with a high organic load and the combined floc and organic material is then oxygenated for a few hours before being charged again with a new load. In the low charged system the biological stage contains a low organic load and is combined with flocculate for longer times.

Sludge treatment and disposal

The sludges accumulated in a wastewater treatment process must be treated and disposed of in a safe and effective manner. The purpose of digestion is to reduce the amount of organic matter and the number of disease-causing microorganisms present in the solids. The most common treatment options include anaerobic digestion, aerobic digestion, and composting. Incineration is also used albeit to a much lesser degree.

Sludge treatment depends on the amount of solids generated and other site-specific conditions. Composting is most often applied to small-scale plants with aerobic digestion for mid sized operations, and anaerobic digestion for the larger-scale operations.

Anaerobic digestion

Anaerobic digestion is a bacterial process that is carried out in the absence of oxygen. The process can either be *thermophilic* digestion, in which sludge is fermented in tanks at a temperature of 55°C, or *mesophilic*, at a temperature of around 36°C. Though allowing shorter retention time (and thus smaller tanks), thermophilic digestion is more expensive in terms of energy consumption for heating the sludge.

Anaerobic digestion is the most common (mesophilic) treatment of domestic sewage in septic tanks, which normally retain the sewage from one day to two days, reducing the BOD by about 35 to 40 percent. This reduction can be increased with a combination of anaerobic and aerobic treatment by installing *Aerobic Treatment Units* (ATUs) in the septic tank.

One major feature of anaerobic digestion is the production of biogas (with the most useful component being methane), which can be used in generators for electricity production and/or in boilers for heating purposes.

Aerobic digestion

Aerobic digestion is a bacterial process occurring in the presence of oxygen. Under aerobic conditions, bacteria rapidly consume organic matter and convert it into carbon dioxide. The operating costs used to be characteristically much greater for aerobic digestion because of the energy used by the blowers, pumps and motors needed to add oxygen to the process.

Aerobic digestion can also be achieved by using diffuser systems or jet aerators to oxidize the sludge.

Composting

Composting is also an aerobic process that involves mixing the sludge with sources of carbon such as sawdust, straw or wood chips. In the presence of oxygen, bacteria digest both the wastewater solids and the added carbon source and, in doing so, produce a large amount of heat.

Incineration

Incineration of sludge is less common because of air emissions concerns and the supplemental fuel (typically natural gases or fuel oil) required to burn the low calorific value sludge and vaporize residual water. Stepped multiple hearth incinerators with high residence time and fluidized bed incinerators are the most common systems used to combust wastewater sludge. Co-firing in municipal waste-to-energy plants is occasionally done, this option being less expensive assuming the facilities already exist for solid waste and there is no need for auxiliary fuel.

Sludge disposal

When a liquid sludge is produced, further treatment may be required to make it suitable for final disposal. Typically, sludges are thickened (dewatered) to reduce the volumes transported off-site for disposal. There is no process which completely eliminates the need to dispose of biosolids. There is, however, an additional step some cities are taking to superheat sludge and convert it into small pelletized granules that are high in nitrogen and other organic materials. In New York City, for example, several sewage treatment plants have dewatering facilities that use large centrifuges along with the addition of chemicals such as polymer to further remove liquid from the sludge. The removed fluid, called centrate, is typically reintroduced into the wastewater process. The product which is left is called "cake" and that is picked up by companies which turn it into fertilizer pellets. This product is then sold to local farmers and turf farms as a soil amendment or fertilizer, reducing the amount of space required to dispose of sludge in landfills. Much sludge originating from commercial or industrial areas is contaminated with toxic materials that are released into the sewers from the industrial processes. Elevated concentrations of such materials may make the sludge unsuitable for agricultural use and it may then have to be incinerated or disposed of to landfill.

Treatment in the receiving environment

The outlet of a wastewater treating plant flows into a small river

Many processes in a wastewater treatment plant are designed to mimic the natural treatment processes that occur in the environment, whether that environment is a natural water body or the ground. If not overloaded, bacteria in the environment will consume organic contaminants, although this will reduce the levels of oxygen in the water and may significantly change the overall ecology of the receiving water. Native bacterial populations feed on the organic contaminants, and the numbers of disease-causing microorganisms are reduced by natural environmental conditions such as predation or exposure to ultraviolet radiation. Consequently, in cases where the receiving environment provides a high level of dilution, a high degree of wastewater treatment may not be required. However, recent evidence has demonstrated that very low levels of specific contaminants in wastewater, including hormones (from animal husbandry and residue from human hormonal contraception methods) and synthetic materials such as phthalates that mimic hormones in their action, can have an unpredictable adverse impact on the natural biota and potentially on humans if the water is re-used for drinking water. In the

US and EU, uncontrolled discharges of wastewater to the environment are not permitted under law, and strict water quality requirements are to be met. A significant threat in the coming decades will be the increasing uncontrolled discharges of wastewater within rapidly developing countries.

Effects on Biology

Sewage treatment plants can have multiple effects on nutrient levels in the water that the treated sewage flows into. These effects on nutrients can have large effects on the biological life in the water in contact with the effluent. Stabilization ponds (or treatment ponds) can include any of the following:

- Oxidation ponds, which are aerobic bodies of water usually 1–2 meters in depth that receive effluent from sedimentation tanks or other forms of primary treatment.
    - Dominated by algae
- Polishing ponds are similar to oxidation ponds but receive effluent from an oxidation pond or from a plant with an extended mechanical treatment.
    - Dominated by zooplankton
- Facultative lagoons, raw sewage lagoons, or sewage lagoons are ponds where sewage is added with no primary treatment other than coarse screening. These ponds provide effective treatment when the surface remains aerobic; although anaerobic conditions may develop near the layer of settled sludge on the bottom of the pond.
- Anaerobic lagoons are heavily loaded ponds.
    - Dominated by bacteria
- Sludge lagoons are aerobic ponds, usually 2–5 meters in depth, that receive anaerobically digested primary sludge, or activated secondary sludge under water.
    - Upper layers are dominated by algae

Phosphorous limitation is a possible result from sewage treatment and results in flagellate-dominated plankton, particularly in summer and fall.

At the same time a different study found high nutrient concentrations linked to sewage effluents. High nutrient concentration leads to high chlorophyll a concentrations, which is a proxy for primary production in marine environments. High primary production means high phytoplankton populations and most likely high zooplankton populations because zooplankton feed on phytoplankton. However, effluent released into marine systems also leads to greater population instability.

A study done in Britain found that the quality of effluent effected the planktonic life in the water in direct contact with the wastewater effluent. Turbid, low-quality effluents either did not contain ciliated protozoa or contained only a few species in small numbers. On the other hand, high-quality effluents contained a wide variety of ciliated protozoa in large numbers. Due to these findings, it seems unlikely that any particular component of the industrial effluent has, by itself, any harmful effects on the protozoan populations of activated sludge plants.

The planktonic trends of high populations close to input of treated sewage is contrasted by the bacterial trend. In a study of *Aeromonas* spp. in increasing distance from a wastewater source, greater change in seasonal cycles was found the furthest from the effluent. This trend is so strong that the furthest location studied actually had an inversion of the *Aeromonas* spp. cycle in comparison to that of fecal coliforms. Since there is a main pattern in the cycles that occurred simultaneously at all stations it indicates seasonal factors (temperature, solar radiation, phytoplankton) control of the bacterial population. The effluent dominant species changes from *Aeromonas caviae* in winter to *Aeromonas sobria* in the spring and fall while the inflow dominant species is *Aeromonas caviae*, which is constant throughout the seasons.

Sewage treatment in developing countries

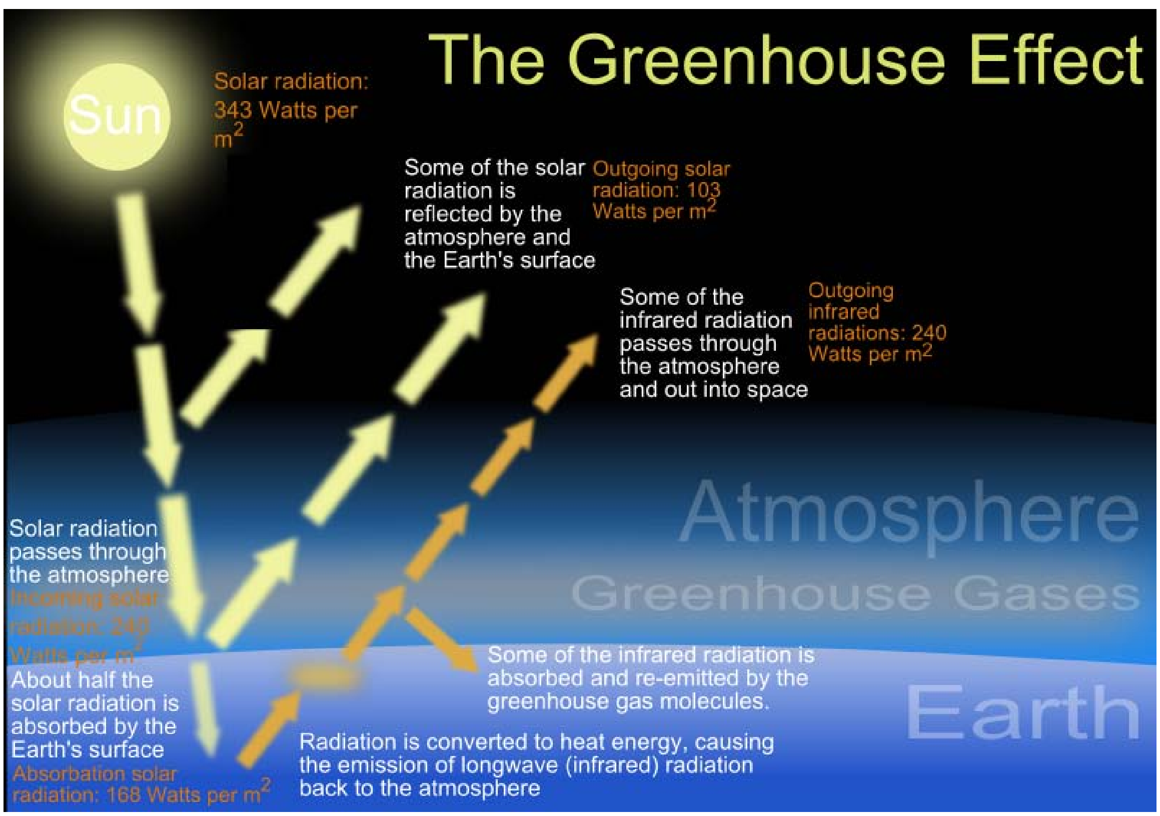
Few reliable figures on the share of the wastewater collected in sewers that is being treated in the world exist. In many developing countries the bulk of domestic and industrial wastewater is discharged without any treatment or after primary treatment only. In Latin America about 15% of collected wastewater passes through treatment plants (with varying levels of actual treatment). In Venezuela, a below average country in South America with respect to wastewater treatment, 97 percent of the country's sewage is discharged raw into the environment. In a relatively developed Middle Eastern country such as Iran, Tehran's majority of population has totally untreated sewage injected to the city's groundwater. However now the construction of major parts of the sewage system, collection and treatment, in Tehran is almost complete, and under development, due to be fully completed by the end of 2012.

In Israel, about 50 percent of agricultural water usage (total use was 1 billion cubic metres in 2008) is provided through reclaimed sewer water. Future plans call for increased use of treated sewer water as well as more desalination plants.

Most of sub-Saharan Africa is without wastewater treatment.

Chapter 4

Greenhouse Gas

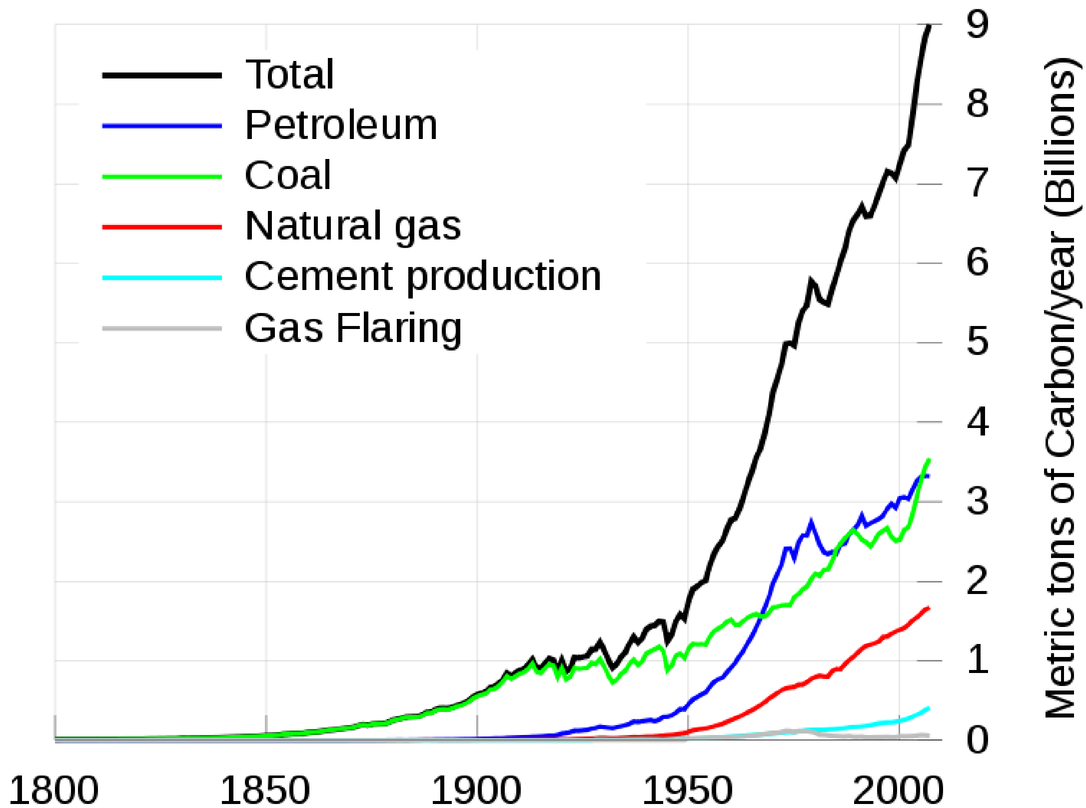


Simple diagram of greenhouse effect.

A **greenhouse gas** (sometimes abbreviated **GHG**) is a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect. The primary greenhouse gases in the Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone. In the Solar System, the atmospheres of Venus, Mars, and Titan also contain gases that cause greenhouse effects. Greenhouse gases greatly affect the temperature of the Earth; without them, Earth's surface would be on average about 33 °C (59 °F) colder than at present.

Since the beginning of the Industrial revolution, the burning of fossil fuels has increased the levels of carbon dioxide in the atmosphere from 280ppm to 390ppm. Unlike other pollutants, carbon dioxide emissions do not result from inefficient combustion: CO_2 is a product of ideal, stoichiometric combustion of carbon. The emissions of carbon are directly proportional to energy consumption.

Greenhouse effects in Earth's atmosphere



Modern global anthropogenic Carbon emissions.

In order, the most abundant greenhouse gases in Earth's atmosphere are:

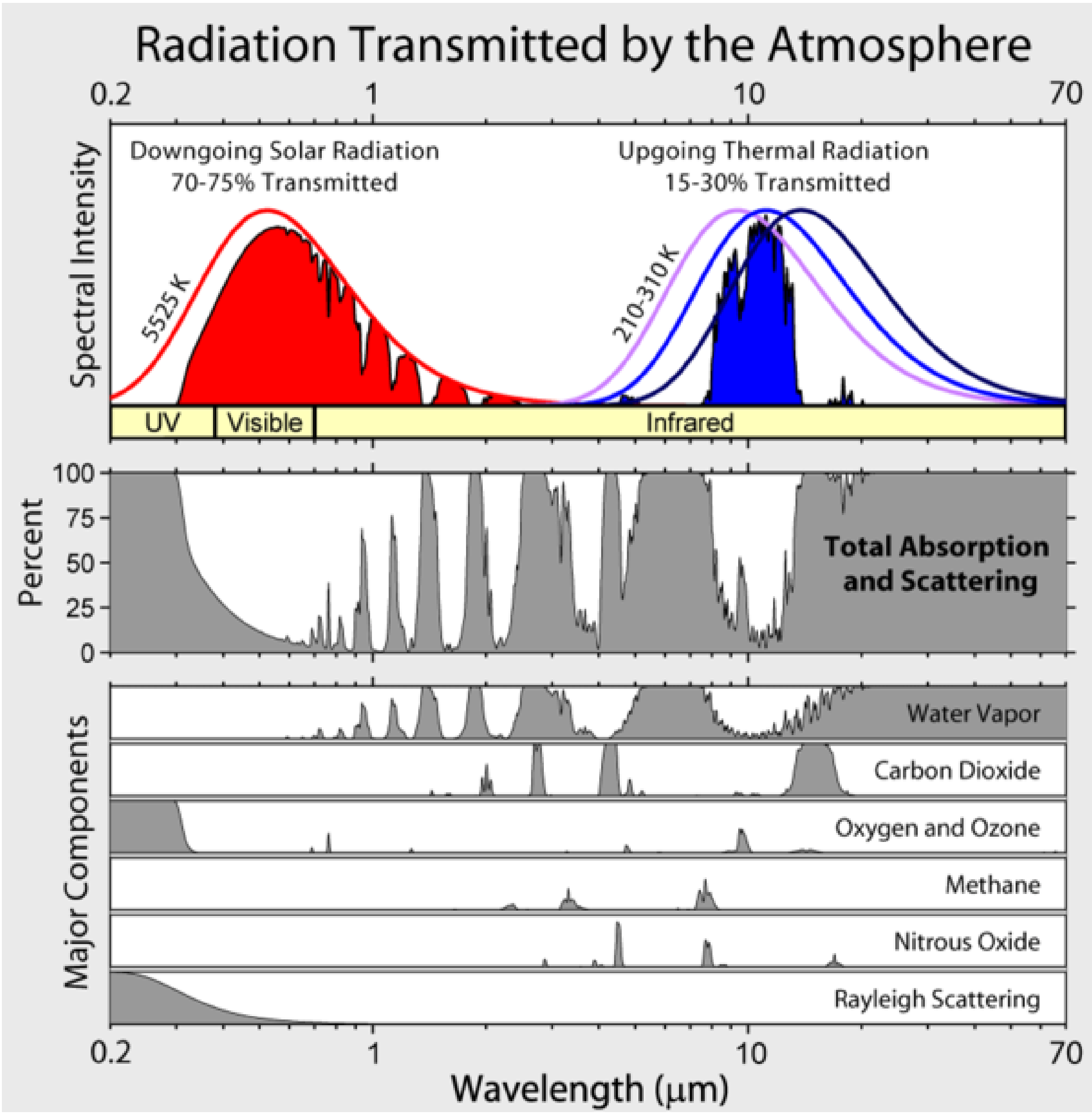
- water vapor
- carbon dioxide
- methane
- nitrous oxide
- ozone
- chlorofluorocarbons

The contribution to the greenhouse effect by a gas is affected by both the characteristics of the gas and its abundance. For example, on a molecule-for-molecule basis methane is about eighty times stronger greenhouse gas than carbon dioxide , but it is present in much smaller concentrations so that its total contribution is smaller. When these gases are ranked by their contribution to the greenhouse effect, the most important are:

Gas	**Formula**	**Contribution (%)**
Water Vapor	H_2O	36 – 72 %
Carbon Dioxide	CO_2	9 – 26 %
Methane	CH_4	4 – 9 %
Ozone	O_3	3 – 7 %

It is not possible to state that a certain gas causes an exact percentage of the greenhouse effect. This is because some of the gases absorb and emit radiation at the same frequencies as others, so that the total greenhouse effect is not simply the sum of the influence of each gas. The higher ends of the ranges quoted are for each gas alone; the lower ends account for overlaps with the other gases. The major non-gas contributor to the Earth's greenhouse effect, clouds, also absorb and emit infrared radiation and thus have an effect on radiative properties of the greenhouse gases.

In addition to the main greenhouse gases listed above, other greenhouse gases include sulfur hexafluoride, hydrofluorocarbons and perfluorocarbons. Some greenhouse gases are not often listed. For example, nitrogen trifluoride has a high global warming potential (GWP) but is only present in very small quantities.

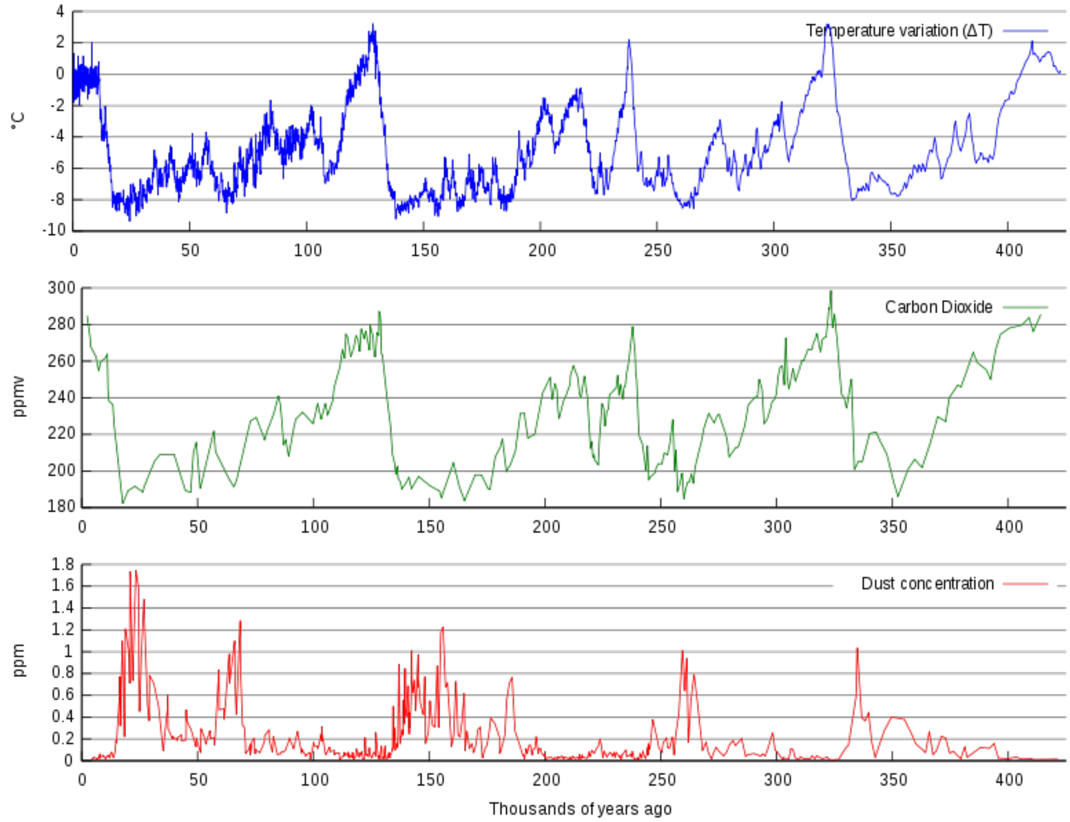


Atmospheric absorption and scattering at different electromagnetic wavelengths. The largest absorption band of carbon dioxide is in the infrared.

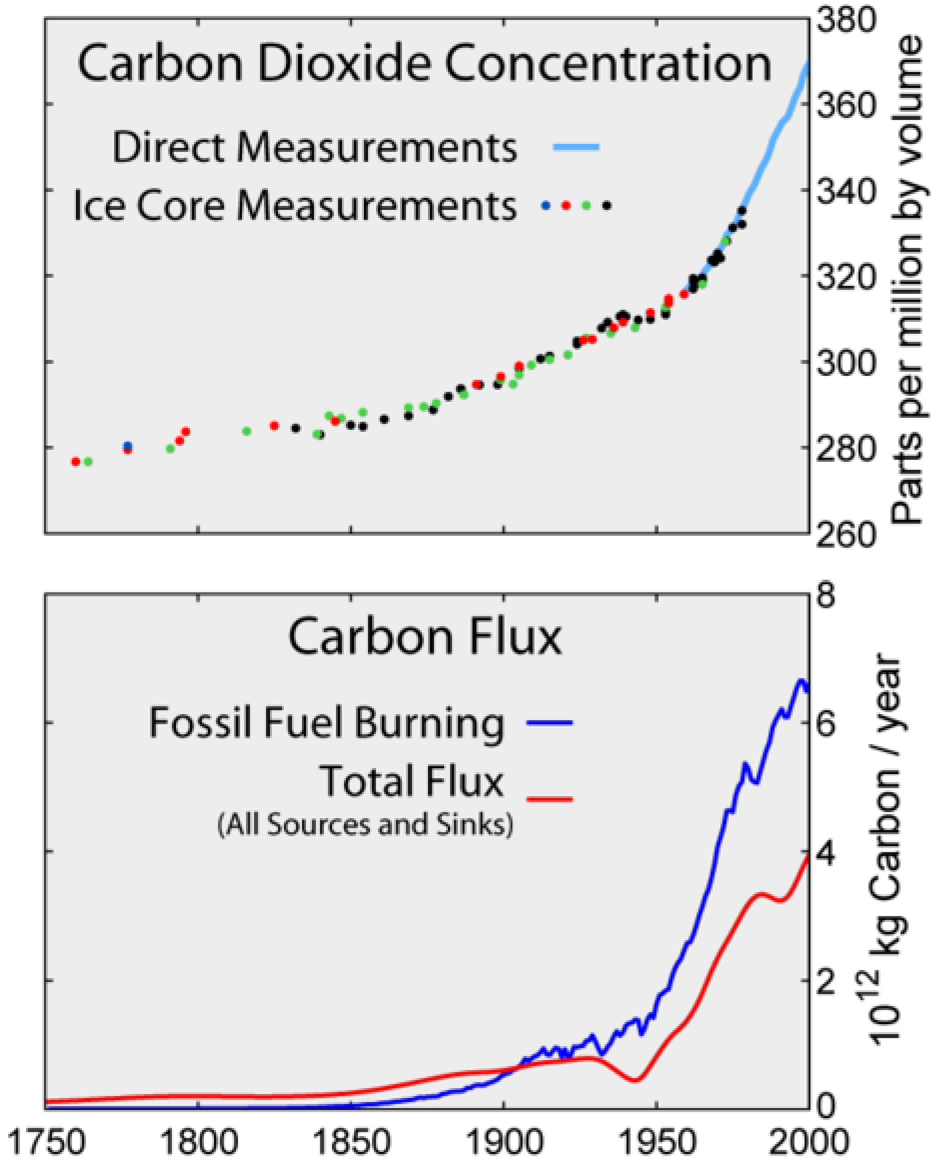
Scientists who have elaborated on Arrhenius' theory of global warming are concerned that increasing concentrations of greenhouse gases in the atmosphere are causing an unprecedented rise in global temperatures, with potentially harmful consequences for the environment and human health. Although contributing to many other physical and chemical reactions, the major atmospheric constituents, nitrogen (N_2), oxygen (O_2), and argon (Ar), are not greenhouse gases. This is because molecules containing two atoms of the same element such as N_2 and O_2 and monatomic molecules such as Ar have no net change in their dipole moment when they vibrate and hence are almost totally unaffected by infrared light. Although molecules containing two atoms of different elements such as carbon monoxide (CO) or hydrogen chloride (HCl) absorb IR, these molecules are short-lived in the atmosphere owing to their reactivity and solubility. As a consequence they do not contribute significantly to the greenhouse effect and are not often included when discussing greenhouse gases.

Late 19th century scientists experimentally discovered that N_2 and O_2 do not absorb infrared radiation (called, at that time, "dark radiation") while, at the contrary, water, as true vapour or condensed in the form of microscopic droplets suspended in clouds, CO_2 and other poly-atomic gaseous molecules do absorb infrared radiation. It was recognized in the early 20th century that the greenhouse gases in the atmosphere caused the Earth's overall temperature to be higher than it would be without them.

Natural and anthropogenic sources



400,000 years of ice core data.



Top: Increasing atmospheric carbon dioxide levels as measured in the atmosphere and reflected in ice cores. Bottom: The amount of net carbon increase in the atmosphere, compared to carbon emissions from burning fossil fuel.

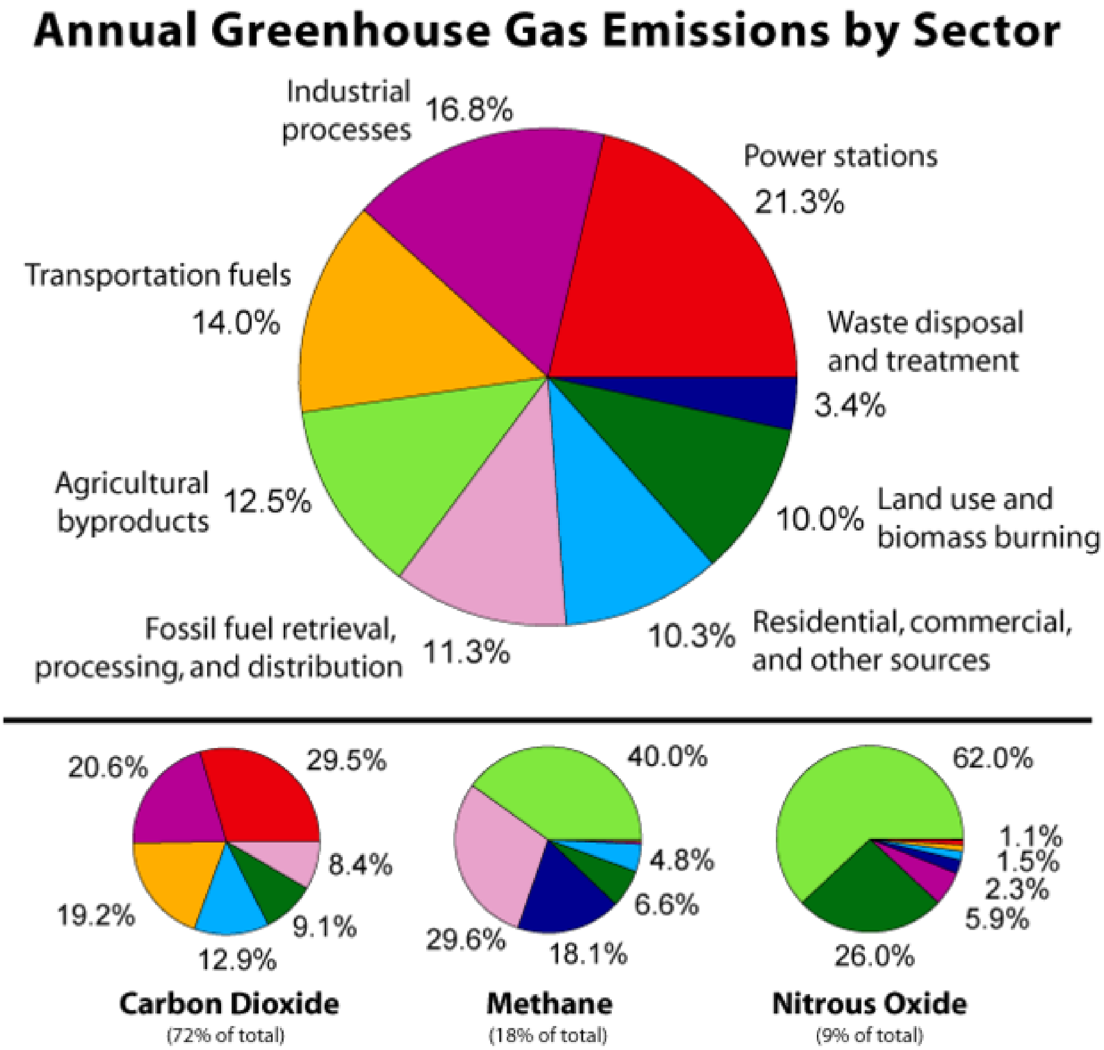
Aside from purely human-produced synthetic halocarbons, most greenhouse gases have both natural and human-caused sources. During the pre-industrial Holocene, concentrations of existing gases were roughly constant. In the industrial era, human activities have added greenhouse gases to the atmosphere, mainly through the burning of fossil fuels and clearing of forests.

The 2007 Fourth Assessment Report compiled by the IPCC (AR4) noted that "changes in atmospheric concentrations of greenhouse gases and aerosols, land cover and solar radiation alter the energy balance of the climate system", and concluded that "increases in anthropogenic greenhouse gas concentrations is very likely to have caused most of the increases in global average temperatures since the mid-20th century". In AR4, "most of" is defined as more than 50%.

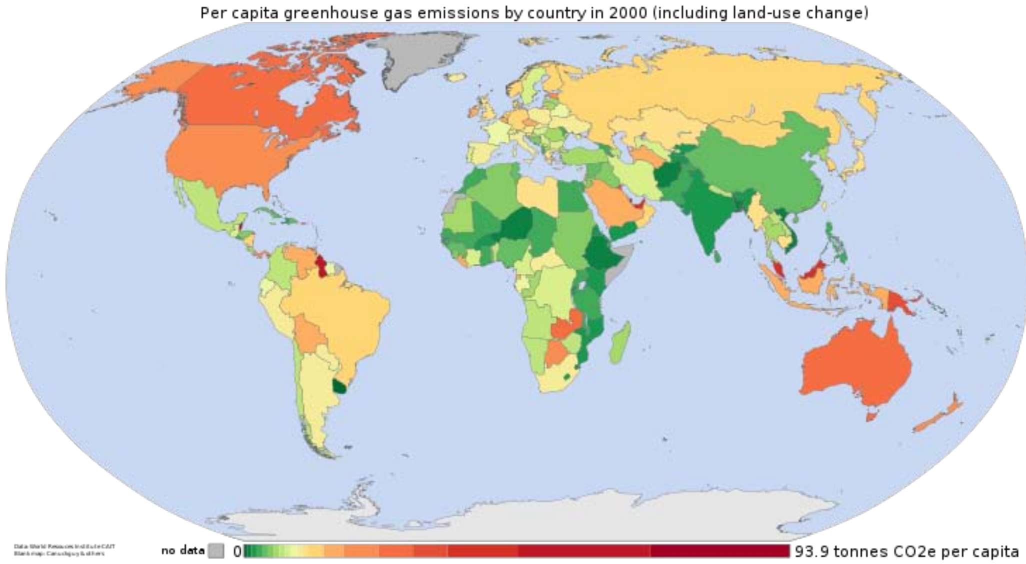
Gas	Preindustrial level	Current level	Increase since 1750	Radiative forcing (W/m^2)
Carbon dioxide	280 ppm	388 ppm	108 ppm	1.46
Methane	700 ppb	1745 ppb	1045 ppb	0.48
Nitrous oxide	270 ppb	314 ppb	44 ppb	0.15
CFC-12	0	533 ppt	533 ppt	0.17

Ice cores provide evidence for variation in greenhouse gas concentrations over the past 800,000 years. Both CO_2 and CH_4 vary between glacial and interglacial phases, and concentrations of these gases correlate strongly with temperature. Direct data does not exist for periods earlier than those represented in the ice core record, a record which indicates CO_2 levels staying within a range of between 180ppm and 280ppm throughout the last 800,000 years, until the increase of the last 250 years. However, various proxies and modeling suggests larger variations in past epochs; 500 million years ago CO_2 levels were likely 10 times higher than now. Indeed higher CO_2 concentrations are thought to have prevailed throughout most of the Phanerozoic eon, with concentrations four to six times current concentrations during the Mesozoic era, and ten to fifteen times current concentrations during the early Palaeozoic era until the middle of the Devonian period, about 400 Ma. The spread of land plants is thought to have reduced CO_2 concentrations during the late Devonian, and plant activities as both sources and sinks of CO_2 have since been important in providing stabilising feedbacks. Earlier still, a 200-million year period of intermittent, widespread glaciation extending close to the equator (Snowball Earth) appears to have been ended suddenly, about 550 Ma, by a colossal volcanic outgassing which raised the CO_2 concentration of the atmosphere abruptly to 12%, about 350 times modern levels, causing extreme greenhouse conditions and carbonate deposition as limestone at the rate of about 1 mm per day. This episode marked the close of the Precambrian eon, and was succeeded by the generally warmer conditions of the Phanerozoic, during which multicellular animal and plant life evolved. No volcanic carbon dioxide emission of comparable scale has occurred since. In the modern era, emissions to the atmosphere from volcanoes are only about 1% of emissions from human sources.

Anthropogenic greenhouse gases



Global anthropogenic greenhouse gas emissions broken down into 8 different sectors for the year 2000.



Per capita anthropogenic greenhouse gas emissions by country for the year 2000 including land-use change.

Since about 1750 human activity has increased the concentration of carbon dioxide and other greenhouse gases. Measured atmospheric concentrations of carbon dioxide are currently 100 ppmv higher than pre-industrial levels. Natural sources of carbon dioxide are more than 20 times greater than sources due to human activity, but over periods longer than a few years natural sources are closely balanced by natural sinks, mainly photosynthesis of carbon compounds by plants and marine plankton. As a result of this balance, the atmospheric concentration of carbon dioxide remained between 260 and 280 parts per million for the 10,000 years between the end of the last glacial maximum and the start of the industrial era.

It is likely that anthropogenic warming, such as that due to elevated greenhouse gas levels, has had a discernible influence on many physical and biological systems. Warming is projected to affect various issues such as freshwater resources, industry, food and health.

The main sources of greenhouse gases due to human activity are:

- burning of fossil fuels and deforestation leading to higher carbon dioxide concentrations in the air. Land use change (mainly deforestation in the tropics) account for up to one third of total anthropogenic CO_2 emissions.
- livestock enteric fermentation and manure management, paddy rice farming, land use and wetland changes, pipeline losses, and covered vented landfill emissions leading to higher methane atmospheric concentrations. Many of the newer style fully vented septic systems that enhance and target the fermentation process also are sources of atmospheric methane.
- use of chlorofluorocarbons (CFCs) in refrigeration systems, and use of CFCs and halons in fire suppression systems and manufacturing processes.

- agricultural activities, including the use of fertilizers, that lead to higher nitrous oxide (N_2O) concentrations.

The seven sources of CO_2 from fossil fuel combustion are (with percentage contributions for 2000–2004):

Seven main fossil fuel combustion sources	Contribution (%)
Liquid fuels (e.g., gasoline, fuel oil)	36 %
Solid fuels (e.g., coal)	35 %
Gaseous fuels (e.g., natural gas)	20 %
Cement production	3 %
Flaring gas industrially and at wells	< 1 %
Non-fuel hydrocarbons	< 1 %
"International bunker fuels" of transport not included in national inventories	4 %

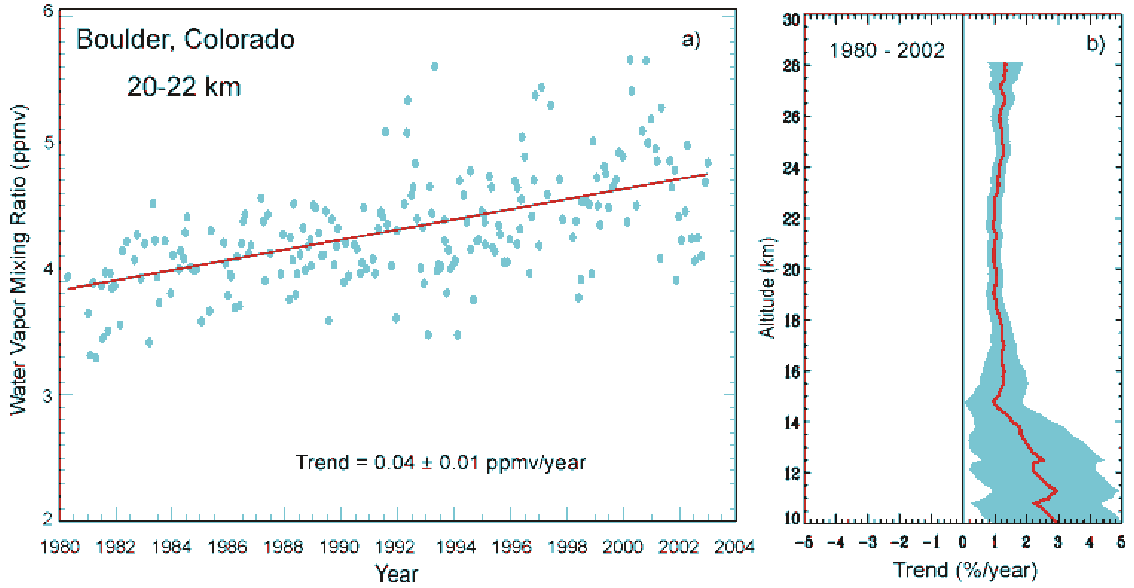
The US Environmental Protection Agency (EPA) ranks the major greenhouse gas contributing end-user sectors in the following order: industrial, transportation, residential, commercial and agricultural. Major sources of an individual's greenhouse gas include home heating and cooling, electricity consumption, and transportation. Corresponding conservation measures are improving home building insulation, installing geothermal heat pumps and compact fluorescent lamps, and choosing energy-efficient vehicles.

Carbon dioxide, methane, nitrous oxide and three groups of fluorinated gases (sulfur hexafluoride, HFCs, and PFCs) are the major greenhouse gases and the subject of the Kyoto Protocol, which came into force in 2005.

Although CFCs are greenhouse gases, they are regulated by the Montreal Protocol, which was motivated by CFCs' contribution to ozone depletion rather than by their contribution to global warming. Note that ozone depletion has only a minor role in greenhouse warming though the two processes often are confused in the media.

On December 7, 2009, the US Environmental Protection Agency released its final findings on greenhouse gases, declaring that "greenhouse gases (GHGs) threaten the public health and welfare of the American people". The finding applied to the same "six key well-mixed greenhouse gases" named in the Kyoto Protocol: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

Role of water vapor



Increasing water vapor in the stratosphere at Boulder, Colorado.

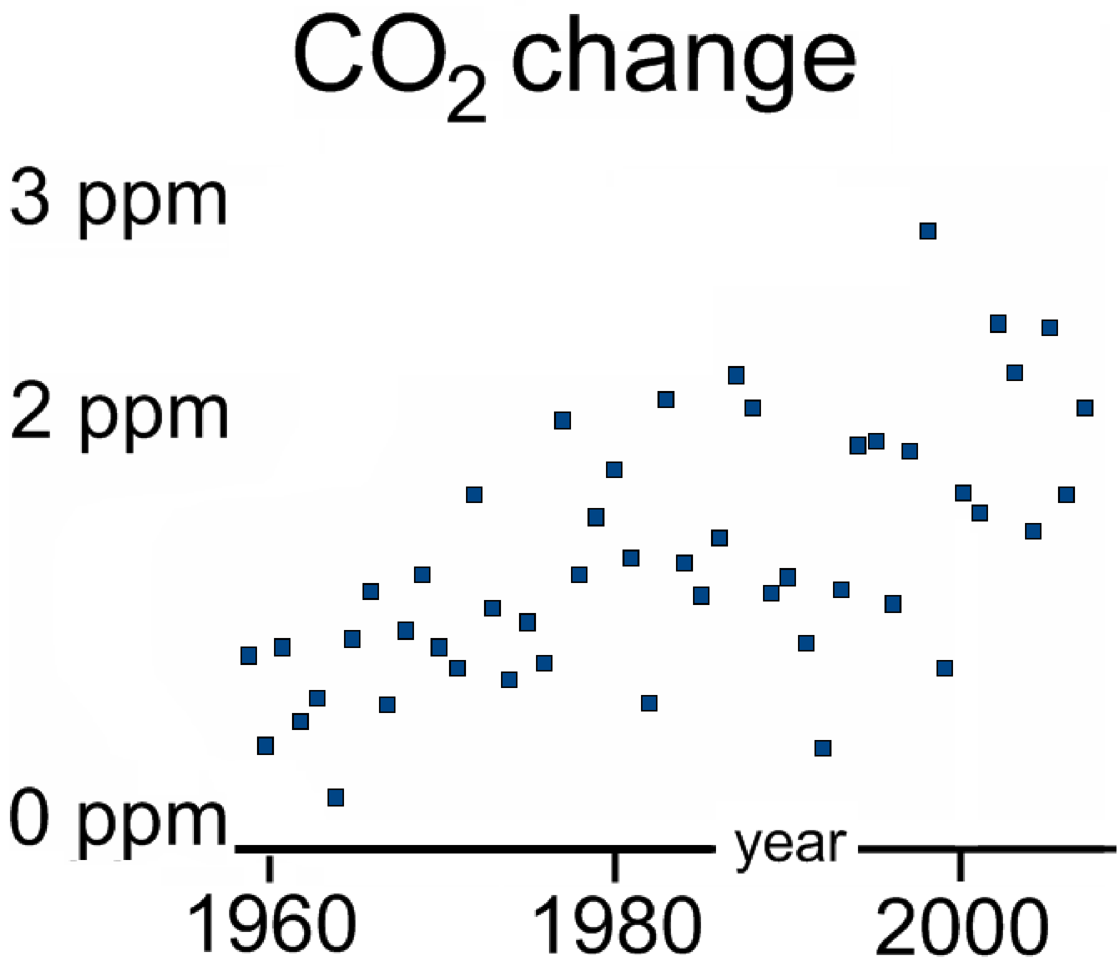
Water vapor accounts for the largest percentage of the greenhouse effect, between 36% and 66% for clear sky conditions and between 66% and 85% when including clouds. Water vapor concentrations fluctuate regionally, but human activity does not significantly affect water vapor concentrations except at local scales, such as near irrigated fields. According to the Environmental Health Center of the National Safety Council, water vapor constitutes as much as 2% of the atmosphere.

The Clausius-Clapeyron relation establishes that air can hold more water vapor per unit volume when it warms. This and other basic principles indicate that warming associated with increased concentrations of the other greenhouse gases also will increase the concentration of water vapor. Because water vapor is a greenhouse gas this results in further warming, a "positive feedback" that amplifies the original warming. This positive feedback does not result in runaway global warming because it is offset by other processes that induce negative feedbacks, which stabilize average global temperatures.

Greenhouse gas emissions

The two primary sources of CO_2 emissions are from burning coal used for electricity generation and petroleum used for motor transport.

Measurements from Antarctic ice cores show that before industrial emissions started atmospheric CO_2 levels were about 280 parts per million by volume (ppmv), and stayed between 260 and 280 during the preceding ten thousand years. Carbon dioxide concentrations in the atmosphere have gone up by approximately 35 percent since the 1900s, rising from 280 parts per million by volume to 387 parts per million in 2009. One study using evidence from stomata of fossilized leaves suggests greater variability, with carbon dioxide levels above 300 ppm during the period seven to ten thousand years ago, though others have argued that these findings more likely reflect calibration or contamination problems rather than actual CO_2 variability. Because of the way air is trapped in ice (pores in the ice close off slowly to form bubbles deep within the firn) and the time period represented in each ice sample analyzed, these figures represent averages of atmospheric concentrations of up to a few centuries rather than annual or decadal levels.



Recent year-to-year increase of atmospheric CO_2.

Since the beginning of the Industrial Revolution, the concentrations of most of the greenhouse gases have increased. For example, the concentration of carbon dioxide has increased by about 36% to 380 ppmv, or 100 ppmv over modern pre-industrial levels. The first 50 ppmv increase took place in about 200 years, from the start of the Industrial Revolution to around 1973; however the next 50 ppmv increase took place in about 33 years, from 1973 to 2006.

Recent data also shows that the concentration is increasing at a higher rate. In the 1960s, the average annual increase was only 37% of what it was in 2000 through 2007.

The other greenhouse gases produced from human activity show similar increases in both amount and rate of increase. Many observations are available online in a variety of Atmospheric Chemistry Observational Databases.

Relevant to radiative forcing

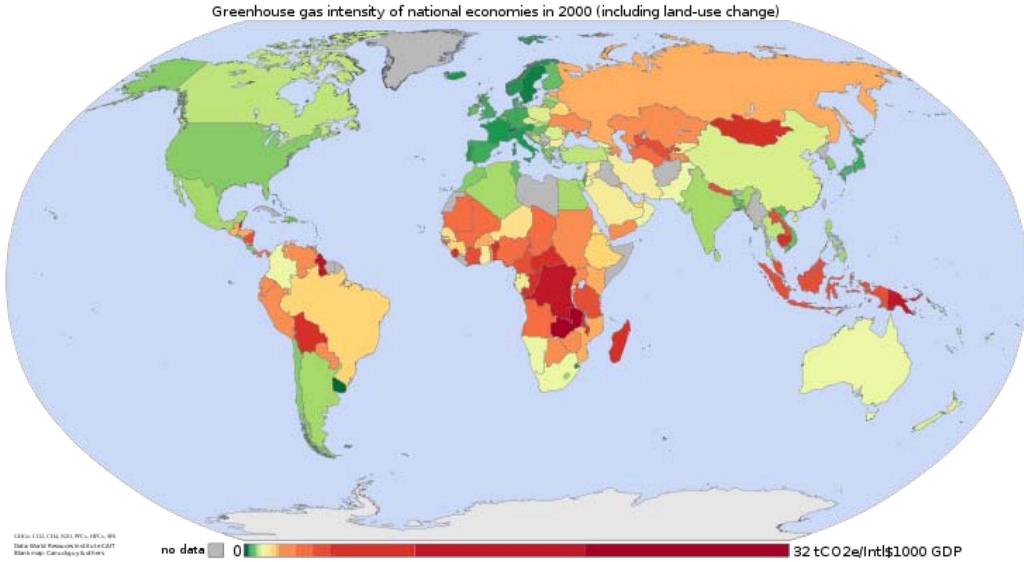
Gas	Current (1998) Amount by volume	Increase (absolute, ppm) over pre-industrial (1750)	Increase (relative, %) over pre-industrial (1750)	Radiative forcing (W/m^2)
Carbon dioxide	365 ppm (383 ppm, 2007.01)	87 ppm (105 ppm, 2007.01)	31 % (38 %, 2007.01)	1.46 (~1.53, 2007.01)
Methane	1745 ppb	1045 ppb	150 %	0.48
Nitrous oxide	314 ppb	44 ppb	16 %	0.15

Relevant to both radiative forcing and ozone depletion; all of the following have no natural sources and hence zero amounts pre-industrial

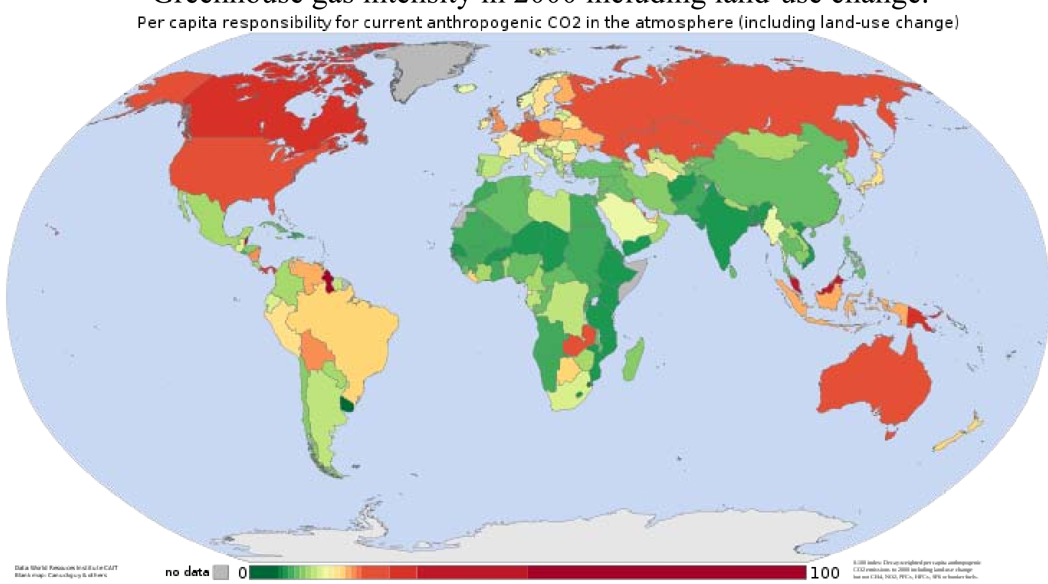
Gas	Current (1998) Amount by volume	Radiative forcing (W/m^2)
CFC-11	268 ppt	0.07
CFC-12	533 ppt	0.17
CFC-113	84 ppt	0.03
Carbon tetrachloride	102 ppt	0.01
HCFC-22	69 ppt	0.03

(Source: IPCC radiative forcing report 1994 updated (to 1998) by IPCC TAR table 6.1).

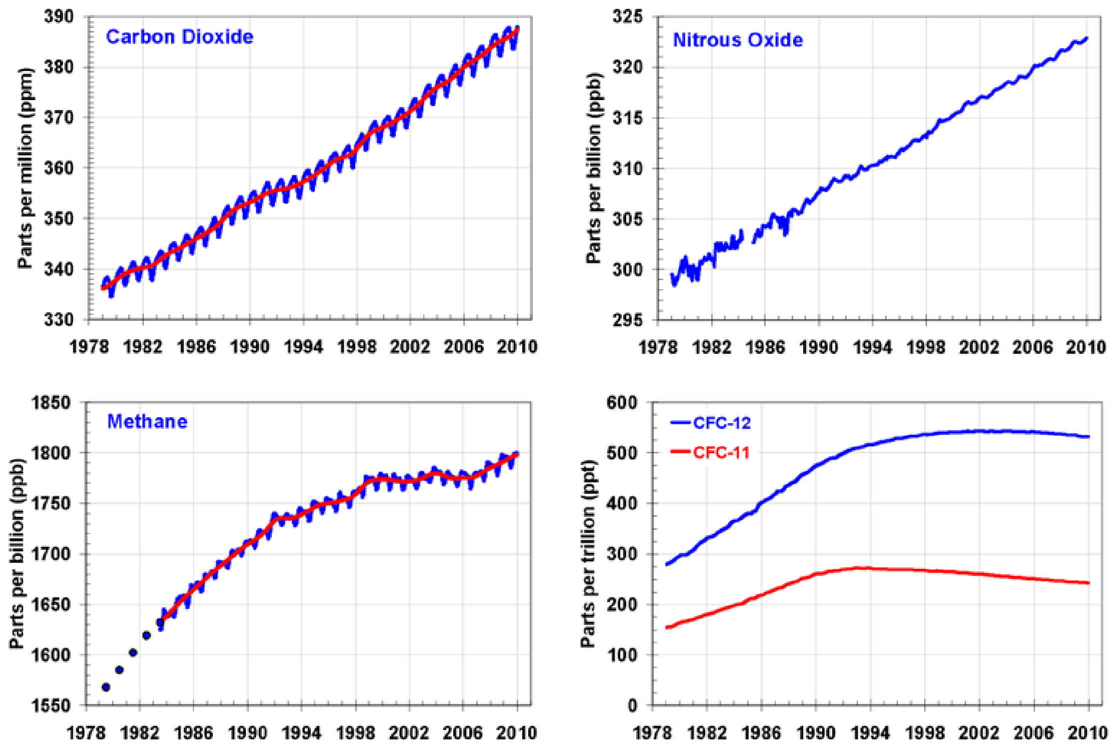
Regional and national attribution of emissions



Greenhouse gas intensity in 2000 including land-use change.



Per capita responsibility for current anthropogenic atmospheric CO_2.



Major greenhouse gas trends.

There are several different ways of measuring GHG emissions for a table of national emissions data).

Some variables that have been reported include:

- Definition of measurement boundaries. Emissions can be attributed geographically, to the area where they were emitted (the territory principle) or by the activity principle to the territory that caused the emissions to be produced. These two principles would result in different totals when measuring for example the importation of electricity from one country to another or the emissions at an international airport.
- The time horizon of different GHGs. Contribution of a given GHG is reported as a CO2 equivalent; the calculation to determine this takes into account how long that gas remains in the atmosphere. This is not always known accurately and calculations must be regularly updated to take into account new information.
- What sectors are included in the calculation (e.g. energy industries, industrial processes, agriculture etc.). There is often a conflict between transparency and availability of data.
- The measurement protocol itself. This may be via direct measurement or estimation; the four main methods are the emission factor-based method, the mass balance method, the predictive emissions monitoring system and the continuing

emissions monitoring systems. The methods differ in accuracy, but also in cost and usability.

The different measures are sometimes used by different countries in asserting various policy/ethical positions to do with climate change (Banuri *et al.*, 1996, p. 94). This use of different measures leads to a lack of comparability, which is problematic when monitoring progress towards targets. There are arguments for the adoption of a common measurement tool, or at least the development of communication between different tools.

Emissions may be measured over long time periods. This measurement type is called historical or cumulative emissions. Cumulative emissions give some indication of who is responsible for the build-up in the atmospheric concentration of GHGs (IEA, 2007, p. 199).

Emissions may also be measured across shorter time periods. Emissions changes may, for example, be measured against a base year of 1990. 1990 was used in the United Nations Framework Convention on Climate Change (UNFCCC) as the base year for emissions, and is also used in the Kyoto Protocol (some gases are also measured from the year 1995) (Grubb, 2003, pp. 146, 149). A country's emissions may also be reported as a proportion of global emissions for a particular year.

Another measurement is of per capita emissions. This divides a country's total annual emissions by its mid-year population (World Bank, 2010, p. 370). Per capita emissions may be based on historical or annual emissions (Banuri *et al.*, 1996, pp. 106–107).

Cumulative emissions

Over the 1900-2005 period, the US was the world's largest cumulative emitter of energy-related CO_2 emissions, and accounted for 30% of total cumulative emissions (IEA, 2007, p. 201). The second largest emitter was the EU, at 23%; the third largest was China, at 8%; fourth was Japan, at 4%; fifth was India, at 2%. The rest of the world accounted for 33% of global, cumulative, energy-related CO_2 emissions.

Changes since a particular base year

In total, Annex I Parties managed a cut of 3.3% in GHG emissions between 1990 and 2004 (UNFCCC, 2007, p. 11). Annex I Parties are those countries listed in Annex I of the UNFCCC, and are the industrialized countries. For non-Annex I Parties, emissions in several large developing countries and fast growing economies (China, India, Thailand, Indonesia, Egypt, and Iran) GHG emissions have increased rapidly over this period (PBL, 2009).

The sharp acceleration in CO_2 emissions since 2000 to more than a 3% increase per year (more than 2 ppm per year) from 1.1% per year during the 1990s is attributable to the lapse of formerly declining trends in carbon intensity of both developing and developed nations. China was responsible for most of global growth in emissions during this period.

Localised plummeting emissions associated with the collapse of the Soviet Union have been followed by slow emissions growth in this region due to more efficient energy use, made necessary by the increasing proportion of it that is exported. In comparison, methane has not increased appreciably, and N_2O by 0.25% y^{-1}.

Annual and per capita emissions

At the present time, total annual emissions of GHGs are rising (Rogner *et al.*, 2007). Between the period 1970 to 2004, emissions increased at an average rate of 1.6% per year, with CO_2 emissions from the use of fossil fuels growing at a rate of 1.9% per year.

Per capita emissions in the industrialized countries are typically as much as ten times the average in developing countries (Grubb, 2003, p. 144). Due to China's fast economic development, its per capita emissions are quickly approaching the levels of those in the Annex I group of the Kyoto Protocol (PBL, 2009). Other countries with fast growing emissions are South Korea, Iran, and Australia. On the other hand, per capita emissions of the EU-15 and the USA are gradually decreasing over time. Emissions in Russia and the Ukraine have decreased fastest since 1990 due to economic restructuring in these countries (Carbon Trust, 2009, p. 24).

Energy statistics for fast growing economies are less accurate than those for the industrialized countries. For China's annual emissions in 2008, PBL (2008) estimated an uncertainty range of about 10%.

Top emitters

In 2005, the world's top-20 emitters comprised 80% of total GHG emissions. Tabulated below are the top-5 emitters for the year 2005 (MNP, 2007). The second column is the country's or region's share of the global total of annual emissions. The third column is the country's or region's average annual per capita emissions, in tonnes of GHG per head of population:

Top-5 emitters for the year 2005

Country or region	% of global total annual emissions	Tonnes of GHG per capita
United States[a]	16 %	24.1
Indonesia[c]	6 %	12.9
European Union-27[a]	11 %	10.6
China[b]	17 %	5.8
India	5 %	2.1

Table footnotes:

- These values are for the GHG emissions from fossil fuel use and cement production. Calculations are for carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and gases containing fluorine (the F-gases HFCs, PFCs and SF_6).
- These estimates are subject to large uncertainties regarding CO_2 emissions from deforestation; and the per country emissions of other GHGs (e.g., methane). There are also other large uncertainties which mean that small differences between countries are not significant. CO_2 emissions from the decay of remaining biomass after biomass burning/deforestation are not included.
- [a] Industrialised countries: official country data reported to UNFCCC.
- [b] Excluding underground fires.
- [c] Including an estimate of 2000 million tonnes CO_2 from peat fires and decomposition of peat soils after draining. However, the uncertainty range is very large.

Effect of policy

Rogner *et al.* (2007) assessed the effectiveness of policies to reduce emissions (mitigation of climate change). They concluded that mitigation policies undertaken by UNFCCC Parties were inadequate to reverse the trend of increasing GHG emissions. The impacts of population growth, economic development, technological investment, and consumption had overwhelmed improvements in energy intensities and efforts to decarbonize (energy intensity is a country's total primary energy supply (TPES) per unit of GDP (Rogner *et al.*, 2007). TPES is a measure of commercial energy consumption (World Bank, 2010, p. 371)).

Projections

Based on then-current energy policies, Rogner et al. (2007) projected that energy-related CO_2 emissions in 2030 would be 40-110% higher than in 2000. Two-thirds of this increase was projected to come from non-Annex I countries. Per capita emissions in Annex I countries were still projected to remain substantially higher than per capita emissions in non-Annex I countries. Projections consistently showed a 25-90% increase in the Kyoto gases (carbon dioxide, methane, nitrous oxide, sulphur hexafluoride) compared to 2000.

Relative CO_2 emission from various fuels

One liter of gasoline, when used as a fuel, produces about 2.32 kg (19.4 lb/US gallon) of carbon dioxide, a greenhouse gas.

Mass of carbon dioxide emitted per quantity of energy for various fuels

Fuel name	CO_2 emitted (lbs/10^6 Btu)	CO_2 emitted (g/10^6 J)
Natural gas	117	50.30
Liquefied petroleum gas	139	59.76
Propane	139	59.76
Aviation gasoline	153	65.78

Automobile gasoline	156	67.07
Kerosene	159	68.36
Fuel oil	161	69.22
Tires/tire derived fuel	189	81.26
Wood and wood waste	195	83.83
Coal (bituminous)	205	88.13
Coal (subbituminous)	213	91.57
Coal (lignite)	215	92.43
Petroleum coke	225	96.73
Coal (anthracite)	227	97.59

Removal from the atmosphere and global warming potential

Natural processes

Greenhouse gases can be removed from the atmosphere by various processes, as a consequence of:

- a physical change (condensation and precipitation remove water vapor from the atmosphere).
- a chemical reactions within the atmosphere. For example, methane is oxidized by reaction with naturally occurring hydroxyl radical, OH· and degraded to CO_2 and water vapor (CO_2 from the oxidation of methane is not included in the methane Global warming potential). Other chemical reactions include solution and solid phase chemistry occurring in atmospheric aerosols.
- a physical exchange between the atmosphere and the other compartments of the planet. An example is the mixing of atmospheric gases into the oceans.
- a chemical change at the interface between the atmosphere and the other compartments of the planet. This is the case for CO_2, which is reduced by photosynthesis of plants, and which, after dissolving in the oceans, reacts to form carbonic acid and bicarbonate and carbonate ions.
- a photochemical change. Halocarbons are dissociated by UV light releasing Cl· and F· as free radicals in the stratosphere with harmful effects on ozone (halocarbons are generally too stable to disappear by chemical reaction in the atmosphere).

Atmospheric lifetime

Aside from water vapor, which has a residence time of about nine days, major greenhouse gases are well-mixed, and take many years to leave the atmosphere. Although it is not easy to know with precision how long it takes greenhouse gases to leave the atmosphere, there are estimates for the principal greenhouse gases. Jacob (1999) defines the lifetime τ of an atmospheric species X in a one-box model as the average time that a molecule of X remains in the box. Mathematically τ can be defined as the ratio of the mass *m* (in kg) of X in the box to its removal rate, which is the sum of the flow of X out of the box (F_{out}), chemical loss of X (L), and deposition of X (D) (all in kg/sec):

$$\tau = \frac{m}{F_{out} + L + D}$$

The atmospheric lifetime of a species therefore measures the time required to restore equilibrium following an increase in its concentration in the atmosphere. Individual atoms or molecules may be lost or deposited to sinks such as the soil, the oceans and other waters, or vegetation and other biological systems, reducing the excess to background concentrations. The average time taken to achieve this is the mean lifetime. The atmospheric lifetime of CO_2 is often incorrectly stated to be only a few years because that is the average time for any CO_2 molecule to stay in the atmosphere before being removed by mixing into the ocean, photosynthesis, or other processes. However, this ignores the balancing fluxes of CO_2 into the atmosphere from the other reservoirs. It is the net concentration changes of the various greenhouse gases by *all sources and sinks* that determines atmospheric lifetime, not just the removal processes.

Global warming potential

The global warming potential (GWP) depends on both the efficiency of the molecule as a greenhouse gas and its atmospheric lifetime. GWP is measured relative to the same **mass** of CO_2 and evaluated for a specific timescale. Thus, if a gas has a high radiative forcing but also a short lifetime, it will have a large GWP on a 20 year scale but a small one on a 100 year scale. Conversely, if a molecule has a longer atmospheric lifetime than CO_2 its GWP will increase with the timescale considered.

Carbon dioxide has a variable atmospheric lifetime, and cannot be specified precisely. Recent work indicates that recovery from a large input of atmospheric CO_2 from burning fossil fuels will result in an effective lifetime of tens of thousands of years. Carbon dioxide is defined to have a GWP of 1 over all time periods.

Methane has an atmospheric lifetime of 12 ± 3 years and a GWP of 72 over 20 years, 25 over 100 years and 7.6 over 500 years. The decrease in GWP at longer times is because methane is degraded to water and CO_2 through chemical reactions in the atmosphere.

Examples of the atmospheric lifetime and GWP relative to CO_2 for several greenhouse gases are given in the following table:

Atmospheric lifetime and GWP relative to CO_2 at different time horizon for various greenhouse gases.

Gas name	**Chemical formula**	**Lifetime (years)**	**Global warming potential (GWP) for given time horizon**		
			20-yr	**100-yr**	**500-yr**

Carbon dioxide	CO_2	See above	1	1	1
Methane	CH_4	12	72	25	7.6
Nitrous oxide	N_2O	114	289	298	153
CFC-12	CCl_2F_2	100	11 000	10 900	5 200
HCFC-22	$CHClF_2$	12	5 160	1 810	549
Tetrafluoromethane	CF_4	50 000	5 210	7 390	11 200
Hexafluoroethane	C_2F_6	10 000	8 630	12 200	18 200
Sulphur hexafluoride	SF_6	3 200	16 300	22 800	32 600
Nitrogen trifluoride	NF_3	740	12 300	17 200	20 700

The use of CFC-12 (except some essential uses) has been phased out due to its ozone depleting properties. The phasing-out of less active HCFC-compounds will be completed in 2030.

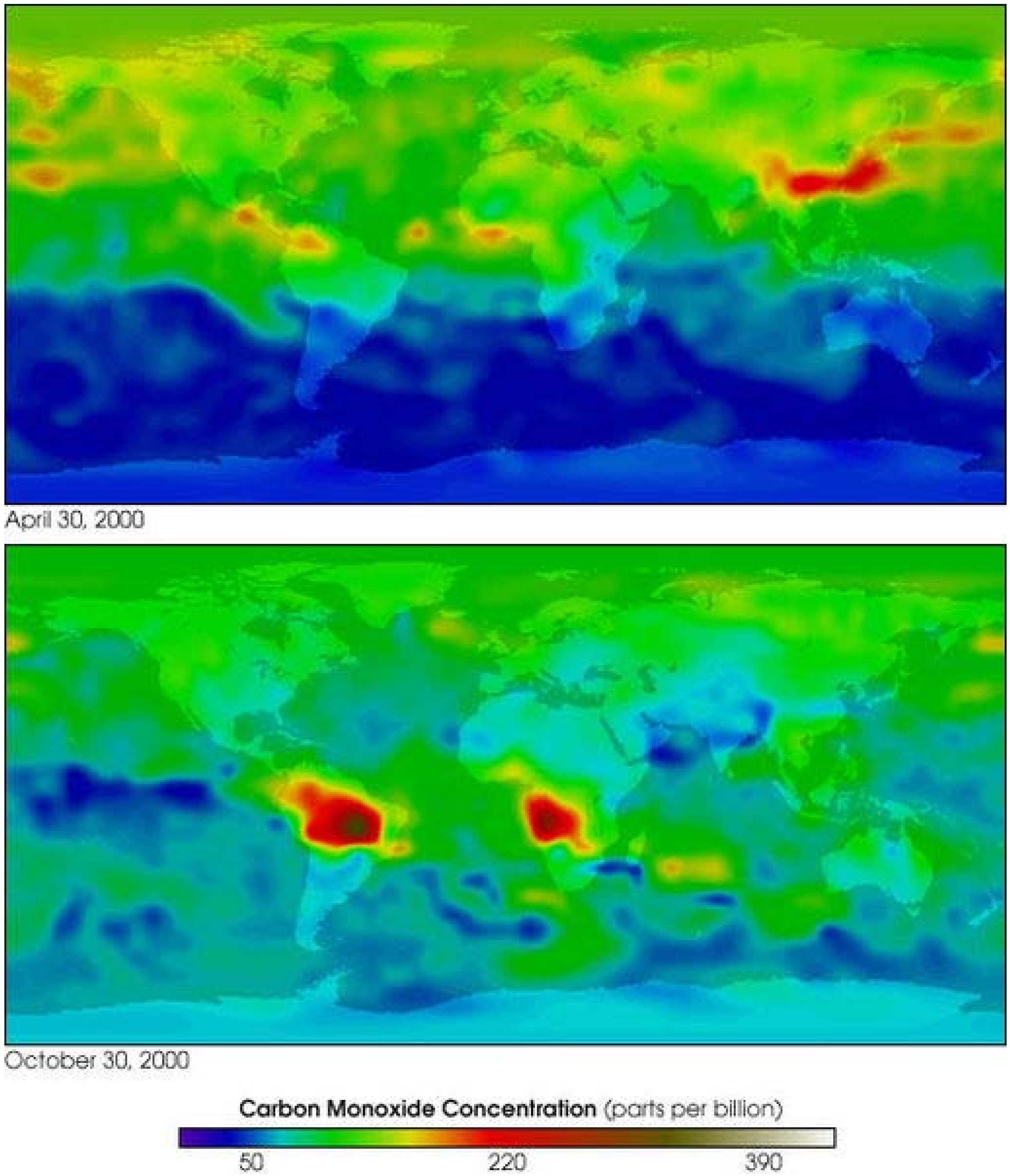
Airborne fraction

Airborne fraction (AF) is the proportion of an emission (e.g. CO_2) remaining in the atmosphere after a specified time. Canadell (2007) define the annual AF as the ratio of the atmospheric CO_2 increase in a given year to that year's total emissions, and calculate that of the average 9.1 PgC y^{-1} of total anthropogenic emissions from 2000 to 2006, the AF was 0.45. For CO_2 the AF over the last 50 years (1956–2006) has been increasing at 0.25 ± 0.21%/year.

Negative emissions

There exists a number of technologies which produce negative emissions of greenhouse gases. Most widely analysed are those which remove carbon dioxide from the atmosphere, either to geologic formations such as bio-energy with carbon capture and storage and carbon dioxide air capture, or to the soil as in the case with biochar. It has been pointed out by the IPCC, that many long-term climate scenario models require large scale manmade negative emissions in order to avoid serious climate change.

Related effects



MOPITT 2000 global carbon monoxide.

Carbon monoxide has an indirect radiative effect by elevating concentrations of methane and tropospheric ozone through scavenging of atmospheric constituents (e.g., the hydroxyl radical, **OH**) that would otherwise destroy them. Carbon monoxide is created when carbon-containing fuels are burned incompletely. Through natural processes in the atmosphere, it is eventually oxidized to carbon dioxide. Carbon monoxide has an atmospheric lifetime of only a few months and as a consequence is spatially more variable than longer-lived gases.

Another potentially important indirect effect comes from methane, which in addition to its direct radiative impact also contributes to ozone formation. Shindell *et al.* (2005) argue that the contribution to climate change from methane is at least double previous estimates as a result of this effect.

Chapter 5

Desalination

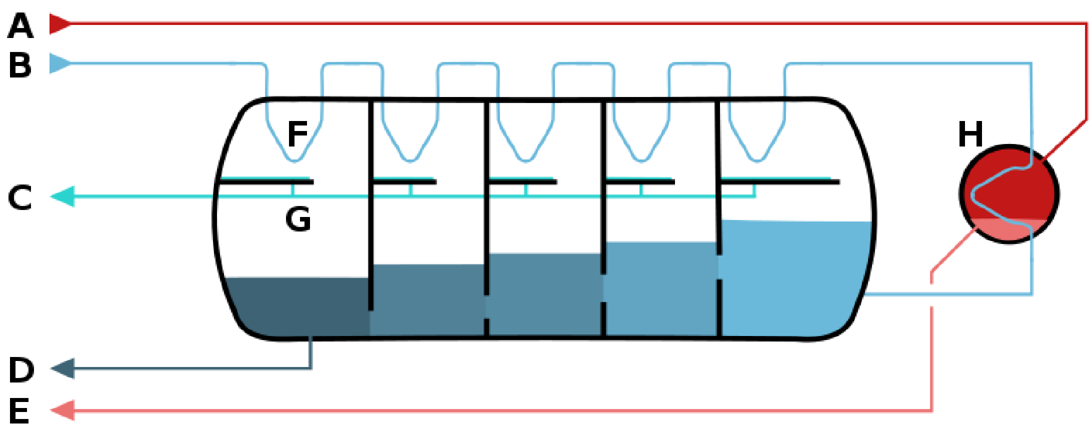
Desalination, **desalinization**, or **desalinisation** refers to any of several processes that remove some amount of salt and other minerals from water. More generally, desalination may also refer to the removal of salts and minerals, as in soil desalination.

Water is desalinated in order to convert salt water to fresh water so it is suitable for human consumption or irrigation. Sometimes the process produces table salt as a by-product. Desalination is used on many seagoing ships and submarines. Most of the modern interest in desalination is focused on developing cost-effective ways of providing fresh water for human use in regions where the availability of fresh water is, or is becoming, limited.

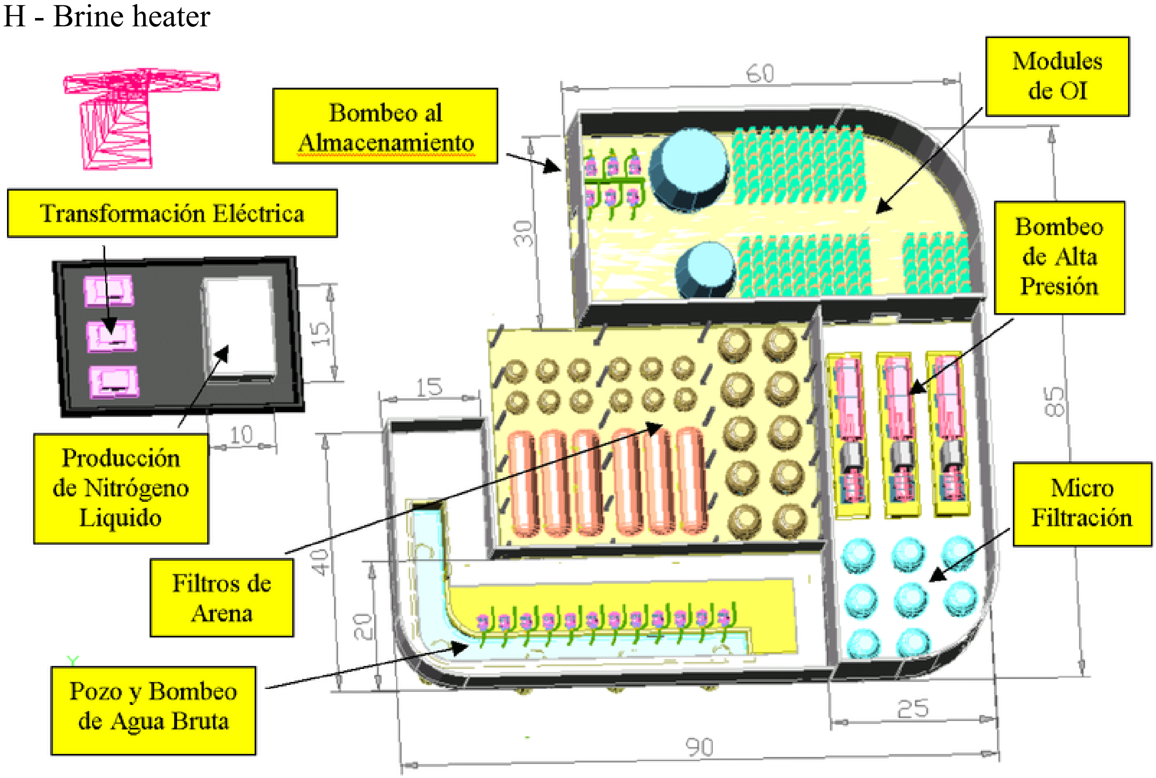
Large-scale desalination typically uses extremely large amounts of energy as well as specialized, expensive infrastructure, making it very costly compared to the use of fresh water from rivers or groundwater.

However, along with recycled water this is one of the only non-rainfall dependent water sources particularly relevant to countries like Australia which traditionally have relied on rainfall in dams to provide their drinking water supplies.

The world's largest desalination plant is the Jebel Ali Desalination Plant (Phase 2) in the United Arab Emirates. It is a dual-purpose facility that uses multi-stage flash distillation and is capable of producing 300 million cubic metres of water per year. By comparison the largest desalination plant in the United States is located in Tampa Bay, Florida and operated by Tampa Bay Water, which began desalinating 34.7 million cubic meters of water per year in December 2007. The Tampa Bay plant runs at around 12% the output of the Jebel Ali Desalination Plants. A January 17, 2008, article in the *Wall Street Journal* states, "World-wide, 13,080 desalination plants produce more than 12 billion gallons of water a day, according to the International Desalination Association."



Schematic of a multi-stage flash desalinator
A - Steam in
B - Seawater in
C - Potable water out
D - Waste out
E - Steam out
F - Heat exchange
G - Condensation collection
H - Brine heater



Plan of a typical reverse osmosis desalination plant

Methods

The traditional process used in these operations is vacuum distillation—essentially the boiling of water at less than atmospheric pressure and thus a much lower temperature than normal. This is because the boiling of a liquid occurs when the vapor pressure equals the ambient pressure and vapor pressure increases with temperature. Thus, because of the reduced temperature, energy is saved. A leading distillation method is multi-stage flash distillation accounting for 85% of production worldwide in 2004.

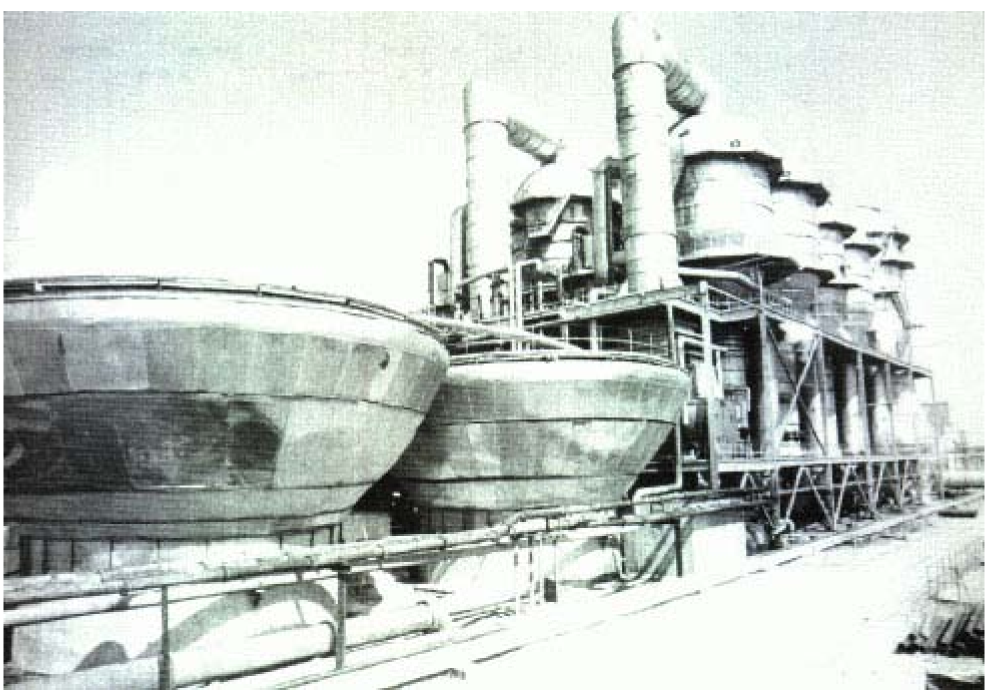
Reverse osmosis desalination plant in Barcelona, Spain

The principal competing processes use membranes to desalinate, principally applying reverse osmosis technology. Membrane processes use semi-permeable membranes and pressure to separate salts from water. Reverse osmosis plant membrane systems typically use less energy than thermal distillation, which has led to a reduction in overall desalination costs over the past decade. Desalination remains energy intensive, however, and future costs will continue to depend on the price of both energy and desalination technology.

Considerations and criticism

Cogeneration

Cogeneration is the process of using excess heat from power production to accomplish another task. For desalination, cogeneration is the production of potable water from seawater or brackish groundwater in an integrated, or "dual-purpose", facility in which a power plant is used as the source of energy for the desalination process. The facility's energy production may be dedicated entirely to the production of potable water (a stand-alone facility), or excess energy may be produced and incorporated into the energy grid (a true cogeneration facility). There are various forms of cogeneration, and theoretically any form of energy production could be used. However, the majority of current and planned cogeneration desalination plants use either fossil fuels or nuclear power as their source of energy. Most plants are located in the Middle East or North Africa, due to their petroleum resources and subsidies. The advantage of dual-purpose facilities is that they can be more efficient in energy consumption, thus making desalination a more viable option for drinking water in areas of scarce water resources.



Shevchenko BN350, a nuclear-heated desalination unit

In a December 26, 2007, opinion column in the *The Atlanta Journal-Constitution*, Nolan Hertel, a professor of nuclear and radiological engineering at Georgia Tech, wrote, "... nuclear reactors can be used ... to produce large amounts of potable water. The process is already in use in a number of places around the world, from India to Japan and Russia. Eight nuclear reactors coupled to desalination plants are operating in Japan alone ... nuclear desalination plants could be a source of large amounts of potable water transported by pipelines hundreds of miles inland..."

Additionally, the current trend in dual-purpose facilities is hybrid configurations, in which the permeate from an RO desalination component is mixed with distillate from thermal desalination. Basically, two or more desalination processes are combined along with power production. Such facilities have already been implemented in Saudi Arabia at Jeddah and Yanbu.

A typical aircraft carrier in the U.S. military uses nuclear power to desalinate 400,000 US gallons (1,500,000 l; 330,000 imp gal) of water per day.

Economics

A number of factors determine the capital and operating costs for desalination: capacity and type of facility, location, feed water, labor, energy, financing, and concentrate disposal. Desalination stills now control pressure, temperature and brine concentrations to optimize the water extraction efficiency. Nuclear-powered desalination might be economical on a large scale.

While noting that costs are falling, and generally positive about the technology for affluent areas that are proximate to oceans, one study argues that "Desalinated water may be a solution for some water-stress regions, but not for places that are poor, deep in the interior of a continent, or at high elevation. Unfortunately, that includes some of the places with biggest water problems." and "Indeed, one needs to lift the water by 2,000 metres (6,600 ft), or transport it over more than 1,600 kilometres (990 mi) to get transport costs equal to the desalination costs. Thus, it may be more economical to transport fresh water from somewhere else than to desalinate it. In places far from the sea, like New Delhi, or in high places, like Mexico City, high transport costs would add to the high desalination costs. Desalinated water is also expensive in places that are both somewhat far from the sea and somewhat high, such as Riyadh and Harare. In many places, the dominant cost is desalination, not transport; the process would therefore be relatively less expensive in places like Beijing, Bangkok, Zaragoza, Phoenix, and, of course, coastal cities like Tripoli." After being desalinated at Jubail, Saudi Arabia, water is pumped 200 miles (320 km) inland through a pipeline to the capital city of Riyadh. For cities on the coast, desalination is being increasingly viewed as an untapped and unlimited water source.

Desalination makes sense only after less expensive options are exhausted, including recycling water and fixing broken infrastructure. Water is reused in Las Vegas NV, Fountain Valley CA, Fairfax VA, El Paso TX and Scottsdale AZ. Compared to desalinated sea water, recycling requires 50% less energy due to the significantly lower salt content and produces new water at 30% less cost to the consumer, without the damage to marine life and ecosystems common to desalination plants.

Israel is now desalinating water at a cost of US$0.53 per cubic meter. Singapore is desalinating water for US$0.49 per cubic meter. Many large coastal cities in developed countries are considering the feasibility of seawater desalination, due to its cost effectiveness compared with other water supply options, which can include mandatory installation of rainwater tanks or stormwater harvesting infrastructure. Studies have shown that the desalination option is more cost-effective than large-scale recycled water for drinking, and more cost-effective in Sydney than the vastly expensive option of mandatory installation of rainwater tanks or stormwater harvesting infrastructure. The city of Perth has been successfully operating a reverse osmosis seawater desalination plant since 2006, and the Western Australian government have announced that a second plant will be built to serve the city's needs. A desalination plant is now operating in Australia's largest city of Sydney, and the Wonthaggi desalination plant under construction in Wonthaggi, Victoria.

The Perth desalination plant is powered partially by renewable energy from the Emu Downs Wind Farm. A wind farm at Bungendore in NSW has been purpose-built to generate enough renewable energy to offset the energy use of the Sydney plant, mitigating concerns about harmful greenhouse gas emissions, a common argument used against seawater desalination due to the energy requirements of the technology. The purchase or production of renewable energy to power desalination plants naturally adds to the capital and/or operating costs of desalination. However, recent experience in Perth and Sydney indicates that the additional cost is acceptable to communities, as a city may then augment its water supply without doing environmental harm to the atmosphere. The Queensland state government also purchased renewable energy certificates on behalf of its Gold Coast plant which will see the plant offset its carbon emissions for the initial 18 to 20 months of operations, bringing its environmental footprint down, in line with the other major plants that will be operating around the same time, in Perth and Sydney.

In December 2007, the South Australian government announced that it would build a seawater desalination plant for the city of Adelaide, Australia, located at Port Stanvac. The desalination plant is to be funded by raising water rates to achieve full cost recovery. An online, unscientific poll showed that nearly 60% of votes cast were in favor of raising water rates to pay for desalination.

A January 17, 2008, article in the *Wall Street Journal* states, "In November, Connecticut-based Poseidon Resources Corp. won a key regulatory approval to build the US$300 million water-desalination plant in Carlsbad, north of San Diego. The facility would be the largest in the Western Hemisphere, producing 50,000,000 US gallons (190,000,000 l; 42,000,000 imp gal) of drinking water per day, enough to supply about 100,000 homes ... Improved technology has cut the cost of desalination in half in the past decade, making it more competitive ... Poseidon plans to sell the water for about US $950 per acre-foot [1,200 cubic metres (42,000 cu ft)]. That compares with an average US$700 an acre-foot

[1200 m^3] that local agencies now pay for water." $1,000 per acre-foot works out to $3.06 for 1,000 gallons, or $.81 for 1 cubic meter, which is the unit of water measurement that residential water users are accustomed to being billed in. .

While this regulatory hurdle was met, Poseidon Resources is not able to break ground until the final approval of a mitigation project for the damage done to marine life through the intake pipe, as is required by California law. Poseidon Resources has made progress in Carlsbad, CA, despite its unsuccessful attempt to complete construction of Tampa Bay Desal, a desalination plant in Tampa Bay, FL, in 2001. The Board of Directors of Tampa Bay Water were forced to buy Tampa Bay Desal from Poseidon Resources in 2001 to prevent a third failure of the project. Tampa Bay Water faced five years of engineering problems and operation at 20% capacity due to marine life and growth captured and stuck to reverse osmosis filters prior to fully utilizing this facility in 2007.

According to a May 9, 2008, article in *Forbes*, a San Leandro, California, company called Energy Recovery Inc. has been desalinating water for US $0.46 per cubic meter.

According to a June 5, 2008, article in the *Globe and Mail*, a Jordanian-born chemical engineering doctoral student at the University of Ottawa, named Mohammed Rasool Qtaisha, has invented a new desalination technology that is alleged to be between 600% and 700% more water output per square meter of membrane than current technology.

While desalinating 1,000 US gallons (3,800 l; 830 imp gal) of water can cost as much as $3, the same amount of bottled water costs $7,945.

Environmental

One of the main environmental considerations of ocean water desalination plants is the impact of the open ocean water intakes, especially when co-located with power plants. Many proposed ocean desalination plants' initial plans relied on these intakes despite perpetuating ongoing impacts on marine life. In the United States, due to a recent court ruling under the Clean Water Act, these intakes are no longer viable without reducing mortality, by ninety percent, of the life in the ocean; the plankton, fish eggs and fish larvae. There are alternatives, including beach wells that eliminate this concern, but require more energy and higher costs while limiting output. Other environmental concerns include air pollution and greenhouse gas emissions from the power plants.

To limit the environmental impact of returning the brine to the ocean, it can be diluted with another stream of water entering the ocean, such as the outfall of a waste water treatment plant or power plant. While seawater power plant cooling water outfalls are not freshwater like waste water treatment plant outfalls, the salinity of the brine will still be reduced. If the power plant is medium- to large-sized and the desalination plant is not enormous, the flow of the power plant's cooling water is likely to be at least several times larger than that of the desalination plant. Another method to reduce the increase in salinity is to spread the brine via a diffuser to mix in a mixing zone so that there is only a slight increase in salinity. For example, once the pipeline containing the brine reaches the sea floor, it can split off into many branches, each one releasing the brine gradually along its length through small holes. This method can be used in combination with the joining of the brine with power plant or waste water plant outfalls.

The concentrated seawater has the potential to harm ecosystems, especially marine environments in regions with low turbidity and high evaporation that already have elevated salinity. Examples of such locations are the Persian Gulf, the Red Sea and, in particular, coral lagoons of atolls and other tropical islands around the world.

The UAE, Qatar, Bahrain, Saudi Arabia, Kuwait and Iran have 120 desalination plants between them. These plants flush nearly 24 tons of chlorine, 65 tons of algae-harming antiscalants used to descale pipes, and around 300kg of copper into the Persian Gulf every day.

Because the brine is denser than the surrounding sea water due to the higher solute concentration, discharge into water bodies means that the ecosystems on the bed of the water body are most at risk because the brine sinks and remains there long enough to damage the ecosystems. Careful re-introduction can minimize this problem. For example, for the desalination plant and ocean outlet structures to be built in Sydney from late 2007, the water authority states that the ocean outlets will be placed in locations at the seabed that will maximize the dispersal of the concentrated seawater, such that it will be indistinguishable from normal seawater between 50 and 75 metres (160 and 246 ft) from the outlet points. Sydney is fortunate to have typical oceanographic conditions off the coast that allow for such rapid dilution of the concentrated byproduct, thereby minimizing harm to the environment.

In Perth, Australia, in 2007, the Kwinana Desalination Plant was opened. The water is sucked in from the ocean at only 0.1 metres per second (0.33 ft/s), which is slow enough to let fish escape. The plant provides nearly 140,000 cubic metres (4,900,000 cu ft) of clean water per day. . This is the same at Queensland's Gold Coast Desalination Plant and Sydney's Desalination Plant.

Desalination compared to other water supply options

Increased water conservation and water use efficiency remain the most cost-effective priorities in areas of the world where there is a large potential to improve the efficiency of water use practices. While comparing ocean water desalination to waste water reclamation for drinking water shows desalination as the first option, using reclamation for irrigation and industrial use provides multiple benefits. Urban runoff and storm water capture also provide benefits in treating, restoring and recharging groundwater. A proposed alternative to desalinization in the state of California and other areas in the American Southwest is the commercial importation of bulk water either by very large crude carriers converted to water carriers, or via pipelines. The idea is politically unpopular in Canada, where governments have been scrambling to impose trade barriers to bulk water exports as a result of a claim filed in 1999 under Chapter 11 of the North American Free Trade Agreement (NAFTA) by Sun Belt Water Inc. a company established in 1990 in Santa Barbara, California, to address pressing local needs due to a severe drought in that area. Sun Belt maintains a web site where documents relating to their dispute are posted online.

Experimental techniques and other developments

In the past, many novel desalination techniques have been researched with varying degrees of success. Some, such as forward osmosis, are still on the drawing board now while others have attracted research funding. For example, to offset the energy requirements of desalination, the U.S. government is working to develop practical solar desalination.

As an example of newer theoretical approaches for desalination, focusing specifically on maximizing energy efficiency and cost effectiveness, the Passarell Process may be considered.

Other approaches involve the use of geothermal energy. From an environmental and economic point of view, in most locations geothermal desalination can be preferable to using fossil groundwater or surface water for human needs, as in many regions the available surface and groundwater resources already have long been under severe stress.

Recent research in the U.S. indicates that nanotube membranes may prove to be extremely effective for water filtration and may produce a viable water desalination process that would require substantially less energy than reverse osmosis.

Another method being looked into for water desalination is the use of biomimetic membranes

On June 23, 2008, it was reported that Siemens Water Technologies had developed a new technology, based on applying electric field on seawater, that desalinates one cubic meter of water while using only 1.5 kWh of energy, which, according to the report, is one half the energy that other processes use.

Fresh water can also be produced by freezing seawater, as happens naturally in the polar regions, and is known as freeze-thaw desalination.

According to MSNBC, a report by Lux Research estimated that the worldwide desalinated water supply will triple between 2008 and 2020.

Low Temperature Thermal Desalination

Low Temperature Thermal Desalination (LTTD) takes advantage of the fact that water boils at low pressures, even as low as ambient temperature. The system uses vacuum pumps to create a low pressure, low-temperature environment in which water boils at a temperature gradient of 8 to 10 degrees C between two volumes of water. Cooling water is supplied from sea depths of as much as 600 metres (2,000 ft). This cold water is pumped through coils to condense the evaporated water vapor. The resulting condensate is purified water. The LTTD process may also take advantage of the temperature gradient available at power plants, where large quantities of warm waste water are discharged from the plant, reducing the energy input needed to create a temperature gradient.

LTTD was developed by India's National Institute of Ocean Technology (NIOT) from 2004. The world's first LTTD plant was opened in 2005 at Kavaratti in the Lakshadweep islands. The plant's capacity is 100,000 litres (22,000 imp gal; 26,000 US gal) /day, at a capital cost of INR 50 million (€922,000). The plant uses deep water at a temperature of 7 to 15 °C (45 to 59 °F). In 2007, NIOT opened an experimental floating LTTD plant off the coast of Chennai with a capacity of 1,000,000 litres (220,000 imp gal; 260,000 US gal)/day. A smaller plant was established in 2009 at the North Chennai Thermal Power Station to prove the LTTD application where power plant cooling water is available..

Thermo-ionic process

In October 2009, Saltworks Technologies, a Canadian firm, announced a process that uses solar or other thermal heat to drive an ionic current that empties all the sodium and chlorine ions from the water.

Existing facilities and facilities under construction

Abu Dhabi, United Arab Emirates

- Taweelah A1 Power and Desalination Plant has an output 385,000,000 litres (85,000,000 imp gal; 102,000,000 US gal) per day of clean water
- Umm Al Nar Desalination Plant has an output of 394,000,000 litres (87,000,000 imp gal; 104,000,000 US gal) per day of clean water
- Fujairah F2 is to be completed by July 2010 will have a water production capacity of 492,000,000 litres (108,000,000 imp gal; 130,000,000 US gal) per day.

Aruba

The island of Aruba has a large (world’s largest at the time of its inauguration) desalination plant with the total installed capacity of 42,000 metric tons (11.1 million gallons or 42×10^3 m^3) per day.

Australia

A combination of increased water usage and lower rainfall/drought in Australia has caused State governments to build a number of desalination plants, including the recently commissioned Kurnell Desalination Plant serving the Sydney area. While desalination has been adopted by state governments to secure water supply, it is highly energy intensive (~$140 energy demand/ML) and has a high carbon footprint due to continued reliance on Australia's coal-based energy generation.

Cyprus

There are also desalination plants in Cyprus, like the one near the town of Larnaca. This is called the Dhekelia Desalination Plant, which utilises the reverse osmosis system.

Gibraltar

Most of the fresh water supply in Gibraltar is supplied by a reverse osmosis plant.

Israel

The Hadera seawater reverse osmosis (SWRO) desalination plant in Israel is the largest of its kind in the world. The project was developed as a BOT (Build-Operate-Transfer) by a consortium of three international companies: Veolia water, IDE Technologies and Elran.

Existing Israeli water desalination facilities

Location	Opening	Capacity (mln m^3/year)	Cost of water (per m^3)	Notes
Ashkelon	August 2005	120 (as of 2010)	NIS 2.60	
Palmachim	May 2007	45	NIS 2.90	
Hadera	December 2009	127	NIS 2.60	

Israeli water desalination facilities under construction

Location	Opening	Capacity (mln m^3/year)	Cost of water (per m^3)	Notes
Ashdod	2012	100 (expansion up to 150 possible)	NIS 2.40	
Soreq	2013	150 (expansion up to 300 approved)	NIS 2.01 - 2.19	

Maldives

Maldives is a small island nation and most of the islands depend on desalination as a source of water.

Saudi Arabia

The Saline Water Conversion Corporation of Saudi Arabia provides 50% of the municipal water in the Kingdom, operates a number of desalination plants, and has contracted $1892 million to a Japanese-South Korean consortium to build one capable of producing a billion litres a day, opening at the end of 2013. They currently operate approximately 14 plants in the kingdom ; one example at Shoaiba cost $1060 million and produces 450 million litres a day.

United Kingdom

Beckton Desalination Plant

The first water desalination plant in the United Kingdom, the Thames Water Desalination Plant, has been built in Beckton, east London for Thames Water by Acciona Agua

United States

El Paso (Texas) Desalination Plant

Brackish groundwater has been treated at the El Paso plant since around 2004. Producing 27,500,000 US gallons (104,000,000 l; 22,900,000 imp gal) of fresh water daily (about 25% of total freshwater deliveries) by reverse osmosis, it is a crucial contribution to water supplies in this water-stressed city.

Tampa Bay Water Desalination Project

The Tampa Bay Water Desalination project was originally a private venture led by Poseidon Resources. This project was delayed by the bankruptcy of Poseidon Resources' successive partners in the venture, Stone & Webster, then Covanta (formerly Ogden) and its principal subcontractor Hydranautics. Poseidon's relationship with Stone & Webster through S & W Water LLC ended in June 2000 when Stone & Webster declared bankruptcy and Poseidon Resources purchased Stone & Webster's stake in S & W Water LLC. Poseidon Resources partnered with Covanta and Hydranautics in 2001, changing the consortium name to Tampa Bay Desal. Through the inability of Covanta to complete construction bonding of the project, the Tampa Bay Water agency was forced to purchase the project from Poseidon on May 15, 2002, and underwrite the project financing under its own credit rating. Tampa Bay Water then contracted with Covanta Tampa Construction, which produced a project that did not meet required performance tests. Covanta Tampa Construction's parent company filed bankruptcy in October 2003 to prevent losing the contract with Tampa Bay Water. Then, Covanta Tampa Construction filed bankruptcy prior to performing renovations that would have satisfied contractual agreements. This resulted in nearly six months of litigation between Covanta Tampa Construction and Tampa Bay Water. In 2004, Tampa Bay Water hired a renovation team, American Water/Acciona Aqua, to bring the plant to its original, anticipated design. The plant was deemed fully operational in 2007 and is designed to run at a maximum capacity of 25 million gallons per day. Nevertheless, the plant continues to be set with problems limiting it to producing only about half that amount (14 million gallons per day or 42 af / day in 2009.

Yuma Desalting Plant (Arizona)

The Yuma Desalting Plant was constructed under authority of the Colorado River Basin Salinity Control Act of 1974 to treat saline agricultural return flows from the Wellton-Mohawk Irrigation and Drainage District. The treated water is intended for inclusion in water deliveries to Mexico thereby preserving the like amount of water in Lake Mead. Construction of the plant was completed in 1992 and it has operated on two occasions since then. The plant has been maintained, but largely not operated due to surplus and then normal water supply conditions on the Colorado River. An agreement was reached in April 2010 between the Southern Nevada Water Authority, the Metropolitan Water District of Southern California, the Central Arizona Project and the U.S. Bureau of Reclamation to underwrite the cost of running the plant in a year long pilot project.

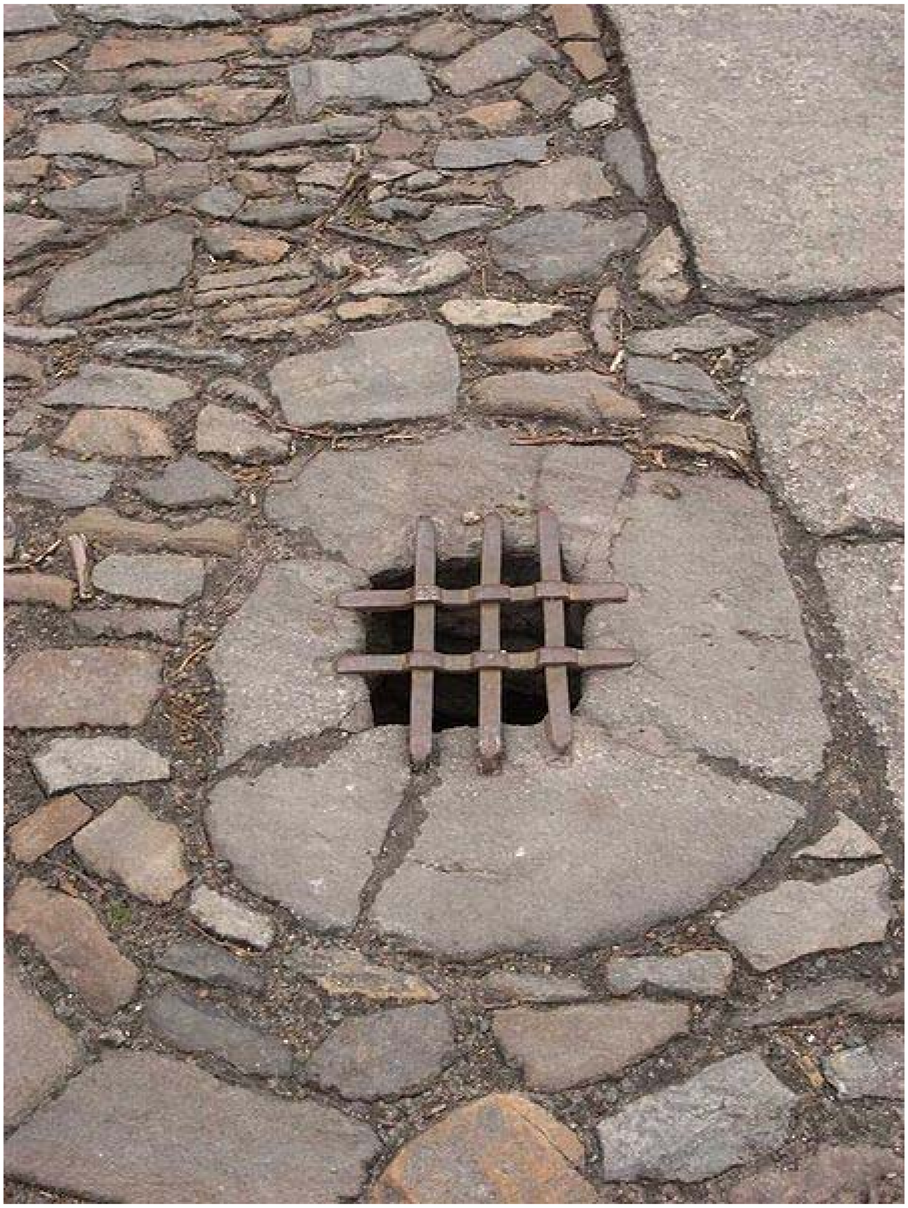
Trinidad and Tobago

The Republic of Trinidad and Tobago is using desalination to free up more of the island's water supply for drinking purposes. The desalination facility, opened in March 2003, is considered to be the first of its kind. It is the largest desalination facility in the Americas and will process 28,800,000 US gallons (109,000,000 l; 24,000,000 imp gal) of water a day and sell water at the price of $2.67 per 1,000 US gallons (3,800 l; 830 imp gal). This facility will be located at Trinidad's Point Lisas Industrial Estate, a park of more than 12 companies in various manufacturing and processing functions and will allow for easy access to water for both factories and residents in the country.

Chapter 6

Storm Drain

Storm drain receiving urban runoff



Old storm drain in Kutná Hora

A **storm drain**, **storm sewer** (U.S.), **stormwater drain** (Australia and New Zealand) or **drainage well** system (UK) or simply a **drain** or **drain system** is designed to drain excess rain and ground water from paved streets, parking lots, sidewalks, and roofs. Storm drains vary in design from small residential dry wells to large municipal systems. They are fed by street gutters on most motorways, freeways and other busy roads, as well as towns in areas which experience heavy rainfall, flooding and coastal towns which experience regular storms.

Function

Inlet

Full view of a storm drain

There are two main types of stormwater drain (sewer) inlets; side inlets and grated inlets. Side inlets are located adjacent to the curb (kerb) and rely on the ability of the opening under the backstone or lintel to capture flow. They are usually depressed at the invert of the channel to improve capture capacity. Grated inlets have gratings or grids to prevent large objects and debris from falling into the sewer system. However, their bars are fairly widely spaced so that the flow of water is not impeded. Consequently, many small objects can fall through.

Many of these small objects are caught by the catchbasin, or sump, which lies immediately below the grating. Water from the top of the catchbasin drains into the sewer proper. The catchbasin serves much the same function as the "trap" in household wastewater plumbing in trapping objects.

In the United States, unlike the trap, the catchbasin does not necessarily prevent sewer gases such as hydrogen sulfide and methane from escaping. However in the United Kingdom, where they are called *gulley-pots*, they are designed as true water-filled traps and do block the egress of gases and rodents.

Most catchbasins will contain stagnant water during the drier parts of the year and can be used by mosquitoes for breeding. The performance of catchbasins at removing sediment and other pollutants depends on the design of the catchbasin (e.g., the size of the sump), and routine maintenance to retain the storage available in the sump to capture sediment. Municipalities typically have large vacuum trucks that perform this task.

Catchbasins act as pretreatment for other treatment practices, such as retention basins, by capturing large sediments.

Piping

Pipes can come in many different shapes (rectangular, square, bread loaf shaped, oval and, more commonly, circular) and have many different features (including waterfalls, stairways, balconies and pits for catching rubbish or Gross Pollutant Traps (GPTs). Several different materials can also be used, such as brick, concrete, metal and even plastic in some cases.

Outlet

Most drains have a single large exit at their point of discharge (often covered by a grating) into a canal, river, lake, reservoir, sea or ocean. Other than catchbasins, typically there are no treatment facilities in the piping system. Small storm drains may discharge into individual dry wells. Storm drains may be interconnected using slotted pipe, to make a larger dry well system. Storm drains may discharge into man-made excavations known as recharge basins or retention ponds.

Environmental impacts

Water quality

The *first flush* from urban runoff can be extremely dirty. Storm water may become contaminated while running down the road or other impervious surface, or from lawn chemical run-off, before entering the sewer.

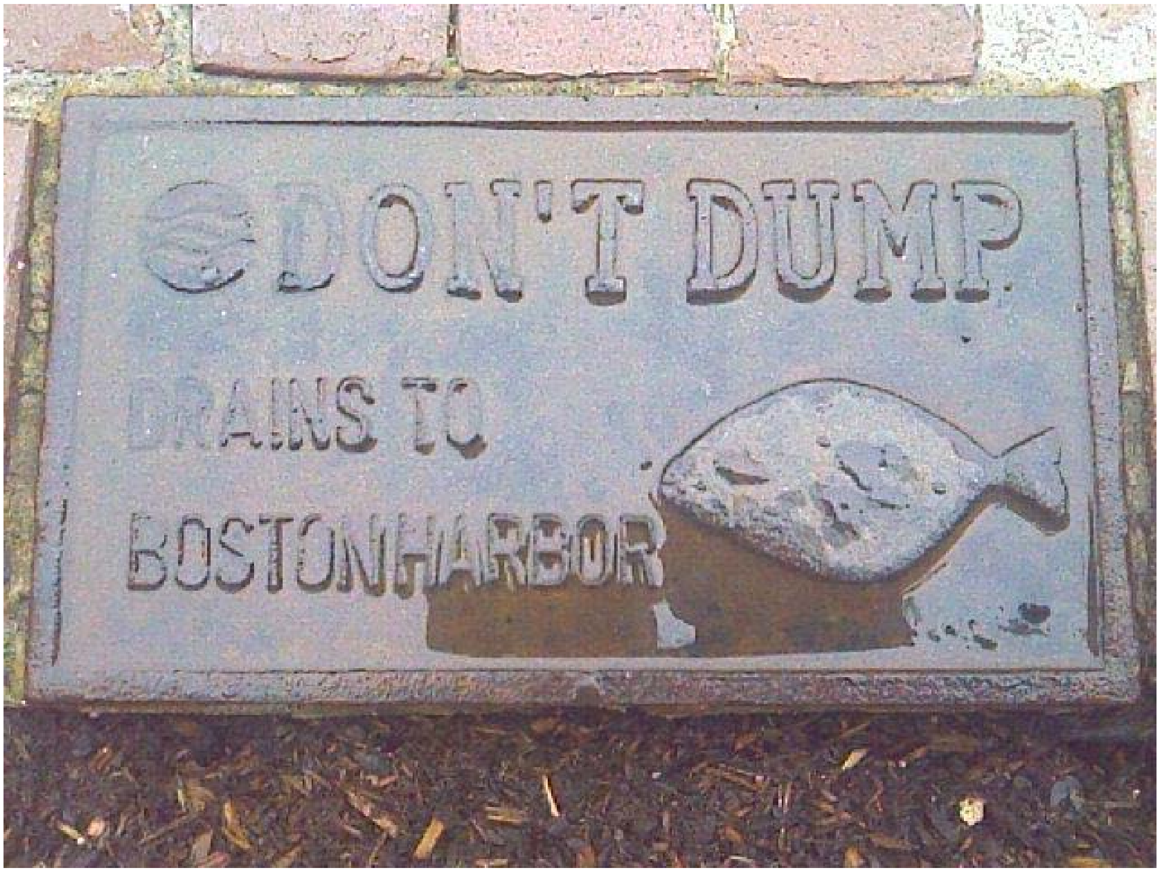
Water running off these impervious surfaces tends to pick up gasoline, motor oil, heavy metals, trash and other pollutants from roadways and parking lots, as well as fertilizers and pesticides from lawns. Roads and parking lots are major sources of nickel, copper, zinc, cadmium, lead and polycyclic aromatic hydrocarbons (PAHs), which are created as combustion byproducts of gasoline and other fossil fuels. Roof runoff contributes high levels of synthetic organic compounds and zinc (from galvanized gutters). Fertilizer use on residential lawns, parks and golf courses is a significant source of nitrates and phosphorus.

Reducing stormwater flows

Runoff into storm sewers can be minimized by including *sustainable urban drainage systems* (UK term) or *low impact development* practices (U.S. term) into municipal plans. To reduce stormwater from rooftops, flows from eaves troughs (rain gutters and downspouts) may be infiltrated into adjacent soil, rather than discharged into the storm sewer system. Storm water runoff from paved surfaces can be directed to unlined ditches (sometimes called swales or bioswales) before flowing into the storm sewers, again to allow the runoff to soak into the ground. Permeable paving materials can be used in building sidewalks, driveways and in some cases, parking lots, to infiltrate a portion of the stormwater volume.

Relationship to sanitary sewer systems

Sign alerting public to avoid dumping waste into storm drains



Typical storm drain signage on the streets of Boston

Storm drains are separate and distinct from sanitary sewer systems. The separation of storm sewers from sanitary sewers helps to prevent sewage treatment plants becoming overwhelmed by Infiltration/Inflow during a rainstorm, which can result in untreated sewage being discharged into the environment.

Many storm drainage systems are designed to drain the storm water, untreated, into rivers or streams. Special care must be taken to ensure the citizenry is aware of this, lest waste be dumped into the storm drain system. In the city of Cleveland, Ohio, for example, all new catch basins installed have inscriptions on them not to dump any waste, and usually include a fish imprint as well. Trout Unlimited Canada recommends that a yellow fish symbol be painted next to existing storm drains.

Combined sewers

Cities that installed their sewage collection systems before the 1930s typically used single piping systems to transport both urban runoff and sewage. This type of collection system is referred to as a **combined sewer system** or a CSS. Storm drains are typically at shallower depths than combined sewers; because, while storm drains are designed to accept surface runoff from streets, combined sewers were designed to also accept flow from cellar drains. The cities' rationale when combined sewers were built was that it would be cheaper to build just a single system. In these systems a sudden large rainfall that exceeds sewage treatment capacity will be allowed to overflow directly from the storm drains into receiving waters via structures called *combined sewer overflows*.

New York City, Washington, D.C., Seattle and other cities with combined systems have this problem due to a large influx of storm water after every heavy rain. Some cities have dealt with this by adding large storage tanks or ponds to hold the water until it can be treated. Chicago has a system of tunnels, collectively called the Deep Tunnel, underneath the city for storing its stormwater.

Separation of undesired runoff can be done within the storm sewer system, but such devices are new to the market and can only be installed with new development or during major upgrades. They are referred to as oil-grit separators (OGS) or oil-sediment separators (OSS). They consist of a specialized manhole chamber, and use the water flow and/or gravity to separate oil and grit.

Local building codes

Building codes and local government ordinances vary greatly on the handling of storm drain runoff. New developments might be required to construct their own storm drain processing capacity for returning the runoff to the water table and bioswales may be required in sensitive ecological areas to protect the watershed.

In the United States, cities, suburban communities and towns with over 10,000 population are required to obtain discharge permits for their storm sewer systems, under the Clean Water Act. The Environmental Protection Agency (EPA) issued stormwater regulations for large cities in 1990 and for other communities in 1999. The permits require local governments to operate stormwater management programs, covering both construction of new buildings and facilities, and maintenance of their existing municipal drainage networks. Many municipalities have revised their local ordinances covering management of runoff. State government facilities, such as roads and highways, are also subject to the stormwater management regulations.

Exploration

An international subculture has grown up around the exploration of stormwater drains. Societies such as the Cave Clan regularly explore the drains underneath cities. This is commonly known as 'urban exploration', but is also known as 'draining' when in specific relation to storm drains.

Residence

In several large American cities, homeless people live in storm drains. At least 300 people live in the 200 miles of underground storm drains of Las Vegas, many of them making a living finding unclaimed winnings in the gambling machines. An organisation called Shine a Light was founded in 2009 to help the drain residents after over 20 drowning deaths occurred in the preceding years. A man in San Diego was evicted from a storm drain after living there for nine months in 1986.

Ancient history

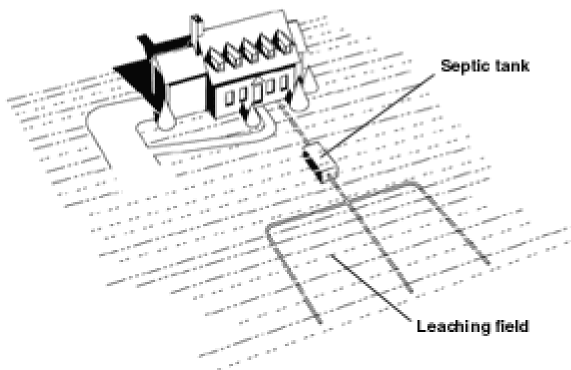
Ancient Roman gully hole in Ostia Antica in Italy

Archaeological studies have revealed use of rather sophisticated stormwater runoff systems in ancient cultures. For example, in Minoan Crete approximately 4000 years before present, cities such as Phaistos were designed to have storm drains and channels to collect precipitation runoff. At Cretan Knossos storm drains include stone lined structures large enough for a person to crawl through. Other examples of early civilizations with elements of stormwater drain systems include early people of Mainland Orkney such as Gurness and the Brough of Birsay in Scotland.

Chapter 7

Septic Drain Field

Septic drain fields are used to remove contaminants and impurities from the liquid that emerges from the septic tank. Another term for this is a **leach field** or leach drain. A septic tank, the septic drain field, and the associated piping compose a complete septic system. The septic drain field is effective for disposal of organic materials readily catabolized by a microbial ecosystem. The drain field typically consists of an arrangement of trenches containing perforated pipes and porous material (often gravel) covered by a layer of soil to prevent animals and surface runoff from reaching the wastewater distributed within those trenches. Primary design considerations are hydraulic for the volume of wastewater requiring disposal and catabolic for the long-term biochemical oxygen demand of that wastewater.



Septic tank and septic drain field.

Hydraulic design

Many health departments require a percolation test ("perc" test) to establish suitability of drain field soil to receive septic tank effluent. An engineer or licensed designer may be required to work with the local governing agency to design a system that conforms to these criteria.

Wastewater from toilets is assumed to contain bacteria and viruses capable of transmitting disease. Disinfection methods used prior to surface disposal of municipal sewage cannot be used with septic tanks because disinfection would prevent wastewater treatment by killing the septic tank and soil ecosystems catabolizing the putrescible contents of the wastewater. A properly functioning drain field holds and deactivates pathogens before they leave the drain field soil.

The goal of percolation testing is to ensure the soil is permeable enough for septic tank effluent to percolate away from the drain field, but fine grained enough to filter out pathogenic bacteria and viruses before they travel far enough to reach a water well or surface water supply. Coarse soils – sand and gravel – can transmit wastewater away from the drain field before pathogens are destroyed. Silt and clay effectively filter out pathogens but allow very limited wastewater flow rates. Percolation tests measure the rate at which clean water disperses through a disposal trench into the soil. Several factors may reduce observed percolation rates when the drain field receives anoxic septic tank effluent:

- Microbial colonies catabolizing soluble organic compounds from the septic tank effluent will adhere to soil particles and reduce the interstitial area available for water flow between soil particles. These colonies tend to form a low-permeability biofilm of gelatinous slime at the soil interface of the disposal trench.
- Insoluble particles small enough to be carried through the septic tank will accumulate at the soil interface of the disposal trench; non-biodegradable particles like mineral soil from laundry or vegetable washing, or bone and eggshell fragments from garbage disposals will remain to fill interstitial areas formerly available for water flow out of the trench.
- Cooking fats or petroleum products emulsified by detergents or dissolved by solvents can flow through prior to anaerobic liquifaction when septic tank volume is too small to offer adequate residence time, and may congeal as a hydrophobic layer on the soil interface of the disposal trench.
- Rising groundwater levels may reduce the available hydraulic head (or vertical distance) causing gravitational water flow away from the disposal trench. Effluent initially flowing downward from the disposal trench ultimately encounters groundwater or impermeable rock or clay requiring a directional shift to horizontal movement away from the drain field. A certain vertical distance is required between the effluent level in the disposal trench and the water level where the effluent is leaving the drain field for gravitational force to overcome viscous frictional forces resisting flow through porous soil. Effluent levels in the vicinity of the drain field will appear to rise toward the ground surface to preserve that vertical distance difference if groundwater levels surrounding the drain field approach the level of effluent in the disposal trench.
- Frozen ground may seasonally reduce the cross-sectional area available for flow or evaporation.

Dosing schedules or resting periods

A drain field may be designed to offer several separate disposal areas for effluent from a single septic tank. One area may be "rested" while effluent is routed to a different area. The nematode community in the resting drain field continues feeding on the accumulated biofilm and fats when the anaerobic septic tank effluent is no longer available. This natural cleansing process may improve hydraulic capacity of the field by increasing available interstitial area of the soil as accumulated organic material is oxidized. The resting improvement may approach, but is unlikely to exceed, the original clean water percolation rate of the site.

Catabolic design

Just as the septic tank is sized to support a community of anaerobic organisms capable of liquifying anticipated amounts of putresible materials in wastewater, the drain field should be sized to support a community of aerobic soil microorganisms capable of decomposing the anaerobic septic tank's effluent into aerobic water. Hydrogen sulfide odors or iron bacteria may be observed in nearby wells or surface waters when effluent has not been completely oxidized prior to reaching those areas. The biofilm on the walls of the drain field trenches will use atmospheric oxygen in the trenches to catabolize organic compounds in septic tank effluent. Groundwater flow is laminar in the aquifer soils surrounding the drain field. Septic tank effluent with soluble organic compounds passing through the biofilm forms a mounded lens atop groundwater underlying the drain field. Molecular diffusion controls mixing of soluble organic compounds into groundwater and transport of oxygen from underlying groundwater or the capillary fringe of the groundwater surface to micro-organisms capable of catabolizing dissolved organic compounds remaining in the effluent plume.

Biofilter

When a septic tank is used in combination with a biofilter, the height and catabolic area of the drain field may be reduced. This technology may allow higher density residential construction, minimal site disturbance, more usable land for trees, swimming pools, or gardens. With adequate routine maintenance it may reduce the chances of the drain field plugging up. The biofilter will not reduce the volume of liquid that must percolate into soil, but it may reduce the oxygen demand of organic materials in that liquid.

Inappropriate wastes

Septic drain field exposed by flood damage.

Septic tank and drain field microorganisms have very limited capability for catabolizing petroleum products and chlorinated solvents, and cannot remove dissolved metals; although some may sorb onto septic tank sludge or drain field soils, and concentrations may be diluted by other groundwater in the vicinity of the drain field. Cleaning formulations may reduce drain field efficiency. Laundry bleach may slow or stop microbial activity in the drain field, and sanitizing or deodorizing chemicals may have similar effects. Detergents, solvents and drain cleaners may transport emulsified, saponified or dissolved fats into the drain field before they can be catabolized to short-chain organic acids in the septic tank scum layer.

Chapter 8

Environmental Monitoring

Environmental monitoring describes the processes and activities that need to take place to characterise and monitor the quality of the environment. Environmental monitoring is used in the preparation of environmental impact assessments, as well as in many circumstances in which human activities carry a risk of harmful effects on the natural environment. All monitoring strategies and programmes have reasons and justifications which are often designed to establish the current status of an environment or to establish trends in environmental parameters. In all cases the results of monitoring will be reviewed, analysed statistically and published. The design of a monitoring programme must therefore have regard to the final use of the data before monitoring starts.

Design of Environmental monitoring programmes

Monitoring is of little use without a clear and unambiguous definition of the reasons for the monitoring and the objectives that it will satisfy. Almost all monitoring (except perhaps remote sensing) is in some part invasive of the environment under study and extensive and poorly planned monitoring carries a risk of damage to the environment. This may be a critical consideration in wilderness areas or when monitoring very rare organisms or those that are averse to human presence. Some monitoring techniques, such a gill netting fish to estimate populations, can be very damaging, at least to the local population and can also degrade public trust in scientists carrying out the monitoring.

Almost all mainstream environmentalism monitoring projects form part of an overall monitoring strategy or research field, and these field and strategies are themselves derived from the high levels objectives or aspirations of an organisation. Unless individual monitoring projects fit into a wider strategic framework, the results are unlikely to be published and the environmental understanding produced by the monitoring will be lost.

Parameters

Chemical

The range of chemical parameters that have the potential to affect any ecosystem is very large and in all monitoring programmes it is necessary to target a suite of parameters based on local knowledge and past practice for an initial review. The list can be expanded or reduced based on developing knowledge and the outcome of the initial surveys.

Freshwater environments have been extensively studied for many years and there is a robust understanding of the interactions between chemistry and the environment across much of the world. However, as new materials are developed and new pressures come to bear, revisions to monitoring programmes will be required. In the last 20 years acid rain, synthetic hormone analogues, halogenated hydrocarbons, greenhouse gases and many others have required changes to monitoring strategies.

Biological

In ecological monitoring, the monitoring strategy and effort is directed at the plants and animals in the environment under review and is specific to each individual study.

However in more generalised environmental monitoring,cz its very dangerous many animals act as robust indicators of the quality of the environment that they are experiencing or have experienced in the recent past. One of the most familiar examples is the monitoring of numbers of Salmonid fish such as Brown trout or Salmon in river systems and lakes to detect slow trends in adverse environmental effects. The steep decline in salmonid fish populations was one of the early indications of the problem that later became known as acid rain.

In recent years much more attention has been given to a more holistic approach in which the ecosystem health is assessed and used as the monitoring tool itself. It is this approach that underpins the monitoring protocols of the Water Framework Directive in the European Union.

Radiological

The radiation monitoring involves the measurement of radiation dose or radionuclide contamination for reasons related to the assessment or control of exposure to ionizing radiation or radioactive substances, and the interpretation of the results . The ‘measurement’ of dose often means the measurement of a dose equivalent quantity as a proxy (i.e. substitute) for a dose quantity that cannot be measured directly. Also, sampling may be involved as a preliminary step to measurement of the content of radionuclides in environmental media. The methodological and technical details of the design and operation of monitoring programmes and systems for different radionuclides, environmental media and types of facility are given in IAEA Safety Guide RS–G-1.8 and in IAEA Safety Report No. 64.

Microbiological

Bacteria and viruses are the most commonly monitored groups of microbiological organisms monitored and even these are only of great relevance where water in the aquatic environment is subsequently used as drinking water or where water contact recreation such as swimming or canoeing is practised.

Although pathogens are the primary focus of attention, the principal monitoring effort is almost always directed at much more common indicator species such as *Escherichia coli* supplemented by overall coliform bacteria counts. The rational behind this monitoring strategy is that most human pathogens originate from other humans via the sewage stream. Many sewage treatment plants have no sterilisation final stage and therefore discharge an effluent which, although having a clean appearance, still contains many millions of bacteria per litre, the majority of which are relatively harmless coliform bacteria. Counting the number of harmless (or less harmful) sewage bacteria allows a judgement to be made about the probability of significant numbers of pathogenic bacteria or viruses being present. Where *E. coli* or coliform levels exceed pre-set trigger values, more intensive monitoring including specific monitoring for pathogenic species is then initiated.

Populations

Monitoring strategies can produce misleading answers when relaying on counts of species or presence or absence of particular organisms if there is no regard to population size. Understanding the populations dynamics of an organism being monitored is critical.

As an example if presence or absence of a particular organism within a 10 km square is the measure adopted by a monitoring strategy, then a reduction of population from 10,000 per square to 10 per square will go unnoticed despite the very significant impact experienced by the organism.

Monitoring programmes

All scientifically reliable environmental monitoring is performed in line with a published programme. The programme may include the overall objectives of the organisation, references to the specific strategies that helps deliver the objective and details of specific projects or tasks within those strategies. However the key feature of any programme is the listing of what is being monitored and how that monitoring is to take place and the time-scale over which it should all happen. Typically, and often as an appendix, a monitoring programme with provide a table of locations, dates and sampling methods that are proposed and which, if undertaken in full, will deliver the published monitoring programme.

There are a number of commercial software packages which can assist with the implementation of the programme, monitor its progress and flag up inconsistencies or omissions but none of these can provide the key building block which is the programme itself.

Sampling methods

There are a wide range of sampling methods which depend on the type of environment, the material being sampled and the subsequent analysis of the sample.

At its simplest a sample can be filling a clean bottle with river water and submitting it for conventional chemical analysis. At the more complex end, sample data may be produced by complex electronic sensing devices taking sub-samples over fixed or variable time periods.

Grab samples

Grab samples are samples taken of a homogeneous material, usually water, in a single vessel. Filling a clean bottle with river water is a very common example. Grab samples provide a good snap-shot view of the quality of the sampled environment at the point of sampling and at the time of sampling. Without additional monitoring, the results cannot be extrapolated to other times or to other parts of the river, lake or ground-water.

In order to enable grab samples or rivers to be treated as representative, repeat transverse and longitudinal transect surveys taken at different times of day and times of year are required to establish that the grab-sample location is as representative as is reasonably possible. For large rivers such surveys should also have regard to the depth of the sample and how to best manage the sampling locations at times of flood and drought.

In lakes grab samples are relatively simple to take using depth samplers which can be lowered to a pre-determined depth and then closed trapping a fixed volume of water from the required depth. In all but the shallowest lakes, there are major changes in the chemical composition of lake water at different depths, especially during the summer months when many lakes stratify into a warm, well oxygenated upper layer (*epilimnion*) and a cool de-oxygenated lower layer *(hypolimnion*).

In the open seas marine environment grab samples can establish a wide range of base-line parameters such as salinity and a range of cation and anion concentrations. However, where changing conditions are an issue such as near river or sewage discharges, close to the effects of volcanism or close to areas of freshwater input from melting ice, a grab sample can only give a very partial answer when taken on its own.

Semi-continuous monitoring and continuous

There are a wide range of specialist sampling equipment available that can be programmed to take samples at fixed or variable time intervals or in response to an external trigger. For example a sampler can be programmed to start take samples of a river at 8 minute intervals when the rainfall intensity rises above 1 mm / hour. The trigger in this case may be a remote rain gauge communicating with the sampler by using cell phone or meteor burst technology. Samplers can also take individual discrete samples at each sampling occasion or bulk up samples into composite so that in the course of one day, such a sampler might produce 12 composite sample each composed of 6 sub-samples taken at 20 minute intervals.

Continuous or quasi-continuous monitoring involves having an automated analytical facility close to the environment being monitored so that results can, if required, be viewed in real time. Such systems are often established to protect important water supplies such as in the River Dee regulation system but may also be part of an overall monitoring strategy on large strategic rivers where early warning of potential problems is essential. Such systems routinely provide data on parameters such as pH, dissolved oxygen, conductivity, turbidity and colour but it is also possible to operate gas liquid chromatography with mass spectrometry technologies (GLC/MS) to examine a wide range of potential organic pollutants. In all examples of automated bank-side analysis there is a requirement for water to be pumped from the river into the monitoring station. Choosing a location for the pump inlet is equally as critical as deciding on the location for a river grab sample. The design of the pump and pipework also requires careful design to avoid artefacts being introduced through the action of pumping the water. Dissolved oxygen concentration is difficult to sustain through a pumped system and GLC/MS facilities can detect micro-organic contaminants from the pipework and glands.

Remote surveillance

Although on-site data collection using electronic measuring equipment is common-place, many monitoring programmes also use remote surveillance and remote access to data in real time. This requires the on-site monitoring equipment to be connected to a base station via either a telemetry network,land-line, cell phone network or other telemetry system such as Meteor burst. The advantage of remote surveillance is that many data feeds can come into a single base station for storing and analysis. It also enable trigger levels or alert levels to be said for individual monitoring sites and/or parameters so that immediate action can be initiated if a trigger level is exceeded. The use of remote surveillance also allows for the installation of very discrete monitoring equipment which can often be buried, camouflaged or tethered at depth in a lake or river with only a short whip aerial protruding. Use of such equipment tends to reduce vandalism and theft when monitoring in locations easily accessible by the public.

Remote sensing

Environmental remote sensing uses aircraft or satellites to monitor the environment using multi-channel sensors.

There are two kinds of remote sensing. Passive sensors detect natural radiation that is emitted or reflected by the object or surrounding area being observed. Reflected sunlight is the most common source of radiation measured by passive sensors and in environmental remote sensing, the sensors used are tuned to specific wavelengths from far infra-red through visible light frequencies through to far ultra violet. The volumes of data that can be collected are very large and require dedicated computational support . The output of data analysis from remote sensing are false colour images which differentiate small differences in the radiation characteristics of the environment being monitored. With a skilful operator choosing specific channels it is possible to amplify differences which are imperceptible to the human eye. In particular it is possible to discriminate subtle changes in chlorophyll a and chlorophyll b concentrations in plants and show areas of an environment with slightly different nutrient regimes.

Active remote sensing emits energy and uses a passive sensor to detect and measure the radiation that is reflected or backscattered from the target. LIDAR is often used to acquire information about the topography of an area, especially when the area is large and manual surveying would be prohibitively expensive or difficult.

Remote sensing makes it possible to collect data on dangerous or inaccessible areas. Remote sensing applications include monitoring deforestation in areas such as the Amazon Basin, the effects of climate change on glaciers and Arctic and Antarctic regions, and depth sounding of coastal and ocean depths.

Orbital platforms collect and transmit data from different parts of the electromagnetic spectrum, which in conjunction with larger scale aerial or ground-based sensing and analysis, provides information to monitor trends such as El Niño and other natural long and short term phenomena. Other uses include different areas of the earth sciences such as natural resource management, land use planning and conservation.

Bio-monitoring

The use of living organisms as monitoring tools has many advantages. Organisms living in the environment under study are constantly exposed to the physical, biological and chemical influences of that environment. Organisms that have a tendency to accumulate chemical species can often accumulate significant quantities of material from very low concentrations in the environment. Mosses have been used by many investigators to monitor heavy metal concentrations because of their tendency to selectively adsorb heavy metals.

Similarly, eels have been used to study halogenated organic chemicals, as these are adsorbed into the fatty deposits within the eel.

Other sampling methods

Ecological sampling requires careful planning to be representative and as non invasive as possible. For grasslands and other low growing habitats the use of a quadrat - a 1 metre square frame - is often used with the numbers and types of organisms growing within each quadrat area counted

Sediments and soils require specialist sampling tools to ensure that the material recovered is representative. Such samplers are frequently designed to recover a specified volume of material and may also be designed to recover the sediment or soil living biota as well such as the Ekman grab sampler.

Data interpretations

The interpretation of environmental data produced from a well designed monitoring programme is a large and complex topic addressed by many publications. Regrettably it is sometimes the case that scientists approach the analysis of results with a pre-conceived outcome in mind and use or misuse statistics to demonstrate that their own particular point of view is correct. This can be clearly seen in the debate about global warming controversy where, for example supporters argue that CO_2 levels have increased by 25% over the last one hundred years whilst opponents argue that CO_2 level have only risen by one percentage point from 3 to 4.

Many other scientific debates have less clear-cut positions, but statistics remains a tool that is equally easy to use or to misuse to demonstrate the lessons learnt from environmental monitoring

Environmental quality indices

Since the start of science based environmental monitoring, a number of quality indices have been devised to help classify and clarify the meaning of the considerable volumes of data involved. Stating that a river stretch is in "Class B" is likely to be much more informative than stating that this river stretch has a mean BOD of 4.2, a mean dissolved oxygen of 85%, etc. In the UK the Environment Agency uses a system called *GQA - General Quality Assessment* which classifies rivers into six quality bands—a, b, c, d, e and f—based on chemical criteria and on biological criteria.