Environmental engineering-I

UNIT-I PLANNING FOR WATER SUPPLY SYSTEM

Introduction to Environmental Engineering

What is Environmental Engineering?

It is the application of scientific and engineering principles to the environmental issues and their solutions. Generally, it includes supply of water, disposal and recycling of wastes, drainage of communities, control of water, soil, atmospheric pollution and environmental impacts of different activities carried out on earth.

The practice and application of engineering laws in compliance with the safety of environment and the code of ethics prescribed as standards. Some of those are as below

Environmental engineering is the application of science and engineering principles to improve the natural 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. It 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.

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.[7] 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.[8]

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."[9]

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. 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.[10] 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.

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The practice of environmental assessment was initiated 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. [10]

**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**

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.
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.[71]

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

Water supply and sanitation in India
**Water supply and sanitation in India** continue to be inadequate, despite longstanding efforts by the various levels of government and communities at improving coverage. The level of investment in water and sanitation, albeit low by international standards, has increased during the 2000s. Access has also increased significantly. For example, in 1980 rural sanitation coverage was estimated at 1% and reached 21% in 2008. Also, the share of Indians with access to improved sources of water has increased significantly from 72% in 1990 to 88% in 2008. At the same time, local government institutions in charge of operating and maintaining the infrastructure are seen as weak and lack the financial resources to carry out their functions. In addition, no major city in India is known to have a continuous water supply and an estimated 72% of Indians still lack access to improved sanitation facilities.

A number of innovative approaches to improve water supply and sanitation have been tested in India, in particular in the early 2000s. These include demand-driven approaches in rural water supply since 1999, community-led total sanitation, a public-private partnerships to improve the continuity of urban water supply in Karnataka, and the use of micro-credit to women in order to improve access to water.

In 2008, 88% of the population in India had access to an improved water source, but only 31% had access to improved sanitation. In rural areas, where 72% of India’s population lives, the respective shares are 84% for water and only 21% for sanitation. In urban areas, 96% had access to an improved water source and 54% to improved sanitation. Access has improved substantially since 1990 when it was estimated to stand at 72% for water and 18% for sanitation.

According to Indian norms, access to improved water supply exists if at least 40 liters/capita/day of safe drinking water are provided within a distance of 1.6 km or 100 meter of elevation difference, to be relaxed as per field conditions. There should be at least one pump per 250 persons.

**Service quality**

Water and sanitation service quality in India is generally poor, although there has been some limited progress concerning continuity of supply in urban areas and access to sanitation in rural areas.

**Water supply**

Four girls carrying water in India.
**Challenges.** None of the 35 Indian cities with a population of more than one million distribute water for more than a few hours per day, despite generally sufficient infrastructure. Owing to inadequate pressure people struggle to collect water even when it is available. According to the World Bank, none have performance indicators that compare with average international standards.\[8\] A 2007 study by the Asian Development Bank showed that in 20 cities the average duration of supply was only 4.3 hours per day. No city had continuous supply. The longest duration of supply was 12 hours per day in Chandigarh, and the lowest was 0.3 hours per day in Rajkot.\[3\] In Delhi residents receive water only a few hours per day because of inadequate management of the distribution system. This results in contaminated water and forces households to complement a deficient public water service at prohibitive 'coping' costs; the poor suffer most from this situation. For example, according to a 1996 survey households in Delhi spent an average of 2,182 (US$48.4) per year in time and money to cope with poor service levels.\[9\] This is more than three times as much as the 2001 water bill of about US$18 per year of a Delhi household that uses 20 cubic meters per month.

**Achievements.** Jamshedpur, a city in Jharkhand with 573,000 inhabitants, provided 25% of its residents with continuous water supply in 2009.\[10\] Navi Mumbai, a planned city with more than 1m inhabitants, has achieved continuous supply for about half its population as of January 2009.\[11\] Badlapur, another city in the Mumbai Conurbation with a population of 140,000, has achieved continuous supply in 3 out of 10 operating zones, covering 30% of its population.\[12\] Thiruvananthapuram, the capital of Kerala state with a population of 745,000 in 2001, is probably the largest Indian city that enjoys continuous water supply.\[13\]

**Sanitation**

Most Indians depend on on-site sanitation facilities. Recently, access to on-site sanitation have increased in both rural and urban areas. In rural areas, total sanitation has been successful (see below). In urban areas, a good practice is the Slum Sanitation Program in Mumbai that has provided access to sanitation for a quarter million slum dwellers.\[14\] Sewerage, where available, is often in a bad state. In Delhi the sewerage network has lacked maintenance over the years and overflow of raw sewage in open drains is common, due to blockage, settlements and inadequate pumping capacities. The capacity of the 17 existing wastewater treatment plants in Delhi is adequate to cater a daily production of waste water of less than 50% of the drinking water produced.\[8\] Of the 2.5 Billion people in the world that defecate openly, some 665 million live in India. This is of greater concern as 88% of deaths from diarrhea occur because of unsafe water, inadequate sanitation and poor hygiene.\[15\][16][17][18]

**Environment**
Millions depend on the polluted Ganges river.

See also: Environment of India

As of 2003, it was estimated that only 27% of India's wastewater was being treated, with the remainder flowing into rivers, canals, groundwater or the sea. For example, the sacred Ganges river is infested with diseases and in some places "the Ganges becomes black and septic. Corpses, of semi-cremated adults or enshrouded babies, drift slowly by." NewsWeek describes Delhi's sacred Yamuna River as "a putrid ribbon of black sludge" where fecal bacteria is 10,000 over safety limits despite a 15-year program to address the problem. Cholera epidemics are not unknown.

Health impact

The lack of adequate sanitation and safe water has significant negative health impacts including diarrhea, referred to by travelers as the "Delhi Belly", and experienced by about 10 million visitors annually. While most visitors to India recover quickly and otherwise receive proper care, the World Health Organisation estimated that around 700,000 Indians die each year from diarrhea. The dismal working conditions of sewer workers are another concern. A survey of the working conditions of sewage workers in Delhi showed that most of them suffer from chronic diseases, respiratory problems, skin disorders, allergies, headaches and eye infections.

Water supply and water resources

Depleting ground water table and deteriorating ground water quality are threatening the sustainability of both urban and rural water supply in many parts of India. The supply of cities that depend on surface water is threatened by pollution, increasing water scarcity and conflicts among users. For example, Bangalore depends to a large extent on water pumped since 1974 from the Kaveri river, whose waters are disputed between the states of Karnataka and Tamil Nadu. As in other Indian cities, the response to water scarcity is to transfer more water over large distances at high costs. In the case of Bangalore, the 3,384 crore (US$751.2 million) Kaveri Stage IV project, Phase II, includes the supply of 500,000 cubic meter of water per day over a distance of 100 km, thus increasing the city's supply by two thirds.

Responsibility for water supply and sanitation

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Water supply and sanitation is a State responsibility under the Indian Constitution. States may give the responsibility to the Panchayati Raj Institutions (PRI) in rural areas or municipalities in urban areas, called Urban Local Bodies (ULB). At present, states generally plan, design and execute water supply schemes (and often operate them) through their State Departments (of Public Health Engineering or Rural Development Engineering) or State Water Boards.

Highly centralized decision-making and approvals at the state level, which are characteristic of the Indian civil service, affect the management of water supply and sanitation services. For example, according to the World Bank in the state of Punjab the process of approving designs is centralized with even minor technical approvals reaching the office of chief engineers. A majority of decisions are made in a very centralized manner at the headquarters. In 1993 the Indian constitution and relevant state legislations were amended in order to decentralize certain responsibilities, including water supply and sanitation, to municipalities. Since the assignment of responsibilities to municipalities is a state responsibility, different states have followed different approaches. According to a Planning Commission report of 2003 there is a trend to decentralize capital investment to engineering departments at the district level and operation and maintenance to district and gram panchayat levels.

Policy and regulation

The responsibility for water supply and sanitation at the central and state level is shared by various Ministries. At the central level, The Ministry of Rural Development is responsible for rural water supply through its Department of Drinking Water Supply (DDWS) and the Ministry of Housing and Urban Poverty Alleviation is responsible for urban water supply. However, except for the National Capital Territory of Delhi and other Union Territories, the central Ministries only have an advisory capacity and a very limited role in funding. Sector policy thus is a prerogative of state governments.

Service provision

Urban areas. Institutional arrangements for water supply and sanitation in Indian cities vary greatly. Typically, a state-level agency is in charge of planning and investment, while the local government (Urban Local Bodies) is in charge of operation and maintenance. Some of the largest cities have created municipal water and sanitation utilities that are legally and financially separated from the local government. However, these utilities remain weak in terms of financial capacity. In spite of decentralization, ULBs remain dependent on capital subsidies from state governments. Tariffs are also set by state governments, which often even subsidize operating costs. Furthermore, when no separate utility exists there is no separation of accounts for different activities within a municipality. Some states and cities have non-typical institutional arrangements. For example, in Rajasthan the sector is more centralized and the state government is also in charge of operation and maintenance, while in Mumbai the sector is more decentralized and local government is also in charge of planning and investment.

Private sector participation. The private sector plays a limited, albeit recently increasing role in operating and maintaining urban water systems on behalf of ULBs. For example, the Jamshedpur Utilities & Services Company (Jusco), a subsidiary of Tata Steel, has a lease contract for
Jamshedpur (Jharkhand), a management contract in Haldia (West Bengal), another contract in Mysore (Karnataka) and since 2007 a contract for the reduction of non-revenue water in parts of Bhopal (Madhya Pradesh). The French water company Veolia won a management contract in three cities in Karnataka in 2005. In 2002 a consortium including Thames Water won a pilot contract covering 40,000 households to reduce non-revenue water in parts of Bangalore, funded by the Japan Bank for International Cooperation. The contract was scaled up in 2004. The Cypriot company Hydro-Comp, together with two Indian companies, won a 10-year concession contract for the city of Latur City (Maharashtra) in 2007 and an operator-consultant contract in Madurai (Tamil Nadu). Furthermore, the private Indian infrastructure development company SPML is engaged in Build-Operate-Transfer (BOT) projects, such as a bulk water supply project for Bhiwandi (Maharashtra).

**Rural areas.** There are about 100,000 rural water supply systems in India. At least in some states responsibility for service provision is in the process of being partially transferred from State Water Boards and district governments to Panchayati Raj Institutions (PRI) at the block or village level (there were about 604 districts and 256,000 villages in India in 2002, according to Subdivisions of India. Blocks are an intermediate level between districts and villages). Where this transfer has been initiated, it seems to be more advanced for single-village water schemes than for more complex multi-village water schemes. Despite their professed role Panchayati Raj Institutions currently play only a limited role in provision of rural water supply and sanitation. There has been limited success in implementing decentralization, partly due to low priority by some state governments. Rural sanitation is typically provided by households themselves in the form of latrines.

**Innovative approaches**

A number of innovative approaches to improve water supply and sanitation have been tested in India, in particular in the early 2000s. These include community-led total sanitation, demand-driven approaches in rural water supply, a public-private partnerships to improve the continuity of urban water supply in Karnataka, and the use of micro-credit to women in order to improve access to water.

**Community-led total sanitation**

In 1999 a demand-driven and people-centered sanitation program was initiated under the name Total Sanitation Campaign (TSC) or Community-led total sanitation. It evolved from the limited achievements of the first structured programme for rural sanitation in India, the Central Rural Sanitation Programme, which had minimal community participation. Community-led total sanitation is not focused on building infrastructure, but on preventing open defecation through peer pressure and shame. In Maharashtra where the program started more than 2000 Gram Panchayats have achieved "open defecation free" status. Villages that achieve this status receive monetary rewards and high publicity under a program called Nirmal Gram Puraskar.

**Demand-driven approaches in rural water supply**

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Most rural water supply schemes in India use a centralized, supply-driven approach, i.e. a government institution designs a project and has it built with little community consultation and no capacity building for the community, often requiring no water fees to be paid for its subsequent operation. Since 2002 the Government of India has rolled out at the national level a program to change the way in which water and sanitation services are supported in rural areas. The program, called Swajaldhara, decentralizes service delivery responsibility to rural local governments and user groups. Under the new approach communities are being consulted and trained, and users agree up-front to pay a tariff that is set at a level sufficiently high to cover operation and maintenance costs. It also includes measures to promote sanitation and to improve hygiene behavior. The national program follows a pilot program launched in 1999.[39]

According to a 2008 World Bank study in 10 Indian states, Swajaldhara results in lower capital costs, lower administrative costs and better service quality compared to the supply-driven approach. In particular, the study found that the average full cost of supply-driven schemes is 38 (US$0.8) per cubic meter, while it is only 26 (US$0.6) per cubic meter for demand-driven schemes. These costs include capital, operation and maintenance costs, administrative costs and coping costs incurred by users of malfunctioning systems. Coping costs include traveling long distances to obtain water, standing in long queues, storing water and repairing failed systems. Among the surveyed systems that were built using supply-driven approach system breakdowns were common, the quantity and quality of water supply were less than foreseen in designs, and 30% of households did not get daily supply in summer. The poor functioning of one system sometimes leads to the construction of another system, so that about 30% of households surveyed were served by several systems. Currently only about 10% of rural water schemes built in India use a demand-driven approach. Since water users have to pay lower or no tariffs under the supply-driven approach, this discourages them to opt for a demand-driven approach, even if the likelihood of the systems operating on a sustainable basis is higher under a demand-driven approach.[40]

Achieving continuous water supply with the help of a private operator in Karnataka

In the cities of Hubli, Belgaum and Gulbarga in the state of Karnataka, the private operator Veolia increased water supply from once every 2–15 days for 1–2 hours, to 24 hours per day for 180,000 people (12% of the population of the 3 cities) within 2 years (2006–2008). This was achieved by carefully selecting and ring-fencing demonstration zones (one in each city), renovating the distribution network, installing meters, introducing a well-functioning commercial system, and effective grass-roots social intermediation by an NGO, all without increasing the amount of bulk water supplied. The project, known by its acronym as KUWASIP (Karnataka Urban Water Sector Improvement Project), was supported by a US$39.5 million loan from the World Bank. It constitutes a milestone for India, where no large city so far has achieved continuous water supply. The project is expected to be scaled-up to cover the entire area of the three cities.[30][31][32]

Micro-credit for water connections in Tamil Nadu

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In Tiruchirapalli in Tamil Nadu, the NGO Gramalaya, established in 1987, and women self-help groups promote access to water supply and sanitation by the poor through micro-credit. Among the benefits are that women can spend more time with their children, earn additional income, and sell surplus water to neighbors. This money contributes to her repayment of the WaterCredit loan. The initiative is supported by the US-based non-profit Water Partners International.\[41\]

The Jamshedpur Utilities and Services Company

The Jamshedpur Utilities and Services Company (JUSCO) provides water and sanitation services in Jamshedpur, a major industrial center in East India that is home to Tata Steel. Until 2004 a division of Tata Steel provided water to the city’s residents. However, service quality was poor with intermittent supply, high water losses and no metering.\[10\] To improve this situation and to establish good practices that could be replicated in other Indian cities, JUSCO was set up as a wholly owned subsidiary of Tata Steel in 2004.

Efficiency and service quality improved substantially over the following years. The level on non-revenue water decreased from an estimated 36% in 2005 to 10% in 2009; one quarter of residents received continuous water supply (although the average supply remained at only 7 hours per day) in 2009; the share of metered connections increased from 2% in 2007 to 26% in 2009; the number of customers increased; and the company recovered its operating costs plus a portion of capital costs. Identifying and legalizing illegal connections was an important element in the reduction of non-revenue water. The utility prides itself today of the good drinking water quality provided and encourages its customers to drink from the tap. The utility also operates a wastewater treatment plant that meets discharge standards. The private utility pays salaries that are higher than civil service salaries and conducts extensive training programs for its staff. It has also installed a modern system to track and resolve customer complaints. Furthermore, it conducts independent annual customer satisfaction surveys. JUSCO’s vision is to be the preferred provider of water supply and other urban services throughout India. Together with Ranhill Malaysia it won a 25-year concession contract for providing the water supply in Haldia City, West Bengal.\[10\]

Efficiency

There are only limited data on the operating efficiency of utilities in India, and even fewer data on the efficiency of investments.

Concerning operating efficiency, a study of 20 cities by the Jawaharlal Nehru National Urban Renewal Mission with the support of the Asian Development Bank showed an average level of non-revenue water (NRW) of 32%. However, 5 out of the 20 cities did not provide any data. For those that provided data there probably is a large margin of error, since only 25% of connections are metered, which makes it very difficult to estimate non-revenue water. Also, three utilities show NRW levels of less than 20%, two of which have practically no metering, which indicates that the numbers are not reliable and actual values are likely to be higher.\[3\] In Delhi, which was not included in the ADB study, non-revenue water stood at 53% and there were about 20 employees per 1000 connections. Furthermore, only 70% of revenue billed was actually collected.\[42\]
Concerning labor productivity, the 20 utilities in the sample had on average 7.4 employees per 1,000 connections, which is much higher than the estimated level for an efficient utility. A survey of a larger sample of Indian utilities showed an average ratio of 10.9 employees per 1,000 connections.

**Tariffs, cost recovery and subsidies**

Water and sewer tariffs in India are low in both urban and rural areas. In urban areas they were set at the equivalent of about US$0.10 per cubic meter in 2007 and recovered about 60% of operating and maintenance costs, with large differences between cities. Some cities such as Kolkata do not bill residential users at all. In rural areas the level of cost recovery often is even lower than in urban areas and was estimated at only 20% in rural Punjab. Subsidies were estimated at US$1.1 billion per year in the mid-1990s, accounting to 4% of all government subsidies in India. 70% of those benefiting from the subsidies are not poor.

**Urban areas**

**Metering.** Water metering is the precondition for billing water users on the basis of volume consumed. According to a 1999 survey of 300 cities about 62% of urban water customers in metropolitan areas and 50% in smaller cities are metered (average 55%). However, meters often do not work so that many "metered" customers are charged flat rates. Bangalore and Pune are among the few Indian cities that meter all their customers. Many other cities have no metering at all or meter only commercial customers. Users of standposts receive water free of charge. A 2007 study of 20 cities by the Jawaharlal Nehru National Urban Renewal Mission with the support of the Asian Development Bank (ADB) showed that only 25% of customers of these utilities were metered. Most other customers paid a flat tariff independent of consumption. Some utilities, such as the one serving Kolkata, actually do not bill residential users at all.

**Tariff levels.** According to the same ADB study the average tariff for all customers - including industrial, commercial and public customers - is 4.9 (US$0.1) per cubic meter. According to a 2007 global water tariff survey by the OECD the residential water tariff for a consumption of 15 m³ was equivalent to US$0.15 per m³ in Bangalore, US$0.12 per m³ in Calcutta, US$0.11 per m³ in New Delhi and US$0.09 per m³ in Mumbai. Only Bangalore had a sewer tariff of US$0.02 per m³. The other three cities did not charge for sewerage, although the better-off tend to be the ones with access to sewers.

**Tariff structure.** The tariff for customers that are effectively metered is typically a uniform linear tariff, although some cities apply increasing-block tariffs.

**Affordability.** Urban water tariffs were highly affordable according to data from the year 2000. A family of five living on the poverty line which uses 20 cubic meter of water per month would spend less than 1.2% of its budget on its water bill if it had a water meter. If it did not have a water meter and was charged a flat rate, it would pay 2.0% of its budget. This percentage lies below the often used affordability threshold of 5%. However, at that time the average metered tariff was estimated at only US$0.03 per m³, or less than three times what it was estimated to be.
in 2007. Apparently no more up-to-date estimates on the share of the average water bill in the budget of the poor are available.

**Cost recovery.** According to a 2007 study of 20 cities the average rate of cost recovery for operating and maintenance costs of utilities in these cities was 60%. Seven of the 20 utilities generated a cash surplus to partially finance investments. Chennai generated the highest relative surplus. The lowest cost recovery ratio was found in Indore in Madhya Pradesh, which recovered less than 20% of its operating and maintenance costs.[3]

**Delhi example.** In Delhi revenues were just sufficient to cover about 60% of operating costs of the city’s utility in 2004; maintenance has, as a result, been minimal. In the past, the Delhi utility has relied heavily on government financial support for recurrent and capital expenditures in the magnitude of 3 billion (US$66.6 million) per year and 7 billion (US$155.4 million) respectively. As financial support for both capital and recurrent expenditures has been passed on as loans by the Government of the National Capital Territory of Delhi, the utility’s balance sheet is loaded with a huge debt totaling about 50 billion (US$1.1 billion) that it is unlikely to be able to service. Accounts receivable represent more than 12 months of billing, part of it being non recoverable.[8] The average tariff was estimated at US$0.074/m³ in 2001, compared to production costs of US$0.085/m³, the latter probably being a very conservative estimate that does not take into account capital costs.[46]

**Challenges faced in attempting to increase tariffs.** Even if users are willing to pay more for better services, political interests often prevent tariffs from being increased even to a small extent. An example is the city of Jabalpur where the central government and the state government financed a 130 million (US$2.9 million) water supply project from 2000-2004 to be operated by the Jabalpur Municipal Corporation, an entity that collected only less than half of its operational costs in revenues even before this major investment. Even so the municipal corporation initially refused to increase tariffs. Only following pressure from the state government it reluctantly agreed to increase commercial tariffs, but not residential tariffs. [47]

**Rural areas**

Cost recovery in rural areas is low and a majority of the rural water systems are defunct for lack of maintenance. Some state governments subsidize rural water systems, but funds are scarce and insufficient.[48] In rural areas in Punjab, operation and maintenance cost recovery is only about 20%. On one hand, expenditures are high due to high salary levels, high power tariff and a high number of operating staff. On the other hand, revenue is paid only by the 10% of the households who have private connections. Those drawing water from public stand posts do not pay any water charges at all, although the official tariff for public stand post users is 15 (US$0.3) per month per household.[26]

**Subsidies and targeting of subsidies**

There are no accurate recent estimates of the level of subsidies for water and sanitation in India. It has been estimated that transfers to the water sector in India amounted to 5,470.8 crore (US$1.2 billion) per year in the mid-1990s, accounting for 4% of all government subsidies in.
India. About 98% of this subsidy is said to come from State rather than Central budgets.\textsuperscript{[49]} This figure may only cover recurrent cost subsidies and not investment subsidies, which are even higher (see below). There is little targeting of subsidies. According to the World Bank, 70\% of those benefiting from subsidies for public water supply are not poor, while 40\% of the poor are excluded because they do not have access to public water services.\textsuperscript{[45]}

### Investment and financing

Investment in urban water supply and sanitation has increased during the first decade of the 21st century, not least thanks to increased central government grants made available under Jawaharlal Nehru National Urban Renewal Mission alongside with loans from the Housing and Urban Development Corporation.

#### Investment

The Eleventh Five-Year Plan (2007–2012) foresees investments of 127,025 crore (US$28.2 billion) for urban water supply and sanitation, including urban (stormwater) drainage and solid waste management.\textsuperscript{[5]}

#### Financing

55\% of the investments foreseen under the 11th Plan are to be financed by the central government, 28\% by state governments, 8\% by "institutional financing" such as HUDCO, 8\% by external agencies and 1.5\% by the private sector. Local governments are not expected to contribute to the investments. The volume of investments is expected to double to reach 0.7\% of GDP. Also, it implies a shift in financing from state governments to the central government.\textsuperscript{[5]}

During the 9th Plan only 24\% of investments were financed by the central government and 76\% by state governments. Central government financing was heavily focused on water supply in rural areas.\textsuperscript{[50]}

#### Institutions

State Financing Corporations (SFC) play an important role in making recommendations regarding the allocation of state tax revenues between states and municipalities, criteria for grants, and measures to improve the financial position of municipalities. According to the Planning Commission, SFCs are in some cases not sufficiently transparent and/or competent, have high transactions costs, and their recommendations are sometimes not being implemented.\textsuperscript{[51]} An important source of financing are loans from Housing and Urban Development Corporation Ltd (HUDCO), a Central government financial undertaking. HUDCO loans to municipal corporations need to be guaranteed by state governments. HUDCO also on-lends loans from foreign aid, including Japanese aid, to states. The Jawaharlal Nehru National Urban Renewal Mission initiated in 2005 also plays an increasingly important role in financing urban water supply and sanitation through central government grants.
The current system of financing water supply and sanitation is fragmented through a number of different national and state programs. This results in simultaneous implementation with different and conflicting rules in neighboring areas. In rural areas different programs undermine each other, adversely affecting demand driven approaches requiring cost sharing by users.

**External cooperation**

In absolute terms India receives almost twice as much development assistance for water, sanitation and water resources management as any other country, according to data from the Organisation for Economic Co-operation and Development. India accounts for 13 per cent of commitments in global water aid for 2006-07, receiving an annual average of about US$830 million (€620 million), more than double the amount provided to China. India's biggest water and sanitation donor is Japan, which provided US$635 million, followed by the World Bank with US$130 million. The annual average for 2004-06, however, was about half as much at US$448 million, of which Japan provided US$293 million and the World Bank US$87 million. The Asian Development Bank and Germany are other important external partners in water supply and sanitation.

In 2003 the Indian government decided it would only accept bilateral aid from five countries (the United Kingdom, the United States, Russia, Germany and Japan). A further 22 bilateral donors were asked to channel aid through nongovernmental organisations, United Nations agencies or multilateral institutions such as the European Union, the Asian Development Bank or the World Bank.

**Asian Development Bank**

India has increased its loans from the Asian Development Bank (ADB) since 2005 after the introduction of new financing modalities, such as the multitranche financing facility (MFF) which features a framework agreement with the national government under which financing is provided in flexible tranches for subprojects that meet established selection criteria. In 2008 four MFFs for urban development investment programs were under way in North Karnataka (US$862 million), Jammu and Kashmir (US$1,260 million), Rajasthan (US$450 million), and Uttarakhand (US$1,589 million). Included in these MFFs are major investments for the development of urban water supply and sanitation services.

**Germany**

Germany supports access to water and sanitation in India through financial cooperation by KfW development bank and technical cooperation by GTZ. Since the early 1990s both institutions have supported watershed management in rural Maharashtra, using a participatory approach first piloted by the Social Center in Ahmednagar and that constituted a fundamental break with the previous top-down, technical approach to watershed management that had yielded little results. The involvement of women in decision-making is an essential part of the project. While the benefits are mostly in terms of increased agricultural production, the project also increases availability of water resources for rural water supply. In addition, GTZ actively
supports the introduction of ecological sanitation concepts in India, including community toilets and decentralized wastewater systems for schools as well as small and medium enterprises. Many of these systems produce biogas from wastewater, provide fertilizer and irrigation water.\(^\text{[59]}\)

**Japan**

As India's largest donor in the sector the Japan International Cooperation Agency (JICA) finances a multitude of projects with a focus on capital-intensive urban water supply and sanitation projects, often involving follow-up projects in the same locations.

**Current projects.** Projects approved between 2006 and 2009 include the Guwahati Water Supply Project (Phases I and II) in Assam, the Kerala Water Supply Project (Phased II and III), the Hogenakkal Water Supply and Fluorosis Mitigation Project (Phases I and II) in Tamil Nadu, the Goa Water Supply and Sewerage Project, the Agra Water Supply Project, the Amritsar Sewerage Project in Punjab, the Orissa Integrated Sanitation Improvement Project, and the Bangalore Water Supply and Sewerage Project (Phase II).\(^\text{[60]}\)

**Evaluation of past projects.** An ex-post evaluation of one large program, the Urban Water Supply and Sanitation Improvement Program, showed that "some 60%-70% of the goals were achieved" and that "results were moderate". The program was implemented by the Housing and Urban Development Corporation, Ltd. (HUDCO) from 1996 to 2003 in 26 cities. The evaluation says that "state government plans were not based on sufficient demand research, including the research for residents’ willingness to pay for services", so that demand for connections was overestimated. Also fees (water tariffs) were rarely increased despite recommendations to increase them. The evaluation concludes that "HUDCO was not able to make significant contributions to the effectiveness, sustainability, or overall quality of individual projects. One of the reasons that not much attention was given to this problem is probably that there was little risk of default on the loans thanks to state government guarantees."\(^\text{[61]}\)

**World Bank**

**Current projects.** The World Bank finances a number of projects in urban and rural areas that are fully or partly dedicated to water supply and sanitation.\(^\text{[62]}\) In urban areas the World Bank supports the Andhra Pradesh Municipal Development Project (approved in 2009, US$300 million loan), the Karnataka Municipal Reform Project (approved in 2006, US$216 million loan), the Third Tamil Nadu Urban Development Project (approved in 2005, US$300 million loan) and the Karnataka Urban Water Sector Improvement Project (approved in 2004, US$39.5 million loan). In rural areas it supports the Andhra Pradesh Rural Water Supply and Sanitation (US$150 million loan, approved in 2009), the Second Karnataka Rural Water Supply and Sanitation Project (approved in 2001, US$151.6 million loan), the Uttarakhal Rural Water Supply and Sanitation Project (approved in 2006, US$120 million loan) and the Punjab Rural Water Supply and Sanitation Project (approved in 2006, US$154 million loan).

**Evaluation of past projects.** A study by the World Bank's independent evaluation department evaluated the impact of the World Bank-supported interventions in the provision of urban water
supply and wastewater services in Mumbai between 1973 and 1990. It concluded that water supply and sewerage planning, construction and operations in Bombay posed daunting challenges to those who planned and implemented the investment program. At the outset, there was a huge backlog of unmet demand because of underinvestment. Population and economic growth accelerated in the following decades and the proportion of the poor increased as did the slums which they occupied. The intended impacts of the program have not been realized. Shortcomings include that "water is not safe to drink; water service, especially to the poor, is difficult to access and is provided at inconvenient hours of the day; industrial water needs are not fully met; sanitary facilities are too few in number and often unusable; and urban drains, creeks and coastal waters are polluted with sanitary and industrial wastes."

1. (a) Name any four important waterborne diseases. What are the sources, symptoms, significance and methods of prevention and (or) control of these diseases.  
   (b) Give the Process flow diagram of a typical Protected Water Supply Scheme for a Town of population 1 lakh using River Water as its source. [8+8]

2. (a) Distinguish between a ‘Reservoir Intake’ and a ‘Portable Intake’.  
   (b) Discuss the Criteria for ‘Location of Intakes’. [16]

3. Discuss in detail, with the help of sketches, the role of following design considerations while designing a Settling/Sedimentation system like a clarifier. 
   (a) Surface loading  
   (b) Detention Time  
   (c) Shape of the Reactor  
   (d) Depth  
   (e) Types of Sedimentation. [16]

4. (a) Describe the working of a Pressure Filter with the help of a sketch.  
   (b) A private estate uses a Pressure filter to treat 500 cu.m./day of turbid water. If filter operates from 04.00 pm to 08.00 am every day, find the size of pressure filter. Also find the approximate HP of the pump that supplies water to pressure filter under pressure. [16]

5. (a) Explain the general methods of distribution of water employed in municipal water supply schemes.  
   (b) Illustrate with sketch the Grid iron type of layout of pipe system in distributing water, and compare its merits and demerits. [6+10]

6. (a) Name the two factors used as criteria for selection of pipe diameter and slope in design of sewer.  
   (b) Calculate the ratio of discharge of a sewer when flowing at full depth to that when flowing at 3/4 depth. [8+8]

7. Write short notes on the following” 
   (a) Humus tank  
   (b) Contact bed  
   (c) Dunbar filter  
   (d) Bio-filter. [4+4+4+4]

8. (a) Design a septic tank for 100 users in a hostel. Assume per capita water demand as 150 litres.  
   (b) Write a note on soak pit. [8+8]

**Population Forecasting Methods**

Population is one of the most important factors for design of the water systems, so it should be estimated, so as to know the increasing demand and ensure continuous supply to them.

Population data is obtained by previous records and the rate of increase is found out and this used for further analysis, which
may be by using the methods described below

1. **Arithmetic growth method**
2. **Geometric growth method**
3. **Curvilinear method**
4. **Logistic method**
5. **Decline growth method**
6. **Ratio growth**

---

**Arithmetic growth method:**

It is based on the assumption that the rate of growth of population is constant. It means that the each year population increase by the same increment.

Mathematically;

\[
\frac{dp}{dt} = Ka
\]

Where,

\[
\frac{dp}{dt} \text{ is the rate of change of population}
\]

\[
Ka = \text{the constant arithmetic increment}
\]

Ka can be determined by finding the slope of the graph of population against time. The population in the future is thus estimated.

---

**Geometric method:**

It is based on the hypothesis that rate of change of population is proportional to the population. According to this, method it is assumed that the rate of increase of population growth in a community is proportional to the present population.

Mathematically:

\[
\frac{dP}{dt} \propto P \Rightarrow \frac{dp}{dt} = K_g \text{ \ where } K_g = \text{Geometric Growth constant.}
\]

If \( P \) is the population at any time \( t \) and \( \frac{dp}{dt} \)
is the population at time \( t \) then

\[
\int P \frac{dp}{p} = K \quad \int \frac{t}{t_0} dt = \ln \left( \frac{P}{P_0} \right) = K \quad g
\]

\[
\Rightarrow \ln \left( \frac{P}{P_0} \right) = K \quad \Delta t
\]

\[
\Rightarrow \left( \frac{P}{P_0} \right) = (e)^K \quad \Delta t \quad \text{and} \quad P = P_0 (e)^K \quad \Delta t
\]

This method gives somewhat larger value as compared to arithmetic method and can be used for new cities with rapid growth. In normal practice, arithmetic and geometric growth average is taken.

**Curvilinear method:**

In this it is assumed that the population of a city will grow, in the same manner as in other cities in the past. This similarity between the cities includes geographical proximity, similarity of economic base, access to similar transportation system etc. **In practice it is difficult to find similar cities.**

**Logistic method:**

When the growth rate of population due to birth, death and migration are under normal situation and not subjected to extraordinary changes due to unusual situation like war, epidemics earthquakes and refugees etc. Then this method is used:

According to this method

\[
P = \frac{P_{sat}}{(1 + e^{a+bt})}
\]

where \( P_{sat} \) is the saturation population, of the community and \( a, b \) are constants.

\( P_{sat}, a \) and \( b \) can be determined from three successive census populations and the equations are

\[
P_{sat} = 2 P_1 P_2 - P_1 P_2 (P_0 + P_2)^2 (P P_1 P_2)
\]

**Decline growth method:**

This method like, logistic, assumes that the city has some limiting saturation population and that its rate of growth is a function of population deficit;

**Ratio method:**
Ratio method of forecasting is based on the assumption that the population of a certain area or a city will increase in the same manner to a larger entity like a province, or a country. It requires calculation of ratio of locals to required population in a series of census years.

Projection of the trend line using any of the technique and application of projected ratio to the estimated required population of projected ratio to the estimated required population in the year of interest. This method of forecasting does not take into account some special calculations in certain area but have the following advantages.

Consumption of water

Uses

1. Domestic use
2. Commercial use
3. Public use
4. Loss and waste

Domestic use of water:

Advertisements

Domestic uses of water include the consumption of water for drinking, washing, cooking, toilets, livestock etc. the domestic average use per capita per day is 50 – 90 gallons (70 – 380 liters per capita per day). This use is increasing by 0.5% - 1.0% per year and at this time comprises 50% of all the uses of water.

Water uses are for drinking, cooking, meeting of sanitary needs in houses and hotels, irrigating lawns etc. Residential water use rates fluctuate regularly.

Average daily winter consumption is less than annual daily average, whereas summer consumption averages are greater. Similarly, peak hourly demand, is higher than maximum. No universally applied rule for prediction

Commercial and industrial:

This is the amount of water used by the shops, markets, industries, factories etc. It contributes 15 – 24% of total use of water.

It includes factories, offices and commercial places demand. It is based on either having a separate or combined water supply system. Demand of water based on unit production: No. of persons working and floor area

Public use:

The public use of water is that one which is used by city halls, jails, hospitals, offices, schools etc. This consumes 9% of total use of water. Its water demand is 50 – 75 liters per capita per day. Fire protection's
need of water is also fulfilled by this sector. The fire demand does not greatly affect the average consumption but has a considerable effect on peak rates. Schools, hospitals, fire fighting etc

Loss and wastes:

Unauthorized, connections; leakage in distribution system, Hydrant flushing, major line breakage and cleaning of streets, irrigating parks. Total consumption is sum of the above demands. The water which is not intended for specific purpose or use is also called "Un-accounted for". Loss and wastage of water is due to:

1. Errors in measurements
2. Leakages, evaporation or overflow
3. Un-metered uses e.g. fire fighting, main flushing
4. Un-authorized connections

Factors affecting the use of water

- Size of the city
- Industry and commerce
- Climate
- Time of the day
- Day of the week or month

Estimation of Water Demand

While estimating the water demand, the above factors should be considered e.g. the size of the city; its population does matter when estimating the water demand. The more the size of population, more will be the demand. Estimation of water demand is necessary to:

- Calculate design flow
- Determine the pumping power of machines to be used
- Reservoir capacity
- Pipe capacity

To estimate water demand, following parameters must be determined or calculated.

1. Averagedaily water consumption: It is based on complete one year supply of water. It is the total consumption during one year, divided by the population.
   \[ q = \frac{Q}{P \times 365} \text{ lpcd} \] (liters per capita per day)
2. Maximum daily consumption: It is the maximum amount of water used during one day in the year. This amount is 180% of the average daily consumption
   \[ \text{MDC} = 1.8 \times \text{Avg. daily consumption} \]
   It is usually a working day (Monday) of summer season.
3. Maximum weekly demand: The amount of water used by a population during a whole single week in a study span of 1 year.
   Maximum weekly demand = 1.48 x Avg. D. C
   Maximum monthly demand = 1.28 x Avg. D. C
The quantity of water required for a community depends upon:

1. Forecasted population
2. Types and variation in demand (e.g. seasonal variation)
3. Maximum demand (Per day/Per month)
4. Fire demand
5. Rural demand and supplies
6. Appropriate / Available technology

**Sources of Fresh water**

- **Surface water sources**: Lakes impounding reservoirs, streams, seas, irrigation canals
- **Ground water sources**: Springs, wells, infiltration wells

Above are the common sources of clean drinking water, other different sources of drinking water are

**Merits of surface sources**

**Merits of ground water sources**

1. Being underground, the ground water supply has less chance of being contaminated by atmospheric pollution.
2. The water quality is good and better than surface source.
3. Prevention of water through evaporation is ensured and thus loss of water is reduced.
4. Ground water supply is available and can even be maintained in deserted areas.
5. The land above ground water source can be used for other purposes and has less environmental impacts.

**Demerits of ground water source**

1. The water obtained from ground water source is always pressure less. A mump is required to take the water out and is then again pumped for daily use.
2. The transport / transmission of ground water is a problem and an expensive work. The water has to be surfaced or underground conduits are required.
3. Boring and excavation for finding and using ground water is expensive work.
4. The modeling, analysis and calculation of ground water is less reliable and based on the past experience, thus posing high risk of uncertainty.

**Demerits of surface source**

**Chemical Characteristics of water**

- **Acidity**
- **Alkalinity**
Acidity:

Acidity or alkalinity is measured by pH. PH measures the concentration of Hydrogen ions in water. Ionization of water is

\[ \text{HOH} H^+ + \text{OH}^- \]

In neutral solutions \([\text{OH}] = [\text{H}]\) hence \(\text{pH} = 7\)

If acidity is increased, \([\text{H}]\) increases and \(\text{pH}\) reduces from 7 (because \(H\) is \(\log\) of \([\text{H}]\)). The value of \(\text{pH}\) of water is important in the operations of many water and waste water treatment processes and in the control of corrosion.

Alkalinity:

The values of \(\text{pH}\) higher than 7, shows alkalinity. The alkaline species in water can neutralize acids. The major constituents of alkalinity (or causticity) are \(\text{OH}^-\), \(\text{CO}_3^{2-}\) and bicarbonates \(\text{HCO}_3^-\) ions. Alkalinity in water is usually caused by bicarbonate ions.

**Hardness of water: Definition of hard water**

Hardness is the property that makes water to require more soap to produce a foam or lather. **Hardness of water** is not harmful for human health but can be precipitated by heating so can produce damaging effects in boilers, hot pipes etc by depositing the material and reducing the water storage and carriage capacity.

**Absolute softwater** on the other hand is not acceptable for humans because it may cause ailments, especially to heart patients.

Hardness in water is commonly classified in terms of the amount of \(\text{CaCO}_3\) (Calcium Carbonate) in it.

<table>
<thead>
<tr>
<th>Concentration of (\text{CaCO}_3)</th>
<th>Degree of hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 75 mg / L</td>
<td>Soft</td>
</tr>
<tr>
<td>75 – 150 mg / L</td>
<td>Moderately hard</td>
</tr>
<tr>
<td>150 – 300 mg / L</td>
<td>Hard</td>
</tr>
<tr>
<td>300 up mg / L</td>
<td>Very Hard</td>
</tr>
</tbody>
</table>

Table 1 - Degree of Hardness
Low level of hardness can be removed just by boiling but high degree of hardness can be removed by addition of lime. This method has also the benefit that iron and manganese contents are removed and suspended particles including microorganisms are reduced.

**Reservoir**

A reservoir (etymology from French réservoir a "storehouse[1]") or an artificial lake is used to store water. Reservoirs may be created in river valleys by the construction of a dam or may be built by excavation in the ground or by conventional construction techniques such as brickwork or cast concrete.

The term reservoir may also be used to describe underground reservoirs such as an oil or water well.

A dam is any barrier that holds back water; dams are primarily used to save, manage, and/or prevent the flow of excess water into specific regions. In addition, some dams are used to generate hydropower. This article examines man-made dams but dams can also be created by natural causes like mass wasting events or even animals like the beaver.

Another term often used when discussing dams is reservoir. A reservoir is a man-made lake that is primarily used for storing water. They can also be defined as the specific bodies of water formed by the construction of a dam. For example, the Hetch Hetchy Reservoir in California’s Yosemite National Park is the body of water created and held back by the O’Shaughnessy Dam.

**Types of Dams**

Today, there are several different types of dams and the man-made ones are classified by their size and structure. Typically a large dam is classified as being higher than 50-65 feet (15-20 meters) while major dams are those over 492-820 feet (150-250 meters).

One of the most common types of major dams is the arch dam. These masonry or concrete dams are ideal for narrow and/or rocky locations because their curved shape easily holds back water via gravity without the need for a lot of construction materials. Arch dams can have one large single arch or they can have multiple small arches separated by concrete buttresses. The Hoover Dam which is on the border of the U.S. state Another type of dam is the buttress dam. These can have multiple arches, but unlike a traditional arch dam, they can be flat as well. Normally buttress dams are made of concrete and feature a series braces called buttresses along the downstream side of the dam to prevent the natural flow of water. The Daniel-Johnson Dam in Quebec, Canada is a multiple arch buttress dam.
In the U.S., the most common type of dam is the embankment dam. These are large dams made out of soil and rock which use their weight to hold back water. To prevent water from moving through them, embankment dams also have a thick waterproof core. The Tarbela Dam in Pakistan is the world’s largest embankment dam.

Finally, gravity dams are huge dams that are constructed to hold back water using only their own weight. To do this, they are constructed using extensive amounts of concrete, making them difficult and expensive to build. The Grand Coulee Dam in the U.S. state of Washington is a gravity dam.

Types of Reservoirs and Construction

Like dams, there are different types of reservoirs as well but they are classified based on their use. The three types are called: a valley dammed reservoir, a bank-side reservoir, and a service reservoir. Bank-side reservoirs are those formed when water is taken from an existing stream or river and stored in a nearby reservoir. Service reservoirs are mainly constructed to store water for later use. They often appear as water towers and other elevated structures.

The first and usually largest type of reservoir is called a valley dammed reservoir. These are reservoirs that are located in narrow valley areas where tremendous amounts of water can be held in by the valley’s sides and a dam. The best location for a dam in these types of reservoirs is where it can be built into the valley wall most effectively to form a water tight seal.

To construct a valley dammed reservoir, the river must be diverted, usually through a tunnel, at the start of work. The first step in creating this type of reservoir is the pouring of a strong foundation for the dam, after which construction on the dam itself can begin. These steps can take months to years to complete, depending on the size and complexity of the project. Once finished, the diversion is removed and the river is able to flow freely toward the dam until it gradually fills the reservoir.

Dam Controversy

In addition to the high cost of construction and river diversion, dams and reservoirs are often controversial projects because of their social and environmental impacts. Dams themselves affect many different ecological components of rivers such as fish migrations, erosion, changes in water temperature and therefore changes in oxygen levels, creating inhospitable environments for many species.

In addition, the creation of a reservoir requires the flooding of large areas of land, at the expense of the natural environment and sometimes villages, towns and small cities. The construction of China’s
Three Gorges Dam, for example, required the relocation of over one million people and flooded many different archaeological and cultural sites.

Main Uses of Dams and Reservoirs

Despite their controversy, dams and reservoirs serve a number of different functions but one of the largest is to maintain an area’s water supply. Many of the world’s largest urban areas are supplied with water from rivers that are blocked via dams. San Francisco, California for example, gets the majority of its water supply from the Hetch Hetchy Reservoir via the Hetch Hetchy Aqueduct running from Yosemite to the San Francisco Bay Area.

Another major use of dams is power generation as hydroelectric power is one of the world’s major sources of electricity. Hydropower is generated when the potential energy of the water on the dam drives a water turbine which in then turns a generator and creates electricity. To best make use of the water’s power, a common type of hydroelectric dam uses reservoirs with different levels to adjust the amount of energy generated as it is needed. When demand is low for instance, water is held in an upper reservoir and as demand increases, the water is released into a lower reservoir where it spins a turbine.

Some other important uses of dams and reservoirs include a stabilization of water flow and irrigation, flood prevention, water diversion and recreation.

Water quality

Water quality is the physical, chemical and biological characteristics of water.[1] It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose.[2] It is most frequently used by reference to a set of standards against which compliance can be assessed. The most common standards used to assess water quality relate to drinking water, safety of human contact and for the health of ecosystems.

Standards

In the setting of standards, agencies make political and technical/scientific decisions about how the water will be used.[3] In the case of natural water bodies, they also make some reasonable estimate of pristine conditions. Different uses raise different concerns and therefore different standards are considered. Natural water bodies will vary in response to environmental conditions. Environmental scientists work to understand how these systems function which in turn helps to identify the sources and fates of contaminants. Environmental lawyers and policy makers work to define legislation that ensure that water is maintained at an appropriate quality for its identified use.
The vast majority of surface water on the planet is neither potable nor toxic. This remains true even if sea water in the oceans (which is too salty to drink) is not counted. Another general perception of water quality is that of a simple property that tells whether water is polluted or not. In fact, water quality is a very complex subject, in part because water is a complex medium intrinsically tied to the ecology of the Earth. Industrial pollution is a major cause of water pollution, as well as runoff from agricultural areas, urban stormwater runoff and discharge of treated and untreated sewage (especially in developing countries).

Categories

The parameters for water quality are determined by the intended use. Work in the area of water quality tends to be focused on water that is treated for human consumption or in the environment.

Human consumption

Contaminants that may be in untreated water include microorganisms such as viruses and bacteria; inorganic contaminants such as salts and metals; organic chemical contaminants from industrial processes and petroleum use; pesticides and herbicides; and radioactive contaminants. Water quality depends on the local geology and ecosystem, as well as human uses such as sewage dispersion, industrial pollution, use of water bodies as a heat sink, and overuse (which may lower the level of the water).

In the United States, the U.S. Environmental Protection Agency (EPA) limits the amounts of certain contaminants in tap water provided by public water systems. The Safe Drinking Water Act authorizes EPA to issue two types of standards: primary standards regulate substances that potentially affect human health, and secondary standards prescribe aesthetic qualities, those that affect taste, odor, or appearance. The U.S. Food and Drug Administration (FDA) regulations establish limits for contaminants in bottled water that must provide the same protection for public health. Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants does not necessarily indicate that the water poses a health risk.

Some people use water purification technology to remove contaminants from the municipal water supply they get in their homes, or from local pumps or bodies of water. For people who get water from a local stream, lake, or aquifer (well), their drinking water is not filtered by the local government.

Environmental water quality
Environmental water quality, also called **ambient water quality**, relates to water bodies such as lakes, rivers, and oceans. Water quality standards vary significantly due to different environmental conditions, ecosystems, and intended human uses. Toxic substances and high populations of certain microorganisms can present a health hazard for non-drinking purposes such as irrigation, swimming, fishing, rafting, boating, and industrial uses. These conditions may also affect wildlife which use the water for drinking or as a habitat. Modern water quality laws generally specify protection of fisheries and recreational use and require as a minimum, retention of current quality standards.

There is some desire among the public to return water bodies to pristine, or pre-industrial conditions. Most current environmental laws focus on the designation of uses. In some countries, these allow for some water contamination as long as the particular type of contamination is not harmful to the designated uses. Given the landscape changes in the watersheds of many freshwater bodies, returning to pristine conditions would be a significant challenge. In these cases, environmental scientists focus on achieving goals for maintaining healthy eco-systems and may concentrate on the protection of populations of endangered species and protecting human health.

**Measurement**

The complexity of water quality as a subject is reflected in the many types of measurements of water quality indicators. Some of the simple measurements listed below can be made on site—temperature, pH, dissolved oxygen, conductivity, Oxygen Reduction potential (ORP), turbidity, Secchi disk depth—in direct contact with the water source in question. More complex measurements that must be made in a lab setting require a water sample to be collected, preserved, and analyzed at another location. Making these complex measurements can be expensive. Because direct measurements of water quality can be expensive, ongoing monitoring programs are typically conducted by government agencies. However, there are local volunteer programs and resources available for some general assessment. Tools available to the general public are on-site test kits commonly used for home fish tanks and biological assessments.
Testing in response to natural disasters and other emergencies

Inevitably after events such as earthquakes and Tsunamis, there is an immediate response by the aid agencies as relief operations get underway to try and restore basic infrastructure and provide the basic fundamental items that are necessary for survival and subsequent recovery. Access to clean drinking water and adequate sanitation is a priority at times like this. The threat of disease increases hugely due to the large numbers of people living close together, often in squalid conditions, and without proper sanitation.

After a natural disaster, as far as water quality testing is concerned there are widespread views on the best course of action to take and a variety of methods can be employed. The key basic water quality parameters that need to be addressed in an emergency are bacteriological indicators of fecal contamination, Free Chlorine Residual, pH, turbidity and possibly Conductivity/TDS. There are a number of portable water test kits on the market widely used by aid and relief agencies for carrying out such testing.

The following is a list of indicators often measured by situational category:

**Drinking water**

- Alkalinity
- Color of water
- pH
- Taste and odor (geosmin, 2-methylisoborneol (MIB), etc)
- Dissolved metals and salts (sodium, chloride, potassium, calcium, manganese, magnesium)
- Microorganisms such as fecal coliform bacteria (*Escherichia coli*), Cryptosporidium, and Giardia lamblia
- Dissolved metals and metalloids (lead, mercury, arsenic, etc.)
- Dissolved organics: colored dissolved organic matter (CDOM), dissolved organic carbon (DOC)
- Radon
- Heavy metals
- P armaceuticals
- Hormone analogs

**Environmental**
Chemical assessment

- (also see salinity)
- Dissolved Oxygen (DO)
- nitrate-N
- orthophosphates
- Chemical oxygen demand (COD)
- Biochemical oxygen demand (BOD)
- Pesticides

Physical assessment

- pH
- Temperature
- Total suspended solids (TSS)
- Turbidity

Biological assessment

Biological monitoring metrics have been developed in many places, and one widely used measure is the presence and abundance of members of the insect orders Ephemeroptera, Plecoptera and Trichoptera. (Common names are, respectively, Mayfly, Stonefly and Caddisfly.) EPT indexes will naturally vary from region to region, but generally, within a region, the greater the number of taxa from these orders, the better the water quality. EPA and other organizations in the United States offer guidance on developing a monitoring program and identifying members of these and other aquatic insect orders.

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UNIT-II CONVEYANCE SYSTEM

Water supply network

A **water supply system** or **water supply network** is a system of engineered hydrologic and hydraulic components which provide water supply. A water supply system typically includes:

1. A drainage basin (see water purification - sources of drinking water);
2. A raw (untreated) water collection point (above or below ground) where the water accumulates, such as a lake, a river, or groundwater from an underground aquifer. Untreated drinking water (usually water being transferred to the water purification facilities) may be transferred using uncovered ground-level aqueducts, covered tunnels or underground water pipes.
3. Water purification facilities. Treated water is transferred using water pipes (usually underground).
4. Water storage facilities such as reservoirs, water tanks, or watertowers. Smaller water systems may store the water in cisterns or pressure vessels. (Tall buildings may also need to store water locally in pressure vessels in order for the water to reach the upper floors.)
5. Additional water pressurizing components such as pumping stations may need to be situated at the outlet of underground or above ground reservoirs or cisterns (if gravity flow is impractical).
6. A pipe network for distribution of water to the consumers (which may be private houses or industrial, commercial or institution establishments) and other usage points (such as fire hydrants).
7. Connections to the sewers (underground pipes, or aboveground ditches in some developing countries) are generally found downstream of the water consumers, but the sewer system is considered to be a separate system, rather than part of the water supply system.

Water abstraction and raw water transfer

Raw water (untreated) is collected from a surface water source (such as an intake on a lake or a river) or from a groundwater source (such as a water well drawing from an underground aquifer) within the watershed that provides the water resource.

Shallow dams and reservoirs are susceptible to outbreaks of toxic algae, especially if the water is warmed by a hot sun. The bacteria grow from stormwater runoff carrying fertilizer into the river where it acts as a nutrient for the algae. Such outbreaks render the water unfit for human consumption.

The raw water is transferred to the water purification facilities using uncovered aqueducts, covered tunnels or underground water pipes.

**Water treatment**
Virtually all large systems must treat the water; a fact that is tightly regulated by global, state and federal agencies, such as the World Health Organization (WHO) or the United States Environmental Protection Agency (EPA). Water treatment must occur before the product reaches the consumer and afterwards (when it is discharged again). Water purification usually occurs close to the final delivery points to reduce pumping costs and the chances of the water becoming contaminated after treatment.

Traditional surface water treatment plants generally consists of three steps: clarification, filtration and disinfection. Clarification refers to the separation of particles (dirt, organic matter, etc.) from the water stream. Chemical addition (i.e. alum, ferric chloride) destabilizes the particle charges and prepares them for clarification either by settling or floating out of the water stream. Sand, anthracite or activated carbon filters refine the water stream, removing smaller particulate matter. While other methods of disinfection exist, the preferred method is via chlorine addition. Chlorine effectively kills bacteria and most viruses and maintains a residual to protect the water supply through the supply network.

**Water distribution network**

The Central Arizona Project Aqueduct transfers untreated water
Pressurizing the water is required between the small water reserve and the end-user.

The product, delivered to the point of consumption, is called fresh water if it receives little or no treatment, or drinking water if the treatment achieves the water quality standards required for human consumption.

Once treated, chlorine is added to the water and it is distributed by the local supply network. Today, water supply systems are typically constructed of plastic, ferrous, or concrete circular pipe. However, other "pipe" shapes and material may be used, such as square or rectangular concrete boxes, arched brick pipe, or wood. Near the end point, the network of pipes through which the water is delivered is often referred to as the water mains.

The energy that the system needs to deliver the water is called pressure. That energy is transferred to the water, therefore becoming water pressure, in a number of ways: by a pump, by gravity feed from a water source (such as a water tower) at a higher elevation, or by compressed air.[1]

The water is often transferred from a water reserve such as a large communal reservoir before being transported to a more pressurised reserve as a watertower.

In small domestic systems, the water may be pressurised by a pressure vessel or even by an underground cistern (the latter however does need additional pressurizing). This eliminates the need of a water-tower or any other heightened water reserve to supply the water pressure.

These systems are usually owned and maintained by local governments, such as cities, or other public entities, but are occasionally operated by a commercial enterprise (see water privatization). Water supply networks are part of the master planning of communities, counties, and municipalities. Their planning and design requires the expertise of city planners and civil engineers, who must consider many factors, such as location, current demand, future growth, leakage, pressure, pipe size, pressure loss, fire fighting flows, etc. — using pipe network analysis and other tools. Constructioncomparable sewage systems, was one of the great engineering advances that made urbanization possible. Improvement in the quality of the water has been one of the great advances in public health.
As water passes through the distribution system, the water quality can degrade by chemical reactions and biological processes. Corrosion of metal pipe materials in the distribution system can cause the release of metals into the water with undesirable aesthetic and health effects. Release of iron from unlined iron pipes can result in customer reports of "red water" at the tap. Release of copper from copper pipes can result in customer reports of "blue water" and/or a metallic taste. Release of lead can occur from the solder used to join copper pipe together or from brass fixtures. Copper and lead levels at the consumer's tap are regulated to protect consumer health.

Utilities will often adjust the chemistry of the water before distribution to minimize its corrosiveness. The simplest adjustment involves control of pH and alkalinity to produce a water that tends to passivate corrosion by depositing a layer of calcium carbonate. Corrosion inhibitors are often added to reduce release of metals into the water. Common corrosion inhibitors added to the water are phosphates and silicates.

Maintenance of a biologically safe drinking water is another goal in water distribution. Typically, a chlorine based disinfectant, such as sodium hypochlorite or monochloramine is added to the water as it leaves the treatment plant. Booster stations can be placed within the distribution system to ensure that all areas of the distribution system have adequate sustained levels of disinfection.

**Topologies of water distribution networks**

Like electric power lines, roads, and microwave radio networks, water systems may have a loop or branch network topology, or a combination of both. The piping networks are circular or rectangular. If any one section of water distribution main fails or needs repair, that section can be isolated without disrupting all users on the network.

Most systems are divided into zones. Factors determining the extent or size of a zone can include hydraulics, telemetry systems, history, and population density. Sometimes systems are designed for a specific area then are modified to accommodate development. Terrain affects hydraulics and some forms of telemetry. While each zone may operate as a stand-alone system, there is usually some arrangement to interconnect zones in order to manage equipment failures or system failures.

**Water network maintenance**

Water supply networks usually represent the majority of assets of a water utility. Systematic documentation of maintenance works using a Computerized Maintenance Management System is a key to a successful operation of a water utility.
**Water pipes** are pipes or tubes, frequently made of polyvinyl chloride (PVC/uPVC), ductile iron, steel, cast iron, polypropylene, polyethylene, or copper, that carry pressurized and treated fresh water to buildings (as part of a municipal water system), as well as inside the building.

**Pipe vs. tube**

Piping is available in rigid "joints", which come in various lengths depending on the material. Tubing, in particular copper, comes in rigid hard tempered "joints" or soft tempered (annealed)
rolls. PeX and CPVC tubing also comes in rigid "joints" or flexible rolls. The temper of the copper, that is whether it is a rigid "joint" or flexible roll, does not affect the sizing.

The thicknesses of the water pipe and tube walls can vary. Pipe wall thickness is denoted by various schedules. Pipe wall thickness increases with schedule, and is available in schedules 20, 40, 80, and higher in special cases. The schedule is largely determined by the operating pressure of the system, with higher pressures commanding greater thickness. Copper tubing is available in four wall thicknesses: type DWV (thinnest wall; only allowed as drain pipe per UPC), type 'M' (typically only allowed as drain pipe by IPC code), type 'L' (thicker, standard duty for water lines and water service), and type 'K' (thickest, typically used underground between the main and the meter). Because piping and tubing are commodities, having a greater wall thickness implies higher initial cost. Thicker walled pipe generally implies greater durability and higher pressure tolerances.

Wall thickness does not affect pipe or tubing size. 1/2" L copper has the same outer diameter as 1/2" K or M copper. The same applies to pipe schedules. As a result, a slight increase in pressure losses is realized due to a decrease in flowpath as wall thickness is increased. In other words, 1 foot of 1/2" L copper has slightly less volume than 1 foot of 1/2 M copper. [citation needed]

Demand for copper products have fallen due to the dramatic increase in the price of copper, resulting in increased demand for alternative products including PEX and stainless steel.

**Tap water**

**Tap water** (running water, city water, municipal water, etc.) is a principal component of "indoor plumbing", which became available in urban areas of the developed world during the last quarter of the 19th century, and common during the mid-20th century. The application of technologies involved in providing clean or "potable" water to homes, businesses and public buildings is a major subfield of sanitary engineering.

Potable water supply

This supply may come from several possible sources.

- Municipal water supply
- Water wells
- Delivered by truck
- Processed water from creeks, streams, rivers, lakes, rainwater, etc.

Domestic water systems have been evolving since people first located their homes near a running water supply, e.g., a stream or river. The water flow also allowed sending waste water away from the domiciles.

Modern indoor plumbing delivers clean, safe, potable water to each service point in the distribution system. It is imperative that the clean water not be contaminated by the waste water.
(disposal) side of the process system. Historically, this contamination of drinking water has been the largest killer of humans.\textsuperscript{[1]}

[edit] Hot water supply

Domestic hot water is provided by means of water heater appliances, or through district heating. The hot water from these units is then piped to the various fixtures and appliances that require hot water, such as lavatories, sinks, bathtubs, showers, washing machines, and dishwashers.

[edit] Fixtures and appliances

Everything in a building that uses water falls under one of two categories; Fixture or Appliance. As the consumption points above perform their function, most produce waste/sewage components that will require removal by the waste/sewage side of the system. The minimum is an air gap. See cross connection control & backflow prevention for an overview of backflow prevention methods and devices currently in use, both through the use of mechanical and physical principles.

Fixtures are devices that use water without an additional source of power.

[edit] Pipe materials

The earliest known evidence of drain tile being used for plumbing was found in Mesopotamia and is estimated to have been made around 3000 BC. The tiles were made from clay mixed with short lengths of straw. Both brass and copper pipes have been found in Egypt believed to have been made close to 2500 BC. The Romans made extensive use of lead pipe by joining sheets of lead into piping to carry their water supply and waste. During the Dark Ages following the fall of the Roman Empire, plumbing development virtually ceased for centuries except for isolated cases of plumbing installed in palaces and castles. In the 13th century, blacksmiths formed sheets of iron and lap welded the seam to create iron pipe. Though it is unclear as to when galvanized iron pipe was first used, a French chemist named Melouin is credited with developing the process in 1742. The earliest known use for cast iron pipe is for the water supply to a fountain in Langensalza, Germany, built around 1560. In 1819 the first cast iron pipe constructed in the US, was manufactured in Weymouth, New Jersey. Before that time, cast iron pipe and fittings had to be imported from Europe. It was not until the 1960's that the hubless cast iron pipe was brought to the U.S. from Europe by way of Canada. During the early 1900's, heavy-walled copper joined with threaded fittings was in use, but limited to public buildings because of its high cost. However, during the 1930's light-gauge Copper tube and fittings were developed which made copper economically feasible and increased its popularity. Polyvinyl Chloride(PVC) was produced experimentally in the 19th century but did not become practical to manufacture until 1926, when Waldo Semon of BF Goodrich Co. developed a method to plasticize PVC, making it easier to process. PVC pipe began to be manufactured in the 1940's and was in wide use during the DWV reconstruction of Germany and Japan following WWII. In the 1950's, plastics manufacturers in Western Europe and Japan began producing acrylonitrile butadiene
styrene(ABS) pipe. The methods for producing cross-linked polyethylene (PEX) was also developed in the 1950's. Plastic supply pipes have become increasingly common, with a variety of materials and fittings employed, however plastic water pipes do not keep water as clean as copper and brass piping does. Copper pipe plumbing is bacteriostatic. This means that bacteria can't grow in the copper pipes. Plumbing codes define which materials may be used, and all materials must be proven by ASTM, UL, and/or NFPA testing.

[edit] Steel

Galvanized steel potable water supply and distribution pipes are commonly found with nominal diameters from 3/8" to 2". It is rarely used today for new residential plumbing. Steel pipe has National Pipe Thread (NPT) standard tapered male threads, which connect with female tapered threads on elbows, tees, couplers, valves, and other fittings. Galvanized steel (often known simply as "galv" or "iron" in the plumbing trade) is relatively expensive, difficult to work with due to weight and requirement of a pipe threader. It remains in common use for repair of existing "galv" systems and to satisfy building code non-combustibility requirements typically found in hotels, apartment buildings and other commercial applications. It is also extremely durable. Black lacquered steel pipe is the most widely used pipe material for fire sprinklers and natural gas.

Most single family homes' systems typically won't require supply piping larger than 3/4". In addition to expense, another downside is it suffers from a tendency to obstruction due to internal tubing. Types K and L are generally found in both sides of the "tube" and L filler (similar to a "copper tubing") in the plumbing industry. The service, galvanized steel pipe has a service life of about 30 to 50 years, although it is not uncommon for it to be less in beer plumbing with the size of copper contaminants.

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Common wall-thicknesses in Europe are "Type X", "Type Y" and "Type Z", defined by the EN 1057 standard.

- Type X is the most common, and is used in above ground services including drinking water supply, hot and cold water systems, sanitation, central heating and other general purpose applications.
Type Y is a thicker walled pipe, used for underground works and heavy duty requirements including hot and cold water supply, gas reticulation, sanitary plumbing, heating and general engineering.

Type Z is a thinner walled pipe, also used for above ground services including drinking water supply, hot and cold water systems, sanitation, central heating and other general purpose applications.

In the plumbing trade the size of copper tubing is measured by its outside diameter in millimetres. Common sizes are 15 mm and 22 mm.\[3\]

Thin-walled types used to be relatively inexpensive, but since 2002 copper prices have risen considerably due to rising global demand and a stagnant supply.

[edit] Lead leaching

Generally, copper tubes are soldered directly into copper or brass fittings, although compression, crimp, or flare fittings are also used. Formerly, concerns with copper supply tubes included the lead used in the solder at joints (50% tin and 50% lead). Some studies have shown significant "leaching" of the lead into the potable water stream, particularly after long periods of low usage, followed by peak demand periods. In hard water applications, shortly after installation, the interior of the pipes will be coated with the deposited minerals that had been dissolved in the water, and therefore the vast majority of exposed lead is prevented from entering the potable water. Building codes now require lead-free solder. Building Codes throughout the U.S. require the use of virtually "lead-free" (<.2% lead) solder or filler metals in plumbing fittings and appliances as well.

[edit] Corrosion

Copper water tubes are susceptible to: cold water pitting caused by contamination of the pipe interior typically with soldering flux; erosion corrosion caused by high speed or turbulent flow; and stray current corrosion, caused by poor electrical wiring technique, such as improper grounding and bonding.

[edit] Pin holes due to poor plumbing electrical grounding and/or bonding

Pin-hole leaks can occur anytime copper piping is improperly grounded and/or bonded; nonmetal piping, such as Pex or PVC, does not suffer from this problem. The phenomenon is known technically as stray current corrosion or electrolytic pitting. Pin-holing due to poor grounding or poor bonding occurs typically in homes where the original plumbing has been modified; homeowners may find a new plastic water filtration device or plastic repair union has interrupted the water pipe's electrical continuity to ground when they start seeing pinhole water leaks after a recent install. Damage occurs rapidly, usually being seen about six months after the ground interruption. Correctly installed plumbing appliances will have a copper bonding jumper cable connecting the interrupted pipe sections. Pinhole leaks from stray current corrosion can result in
thousands of dollars in plumbing bills, and sometimes necessitating the replacement of the entire affected line. The cause is an electrical problem, not a plumbing problem; once the plumbing damage is repaired, an electrician should be consulted to evaluate the grounding and bonding of the entire plumbing system.

The difference between a ground and a bond is subtle. See Ground (electricity), find the heading AC power wiring installations for a complete description.

Stray current corrosion occurs because: 1) the piping system is connected accidentally or intentionally to a DC voltage source; 2) the piping does not have metal-to-metal electrical continuity; 3) if the voltage source is AC, one or more naturally occurring minerals coating the pipe interior act as a rectifier, converting AC current to DC. The DC voltage forces the water within the piping to act as an electrical conductor (an electrolyte). Electric current leaves the copper pipe, moves though the water across the nonconductive section (the plastic filter housing in the example above), and reenters the pipe on the opposite side. Pitting occurs at the electrically negative side (the cathode), which may be upstream or downstream with respect to the water flow direction. Pitting occurs because the electrical voltage ionizes the pipe's interior copper metal, which reacts chemically with dissolved minerals in the water creating copper salts; these copper salts are soluble in water and wash away. Pits eventually grow and consolidate to form pin holes. Where there is one, there are almost certainly more. A complete discussion of stray current corrosion can be found in chapter 11, section 11.4.3, of Handbook of Corrosion Engineering, by Pierre Roberge.[4]

Detecting and eliminating poor bonding is relatively straightforward. Detection is accomplished by use of a simple voltmeter set to DC with the leads placed in various places in the plumbing. Typically, a probe on a hot pipe and a probe on a cold pipe will tell you if there is improper grounding. Anything beyond a few millivolts is important, potentials of 200 mV are common. A missing bond will show up best in the area of the gap, as potential disperses as the water runs. Since the missing bond is usually seen near the water source, as filtration and treatment equipment are added, pinhole leaks can occur anywhere downstream. It is usually the cold water pipe, as this is the one that gets the treatment devices.

Correcting the problem is a simple matter of either purchasing a copper bonding jumper kit, composed of copper cable at least #6 AWG in diameter and two bronze ground clamps for affixing it the plumbing. See NFPA 70, the U.S. National Electrical Code Handbook (NEC), section on bonding and ground for details on selecting the correct bonding conductor wire size.

A similar bonding jumper wire can also be seen crossing gas meters, but for a different reason.

Note, if homeowners are experiencing shocks or sparks from plumbing fixtures or pipes, it is more than a missing bond, it is likely a live electrical wire is bridging to the plumbing and the plumbing system is not grounded. This is an electrical shock hazard and potential fire danger.
Plastic piping placed for a sink

Plastic pipe is in wide use for domestic water supply and drainage, waste, and vent (DWV) pipe. For example, polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC), polypropylene (PP), polybutylene (PB), and polyethylene (PE) may be allowed by code for certain uses. Some examples of plastics in water supply systems are:

- **PVC/CPVC** - rigid plastic pipes similar to PVC drain pipes but with thicker walls to deal with municipal water pressure, introduced around 1970. PVC should be used for cold water only, or venting. CPVC can be used for hot and cold potable water supply. Connections are made with primers and solvent cements as required by code.

- **PP** - The material is used primarily in housewares, food packaging, and clinical equipment,[5] but since the early 1970s has seen increasing use worldwide for both domestic hot and cold water. PP pipes are heat fused, preventing the use of glues, solvents, or mechanical fittings. PP pipe is often used in green building projects.[6][7]

- **PBT** - flexible (usually gray or black) plastic pipe which is attached to barbed fittings and secured in place with a copper crimp ring. The primary manufacturer of PBT tubing and fittings was driven into bankruptcy by a class-action lawsuit over failures of this system. However, PB and PBT tubing has returned to the market and codes, typically first for 'exposed locations' such as risers.

- **PEX** - cross linked polyethylene system with mechanically joined fittings employing barbs and crimped steel or copper fittings.

- Polytanks - plastic polyethylene cisterns, underground water tanks, above ground water tanks, are made of linear polyethylene suitable as a potable water storage tank, provided in white, black or green, approved by NSF and made of FDA approved materials.

- Aqua - known as PEX-Al-PEX, for its PEX/aluminum sandwich - aluminum pipe sandwiched between layers of PEX and connected with brass compression fittings. In 2005, a large number of these fittings were recalled.

[edit] Plastics
[edit] Fittings and valves

Potable water supply systems require not only pipe, but also many fittings and valves which add considerably to their functionality as well as cost. The Piping and plumbing fittings and Valves articles discuss them further.

[edit] Regulation and compliance

Before a water supply system is constructed or modified, the designer and contractor need to consult the local plumbing code and obtain a building permits prior to construction. Even replacing an existing water heater may require a permit and inspection of the work. NSF 61 is the U.S. national standard for potable water piping guidelines. National and local fire codes should be integrated in the design phase of the water system too to prevent "failure comply with regulations" notices. Some areas of the United States require on-site water reserves of potable and fire water by law.
UNIT-III WATER TREATMENT

WaterTreatment

Introduction
All surface water and some groundwaters require treatment prior to consumption to ensure that they do not represent a health risk to the user. Health risks to consumers from poor quality water can be due to microbiological, chemical, physical or radioactive contamination. However, microbiological contamination is generally the most important to human health as this leads to infectious diseases which affect all populations groups, many of which may cause epidemics and can be fatal. Chemical contamination, with the exception of a few substances such as cyanide and nitrate, tends to represent a more long-term health risk. An example of this is nitrate which can cause methaemoglobinaemia in babies. Substances in water which affect the clarity, colour or taste of water may make water objectionable to consumers and hence ability to recover costs. As many microorganisms are found associated with particles in water, physical contamination may also represent a health risk as it extends microbial survival.

Most treatment systems are designed to remove microbiological contamination and those physical constituents which affect the acceptability or promote microorganism survival - largely related to the suspended solids in the water. A disinfectant is nearly always included in treatment plants of any size. This is done for two main reasons: firstly it is added to inactivate any remaining bacteria as the final unit of treatment; and, more importantly, to provide a residual disinfectant which will kill any bacteria introduced during storage and/or distribution.

The multiple barrier principle
Treatment processes usually function either through the physical removal of contaminants through filtration, settling (often aided by some form of chemical addition) or biological removal of microorganisms. It is usual for treatment to be in a number of stages, with initial pretreatment by settling or pre-filtration through coarse media, sand filtration (rapid or slow) followed by chlorination. This is called the multiple barrier principle.

This is an important concept as it provides the basis of comprehensive treatment of water and provides a system to prevent complete treatment failure due to a breakdown of a single process. For instance, with a system which comprises addition of coagulation-flocculation-settling, followed by rapid sand filtration with terminal disinfection, failure of the rapid sand filter does not mean that untreated water will be supplied. The coagulation-flocculation-settling process will remove a great deal of the suspended particles, and therefore many of the microorganisms in the water, and the terminal disinfection will remove many of the remainder. Provided the rapid sand filter is repaired reasonable quickly, there should be little decrease in water quality. A key element in the multiple barrier principle is to ensure that the source of water is protected and maintained at as high a quality as possible. This is sometimes easier for groundwater sources on a local scale, although there are obvious difficulties for both ground and surface water on a larger scale.

DRINKING-WATER QUALITY

Treatment processes - advantages and disadvantages
There are many different treatment process available and whose suitability is a function of the source water quality, level of operator training and resources available for operation and maintenance. It is imperative that the selection of technology for treatment plants is done taking the above into consideration to ensure that they remain sustainable.
Prefiltration
As many secondary filtration processes, and in particular slow sand filtration, require low influent turbidities, some form of pretreatment to reduce suspended solids load is required. One way to achieve this is by using prefiltration of water through coarse media, usually gravel or coarse sand. Prefilters can have many different configurations: horizontal; vertical upflow; and vertical upflow-downflow. Vertical prefilters have become increasingly popular as they require far less land than horizontal prefilters and can take faster flow runs through them. An alternative are pressure filters, through which water is pumped at pressure to remove the suspended solids load.

Prefilters have an advantage in that they do not require chemicals, have limited working parts and are robust. They do however, require frequent cleaning and maintenance and are ineffective in removing fine particles, thus where the suspended solid load is primarily made up of silt and clay particles prefiltration is ineffective. Prefiltration is a physical process designed to remove suspended solids and therefore its efficiency in removal of microorganisms is a function of the microbes associated with particles. Virus removal is poor and prefiltration is not effective in the removal of cysts or bacteria associated with fine particles.

Sedimentation
Sedimentation is the removal of suspended solids through the settling of particles moving through a tank at a slow rate. There are a number of forms of sedimentation. In water treatment plants treating source water a high proportion of suspended solids of coarser grades (e.g. sand and coarse silt) a grit chamber may be used to remove the largest particles through simple sedimentation. In this process, water is passed through a tank at a slow rate and suspended solids fall out of suspension. In small supplies, simple sedimentors may also be used, which functioning in a similar fashion to grit chambers, although with a slower rate of water throughflow. Simple sedimentation will not remove fine grained particles because the flow rates remain too high and the retention time is insufficient. A further common fault with simple sedimenters is that design flow rates are rarely achieved in practice and a certain element of ‘short-circuiting’ can occur unless construction, operation and maintenance is very careful.

As a result of the drawbacks in simple sedimentation, it is common to find that the sedimentation process is enhanced through the addition of chemicals - or coagulation. Coagulants carry a charge and therefore attract charged clay particles. The particles begin to aggregate and form ‘flocs’. Once the flocs reach a critical mass, they sink to the bottom of the settler. The outlet of the sedimentor is generally around the top of the structure, thus the clear water is removed by a surface channel. This system can be further refined with the use of modular or plate settlers which reduces the time require for settling by providing a wider surface area for aggregation of particles.

The most commonly used coagulants is aluminium sulphate, although there are other coagulants available including ferric salts (sulphates and chlorides) and polyelectrolytes. Coagulants are dosed in solution at a rate determined by raw water quality near the inlet of a mixing tank or flocculator. It is essential that the coagulant is rapidly and thoroughly mixed on dosing, this is may be achieved through the use of a hydraulic jump. The water then passes into the settler to allow aggregation of the flocs. Increasing use is now being made of synthetic polymer compounds or polyelectrolytes. As these are highly charged, there is a rapid increase in the formation of flocs, particularly where clay makes up a large proportion of the suspended solid load.

The advantages of the coagulation is that it reduces the time required to settle out suspended
solids and is very effective in removing fine particles which are otherwise very difficult to remove from water. Coagulation can also be effective in removing protozoa, bacteria and viruses, particularly when polyelectrolyte is used, as the highly charged coagulant attracts the charged microorganisms into the flocs. Coagulation can also be effective in removing by precipitation certain contaminants such as lead and barium.

The principle disadvantages of using coagulants are the cost and the need for accurate dosing, jar testing and dose adjustment and frequent monitoring. Coagulants can be expensive to buy (particularly polyelectrolyte) and need accurate dosing equipment to function efficiently. Staff need to be adequately trained to carry out jar tests to determine coagulant dosage.

**Sand Filtration**

Sand filtration can be either rapid or slow. The difference between the two is not a simple matter of the speed of filtration, but in the underlying concept of the treatment process. Slow sand filtration is essentially a biological process whereas rapid sand filtration is a physical treatment process.

Slow sand filters have an advantage over rapid sand filters in that they produce microbiologically "clean" water which should not require disinfection to inactivate any bacteria, although the addition of a disinfectant to provide a residual for the distribution system is still advisable. However, because of their slow flow rate, slow sand filters require large tracts of land if they are to supply large populations and can be relatively labour intensive to operate and maintain. As the reestablishment of the schumtzdecke takes several days, the plant has to have sufficient capacity to supply the water demand when one or more filters are out of action.

Rapid sand filtration is now commonly used worldwide and is far more popular than slow sand filtration. The principal factor in this decision has been the smaller land requirement for rapid sand filters and lower labour costs. However, rapid sand filters do not produce water of the same quality as slow sand filters and a far greater reliance is placed on disinfection to inactivate bacteria. It is also worth noting that rapid sand filters are not effective in removing viruses.

**Slow sand filters**

Slow sand filters operate at slow flow rates, 0.1 - 0.3 metres per hour. The top layers of the sand become biologically active by the establishment of a microbial community on the top layer of the sand substrate. These microbes usually come from the source water and establish a community within a matter of a few days. The fine sand and slow filtration rate facilitate the establishment of this microbial community. The majority of the community are predatory bacteria who feed on water-borne microbes passing through the filter. The microbial community forms a layer called the schumtzdecke and can develop up to 2cm thick before the filter requires cleaning. Once the schumtzdecke becomes too thick and the rate of filtration declines further it is scraped off, a process done every couple of months or so depending on the source water. Once this has been carried out, the slow sand filter will not be fully functional for another 3 to 4 days until a new schumtzdecke has developed, although this procedure can be speeded up by seeding the filter with bacteria from the removed schumtzdecke. Slow sand filtration is extremely good at removing microbial contamination and will usually have no indicator bacteria present at the outlet. Slow sand filters are also effective in removing protozoa and viruses.

Slow sand filters require low influent turbidity, below 20TU and preferably below 10TU. This means that efficient pretreatment is required to ensure that the filters do not become overloaded. Slow sand filters can cope with shock turbidities of up to 50TU, but only for very short periods of time before they block. The sand used in slow sand filters is fine, thus high turbidities cause
the bed to block rapidly and necessitates more frequent cleaning and therefore greater time out of action. Nevertheless, slow sand filters are still used in London and were relatively common in Western Europe until comparatively recently and are still common elsewhere in the world. The move away from slow sand filtration has largely been a function of rising land prices and labour costs which increased the cost of slow sand filter produced water, where this is not the case, slow sand filters still represent a cost-effective method of water treatment.

**Rapid sand filters**
Rapid sand filters work at much higher rates of flow (up to 20 meters per hour) and essentially rely on physical removal of suspended solids, including any floc carried over from the settlers. Although rapid sand filters achieve some reduction in microbial populations in water as it removes particles to which bacteria are attached, it is not a biological treatment and the use of a terminal disinfectant is vital to ensure that bacteria in the water have been inactivated. Rapid sand filters require frequent cleaning (daily or twice daily) which is achieved through backwashing filters with clean water to re-suspended the sediment. Cleaning takes relatively little time and the filters can be put back into operation immediately.

Rapid sand filters are far smaller than slow sand filters and are commonly employed in ‘batteries’. The rapid flow rate through these filters means that demand can be more easily met from smaller plants. Rapid sand filters do not require low influent turbidities, as they are essentially a physical treatment process, although higher suspended solids loads will result in more frequent cleaning. Backwashing is usually rapid and filters are not out of commission for more than a matter of minutes. Cleaning and operation can be largely mechanised and air scour is commonly employed to make backwashing more effective. With the small land requirement, several rapid sand filters can be accommodated in small area and thus it is easy to maintain capacity to meet demand when filters are being cleaned.

**Disinfection**
All water supplies should be disinfected in order to protect public health. Disinfection inactivates any remaining bacteria in the water after previous treatment steps and provides a residual disinfectant to inactivate bacteria introduced by any subsequent ingress of contaminated water during storage or distribution.

At present, the principal disinfectant used worldwide is chlorine, although alternatives are being increasingly investigated and process such as ozonation are becoming more important in industrialized countries. It is important to note that all disinfectants produce by-products and that the greater knowledge about the by-products formed from the use of chlorine because it is this most widely used disinfectant should not compromise it’s use. It is also important that disinfection of water supplies is never compromised because of a risk of potential health effects from by-products in the final water. Any health impacts from chemical contamination is likely to be long-term, whereas the absence of disinfection puts the consumers at risk from infectious diarrhoeal disease.

**Other Treatment Processes**
The above treatment process are all designed to make drinking-water safe by the removal of microorganisms and suspended solids. However, drinking-water, particularly from groundwater sources, may also contain chemical contaminants which must be removed. Generally the removal of chemicals from water is more difficult and much more expensive than removing microbiological or physical contaminants. Basic filtration and coagulation techniques are not generally effective for the majority of chemicals.

As there are many different chemicals which could be dealt with, a few relevant examples will
be provided. Iron can be a major constituent of both ground and surface waters (where it is commonly associated with bacteria and algae). Although iron does not represent any health risk, it causes problems of acceptability of the water as many consumers find the colour off-putting and because it stains clothes. The principal method of removing iron from water is through aeration or oxidation of the Fe$^{2+}$ to the Fe$^{3+}$ species. This is easily achieved by flowing the water over a simple cascade and followed by sedimentation. Note aeration is also used for waters known to be anoxic or oxygen deficient.

A variety of processes are used for the removal of organic and inorganic contaminants including ion exchange and precipitation. For instance, fluoride may be removed through coagulation with lime or by ion exchange using calcined burnt bone or activate alumina. Granulated activated carbon (GAC) is commonly used for pesticide removal through adsorption. This is expensive but unfortunately no other process appears to work effectively and therefore GAC remains the sole option.

**Selecting Technology**
When selecting technology and systems of treatment it is vital that as full a picture as possible of the source water quality is available. It is important to know what is in the water before trying to design appropriate treatment systems. It is equally important to maintain a thorough monitoring programme through the plant to ensure that each stage of treatment is working effectively and efficiently.

All waters may need treatment before they are fit for human consumption, although surface waters tend to be more vulnerable to contamination than groundwater. All surface waters will require treatment prior to consumption. Furthermore, all water supplied through distribution systems should be disinfected to provide a residual disinfectant which provides ongoing protection from bacterial growth and survival.

**Water Treatment**

Presentation Plan

**Section Key points OHP**

**Introduction**
- need to treat all surface waters and some groundwaters
- contamination may be microbiological, chemical or physical
- microbiological contamination is most important as it causes highly infectious disease with short-term impacts chemical contamination tends to have longer term effects on health
- suspended solids affect microbial survival and the acceptability of water always disinfect water supplies and maintain a residual in the water for protection against contamination during distribution and storage

**Multiple Barrier Principle**
- need to have more than a single process during treatment prevents breakdown in one process leading to complete treatment failure source must be well protected

**Treatment processes**
- many processes available, the suitability of each is a function of source quality, operator capacity and financial resources
technology selection must be made on the basis of the above to ensure sustainability
- often need to reduce turbidity before treating water as this may interfere with treatment
- prefiltration is a physical process which removes suspended solids
- prefilters can be horizontal, vertical upflow or vertical upflow-downflow main advantage is limited working parts and doesn't use chemicals

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disadvantages include poor ability to remove fine material, microbial removal poor and may need frequent cleaning. Sedimentation is achieved by the settling of particles in slow moving water. Simple sedimenters do not use chemical coagulants and are not effective in removing fine material.

**Section Key Points OHP**

- Settling is improved through addition of coagulants to form larger aggregates which speeds up settling and removes fine material.
- Modular and plate settlers improve settling efficiency.
- Alum is the most common coagulant, others include polyelectrolytes and ferric salts such as sulphate and chloride.
- Advantages include removal of fine particles, removal of some viruses, quick, compact treatment processes.

**Treatment processes**

- Sand filtration can be rapid or slow.
- Slow sand filtration is a biological process and rapid sand filtration a physical process.
- Slow sand filters a biologically active top layer called the schmutzdecke which is composed of predatory bacteria.
- Schmutzdecke kills bacteria and viruses.
- Require cleaning every 2 months, take 3-4 days to recover.
- Rapid sand filters work at much faster rates and remove suspended solids.
- Advantages of slow sand filtration include production of good quality water, relatively simple to operate.
- Disadvantages include large land requirement, labour intensive, requires low turbidity water.
- Advantages of rapid sand filtration include small land requirement.

**Treatment plant assessments**

- Assessments of treatment plants may be carried out for a number of different reasons.
- Routine assessments often carried out by water suppliers to ensure performance is efficient and optimised.
- Assessments may also be undertaken when there is a failure in water quality or a failure to produce water of adequate quality.
- Assessments involve the evaluation of each unit process to ensure that it performs efficiently and to identify any process failures and causes of failures.
- Assessments should also evaluate the suitability of combinations of technologies (e.g., sometimes find simple sedimenters combined with slow sand filters when turbidity was relatively high - led to failure).
- Assessments should be linked to performance optimisation.

**Section Key Points OHP Conclusion**

- Both surface and groundwater may require treatment before distribution.
- Source water quality (and likely variations) should be known before selecting technologies.
- Technologies should be used which reflect capacity to operate the plant and which provide adequate treatment.

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a multiple barrier principle should always be used when treating water
source protection is also vital

The Multiple Barrier Principle of Water Treatment

Upflow-Downflow Prefilter

Horizontal Flow Prefilter

Flocculator

Coagulant Dosing

Slow Sand Filter

Rapid Sand Filter

Water Treatment Plant Assessments

*When and why the should be carried out:*  
Routine assessment of operational efficiency and state of equipment  
When contamination is found  
When disease outbreaks occur  
If disinfection dosing requirements suddenly change

Water Treatment Plant Assessments

**Parameters**

**Raw Water:**
turbidity, pH, alkalinity, coliforms, major ions, nutrients, known problem substances

**Coagulation-flocculation-settling:**
turbidity, pH, residual aluminum, residual acrylamide, coliforms

**Prefiltration:**
turbidity, pH, coliforms

**Sand filtration (rapid/slow):**
turbidity, pH, coliforms

**Disinfection:**
Residual (usually chlorine), pH, turbidity, coliforms (thermotolerant and total)
Principles of Unit operations and processes in water and wastewater treatment and disposal

Water and waste water differ only in the way that solids concentration will be more in waste water and which will be there in water too if the same is taken from the river water which makes the treatment process to both the same except that filtration is on straining the finer particles in water treatment and is towards biological action of bacteria on the trickling filter to remove organic solids.

Unit operations are the physical operations to remove the impurities present in the water and waste water where as the unit processes are the chemical and biological conversion on the status of the impurities that they will be easily removed by chemical or biological processes, both are applied especially to make the fine colloidal particles to coalesce and grow in size to be removed from the water or waste water.

Screens are in use from the intake structure where they prevent the floating matter to enter into the pumping units, and fine and coarse screens are in use to treat waste water to prevent the entry of floating wastes and coarse solids into the treatment.

Sedimentation is simply detaining water for a sufficient time mostly in stagnant or relatively stagnant position to make the flow velocity of water less than the settling velocity of the solid particles that they without being driven by horizontal force settles down by gravity. The efficiency of the process depends on the detention time, how long the waste water remains within the sedimentation tank. When applied to individual units we need not reduce the flow velocity but make it stagnant as fill and draw type that the efficiency will be more. In the continuous flow type the flow velocity is reduced to the level of the minimum velocity which will not carry the particles with it according to stokes law that the vertical velocity, which is the settling velocity of the particle will be more than the horizontal drag velocity and the particle settles down. Mostly the tanks will be rectangular and we also have circular tanks where the flow will be from centre to periphery. Whatever may be the shape of the tank, it is the surface area which makes the travel of particles independent of others which makes the settling efficient that the depth has to be considered taking into effect the sludge accumulation and to prevent the reentry of particles back to flow.

Coagulants are added to the water that the flocculent particles grow bigger in size which is by chemical reaction by rapid mixing and slow mixing and the coalescent particles which grew in size gets removed by settling. The coagulant we add
changes the quality of water and the sludge volume too, and some of the coagulants add to bulking of sludge where the removal of moisture is difficult. Lime water instead of lime reduces the volume of sludge which is to all the solid coagulants. Liquid coagulants have more influence readily on coagulant particles than the solid coagulants which itself will take time to dissolve and react with the particles.

Filtration is to the removal of fine particle sand dissolved solids where the fine sand layer and coarse sand layer below serves as the media to remove colloidal solids and the water remains completely free of solids. In trickling filters the waste water that trickles down gets oxidized that the organic matter grows in size and retained over the sand medium and bacteria assimilate on the organic matter to form layer on the surface which grows thicker and thicker to give more bacterial mass to act upon the organic solids. The bottom most layer becomes deprived of oxygen in due course of time that it sloughs and the same reaches the secondary settling tank where the same gets settled for its increased density. The activated sludge process is by induced aeration where the reactor is completely mixed with sludge and air, that there will be complete oxidation after which the waste water enters the secondary settling tank.

When all solids are removed the minerals present in the water and waste water is removed by reverse osmosis, demineralization process which is basically ion exchange process.

Odour and colour present in water and waste water are removed by aeration and adsorption process. The odour and colour causing elements are adsorbed and aerated that the water is free from impurities for use and waste water for reuse and recycling. Toxic chemicals and metals too get adsorbed with suitable media for adsorption.

The waste water if not intended for recycling or reuse, they can be altered with low cost biological treatment as septic tank, cess pools, oxidation ponds and ditches which are long time process and adds nutrient value to the soil and can be used for agriculture and this leads to lot of troubles as soil sickness, fly nuisance and skin diseases as the sewage directly comes into contact with the plants. The unit operations and processes can be applied in individual units of houses, colonies and industries that it gives fewer problems to the environment and handled with more efficiency. The entire process of sedimentation, filtration and hardness removal can be done at home, for removal of hardness we need not go for reverse osmosis which is much expensive on installation and maintenance but
the simple lime soda process or boiling serve the purpose of both disinfection and hardness removal as the water from the top stratum of aquifer will not be saline in nature with chlorides and sulphates of calcium and magnesium as is seen common with river water discharged with domestic and industrial wastes. Apply the lean concepts to treat water and waste water and which will lead to a compact cost effective unit which is holistic and beneficial in the long run for which the perspectives must be in line with the nature, Nature has answers to all in a much simple way and we think we are superior to nature which makes us live a life with complications. We cannot put the burden on government and make them work for us which are proving futile neither we nor the government show the inclusion for which we experience inefficiency all through.

**Threads**

1. Study the structure of an intake unit and find whether the same to take water from the bottom of the river is right for the purpose or not. If not from where the water should be drawn?
2. Discuss on the water quality parameters.
3. Discuss on the principle of sedimentation and the types of settling.
4. What do you mean by flocculation? What are the ways to improve coagulation?
5. What are the different types of filtration? Explain the problems associated with filtration?
7. How could you combine filtration with hardness removal?
8. Narrate an individual water treatment unit for a dwelling?
9. Explain how the waste water treatment train is completely incorporated in septic tank and cess pools which can be accommodated to any type of activity.
10. How do you handle the wastes from hospitals and pharmaceutical wastes. Strptococci group is flesh eating and helps in most of the activities that handle flesh laden wastes. Comment and elaborate on this.
11. Metal eating bacteria are there which is viewed as due to mutagenic activities. Discuss on this and their efficacy.
12. Grass has a particular type of enzyme that promotes bacterial growth that helps in waste assimilation to a great extend for which cow and hoarse dung are used as seed. Discuss on this.
13. Prebiotic and probiotics bacteria helps in easy digestion of organic wastes which dominate and adds the toxic wastes removal too. Comment on this.
14. Lemon juice, detoxifying juice with beet root, carrot, cabbage detox the body which shows the enzymes present in them are for the removal of toxins. Discuss on this.
15. Human life system is natural towards eating raw plant food and milk. The waste handling became complex with changed life styles on flesh eating habits. Discuss on this.
16. Common effluent treatment is not an effective waste treatment method. Discuss the problems associated with the same.

**Settling**

Solid liquid separation process in which a suspension is separated into two phases –

- Clarified supernatant leaving the top of the sedimentation tank (overflow).
- Concentrated sludge leaving the bottom of the sedimentation tank (underflow).

**Purpose of Settling**

- To remove coarse dispersed phase.
- To remove coagulated and flocculated impurities.
- To remove precipitated impurities after chemical treatment.
To settle the sludge (biomass) after activated sludge process / tricking filters.

**Principle of Settling**

- Suspended solids present in water having specific gravity greater than that of water tend to settle down by gravity as soon as the turbulence is retarded by offering storage.
- Basin in which the flow is retarded is called **settling tank**.
- Theoretical average time for which the water is detained in the settling tank is called the **detention period**.

**Types of Settling**

**Type I: Discrete particle settling** - Particles settle individually without interaction with neighboring particles.
**Type II: Flocculent Particles** – Flocculation causes the particles to increase in mass and settle at a faster rate.
**Type III: Hindered or Zone settling** – The mass of particles tends to settle as a unit with individual particles remaining in fixed positions with respect to each other.
**Type IV: Compression** – The concentration of particles is so high that sedimentation can only occur through compaction of the structure.

**Type I Settling**

- Size, shape and specific gravity of the particles do not change with time.
- Settling velocity remains constant.

If a particle is suspended in water, it initially has two forces acting upon it:

1. **Force of gravity**: \( F = \rho g V_p \)
2. the **buoyant force** quantified by Archimedes as: \( F_b = \rho g V_p \)

If the density of the particle differs from that of the water, a net force is exerted and the particle is accelerated in the direction of the force:

\[ F_{net} = (\rho - \rho) g V_p \]

This net force becomes the driving force.

Once the motion has been initiated, a third force is created due to viscous friction. This force, called the **drag force**, is quantified by:

\[ F_d = C_p A_p \rho \frac{V^2}{2} \]

\( C_p \) = drag coefficient. 
\( A_p \) = projected area of the particle. 

Because the drag force acts in the opposite direction to the driving force and increases as the square of the velocity, acceleration occurs at a decreasing
rate until a steady velocity is reached at a point where the drag force equals the driving force:
\[(\rho - \rho) g V_p = C \pi A \rho \frac{y^2}{2}\]
For spherical particles,
\[V_p = \frac{3d^3}{6} \text{ and } A = \frac{d^2}{4}\]
Thus, \[v = \sqrt{4g(\rho - \rho) \frac{d}{3C_D}}\]

Expressions for \(C_D\) change with characteristics of different flow regimes. For laminar, transition, and turbulent flow, the values of \(C_D\) are:
\[C_D = \begin{cases} 24 & \text{(laminar)} \\ 24 + \frac{3}{Re} + 0.34 & \text{(transition)} \\ 0.4 & \text{(turbulent)} \end{cases}\]
where \(Re\) is the Reynolds number:
\[Re = \frac{\rho v d}{\mu}\]

Reynolds number less than 1.0 indicate laminar flow, while values greater than 10 indicate turbulent flow. Intermediate values indicate transitional flow.

**Stokes Flow**

For laminar flow, terminal settling velocity equation becomes:
\[v = \sqrt{4g(\rho - \rho) \frac{gd^2}{18}}\]
which is known as the *stokes equation*.

**Transition Flow**

Need to solve non-linear equations:
\[v^2 = 4g(\rho - \rho) \frac{d}{3C_D}\]
\[C_D = \begin{cases} 24 + \frac{3}{Re} + 0.34 & \text{(transition)} \\ 0.4 & \text{(turbulent)} \end{cases}\]

\[Re = \frac{\rho v d}{\mu}\]

- Calculate velocity using Stokes law or turbulent expression.
- Calculate and check Reynolds number.
- Calculate \(C_D\).
- Use general formula.
Repeat from step 2 until convergence.

**Types of Settling Tanks**

- Sedimentation tanks may function either intermittently or continuously. The intermittent tanks also called quiescent type tanks are those which store water for a certain period and keep it in complete rest. In a continuous flow type tank, the flow velocity is only reduced and the water is not brought to complete rest as is done in an intermittent type.
- Settling basins may be either long rectangular or circular in plan. Long narrow rectangular tanks with horizontal flow are generally preferred to the circular tanks with radial or spiral flow.

**Long Rectangular Settling Basin**

- Long rectangular basins are hydraulically more stable, and flow control for large volumes is easier with this configuration.
- A typical long rectangular tank have length ranging from 2 to 4 times their width. The bottom is slightly sloped to facilitate sludge scraping. A slow moving mechanical sludge scraper continuously pulls the settled material into a sludge hopper from where it is pumped out periodically.
A long rectangular settling tank can be divided into four different functional zones:

**Inlet zone**: Region in which the flow is uniformly distributed over the cross section such that the flow through settling zone follows horizontal path.

**Settling zone**: Settling occurs under quiescent conditions.

**Outlet zone**: Clarified effluent is collected and discharge through outlet weir.

**Sludge zone**: For collection of sludge below settling zone.

**Inlet and Outlet Arrangement**

**Inlet devices**: Inlets shall be designed to distribute the water equally and at uniform velocities. A baffle should be constructed across the basin close to the inlet and should project several feet below the water surface to dissipate inlet velocities and provide uniform flow;

**Outlet Devices**: Outlet weirs or submerged orifices shall be designed to maintain velocities suitable for settling in the basin and to minimize short circuiting. Weirs shall be adjustable, and at least equivalent in length to the perimeter of the tank. However, peripheral weirs are not acceptable as they tend to cause excessive short-circuiting.
**Weir Overflow Rates**

Large weir overflow rates result in excessive velocities at the outlet. These velocities extend backward into the settling zone, causing particles and flocs to be drawn into the outlet. Weir loadings are generally used up to 300 m$^3$/d/m. It may be necessary to provide special inboard weir designs as shown to lower the weir overflow rates.

**Inboard Weir Arrangement to Increase Weir Length**

![Image of weir arrangement](image)

**Circular Basins**

- Circular settling basins have the same functional zones as the long rectangular basin, but the flow regime is different. When the flow enters at the center and is baffled to flow radially towards the perimeter, the horizontal velocity of the water is continuously decreasing as the distance from the center increases. Thus, the particle path in a circular basin is a parabola as opposed to the straight line path in the long rectangular tank.
- Sludge removal mechanisms in circular tanks are simpler and require less maintenance.
Settling Operations

- Particles falling through the settling basin have two components of velocity:
  1) Vertical component: \( v = \left( \frac{t}{\rho} \right) g d^2 \)

  2) Horizontal component: \( v = \frac{h}{Q/A} \)

The path of the particle is given by the vector sum of horizontal velocity \( v \) and vertical settling velocity \( v \).

- Assume that a settling column is suspended in the flow of the settling zone and that the column travels with the flow across the settling zone. Consider the particle in the batch analysis for type-1 settling which was initially at the surface and settled through the depth of the column \( Z \), in the time \( t \). If \( t \) also corresponds to the time required for the column to be carried horizontally across the settling zone, then the particle will fall into the sludge zone and be removed from the suspension at the point at which the column reaches the end of the settling zone.

All particles with \( v > v \) will be removed from suspension at some point along the settling zone.

- Now consider the particle with settling velocity \( < v \). If the initial depth of this particle was such that \( Z/v = t \), this particle will also be
removed. Therefore, the removal of suspended particles passing through the settling zone will be in proportion to the ratio of the individual settling velocities to the settling velocity \( v_0 \). The time \( t \) corresponds to the retention time in the settling zone.

\[
t = \frac{LZ - W}{Q}
\]

Also, \( t = \frac{Z}{v_0} \)

Therefore, \( Z = \frac{LZ - W}{Q} \) and \( v = \frac{Q}{LW} \)

or \( v = \frac{Q}{A} \)

Thus, the depth of the basin is not a factor in determining the size particle that can be removed completely in the settling zone. The determining factor is the quantity \( Q/A \), which has the units of velocity and is referred to as the overflow rate \( q \). This overflow rate is the design factor for settling basins and corresponds to the terminal setting velocity of the particle that is 100% removed.

**Design Details**

1. Detention period: for plain sedimentation: 3 to 4 h, and for coagulated sedimentation: 2 to 2.5 h.
2. Velocity of flow: Not greater than 30 cm/min (horizontal flow).
3. Tank dimensions: \( L:B = 3:1 \). Generally \( L = 30 \) m (common) maximum 100 m. Breadth= 6 m to 10 m. Circular: Diameter not greater than 60 m. generally 20 to 40 m.
4. Depth 2.5 to 5.0 m (3 m).
5. Surface Overflow Rate: For plain sedimentation 12000 to 18000 L/d/m² tank area; for thoroughly flocculated water 24000 to 30000 L/d/m² tank area.
6. Slopes: Rectangular 1% towards inlet and circular 8%.

**Sedimentation** is a physical water treatment process used to settle out suspended solids in water under the influence of gravity.
**Basics**

Suspended solids (or SS), is the mass of dry solids retained by a filter of a given porosity related to the volume of the water sample. This includes particles of a size not lower than 10 μm.
Colloids are particles of a size between 0.001 nm and 1 nm depending on the method of quantification. Due to electrostatic forces balancing the gravity, they are not likely to settle naturally.

The limit sedimentation velocity of a particle is its theoretical descending speed in clear and still water. In settling process theory, a particle will settle only if:

1. In a vertical ascending flow, the ascending water velocity is lower than the limit sedimentation velocity.
2. In a longitudinal flow, the ratio of the length of the tank to the height of the tank is higher than the ratio of the water velocity to the limit sedimentation velocity.

There are four types of sedimentation processes:

- Type 1 - Dilutes, non-flocculent, free-settling. (Every particle settles independently.)
- Type 2 - Dilute, flocculent. (Particles can flocculate as they settle.)
- Type 3 - Concentrated Suspensions, Zone Settling (Sludge Thickening).
- Type 4 - Concentrated Suspensions, Compression (Sludge Thickening).

**Applications**

**Potable Water Treatment**

Sedimentation in potable water treatment generally follows a step of chemical coagulation and flocculation, which allows grouping particles together into flocs of a bigger size. This increases the settling speed of suspended solids and allows settling colloids.

**Waste Water Treatment**

Sedimentation is often used as a primary stage in modern waste water treatment plant, reducing the content of suspended solids as well as the pollutant embedded in the suspended solids. Due to the large amount of reagent necessary to treat domestic wastewater, preliminary chemical coagulation and flocculation are generally not used, remaining suspended solids being reduced by following stages of the system. However, coagulation and flocculation can be used for building a compact treatment plant (also called a "package treatment plant"), or for further polishing of the treated water.

In the Activated Sludge treatment process, flocs being created through biological activity are collected in sedimentation tanks, generally referred to as *Secondary Clarifiers* or Secondary Sedimentation Tanks.

**Technology**

Sedimentation tanks can be of different shapes, often rectangular or circular. They are sized in order to have an optimal sedimentation speed. If sedimentation speed is too high, most particles
will not have sufficient time to settle, and will be carried with the treated water. If the speed is too low, the tanks will be of an excessive size.

As turbulence is a damaging factor leading settled particles to go back in suspension, several devices are used to ensure a quiet flow, such as carefully designed water inlet with baffles.

Sedimentation may be made more efficient by the use of stacks of flat pieces that slope slightly upwards in the direction of flow, called lamellar separators. They are parallel and separated by a small distance. These structures work in two ways:

1. They provide a very large surface area onto which particles may fall and become stabilized.
2. Because flow is temporarily accelerated between the plates and then immediately slows down, this helps to aggregate very fine particles that can settle as the flow exits the plates.

The use of lamellar separators may allow the use of a smaller sedimentation tank and may enable finer particles to be separated. Typically such structures are used for difficult-to-treat waters, especially those containing colloidal materials.

Water purification

Water purification is the process of removing undesirable chemicals, materials, and biological contaminants from contaminated water. The goal is to produce water fit for a specific purpose. Most water is purified for human consumption (drinking water) but water purification may also be designed for a variety of other purposes, including meeting the requirements of medical, pharmacology, chemical and industrial applications. In general the methods used include physical processes such as filtration and sedimentation, biological processes such as slow sand filters or activated sludge, chemical processes such as flocculation and chlorination and the use of electromagnetic radiation such as ultraviolet light.

The purification process of water may reduce the concentration of particulate matter including suspended particles, parasites, bacteria, algae, viruses, fungi; and a range of dissolved and particulate material derived from the surfaces that water may have made contact with after falling as rain.

The standards for drinking water quality are typically set by governments or by international standards. These standards will typically set minimum and maximum concentrations of contaminants for the use that is to be made of the water.

It is not possible to tell whether water is of an appropriate quality by visual examination. Simple procedures such as boiling or the use of a household activated carbon filter are not sufficient for treating all the possible contaminants that may be present in water from an unknown source. Even natural spring water – considered safe for all practical purposes in the 19th century – must now be tested before determining what kind of treatment, if any, is needed. Chemical analysis, while expensive, is the only way to obtain the information necessary for deciding on the appropriate method of purification.
According to a 2007 World Health Organization report, 1.1 billion people lack access to an improved drinking water supply, 88% of the 4 billion annual cases of diarrheal disease are attributed to unsafe water and inadequate sanitation and hygiene, and 1.8 million people die from diarrheal diseases each year. The WHO estimates that 94% of these diarrheal cases are preventable through modifications to the environment, including access to safe water.  

Simple techniques for treating water at home, such as chlorination, filters, and solar disinfection, and storing it in safe containers could save a huge number of lives each year. Reducing deaths from waterborne diseases is a major public health goal in developing countries.

Sources of water

1. **Groundwater**: The water emerging from some deep ground water may have fallen as rain many tens, hundreds, thousands of years ago. Soil and rock layers naturally filter the ground water to a high degree of clarity before the treatment plant. Such water may emerge as springs, artesian springs, or may be extracted from boreholes or wells. Deep ground water is generally of very high bacteriological quality (i.e., pathogenic bacteria or the pathogenic protozoa are typically absent), but the water typically is rich in dissolved solids, especially carbonates and sulfates of calcium and magnesium. Depending on the strata through which the water has flowed, other ions may also be present including chloride, and bicarbonate. There may be a requirement to reduce the iron or manganese content of this water to make it pleasant for drinking, cooking, and laundry use. Disinfection may also be required. Where groundwater recharge is practised; a process in which river water is injected into an aquifer to store the water in times of plenty so that it is available in times of drought; it is equivalent to lowland surface waters for treatment purposes.

2. **Upland lakes and reservoirs**: Typically located in the headwaters of river systems, upland reservoirs are usually sited above any human habitation and may be surrounded by a protective zone to restrict the opportunities for contamination. Bacteria and pathogen levels are usually low, but some bacteria, protozoa or algae will be present. Where uplands are forested or peaty, humic acids can colour the water. Many upland sources have low pH which require adjustment.

3. **Rivers, canals** and low land reservoirs: Low land surface waters will have a significant bacterial load and may also contain algae, suspended solids and a variety of dissolved constituents.

4. **Atmospheric water generation** is a new technology that can provide high quality drinking water by extracting water from the air by cooling the air and thus condensing water vapor.

5. **Rainwater harvesting** or fog collection which collects water from the atmosphere can be used especially in areas with significant dry seasons and in areas which experience fog even when there is little rain.

6. **Desalination of seawater** by distillation or reverse osmosis.

**Treatment**

The processes below are the ones commonly used in water purification plants. Some or most may not be used depending on the scale of the plant and quality of the water.

**Pre-treatment**
1. Pumping and containment – The majority of water must be pumped from its source or directed into pipes or holding tanks. To avoid adding contaminants to the water, this physical infrastructure must be made from appropriate materials and constructed so that accidental contamination does not occur.

2. Screening (see also screen filter) – The first step in purifying surface water is to remove large debris such as sticks, leaves, trash and other large particles which may interfere with subsequent purification steps. Most deep groundwater does not need screening before other purification steps.

3. Storage – Water from rivers may also be stored in bankside reservoirs for periods between a few days and many months to allow natural biological purification to take place. This is especially important if treatment is by slow sand filters. Storage reservoirs also provide a buffer against short periods of drought or to allow water supply to be maintained during transitory pollution incidents in the source river.

4. Pre-conditioning – Water rich in hardness salts is treated with soda-ash (sodium carbonate) to precipitate calcium carbonate out utilising the common-ion effect.

5. Pre-chlorination – In many plants the incoming water was chlorinated to minimise the growth of fouling organisms on the pipe-work and tanks. Because of the potential adverse quality effects (see chlorine below), this has largely been discontinued.

Widely varied techniques are available to remove the fine solids, micro-organisms and some dissolved inorganic and organic materials. The choice of method will depend on the quality of the water being treated, the cost of the treatment process and the quality standards expected of the processed water.

**pH adjustment**

Distilled water has a **pH** of 7 (neither alkaline nor acidic) and sea water has an average pH of 8.3 (slightly alkaline). If the water is acidic (lower than 7), lime, soda ash, or sodium hydroxide is added to raise the pH. For somewhat acidic waters (lower than 6.5), forced draft degasifiers are the cheapest way to raise the pH, as the process raises the pH by stripping dissolved carbon dioxide (carbonic acid) from the water. Lime is commonly used for pH adjustment for municipal water, or at the start of a treatment plant for process water, as it is cheap, but it also increases the ionic load by raising the water hardness. Making the water slightly alkaline ensures that coagulation and flocculation processes work effectively and also helps to minimize the risk of lead being dissolved from lead pipes and lead solder in pipe fittings. Acid (HCl or H2SO4) may be added to alkaline waters in some circumstances to lower the pH. Having alkaline water does not necessarily mean that lead or copper from the plumbing system will not be dissolved into the water but as a generality, water with a pH above 7 is much less likely to dissolve heavy metals than water with a pH below 7.
Floc floating at the surface of a basin

Mechanical system to push floc out of the water basin

**Flocculation**

*See also: Alum#Industrial*

Flocculation is a process which clarifies the water. Clarifying means removing any turbidity or colour so that the water is clear and colourless. Clarification is done by causing a precipitate to form in the water which can be removed using simple physical methods. Initially the precipitate forms as very small particles but as the water is gently stirred, these particles stick together to form bigger particles. Many of the small particles that were originally present in the raw water adsorb onto the surface of these small precipitate particles and so get incorporated into the larger particles that coagulation produces. In this way the coagulated precipitate takes most of the suspended matter out of the water and is then filtered off, generally by passing the mixture through a coarse sand filter or sometimes through a mixture of sand and granulated anthracite (high carbon and low volatiles coal). Coagulants / flocculating agents that may be used include:

1. **Iron (III) hydroxide.** This is formed by adding a solution of an iron (III) compound such as iron(III) chloride to pre-treated water with a pH of 7 or greater. Iron (III) hydroxide is extremely insoluble and forms even at a pH as low as 7. Commercial formulations of iron salts were traditionally marketed in the UK under the name Cuprus.
2. Aluminium hydroxide is also widely used as the flocculating precipitate although there have been concerns about possible health impacts and mis-handling led to a severe poisoning incident in 1988 at Camelford in south-west UK when the coagulant was introduced directly into the holding reservoir of final treated water.
3. PolyDADMAC is an artificially produced polymer and is one of a class of synthetic polymers that are now widely used. These polymers have a high molecular weight and form very stable and
readily removed flocs, but tend to be more expensive in use compared to inorganic materials. The materials can also be biodegradable.

**Sedimentation**

Waters exiting the flocculation basin may enter the sedimentation basin, also called a clarifier or settling basin. It is a large tank with slow flow, allowing floc to settle to the bottom. The sedimentation basin is best located close to the flocculation basin so the transit between does not permit settlement or floc break up. Sedimentation basins may be rectangular, where water flows from end to end, or circular where flow is from the centre outward. Sedimentation basin outflow is typically over a weir so only a thin top layer—that furthest from the sediment—exits. The amount of floc that settles out of the water is dependent on basin retention time and on basin depth. The retention time of the water must therefore be balanced against the cost of a larger basin. The minimum clarifier retention time is normally 4 hours. A deep basin will allow more floc to settle out than a shallow basin. This is because large particles settle faster than smaller ones, so large particles collide with and integrate smaller particles as they settle. In effect, large particles sweep vertically through the basin and clean out smaller particles on their way to the bottom.

As particles settle to the bottom of the basin, a layer of sludge is formed on the floor of the tank. This layer of sludge must be removed and treated. The amount of sludge that is generated is significant, often 3 to 5 percent of the total volume of water that is treated. The cost of treating and disposing of the sludge can be a significant part of the operating cost of a water treatment plant. The tank may be equipped with mechanical cleaning devices that continually clean the bottom of the tank or the tank can be taken out of service when the bottom needs to be cleaned.

**Filtration**

After separating most floc, the water is filtered as the final step to remove remaining suspended particles and unsettled floc.

*Rapid sand filters*

![Cutaway view of a typical rapid sand filter](image)

The most common type of filter is a rapid sand filter. Water moves vertically through sand which often has a layer of activated carbon or anthracite coal above the sand. The top layer removes
organic compounds, which contribute to taste and odour. The space between sand particles is larger than the smallest suspended particles, so simple filtration is not enough. Most particles pass through surface layers but are trapped in pore spaces or adhere to sand particles. Effective filtration extends into the depth of the filter. This property of the filter is key to its operation: if the top layer of sand were to block all the particles, the filter would quickly clog.

To clean the filter, water is passed quickly upward through the filter, opposite the normal direction (called backflushing or backwashing) to remove embedded particles. Prior to this, compressed air may be blown up through the bottom of the filter to break up the compacted filter media to aid the backwashing process; this is known as air scouring. This contaminated water can be disposed of, along with the sludge from the sedimentation basin, or it can be recycled by mixing with the raw water entering the plant although this is often considered poor practice since it re-introduces an elevated concentration of bacteria into the raw water.

Some water treatment plants employ pressure filters. These work on the same principle as rapid gravity filters, differing in that the filter medium is enclosed in a steel vessel and the water is forced through it under pressure.

Advantages:

- Filters out much smaller particles than paper and sand filters can.
- Filters out virtually all particles larger than their specified pore sizes.
- They are quite thin and so liquids flow through them fairly rapidly.
- They are reasonably strong and so can withstand pressure differences across them of typically 2–5 atmospheres.

**Membrane filtration**

Membrane filters are widely used for filtering both drinking water and sewage. For drinking water, membrane filters can remove virtually all particles larger than 0.2 um—including giardia and cryptosporidium. Membrane filters are an effective form of tertiary treatment when it is desired to reuse the water for industry, for limited domestic purposes, or before discharging the water into a river that is used by towns further downstream. They are widely used in industry, particularly for beverage preparation (including bottled water). However no filtration can remove substances that are actually dissolved in the water such as phosphorus, nitrates and heavy metal ions.

**Slow sand filters**

![Slow sand filters](www.studentsfocus.com)
Slow "artificial" filtration (a variation of bank filtration) to the ground, Water purification plant Káraný, Czech Republic

Slow sand filters may be used where there is sufficient land and space as the water must be passed very slowly through the filters. These filters rely on biological treatment processes for their action rather than physical filtration. The filters are carefully constructed using graded layers of sand with the coarsest sand, along with some gravel, at the bottom and finest sand at the top. Drains at the base convey treated water away for disinfection. Filtration depends on the development of a thin biological layer, called the zoogaeal layer or Schmutzdecke, on the surface of the filter. An effective slow sand filter may remain in service for many weeks or even months if the pre-treatment is well designed and produces water with a very low available nutrient level which physical methods of treatment rarely achieve. Very low nutrient levels allow water to be safely sent through distribution system with very low disinfectant levels thereby reducing consumer irritation over offensive levels of chlorine and chlorine by-products. Slow sand filters are not backwashed; they are maintained by having the top layer of sand scraped off when flow is eventually obstructed by biological growth. [citation needed]

A specific 'large-scale' form of slow sand filter is the process of bank filtration, in which natural sediments in a riverbank are used to provide a first stage of contaminant filtration. While typically not clean enough to be used directly for drinking water, the water gained from the associated extraction wells is much less problematic than river water taken directly from the major streams where bank filtration is often used.

**Removal of ions and other dissolved substances**

Ultrafiltration membranes use polymer membranes with chemically formed microscopic pores that can be used to filter out dissolved substances avoiding the use of coagulants. The type of membrane media determines how much pressure is needed to drive the water through and what sizes of micro-organisms can be filtered out.

**Ion exchange:** Ion exchange systems use ion exchange resin- or zeolite-packed columns to replace unwanted ions. The most common case is water softening consisting of removal of \( \text{Ca}^{2+} \) and \( \text{Mg}^{2+} \) ions replacing them with benign (soap friendly) Na or K ions. Ion exchange resins are also used to remove toxic ions such as nitrate, nitrite, lead, mercury, arsenic and many others.

**Electrodeionization:** Water is passed between a positive electrode and a negative electrode. Ion exchange membranes allow only positive ions to migrate from the treated water toward the negative electrode and only negative ions toward the positive electrode. High purity deionized water is produced with a little worse degree of purification in comparison with ion exchange treatment. Complete removal of ions from water is regarded as electrodialysis. The water is often pre-treated with a reverse osmosis unit to remove non-ionic organic contaminants.

**Other mechanical and biological techniques**

*See also: Greywater and Ecological sanitation*
In addition to the many techniques used in large-scale water treatment, several small-scale, less (or non)-polluting techniques are also being used to treat polluted water. These techniques include those based on mechanical and biological processes. An overview:

- mechanical systems: sand filtration, lava filter systems and systems based on UV-radiation
- biological systems:
  - plant systems as constructed wetlands and treatment ponds (sometimes incorrectly called reedbeds and living walls) and
  - compact systems as activated sludge systems, biorotors, aerobic biofilters and anaerobic biofilters, submerged aerated filters, and biorolls

In order to purify the water adequately, several of these systems are usually combined to work as a whole. Combination of the systems is done in two to three stages, namely primary and secondary purification. Sometimes tertiary purification is also added.

**Disinfection**

Disinfection is accomplished both by filtering out harmful microbes and also by adding disinfectant chemicals in the last step in purifying drinking water. Water is disinfected to kill any pathogens which pass through the filters. Possible pathogens include viruses, bacteria, including *Escherichia coli*, *Campylobacter* and *Shigella*, and protozoa, including *Giardia lamblia* and other *cryptosporidium*. In most developed countries, public water supplies are required to maintain a residual disinfecting agent throughout the distribution system, in which water may remain for days before reaching the consumer. Following the introduction of any chemical disinfecting agent, the water is usually held in temporary storage – often called a contact tank or clear well to allow the disinfecting action to complete.

**Chlorine disinfection**

*Main article: Chlorination*

The most common disinfection method involves some form of chlorine or its compounds such as chloramine or chlorine dioxide. Chlorine is a strong oxidant that rapidly kills many harmful micro-organisms. Because chlorine is a toxic gas, there is a danger of a release associated with its use. This problem is avoided by the use of sodium hypochlorite, which is a relatively inexpensive solution that releases free chlorine when dissolved in water. Chlorine solutions can be generated on site by electrolyzing common salt solutions. A solid form, calcium hypochlorite exists that releases chlorine on contact with water. Handling the solid, however, requires greater routine human contact through opening bags and pouring than the use of gas cylinders or bleach which are more easily automated. The generation of liquid sodium hypochlorite is both inexpensive and safer than the use of gas or solid chlorine. All forms of chlorine are widely used despite their respective drawbacks. One drawback is that chlorine from any source reacts with natural organic compounds in the water to form potentially harmful chemical by-products trihalomethanes (THMs) and haloacetic acids (HAAs), both of which are carcinogenic in large quantities and regulated by the United States Environmental Protection Agency (EPA) and the Drinking Water Inspectorate in the UK. The formation of THMs and haloacetic acids may be
minimized by effective removal of as many organics from the water as possible prior to chlorine addition. Although chlorine is effective in killing bacteria, it has limited effectiveness against protozoa that form cysts in water (*Giardia lamblia* and *Cryptosporidium*, both of which are pathogenic).

**Chlorine dioxide disinfection**

Chlorine dioxide is a faster-acting disinfectant than elemental chlorine, however it is relatively rarely used, because in some circumstances it may create excessive amounts of chlorite, which is a by-product regulated to low allowable levels in the United States. Chlorine dioxide is supplied as an aqueous solution and added to water to avoid gas handling problems; chlorine dioxide gas accumulations may spontaneously detonate.

**Chloramine disinfection**

The use of chloramine is becoming more common as a disinfectant. Although chloramine is not as strong an oxidant, it does provide a longer-lasting residual than free chlorine and it won't form THMs or haloacetic acids. It is possible to convert chlorine to chloramine by adding ammonia to the water after addition of chlorine. The chlorine and ammonia react to form chloramine. Water distribution systems disinfected with chloramines may experience nitrification, as ammonia is a nutrient for bacterial growth, with nitrates being generated as a by-product.

/Ozone disinfection/

Ozone is an unstable molecule which readily gives up one atom of oxygen providing a powerful oxidizing agent which is toxic to most waterborne organisms. It is a very strong, broad spectrum disinfectant that is widely used in Europe. It is an effective method to inactivate harmful protozoa that form cysts. It also works well against almost all other pathogens. Ozone is made by passing oxygen through ultraviolet light or a "cold" electrical discharge. To use ozone as a disinfectant, it must be created on-site and added to the water by bubble contact. Some of the advantages of ozone include the production of fewer dangerous by-products (in comparison to chlorination) and the lack of taste and odour produced by ozonisation. Although fewer by-products are formed by ozonation, it has been discovered that the use of ozone produces a small amount of the suspected carcinogen bromate, although little bromine should be present in treated water. Another of the main disadvantages of ozone is that it leaves no disinfectant residual in the water. Ozone has been used in drinking water plants since 1906 where the first industrial ozonation plant was built in Nice, France. The U.S. Food and Drug Administration has accepted ozone as being safe; and it is applied as an anti-microbiological agent for the treatment, storage, and processing of foods.

**Ultraviolet disinfection**

Ultraviolet light is very effective at inactivating cysts, in low turbidity water. UV light's disinfection effectiveness decreases as turbidity increases, a result of the absorption, scattering, and shadowing caused by the suspended solids. The main disadvantage to the use of UV...
radiation is that, like ozone treatment, it leaves no residual disinfectant in the water; therefore, it is sometimes necessary to add a residual disinfectant after the primary disinfection process. This is often done through the addition of chloramines, discussed above as a primary disinfectant. When used in this manner, chloramines provide an effective residual disinfectant with very few of the negative aspects of chlorination.

**Hydrogen peroxide disinfection**

Works in a similar way to ozone. Activators such as formic acid are often added to increase the efficacy of disinfection. It has the disadvantages that it is slow-working, phytotoxic in high dosage, and decreases the pH of the water it purifies.

**Various portable methods of disinfection**

Available for disinfection in emergencies or in remote locations. Disinfection is the primary goal, since aesthetic considerations such as taste, odour, appearance, and trace chemical contamination do not affect the short-term safety of drinking water.

**Solar water disinfection**

One low-cost method of disinfecting water that can often be implemented with locally available materials is solar disinfection (SODIS). Unlike methods that rely on firewood, it has low impact on the environment.

One recent study has found that the wild Salmonella which would reproduce quickly during subsequent dark storage of solar-disinfected water could be controlled by the addition of just 10 parts per million of hydrogen peroxide.

**Additional treatment options**

1. **Water fluoridation**: in many areas fluoride is added to water with the goal of preventing tooth decay. Fluoride is usually added after the disinfection process. In the U.S., fluoridation is usually accomplished by the addition of hexafluorosilicic acid, which decomposes in water, yielding fluoride ions.
2. **Water conditioning**: This is a method of reducing the effects of hard water. Hardness salts are deposited in water systems subject to heating because the decomposition of bicarbonate ions creates carbonate ions that crystallise out of the saturated solution of calcium or magnesium carbonate. Water with high concentrations of hardness salts can be treated with soda ash (sodium carbonate) which precipitates out the excess salts, through the common-ion effect, producing calcium carbonate of very high purity. The precipitated calcium carbonate is traditionally sold to the manufacturers of toothpaste. Several other methods of industrial and residential water treatment are claimed (without general scientific acceptance) to include the use of magnetic or electrical fields reducing the effects of hard water.
3. **Plumbosolvency reduction**: In areas with naturally acidic waters of low conductivity (i.e. surface rainfall in upland mountains of igneous rocks), the water may be capable of dissolving lead from
any lead pipes that it is carried in. The addition of small quantities of phosphate ion and increasing the pH slightly both assist in greatly reducing plumbo-solvency by creating insoluble lead salts on the inner surfaces of the pipes.

4. Radium Removal: Some groundwater sources contain radium, a radioactive chemical element. Typical sources include many groundwater sources north of the Illinois River in Illinois. Radium can be removed by ion exchange, or by water conditioning. The back flush or sludge that is produced is, however, a low-level radioactive waste.

5. Fluoride Removal: Although fluoride is added to water in many areas, some areas of the world ave excessive levels of natural fluoride in the source water. Excessive levels can be toxic or cause undesirable cosmetic effects such as staining of teeth. Methods of reducing fluoride levels is through treatment with activated alumina and bone charcoal filter media.

Other water purification techniques

Other popular methods for purifying water, especially for local private supplies are listed below. In some countries some of these methods are also used for large scale municipal supplies. Particularly important are distillation (de-salination of seawater) and reverse osmosis.

1. Boiling: Water is heated hot enough and long enough to inactivate or kill micro-organisms that normally live in water at room temperature. Near sea level, a vigorous rolling boil for at least one minute is sufficient. At high altitudes (greater than two kilometres or 5000 feet) three minutes is recommended. In areas where the water is "hard" (that is, containing significant dissolved calcium salts), boiling decomposes the bicarbonate ions, resulting in partial precipitation as calcium carbonate. This is the "fur" that builds up on kettle elements, etc., in hard water areas. With the exception of calcium, boiling does not remove solutes of higher boiling point than water and in fact increases their concentration (due to some water being lost as vapour). Boiling does not leave a residual disinfectant in the water. Therefore, water that has been boiled and then stored for any length of time may have acquired new pathogens.

2. Granular Activated Carbon filtering: a form of activated carbon with a high surface area, adsorbs many compounds including many toxic compounds. Water passing through activated carbon is commonly used in municipal regions with organic contamination, taste or odors. Many household water filters and fish tanks use activated carbon filters to further purify the water. Household filters for drinking water sometimes contain silver as metallic silver nanoparticle. if water is held in the carbon block for longer period, microorganisms can grow inside which results in fouling and contamination. Silver nanoparticles are excellent anti-bacterial material and they can decompose toxic halo-organic compounds such as pesticides into non-toxic organic products.

3. Distillation involves boiling the water to produce water vapour. The vapour contacts a cool surface where it condenses as a liquid. Because the solutes are not normally vaporised, they remain in the boiling solution. Even distillation does not completely purify water, because of contaminants with similar boiling points and droplets of unvapourised liquid carried with the steam. However, 99.9% pure water can be obtained by distillation.

4. Reverse osmosis: Mechanical pressure is applied to an impure solution to force pure water through a semi-permeable membrane. Reverse osmosis is theoretically the most thorough method of large scale water purification available, although perfect semi-permeable membranes are difficult to create. Unless membranes are well-maintained, algae and other life forms can colonize the membranes.

www.studentsfocus.com
5. The use of iron in removing arsenic from water. See Arsenic contamination of groundwater.

6. Direct contact membrane distillation (DCMD). Applicable to desalination. Heated seawater is passed along the surface of a hydrophobic polymer membrane. Evaporated water passes from the hot side through pores in the membrane into a stream of cold pure water on the other side. The difference in vapour pressure between the hot and cold side helps to push water molecules through.

7. Gas hydrate crystals centrifuge method. If carbon dioxide gas is mixed with contaminated water at high pressure and low temperature, gas hydrate crystals will contain only clean water. This is because the water molecules bind to the gas molecules at molecular level. The contaminated water is in liquid form. A centrifuge may be used to separate the crystals and the concentrated contaminated water.

8. In Situ Chemical Oxidation, a form of advanced oxidation processes and advanced oxidation technology, is an environmental remediation technique used for soil and/or groundwater remediation to reduce the concentrations of targeted environmental contaminants to acceptable levels. ISCO is accomplished by injecting or otherwise introducing strong chemical oxidizers directly into the contaminated medium (soil or groundwater) to destroy chemical contaminants in place. It can be used to remediate a variety of organic compounds, including some that are resistant to natural degradation.

**Hydrogen production**

For the small scale production of hydrogen, water purifiers are installed to prevent formation of minerals on the surface of the electrodes and to remove organics and chlorine from utility water. First, the water passes through a 20 micrometre interference (mesh or screen filter) filter to remove sand and dust particles, then a charcoal filter using activated carbon to remove organics and chlorine and finally a de-ionizing filter to remove metallic ions. Testing can be done before and after the filter to verify the proper removal of barium, calcium, potassium, magnesium.
UNIT-IV ADVANCED WATER TREATMENT

INTRODUCTION

Aeration is a unit process in which air and water are brought into intimate contact. Turbulence increases the aeration of flowing streams (Figure 4-1). In industrial processes, water flow is usually directed countercurrent to atmospheric or forced-draft air flow. The contact time and the ratio of air to water must be sufficient for effective removal of the unwanted gas.

Aeration as a water treatment practice is used for the following operations:

- carbon dioxide reduction (decarbonation)
- oxidation of iron and manganese found in many well waters (oxidation tower)
- ammonia and hydrogen sulfide reduction (stripping)

Aeration is also an effective method of bacteria control.

METHODS OF AERATION

Two general methods may be used for the aeration of water. The most common in industrial use is the water-fall aerator. Through the use of spray nozzles, the water is broken up into small droplets or a thin film to enhance countercurrent air contact.

In the air diffusion method of aeration, air is diffused into a receiving vessel containing countercurrent flowing water, creating very small air bubbles. This ensures good air-water contact for "scrubbing" of undesirable gases from the water.

Water-Fall Aerators

Many variations of the water-fall principle are used for this type of aeration. The simplest configuration employs a vertical riser that discharges water by free fall into a basin (Figure 4-2). The riser usually operates on the available head of water. The efficiency of aeration is improved as the fall distance is increased. Also, steps or shelves may be added to break up the fall and spread the water into thin sheets or films, which increases contact time and aeration efficiency.
Coke tray and wood or plastic slat water-fall aerators are relatively similar in design and have the advantage of small space requirements.

Coke tray aerators are widely used in iron and manganese oxidation because a catalytic effect is secured by contact of the iron/manganese-bearing water with fresh precipitates. These units consist of a series of coke-filled trays through which the water percolates, with additional aeration obtained during the free fall from one tray to the next.

Wood or plastic slat tray aerators are similar to small atmospheric cooling towers. The tray slats are staggered to break up the free fall of the water and create thin films before the water finally drops into the basin.

Forced draft water-fall aerators (see Figure 4-3) are used for many industrial water conditioning purposes. Horizontal wood or plastic slat trays, or towers filled with packing of various shapes and materials, are designed to maximize disruption of the falling water into small streams for greater air-water contact. Air is forced through the unit by a blower which produces uniform air distribution across the entire cross section, cross current or countercurrent to the fall of the water. Because of these features, forced draft aerators are more efficient for gas removal and require less space for a given capacity.

**Air Diffusion Aerators**

Air diffusion systems aerate by pumping air into water through perforated pipes, strainers, porous plates, or tubes. Aeration by diffusion is theoretically superior to water-fall aeration because a fine bubble of air rising through water is continually exposed to fresh liquid surfaces, providing maximum water surface per unit volume of air. Also, the velocity of bubbles ascending through the water is much lower than the velocity of free-falling drops of water, providing a longer contact time. Greatest efficiency is achieved when water flow is countercurrent to the rising air bubbles.

**APPLICATIONS**

In industrial water conditioning, one of the major objectives of aeration is to remove carbon dioxide. Aeration is also used to oxidize soluble iron and manganese (found in many well waters) to insoluble precipitates. Aeration is often used to reduce the carbon dioxide liberated by a treatment process. For example, acid may be fed to the effluent of sodium zeolite softeners for boiler alkalinity control. Carbon dioxide is produced as a result of the acid treatment, and aeration is employed to rid the water of this corrosive gas. Similarly, when the effluents of hydrogen and sodium zeolite units are blended, the carbon dioxide formed is removed by aeration.

In the case of cold lime softening, carbon dioxide may be removed from the water before the water enters the equipment. When carbon dioxide removal is the only objective, economics usually favor removal of high concentrations of carbon dioxide by aeration rather than by chemical precipitation with lime.

Air stripping may be used to reduce concentrations of volatile organics, such as chloroform, as well as dissolved gases, such as hydrogen sulfide and ammonia. Air pollution standards must be considered when air stripping is used to reduce volatile organic compounds.
Iron and Manganese Removal

Iron and manganese in well waters occur as soluble ferrous and manganous bicarbonates. In the aeration process, the water is saturated with oxygen to promote the following reactions:

\[
4\text{Fe(HCO}_3\text{)}_2 + \text{O}_2 + 2\text{H}_2\text{O} = 4\text{Fe(OH)}_3^- + 8\text{CO}_2
\]

ferrous bicarbonate oxygen water ferric hydroxide carbon dioxide

\[
2\text{Mn(HCO}_3\text{)}_2 + \text{O}_2 = 2\text{MnO}_2 + 4\text{CO}_2^- + 2\text{H}_2\text{O}
\]
manganese bicarbonate oxygen manganese dioxide carbon water

The oxidation products, ferric hydroxide and manganese dioxide, are insoluble. After aeration, they are removed by clarification or filtration.

Occasionally, strong chemical oxidants such as chlorine (Cl\textsubscript{2}) or potassium permanganate (KMnO\textsubscript{4}) may be used following aeration to ensure complete oxidation.

Dissolved Gas Reduction

Gases dissolved in water follow the principle that the solubility of a gas in a liquid (water) is directly proportional to the partial pressure of the gas above the liquid at equilibrium. This is known as Henry's Law and may be expressed as follows:

\[
C_\text{total} = kP
\]

where

\[
C_\text{total} = \text{total concentration of the gas in solution}
\]

\[
P = \text{partial pressure of the gas above the solution}
\]

\[
k = \text{a proportionality constant known as Henry's Law Constant}
\]

However, the gases frequently encountered in water treatment (with the exception of oxygen) do not behave in accordance with Henry's Law because they ionize when dissolved in water. For example:

\[
\text{H}_2\text{O} + \text{CO}_2 \rightleftharpoons \text{H}^+ + \text{HCO}_3^- \]

water carbon dioxide hydrogen ion bicarbonate ion

\[
\text{H}_2\text{S} \rightleftharpoons \text{H}^+ + \text{HS}^- \]

hydrogen sulfide hydrogen ion hydrosulfide ion
\[
\text{H}_2\text{O} + \text{NH}_3 \rightleftharpoons \text{NH}_4^+ + \text{OH}^-
\]

Water  ammonia  ammonium  hydroxide

ion  ion

Carbon dioxide, hydrogen sulfide, and ammonia are soluble in water under certain conditions to the extent of 1,700, 3,900, and 531,000 ppm, respectively. Rarely are these concentrations encountered except in certain process condensates. In a normal atmosphere, the partial pressure of each of these gases is practically zero. Consequently, the establishment of a state of equilibrium between water and air by means of aeration results in saturation of the water with nitrogen and oxygen and nearly complete removal of other gases.

As the equations above show, ionization of the gases in water is a reversible reaction. The common ion effect may be used to obtain almost complete removal of these gases by aeration. If the concentration of one of the ions on the right side of the equation is increased, the reaction is driven to the left, forming the gas. In the case of carbon dioxide and hydrogen sulfide, hydrogen ion concentration may be increased by the addition of an acid. Bicarbonate and carbonate ions in the water will form carbon dioxide, which can be removed by aeration.

In a similar manner, an increase in hydroxyl ion concentration through the addition of caustic soda aids in the removal of ammonia.

Figures 4-4, 4-5, and 4-6 show the percentage of gas removal that may be obtained at various pH levels.

Gas removal by aeration is achieved as the level of gas in the water approaches equilibrium with the level of the gas in the surrounding atmosphere. The process is improved by an increase in temperature, aeration time, the volume of air in contact with the water, and the surface area of water exposed to the air. As previously indicated, pH is an important consideration. The efficiency of aeration is greater where the concentration of the gas to be removed is high in the water and low in the atmosphere.

**LIMITATIONS**

Temperature significantly affects the efficiency of air stripping processes. Therefore, these processes may not be suitable for use in colder climates. Theoretically, at 68°F the carbon dioxide content of the water can be reduced to 0.5 ppm by aeration to equilibrium conditions. This is not always practical from an economic standpoint, and reduction of carbon dioxide to 10 ppm is normally considered satisfactory.

Although removal of free carbon dioxide increases the pH of the water and renders it less corrosive from this standpoint, aeration also results in the saturation of water with dissolved oxygen. This does not generally present a problem when original oxygen content is already high. However, in the case of a well water supply that is high in carbon dioxide but devoid of oxygen, aeration simply exchanges one corrosive gas for another.

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The efficiency of aeration increases as the initial concentration of the gas to be removed increases above its equilibrium value. Therefore, with waters containing only a small amount of carbon dioxide, neutralization by alkali addition is usually more cost-effective.

The complete removal of hydrogen sulfide must be combined with pH reduction or chemical oxidation.

Nonvolatile organic compounds cannot be removed by air stripping. For example, phenols and creosols are unaffected by the aeration process alone.

Suspended matter in raw water supplies is removed by various methods to provide a water suitable for domestic purposes and most industrial requirements. The suspended matter can consist of large solids, settleable by gravity alone without any external aids, and nonsettleable material, often colloidal in nature. Removal is generally accomplished by coagulation, flocculation, and sedimentation. The combination of these three processes is referred to as conventional clarification.

Coagulation is the process of destabilization by charge neutralization. Once neutralized, particles no longer repel each other and can be brought together. Coagulation is necessary for the removal of the colloidal-sized suspended matter.

Flocculation is the process of bringing together the destabilized, or "coagulated," particles to form a larger agglomeration, or "floc."

Sedimentation refers to the physical removal from suspension, or settling, that occurs once the particles have been coagulated and flocculated. Sedimentation or subsidence alone, without prior coagulation, results in the removal of only relatively coarse suspended solids.

**Steps of Clarification**

Finely divided particles suspended in surface water repel each other because most of the surfaces are negatively charged. The following steps in clarification are necessary for particle agglomeration:

- **Coagulation.** Coagulation can be accomplished through the addition of inorganic salts of aluminum or iron. These inorganic salts neutralize the charge on the particles causing raw water turbidity, and also hydrolyze to form insoluble precipitates, which entrap particles. Coagulation can also be effected by the addition of water-soluble organic polymers with numerous ionized sites for particle charge neutralization.

- **Flocculation.** Flocculation, the agglomeration of destabilized particles into large particles, can be enhanced by the addition of high-molecular-weight, water-soluble organic polymers. These polymers increase floc size by charged site binding and by molecular bridging.

Therefore, coagulation involves neutralizing charged particles to destabilize suspended solids. In most clarification processes, a flocculation step then follows. Flocculation starts when neutralized or entrapped particles begin to collide and fuse to form larger particles. This process can occur naturally or can be enhanced by the addition of polymeric flocculant aids.

**Inorganic Coagulants**
Table 5-1 lists a number of common inorganic coagulants. Typical iron and aluminum coagulants are acid salts that lower the pH of the treated water by hydrolysis. Depending on initial raw water alkalinity and pH, an alkali such as lime or caustic must be added to counteract the pH depression of the primary coagulant. Iron and aluminum hydrolysis products play a significant role in the coagulation process, especially in cases where low-turbidity influent waters benefit from the presence of additional collision surface areas.

Table 5-1. Common inorganic coagulants

<table>
<thead>
<tr>
<th>Name</th>
<th>Typical Formula</th>
<th>Typical Strength</th>
<th>Typical Forms Used in Water Treatment</th>
<th>Density</th>
<th>Typical Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum sulfate</td>
<td>Al(SO₄)₃</td>
<td>17% Al₂O₃</td>
<td>lump, granular, or powder</td>
<td>60-70 lb/ft³</td>
<td>primary coagulant</td>
</tr>
<tr>
<td>Alum</td>
<td>AlCl₃·6H₂O</td>
<td>8.25% Al₂O₃</td>
<td>liquid</td>
<td>11.1 lb/gal</td>
<td>primary coagulant</td>
</tr>
<tr>
<td>Aluminum chloride</td>
<td></td>
<td>35% AlCl₃</td>
<td>liquid</td>
<td>12.5 lb/gal</td>
<td>primary coagulant</td>
</tr>
<tr>
<td>Ferric sulfate</td>
<td>Fe₂(SO₄)₃·9H₂O</td>
<td>68% Fe₂O₃</td>
<td>granular</td>
<td>70-72 lb/ft³</td>
<td>primary coagulant</td>
</tr>
<tr>
<td>Ferric-floc Fe</td>
<td>(SO₄)₃·9H₂O</td>
<td>41% Fe₃O₄</td>
<td>solution</td>
<td>12.3 lb/gal</td>
<td>primary coagulant</td>
</tr>
<tr>
<td>Ferric chloride</td>
<td>FeCl₃</td>
<td>60% FeCl₃, 35-45%</td>
<td>crystal, solution</td>
<td>60-64 lb/ft³</td>
<td>primary coagulant</td>
</tr>
<tr>
<td>Sodium aluminate</td>
<td>Na₂AlO₄</td>
<td>38-46% Na₂AlO₄</td>
<td>liquid</td>
<td>12.3-12.9 lb/gal</td>
<td>primary coagulant; cold/hot precipitation softening</td>
</tr>
</tbody>
</table>

Variation in pH affects particle surface charge and floc precipitation during coagulation. Iron and aluminum hydroxide flocs are best precipitated at pH levels that minimize the coagulant solubility. However, the best clarification performance may not always coincide with the optimum pH for hydroxide floc formation. Also, the iron and aluminum hydroxide flocs increase volume requirements for the disposal of settled sludge.

With aluminum sulfate, optimum coagulation efficiency and minimum floc solubility normally occur at pH 6.0 to 7.0. Iron coagulants can be used successfully over the much broader pH range of 5.0 to 11.0. If ferrous compounds are used, oxidation to ferric iron is needed for complete precipitation. This may require either chlorine addition or pH adjustment. The chemical reactions between the water's alkalinity (natural or supplemented) and aluminum or iron result in the formation of the hydroxide coagulant as in the following:

$$\text{Al}_2\text{SO}_4 + 6\text{NaHCO}_3 = 2\text{Al(OH)}_3 + 3\text{Na}_2\text{SO}_4 + 6\text{CO}_2$$
### Polyelectrolytes

The term polyelectrolytes refers to all water-soluble organic polymers used for clarification, whether they function as coagulants or flocculants.

Water-soluble polymers may be classified as follows:

- **Anionic**: Ionize in water solution to form negatively charged sites along the polymer chain
- **Cationic**: Ionize in water solution to form positively charged sites along the polymer chain
- **Nonionic**: Ionize in water solution to form very slight negatively charged sites along the polymer chain

Polymeric primary coagulants are cationic materials with relatively low molecular weights (under 500,000). The cationic charge density (available positively charged sites) is very high. Polymeric flocculants or coagulant aids may be anionic, cationic, or nonionic. Their molecular weights may be as high as 50,000,000. Table 5-2 describes some typical organic polyelectrolytes.

For any given particle there is an ideal molecular weight and an ideal charge density for optimum coagulation. There is also an optimum charge density and molecular weight for the most efficient flocculant.

Because suspensions are normally nonuniform, specific testing is necessary to find the coagulants and flocculants with the broadest range of performance.

### Primary Coagulant Polyelectrolytes

The cationic polyelectrolytes commonly used as primary coagulants are polyamines and poly-(DADMACS). They exhibit strong cationic ionization and typically have molecular weights of less than 500,000. When used as primary coagulants, they adsorb on particle surfaces, reducing the repelling negative charges. These polymers may also bridge, to some extent, from one particle to another but are not particularly effective flocculants. The use of polyelectrolytes permits water clarification without the precipitation of additional hydroxide solids formed by inorganic coagulants. The pH of the treated water is unaffected.
The efficiency of primary coagulant poly-electrolytes depends greatly on the nature of the turbidity particles to be coagulated, the amount of turbidity present, and the mixing or reaction energies available during coagulation. With lower influent turbidities, more turbulence or mixing is required to achieve maximum charge neutralization.

Raw waters of less than 10 NTU (Nephelometric Turbidity Units) usually cannot be clarified with a cationic polymer alone. Best results are obtained by a combination of an inorganic salt and cationic polymer. In-line clarification should be considered for raw waters with low turbidities.

Generally, waters containing 10 to 60 NTU are most effectively treated with an inorganic coagulant and cationic polymer. In most cases, a significant portion of the inorganic coagulant demand can be met with the cationic polyelectrolyte. With turbidity greater than 60 NTU, a polymeric primary coagulant alone is normally sufficient.

In low-turbidity waters where it is desirable to avoid using an inorganic coagulant, artificial turbidity can be added to build floc. Bentonite clay is used to increase surface area for adsorption and entrapment of finely divided turbidity. A polymeric coagulant is then added to complete the coagulation process.

The use of organic polymers offers several advantages over the use of inorganic coagulants:

- The amount of sludge produced during clarification can be reduced by 50-90%. The approximate dry weight of solids removed per pound of dry alum and ferric sulfate are approximately 0.25 and 0.5 lb, respectively.
- The resulting sludge contains less chemically bound water and can be more easily dewatered.
- Polymeric coagulants do not affect pH. Therefore, the need for supplemental alkalinity, such as lime, caustic, or soda ash, is reduced or eliminated.
- Polymeric coagulants do not add to the total dissolved solids concentration. For example, 1 ppm of alum adds 0.45 ppm of sulfate ion (expressed as CaCO3). The reduction in sulfate can significantly extend the capacity of anion exchange systems.
- Soluble iron or aluminum carryover in the clarifier effluent may result from inorganic coagulant use. Therefore, elimination of the inorganic coagulant can minimize the deposition of these metals in filters, ion exchange units, and cooling systems.

**Coagulant Aids (Flocculants)**

In certain instances, an excess of primary coagulant (whether inorganic, polymeric, or a combination of both) may be fed to promote large floc size and to increase settling rate. However, in some waters, even high doses of primary coagulant will not produce the desired effluent clarity. A polymeric coagulant aid added after the primary coagulant may, by developing a larger floc at low treatment levels, reduce the amount of primary coagulant required.

Generally, very high-molecular-weight, anionic polyacrylamides are the most effective coagulant aids. Nonionic or cationic types have proven successful in some clarifier systems. Essentially, the polymer bridges the small floc particles and causes them to agglomerate rapidly.
into larger, more cohesive flocs that settle quickly. The higher-molecular-weight polymers bridge suspended solids most effectively.

Coagulant aids have proven quite successful in precipitation softening and clarification to achieve improved settling rates of precipitates and finished water clarity.

**Color Reduction**

Frequently, the objective of clarification is the reduction of color. Swamps and wetlands introduce color into surface waters, particularly after heavy rainfalls. Color-causing materials can cause various problems, such as objectionable taste, increased microbiological content, fouling of anion exchange resins, and interference with coagulation and stabilization of silt, soluble iron, and manganese.

Most organic color in surface waters is colloidal and negatively charged. Chemically, color-producing compounds are classified as humic and fulvic acids. Color can be removed by chlorination and coagulation with aluminum or iron salts or organic polyelectrolytes. Chlorine oxidizes color compounds, while the inorganic coagulants can physically remove many types of organic color by neutralization of surface charges. The use of chlorine to oxidize organic color bodies may be limited due to the production of chlorinated organic by-products, such as trihalomethanes. Additional color removal is achieved by chemical interaction with aluminum or iron hydrolysis products. Highly charged cationic organic polyelectrolytes can also be used to coagulate some types of color particles.

Coagulation for color reduction is normally carried out at pH 4.5 to 5.5. Optimum pH for turbidity removal is usually much higher than that for color reduction. The presence of sulfate ions can interfere with coagulation for color reduction, whereas calcium and magnesium ions can improve the process and broaden the pH range in which color may be reduced effectively.

**Conventional Clarification Equipment**

The coagulation/flocculation and sedimentation process requires three distinct unit processes:

- high shear, rapid mix for coagulation
- low shear, high retention time, moderate mixing for flocculation
- liquid and solids separation

**Horizontal Flow Clarifiers**

Originally, conventional clarification units consisted of large, rectangular, concrete basins divided into two or three sections. Each stage of the clarification process occurred in a single section of the basin. Water movement was horizontal with plug flow through these systems.

Because the design is suited to large-capacity basins, horizontal flow units are still used in some large industrial plants and for clarifying municipal water. The retention time is normally long (up to 4-6 hr), and is chiefly devoted to settling. Rapid mix is typically designed for 3-5 min and slow mix for 15-30 min. This design affords great flexibility in establishing proper chemical addition points. Also, such units are relatively insensitive to sudden changes in water throughput.
The long retention also allows sufficient reaction time to make necessary adjustments in chemical and polymer feed if raw water conditions suddenly change. However, for all but very large treated water demands, horizontal units require high construction costs and more land space per unit of water capacity.

**Upflow Clarifiers**

Compact and relatively economical, upflow clarifiers provide coagulation, flocculation, and sedimentation in a single (usually circular) steel or concrete tank. These clarifiers are termed "upflow" because the water flows up toward the effluent launders as the suspended solids settle. They are characterized by increased solids contact through internal sludge recirculation. This is a key feature in maintaining a high-clarity effluent and a major difference from horizontal clarifiers.

Because retention time in an upflow unit is approximately 1-2 hr, upflow basins can be much smaller in size than horizontal basins of equal throughput capacity. A rise rate of 0.70-1.25 gpm/ft² of surface area is normal for clarification. Combination softening-clarification units may operate at up to 1.5 gpm/ft² of surface area due to particle size and densities of precipitated hardness.

In order to achieve high throughput efficiency, upflow units are designed to maximize the linear overflow weir length while minimizing the opportunity for short-circuiting through the settling zone. In addition, the two mixing stages for coagulation and flocculation take place within the same clarification tank.

Although upflow units may provide more efficient sedimentation than horizontal designs, many upflow clarifiers compromise on the rapid and slow mix sequences. Some types provide rapid, mechanical mixing and rely on flow turbulence for flocculation; others eliminate the rapid mix stage and provide only moderate turbulence for flocculation. However, in most cases, users can overcome rapid mix deficiencies by adding the primary coagulant further upstream of the clarifier. Figure 5-1 shows the rapid mix, slow mix, and settling zones of a typical upflow, solids-contact clarifier.

**Sludge Blanket and Solids-Contact Clarification**

Most upflow designs are called either "sludge blanket" or "solids-contact" clarifiers. After coagulation and/or flocculation in the sludge blanket units, the incoming water passes through the suspended layer of previously formed floc. Figure 5-2 shows an upflow sludge blanket clarifier.

Because the centerwell in these units is often shaped like an inverted cone, the rise rate of the water decreases as it rises through the steadily enlarging cross section. When the rise rate decreases enough to equal the settling rate of the suspended floc exactly, a distinct sludge/liquid interface forms.

Sludge blanket efficiency depends on the filtering action as the freshly coagulated or flocculated water passes through the suspended floc. Higher sludge levels increase the filtration efficiency. In practice, the top sludge interface is carried at the highest safe level to prevent upsets that might result in large amounts of floc carryover into the overflow. Excessive sludge withdrawal...
or blowdown should also be avoided. The sludge blanket level is often highly sensitive to changes in throughput, coagulant addition, and changes in raw water chemistry and temperature.

"Solids-contact" refers to units in which large volumes of sludge are circulated internally. The term also describes the sludge blanket unit and simply means that prior to and during sedimentation the chemically treated water contacts previously coagulated solids. Solids-contact, slurry pool units do not rely on filtration as in sludge blanket designs.

Solids-contact units often combine clarification and precipitation softening. Bringing the incoming raw water into contact with recirculated sludge improves the efficiency of the softening reactions and increases the size and density of the floc particles. Figure 5-3 illustrates a typical solids-contact unit.

In-Line Clarification

In-line clarification is the process of removing raw water turbidity through the addition of coagulant just prior to filtration. In-line clarification is generally limited to raw waters with typical turbidities of less than 20 NTU, although upflow filters may tolerate higher loading. Polyelectrolytes and/or inorganic coagulants are used to improve filtration efficiency and run length. Polymers are favored because they do not create additional suspended solids loading, which can shorten filter run length.

Filter design may be downflow or upflow, depending on raw water turbidity and particle size. The downflow dual-media unit generally consists of layers of various grades of anthracite and sand supported on a gravel bed. After backwashing, the larger anthracite particles separate to the top of the bed, while the more dense, smaller sand particles are at the bottom. The purpose is to allow bed penetration of the floc, which reduces the potential for excessive pressure drops due to blinding off the top portion of filter media. Thus, higher filtration rates are realized without a significant loss in effluent quality. Normal filtration rates are 5-6 gpm/ft².

Coagulant Selection and Feeding for In-Line Clarification

The choice of a polymer coagulant and feed rate depends on equipment design and influent water turbidity. Initially, in-line clarification was used in the treatment of low-turbidity waters, but it is now being used on many types of surface waters. For most waters, the use of a polymeric cationic coagulant alone is satisfactory. However, the addition of a high-molecular-weight, anionic polymer may improve filtration efficiency.

Polymer feed rates are usually lower than those used in conventional clarification, given the same raw water characteristics. Complete charge neutralization and bridging are not necessary and should be avoided, because total coagulation or flocculation may promote excessive entrapment of suspended solids in the first portion of the filter media. This can cause blinding of the media, high pressure drops, and short operating runs.

Sufficient polymer is applied only to initiate neutralization, which allows attraction and adsorption of particles through the entire bed. Often, polymer feed rates are regulated by trial and error on the actual units to minimize effluent turbidity and maximize service run length.

Because optimum flocculation is undesirable, polymers are injected just upstream of the units. Normally, a short mixing period is required to achieve the degree of reaction most suitable for unit operation. Dilution water may be recommended to disperse the polymer properly
throughout the incoming water. However, it may be necessary to move the polymer injection point several times to improve turbidity removal. Due to the nature of operation, a change of polymer feed rate will typically show a change in effluent turbidity in a relatively short period of time.

Coagulation Testing

Raw water analyses alone are not very useful in predicting coagulation conditions. Coagulation chemicals and appropriate feed rates must be selected according to operating experience with a given raw water or by simulation of the clarification step on a laboratory scale.

Jar testing is the most effective way to simulate clarification chemistry and operation. A multiple-paddle, beaker arrangement (Figure 5-4) permits the comparison of various chemical combinations, all of which are subjected to identical hydraulic conditions. The effects of rapid and slow mix intensity and duration may also be observed.

In addition to determining the optimum chemical program, it is possible to establish the correct order of addition. The most critical measurements in the jar test are coagulant and/or flocculant dosages, pH, floc size and settling characteristics, floc-forming time, and finished water clarity. To simulate sludge circulation, sludge formed in one series of jar tests (or a sludge sample from an operating clarifier) may be added to the next jar test. Results of jar tests are only relative, and frequent adjustments are necessary in full-scale plant operation. Monitoring and control units, such as a streaming current detector, can be used for on-line feedback control.

Zeta potential measurements have been used experimentally to predict coagulant requirements and optimum pH levels. Because the measurement technique requires special apparatus and a skilled technician, zeta potential has never become practical for controlling industrial water clarification plants. Also, because zeta potential measures only one aspect of the entire process, it may not reflect all conditions leading to coagulation efficiency.

Chemical Additions

The most efficient method for adding coagulation chemicals varies according to the type of water and system used, and must be checked by means of jar testing. However, there is a usual sequence:

1. chlorine
2. bentonite (for low-turbidity waters)
3. primary inorganic and/or polymer coagulant
4. pH-adjusting chemicals
5. coagulant aid

Waters with a high organic content exhibit an increased primary coagulant demand. Chlorine may be used to assist coagulation by oxidizing organic contaminants which have dispersing properties. Chlorination prior to primary coagulant feed also reduces the coagulant dosage. When an inorganic coagulant is used, the addition of pH-adjusting chemicals prior to the coagulant establishes the proper pH environment for the primary coagulant.
All treatment chemicals, with the exception of coagulant aids, should be added during very turbulent mixing of the influent water. Rapid mixing while the aluminum and iron coagulants are added ensures uniform cation adsorption onto the suspended matter.

High shear mixing is especially important when cationic polymers are used as primary coagulants. In general, it is advisable to feed them as far ahead of the clarifier as possible. However, when a coagulant aid is added, high shear mixing must be avoided to prevent interference with the polymer's bridging function. Only moderate turbulence is needed to generate floc growth.

Filtration is used in addition to regular coagulation and sedimentation for removal of solids from surface water or wastewater. This prepares the water for use as potable, boiler, or cooling make-up. Wastewater filtration helps users meet more stringent effluent discharge permit requirements.

Filtration, usually considered a simple mechanical process, actually involves the mechanisms of adsorption (physical and chemical), straining, sedimentation, interception, diffusion, and inertial compaction.

Filtration does not remove dissolved solids, but may be used together with a softening process, which does reduce the concentration of dissolved solids. For example, anthracite filtration is used to remove residual precipitated hardness salts remaining after clarification in precipitationsoftening.

In most water clarification or softening processes where coagulation and precipitation occur, at least a portion of the clarified water is filtered. Clarifier effluents of 2-10 NTU may be improved to 0.1-1.0 NTU by conventional sand filtration. Filtration ensures acceptable suspended solids concentrations in the finished water even when upsets occur in the clarification processes.

**TYPICAL CONSTRUCTION**
Conventional gravity and pressure rapid filters operate downflow. The filter medium is usually a 15-30 in. deep bed of sand or anthracite. Single or multiple grades of sand or anthracite may be used.

A large particle bed supports the filter media to prevent fine sand or anthracite from escaping into the underdrain system. The support bed also serves to distribute backwash water. Typical support beds consist of 1 8-1 in. gravel or anthracite in graded layers to a depth of 12-16 in.

**TYPES OF MEDIA**
Quartz sand, silica sand, anthracite coal, garnet, magnetite, and other materials may be used as filtration media. Silica sand and anthracite are the most commonly used types. When silica is not suitable (e.g., in filters following a hot process softener where the treated water is intended for boiler feed), anthracite is usually used.

The size and shape of the filter media affect the efficiency of the solids removal. Sharp, angular media form large voids and remove less fine material than rounded media of equivalent size. The media must be coarse enough to allow solids to penetrate the bed for 2-4 in. Although most suspended solids are trapped at the surface or in the first 1-2 in. of bed depth, some penetration is essential to prevent a rapid increase in pressure drop.
Sand and anthracite for filters are rated by effective particle size and uniformity. The effective size is such that approximately 10% of the total grains by weight are smaller and 90% are larger. Therefore, the effective size is the minimum size of most of the particles. Uniformity is measured by comparison of effective size to the size at which 60% of the grains by weight are smaller and 40% are larger. This latter size, divided by the effective size, is called the uniformity coefficient—the smaller the uniformity coefficient, the more uniform the media particle sizes.

Finer sands result in shallower zones for the retention of suspended matter. The most desirable media size depends on the suspended solids characteristics as well as the effluent quality requirements and the specific filter design. In general, rapid sand filters use sand with an effective size of 0.35-0.60 mm (0.014-0.024 in.) and a maximum uniformity coefficient of 1.7. Coarse media, often 0.6-1.0 mm (0.024-0.04 in.), are used for closely controlled coagulation and sedimentation.

MIXED MEDIA FILTER BEDS

The terms "multilayer," "in-depth," and "mixed media" apply to a type of filter bed which is graded by size and density. Coarse, less dense particles are at the top of the filter bed, and fine, more dense particles are at the bottom. Downflow filtration allows deep, uniform penetration by particulate matter and permits high filtration rates and long service runs. Because small particles at the bottom are also more dense (less space between particles), they remain at the bottom. Even after high-rate backwashing, the layers remain in their proper location in the mixed media filter bed.

Table 6-1 lists four media that are used in multilayer filtration. Several other mixed media combinations have also been tested and used effectively. The use of too many different media layers can cause severe backwashing difficulties. For example, if all four materials listed in Table 6-1 were used in the same filter, a wash rate high enough to expand the magnetite layer might wash the anthracite from the filter. High wash water requirements would also result.

<table>
<thead>
<tr>
<th>Media</th>
<th>Effective size, mm (in.)</th>
<th>Specific gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthracite</td>
<td>0.7-1.7 (0.03-0.07)</td>
<td>1.4</td>
</tr>
<tr>
<td>Sand</td>
<td>0.3-0.7 (0.01-0.03)</td>
<td>2.6</td>
</tr>
<tr>
<td>Garnet</td>
<td>0.4-0.6 (0.016-0.024)</td>
<td>3.8</td>
</tr>
<tr>
<td>Magnetite</td>
<td>0.3-0.5 (0.01-0.02)</td>
<td>4.9</td>
</tr>
</tbody>
</table>

Anthracite/sand filter beds normally provide all of the advantages of single-media filtration but require less backwash water than sand or anthracite alone. Similar claims have been made for anthracite/sand/garnet mixed units. The major advantages of dual-media filtration are higher rates and longer runs. Anthracite/sand/garnet beds have operated at normal rates of approximately 5 gpm/ft² and peak rates as high as 8 gpm/ft² without loss of effluent quality.

CAPPING OF SAND FILTERS
Rapid sand filters can be converted for mixed media operation to increase capacity by 100%. The cost of this conversion is much lower than that of installing additional rapid sand filters.

Capping involves the replacement of a portion of the sand with anthracite. In this conversion, a 2-6 in. layer of 0.4-0.6 mm (0.016-0.024 in.) sand is removed from the surface of a bed and replaced with 4-8 in. of 0.9 mm (0.035 in.) anthracite. If an increase in capacity is desired, a larger amount of sand is replaced. Pilot tests should be run to ensure that a reduction in the depth of the finer sand does not reduce the quality of the effluent.

**GRAVITY FILTERS**

Gravity filters (see Figure 6-1) are open vessels that depend on system gravity head for operation. Apart from the filter media, the essential components of a gravity filter include the following:

- The filter shell, which is either concrete or steel and can be square, rectangular, or circular. Rectangular reinforced concrete units are most widely used.
- The support bed, which prevents loss of fine sand or anthracite through the underdrain system. The support bed, usually 1-2 ft deep, also distributes backwash water.
- An underdrain system, which ensures uniform collection of filtered water and uniform distribution of backwash water. The system may consist of a header and laterals, with perforations or strainers spaced suitably. False tank bottoms with appropriately spaced strainers are also used for underdrain systems.
- Wash water troughs, large enough to collect backwash water without flooding. The troughs are spaced so that the horizontal travel of backwash water does not exceed 3-3 ft. In conventional sand bed units, wash troughs are placed approximately 2 ft above the filter surface. Sufficient freeboard must be provided to prevent loss of a portion of the filter media during operation at maximum backwash rates.
- Control devices that maximize filter operation efficiency. Flow rate controllers, operated by venturi tubes in the effluent line, automatically maintain uniform delivery of filtered water. Backwash flow rate controllers are also used. Flow rate and head loss gauges are essential for efficient operation.

**PRESSURE FILTERS**

Pressure filters are typically used with hot process softeners to permit high-temperature operation and to prevent heat loss. The use of pressure filters eliminates the need for repumping of filtered water. Pressure filters are similar to gravity filters in that they include filter media, supporting bed, underdrain system, and control device; however, the filter shell has no wash water troughs.

Pressure filters, designed vertically or horizontal, have cylindrical steel shells and dished heads. Vertical pressure filters (see Figure 6-2) range in diameter from 1 to 10 ft with capacities as great as 300 gpm at filtration rates of 3 gpm/ft². Horizontal pressure filters, usually 8 ft in diameter, are 10-25 ft long with capacities from 200 to 600 gpm. These filters are separated into compartments to allow individual backwashing. Backwash water may be returned to the clarifier or softener for recovery.
Pressure filters are usually operated at a service flow rate of 3 gpm/ft². Dual or multimedia filters are designed for 6-8 gpm/ft². At ambient temperature, the recommended filter backwash rate is 6-8 gpm/ft² for anthracite and 13-15 gpm/ft² for sand. Anthracite filters associated with hot process softeners require a backwash rate of 12-15 gpm/ft² because the water is less dense at elevated operating temperatures. Cold water should not be used to backwash a hot process filter. This would cause expansion and contraction of the system metallurgy, which would lead to metal fatigue. Also, the oxygen-laden cold water would accelerate corrosion.

**UPFLOW FILTERS**

Upflow units contain a single filter medium–usually graded sand. The finest sand is at the top of the bed with the coarsest sand below. Gravel is retained by grids in a fixed position at the bottom of the unit. The function of the gravel is to ensure proper water distribution during the service cycle. Another grid above the graded sand prevents fluidization of the media. Air injection during cleaning (not considered backwash because the direction of flow is the same as when in-service) assists in the removal of solids and the reclassification of the filter media. During operation, the larger, coarse solids are removed at the bottom of the bed, while smaller solids particles are allowed to penetrate further into the media. Typical service flow rates are 5-10 gpm/ft². An example of this unit is shown in Figure 6-3.

**AUTOMATIC GRAVITY FILTERS**

Several manufacturers have developed gravity filters that are backwashed automatically at a preset head loss. Head loss (water level above the media) actuates a backwash siphon and draws wash water from storage up through the bed and out through the siphon pipe to waste. A low level in the backwash storage section breaks the siphon, and the filter returns to service.

Automatic gravity filters are available in diameters of up to 15 ft. When equipped with a high-rate, multilayer media, a single large-diameter unit can filter as much as 1,000 gpm. An example is shown in Figure 6-4.

**CONTINUOUS CLEANING FILTERS**

Continuous cleaning filter systems eliminate off-line backwash periods by backwashing sections of the filter or portions of the filter media continuously, on-line. Various designs have been introduced. An example is shown in Figure 6-5.

**FILTER WASHING-GRAVITY FILTERS**

Periodic washing of filters is necessary for the removal of accumulated solids. Inadequate cleaning permits the formation of permanent clumps, gradually decreasing filter capacity. If fouling is severe, the media must be cleaned chemically or replaced.

For cleaning of rapid downflow filters, clean water is forced back up and through the media. In conventional gravity units, the backwash water lifts solids from the bed into wash troughs and carries them to waste. Either of two backwash techniques can be used, depending on the design of the media support structure and the accessory equipment available:

- High-rate backwash, which expands the media by at least 10%. Backwash rates of 12-15 gpm/ft² or higher are common for sand, and rates for anthracite may range from 8 to 12 gpm/ft².
Low-rate backwash, with no visible bed expansion, combined with air scouring.

Where only water is used for backwash, the backwash may be preceded by surface washing. In surface washing, strong jets of high-pressure water from fixed or revolving nozzles assist in breaking the filter surface crust. After the surface wash (when there is provision for surface washing), the unit is backwashed for approximately 5-10 min. Following backwash, a small amount of rinse water is filtered to waste, and the filter is returned to service.

High-rate backwash can cause the formation of mud balls inside the filter bed. A high backwash rate and resulting bed expansion can produce random currents in which certain zones of the expanded bed move upward or downward. Encrusted solids from the surface can be carried down to form mud balls. Efficient surface washing helps prevent this condition.

Air scouring with low-rate backwashing can break up the surface crust without producing random currents, if the underdrain system is designed to distribute air uniformly. Solids removed from the media collect in the layer of water between the media surface and wash channels. After the air is stopped, this dirty water is normally flushed out by increased backwash water flow rate or by surface draining. Wash water consumption is approximately the same whether water-only or air/water backwashing is employed.

IN-LINE CLARIFICATION

In-line clarification is the removal of suspended solids through the addition of in-line coagulant followed by rapid filtration. This process is also referred to as in-line filtration, or contact filtration. The process removes suspended solids without the use of sedimentation basins. Coagulation may be achieved in in-line clarification by either of two methods:

- an inorganic aluminum or iron salt used alone or with a high molecular weight polymeric coagulant
- a strongly cationic organic polyelectrolyte

Because metal hydroxides form precipitates, only dual-media filters should be used with inorganic coagulant programs. Floc particles must be handled in filters with coarse-to-fine graded media to prevent rapid blinding of the filter and eliminate backwashing difficulties. Where a high molecular weight polymeric coagulant is used, feed rates of less than 0.1 ppm maximize solids removal by increasing floc size and promoting particle absorption within the filter. This filtration technique readily yields effluent turbidities of less than 0.5 NTU. The second method of coagulant pretreatment involves the use of a single chemical, a strongly charged cationic polyelectrolyte. This treatment forms no precipitation floc particles, and usually no floc formation is visible in the filter influent. Solids are removed within the bed by adsorption and by flocculation of colloidal matter directly onto the surface of the sand or anthracite media. The process may be visualized as seeding of the filter bed surfaces with positive cationic charges to produce a strong pull on the negatively charged particles. Because gelatinous hydroxide precipitates are not present in this process, single-media or upflow filters are suitable for poly-electrolyte clarification.

In-line clarification provides an excellent way to improve the efficiency of solids removal from turbid surface waters. Effluent turbidity levels of less than 1 NTU are common with this method.
PRECOAT FILTRATION

Precoat filtration is used to remove very small particulate matter, oil particles, and even bacteria from water. This method is practical only for relatively small quantities of water which contain low concentrations of contaminants.

Precoat filtration may be used following conventional clarification processes to produce water of very low suspended solids content for specific application requirements. For example, precoat filters are often used to remove oil from contaminated condensate.

In precoat filtration, the precoat media, typically diatomaceous earth, acts as the filter media and forms a cake on a permeable base or septum. The base must prevent passage of the precoat media without restricting the flow of filtered water and must be capable of withstanding high pressure differentials. Filter cloths, porous stone tubes, porous paper, wire screens, and wire-wound tubes are used as base materials.

The supporting base material is first precoated with a slurry of precoat media. Additional slurry (body feed) is usually added during the filter run. When the accumulation of matter removed by filtration generates a high pressure drop across the filter, the filter coating is sloughed off by backwashing. The filter bed is then precoated and returned to service. Chemical coagulants are not usually needed but have been used where an ultrapure effluent is required.

Softening

Precipitation softening processes are used to reduce raw water hardness, alkalinity, silica, and other constituents. This helps prepare water for direct use as cooling tower makeup or as a first-stage treatment followed by ion exchange for boiler makeup or process use. The water is treated with lime or a combination of lime and soda ash (carbonate ion). These chemicals react with the hardness and natural alkalinity in the water to form insoluble compounds. The compounds precipitate and are removed from the water by sedimentation and, usually, filtration. Waters with moderate to high hardness and alkalinity concentrations (150-500 ppm as CaCO₃) are often treated in this fashion.

Chemistry of Precipitation Softening

In almost every raw water supply, hardness is present as calcium and magnesium bicarbonate, often referred to as carbonate hardness or temporary hardness. These compounds result from the action of acidic, carbon dioxide laden rain water on naturally occurring minerals in the earth, such as limestone. For example:

\[
\begin{align*}
\text{CO}_2 + \text{H}_2\text{O} &= \text{H}_4\text{CO}_3 \\
\text{carbon dioxide} &+ \text{water} &\text{carbonic acid} \\
\text{H}_2\text{CO}_3 &+ \text{CaCO}_3^- = \text{Ca(HCO}_3^\text{)}_2 \\
\text{carbonic} &+ \text{calcium} &\text{calcium} \\
\text{acid} &+ \text{carbonate} &\text{bicarbonate}
\end{align*}
\]
Hardness may also be present as a sulfate or chloride salt, referred to as noncarbonate or permanent hardness. These salts are caused by mineral acids present in rain water or the solution of naturally occurring acidic minerals.

The significance of "carbonate" or "temporary" hardness as contrasted to "noncarbonate" or "permanent" hardness is that the former may be reduced in concentration simply by heating. In effect, heating reverses the solution reaction:

\[
\text{Ca(HCO}_3\text{)}_2 + \text{Heat} = \text{CaCO}_3^- + \text{H}_2\text{O} + \text{CO}_2
\]

Calcium bicarbonate calcium carbonate water carbon dioxide

Reduction of noncarbonate hardness, by contrast, requires chemical addition. A combination of lime and soda ash, along with coagulant and flocculant chemicals, is added to raw water to promote a precipitation reaction. This allows softening to take place.

**Cold Lime Softening**

Precipitation softening accomplished at ambient temperatures is referred to as cold lime softening. When hydrated lime, Ca(OH)\(_2\), is added to the water being treated, the following reactions occur:

\[
\text{CO}_2 + \text{Ca(OH)}_2 = \text{CaCO}_3^- + \text{H}_2\text{O}
\]

Carbon dioxide calcium hydroxide calcium carbonate water

\[
\text{Ca(HCO}_3\text{)}_2 + \text{Ca(OH)}_2 = 2\text{CaCO}_3^- + 2\text{H}_2\text{O}
\]

Calcium bicarbonate calcium hydroxide calcium carbonate water

\[
\text{Mg(HCO}_3\text{)}_2 + 2\text{Ca(OH)}_2 = \text{Mg(OH)}_2^- + 2\text{CaCO}_3^- + 2\text{H}_2\text{O}
\]

Magnesium bicarbonate calcium hydroxide magnesium hydroxide calcium carbonate water

If the proper chemical control is maintained on lime feed, the calcium hardness may be reduced to 35-50 ppm. Magnesium reduction is a function of the amount of hydroxyl (OH\(^-\)) alkalinity excess maintained. Figures 7-1 and 7-2 show these relationships.

Noncarbonate or permanent calcium hardness, if present, is not affected by treatment with lime alone. If noncarbonate magnesium hardness is present in an amount greater than 70 ppm and an excess hydroxyl alkalinity of about 5 ppm is maintained, the magnesium will be reduced to about 70 ppm, but the calcium will increase in proportion to the magnesium reduction.
For example, in cold lime treatment of a water containing 110 ppm of calcium, 95 ppm of magnesium, and at least 110 ppm of alkalinity (all expressed as calcium carbonate), calcium could theoretically be reduced to 35 ppm and the magnesium to about 70 ppm. However, an additional 25 ppm of calcium would be expected in the treated water due to the following reactions:

\[
\text{MgSO}_4 + \text{Ca(OH)}_2 \rightarrow \text{Mg(OH)}_2 + \text{CaSO}_4
\]

\[
\text{MgCl}_2 + \text{Ca(OH)}_2 \rightarrow \text{Mg(OH)}_2 + \text{CaCl}_2
\]

To improve magnesium reduction, which also improves silica reduction in cold process softening, sodium aluminate may be used. The sodium aluminate provides hydroxyl ion (OH\(^-\)) needed for improved magnesium reduction, without increasing calcium hardness in the treated water. In addition, the hydrolysis of sodium aluminate results in the formation of aluminum hydroxide, which aids in floc formation, sludge blanket conditioning, and silica reduction. The reactions are as follows:

\[
\text{Na}_2\text{AlO}_4 + 4\text{H}_2\text{O} = 2\text{Al(OH)}_3 + 2\text{NaOH}
\]

\[
\text{Mg}^{2+}[\text{SO}_4^{2-}] + 2\text{NaOH} = \text{Mg(OH)}_2 + [\text{Na}_2\text{SO}_4]
\]

Soda ash (Na\(_2\)CO\(_3\)) may be used to improve hardness reduction. It reacts with noncarbonate calcium hardness according to the following:

\[
\text{CaSO}_4 + \text{Na}_2\text{CO}_3 = \text{CaCO}_3 + \text{Na}_2\text{SO}_4
\]

\[
\text{CaCl}_2 + \text{Na}_2\text{CO}_3 = \text{CaCO}_3 + 2\text{NaCl}
\]
However, noncarbonate magnesium hardness reduction in cold process softening requires added lime. The reactions are as follows:

\[
\text{MgSO}_4 + \text{Ca(OH)}_2 + \text{Na}_2\text{CO}_3 = \text{Mg(OH)}_2^- + \text{CaCO}_3^- + \text{Na}_2\text{SO}_4
\]

magnesium sulfate calcium hydroxide sodium carbonate magnesium hydroxide calcium carbonate sodium sulfate

\[
\text{MgCl}_2 + \text{Ca(OH)}_2 + \text{Na}_2\text{CO}_3 = \text{Mg(OH)}_2^- + \text{CaCO}_3^- + 2\text{NaCl}
\]

magnesium chloride calcium hydroxide sodium carbonate magnesium hydroxide calcium carbonate sodium chloride

In these reactions, dissolved solids are not reduced because a solution reaction product (sodium sulfate or sodium chloride) is formed.

**Warm Lime Softening**

The warm lime softening process operates in the temperature range of 120-140°F (49-60°C). The solubilities of calcium, magnesium, and silica are reduced by increased temperature. Therefore, they are more effectively removed by warm lime softening than by cold lime softening. This process is used for the following purposes:

- **To recover waste heat as an energy conservation measure.** The water to be treated is heated by a waste stream, such as boiler blowdown or low-pressure exhaust steam, to recover the heat content.

- **To prepare feed to a demineralization system.** The lower levels of calcium, magnesium, and especially silica reduce the ionic loading on the demineralizer when warm lime-softened water is used rather than cold lime-softened water. This may reduce both the capital and operating costs of the demineralizer. However, most strong base anion resins have a temperature limitation of 140°F (60°C); therefore, additional increases in temperature are not acceptable for increasing the effectiveness of contaminant reduction.

- **To lower the blowdown discharge from cooling systems.** Cooling tower blowdown may be treated with lime and soda ash or caustic to reduce calcium and magnesium levels so that much of the blowdown may be returned to the cooling system. Silica levels in the recirculating cooling water are also controlled in this manner.
In any warm lime or warm lime-soda ash process, temperature control is critical because temperature variations of as little as 4°F/hr (2°C/hr) can cause gross carryover of the softener precipitates.

**Hot Process Softening**

Hot process softening is usually carried out under pressure at temperatures of 227-240°F (108-116°C). At the operating temperature, hot process softening reactions go essentially to completion. This treatment method involves the same reactions described above, except that raw water CO₂ is vented and does not participate in the lime reaction. The use of lime and soda ash permits hardness reduction down to 0.5 gr/gal, or about 8 ppm, as calcium carbonate.

Magnesium is reduced to 2-5 ppm because of the lower solubility of magnesium hydroxide at the elevated temperatures.

**Silica Reduction**

Hot process softening can also provide very good silica reduction. The silica reduction is accomplished through adsorption of the silica on the magnesium hydroxide precipitate. If there is insufficient magnesium present in the raw water to reduce silica to the desired level, magnesium compounds (such as magnesium oxide, magnesium sulfate, magnesium carbonate, or dolomitic lime) may be used. Figure 7-3 is a plot of magnesium oxide vs. raw water silica (in ppm), which may be used to estimate the quantity of magnesium oxide required to reduce silica to the levels indicated. Magnesium oxide is the preferred chemical because it does not increase the dissolved solids concentration of the water.

Good sludge contact enhances silica reduction. To ensure optimum contact, sludge is frequently recirculated back to the inlet of the unit.

Cold or warm process softening is not as effective as hot process softening for silica reduction. However, added magnesium oxide and good sludge contact will improve results.

Predicted analyses of a typical raw water treated by various lime and lime-soda softening processes are presented in Table 7-1.

**Table 7-1. Typical softener effluent analyses.**

<table>
<thead>
<tr>
<th></th>
<th>Raw Water</th>
<th>Removal of Calcium Alkalinity Cold-Lime</th>
<th>Lime-soda Softening (Cold)</th>
<th>Lime-soda Softening (Hot)</th>
<th>Lime Softening (Hot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Hardness (as CaCO₃), ppm</td>
<td>250</td>
<td>145</td>
<td>81</td>
<td>20</td>
<td>120</td>
</tr>
<tr>
<td>Calcium Hardness (as CaCO₃), ppm</td>
<td>150</td>
<td>85</td>
<td>35</td>
<td>15</td>
<td>115</td>
</tr>
<tr>
<td>Magnesium Hardness (as CaCO₃), ppm</td>
<td>100</td>
<td>60</td>
<td>46</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

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"P" Alkalinity (as CaCO₃), ppm
150 44 55 40 28

"M" Alkalinity (as CaCO₃), ppm
0 27 37 23 18

Silica (as SiO₂), ppm
20 19 18 1-2 1-2

pH
7.5 10.3 10.6 10.5 10.4

Reduction of Other Contaminants

Treatment by lime precipitation reduces alkalinity. However, if the raw water alkalinity exceeds the total hardness, sodium bicarbonate alkalinity is present. In such cases, it is usually necessary to reduce treated water alkalinity in order to reduce condensate system corrosion or permit increased cycles of concentration.

Treatment by lime converts the sodium bicarbonate in the raw water to sodium carbonate as follows:

\[
2NaHCO_3 + Ca(OH)_2 \rightarrow CaCO_3 + Na_2CO_3 + 2H_2O
\]

Calcium sulfate (gypsum) may be added to reduce the carbonate to required levels. The reaction is as follows:

\[
Na_2CO_3 + CaSO_4 \rightarrow CaCO_3 + Na_2SO_4
\]

This is the same reaction involved in the reduction of noncarbonate calcium hardness previously discussed. Table 7-2 shows the treated water alkalinity relationships to be expected in lime-soda ash softened water.

Table 7-2. Alkalinity relationships as determined by titrations.

<table>
<thead>
<tr>
<th>Hydroxide Carobnate</th>
<th>Bicarbonate</th>
</tr>
</thead>
<tbody>
<tr>
<td>P = O</td>
<td>O</td>
</tr>
<tr>
<td>P = M</td>
<td>P</td>
</tr>
<tr>
<td>2P = M</td>
<td>O</td>
</tr>
<tr>
<td>2P &lt; M</td>
<td>O</td>
</tr>
</tbody>
</table>

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Reduction of Other Contaminants

Lime softening processes, with the usual filters, will reduce oxidized iron and manganese to about 0.05 and 0.01 ppm, respectively. Raw water organics (color-contributing colloids) are also reduced.

Turbidity, present in most surface supplies, is reduced to about 1.0 NTU with filtration following chemical treatment. Raw water turbidity in excess of 100 NTU may be tolerated in these systems; however, it may be necessary to coagulate raw water solids with a cationic polymer before the water enters the softener vessel to assist liquid-solids separation.

Oil may also be removed by adsorption on the precipitates formed during treatment. However, oil in concentrations above about 30 ppm should be reduced before lime treatment because higher concentrations of oil may exert a dispersing influence and cause floc carryover.

Precipitation Process (Chemical) Control

Lime or lime-soda softener control is usually based on treated water alkalinity and hardness. Samples are tested to determine the alkalinity to the P (phenolphthalein, pH 8.3) and M (methyl orange or methyl purple, pH 4.3) end points. The following relationships apply:

\[
P \text{ (ppm as CaCO}_3\text{)} = \text{OH}^- + \frac{1}{2} \text{CO}_3^{2-} \\
\text{hydroxyl carbonate}
\]

\[
M \text{ (ppm CaCO}_3\text{)} = \text{OH}^- + \text{CO}_3^{2-} + \text{HCO}_3^- \\
\text{hydroxyl carbonate bicarbonate}
\]

In the presence of hydroxyl ion (OH\(^-\)), bicarbonate concentration is so low that it may be assumed to be zero.

In the precipitation process, it is advisable to ensure that all of the bicarbonate has been converted to carbonate (the least soluble form of the calcium); therefore, a slight excess of hydroxyl ion should be maintained in the treated water. When the equations above are combined, it can be shown that when \(2P - M\) is positive, hydroxyl ion is present. The usual control range is:

\[
2P - M = 5-15 \text{ ppm}
\]

This corresponds to a pH of approximately 10.2.

If soda ash is also used, the control is on the excess carbonate ion. As shown in Figure 7-1 (above), excess carbonate will depress the calcium to the level desired. The usual control range for hot lime-soda units is:

\[
M \text{ (alkalinity) - TH (total hardness)} = 20-40 \text{ ppm}
\]
For cold lime-soda softening, where effluent magnesium hardness is significantly greater than in hot lime or soda, the control range above may be inappropriate. For cold lime—soda units, soda ash can be controlled such that:

\[ 2(M - P) - \text{Calcium hardness} = 20-40 \text{ ppm} \]

Care must be exercised in the specification of soda ash control ranges. If the softened water is to be used as boiler feedwater, hardness removal by the addition of soda ash may not be worth the cost of the resulting increase in steam condensate system corrosion. This corrosion is caused by the higher levels of carbon dioxide in the steam resulting from the higher carbonate alkalinity of the feedwater.

**Coagulants/Flocculants/Sludge Conditioners**

Organic polymer flocculants and coagulants are preferred over inorganic salts of aluminum or iron. Polymers add minimal dissolved solids to the water and their use results in reduced sludge quantity compared to the use of inorganic coagulants. Inorganic coagulants must react with raw water alkalinity to form the metallic precipitate that aids in clarification and sludge bed conditioning. For example, alum reacts as follows:

\[
3\text{Ca(HCO}_3\text{)}_2 + \text{Al}_3\text{(SO}_4\text{)}_3 = 3\text{CaSO}_4 + 2\text{Al(OH)}_3 + 6\text{CO}_2
\]

The precipitated aluminum hydroxide is incorporated within the sludge produced by the softening reactions. This increases the fluidity of the softener sludge, which allows for increased solids contact, improving softening and effluent clarity.

Waters producing high calcium-to-magnesium precipitation ratios usually need sludge bed conditioning chemical feed for proper operation. Specialized organic polymers are available for proper conditioning of the sludge bed without the use of inorganic salts.

Four potentially adverse effects of using inorganic salts may be noted:

- **The inorganic salt reduces the alkalinity.** This converts the hardness to noncarbonate hardness, which is not affected by lime. As a result, inorganic salts increase hardness in water that is naturally deficient in bicarbonate alkalinity.
- **When the water is to be treated further by ion exchange, regenerant consumption is increased.** This is due to the higher hardness and the added soluble sulfate/chloride load.
- **The carbon dioxide generated by the reaction has a lime demand which is twice that of the bicarbonate.** Therefore, increased chemical addition is required.
- **Soluble aluminum in the softener effluent interferes with softened water alkalinity titrations, even when very low levels of soluble aluminum exist.** This interference, which necessitates an increase in lime feed, causes falsely low \((2P - M)\) readings and may be partly responsible for the additional removal of magnesium seen when aluminum salts are used.

**Equipment Employed**
**Cold Process**

The first cold lime-soda softening was carried out in "batch" fashion. An excess of treating chemicals was mixed with the water in a large basin. After approximately 4 hr, the treated water was decanted from the basin, leaving the settled precipitates in the basin.

Today, continuous sludge-contact softeners (see Figures 7-4 and 7-5 ) are used to provide a constant flow with effluent quality superior to that obtained through batch treatment. Treating chemicals are added as a function of flow rate and water quality to the rapid mix zone of the unit. Sludge, recirculated either internally or externally to the unit, may be returned to this rapid mix zone for improved softening, softened water clarity, and silica reduction.

The water then flows to the slow mix zone of the unit. Here, the precipitation reactions continue and the precipitates formed become large enough to begin settling. In the sludge-contact unit, the water flows through a bed of sludge for additional contact. The sludge level is maintained by the proper combination of sludge bed conditioning chemicals, mechanical agitation, hydraulic suspension, and sludge blowdown. A discernible line of separation between clarified water and slurry pool should exist in a properly operated unit. Effluent turbidity is usually less than 10 NTU.

Flow rate is usually limited to less than 1.5 gpm/ft2 of settling area. A retention time of 1 hr is required to allow the softening reactions to come as close to completion as possible.

Because the reactions in cold process softening are not complete, the water contaminant levels leaving the unit are unstable. With additional time and/or increased temperature, further precipitation will occur downstream of the unit. Frequently, acid or carbon dioxide is added to stabilize the water. The pH is reduced from about 10.2 to between 8.0 and 9.0, which converts the carbonate to the more soluble bicarbonate. Ionically, the reaction is:

\[
\text{H}^+ + \text{CO}_3^{2-} = \text{HCO}_3^{-}
\]

A typical cold lime softener system is shown in Figure 7-6.

**Hot Process**

Two hot process softener designs are illustrated in Figures 7-7 and 7-8. The former, the simplest in design and fabrication, is referred to as a "downflow" unit. The latter, which incorporates additional features, is referred to as an "upflow" unit. Many variations in design of both units exist, but the principle of operation is quite similar.

In each unit, water is admitted to the top of the vessel designed to operate at 5-15 psig saturated steam pressure (227-240°F, 108-116°C). An inlet valve is used to control the inlet water flow as a function of the operating level of the vessel. The water is sprayed into the steam space of the unit and is heated to within 2 or 3 degrees of the saturation temperature of the steam. Heating reduces the noncondensible gas content of the water. Oxygen and carbon dioxide are released.
and vented to the atmosphere with a controlled loss of heating steam. Although they are not deaerators, hot process units reduce oxygen to about 0.3 ppm (0.21 cm³/L) and carbon dioxide to 0.

This residual oxygen level in the high-temperature water is aggressive and will attack downstream equipment such as filters and zeolites. Therefore, users should consider feeding a chemical oxygen scavenger to the effluent of hot process softeners.

Treatment chemicals are introduced into the top of the vessel as a function of flow and raw water analysis. Although the reactions go essentially to completion quite rapidly, a minimum of 1 hr of retention is designed into the unit. Also, flow rate through the unit is limited to 1.7-2.0 gpm/ft². Filter backwash water may be withdrawn from the outlet of the unit, from the filtered water header, or from internal or external storage. Internal storage compartments are illustrated in Figure 7-8. Filter backwash water is usually returned to the unit for recovery.

In the downflow design, the water leaves the vessel after reversing direction and enters the internal hood. Precipitates separate from the water at the hood and continue downward into the cone for removal by blowdown. Sludge blowdown is proportioned to raw water flow. For improved silica reduction, sludge is recirculated from the cone back to the top of the unit. For optimum silica reduction, a sludge-contact unit (shown in Figure 7-8) is used. Water and chemicals enter the top of the unit and flow to the bottom of the softener through a downcomer. The sludge level is maintained in such a way that the downcomer always discharges into the sludge bed. This ensures good contact with the sludge, which is rich in magnesium hydroxide. Also, the sludge bed acts as a filter, entrapping finer solids before the water exits near the top of the vessel. Sludge recycle may also be used.

The upflow design also lends itself to easier incorporation of internal compartments for filter backwash storage and return, and condensate or treated water deaeration.

Limitations

Given proper consideration of raw water quality and ultimate end use of the treated water, the application of precipitation processes has few limitations. However, operational difficulties may be encountered unless the following factors are controlled:

- **Temperature.** Cold and warm units are subject to carryover if the temperature varies more than 4°F/hr (2°C/hr). Hot process units are less sensitive to slight temperature variations. However, a clogged or improper spray pattern can prevent proper heating of the water, and carryover can result.
- **Hydraulics.** In any system, steady-state operation within design limits optimizes the performance of the equipment. Rapid flow variations can cause severe system upsets. Suitable treated water storage capacity should be incorporated into the total system design to minimize load swings on the softener.
- **Chemical Control.** This should be as precise as possible to prevent poor water quality. Because of the comparatively constant quality of most well waters, changes in chemical feed rates are largely a function of flow only. However, surface water quality may vary hourly. Therefore, for proper control, it is imperative that users perform frequent testing of the raw water as well as the treated effluent, and adjust chemical feed accordingly.
Iron Exchange

- History
- Classifications of ion exchange resins
- Sodium zeolite softening
- Hot zeolite softening
- Demineralization
- Dealkalization
- Counterflow and mixed bed deionization
- Other demineralization processes
- Condensate polishing
- Common ion exchange system problems
- Resin fouling and degradation
- Resin testing and analysis

All natural waters contain, in various concentrations, dissolved salts which dissociate in water to form charged ions. Positively charged ions are called cations; negatively charged ions are called anions. Ionic impurities can seriously affect the reliability and operating efficiency of a boiler or process system. Overheating caused by the buildup of scale or deposits formed by these impurities can lead to catastrophic tube failures, costly production losses, and unscheduled downtime. Hardness ions, such as calcium and magnesium, must be removed from the water supply before it can be used as boiler feedwater. For high-pressure boiler feedwater systems and many process systems, nearly complete removal of all ions, including carbon dioxide and silica, is required. Ion exchange systems are used for efficient removal of dissolved ions from water.

Ion exchangers exchange one ion for another, hold it temporarily, and then release it to a regenerant solution. In an ion exchange system, undesirable ions in the water supply are replaced with more acceptable ions. For example, in a sodium zeolite softener, scale-forming calcium and magnesium ions are replaced with sodium ions.

HISTORY

In 1905, Gans, a German chemist, used synthetic aluminosilicate materials known as zeolites in the first ion exchange water softeners. Although aluminosilicate materials are rarely used today, the term "zeolite softener" is commonly used to describe any cation exchange process.

The synthetic zeolite exchange material was soon replaced by a naturally occurring material called Greensand. Greensand had a lower exchange capacity than the synthetic material, but its greater physical stability made it more suitable for industrial applications. Capacity is defined as the amount of exchangeable ions a unit quantity of resin will remove from a solution. It is usually expressed in kilograins per cubic foot as calcium carbonate.

Figure 8-1. Microscopic view of cellular resin beads (20-50 mesh) of a sulfonated styrene-divinylbenzene strong acid cation exchanger. (Courtesy of Rohm and Haas Company.)

The development of a sulfonated coal cation exchange medium, referred to as carbonaceous zeolite, extended the application of ion exchange to hydrogen cycle operation, allowing for the reduction of alkalinity as well as hardness. Soon, an anion exchange resin (a condensation
product of polyamines and formaldehyde) was developed. The new anion resin was used with the hydrogen cycle cation resin in an attempt to demineralize (remove all dissolved salts from) water. However, early anion exchangers were unstable and could not remove such weakly ionized acids as silicic and carbonic acid.

In the middle 1940's, ion exchange resins were developed based on the copolymerization of styrene cross-linked with divinylbenzene. These resins were very stable and had much greater exchange capacities than their predecessors. The polystyrene-divinylbenzene-based anion exchanger could remove all anions, including silicic and carbonic acids. This innovation made the complete demineralization of water possible.

Polystyrene-divinylbenzene resins are still used in the majority of ion exchange applications. Although the basic resin components are the same, the resins have been modified in many ways to meet the requirements of specific applications and provide a longer resin life. One of the most significant changes has been the development of the macroreticular, or macroporous, resin structure.

Standard gelular resins, such as those shown in Figure 8-1, have a permeable membrane structure. This structure meets the chemical and physical requirements of most applications. However, in some applications the physical strength and chemical resistance required of the resin structure is beyond the capabilities of the typical gel structure. Macroreticular resins feature discrete pores within a highly cross-linked polystyrene-divinylbenzene matrix. These resins possess a higher physical strength than gels, as well as a greater resistance to thermal degradation and oxidizing agents. Macroreticular anion resins (Figure 8-2) are also more resistant to organic fouling due to their more porous structure. In addition to polystyrene-divinylbenzene resins (Figure 8-3), there are newer resins with an acrylic structure, which increases their resistance to organic fouling.

In addition to a plastic matrix, ion exchange resin contains ionizable functional groups. These functional groups consist of both positively charged cation elements and negatively charged anion elements. However, only one of the ionic species is mobile. The other ionic group is attached to the bead structure. Figure 8-4 is a schematic illustration of a strong acid cation exchange resin bead, which has ionic sites consisting of immobile anionic (SO₃⁻) radicals and mobile sodium cations (Na⁺). Ion exchange occurs when raw water ions diffuse into the bead structure and exchange for the mobile portion of the functional group. Ions displaced from the bead diffuse back into the water solution.

CLASSIFICATIONS OF ION EXCHANGE RESINS

Ionizable groups attached to the resin bead determine the functional capability of the resin. Industrial water treatment resins are classified into four basic categories:

- Strong Acid Cation (SAC)
- Weak Acid Cation (WAC)
- Strong Base Anion (SBA)
- Weak Base Anion (WBA)

SAC resins can neutralize strong bases and convert neutral salts into their corresponding acids.
SBA resins can neutralize strong acids and convert neutral salts into their corresponding bases. These resins are utilized in most softening and full demineralization applications. WAC and WBA resins are able to neutralize strong bases and acids, respectively. These resins are used for dealkalization, partial demineralization, or (in combination with strong resins) full demineralization.

SAC resins derive their functionality from sulfonic acid groups (HSO₃⁻). When used in demineralization, SAC resins remove nearly all raw water cations, replacing them with hydrogen ions, as shown below:

\[
\left[ \text{Ca} \right]_{\text{Mg}}^{2\text{Na}} \cdot \text{(HCO}_3\text{)}_2 + 2\text{ZCOO} \cdot \text{H} \rightleftharpoons 2\text{ZCOO} \cdot \left[ \text{Ca} \right]_{\text{Mg}}^{2\text{Na}} + 2\text{H}_2\text{CO}_3
\]

The exchange reaction is reversible. When its capacity is exhausted, the resin can be regenerated with an excess of mineral acid.

Strong acid cation exchangers function well at all pH ranges. These resins have found a wide range of applications. For example, they are used in the sodium cycle (sodium as the mobile ion) for softening and in the hydrogen cycle for decationization.

Weak acid cation exchange resins derive their exchange activity from a carboxylic group (-COOH). When operated in the hydrogen form, WAC resins remove cations that are associated with alkalinity, producing carbonic acid as shown:

\[
\left[ \text{Ca} \right]_{\text{Mg}}^{2\text{Na}} \cdot \text{(HCO}_3\text{)}_2 + 2\text{ZCOO} \cdot \text{H} \rightleftharpoons 2\text{ZCOO} \cdot \left[ \text{Ca} \right]_{\text{Mg}}^{2\text{Na}} + 2\text{H}_2\text{CO}_3
\]

These reactions are also reversible and permit the return of the exhausted WAC resin to the regenerated form. WAC resins are not able to remove all of the cations in most water supplies. Their primary asset is their high regeneration efficiency in comparison with SAC resins. This high efficiency reduces the amount of acid required to regenerate the resin, thereby reducing the waste acid and minimizing disposal problems.

Weak acid cation resins are used primarily for softening and dealkalization of high-hardness, high-alkalinity waters, frequently in conjunction with SAC sodium cycle polishing systems. In full demineralization systems, the use of WAC and SAC resins in combination provides the economy of the more efficient WAC resin along with the full exchange capabilities of the SAC resin.

SBA resins derive their functionality from quaternary ammonium functional groups. Two types of quaternary ammonium groups, referred to as Type I and Type II, are used. Type I sites have three methyl groups:
In a Type II resin one of the methyl groups is replaced with an ethanol group. The Type I resin has a greater stability than the Type II resin and is able to remove more of the weakly ionized acids. Type II resins provide a greater regeneration efficiency and a greater capacity for the same amount of regenerant chemical used.

When in the hydroxide form, SBA resins remove all commonly encountered anions as shown below:

\[
\begin{align*}
\left[ \frac{H_2SO_4}{2HCl} \right] + 2Z \cdot OH & \rightleftharpoons 2Z \cdot \left[ \frac{SO_4}{2Cl} \right] + 2H_2O \\
\left[ \frac{2H_2SiO_3}{2H_2CO_3} \right] & \\
\end{align*}
\]

As with the cation resins, these reactions are reversible, allowing for the regeneration of the resin with a strong alkali, such as caustic soda, to return the resin to the hydroxide form.

Weak base resin functionality originates in primary (R-NH₂), secondary (R-NHR'), or tertiary (R-NR'₂) amine groups. WBA resins readily remove sulfuric, nitric, and hydrochloric acids, as represented by the following reaction:

\[
\begin{align*}
\left[ \frac{H_2SO_4}{2HCl} \right] + 2Z \cdot OH & \rightleftharpoons 2Z \cdot \left[ \frac{SO_4}{2Cl} \right] + 2H_2O \\
\left[ \frac{2HNO_3}{2HND_3} \right] & \\
\end{align*}
\]

**SODIUM ZEOLITE SOFTENING**

Sodium zeolite softening is the most widely applied use of ion exchange. In zeolite softening, water containing scale-forming ions, such as calcium and magnesium, passes through a resin bed containing SAC resin in the sodium form. In the resin, the hardness ions are exchanged with the sodium, and the sodium diffuses into the bulk water solution. The hardness-free water, termed soft water, can then be used for low to medium pressure boiler feedwater, reverse osmosis system makeup, some chemical processes, and commercial applications, such as laundries.

**Principles of Zeolite Softening**

The removal of hardness from water by a zeolite softening process is described by the following reaction:
Water from a properly operated zeolite softener is nearly free from detectable hardness. However, some small amounts of hardness, known as leakage, are present in the treated water. The level of hardness leakage is dependent on the hardness and sodium level in the influent water and the amount of salt used for regeneration.

Figure 8-5 is a typical profile of effluent hardness from a zeolite softener during a service cycle. After final rinse, the softener produces a low, nearly constant level of hardness until the ion exchange resin nears exhaustion. At exhaustion, the effluent hardness increases sharply, and regeneration is required.

As illustrated by the softening reactions, SAC resin readily accepts calcium and magnesium ions in exchange for sodium ions. When exhausted resin is regenerated, a high concentration of sodium ions is applied to the resin to replace calcium and magnesium. The resin is treated with a 10% sodium chloride solution, and regeneration proceeds according to the following equation:

\[ Z \cdot \frac{Ca}{Mg} + 2NaCl \rightarrow Na_2 \cdot Z + \frac{Ca}{Mg} \cdot Cl_2 \]

During regeneration, a large excess of regenerant (approximately 3 times the amount of calcium and magnesium in the resin) is used. The eluted hardness is removed from the softening unit in the waste brine and by rinsing.

After regeneration, small residual amounts of hardness remain in the resin. If resin is allowed to sit in a stagnant vessel of water, some hardness will diffuse into the bulk water. Therefore, at the initiation of flow, the water effluent from a zeolite softener can contain hardness even if it has been regenerated recently. After a few minutes of flow, the hardness is rinsed from the softener, and the treated water is soft.

The duration of a service cycle depends on the rate of softener flow, the hardness level in the water, and the amount of salt used for regeneration. Table 8-1 shows the effect of regenerant level on the softening capacity of a gelular strong cation resin. Note that the capacity of the resin increases as the regenerant dosage increases, but the increase is not proportional. The regeneration is less efficient at the higher regenerant levels. Therefore, softener operating costs increase as the regenerant level increases. As shown by the data in Table 8-1, a 150% increase in regenerant salt provides only a 67% increase in operating capacity.

<table>
<thead>
<tr>
<th>Salt (lb/ft³)</th>
<th>Capacity (gr/ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>18,000</td>
</tr>
<tr>
<td>8</td>
<td>20,000</td>
</tr>
<tr>
<td>10</td>
<td>24,000</td>
</tr>
</tbody>
</table>

Table 8-1. Effect of regenerant salt level on strong acid cation resin softening capacity.
**Equipment**

The equipment used for sodium zeolite softening consists of a softener exchange vessel, control valves and piping, and a system for brining, or regenerating, the resin. Usually, the softener tank is a vertical steel pressure vessel with dished heads as shown in Figure 8-6. Major features of the softening vessel include an inlet distribution system, free-board space, a regenerant distribution system, ion exchange resin, and a resin-retaining underdrain collection system.

The inlet distribution system is usually located at the top of the tank. The inlet system provides even distribution of influent water. This prevents the water from hollowing out flow channels in the resin bed, which would reduce system capacity and effluent quality. The inlet system also acts as a collector for backwash water.

The inlet distributor consists of a central header/hub with distributing laterals/radials or simple baffle plates, which direct the flow of water evenly over the resin bed. If water is not prevented from flowing directly onto the bed or tank walls, channeling will result.

The volume between the inlet distributor and the top of the resin bed is called the free-board space. The free-board allows for the expansion of the resin during the backwash portion of the regeneration without loss of resin. It should be a minimum of 50% of the resin volume (80% preferred).

The regenerant distributor is usually a header-lateral system that evenly distributes the regenerant brine during regeneration. The location of the distributor, 6 in. above the top of the resin bed, prevents the dilution of regenerant by water in the free-board space. It also reduces water and time requirements for displacement and fast rinse. The regenerant distributor should be secured to the tank structure to prevent breakage and subsequent channeling of the regenerant.

Water is softened by the bed of strong acid cation exchange resin in the sodium form. The quantity of resin required depends on the water flow, total hardness, and time desired between regeneration cycles. A minimum bed depth of 24 in. is recommended for all systems.

The underdrain system, located at the bottom of the vessel, retains ion exchange resin in the tank, evenly collects the service flow, and evenly distributes the backwash flow. Uneven collection of water in service or uneven distribution of the backwash water can result in channeling, resin fouling, or resin loss.

Although several underdrain designs are used, there are two primary types—subfill and resin-retaining. A subfill system consists of multiple layers of support media (such as graded gravel or anthracite) which support the resin, and a collection system incorporating drilled pipes or subfill strainers. As long as the support layers remain intact, the resin will remain in place. If the supporting media becomes disturbed, usually due to improper backwash, the resin can move through the disrupted layers and exit the vessel. A resin-retaining collector, such as a screened lateral or profile wire strainer, is more expensive than a subfill system but protects against resin loss.
The main valve and piping system directs the flow of water and regenerant to the proper locations. The valve system consists of a valve nest or a single multiport valve. A valve nest includes six main valves: service inlet and outlet, backwash inlet and outlet, regenerant inlet, and regenerant/rinse drain. The valves may be operated manually, or automatically controlled by air, electrical impulse, or water pressure. In some systems, a single multiport valve is used in place of the valve nest. As the valve rotates through a series of fixed positions, ports in the valve direct flow in the same manner as a valve nest. Multiport valves can eliminate operational errors caused by opening of the incorrect valve but must be properly maintained to avoid leaks through the port seals.

The brining system consists of salt dissolving/brine measuring equipment, and dilution control equipment to provide the desired regenerant strength. The dissolving/measuring equipment is designed to provide the correct amount of concentrated brine (approximately 26% NaCl) for each regeneration, without allowing any undissolved salt into the resin. Most systems use a float-operated valve to control the fill and draw-down of the supply tank, thereby controlling the amount of salt used in the regeneration. Usually, the concentrated brine is removed from the tank by means of an eductor system, which also dilutes the brine to the optimum regenerant strength (8-10% NaCl). The brine can also be pumped from the concentrated salt tank and mixed with dilution water to provide the desired regenerant strength.

**Softener Operation**

A sodium zeolite softener operates through two basic cycles: the service cycle, which produces soft water for use, and the regeneration cycle, which restores resin capacity at exhaustion.

In the service cycle, water enters the softener through the inlet distribution system and flows through the bed. The hardness ions diffuse into the resin and exchange with sodium ions, which return to the bulk water. Soft water is collected in the underdrain system and discharged. Service water flow to the softener should be as constant as possible to prevent sudden surges and frequent on-off operation.

Due to resin requirements and vessel designs, the softening operation is most efficient when a service flow rate between 6 and 12 gpm per square foot of resin surface area is maintained. Most equipment is designed to operate in this range, but some special designs utilize a deep resin bed to permit operation at 15-20 gpm/ft². Continuous operation above the manufacturer's suggested limits can lead to bed compaction, channeling, premature hardness breakthrough, and hardness leakage. Operating well below the manufacturer's recommended flow rates can also negatively affect softener performance. At low flow rates, the water is not sufficiently distributed, and the optimum resin-water contact cannot take place.

When a softener is exhausted, the resin must be regenerated. Monitoring of the effluent hardness reveals resin exhaustion. When hardness increases, the unit is exhausted. Automatic monitors provide a more constant indication of the condition of the softener than periodic operator sampling and testing, but require frequent maintenance to ensure accuracy. Many facilities regenerate softeners before exhaustion, based on a predetermined time period or number of gallons processed.

Most softening systems consist of more than one softener. They are often operated so that one softener is in regeneration or standby while the other units are in service. This ensures an
uninterrupted flow of soft water. Prior to placing a standby softener into service, the unit should be rinsed to remove any hardness that has entered the water during the standing time.

**Softener Regeneration**

The regeneration cycle of a sodium zeolite softener consists of four steps: backwash, regeneration (brining), displacement (slow rinse), and fast rinse.

**Backwash.** During the service cycle, the downward flow of water causes suspended material to accumulate on the resin bed. Resin is an excellent filter and can trap particulate matter that has passed through upstream filtration equipment. The backwash step removes accumulated material and reclassifies the resin bed. In the backwash step, water flows from the underdrain distributor up through the resin bed and out the service distributor to waste. The upward flow lifts and expands the resin, allowing for removal of particulate material and resin fines and the classification of the resin. Resin classification brings the smaller beads to the top of the unit while the larger beads settle to the bottom. This enhances the distribution of the regenerant chemical and service water.

Backwashing should continue for a minimum of 10 min or until effluent from the backwash outlet is clear. The backwash flow should be sufficient to expand the resin bed volume by 50% or more, depending on the available free-board. Insufficient backwash can lead to bed fouling and channeling. Excessive backwash flow rates result in the loss of resin. Backwash flow rates usually vary between 4-8 (ambient temperature) and 12-15 (hot service) gpm per square foot of bed area, but each manufacturer's recommendation should be followed. The ability of water to expand the resin is greatly affected by temperature. Less flow is required to expand the bed with cold water than with warm water. Resin bed expansion should be checked regularly and the flow rate adjusted as needed to maintain proper bed expansion.

Usually, the backwash water is filtered raw water. Water leaving the backwash outlet is unchanged in chemistry but can contain suspended solids. In order to conserve water, the backwash effluent can be returned to the clarifier or filter influent for treatment.

**Regeneration (Brining).** After backwash, regenerant brine is applied. The brine stream enters the unit through the regenerant distributor and flows down through the resin bed at a slow rate (usually between 0.5 and 1 gpm per square foot of resin). Brine flow is collected through the underdrain and sent to waste. The slow flow rate increases contact between the brine and resin. To achieve optimum efficiency from the brine, the solution strength should be 10% during brine introduction.

**Displacement (Slow Rinse).** Following the introduction of regenerant brine, a slow flow of water continues through the regenerant distribution system. This water flow displaces the regenerant through the bed at the desired flow rate. The displacement step completes the regeneration of the resin by ensuring proper contact of the regenerant with the bottom of the resin bed. The flow rate for the displacement water is usually the same rate used for the dilution of the concentrated brine. The duration of the displacement step should be sufficient to allow for approximately one resin bed volume of water to pass through the unit. This provides a "plug" of displacement water which gradually moves the brine completely through the bed.

**Fast Rinse.** After completion of the displacement rinse, water is introduced through the inlet
distributor at a high flow rate. This rinse water removes the remaining brine as well as any residual hardness from the resin bed. The fast rinse flow rate is normally between 1.5 and 2 gpm per square foot of resin. Sometimes it is determined by the service rate for the softener.

Initially, the rinse effluent contains large amounts of hardness and sodium chloride. Usually, hardness is rinsed from the softener before excess sodium chloride. In many operations, the softener can be returned to service as soon as the hardness reaches a predetermined level, but some uses require rinsing until the effluent chlorides or conductivity are near influent levels. An effective fast rinse is important to ensure high effluent quality during the service run. If the softener has been in standby following a regeneration, a second fast rinse, known as a service rinse, can be used to remove any hardness that has entered the water during standby.

HOT ZEOLITE SOFTENING

Zeolite softeners can be used to remove residual hardness in the effluent from a hot process lime or lime-soda softener. The hot process effluent flows through filters and then through a bed of strong acid cation resin in the sodium form (Figure 8-7). The equipment and operation of a hot zeolite softener is identical to that of an ambient temperature softener, except that the valves, piping, controllers, and instrumentation must be suitable for the high temperature (220-250°F). Standard strong cation resin can be used at temperatures of up to 270°F, but for a longer service life a premium gel or macroreticular resin is recommended. When operating a zeolite system following a hot process softener, it is important to design the system to eliminate flow surges in the hot lime unit. Common designs include the use of backwash water storage tanks in the hot lime unit and extended slow rinses for the zeolite in lieu of a standard fast rinse.

Applications and Advantages

Scale and deposit buildup in boilers and the formation of insoluble soap curds in washing operations have created a large demand for softened water. Because sodium zeolite softeners are able to satisfy this demand economically, they are widely used in the preparation of water for low and medium pressure boilers, laundries, and chemical processes. Sodium zeolite softening also offers the following advantages over other softening methods:

- treated water has a very low scaling tendency because zeolite softening reduces the hardness level of most water supplies to less than 2 ppm
- operation is simple and reliable; automatic and semiautomatic regeneration controls are available at a reasonable cost
- salt is inexpensive and easy to handle
- no waste sludge is produced; usually, waste disposal is not a problem
- within certain limits, variations in water flow rate have little effect on treated water quality
- because efficient operation can be obtained in units of almost any size, sodium zeolite softeners are suitable for both large and small installations

Limitations

Although sodium zeolite softeners efficiently reduce the amount of dissolved hardness in a water supply, the total solids content, alkalinity, and silica in the water remain unaffected. A
sodium zeolite softener is not a direct replacement for a hot lime-soda softener. Plants that have replaced their hot process softeners with only zeolite softeners have experienced problems with silica and alkalinity levels in their boilers.

Because the resin is such an efficient filter, sodium zeolite softeners do not function efficiently on turbid waters. Continued operation with an influent turbidity in excess of 1.0 JTU causes bed fouling, short service runs, and poor effluent quality. Most city and well waters are suitable, but many surface supplies must be clarified and filtered before use.

The resin can be fouled by heavy metal contaminants, such as iron and aluminum, which are not removed during the course of a normal regeneration. If excess iron or manganese is present in the water supply, the resin must be cleaned periodically. Whenever aluminum coagulants are used ahead of zeolite softeners, proper equipment operation and close control of clarifier pH are essential to good softener performance.

Strong oxidizing agents in the raw water attack and degrade the resin. Chlorine, present in most municipal supplies, is a strong oxidant and should be removed prior to zeolite softening by activated carbon filtration or reaction with sodium sulfite.

DEMINERALIZATION

Softening alone is insufficient for most high-pressure boiler feedwaters and for many process streams, especially those used in the manufacture of electronics equipment. In addition to the removal of hardness, these processes require removal of all dissolved solids, such as sodium, silica, alkalinity, and the mineral anions (Cl\(^-\), SO\(_4^{2-}\), NO\(_3^-\)).

Demineralization of water is the removal of essentially all inorganic salts by ion exchange. In this process, strong acid cation resin in the hydrogen form converts dissolved salts into their corresponding acids, and strong base anion resin in the hydroxide form removes these acids. Demineralization produces water similar in quality to distillation at a lower cost for most fresh waters.

Principles of Demineralization

A demineralizer system consists of one or more ion exchange resin columns, which include a strong acid cation unit and a strong base anion unit. The cation resin exchanges hydrogen for the raw water cations as shown by the following reactions:

A measure of the total concentration of the strong acids in the cation effluent is the free mineral acidity (FMA). In a typical service run, the FMA content is stable most of the time, as shown in Figure 8-8. If cation exchange were 100% efficient, the FMA from the exchanger would be equal to the theoretical mineral acidity (TMA) of the water. The FMA is usually slightly lower than the TMA because a small amount of sodium leaks through the cation exchanger. The amount of sodium leakage depends on the regenerant level, the flow rate, and the proportion of sodium to the other cations in the raw water. In general, sodium leakage increases as the ratio of
sodium to total cations increases.

As a cation exchange unit nears exhaustion, FMA in the effluent drops sharply, indicating that the exchanger should be removed from service. At this time the resin should be regenerated with an acid solution, which returns the exchange sites to the hydrogen form. Sulfuric acid is normally used due to its affordable cost and its availability. However, improper use of sulfuric acid can cause irreversible fouling of the resin with calcium sulfate.

To prevent this occurrence, the sulfuric acid is usually applied at a high flow rate (1 gpm per square foot of resin) and an initial concentration of 2% or less. The acid concentration is gradually increased to 6-8% to complete regeneration.

Some installations use hydrochloric acid for regeneration. This necessitates the use of special materials of construction in the regenerant system. As with a sodium zeolite unit, an excess of regenerant (sulfuric or hydrochloric acid) is required up to three times the theoretical dose.

To complete the demineralization process, water from the cation unit is passed through a strong base anion exchange resin in the hydroxide form. The resin exchanges hydrogen ions for both highly ionized mineral ions and the more weakly ionized carbonic and silicic acids, as shown below:

\[
\text{H}^+ + \text{Na}^+ + \text{Ca}^{2+} + \text{Mg}^{2+} + \text{Fe}^{3+} + \text{Al}^{3+} + \text{Si}^{4+} + \text{CO}_3^{2-} + \text{HCO}_3^- + \text{SO}_4^{2-} + \text{Cl}^- + \text{SO}_3^{2-} \rightarrow \text{Na}^+ + \text{Ca}^{2+} + \text{Mg}^{2+} + \text{Fe}^{3+} + \text{Al}^{3+} + \text{Si}^{4+} + \text{CO}_3^{2-} + \text{HCO}_3^- + \text{SO}_4^{2-} + \text{Cl}^- + \text{SO}_3^{2-} + \text{H}^+ + \text{OH}^-
\]

To prevent this occurrence, the sulfuric acid is usually applied at a high flow rate (1 gpm per square foot of resin) and an initial concentration of 2% or less. The acid concentration is gradually increased to 6-8% to complete regeneration.

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To complete the demineralization process, water from the cation unit is passed through a strong base anion exchange resin in the hydroxide form. The resin exchanges hydrogen ions for both highly ionized mineral ions and the more weakly ionized carbonic and silicic acids, as shown below:

\[
\text{H}^+ + \text{Na}^+ + \text{Ca}^{2+} + \text{Mg}^{2+} + \text{Fe}^{3+} + \text{Al}^{3+} + \text{Si}^{4+} + \text{CO}_3^{2-} + \text{HCO}_3^- + \text{SO}_4^{2-} + \text{Cl}^- + \text{SO}_3^{2-} \rightarrow \text{Na}^+ + \text{Ca}^{2+} + \text{Mg}^{2+} + \text{Fe}^{3+} + \text{Al}^{3+} + \text{Si}^{4+} + \text{CO}_3^{2-} + \text{HCO}_3^- + \text{SO}_4^{2-} + \text{Cl}^- + \text{SO}_3^{2-} + \text{H}^+ + \text{OH}^-
\]

Demineralization using strong anion resins removes silica as well as other dissolved solids. Effluent silica and conductivity are important parameters to monitor during a demineralizer service run. Both silica and conductivity are low at the end of the fast rinse, as shown in Figure 8-9.

When silica breakthrough occurs at the end of a service run, the treated water silica level increases sharply. Often, the conductivity of the water decreases momentarily, then rises rapidly. This temporary drop in conductivity is easily explained. During the normal service run, most of the effluent conductivity is attributed to the small level of sodium hydroxide produced in the anion exchanger. When silica breakthrough occurs, the hydroxide is no longer available, and the sodium from the cation exchanger is converted to sodium silicate, which is much less conductive than sodium hydroxide. As anion resin exhaustion progresses, the more conductive mineral ions break through, causing a subsequent increase in conductivity.
When the end of a demineralizer run is detected, the unit must be removed from service immediately. If the demineralizer is allowed to remain in service past the breakpoint, the level of silica in the treated water can rise above that of the influent water, due to the concentrating of silica that takes place in the anion resin during the service run.

Strong base anion exchangers are regenerated with a 4% sodium hydroxide solution. As with cation regeneration, the relatively high concentration of hydroxide drives the regeneration reaction. To improve the removal of silica from the resin bed, the regenerant caustic is usually heated to 120°F or to the temperature specified by the resin manufacturer. Silica removal is also enhanced by a resin bed preheat step before the introduction of warm caustic.

**Equipment and Operation**

The equipment used for cation-anion demineralization is similar to that used in zeolite softening. The primary difference is that the vessels, valves, and piping must be made of (or lined with) corrosion-resistant materials. Rubber and polyvinyl chloride (PVC) are commonly used for ion exchange vessel linings. The controls and regenerant systems for demineralizers are more complex, to allow for such enhancements as stepwise acid and warm caustic regenerations.

Demineralizers are similar in operation to zeolite softeners. The service flow rate guidelines for a demineralizer range from 6 to 10 gpm per square foot of resin. Flow rates of over 10 gpm per square foot of resin cause increased sodium and silica leakage with certain waters. Anion resin is much lighter than cation resin. Therefore, the backwash flow rates for anion exchange resins are much lower than those for cation resins, and anion resin expansion is affected by the temperature of the water more than cation resin expansion. The water used for each step of anion resin regeneration should be free from hardness, to prevent precipitation of hardness salts in the alkaline anion resin bed.

Continuous conductivity instruments and silica analyzers are commonly used to monitor anion effluent water quality and detect the need for regeneration. In some instances, conductivity probes are placed in the resin bed above the underdrain collectors to detect resin exhaustion before silica breakthrough into the treated water occurs.

**Advantages and Limitations**

Demineralizers can produce high-purity water for nearly every use. Demineralized water is widely used for high pressure boiler feedwater and for many process waters. The quality of water produced is comparable to distilled water, usually at a fraction of the cost. Demineralizers come in a wide variety of sizes. Systems range from laboratory columns that produce only a few gallons per hour to systems that produce thousands of gallons per minute.

Like other ion exchange systems, demineralizers require filtered water in order to function efficiently. Resin foulants and degrading agents, such as iron and chlorine, should be avoided or removed prior to demineralization. Anion resins are very susceptible to fouling and attack from the organic materials present in many surface water supplies. Some forms of silica, known as colloidal, or non-reactive, are not removed by a demineralizer. Hot, alkaline boiler water dissolves the colloidal material, forming simple silicates that are similar to those that enter the boiler in a soluble form. As such, they can form deposits on tube surfaces and volatilize into the
steam.

**DEALKALIZATION**

Often, boiler or process operating conditions require the removal of hardness and the reduction of alkalinity but not the removal of the other solids. Zeolite softening does not reduce alkalinity, and demineralization is too costly. For these situations, a dealkalization process is used. Sodium zeolite/hydrogen zeolite (split stream) dealkalization, chloride-anion dealkalization, and weak acid cation dealkalization are the most frequently used processes.

**Sodium Zeolite/Hydrogen Zeolite (Split Stream) Dealkalization**

In a split stream dealkalizer, a portion of the raw water flows through a sodium zeolite softener. The remainder flows through a hydrogen-form strong acid cation unit (hydrogen zeolite). The effluent from the sodium zeolite is combined with the hydrogen zeolite effluent. The effluent from the hydrogen zeolite unit contains carbonic acid, produced from the raw water alkalinity, and free mineral acids. When the two streams are combined, free mineral acidity in the hydrogen zeolite effluent converts sodium carbonate and bicarbonate alkalinity in the sodium zeolite effluent to carbonic acid as shown below:

\[
\text{Na}_2\text{SO}_4 + 2\text{Z} \cdot \text{Cl} \rightarrow 2\text{NaCl} + 2\text{Z} \cdot \text{SO}_4^{2-}
\]

Carbonic acid is unstable in water. It forms carbon dioxide gas and water. The blended effluents are sent to a decarbonator or degasser, where the carbon dioxide is stripped from the water by a countercurrent stream of air. Figure 8-10 shows a typical split stream dealkalization system.

The desired level of blended water alkalinity can be maintained through control of the percentage of sodium zeolite and hydrogen zeolite water in the mixture. A higher percentage of sodium zeolite water results in higher alkalinity, and an increased percentage of hydrogen zeolite water reduces alkalinity.

In addition to reducing alkalinity, a split stream dealkalizer reduces the total dissolved solids of the water. This is important in high alkalinity waters, because the conductivity of these waters affects the process and can limit boiler cycles of concentration.

**Sodium Zeolite/Chloride Anion Dealkalization**

Strong base anion resin in the chloride form can be used to reduce the alkalinity of a water. Water flows through a zeolite softener and then an anion unit, which replaces the carbonate, bicarbonate, sulfate, and nitrate ions with chloride ions as shown in these reactions:

\[
\frac{\text{Na}_2\text{SO}_4}{2\text{NaHCO}_3} + 2\text{Z} \cdot \text{Cl} \rightarrow 2\text{NaCl} + 2\text{Z} \cdot \frac{\text{SO}_4^{2-}}{2\text{HCO}_3} + 2\text{Z} \cdot \frac{\text{NO}_3^-}{2\text{NO}_3^-}
\]

The chloride anion dealkalizer reduces alkalinity by approximately 90% but does not reduce
total solids. When the resin nears exhaustion, treated water alkalinity increases rapidly, signaling the need for regeneration.

The zeolite softener is regenerated as previously described. In addition, the anion resin is also regenerated with a sodium chloride brine that returns the resin to the chloride form. Frequently, a small amount of caustic soda is added to the regenerant brine to enhance alkalinity removal.

**Weak Acid Cation Dealkalization**

Another method of dealkalization uses weak acid cation resins. Weak acid resins are similar in operation to strong acid cation resins, but only exchange for cations that are associated with alkalinity, as shown by these reactions:

\[
\text{H}_2\text{CO}_3 + Z \rightarrow \text{HCO}_3^- + Z' + 
\]

where $Z$ represents the resin. The carbonic acid ($\text{H}_2\text{CO}_3$) formed is removed by a decarbonator or degasser as in a split stream system.

The ideal influent for a weak acid cation system has a hardness level equal to the alkalinity (both expressed in ppm as $\text{CaCO}_3$). In waters that are higher in alkalinity than hardness, the alkalinity is not removed to its lowest level. In waters containing more hardness than alkalinity, some hardness remains after treatment. Usually, these waters must be polished by a sodium zeolite softener to remove hardness. During the initial portion of a weak acid cation service run (the first 40-60%) some cations associated with mineral anions exchange, producing small amounts of mineral acids in the effluent. As the service cycle progresses, alkalinity appears in the effluent. When the alkalinity in the effluent exceeds 10% of the influent alkalinity, the unit is removed from service and regenerated with a 0.5% sulfuric acid solution. The concentration of regenerant acid should be kept below 0.5-0.7%, to prevent calcium sulfate precipitation in the resin. Weak acid cation resin exchange is very efficient. Therefore, the amount of acid required is virtually equal (chemically) to the amount of cations removed during the service cycle.

If the materials of construction for the down-stream equipment or overall process cannot tolerate the mineral acidity present during the initial portions of the service cycle, a brine solution is passed through the regenerated weak acid resin prior to the final rinse. This solution removes the mineral acidity without a significant impact on the quality or length of the subsequent run.

Equipment used for a weak acid cation dealkalizer is similar to that used for a strong acid cation exchanger, with the exception of the resin. One variation of the standard design uses a layer of weak acid resin on top of strong acid cation resin. Because it is lighter, the weak acid resin remains on top. The layered resin system is regenerated with sulfuric acid and then with sodium chloride brine. The brine solution converts the strong acid resin to the sodium form. This resin then acts as a polishing softener.

**Direct Acid Injection**

In the process of direct acid injection and decarbonation, acid is used to convert alkalinity to carbonic acid. The carbonic acid dissociates to form carbon dioxide and water and the carbon dioxide is removed in a decarbonator. The use of an acid injection system should be approached
with caution, because an acid overfeed or a breakdown in the pH control system can produce acidic feedwater, which corrodes the iron surfaces of feedwater systems and boilers. Proper pH monitoring and controlled caustic feed after decarbonation are required.

**Advantages and Limitations of Dealkalization Systems**

Ion exchange dealkalization systems produce hardness-free, low-alkalinity water at a reasonable cost, and with a high degree of reliability. They are well suited for processing feedwater for medium-pressure boilers, and for process water for the beverage industry. Split stream and weak acid cation systems also reduce the total dissolved solids. In addition to these advantages, the following disadvantages must be considered:

- dealkalizers do not remove all of the alkalinity and do not affect the silica content of a water
- dealkalizers require the same influent purity as other ion exchange processes; filtered water that is low in potential foulants must be used
- the water produced by a dealkalization system using a forced draft decarbonator becomes saturated with oxygen, so it is potentially corrosive

**COUNTERFLOW AND MIXED BED DEIONIZATION**

Due to increasing boiler operating pressures and the manufacture of products requiring contaminant-free water, there is a growing need for higher water quality than cation-anion demineralizers can produce. Therefore, it has become necessary to modify the standard demineralization process to increase the purity of the treated water. The most significant improvements in demineralized water purity have been produced by counterflow cation exchangers and mixed bed exchangers.

**Counterflow Cation Exchangers**

In a conventional demineralizer system, regenerant flow is in the same direction as the service flow, down through the resin bed. This scheme is known as co-current operation and is the basis for most ion exchange system designs. During the regeneration of a co-current unit, the contaminants are displaced through the resin bed during the regeneration. At the end of the regeneration, some ions, predominately sodium ions, remain in the bottom of the resin bed. Because the upper portion of the bed has been exposed to fresh regenerant, it is highly regenerated. As the water flows through the resin during service, cations are exchanged in the upper portion of the bed first, and then move down through the resin as the bed becomes exhausted. Sodium ions that remained in the bed during regeneration diffuse into the decationized water before it leaves the vessel. This sodium leakage enters the anion unit where anion exchange produces caustic, raising the pH and conductivity of the demineralized water.

In a counterflow regenerated cation exchanger, the regenerant flows in the opposite direction of the service flow. For example, if the service flow is downward through the bed, the regenerant acid flow is up through the bed. As a result, the most highly regenerated resin is located where the service water leaves the vessel. The highly regenerated resin removes the low level of contaminants that have escaped removal in the top of the bed. This results in higher water purity than co-current designs can produce. To maximize contact between the acid and resin and to
keep the most highly regenerated resin from mixing with the rest of the bed, the resin bed must stay compressed during the regenerant introduction. This compression is usually achieved in one of two ways:

- a blocking flow of water or air is used
- the acid flow is split, and acid is introduced at both the top and the bottom of the resin bed (Figure 8-11)

**Mixed Bed Exchangers**

A mixed bed exchanger has both cation and anion resin mixed together in a single vessel. As water flows through the resin bed, the ion exchange process is repeated many times, "polishing" the water to a very high purity. During regeneration, the resin is separated into distinct cation and anion fractions as shown in Figure 8-12. The resin is separated by backwashing, with the lighter anion resin settling on top of the cation resin. Regenerant acid is introduced through the bottom distributor, and caustic is introduced through distributors above the resin bed. The regenerant streams meet at the boundary between the cation and anion resin and discharge through a collector located at the resin interface. Following regenerant introduction and displacement rinse, air and water are used to mix the resins. Then the resins are rinsed, and the unit is ready for service.

Counterflow and mixed bed systems produce a purer water than conventional cation-anion demineralizers, but require more sophisticated equipment and have a higher initial cost. The more complicated regeneration sequences require closer operator attention than standard systems. This is especially true for a mixed bed unit.

**OTHER DEMINERALIZATION PROCESSES**

The standard cation-anion process has been modified in many systems to reduce the use of costly regenerants and the production of waste. Modifications include the use of decarbonators and degassers, weak acid and weak base resins, strong base anion caustic waste (to regenerate weak base anion exchangers), and reclamation of a portion of spent caustic for subsequent regeneration cycles. Several different approaches to demineralization using these processes are shown in Figure 8-13.

**Decarbonators and Degassers**

Decarbonators and degassers are economically beneficial to many demineralization systems, because they reduce the amount of caustic required for regeneration. Water from a cation exchanger is broken into small droplets by sprays and trays or packing in a decarbonator. The water then flows through a stream of air flowing in the opposite direction. Carbonic acid present in the cation effluent dissociates into carbon dioxide and water. The carbon dioxide is stripped from the water by the air, reducing the load to the anion exchangers. Typical forced draft decarbonators are capable of removing carbon dioxide down to 10-15 ppm. However, water effluent from a decarbonator is saturated with oxygen.

In a vacuum degasser, water droplets are introduced into a packed column that is operated under a vacuum. Carbon dioxide is removed from the water due to its decreased partial pressure in a vacuum. A vacuum degasser usually reduces carbon dioxide to less than 2 ppm and also

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removes most of the oxygen from the water. However, vacuum degassers are more expensive to purchase and operate than forced draft decarbonators.

**Weak Acid and Weak Base Resins**

Weak functionality resins have a much higher regeneration efficiency than their strong functionality counterparts. Weak acid cation resins, as described in the dealkalization section, exchange with cations associated with alkalinity. Weak base resins exchange with the mineral acid anions (SO\(_2^-\), Cl\(^-\), NO\(_3^-\)) in a strong acid solution. The regeneration efficiency of weak resins is virtually stoichiometric, the removal of 1 kgr of ions (as CaCO\(_3\)) requires only slightly more than 1 kgr of the regenerant ion (as CaCO\(_3\)). Strong resins require three to four times the regenerant for the same contaminant removal.

Weak base resins are so efficient that it is common practice to regenerate a weak base exchanger with a portion of the "spent" caustic from regeneration of the strong base anion resin. The first fraction of the caustic from the strong base unit is sent to waste to prevent silica fouling of the weak base resin. The remaining caustic is used to regenerate the weak base resin. An additional feature of weak base resins is their ability to hold natural organic materials that foul strong base resins and release them during the regeneration cycle. Due to this ability, weak base resins are commonly used to protect strong base resins from harmful organic fouling.

**Regenerant Reuse**

Due to the high cost of caustic soda and the increasing problems of waste disposal, many demineralization systems are now equipped with a caustic reclaim feature. The reclaim system uses a portion of the spent caustic from the previous regeneration at the beginning of the next regeneration cycle. The reused caustic is followed by fresh caustic to complete the regeneration. The new caustic is then reclaimed for use in the next regeneration. Typically, sulfuric acid is not reclaimed, because it is lower in cost and calcium sulfate precipitation is a potential problem.

**CONDENSATE POLISHING**

Ion exchange uses are not limited to process and boiler water makeup. Ion exchange can be used to purify, or polish, returned condensate, removing corrosion products that could cause harmful deposits in boilers.

Typically, the contaminants in the condensate system are particulate iron and copper. Low levels of other contaminants may enter the system through condenser and pump seal leaks or carry-over of boiler water into the steam. Condensate polishers filter out the particulates and remove soluble contaminants by ion exchange.

Most paper mill condensate polishers operate at temperatures approaching 200°F, precluding the use of anion resin. Cation resin, which is stable up to temperatures of over 270°F, is used for deep bed condensate polishing in these applications. The resin is regenerated with sodium chloride brine, as in a zeolite softener. In situations where sodium leakage from the polisher adversely affects the boiler water internal chemical program or steam attemperating water purity, the resin can be regenerated with an ionized amine solution to prevent these problems.

The service flow rate for a deep bed polisher (20-50 gpm per square foot of resin surface area) is very high compared to that of a conventional softener. High flow rates are permissible because
the level of soluble ions in the condensate can be usually very low. Particulate iron and copper are removed by filtration, while dissolved contaminants are reduced by exchange for the sodium or amine in the resin.

The deep bed cation resin condensate polisher is regenerated with 15 lb of sodium chloride per cubic foot of resin, in a manner similar to that used for conventional sodium zeolite regeneration. A solubilizing or reducing agent is often used to assist in the removal of iron. Sometimes, a supplemental backwash header is located just below the surface of the resin bed. This subsurface distributor, used prior to backwashing, introduces water to break up the crust that forms on the resin surface between regenerations.

An important consideration is the selection of a resin for condensate polishing. Because high pressure drops are generated by the high service flow rates and particulate loadings, and because many systems operate at high temperatures, considerable stress is imposed on the structure of the resin. A premium-grade gelular or macroreticular resin should be used in deep bed condensate polishing applications.

In systems requiring total dissolved solids and particulate removal, a mixed bed condensate polisher may be used. The temperature of the condensate should be below 140°F, which is the maximum continuous operating temperature for the anion resin. Additionally, the flow through the unit is generally reduced to approximately 20 gpm/ft².

Ion exchange resins are also used as part of a precoat filtration system, as shown in Figure 8-14, for polishing condensate. The resin is crushed and mixed into a slurry, which is used to coat individual septums in a filter vessel. The powdered resin is a very fine filtering medium that traps particulate matter and removes some soluble contaminants by ion exchange. When the filter media becomes clogged, the precoat material is disposed of, and the septums are coated with a fresh slurry of powdered resin.

COMMON ION EXCHANGE SYSTEM PROBLEMS

As in any dynamic operating system incorporating electrical and mechanical equipment and chemical operations, problems do occur in ion exchange systems. The problems usually result in poor effluent quality, decreased service run lengths, or increased consumption of regenerant. To keep the ion exchange system operating efficiently and reliably, changes in water quality, run lengths, or regenerant consumption should be considered whenever problems are detected.

The cause-effect diagrams for short runs (Figure 8-15) and poor-quality effluent (Figure 8-16) show that there are many possible causes for reduced performance of a demineralization system. Some of the more common problems are discussed below.

Operational Problems
Changes in raw water quality have a significant impact on both the run length and the effluent quality produced by an ion exchange unit. Although most well waters have a consistent quality, most surface water compositions vary widely over time. A 10% increase in the hardness of the water to a sodium zeolite softener causes a 10% decrease in the service run length. An increase in the ratio of sodium to total cations causes increased sodium leakage from a demineralizer system. Regular chemical analysis of the influent water to ion exchangers should be performed to reveal such variations.
Other causes of ion exchange operational problems include:

- Improper regenerations, caused by incorrect regenerant flows, times, or concentrations. Manufacturer's recommendations should be followed when regenerating ion exchange resins.
- Channeling, resulting from either high or low flow rates, increased suspended solids loading or poor backwashing. This causes premature exhaustion even when much of the bed is in a regenerated state.
- Resin fouling or degradation, caused by poor-quality regenerant.
- Failure to remove silica from the resin, which can result from low regenerant caustic temperature. This can lead to increased silica leakage and short service runs.
- Excess contaminants in the resin, due to previous operation past exhaustion loads. Because the resin becomes loaded with more contaminants than a normal regeneration is designed to remove, a double regeneration is required following an extended service run.

Mechanical Problems

Typical mechanical problems associated with ion exchange systems include:

- Leaking valves, which cause poor quality effluent and prolonged rinses.
- Broken or clogged distributor, which leads to channeling.
- Resin loss, due to excessive backwashing or failure in the underdrain screening or support media.
- Cation resin in the anion unit, causing extended rinse times and sodium leakage into the demineralized water.
- Instrumentation problems, such as faulty totalizers or conductivity meters, which may indicate a problem when none exists, or may introduce poor quality water to service. Instrumentation in the demineralizer area should be checked regularly.

RESIN FOULING AND DEGRADATION

Resin can become fouled with contaminants that hinder the exchange process. Figure 8-17 shows a resin fouled with iron. The resin can also be attacked by chemicals that cause irreversible destruction. Some materials, such as natural organics (Figure 8-18), foul resins at first and then degrade the resin as time passes. This is the most common cause of fouling and degradation in ion exchange systems, and is discussed under "Organic Fouling," later in this chapter.

Causes of Resin Fouling

Iron and Manganese. Iron may exist in water as a ferrous or ferric inorganic salt or as a sequestered organic complex. Ferrous iron exchanges in resin, but ferric iron is insoluble and does not. Ferric iron coats cation resin, preventing exchange. An acid or a strong reducing agent must be used to remove this iron. Organically bound iron passes through a cation unit and fouls the anion resin. It must be removed along with the organic material. Manganese, present in some well waters, fouls a resin in the same manner as iron.

Aluminum. Aluminum is usually present as aluminum hydroxide, resulting from alum or sodium aluminate use in clarification or precipitation softening. Aluminum floc, if carried
through filters, coats the resin in a sodium zeolite softener. It is removed by cleaning with either acid or caustic. Usually, aluminum is not a foulant in a demineralizer system, because it is removed from the resin during a normal regeneration.

**Hardness Precipitates.** Hardness precipitates carry through a filter from a precipitation softener or form after filtration by post-precipitation. These precipitates foul resins used for sodium zeolite softening. They are removed with acid.

Sulfate Precipitation. Calcium sulfate precipitation can occur in a strong acid cation unit operated in the hydrogen cycle. At the end of a service cycle, the top of the resin bed is rich in calcium. If sulfuric acid is used as the regenerant, and it is introduced at too high a concentration or too low a flow rate, precipitation of calcium sulfate occurs, fouling the resin. After calcium sulfate has formed, it is very difficult to redissolve; therefore, resin fouled by calcium sulfate is usually discarded. Mild cases of calcium sulfate fouling may be reversed with a prolonged soak in hydrochloric acid.

Barium sulfate is even less soluble than calcium sulfate. If a water source contains measurable amounts of barium, hydrochloric acid regeneration should be considered.

**Oil Fouling.** Oil coats resin, blocking the passage of ions to and from exchange sites. A surfactant can be used to remove oil. Care must be exercised to select a surfactant that does not foul resin. Oil-fouled anion resins should be cleaned with nonionic surfactants only.

Microbiological Fouling. Microbiological fouling can occur in resin beds, especially beds that are allowed to sit without service flow. Microbiological fouling can lead to severe plugging of the resin bed, and even mechanical damage due to an excessive pressure drop across the fouled resin. If microbiological fouling in standby units is a problem, a constant flow of recirculating water should be used to minimize the problem. Severe conditions may require the application of suitable sterilization agents and surfactants.

**Silica Fouling.** Silica fouling can occur in strong base anion resins if the regenerant temperature is too low, or in weak base resins if the effluent caustic from the SBA unit used to regenerate the weak base unit contains too much silica. At low pH levels, polymerization of the silica can occur in a weak base resin. It can also be a problem in an exhausted strong base anion resin. Silica fouling is removed by a prolonged soak in warm (120°F) caustic soda.

**Causes of Irreversible Resin Degradation**

**Oxidation.** Oxidizing agents, such as chlorine, degrade both cation and anion resins. Oxidants attack the divinylbenzene cross-links in a cation resin, reducing the overall strength of the resin bead. As the attack continues, the cation resin begins to lose its spherical shape and rigidity, causing it to compact during service. This compaction increases the pressure drop across the resin bed and leads to channeling, which reduces the effective capacity of the unit.

In the case of raw water chlorine, the anion resin is not directly affected, because the chlorine is consumed by the cation resin. However, downstream strong base anion resins are fouled by certain degradation products from oxidized cation resin.

If chlorine is present in raw water, it should be removed prior to ion exchange with activated carbon filtration or sodium sulfite. Approximately 1.8 ppm of sodium sulfite is required to
consume 1 ppm of chlorine.

Oxygen-saturated water, such as that found following forced draft decarbonation, accelerates the destruction of strong base exchange sites that occurs naturally over time. It also accelerates degradation due to organic fouling.

**Thermal Degradation.** Thermal degradation occurs if the anion resin becomes overheated during the service or regeneration cycle. This is especially true for acrylic resins, which have temperature limitations as low as 100°F, and Type II strong base anion resins, which have a temperature limit of 105°F when in the hydroxide form.

**Organic Fouling**

Organic fouling is the most common and expensive form of resin fouling and degradation. Usually, only low levels of organic materials are found in well waters. However, surface waters can contain hundreds of parts per million of natural and man-made organic matter. Natural organics are derived from decaying vegetation. They are aromatic and acidic in nature, and can complex heavy metals, such as iron. These contaminants include tannins, tannic acid, humic acid, and fulvic acid.

Initially, organics block the strong base sites on a resin. This blockage causes long final rinses and reduces salt splitting capacity. As the foulant continues to remain on the resin, it begins to degrade the strong base sites, reducing the salt splitting capacity of the resin. The functionality of the site changes from strong base to weak base, and finally to a nonactive site. Thus, a resin in the early stages of degradation exhibits high total capacity, but reduced salt splitting capacity. At this stage, cleaning of the resin can still return some, but not all, of the lost operating capacity. A loss in salt splitting capacity reduces the ability of the resin to remove silica and carbonic acid.

Organic fouling of anion resin is evidenced by the color of the effluent from the anion unit during regeneration, which ranges from tea-colored to dark brown. During operation, the treated water has higher conductivity and a lower pH.

**Prevention.** The following methods are used, either alone or in combination, to reduce organic fouling:

- Prechlorination and clarification. Water is prechlorinated at the source, and then clarified with an organic removal aid.
- Filtration through activated carbon. It should be noted that a carbon filter has a finite capacity for removal of organic material and that the removal performance of the carbon should be monitored frequently.
- Macroporous and weak base resin ahead of strong base resin. The weak base or macroporous resin absorbs the organic material and is eluted during regeneration.
- Specialty resins. Acrylic and other specialty resins that are less susceptible to organic fouling have been developed.

**Inspection and Cleaning.** In addition to these preventive procedures, a program of regular inspection and cleaning of the ion exchange system helps to preserve the life of anion resin. Most cleaning procedures use one of the following:
Warm (120°F) brine and caustic. Mild oxidants or solubilizing agents can be added to improve the cleaning.

- Hydrochloric acid. When resins are also fouled with significant amounts of iron, hydrochloric acids are used.
- Solutions of 0.25-0.5% sodium hypochlorite. This procedure destroys the organic material but also significantly degrades the resin. Hypochlorite cleaning is considered a last resort.

It is important to clean an organically fouled resin before excessive permanent degradation of the strong base sites occurs. Cleaning after permanent degradation has occurred removes significant amounts of organic material but does not improve unit performance. The condition of the resin should be closely monitored to identify the optimum schedule for cleaning.

**RESIN TESTING AND ANALYSIS**

To track the condition of ion exchange resin and determine the best time for cleaning it, the resin should be periodically sampled and analyzed for physical stability, foulant levels, and the ability to perform the required ion exchange.

Samples should be representative of the entire resin bed. Therefore, samples should be collected at different levels within the bed, or a grain thief or hollow pipe should be used to obtain a "core" sample. During sampling, the inlet and regenerant distributor should be examined, and the condition of the top of the resin bed should be noted. Excessive hills or valleys in the resin bed are an indication of flow distribution problems.

The resin sample should be examined microscopically for signs of fouling and cracked or broken beads. It should also be tested for physical properties, such as density and moisture content (Figure 8-19). The level of organic and inorganic foulants in the resin should be determined and compared to known standards and the previous condition of the resin. Finally, the salt splitting and total capacity should be measured on anion resin samples to evaluate the rate of degradation or organic fouling.

Membrane systems

- Membrane processes
- Pretreatment
- Solids removal
- Scale control
- Microbiological fouling

Since the 1940's, ion exchange resins have been used to remove dissolved salts from water. These resins exchange ions in the water for ions on the resin exchange sites and hold them until released by a regeneration solution (see Chapter 8 for a more detailed discussion). Many ion exchange processes exist for a variety of industrial water and wastewater applications. The ion exchange process consumes large quantities of regeneration chemicals, such as brine, acid, and caustic materials that can present significant handling and disposal problems.

In recent years, membrane processes have been used increasingly for the production of "pure"
waters from fresh water and seawater. Membrane processes are also being applied in process and wastewater systems.

Although typically thought to be expensive and relatively experimental, membrane technology is advancing quickly becoming less expensive, improving performance, and extending life expectancy.

MEMBRANE PROCESSES

Common membrane processes include ultrafiltration (UF), reverse osmosis (RO), electrodialysis (ED), and electrodialysis reversal (EDR). These processes (with the exception of UF) reduce most ions; RO and UF systems also provide efficient reduction of nonionized organics and particulates. Because UF membrane porosity is too large for ion rejection, the UF process is used to reduce contaminants, such as oil and grease, and suspended solids.

Reverse Osmosis

Osmosis is the flow of solvent through a semi-permeable membrane, from a dilute solution to a concentrated solution. This flow results from the driving force created by the difference in pressure between the two solutions. Osmotic pressure is the pressure that must be added to the concentrated solution side in order to stop the solvent flow through the membrane. Reverse osmosis is the process of reversing the flow, forcing water through a membrane from a concentrated solution to a dilute solution to produce filtered water. Figure 9-1 illustrates the processes of osmosis and reverse osmosis.

Reverse osmosis is created when sufficient pressure is applied to the concentrated solution to overcome the osmotic pressure. This pressure is provided by feedwater pumps. Concentrated contaminants (brine) are reduced from the high-pressure side of the RO membrane, and filtered water (permeate) is reduced from the low-pressure side. Figure 9-2 is a simplified schematic of an RO process. Membrane modules may be staged in various design configurations, producing the highest-quality permeate with the least amount of waste. An example of a multistage RO configuration is shown in Figure 9-3.

Typically, 95% of dissolved salts are reduced from the brine. All particulates are removed. However, due to their molecular porosity, RO membranes do not remove dissolved gases, such as \( \text{Cl}_2 \), \( \text{CO}_2 \), and \( \text{O}_2 \).

RO Membranes. The two most common RO membranes used in industrial water treatment are cellulose acetate (CA) and polyamide (PA) composite. Currently, most membranes are spiral wound; however, hollow fiber configurations are available. In the spiral wound configuration, a flat sheet membrane and spacers are wound around the permeate collection tube to produce flow channels for permeate and feed water. This design maximizes flow while minimizing the membrane module size.

Hollow fiber systems are bundles of tiny, hair-like membrane tubes. Ions are rejected when the feedwater permeates the walls of these tubes, and permeate is collected through the hollow center of the fibers. Concentrated brine is produced on the outside of the fibers contained by the module housing.

Figure 9-4 shows the construction and flow patterns in a spiral wound membrane.
configuration. Figure 9-5 shows the construction and flow patterns in a hollow fiber membrane system.

**Electrodialysis**

Electrodialysis (ED) processes transfer ions of dissolved salts across membranes, leaving purified water behind. Ion movement is induced by direct current electrical fields. A negative electrode (cathode) attracts cations, and a positive electrode (anode) attracts anions. Systems are compartmentalized in stacks by alternating cation and anion transfer membranes. Alternating compartments carry concentrated brine and filtered permeate. Typically, 40-60% of dissolved ions are removed or rejected. Further improvement in water quality is obtained by staging (operation of stacks in series). ED processes do not remove particulate contaminants or weakly ionized contaminants, such as silica. Figure 9-6 is a simplified schematic of an ED process.

**Electrodialysis Reversal**

Electrodialysis reversal (EDR) processes operate on the same principles as ED; however, EDR operation reverses system polarity (typically 3-4 times per hour). This reversal stops the buildup of concentrated solutions on the membrane and thereby reduces the accumulation of inorganic and organic deposition on the membrane surface. EDR systems are similar to ED systems, designed with adequate chamber area to collect both product water and brine. EDR produces water of the same quality as ED.

**Ultrafiltration**

In many process and wastewater applications, reduction of dissolved ions is not required but efficient reduction of colloidal inorganic or organic molecules is. Ultrafiltration (UF) membrane configurations and system designs are similar to those used in the single-stage RO process. Because the large molecules removed by UF exhibit negligible osmotic pressure, operating pressures are usually much lower than in RO systems. Figure 9-7 illustrates the performance of ultrafiltration membranes. Typical applications include reduction of oil and grease and recovery of valuable contaminants in process waste streams.

**PRETREATMENT**

Processes that rely on microporous membranes must be protected from fouling. Membrane fouling causes a loss of water production (flux), reduced permeate quality, and increased transmembrane pressure drop.

Membrane fouling is typically caused by precipitation of inorganic salts, particulates of metal oxides, colloidal silt, and the accumulation or growth of microbiological organisms on the membrane surface. These fouling problems can lead to serious damage and necessitate more frequent replacement of membranes.

**SOLIDS REDUCTION**

Membrane feedwater should be relatively free from colloidal particulates. The most common particulates encountered in industrial membrane systems are silt, iron oxides, and manganese oxides.
Silt Density Index (SDI) testing should be used to confirm sufficient water quality for the specific membrane system employed. SDI evaluates the potential of feedwater to foul a 0.45 μm filter. Unacceptable SDI measurements can be produced even when water quality is relatively high by most industrial water treatment standards. Where pretreatment is inadequate or ineffective, chemical dispersants may be used to permit operation at higher-than-recommended SDI values. RO systems are highly susceptible to particulate fouling, ED and EDR systems are more forgiving, and UF systems are designed to handle dirty waters. and biodispersants should be used if serious microbiological fouling

**SCALE CONTROL**

Membrane processes produce a concentration gradient of dissolved salts approaching the membrane surfaces. The concentration at the membrane may exceed the solubility limits of certain species. Calcium carbonate (CaCO₃) and calcium sulfate (CaSO₄) are typical precipitates formed. Silica, barium, and strontium salts are also frequently identified in membrane deposits. Because of their low solubility, very low levels of feedwater barium or strontium can cause membrane fouling.

Various saturation indexes, such as the Stiff-Davis and Langelier, should be maintained below precipitating values in the brine (through pH control or deposit control agents) to prevent calcium carbonate fouling. Other precipitates may be controlled by the proper application of deposit control agents.

**MICROBIOLOGICAL FOULING**

Cellulose acetate membranes can be degraded by microbiological activity. Proper maintenance of chlorine residuals can prevent microbiological attack of these membranes.

Polyacrylamide membranes are resistant to microbiological degradation; however, they are susceptible to chemical oxidation. Therefore, chlorination is not an acceptable treatment. If inoculation occurs, microbiological fouling can become a problem. Nonoxidizing antimicrobials potential exists.
UNIT-V WATER DISTRIBUTION AND SUPPLY TO BUILDINGS

A water supply system or water supply network is a system of engineered hydrologic and hydraulic components which provide water supply. A water supply system typically includes:

1. A drainage basin (see water purification - sources of drinking water);
2. A raw (untreated) water collection point (above or below ground) where the water accumulates, such as a lake, a river, or groundwater from an underground aquifer. Untreated drinking water (usually water being transferred to the water purification
facilities) may be transferred using uncovered ground-level aqueducts, covered tunnels or underground water pipes.

3. Water purification facilities. Treated water is transferred using water pipes (usually underground).

4. Water storage facilities such as reservoirs, water tanks, or watertowers. Smaller water systems may store the water in cisterns or pressure vessels. (Tall buildings may also need to store water locally in pressure vessels in order for the water to reach the upper floors.)

5. Additional water pressurizing components such as pumping stations may need to be situated at the outlet of underground or above ground reservoirs or cisterns (if gravity flow is impractical)

6. A pipe network for distribution of water to the consumers (which may be private houses or industrial, commercial or institution establishments) and other usage points (such as fire hydrants)

7. Connections to the sewers (underground pipes, or aboveground ditches in some developing countries) are generally found downstream of the water consumers, but the sewer system is considered to be a separate system, rather than part of the water supply system.

Water distribution network

The Central Arizona Project Aqueduct transfers untreated water
Most (treated) water distribution happens through underground pipes

Pressurizing the water is required between the small water reserve and the end-user.

The product, delivered to the point of consumption, is called fresh water if it receives little or no treatment, or drinking water if the treatment achieves the water quality standards required for human consumption.

Once treated, chlorine is added to the water and it is distributed by the local supply network. Today, water supply systems are typically constructed of plastic, ferrous, or concrete circular pipe. However, other "pipe" shapes and material may be used, such as square or rectangular concrete boxes, archedbrick pipe, or wood. Near the end point, the network of pipes through which the water is delivered is often referred to as the water mains.

The energy that the system needs to deliver the water is called pressure. That energy is transferred to the water, therefore becoming water pressure, in a number of ways: by a pump, by gravity feed from a water source (such as a water tower) at a higher elevation, or by compressed air. [1]
The water is often transferred from a water reserve such as a large communal reservoir before being transported to a more pressurised reserve as a watertower.

In small domestic systems, the water may be pressurised by a pressure vessel or even by an underground cistern (the latter however does need additional pressurizing). This eliminates the need of a water-tower or any other heightened water reserve to supply the water pressure.

These systems are usually owned and maintained by local governments, such as cities, or other public entities, but are occasionally operated by a commercial enterprise (see water privatization). Water supply networks are part of the master planning of communities, counties, and municipalities. Their planning and design requires the expertise of city planners and civil engineers, who must consider many factors, such as location, current demand, future growth, leakage, pressure, pipe size, pressure loss, fire fighting flows, etc. — using pipe network analysis and other tools. Construction comparable sewage systems, was one of the great engineering advances that made urbanization possible. Improvement in the quality of the water has been one of the great advances in public health.

As water passes through the distribution system, the water quality can degrade by chemical reactions and biological processes. Corrosion of metal pipe materials in the distribution system can cause the release of metals into the water with undesirable aesthetic and health effects. Release of iron from unlined iron pipes can result in customer reports of "red water" at the tap. Release of copper from copper pipes can result in customer reports of "blue water" and/or a metallic taste. Release of lead can occur from the solder used to join copper pipe together or from brass fixtures. Copper and lead levels at the consumer's tap are regulated to protect consumer health.

Utilities will often adjust the chemistry of the water before distribution to minimize its corrosiveness. The simplest adjustment involves control of pH and alkalinity to produce a water that tends to passivate corrosion by depositing a layer of calcium carbonate. Corrosion inhibitors are often added to reduce release of metals into the water. Common corrosion inhibitors added to the water are phosphates and silicates.

Maintenance of a biologically safe drinking water is another goal in water distribution. Typically, a chlorine based disinfectant, such as sodium hypochlorite or monochloramine is added to the water as it leaves the treatment plant. Booster stations can be placed within the distribution system to ensure that all areas of the distribution system have adequate sustained levels of disinfection.

Topologies of water distribution networks
Like electric power lines, roads, and microwave radio networks, water systems may have a loop or branch network topology, or a combination of both. The piping networks are circular or rectangular. If any one section of water distribution main fails or needs repair, that section can be isolated without disrupting all users on the network.

Most systems are divided into zones. Factors determining the extent or size of a zone can include hydraulics, telemetry systems, history, and population density. Sometimes systems are designed for a specific area then are modified to accommodate development. Terrain affects hydraulics and some forms of telemetry. While each zone may operate as a stand-alone system, there is usually some arrangement to interconnect zones in order to manage equipment failures or system failures.

COMPONENTS OF WATER DISTRIBUTION SYSTEM

Drainage basin

From Wikipedia, the free encyclopedia

Example of a drainage basin. The dashed line is the main water divide of the hydrographic basin

A drainage basin is an extent or an area of land where surface water from rain and melting snow or ice converges to a single point, usually the exit of the basin, where the waters join another waterbody, such as a river, lake, reservoir, estuary, wetland, sea, or ocean. In closed drainage basins the water converges to a single point inside the basin, known as a sink, which may be a permanent lake, dry lake, or a point where surface water is lost underground.¹ The drainage basin includes both the streams and rivers that convey the water as well as the land
surfaces from which water drains into those channels, and is separated from adjacent basins by a drainage divide.[2]

The drainage basin acts as a funnel by collecting all the water within the area covered by the basin and channelling it to a single point. Each drainage basin is separated topographically from adjacent basins by a geographical barrier such as a ridge, hill or mountain.

Other terms that are used to describe a drainage basin are catchment, catchment area, catchment basin, drainage area, river basin, water basin and watershed.[3] In the technical sense, a watershed refers to a divide that separates one drainage area from another drainage area.[4] However, in the United States and Canada, the term is often used to mean a drainage basin or catchment area itself. Drainage basins drain into other drainage basins in a hierarchical pattern, with smaller sub-drainage basins combining into larger drainage basins.[5]

Drainage basins are similar but not identical to hydrologic units, which are drainage areas delineated so as to nest into a multi-level hierarchical drainage system. Hydrologic units are designed to allow multiple inlets, outlets, or sinks. In a strict sense, all drainage basins are hydrologic units but not all hydrologic units are drainage basins.[1]

The United States Environmental Protection Agency launched the website Watershed Central for the US public to exchange information and locate resources needed to restore local drainage basins in that country.

Importance of drainage basins

Geopolitical boundaries

Drainage basins have been historically important for determining territorial boundaries, particularly in regions where trade by water has been important. For example, the English crown gave the Hudson's Bay Company a monopoly on the fur trade in the entire Hudson Bay basin, an area called Rupert's Land. Today, bioregional democracy can include agreements of states in a particular drainage basin to defend it. One example of this is the Great Lakes Commission.

Hydrology
Drainage basin of the Ohio River, part of the Mississippi River drainage basin.

In **hydrology**, the drainage basin is a logical unit of focus for studying the movement of water within the hydrological cycle, because the majority of water that discharges from the basin outlet originated as **precipitation** falling on the basin. A portion of the water that enters the groundwater system beneath the drainage basin may flow towards the outlet of another drainage basin because groundwater flow directions do not always match those of their overlying drainage network. Measurement of the discharge of water from a basin may be made by a stream gauge located at the basin's outlet.

Rain gauge data is used to measure total precipitation over a drainage basin, and there are different ways to interpret that data. If the gauges are many and evenly distributed over an area of uniform precipitation, using the arithmetic mean method will give good results. In the Thiessen polygon method, the watershed is divided into polygons with the rain gauge in the middle of each polygon assumed to be representative for the rainfall on the area of land included in its polygon. These polygons are made by drawing lines between gauges, then making perpendicular bisectors of those lines form the polygons. The **isohyetal** method involves contours of equal precipitation are drawn over the gauges on a map. Calculating the area between these curves and adding up the volume of water is time consuming.

**Geomorphology**

Drainage basins are the principal hydrologic unit considered in fluvial geomorphology. A drainage basin is the source for water and sediment that moves through the river system and reshapes the channel.

**Ecology**
The Mississippi River drains the largest area of any U.S. river, much of it agricultural regions. Agricultural runoff and other water pollution that flows to the outlet is the cause of the dead zone in the Gulf of Mexico.

Drainage basins are important elements to consider also in ecology. As water flows over the ground and along rivers it can pick up nutrients, sediment, and pollutants. Like the water, they get transported towards the outlet of the basin, and can affect the ecological processes along the way as well as in the receiving water source.

Modern usage of artificial fertilizers, containing nitrogen, phosphorus, and potassium, has affected the mouths of watersheds. The minerals will be carried by the watershed to the mouth and accumulate there, disturbing the natural mineral balance. This can cause eutrophication where plant growth is accelerated by the additional material.

**Resource management**

*Further information: Watershed management*

Because drainage basins are coherent entities in a hydrological sense, it has become common to manage water resources on the basis of individual basins. In the U.S. state of Minnesota, governmental entities that perform this function are called watershed districts. In New Zealand, they are called catchment boards. Comparable community groups based in Ontario, Canada, are called conservation authorities. In North America this function is referred to as watershed management. In Brazil, the National Policy of Water Resources, regulated by Act n°9.433 of 1997, establishes the drainage basin as territorial division of Brazilian water management.

**Catchment factors**

The catchment is the most significant factor determining the amount or likelihood of flooding.
Catchment factors are: topography, shape, size, soil type and land use (paved or roofed areas). Catchment topography and shape determine the time taken for rain to reach the river, while catchment size, soil type and development determine the amount of water to reach the river.

**Topography**

Topography determines the speed with which the runoff will reach a river. Clearly rain that falls in steep mountainous areas will reach the river faster than flat or gently sloping areas.

**Shape**

Shape will contribute to the speed with which the runoff reaches a river. A long thin catchment will take longer to drain than a circular catchment.

**Size**

Size will help determine the amount of water reaching the river, as the larger the catchment the greater the potential for flooding.

**Soil type**

Soil type will help determine how much water reaches the river. Certain soil types such as sandy soils are very free draining and rainfall on sandy soil is likely to be absorbed by the ground. However, soils containing clay can be almost impermeable and therefore rainfall on clay soils will run off and contribute to flood volumes. After prolonged rainfall even free draining soils can become saturated, meaning that any further rainfall will reach the river rather than being absorbed by the ground.

**Land use**

Land use can contribute to the volume of water reaching the river, in a similar way to clay soils. For example, rainfall on roofs, pavements and roads will be collected by rivers with almost no absorption into the groundwater.

**Reservoir**

From Wikipedia, the free encyclopedia

(Redirected from Reservoirs)

*This article is about an artificial body of water. For other uses, see Reservoir (disambiguation).*
The Jhonghua Dam on the Dahan River in Taoyuan County, Taiwan.

A reservoir (etymology from French réservoir a "storehouse" or an artificial lake is used to store water. Reservoirs may be created in river valleys by the construction of a dam or may be built by excavation in the ground or by conventional construction techniques such as brickwork or cast concrete.

The term reservoir may also be used to describe underground reservoirs such as an oil or water well.

Types

Valleydammed reservoir

Lake Vyrnwy Reservoir. The dam spans the Vyrnwy Valley and was the first large stone dam built in the United Kingdom.

Stocks Reservoir in Lancashire, England.
A dam constructed in a valley relies on the natural topography to provide most of the basin of the reservoir. Dams are typically located at a narrow part of a valley downstream of a natural basin. The valley sides act as natural walls with the dam located at the narrowest practical point to provide strength and the lowest practical cost of construction. In many reservoir construction projects people have to be moved and re-housed, historical artifacts moved or rare environments relocated. Examples include the temples of Abu Simbel (which were moved before the construction of the Aswan Dam to create Lake Nasser from the Nile in Egypt) and the re-location of the village of Capel Celyn during the construction of Llyn Celyn.

Construction of a reservoir in a valley will usually necessitate the diversion of the river during part of the build often through a temporary tunnel or bypass channel.

In hilly regions reservoirs are often constructed by enlarging existing lakes. Sometimes in such reservoirs the new top water level exceeds the watershed height on one or more of the feeder streams such as at Llyn Clywedog in Mid Wales. In such cases additional side dams are required to contain the reservoir.

Where the topography is poorly suited to a single large reservoir, a number of smaller reservoirs may be constructed in a chain such as in the River Taff valley where the three reservoirs Llwyn-on Reservoir, Cantref Reservoir and Beacons Reservoir form a chain up the valley.

**Bank-side reservoir**

Where water is taken from a river of variable quality or quantity, bank-side reservoirs may be constructed to store the water pumped or siphoned from the river. Such reservoirs are usually built partly by excavation and partly by the construction of a complete encircling bund or embankment which may exceed 6 km in circumference. Both the floor of the reservoir and the bund must have an impermeable lining or core, often made of puddled clay. The water stored in such reservoirs may have a residence time of several months during which time normal biological processes are able to substantially reduce many contaminants and almost eliminate any turbidity. The use of bank-side reservoirs also allows a water abstraction to be closed down for extended periods at times when the river is unacceptably polluted or when flow conditions are very low due to drought. The London water supply system is one example of the use of bank-side storage for all the water taken from the River Thames and River Lee with many large reservoirs such as Queen Mary Reservoir visible along the approach to London Heathrow Airport.

**Service reservoir**

Service reservoirs store fully treated potable water close to the point of distribution. Many service reservoirs are constructed as water towers, often as elevated structures on concrete pillars where the

[www.studentsfocus.com](http://www.studentsfocus.com)
landscape is relatively flat. Other service reservoirs are entirely underground, especially in more hilly or mountainous country. In the United Kingdom, Thames Water has many underground reservoirs built in the 1800s by the Victorians, most of which are lined with brick. Honor Oak Reservoir, which was completed in 1909, is believed to one of the largest of this type in Europe. The roof is supported on large brick pillars and arches and the outside surface is grassed over. [9]

Service reservoirs perform several functions including ensuring sufficient head of water in the water distribution system and providing hydraulic capacitance in the system to even out peak demand from consumers enabling the treatment plant to run at optimum efficiency. Large service reservoirs can also be managed to so that energy costs in pumping are reduced by concentrating refilling activity at times of day when power costs are low.

History

Five thousand years ago, the craters of extinct volcanoes in Arabia were used as reservoirs by farmers for their irrigation water. [10]

Dry climate and water scarcity in India led to early development of water management techniques, including the building of a reservoir at Girnar in 3000 BC. [11] Artificial lakes dating to the 5th century BC have been found in ancient Greece. [12] An artificial lake in present-day Madhya Pradesh province of India, constructed in the 11th century, covered 650 square metres (7,000 sq ft). [11]

In Sri Lanka large reservoirs have been created by ancient Sinhalese kings in order to save the water for irrigation. The famous Sri Lankan king Parakrama Bahu I of Sri Lanka stated "do not let a drop of water seep into the ocean without benefiting mankind ". He created the reservoir named Parakrama Samudra(sea of King Parakrama), which has astonished archaeologists.

Uses

Direct water supply

Gibson Reservoir, Montana
Many dammed river reservoirs and most bank-side reservoirs are used to provide the raw water feed to a water treatment plant which delivers drinking water through water mains. The reservoir does not simply hold water until it is needed; it can also be the first part of the water treatment process. The time the water is held for before it is released is known as the retention time. This is a design feature that allows particles and silts to settle out, as well as time for natural biological treatment using algae, bacteria and zooplankton that naturally live within the water. However natural limnological processes in temperate climate lakes produces temperature stratification in the water body which tends to partition some elements such as manganese and phosphorus into deep, cold anoxic water during the summer months. In the autumn and winter the lake becomes fully mixed again. During drought conditions, it is sometimes necessary to draw down the cold bottom water and the elevated levels of manganese in particular can cause problems in water treatment plants.  

**Hydroelectricity**

A reservoir generating hydroelectric includes turbines connected to the retained water body by large diameter pipes. These generating sets may be at the base of the dam or some distance away. Some reservoirs generating hydro-electricity use pumped re-charge in which a high level reservoir is filled with water using high performance electric pumps at times when electricity demand is low and then uses this stored water to generate electricity by releasing the stored water into a low level reservoir when electricity demand is high. Such systems are called pump storage schemes.

**Controlling watercourses**

Reservoirs can be used in a number of ways to control how water flows through downstream waterways.

- **Downstream water supply** — water may be released from an upland reservoir so that it can be abstracted for drinking water lower down the system, sometimes hundred of miles further down downstream.
**Irrigation** – water in an irrigation reservoir may be released into networks of canals for use in **farmlands** or secondary water systems. Irrigation may also be supported by reservoirs which maintain river flows allowing water to be abstracted for irrigation lower down the river.  

**Flood control** – also known as an "attenuation" or "balancing" reservoir, flood control reservoirs collect water at times of very high rainfall, then release it slowly over the course of the following weeks or months. Some of these reservoirs are constructed across the river line with the onward flow controlled by an orifice plate. When river flow exceeds the capacity of the orifice plate water builds behind the dam but as soon as the flow rate reduces the water behind the dam slowly releases until the reservoir is empty again. In some cases such reservoirs only function a few times in a decade and the land behind the reservoir may be developed as community or recreational land. A new generation of balancing dams are being developed to combat the climatic consequences of climate change. They are called "Flood Detention Reservoirs". Because these reservoirs will remain dry for long periods, there may be a risk of the clay core drying out reducing its structural stability. Recent developments include the use of composite core fill made from recycled materials as an alternative to clay.

**Canals** – Where a natural watercourse's water is not available to be diverted into a canal, a reservoir may be built to guarantee the water level in the canal; for example, where a canal climbs to cross a range of hills through locks.  

**Recreation** – water may be released from a reservoir to artificially create or supplement white-water conditions for kayaking and other white-water sports. On salmonid rivers special releases (in Britain called freshets) are made to encourage natural migration behaviours in fish and to provide a variety of fishing conditions for anglers.

**Flow balancing**

Reservoirs can be used to balance the flow in highly managed systems, taking in water during high flows and releasing it again during low flows. In order for this to work without pumping requires careful control of water levels using adjustable sluices. Accurate weather forecasts are essential so that dam operators can plan drawdowns prior to a high rainfall or snowmelt event.
operators blamed a faulty weather forecast on the 2010–2011 Queensland floods. Examples of highly managed Reservoirs are Burrendong Dam in Australia and Llyn Tegid in North Wales. Llyn Tegid is a natural lake whose level was raised by a low dam and into which the River Dee flows or discharges depending upon flow conditions at the time as part of the River Dee regulation system. This mode of operation is a form of hydraulic capacitance in the river system.

Recreation

The water bodies provided by many reservoirs often allow some recreational uses such as fishing, boating, and other activities. Special rules may apply for the safety of the public and to protect the quality of the water and the ecology of the surrounding area. Many reservoirs now support and encourage less informal and less structured recreation such as natural history, bird watching, landscape painting, walking and hiking and often provide information boards and interpretation material to encourage responsible use.

Operation

Water falling as rain upstream of the reservoir together with any groundwater emerging as springs is stored in the reservoir. Any excess water can be spilled via a specifically designed spillway. Stored water may be piped by gravity for use as drinking water, to generate hydro-electricity or to maintain river flows to support downstream uses. Occasionally reservoirs can be managed to retain high rain-fall events to prevent or reduce downstream flooding. Some reservoirs support several uses and the operating rules may be complex.
Spillway of Llyn Brianne dam in Wales.

Most modern reservoirs have a specially designed draw-off tower that can discharge water from the reservoir at different levels both to access water as the reservoir draws down but also to allow water of a specific quality to be discharged into the downstream river as compensation water.

The operators of many upland or in-river reservoirs have obligations to release water into the downstream river to maintain river quality, support fisheries, maintain downstream industrial uses, maintain recreational use or for a range of other requirements. Such releases are known as compensation water.

**Terminology**

The terminology for reservoirs varies from country to country. In most of the world reservoir areas are expressed in km whilst in the USA acres are commonly used. For volume either m or ³km are widely used with acre feet used in the USA.

The capacity, volume or storage of a reservoir is usually divided into distinguishable areas. Dead or inactive storage refers to water in a reservoir that cannot be drained by gravity through a dam's outlet works, spillway or power plant intake and can only be pumped out. Dead storage allows sediments to settle which improves water quality and also creates hydraulic head along with an area for fish during low levels. Active or live storage is the portion of the reservoir that can be utilized for flood control, power production, navigation and downstream releases. In addition, a
reservoir's flood control capacity is the amount of water it can regulate during flooding. The surcharge capacity is the capacity of the reservoir above the spillway crest that cannot be regulated.  

In the United States the water below the normal maximum level of a reservoir is called the conservation pool. In the UK top water level describes the reservoir full state whilst fully drawn down describes the minimum retained volume.

**Modelling reservoir management**

There is a wide variety of software for modelling reservoirs, from the specialist Dam Safety Program Management Tools (DSPMT) to the relatively simple WAFLEX, to integrated models like the Water Evaluation And Planning system (WEAP) that place reservoir operations in the context of system-wide demands and supplies.

**Safety**

In many countries large reservoirs are closely regulated to try to prevent or minimise failures of containment. Whilst much of the effort is directed at the dam and its associated structures as the weakest part of the overall structure, the aim of such controls is to prevent an uncontrolled release of water from the reservoir. Reservoir failures can generate huge increases in flow down a river valley with the potential to wash away towns and villages and cause considerable loss of life such as the devastation following the failure of containment at Llyn Eigiau which killed 17 people. (see also List of dam failures)

A notable case of reservoirs being used as an instrument of War involved the British Royal Air Force Dambusters raid on Germany in World War II (codenamed "Operation Chastise"), in which three German reservoir dams were selected to be breached in order to impact on German infrastructure and manufacturing and power capabilities deriving from the Ruhr and Eder rivers. The economic and social impact was derived from the enormous volumes of previously stored water that swept down the valleys wreaking destruction. This raid later became the basis for several films.
Environmental impact

Whole life environmental impact

All reservoirs will have a monetary cost/benefit assessment made before construction to see if the project is worth proceeding with. However, such analysis can often omit the environmental impacts of dams and the reservoirs that they contain. Some impacts such as the greenhouse gas production associated with concrete manufacture are relatively easy to estimate. Other impact on the natural environment and social and cultural effects can be more difficult to assess and to weigh in the balance but identification and quantification of these issues are now commonly required in major construction projects in the developed world.

Climate change

Depending upon the circumstances, a reservoir built for hydro-electricity generation can either reduce or increase the net production of greenhouse gases. An increase can occur if plant material in the flooded areas decays in an anaerobic environment releasing (methane and carbon dioxide). This apparently counterintuitive position arises because much carbon is released as methane which is approximately 8 time more potent as a greenhouse gas than carbon dioxide.

A study for the National Institute for Research in the Amazon found that Hydroelectric reservoirs release a large pulse of carbon dioxide from above-water decay of trees left standing in the reservoirs, especially during the first decade after closing. This elevates the global warming impact of the dams to levels much higher than would occur by generating the same power from fossil fuels. According to the World Commission on Dams report (Dams And Development), when the reservoir is relatively large and no prior clearing of forest in the flooded area was undertaken, greenhouse gas emissions from the reservoir could be higher than those of a conventional oil-fired thermal generation plant. For instance, In 1990, the impoundment behind the Balbina Dam in Brazil (inaugurated in 1987) had over 20 times the impact on global warming than would generating the same power from fossil fuels, due to the large area flooded per unit of electricity generated.
A decrease can occur if the dam is used in place of traditional power generation, since electricity produced from hydroelectric generation does not give rise to any flue gas emissions from fossil fuel combustion (including sulfur dioxide, nitric oxide and carbon monoxide from coal). The Tucurui dam in Brazil (closed in 1984) had only 0.4 times the impact on global warming than would generating the same power from fossil fuels. [28]

**Biology**

Dams can produce a block for migrating fish, trapping them in one area, producing food and a habitat for various water-birds. They can also flood various ecosystems on land and may cause extinctions.

**Human Impact**

Dams can severely reduce the amount of water reaching countries downstream of them, causing water stress between the countries, e.g. the Sudan and Egypt, which damages farming businesses in the downstream countries, and reduces drinking water.

Farms and villages, e.g. Ashopton can be flooded by the creation of reservoirs, ruining many livelihoods. For this very reason, worldwide 80 million people have had to be forcibly relocated due to dam construction.

**Limnology**

The limnology of reservoirs has many similarities to that of lakes of equivalent size. There are however significant differences. [30] Many reservoirs experience considerable variations in level producing significant areas that are intermittently underwater or dried out. This greatly limits the productivity or the water margins and limits the number of species able to survive in these conditions.

Upland reservoirs tend to have a much shorter residence time than natural lakes and this can lead to more rapid cycling of nutrients through the water body so that they are more quickly lost to the system. This may be seen as a mismatch between water chemistry and water biology with a tendency for the biological component to be more oligotrophic than the chemistry would suggest.
Conversely, lowland reservoirs drawing water from nutrient rich rivers, may show exaggerated eutrophic characteristics because the residence time in the reservoir is much greater than in the river and the biological systems have a much greater opportunity to utilise the available nutrients.

Deep reservoirs with multiple level draw off towers can discharge deep cold water into the downstream river greatly reducing the size of any hypolimnion. This in turn can reduce the concentrations of phosphorus released during any annual mixing event and may therefore reduce productivity.

The Dams in front of reservoirs act as knickpoints-the energy of the water falling from them reduces and deposition is a result below the Dams.

**Seismicity**

The filling (impounding) of reservoirs has often been attributed to reservoir-triggered seismicity (RTS) as seismic events have occurred near large dams or within their reservoirs in the past. These events may have been triggered by the filling or operation of the reservoir and are on a small scale when compared to the amount of reservoirs worldwide. Of over 100 recorded events, early examples include the 60 m (197 ft) tall Marathon Dam in Greece (1929), the 221 m (725 ft) tall Hoover Dam in the U.S. (1935). Most events involve large dams and small amounts of seismicity. The only four recorded events above a 6.0- magnitude (M ) are the 103 m (338 ft) tall Koyna Dam in India which registered a M \( m_w \) of 6.3 along with the 120 m (394 ft) Kremasta Dam in Greece which registered a 6.3-M \( m_w \) as well. Following those two, the next largest were the 122 m (400 ft) high Kariba Dam in Zambia at 6.25-M \( m_w \) and the 105 m (344 ft) Xinfengjiang Dam in China at 6.1-M \( m_w \). Disputes occur over when RTS has occurred due to a lack of hydrogeological knowledge at the time of the event. It is accepted though that the infiltration of water into pores and the weight of the reservoir do contribute to RTS patterns. For RTS to occur, there must be a seismic structure near the dam or its reservoir and the seismic structure must be close to failure. Additionally, water must be able to infiltrate the deep rock stratum as the weight of a 100 m (328 ft) deep reservoir will have little impact when compared the deadweight of rock on a crustal stress field which may be located at a depth of 10 km (6 mi) or more. [31]
Micro climate

Reservoirs may change the local micro-climate increasing humidity and reducing extremes of temperature. Such effects are claimed by some South Australian wineries as increasing the quality of the wine production.

List of reservoirs

Main article: List of reservoirs

List of reservoirs by area

Lake Volta from space (April 1993).

The following are the world's ten largest reservoirs by surface area:

1. Lake Volta (8,482 km² or 3,275 sq mi; Ghana)  
2. Smallwood Reservoir (6,527 km² or 2,520 sq mi; Canada)  
3. Kuybyshev Reservoir (6,450 km² or 2,490 sq mi; Russia)  
4. Lake Kariba (5,580 km² or 2,150 sq mi; Zimbabwe, Zambia)  
5. Bukhtarma Reservoir (5,490 km² or 2,120 sq mi; Kazakhstan)  
6. Bratsk Reservoir (5,426 km² or 2,095 sq mi; Russia)  
7. Lake Nasser (5,248 km² or 2,026 sq mi; Egypt, Sudan)  
8. Rybinsk Reservoir (4,580 km² or 1,770 sq mi; Russia)  
9. Caniapiscau Reservoir (4,318 km² or 1,667 sq mi; Canada)  
10. Lake Guri (4,250 km² or 1,640 sq mi; Venezuela)

List of reservoirs by volume
Lake Kariba from space.

*Main article: List of reservoirs by volume*

1. Lake Kariba (180 km or $\frac{3}{4}$ cu mi; Zimbabwe, Zambia)
2. Bratsk Reservoir (169 km or $\frac{3}{4}$ cu mi; Russia)
3. Lake Nasser (157 km or $\frac{3}{8}$ cu mi; Egypt, Sudan)
4. Lake Volta (148 km or $\frac{3}{6}$ cu mi; Ghana)
5. Manicouagan Reservoir (142 km or $\frac{3}{4}$ cu mi; Canada) [39]
6. Lake Guri (135 km or $\frac{3}{8}$ cu mi; Venezuela)
7. Williston Lake (74 km or $\frac{3}{8}$ cu mi; Canada) [40]
8. Krasnoyarsk Reservoir (73 km or $\frac{3}{18}$ cu mi; Russia)
9. Zeya Reservoir (68 km or $\frac{3}{16}$ cu mi; Russia)
<table>
<thead>
<tr>
<th>WATERTREATMENTPLANT</th>
<th>CAPACITY(INMLD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilpauk (1914 / 2005)</td>
<td>270</td>
</tr>
<tr>
<td>Puzhal (1996)</td>
<td>300</td>
</tr>
<tr>
<td>Vadakuthu (Veeranam Lake Source) (2004)</td>
<td>180</td>
</tr>
<tr>
<td>Chemabarambakkam(2007)</td>
<td>530</td>
</tr>
<tr>
<td>K.K.Nagar(1972)</td>
<td>4</td>
</tr>
<tr>
<td>Surapet(2009)</td>
<td>14</td>
</tr>
<tr>
<td>Minjur Desalination Plant</td>
<td>100</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,398</strong></td>
</tr>
</tbody>
</table>

**GROWTHPROFILE:**

The following is the growth profile in water supply since the formation of the Board in 1978 to July 2010.

<table>
<thead>
<tr>
<th>DETAILS</th>
<th>1978</th>
<th>MARCH2010</th>
</tr>
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<tbody>
<tr>
<td><strong>OPERATIONAL AREA</strong></td>
<td>CITY 176 SQ.KM.</td>
<td>CITY+SURROUNDINGAREAS (176+ 7.88SQ.KM.)</td>
</tr>
<tr>
<td>Population</td>
<td>30 Lakh</td>
<td>55 Lakh</td>
</tr>
<tr>
<td>Water produced (Normal years)</td>
<td>240 MLD</td>
<td>760 MLD</td>
</tr>
<tr>
<td>Area covered with piped supply</td>
<td>80%</td>
<td>100%</td>
</tr>
<tr>
<td>Treatment capacity</td>
<td>182 MLD</td>
<td>1,398 MLD</td>
</tr>
<tr>
<td>Length of water mains</td>
<td>1,250 km.</td>
<td>2,930 km.</td>
</tr>
<tr>
<td>No. of consumers</td>
<td>1,16,000</td>
<td>4,97,811</td>
</tr>
<tr>
<td>Distribution Stations</td>
<td>3 No.</td>
<td>16 Nos.</td>
</tr>
</tbody>
</table>

This chapter focuses on the SPU water distribution system, the part of the Transmission and Distribution business area that involves delivery of water for retail use and for fire flow. SPU’s water distribution system consists of water mains, distribution storage facilities and pump stations, and related appurtenances such as valves, hydrants, service connections, and retail billing meters. The supervisory control and data acquisition (SCADA) system
used to monitor and control the water system is also discussed in this chapter. Proper management of the distribution system ensures that SPU meets its service levels for retail customers.

WATER DISTRIBUTION SYSTEM POLICIES

SPU developed the following new policy to describe SPU’s decision-making process and criteria for addressing redundancy in the distribution system.

Distribution System Redundancy Policy Redundancy in the distribution system is one way that SPU can increase the reliability of water delivery to its retail service customers. Distribution system redundancy is provided by the network of water mains, appropriately spaced valves, stand-by pumps, and storage, all of which can help minimize customer outages. Increasing redundancy, however, adds capital and operation and maintenance (O&M) costs that may not necessarily be justified. This policy was developed to incorporate asset management principles, primarily life-cycle benefit and cost analysis, into SPU’s decision-making and clearly establish the criteria that SPU will use for adding or retiring redundancy in its water distribution system. This policy ensures that service reliability is considered along with costs when considering retirement of existing redundant facilities or adding new redundancy. In developing this policy, SPU aimed to balance the consequences and costs of failure with the benefits of redundancy.

It favors adding redundancy only when it is cost-justified - meaning the benefits outweigh the costs.

Policy Statement

Consider redundancy in the distribution system on a case-by-case basis, with decisions based on an evaluation of net present value.

1. For new developments or redevelopments within the distribution system, require developers to install looped systems, intermediate line valves, and/or additional shut-off valves for dead-end water mains when SPU determines that the improvement provides a positive net present value to the water system in the area.

2. Consider retiring existing redundant facilities within the distribution system when they are at the end of their economic life and the costs of a new facility exceeds the avoided risks
costs.

3. Consider adding redundancy within the distribution system when replacing existing facilities that have reached the end of their economic life or when performing repairs on existing facilities that require retail customer outages.

4. To increase redundancy, consider installing temporary or permanent looped systems, crossover valves, intermediate line valves, and/or additional shut-off valves in the distribution system when the improvement provides positive net present value to the system.

5. When evaluating net present value of options over the life of the project, include the capital costs of installing the redundancy improvement and all O&M costs such as those to repair the new facilities or to flush any dead-end mains. Also include the benefits of any avoided risk costs, such as the costs of retail customer outages and temporary loss of fire flow.

**Distribution System Pressure**

Maintaining adequate distribution system pressure is critical to ensure both customer service and drinking water quality.

Adequate water pressure enables customers to have sufficient water flow from their household plumbing fixtures and appliances.

In addition, adequate pressure prevents contaminants from entering the distribution system through pipeline leaks and cross connections. In 2004, SPU developed a service level which meets Washington State Department of Health (WDOH) requirements for pressure and provides a method for an economic analysis of supplying higher pressure levels in new and existing areas of the distribution system. This service level establishes a minimum 20 pounds per square inch (psi) service connection pressure standard for the existing distribution system during normal operations and a minimum 30-psi design standard for new distribution system construction, consistent with the Washington Administrative Code (WAC). Current services with less than 20 psi of pressure will be brought up to at least 20 psi through system improvements. Existing services with pressures less than 30 psi will be brought up to a higher pressure when it is economical to do so.

**Leaks**
While some level of leakage is unavoidable, it is important to SPU to keep leakage to a minimum because it represents a waste of valuable resources and may result in water damage to property.

WDOH is developing a requirement that would limit distribution system losses from all leaks to 10 percent of the total water delivered to the retail service area. SPU intends to meet the WDOH requirements with this service level. SPU’s water system has had a history of low leakage rates. In 2005, SPU’s total non-revenue water was 9.3 million gallons per day (mgd), or 7 percent of the total 128 mgd produced. Leakage is only one component of non-revenue water; other components include seepage and evaporation from open reservoirs, water used for flushing and firefighting, as well as meter errors. Current leakage from SPU’s distribution and transmission system is estimated at between 3.3 mgd and 4.8 mgd, or between 5 and 7 percent of the 67 mgd total produced excluding that sold to wholesale customers in 2005. Approximately 15 percent of the leakage comes from transmission pipelines and water mains, and the remaining 85 percent comes from service connections on SPU’s side of the meter.

**Distribution System Water Storage Facilities**

SPU’s distribution system includes eight in-city reservoirs and ten elevated tanks and standpipes to provide regulating and backup storage capacity to its retail customers.

Distribution System Reservoirs. The City of Seattle owns and SPU operates and maintains eight reservoirs in the distribution system. Bitter Lake was retrofitted with a liner and floating cover beginning in 2001, and Lincoln Reservoir was reconstructed as a buried reservoir beginning in 2004. The Beacon and Myrtle reservoir replacement projects began in 2006, when the existing reservoirs were taken out of service. SPU is investigating the possibility of retiring the last two open reservoirs, Volunteer and Roosevelt.

Condition assessment of in-town reservoirs follows the same procedure as described for the water transmission system reservoirs. Based on inspections, the structures are in good condition. Roosevelt’s high-density polyethylene liner was replaced in 1990 and, with an estimated life expectancy of 20 years, is not likely to need replacement before the reservoir is decommissioned. Volunteer, View Ridge, and Magnolia Reservoirs are unlined. The leakage rate from Bitter Fatima Michael College of Engineering & Technology

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Lake, Roosevelt, and Magnolia Reservoirs is low, measured in 2003-2004 at under 0.6 gallons per minute per million gallons (gpm/MG). The 2003-2004 leakage rates for Volunteer and View Ridge Reservoirs were 3.5 and 2.6 gpm/MG respectively. Leakage from Lincoln Reservoir was tested during construction and found to be minimal and within acceptance criteria.

Distribution System Elevated Tanks and Standpipes. In addition to its in-town reservoirs, the SPU water distribution system includes two elevated tanks and eight standpipes. The elevated tanks and standpipes were constructed between 1907 and 1996. They range in capacity from 0.88 mg to 1.40 mg. This excludes the Queen Anne standpipes, which are both scheduled for demolition in early 2007, and are planned to be replaced with a single 2-mg tank.

**Distribution System Appurtenances**

The SPU water distribution system includes a number of smaller appurtenances, such as valves, hydrants, service lines, and meters. The paragraphs below summarize SPU’s inventory and replacement approach for each class of appurtenance. Distribution System Valves. SPU’s water distribution system includes more than 21,000 valves. More than 16,600 valves control the flow of water through the distribution system, but other valves regulate pressure, bypass other facilities, or allow air to escape the system. Most valves within the distribution system are gate valves. The only significant modification to SPU’s valves planned since the 2001 Water System Plan will be the valve chamber replacement program that will replace existing chamber tops and access maintenance holes with larger diameter tops and new access ladders. This program will provide SPU maintenance staff with safer valve chamber access and meet industry safety standards. SPU has an ongoing program to replace line valves when they fail beyond repair, when no replacement parts are available, or where the cost of repair exceeds the cost of replacement. The determination of when a valve should be replaced instead of repaired is based on consultation among SPU staff experts.

Distribution System Service Connections. SPU maintains approximately 180,000 service connections, 80 percent of which are ¾-inch diameter pipes. Almost 70 percent of service connections are copper, and 20 percent are plastic. The remaining 10 percent are galvanized iron, ductile iron, and other materials.
The most significant change to SPU’s service connections since 2001 is the initiation of a program to proactively replace noncopper service connections with copper connections. This program is intended to reduce the high leakage and failure rate of non-copper service connections and is expected to be complete by 2015. The most appropriate assessment of the condition of SPU’s service connections is their leakage rate. In 2005, SPU’s leakage rate from its service connections was approximately 2.8 leaks per 1,000 service connections. This is lower than the IWA’s target leakage rate of 3.75 leaks per 1,000 service connections for a well-run utility. The current volume of leakage from SPU’s service connections is estimated between 2.8 to 4.0 million gallons per day (mgd), or between 15 to 22 gallons per day per service connection. IWA’s target leakage volume is approximately 15 gallons per day per service connection. SPU’s non-copper service connections have leakage rates that are greater than 5 leaks per 1,000 service connections. By proactively replacing these non-copper service connections with copper connections, SPU expects to reduce the service connection leakage rate down to 1.5 leaks per 1,000 service connections, well below the IWA target. For all other copper services, SPU’s replacement program is a “run-to-failure” strategy, since the impacts of a failed copper service are typically minor, and the services can be quickly replaced. Distribution System Meters. Each service line is fitted with water meters used to determine customer charges. Most of the meters (87 percent) are for residential customers, and the remaining 13 percent are for commercial customers. Nearly 92 percent of SPU meters are small (3/4-inch and 1-inch). Since the 2001 Water System Plan, the most significant change to distribution meters, other than routine meter replacements and repairs, has been the installation of radio frequency modules on difficult-to-read meters in the downtown area. Also, radio frequency modules were installed in 2005 at a group of multifamily residential meters to pilot-test a new technology to collect readings from a single pole-mounted collector.

**Distribution System Maintenance**

Proper maintenance of distribution system components ensures that SPU will be able to deliver reliable water service, reduce the risk of unexpected failures, and provide safe drinking water quality to its customers. SPU has prepared a number of strategic asset management plans (SAMPs) for each major class of distribution system infrastructure components. The SAMPs outline maintenance strategies for each asset. Summaries of those maintenance strategies are provided below.
Water Mains

Water mains located at “dead-ends” or with low flows often accumulate sediment or have the potential for microbial growth. SPU crews flush low-flow or dead-end mains to maintain water quality. SPU has also begun a plot unidirectional flushing program, as described in the Chapter 3. Reservoirs and Tanks

Storage facility cleaning is also performed to remove sediment, debris, and/or microbial growth as described in Chapter 3. Water Pump Stations Pump stations in the distribution system are maintained in the same manner as described for the transmission system pump stations, as described in Chapter 4. Water Appurtenances SPU also performs maintenance activities for its valves, hydrants, service lines, and meters to ensure their continuing operation. A brief description of each follows.

Valves. SPU responds to an average of 100 valve-related problems per year. Most valve problems can be categorized as leaks, casting failures, mechanical inoperability, and valves being buried by new pavement. Deterioration of interior packing, broken and bent stems, and construction projects are usually the causes of valve problems. SPU is responsible for operating and exercising distribution line valves. Large valves, those 16 inches or larger, were exercised and inspected by valve crews annually until 2003. Due to shifts in priorities, this routine operation work is performed less frequently.

Hydrants. Each fire service agency inspects hydrants located within its service area, generally on an annual basis. Defects are reported to SPU for repair. During a twelve month period in 2002-2003, SPU responded to approximately 2,269 work orders to address fire hydrant defects. During maintenance visits, SPU paints hydrants to prevent exterior corrosion and improve their appearance. The average hydrant painting interval is approximately five years.

Service Connections. SPU spends about $1.2 million annually on reactive maintenance and repair of water service lines extending from the water main to a customer’s meter. SPU typically learns of water service failures through customer calls. SPU’s service connection maintenance program is almost entirely reactive since it is generally not economical to perform preventative maintenance activities on water service lines. The consequences of failure on water service lines are low, and therefore it is more economical to run them to failure.

Meters. SPU’s retail water meters ensure proper billing of its drinking water sales, as well as wastewater disposal costs. Billing system-generated meter problem reports may be generated under a variety of different

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conditions: broken meter dials; meters that have been inaccessible for reading for three attempts; consumption that is much higher or lower than what is expected for the customer based on historical information; meter registers that are stuck; and meters that show zero consumption.

Customer-reported problems often arise from billing questions. When these problems arise, SPU works with each customer to quickly resolve the issues. Malfunctioning customer meters are much more likely to underregister than over-register. SPU maintains its distribution system water meters based on meter size and customer type. SPU has a meter testing and maintenance program for its large meters, which represent less than three percent of all retail meters. SPU’s goal is to maintain accuracy of large meters to between 97 and 103 percent as per the guidelines of the American Water Works Association. A large meter with an accuracy falling outside that range is either repaired to restore its performance or replaced.

SPU does not typically perform maintenance activities for small meters since repairing small meters is not cost-effective and it is generally cheaper to replace a small meter than repair it. SPU replaces about 800 small meters each year.

Record Keeping and Reporting

SPU uses its MAXIMO work management system to capture asset failure, repair, and replacement history. Failure history is not completely reliable because many of the failure codes that were originally developed did not adequately describe the nature of the failure. This problem has since been resolved for all new data entered into the system. SPU uses a geographic information system (GIS) to record and display locations of physical assets and problems. This tool is also utilized to review hydrant spacing and identify hydrants that have deficient spacing.

General, definitions, abbreviations, commonly used waterworks pipes fittings, responsibilities of water and consumers/agents, general principles for installing plumbing works, submissions of plumbing proposals, general, submissions, plumbing proposals, format, licensed plumber, commencement of work, interim inspections and final inspections, completion of work, works of a minor nature, metering, general, meterposition, inside service, fresh water supply, flushing supply, fire service, metering requiremnt pipe materials, supply types and arrangements, storage cisterns, water pumps and other miscellaneous, water pumps, valve and taps, earthing, separate metering inexisting premises, authorizing private developers/authorized persons to undertake water supply, connection works, maintenance.
Plumbing installation that receives water supply from the Waterworks has to comply with the Waterworks requirements under the provision of the Waterworks Ordinance/Regulations and Hong Kong Waterworks Standard Requirements for Plumbing Installation in Buildings (HKWSR). Approval from the Water Authority is required in order to construct, install, alter or remove a plumbing installation. Works of a Minor Nature Works of a minor nature are works which can be completed without the involvement of specialized trade skill and those which do not change the general arrangement of the plumbing installation already approved by the Water Authority, or affect the flowconditions of the plumbing system thus causing possible supply problems.

**Fittings and Accessories**

Complete range of fittings & accessories for PE Piping Solutions offered by Dura-line includes compression fittings like couplers/elbows/end caps/tees etc. up to 110 mm and fabricated & moulded like bends, elbows, equal tees, flanges etc. up to 1000 mm diameter.

- Compression fittings : Covering sizes upto 110 mm for water supply and house service connection in accordance with international standards, duly certified by bodies like KIWA, DVGW & Wrc
- Molded & Fabricated fittings like equal/unequal tees, bends, collars, flanges, capends, etc. covering the complete range. Professional Turnkey Support for design, supply, installation, jointing and testing of PE piping systems. Dura-line Pipes Learning Center at Goa for knowledge sharing & training on application, installation, jointing & testing techniques for PE piping systems

**E Pipe and Fittings**

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<thead>
<tr>
<th>Product Features</th>
<th>Specifications</th>
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<tbody>
<tr>
<td>Capability:</td>
<td>As per the buyer's specifications</td>
</tr>
<tr>
<td>Place of origin:</td>
<td>India</td>
</tr>
</tbody>
</table>
Description:
Shreyas Agro Services (P) Ltd. undertakes turnkey projects, which includes design, supply, installation, testing and commissioning of pipelines. We are manufacturers and suppliers of PE pipes which consists of:

- PVC pipes ranging from 20 mm to 560 mm OD, with pressure rating from 2.5 Kg/cm² to 16 Kg/cm²
- Quick fix PVC pipes ranging from 63 mm to 400 mm, with pressure rating-4 Kg/cm² to 12.5 Kg/cm²
- Bore well casing and screen pipes ranging from 48mm to 540 mm for a well depth up to 450 meters
- Plumbing pipes ranging from ½ “ to 1 ½ “
- HDPE water pipes ranging from 20 mm to 1600 mm with pressure rating of 2.5 kg/cm² to 16 Kg/cm²
- MDPE pipes for house service connection, ranging from 20 mm to 63 mm,