Environmental, Health, and Safety Guidelines for Water and Sanitation

Introduction

The Environmental, Health, and Safety (EHS) Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP)[1]. When one or more members of the World Bank Group are involved in a project, these EHS Guidelines are applied as required by their respective policies and standards. These industry sector EHS guidelines are designed to be used together with the **General EHS Guidelines** document, which provides guidance to users on common EHS issues potentially applicable to all industry sectors. For complex projects, use of multiple industry-sector guidelines may be necessary. A complete list of industry-sector guidelines can be found at: www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines

The EHS Guidelines contain the performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets, with an appropriate timetable for achieving them.

The applicability of the EHS Guidelines should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-specific variables, such as host country context, assimilative capacity of the environment, and other project factors, are taken into account. The applicability of specific technical recommendations should be based on the professional opinion of qualified and experienced persons. When host country regulations differ from the levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent. If less stringent levels or measures than those provided in these EHS Guidelines are appropriate, in view of specific project circumstances, a full and detailed justification for any proposed alternatives is needed as part of the site-specific environmental assessment. This justification should demonstrate that the choice for any alternate performance levels is protective of human health and the environment.

Applicability

The EHS Guidelines for Water and Sanitation include information relevant to the operation and maintenance of (i) potable water treatment and distribution systems, and (ii) collection of sewage in centralized systems (such as piped sewer collection networks) or decentralized systems (such as septic tanks subsequently serviced by pump trucks) and treatment of collected sewage at centralized facilities.[2]

This document is organized according to the following sections:

Section 1.0 — Industry-Specific Impacts and Management
Section 2.0 — Performance Indicators and Monitoring
Section 3.0 — References and Additional Sources
Annex A — General Description of Industry Activities

[1] Defined as the exercise of professional skill, diligence, prudence and foresight that would be reasonably expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally. The circumstances that skilled and experienced professionals may find when evaluating the range of pollution prevention and control techniques available to a project may include, but are not limited to, varying levels of environmental degradation and environmental assimilative capacity as well as varying levels of financial and technical feasibility.

[2] Pit latrines and other decentralized systems that do not require servicing and subsequent treatment of contents at centralized treatment facilities are not included in the scope of this document.

1.0 Industry-Specific Impacts and Management

1.1 Environment

Environmental issues associated with water and sanitation projects may principally occur during the construction and operational phases, depending on project-specific characteristics and components. Recommendations for the management of EHS issues associated with construction activities as would typically apply to the construction of civil works are provided in the **General EHS Guidelines**.

1.1.1 Drinking Water

Water Withdrawal

Traditional sources for potable water treatment include surface water from lakes, streams, rivers, etc. and groundwater resources. Where surface or groundwater of adequate quality is unavailable, other sources of water including seawater, brackish water, etc. may be used to produce potable water. Development of water resources often involves balancing competing qualitative and quantitative human needs with the rest of the environment. This is a particularly challenging issue in the absence of a clear allocation of water rights which should be resolved with the participation of appropriate parties in advance of project design and implementation.

Recommended measures to prevent, minimize, and control environmental impacts associated with water withdrawal and to protect water quality include:

- Evaluate potential adverse effects of surface water withdrawal on the downstream ecosystems and use appropriate environmental flow assessment[3] to determine acceptable withdrawal rates;
- Design structures related to surface water withdrawal, including dams and water intake structures, to minimize impacts on aquatic life. For example:
  - Limit maximum through-screen design intake velocity to limit entrainment of aquatic organisms
  - Avoid construction of water intake structures in sensitive ecosystems. If there are threatened, endangered, or other protected species within the hydraulic zone of influence of the surface water intake, ensure reduction of impingement and entrainment of fish and shellfish by the installation of technologies such as barrier nets (seasonal or year-round), screens, and aquatic filter barrier systems
  - Design water containment and diversion structures to allow unimpeded movement of fish and other aquatic organisms and to prevent adverse impacts on water quality
  - Design dam outlet valves with sufficient capacities for releasing the appropriate environmental flows
- Avoid construction of water supply wells and water intake structures in sensitive ecosystems;
- Evaluate potential adverse effects of groundwater withdrawal, including modeling of groundwater level changes and resulting impacts to surface water flows, potential land subsidence, contaminant mobilization and saltwater intrusion. Modify extraction rates and locations as necessary to prevent unacceptable adverse current and future impacts, considering realistic future increases in demand.

Water Treatment

Environmental issues associated with water treatment include:

- Solid waste
- Wastewater
- Hazardous chemicals

[3] World Bank Water Resources and Environment Technical Note C.1 – Environmental Flow Assessment: Concepts and Materials.

- Air emissions
- Ecological impacts

Solid Waste

Solid waste residuals generated by water treatment include process residuals, used filtration membranes, spent media and miscellaneous wastes. Process residuals primarily consist of settled suspended solids from source water and chemicals added in the treatment process, such as lime and coagulants. Pre-sedimentation, coagulation (e.g. with aluminum hydroxide [alum] or ferric hydroxide), lime softening, iron and manganese removal, and slow sand and diatomaceous earth filtration all produce sludge. Composition of the sludge depends on the treatment process and the characteristics of the source water, and may include arsenic and other metals, radionuclides, lime, polymers and other organic compounds, microorganisms, etc. Damaged or exhausted membranes are typically produced from water treatment systems used for desalination. Spent media may include filter media (including sand, coal, or diatomaceous earth from filtration plants), ion exchange resins, granular activated carbon [GAC], etc.

Recommended measures to manage solid wastes from water treatment include:

- Minimize the quantity of solids generated by the water treatment process through optimizing coagulation processes;
- Dispose of lime sludges by land application if allowed, limiting application rates to about 20 dry metric tons per hectare (9 dry tons per acre) to minimize the potential for mobilization of metals into plant tissue and groundwater;[4]
- Dispose of ferric and alum sludges by land application, if allowed and if such application can be shown through modeling and sampling to have no adverse impacts on groundwater or surface water (e.g. from nutrient runoff). Balance use of ferric and alum sludges to bind phosphorous (e.g. from manure application at livestock operations) without causing aluminum phytotoxicity (from alum), iron levels in excess of adulteration levels for metals in fertilizers, or excessively low available phosphorous levels;
- Potential impact on soil, groundwater, and surface water, in the context of protection, conservation and long term sustainability of water and land resources, should be assessed when land is used as part of any waste or wastewater treatment system;
- Sludges may require special disposal if the source water contains elevated levels of toxic metals, such as arsenic, radionuclides, etc.;
- Regenerate activated carbon (e.g. by returning spent carbon to the supplier).

Wastewater

Wastewater from water treatment projects include filter backwash, reject streams from membrane filtration processes, and brine streams from ion exchange or demineralization processes. These waste streams may contain suspended solids and organics from the raw water, high levels of dissolved solids, high or low pH, heavy metals, etc.

Recommended measures to manage wastewater effluents include:

- Land application of wastes with high dissolved solids concentrations is generally preferred over discharge to surface water subject to an evaluation of potential impact on soil, groundwater, and surface water resulting from such application;
- Recycle filter backwash into the process if possible;
- Treat and dispose of reject streams, including brine, consistent with national and local requirements. Disposal

[4] Management of Water Treatment Plant Residuals, Technology Transfer Handbook," EPA/625/R-95/008, April 1996.

options include return to original source (e.g. ocean, brackish water source, etc.) or discharge to a municipal sewerage system, evaporation, and underground injection.

Hazardous Chemicals

Water treatment may involve the use of chemicals for coagulation, disinfection and water conditioning. In general, potential impacts and mitigation measures associated with storage and use of hazardous chemicals are similar to those for other industrial projects and are addressed in the **General EHS Guideline**.

Recommended measures to prevent, minimize, and control potential environmental impacts associated with the storage, handling and use of disinfection chemicals in water treatment facilities include:[5,6,7]

- For systems that use gas chlorination:
  - Install alarm and safety systems, including automatic shutoff valves, that are automatically activated when a chlorine release is detected
  - Install containment and scrubber systems to capture and neutralize chlorine should a leak occur
  - Use corrosion-resistant piping, valves, metering equipment, and any other equipment coming in contact with gaseous or liquid chlorine, and keep this equipment free from contaminants, including oil and grease
  - Store chlorine away from all sources of organic chemicals, and protect from sunlight, moisture, and high temperatures
- Store sodium hypochlorite in cool, dry, and dark conditions for no more than one month, and use equipment constructed of corrosion-resistant materials;
- Store calcium hypochlorite away from any organic materials and protect from moisture; fully empty or re-seal shipping containers to exclude moisture. Calcium hypochlorite can be stored for up to one year;
- Isolate ammonia storage and feed areas from chlorine and hypochlorite storage and feed areas;
- Minimize the amount of chlorination chemicals stored on site while maintaining a sufficient inventory to cover intermittent disruptions in supply;
- Develop and implement a prevention program that includes identification of potential hazards, written operating procedures, training, maintenance, and accident investigation procedures;
- Develop and implement a plan for responding to accidental releases.

Air Emissions

Air emissions from water treatment operations may include ozone (in the case of ozone disinfection) and gaseous or volatile chemicals used for disinfection processes (e.g., chlorine and ammonia). Measures related to hazardous chemicals discussed above will mitigate risks of chlorine and ammonia releases. In addition, specific recommended measures to manage air emissions include installation of an ozone-destroying device at the exhaust of the ozone-reactor (e.g., catalytic oxidation, thermal oxidation, or GAC).

Water Distribution

The most fundamental environmental health issues associated with distribution networks is the maintenance of adequate pressure to protect water quality in the system as well as sizing and adequate maintenance to assure reliable delivery of water of suitable quality. The most significant environmental issues associated with operation of water distribution systems include:

[5] WorkSafeBC, Chlorine Safe Work Practices http://www.worksafebc.com/publications/health_and_safety/by_topic/assets/pdf/chlorine.pdf.

[6] National Drinking Water Clearinghouse Tech Brief: Disinfection, http://www.nesc.wvu.edu/ndwc/pdf/OT/TB/TB1_Disinfection.pdf.

[7] Chlorine Institute, http://www.chlorineinstitute.org/Bookstore/SearchBrowse.cfm

- Water system leaks and loss of pressure
- Water discharges

Water System Leaks and Loss of Pressure

Water system leaks can reduce the pressure of the water system compromising its integrity and ability to protect water quality (by allowing contaminated water to leak into the system) and increasing the demands on the source water supply, the quantity of chemicals, and the amount of power used for pumping and treatment. Leaks in the distribution system can result from improper installation or maintenance, inadequate corrosion protection, settlement, stress from traffic and vibrations, frost loads, overloading, and other factors. Recommended measures to prevent and minimize water losses from the water distribution system include:

- Ensure construction meets applicable standards and industry practices;[8]
- Conduct regular inspection and maintenance;
- Implement a leak detection and repair program (including records of past leaks and unaccounted-for water to identify potential problem areas);
- Consider replacing mains with a history of leaks of with a greater potential for leaks because of their location, pressure stresses, and other risk factors.

Water Discharges

Water lines may be periodically flushed to remove accumulated sediments or other impurities that have accumulated in the pipe. Flushing is performed by isolating sections of the distribution system and opening flushing valves or, more commonly, fire hydrants to cause a large volume of flow to pass through the isolated pipeline and suspend the settled sediment. The major environmental aspect of water pipe flushing is the discharge of flushed water, which may be high in suspended solids, residual chlorine, and other contaminants that can harm surface water bodies. Recommended measures to prevent, minimize, and control impacts from flushing of mains include:

- Discharge the flush water into a municipal sewerage system with adequate capacity;
- Discharge the flush water into a separate storm sewer system with storm water management measures such as a detention pond, where solids can settle and residual chlorine consumed before the water is discharged;
- Minimize erosion during flushing, for example by avoiding discharge areas that are susceptible to erosion and spreading the flow to reduce flow velocities.

1.1.2 Sanitation

A sanitation system comprises the facilities and services used by households and communities for the safe management of their excreta.[9] A sanitation system collects excreta and creates and effective barrier to human contact; transports it to a suitable location; stores and/or treats it; and reuses it or returns it to the environment. In addition to excreta, sanitation systems may also carry household wastewater and storm water.[10] Transport, storage, and disposal facilities may also manage wastes from industries, commercial establishments, and institutions.

Fecal Sludge and Septage Collection

In communities not served by sewerage systems, sanitation may be based on on-site systems, such as pit latrines, bucket latrines or flush toilets connected to septic tanks. While pit and bucket latrines must be emptied frequently (typically daily to weekly), solids that accumulate in septic systems (septage) must also be removed periodically, usually every 2 to 5 years depending on design and usage to maintain proper function and

[8] See, for example, the Canadian National Guide to Sustainable Municipal Infrastructure (InfraGuide); and American Water Works Association standards.

[9] Feces and urine.

[10] The excess water from rainfall that does not naturally percolate into the soil.

prevent plugging, overflows, and the resulting release of septic tank contents. If suitable facilities for storage, handling and treatment of fecal sludge are not available, it may be indiscriminately dumped into the environment or used in unhygienic manner in agriculture.

Recommended measures to prevent, minimize, and control releases of septage and other fecal sludge include:

- Promote and facilitate correct septic tank design and improvement of septic tank maintenance. Septic tank design should balance effluent quality and maintenance needs;[11]
- Consider provision of systematic, regular collection of fecal sludge and septic waste;
- Use appropriate collection vehicles. A combination of vacuum tanker trucks and smaller hand-pushed vacuum tugs may be needed to service all households;
- Facilitate discharge of fecal sludge and septage at storage and treatment facilities so that untreated septage is not discharged to the environment.

Sewerage

Where population density or local conditions preclude effective on-site sanitation systems (e.g., septic tanks and drain fields), sewage is typically conveyed via a system of pipes, pumps, and other associated infrastructure (sewerage) to a centralized storage and/or treatment system. Solids and liquids may be transported to a centralized location, or sewage solids may be collected in and periodically removed from on-site interceptor tanks (see Septage and Fecal Sludge Collection, above) while the liquids are transported to a centralized location for storage, treatment, or disposal. Users of the sewerage system may include industry and institutions, as well as households.

Greywater (water from laundry, kitchen, bath, and other domestic activities that normally does not contain excreta) is sometimes collected and managed separately from sewage. Though greywater is generally less polluted than domestic or industrial wastewater, it may still contain high levels of pathogenic microorganisms, suspended solids and substances such as oil, fat, soaps, detergents, and other household chemicals and can have negative impacts on human health as well as soil and groundwater quality.

The most significant potential environmental impacts associated with wastewater collection arise from:

- Domestic wastewater discharges
- Industrial wastewater discharges
- Leaks and overflows

Domestic Wastewater Discharges

Uncontrolled discharge of domestic wastewater, including sewage and greywater, into aquatic systems can lead to, among other things, microbial and chemical contamination of the receiving water, oxygen depletion, increased turbidity, and eutrophication. Wastewater discharge onto streets or open ground can contribute to spread of disease, odors, contamination of wells, deterioration of streets, etc. Measures to protect the environment as well as public health include:

- Provide systems for effective collection and management of sewage and greywater (separately or combined);
- If greywater is managed separate from sewage, implement greywater source control measures to avoid use and discharge of problematic substances, such as oil and grease, large particles or chemicals.

[11] Examples of key septic system design considerations are presented in the **General EHS Guidelines**. More complicated septic tank designs (e.g., three chambers, added sand filters, etc.) can improve effluent quality, but are usually more susceptible to clogging and other failures, especially if regular maintenance is not performed.

Industrial Wastewater Discharges

Industrial users of a sewerage system can discharge industrial wastewaters to the sewer system. Some industrial wastes can cause fire and explosion hazards in the sewerage system and treatment facility, disrupt biological and other processes at the treatment facility or affect worker health and safety; some waste components may not be effectively treated, and may be stripped to the atmosphere, discharged with treated effluent or partition into treatment plant residuals rendering it potentially hazardous.

Recommended measures to prevent, minimize, and control industrial discharges to the sewerage system include:

- Treatment or pre-treatment to neutralize or remove toxic chemicals should ideally take place at the industrial facility itself, prior to discharge of the effluent to the sewer or water body. Consider collaboration with public authorities in the implementation of a source control program for industrial and commercial users to ensure that any wastewater discharged to the sewer system can be effectively treated.[12] Examples of problematic discharges include: flammable, reactive, explosive, corrosive, or radioactive substances; noxious or malodorous materials; medical or infectious wastes; solid or viscous materials that could cause obstruction to the flow or operation of the treatment plants; toxic substances; non-biodegradable oils; and pollutants that could result in the emission of hazardous gases;
- Collaborate with public authorities in the regular inspection of industrial user facilities and collect samples of wastewater discharges to the sewerage system to ensure compliance with the source control program;
- Conduct surveillance monitoring at sewer maintenance and of the influent to the wastewater treatment facilities;
- Investigate upstream sources of pollutants causing treatment plant upsets or interference;
- Facilitate public reporting of illicit discharges and connections.

Leaks and Overflows

Leaks and overflows from the sewerage system can cause contamination of soil, groundwater, and surface water. Depending on the elevation of groundwater, leaks in gravity mains may also allow groundwater into the sewer system, increasing the volume of wastewater requiring treatment and potentially causing flooding and treatment bypass. Overflows occur when the collection system can not manage the volume of wastewater, for example due to high flows during rain events or as the result of power loss, equipment malfunctions, or blockages. The excess flows may contain raw sewage, industrial wastewater, and polluted runoff.

Recommended measures to prevent, minimize, and control leaks and overflows include:

- Consider the installation of separate sewer systems for domestic wastewater and storm water runoff in the overall planning and design of new sewerage systems;
- When on-site sanitation systems where excreta are mixed with water predominate, consider use of small-diameter sewerage system to collect water effluent from septic systems or interceptor tanks;
- Limit the sewer depth where possible (e.g., by avoiding routes under streets with heavy traffic). For shallower sewers, small inspection chambers can be used in lieu of manholes;
- Use appropriate locally available materials for sewer construction. Spun concrete pipes can be appropriate in some circumstances but can suffer corrosion from hydrogen sulfide if there are blockages and/or insufficient

[12] See, for example Water Environment Federation, Developing Source Control Programs for Commercial and Industrial Wastewater, 1996; Federation of Canadian Municipalities, Wastewater Source Control: A Best Practice by the National Guide to Sustainable Municipal Infrastructure, March 2003; and U.S. EPA Model Pretreatment Ordinance EPA 833-B-06-002.

slope;

- Ensure sufficient hydraulic capacity to accommodate peak flows and adequate slope in gravity mains to prevent buildup of solids and hydrogen sulfide generation;
- Design manhole covers to withstand anticipated loads and ensure that the covers can be readily replace if broken to minimize entry of garbage and silt into the system;
- Equip pumping stations with a backup power supply, such as a diesel generator, to ensure uninterrupted operation during power outages, and conduct regular maintenance to minimize service interruptions. Consider redundant pump capacity in critical areas;
- Establish routine maintenance program, including:
  - Development of an inventory of system components, with information including age, construction materials, drainage areas served, elevations, etc
  - Regular cleaning of grit chambers and sewer lines to remove grease, grit, and other debris that may lead to sewer backups. Cleaning should be conducted more frequently for problem areas. Cleaning activities may require removal of tree roots and other identified obstructions
  - Inspection of the condition of sanitary sewer structures and identifying areas that need repair or maintenance. Items to note may include cracked/deteriorating pipes; leaking joints or seals at manhole; frequent line blockages; lines that generally flow at or near capacity; and suspected infiltration or exfiltration
  - Monitoring of sewer flow to identify potential inflows and outflows
- Conduct repairs prioritized based on the nature and severity of the problem. Immediate clearing of blockage or repair is warranted where an overflow is currently occurring or for urgent problems that may cause an imminent overflow (e.g. pump station failures, sewer line ruptures, or sewer line blockages);
- Review previous sewer maintenance records to help identify "hot spots" or areas with frequent maintenance problems and locations of potential system failure, and conduct preventative maintenance, rehabilitation, or replacement of lines as needed;
- When a spill, leak, and/or overflow occurs, keep sewage from entering the storm drain system by covering or blocking storm drain inlets or by containing and diverting the sewage away from open channels and other storm drain facilities (using sandbags, inflatable dams, etc.). Remove the sewage using vacuum equipment or use other measures to divert it back to the sanitary sewer system.

Wastewater and Sludge Treatment and Discharge

Sewage will normally require treatment before it can be safely discharged to the environment. The degree and nature of wastewater and sludge treatment depends on applicable standards and the planned disposal or use of the liquid effluent and sludge and the application method. The various treatment processes may reduce suspended solids (which can clog rivers, channels, and drip irrigation pipes); biodegradable organics (which are consumed by microorganisms and can result in reduced oxygen levels in the receiving water); pathogenic bacteria and other disease-causing organisms; and nutrients (which stimulate the growth of undesirable algae that, as they die, can result in increased loads of biodegradable organics).

Wastewater discharge and use options include discharge to natural or artificial watercourses or water bodies; discharge to treatment ponds or wetlands (including aquiculture); and direct use in agriculture (e.g., crop irrigation). In all cases, the receiving water body use (e.g. navigation, recreation, irrigation, or drinking) needs to be considered together with its assimilative capacity to establish a site-specific discharge quality that is consistent with the most sensitive use.

The most significant environmental impacts related to wastewater and sludge treatment, discharge, and use include:

- Liquid effluents
- Solid waste
- Air emissions and odors
- Hazardous chemicals
- Ecological impacts

Liquid Effluents

Treated wastewater (liquid effluents) may be reused for irrigation or other purposes or disposed subject to regulatory oversight. If not re-used, treated wastewater can be discharged to the sea; rivers; large surface water bodies; smaller, closed surface water bodies; and wetlands and lagoons.

Recommended measures to prevent, minimize, and control liquid effluents include:

- Minimize bypass of the treatment system by using separate storm water and wastewater systems, if possible, and providing capacity sufficient to treat peak flows;
- Implement an industrial source control program which includes monitoring and effective regulatory enforcement;
- Collaborate with public officials to select appropriate treatment technologies, considering factors such as the quality and quantity of raw wastewater and its variability; available land area for the treatment facility; and resources for capital expenditures, operation, maintenance, and repair; availability of skilled operators, operator training, maintenance personnel, treatment chemicals, and replacement parts;[13]
- Design, construct, operate, and maintain wastewater treatment facilities and achieve effluent water quality consistent with applicable national requirements or internationally accepted standards[14] and consistent with effluent water quality goals based on the assimilative capacity and the most sensitive end use of the receiving water;[15,16]
- Consider discharge of treated wastewater to natural or constructed wetlands, which can buffer the impact f from discharge on the aquatic environment, unless the wetland itself would be degraded by the discharge;
- Treat greywater, if collected separately from sewage, to remove organic pollutants and reduce the levels of suspended solids, pathogenic organisms and other problematic substances to acceptable levels based on applicable national and local regulations.[17] Greywater lines and point of use stations should be clearly marked to prevent accidental use for potable water quality applications;
- Based on an assessment of risks to human health and the environment, consider re-use of treated effluent, especially in areas with limited raw water supplies. Treated wastewater quality for land application or other uses should be consistent with the relevant public health-based guidance from the World Health Organization (WHO)[18] and applicable national requirements.

Solid Waste

Solids removed from wastewater collection and treatment systems may include sludge and solids from cleaning of

[13] See Annex A for a summary of wastewater treatment technologies.

[14] See, for example, U.S. EPA regulations at 40 CFR Part 133 regarding Secondary Treatment, and Council Directive 91/271/EEC of 21 May 1991 Concerning Urban Waste-Water Treatment.

[15] See World Health Organization, Linking Technology Choicewith Operation and Maintenance in the Context of Community Water Supply and Sanitation: A Reference Document for Planners and Project Staff, 1993.

[16] Refer to the section on "Discharge to Surface Water" of the **General EHS Guidelines.**

[17] Few countries have developed greywater-specific regulations, such as some North American States (Arizona, New Mexico, California, New Jersey), Australia (Queensland, New South Wales) or China (Beijing, Tianjin).

[18] WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater (2006).

drainage and sewer collection systems (including seepage systems), screening solids, and sludge from various unit operations used for wastewater treatment.

Recommended strategies for the management of solid wastes include:

- Select appropriate sludge treatment technologies, considering, for example, the quantity and sources of sludge; available resources for capital expenditures, training, operations and maintenance; availability of skilled operators, maintenance personnel, etc.; and the desired disposal methods or end uses of the treated solids. Sludge treatment technologies are discussed in Annex A;
- Land application or other beneficial re-use of wastewater treatment plant residuals should be considered but only based on an assessment of risks to human health and the environment. Quality of residuals for land application should be consistent with the relevant public health-based guidance from the World Health Organization (WHO)[19] and applicable national requirements;
- Processing, disposal and re-use of wastewater treatment plant residuals should be consistent with applicable national requirements or, in their absence, internationally accepted guidance and standards.[20]

Air Emissions and Odors

Air emissions from wastewater treatment operations may include hydrogen sulfide, methane, ozone (in the case of ozone disinfection), volatile organic compounds (such as from industrial discharges), gaseous or volatile chemicals used for disinfection processes (e.g., chlorine and ammonia), and bioaerosols (discussed in Section 1.2 below). Odors from treatment facilities can also be a nuisance to workers and the surrounding community.

Measures related to management of air emissions from drinking water treatment systems, discussed above, are also generally applicable to wastewater treatment facilities. In addition, the following measures are recommended to prevent, minimize, and control air emissions and odors:

- Cover emission points (e.g., aeration basins, clarifiers, sludge thickeners, tanks, and channels), and vent emissions to control systems (e.g., compost beds, bio-filters, chemical scrubbers, etc.) as needed to reduce odors and otherwise meet applicable national requirements and internationally accepted guidelines;
- Where necessary, consider alternate aeration technologies or process configurations to reduce volatilization.

Hazardous Chemicals

Wastewater treatment often includes the use of hazardous chemicals, such as strong acids and bases for pH control, chlorine or other compounds used for disinfection, etc. Environmental impacts and mitigation measures discussed above for disinfection in drinking water treatment are also generally applicable to disinfection in wastewater treatment facilities. Additional guidance on chemicals management is provided in the **General EHS Guidelines**.

1.2 Occupational Health and Safety

Occupational health and safety impacts during the construction and decommissioning of Water and Sanitation facilities are common to other large industrial projects and are addressed in the **General EHS Guidelines**. Occupational health and safety impacts associated with the operational phase of water and sanitation projects primarily include the following:

[19] WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater (2006).

[20] See, for example, U.S. EPA regulations at 40 CFR Part 503—Standards for the Use or Disposal of Sewage Sludge; Council Directive 91/271/EEC of 21 May 1991 Concerning Urban Waste-Water Treatment; and U.S. EPA, Emerging Technologies for Biosolids Management, 832-R-06-005, September 2006.

- Accidents and injuries
- Chemical exposure
- Hazardous Atmosphere
- Exposure to pathogens and vectors
- Noise

Accidents and Injuries

Work at water and sanitation facilities is often physically demanding and may involve hazards such as open water, trenches, slippery walkways, working at heights, energized circuits, and heavy equipment. Work at water and sanitation facilities may also involve entry into confined spaces, including manholes, sewers, pipelines, storage tanks, wet wells, digesters, and pump stations. Methane generated from anaerobic biodegradation of sewage can lead to fires and explosions.

Mitigation measures for accidents and injuries are addressed in the **General EHS Guidelines**. In addition, the following procedures are recommended to prevent, minimize, and control accidents and injuries at water and sanitation facilities:

- Install railing around all process tanks and pits. Require use of a life line and personal flotation device (PFD) when workers are inside the railing, and ensure rescue buoys and throw bags are readily available;
- Use PFDs when working near waterways;
- Implement a confined spaces entry program that is consistent with applicable national requirements and internationally accepted standards.[21] Valves to process tanks should be locked to prevent accidental flooding during maintenance;
- Use fall protection equipment when working at heights;
- Maintain work areas to minimize slipping and tripping hazards;
- Use proper techniques for trenching and shoring;
- Implement fire and explosion prevention measures in accordance with internationally accepted standards;[22]
- When installing or repairing mains adjacent to roadways, implement procedures and traffic controls, such as:
    - Establishment of work zones so as to separate workers from traffic and from equipment as much as possible
    - Reduction of allowed vehicle speeds in work zones;
    - Use of high-visibility safety apparel for workers in the vicinity of traffic
    - For night work, provision of proper illumination for the work space, while controlling glare so as not to blind workers and passing motorists
- Locate all underground utilities before digging.

Chemical Exposure and Hazardous Atmospheres

Water and wastewater treatment involve use of potentially hazardous chemicals, including strong acids and bases, chlorine, sodium and calcium hypochlorite, and ammonia. Water may contain radioactive substances and heavy metals, which typically accumulate in the water treatment sludge. Potential sources of exposure to radionuclides include: pumps and piping where mineral scales accumulate; lagoons, and flocculation and sedimentation tanks where residual sludges accumulate; filters, pumping stations, and storage tanks where scales and sludges accumulate; facilities where filter backwash, brines, or other contaminated water accumulates; facilities that are enclosed (radon); residuals processing or handling areas; and land disposal or application areas where residuals are shoveled, transported, or disposed.

Wastewater may contain potentially hazardous chemicals

[21] See, for example, U.S. Occupational Safety and Health Administration regulations at 29 CFR 1910 Subpart J.

[22] See, for example, National Fire Protection Association (NFPA) 820: Standard for Fire Protection in Wastewater Treatment and Collection Facilities.

depending on the source water quality, drinking water treatment processes, and industries discharging to the sewer, including include chlorinated organic solvents and pesticides, PCBs, polycyclic aromatics, petroleum hydrocarbons, flame retardants, nitrosamines, heavy metals, asbestos, dioxins, and radioactive materials. In addition, workers may be exposed to hydrogen sulfide, methane, carbon monoxide, chloroform, and other chemicals generated during wastewater treatment. Oxygen may be displaced or consumed by microorganisms, thus resulting in an oxygen deficient environment in areas where wastewater or wastewater residues are processed.

Prudent handling and storage of hazardous chemicals, as described in **General EHS Guidelines** and in Section 1.1, above, will help to minimize potential risks to workers. In addition, the following procedures are recommended to prevent, minimize, and control chemical exposure at water and sanitation facilities include:

- Implement a training program for operators who work with chlorine and ammonia regarding safe handling practices and emergency response procedures;
- Provide appropriate personal protective equipment (including, for example, self-contained breathing apparatus) and training on its proper use and maintenance.
- Prepare escape plans from areas where there might be a chlorine or ammonia emission;
- Install safety showers and eye wash stations near the chlorine and ammonia equipment and other areas where hazardous chemicals are stored or used;
- If source water contains radioactive substances, locate water treatment units and water treatment sludge areas as far as possible from common areas (e.g., offices);
- Conduct radiation surveys at least annually, especially in areas where radionuclides are removed;
- Limit wastes entering the sewer system to those that can be effectively treated in the wastewater treatment facility and reduce the amount of air-strippable hazardous compounds entering the system by controlling industrial discharges (e.g., by permit or similar system). Analyze incoming raw wastewater to identify hazardous constituents;
- Ventilate enclosed processing areas and ventilate equipment, such as pump stations, prior to maintenance.
- Use personal gas detection equipment while working in a wastewater facility;
- Continuously monitor air quality in work areas for hazardous conditions (e.g. explosive atmosphere, oxygen deficiency);
- Periodically sample air quality in work areas for hazardous chemicals. If needed to meet applicable occupational health national requirements or internationally accepted standards, install engineering controls to limit worker exposure, for example collection and treatment of off-gases from air stripping;
- Prohibit eating, smoking, and drinking except in designated areas;
- Rotate personnel among the various treatment plant operations to reduce inhalation of air-stripped chemicals, aerosols, and other potentially hazardous materials.

Pathogens and Vectors

Workers and staff at wastewater and sludge treatment facilities and fields where treated wastewater or sludge is applied, as well as operators of sludge collection vehicles, can be exposed to the many pathogens contained in sewage. Processing of sewage can generate bioaerosols which are suspensions of particles in the air consisting partially or wholly of microorganisms, such as bacteria, viruses, molds, and fungi. These microorganisms can remain suspended in the air for long periods of time, retaining viability or infectivity. Workers may also be exposed to endotoxins, which are produced within a microorganism and released upon destruction of the cell and which can be carried by airborne dust particles. Vectors for sewage pathogens include insects (e.g. flies), rodents (e.g. rats) and birds (e.g. gulls).[23]

Recommended measures to prevent, minimize, and control exposure to pathogens and vectors include:

Wastewater and Sludge Treatment

- Include in safety training program for workers, safe handling and personal hygiene practices to minimize exposure to pathogens and vectors;
- Use vacuum trucks or tugs for removal of fecal sludge instead of manual methods;
- Provide and require use of suitable personal protective clothing and equipment to prevent contact with wastewater (e.g., rubber gloves, aprons, boots, etc.). Especially provide prompt medical attention and cover any skin trauma such as cuts and abrasions to prevent infection and use protective clothing and goggles to prevent contact with spray and splashes;
- Provide areas for workers to shower and change clothes before leaving work and provide laundry service for work clothes. This practice also helps to minimize chemical and radionuclide exposure;
- Encourage workers at wastewater facilities to wash hands frequently;
- Provide worker immunization (e.g. for Hepatitis B and tetanus) and health monitoring, including regular physical examinations;
- Reduce aerosol formation and distribution, for example by:
    - Planting trees around the aeration basin to shield the area from wind and to capture the droplets and particles
    - Using diffused aeration rather than mechanical aeration and using finer bubbles for aeration
    - Reducing aeration rate, if possible
    - Use of floating covers on the mixed liquor of the aeration basin
    - Suppression of droplets just above the surface, (e.g. by installing a screen or mesh above the basin);
    - Collection of droplets (e.g. by sedimentation, scrubber, electrostatic precipitator, or fabric filter)
    - Disinfection of airborne particles (e.g., by using ultraviolet lights)
    - Use of submerged effluent collector (such as pipes with orifices) rather than weirs
- Avoid handling screenings by hand to prevent needle stick injuries;
- Maintain good housekeeping in sewage processing and storage areas;
- Advise individuals with asthma, diabetes, or suppressed immune systems not to work at wastewater treatment facilities, especially composting facilities, facility because of their greater risk of infection.

Land Application

- Consider use of drip irrigation of treated wastewater, which minimizes worker exposure and the amount of water needed. Avoid use of spray irrigation of treated wastewater, if possible;
- Provide field workers with personal protective equipment, such as rubber gloves and waterproof shoes;
- Provide access to safe drinking water and sanitation (including hand washing) facilities;
- Provide worker health monitoring, including regular physical examinations;
- Control vectors and intermediate hosts.

[23] U.S. Environmental Protection Agency, Environmental Regulations and Policy Control of Pathogens and Vector Attraction in Sewage Sludge (Including Domestic Septage) Under 40 CRF Part 503, EPA/625/R-92/013, Revised July 2003. http://www.epa.gov/ord/NRMRL/Pubs/1992/625R92013.pdf.

Noise

High noise levels can be present in the vicinity of operating machinery and flowing water at water and sanitation facilities. Impacts and mitigation measures are similar to those at other industrial facilities, and are addressed in the **General EHS Guidelines.**

1.3 Community Health and Safety

Community health and safety impacts during the construction of water and sanitation projects include some which are common to those of other industry sectors and are therefore discussed in the **General EHS Guideline**. Community health and safety impacts associated with operation of water and sanitation projects are discussed separately below.

1.3.1 Drinking Water

Water Intake (Water Supply Protection)

Both surface water and groundwater supplies can become contaminated with potentially toxic substances of natural and anthropogenic origins, including pathogens, toxic metals (e.g. arsenic), anions (e.g. nitrate), and organic compounds. Such contamination might result from natural sources, actions or releases that are routine (e.g. discharges within permit limits), accidental (e.g. from a spill), or intentional (e.g. sabotage).

Recommended measures to protect the quality of the water supply include:[24]

- Determine the area that contributes water to the source (e.g. watershed of a stream or recharge area for groundwater), identify potential sources of contamination with the area, and collaborate with public authorities in the implementation of management approaches to protect the source water quality, such as:
  - o Zoning ordinance provisions
  - o Facility inspection or hazardous material survey program
  - o Information to businesses concerning applicable requirements
  - o Environmental permits checklist for new businesses;
  - o Strategic monitoring within area
  - o Development and implementation of educational campaigns to promote best management practices that reduce the risk of water contamination
  - o Incorporation of surface water protection into regional land use planning
- Evaluate the vulnerability of the water source to disruption or natural events, and implement appropriate security measures as necessary, such as:[25]
  - o Continuously monitor raw water for surrogate parameters (such as pH, conductivity, total organic carbon [TOC], and toxicity)
  - o Inspect sites at random times
  - o For reservoirs and lakes, implement a neighborhood watch program with local park staff and other community users of the reservoir/lake
  - o Equip wellheads with intrusion alarms

Water Treatment

The most significant potential community health and safety impacts associated with water treatment include:

- Drinking water quality and supply
- Hazardous chemicals

[24] Additional information on water resource quality protection is available from numerous publications on the implementation of the European Union Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources (commonly referred to as the Nitrates Directive) and Directive 91/271/EEC (Urban Waste Water Treatment) available at http://ec.europa.eu/environment/water/water-nitrates/report.html.

[25] See, for example, American Water Works Association Interim Voluntary Security Guidance for Water Utilities, December 9, 2004.

Drinking Water Quality and Supply

An adequate supply of clean drinking water is critical to community health and hygiene. Recommended measures related to water treatment include:

- Ensure that treatment capacity is adequate to meet anticipated demand;
- Construct, operate and maintain the water treatment facility in accordance with national requirements and internationally accepted standards[26] to meet national water quality standards or, in their absence, WHO Guidelines for Drinking Water Quality;[27]
- Evaluate the vulnerability of the treatment system and implement appropriate security measures, such as:[28]
    - o Background checks of employees
    - o Perimeter fencing and video surveillance
    - o Improve the electrical power feeds to the facilities. Redundant electrical power systems significantly reduce the vulnerability risk to essential operations

Hazardous Chemicals

Hazardous chemical associated with drinking water treatment and mitigation measures associated with minimizing potential impacts to the environment and to workers are discussed in Sections 1 and 2, respectively. If a worst-case release scenario could affect the general public, prepare and implement a release prevention program for major hazards as described in the **General EHS Guidelines**. The prevention program should include identification of hazards, written operating procedures, training, maintenance, accident investigation, and an emergency response plan.

[26] See, for example, American Water Works Association Standard G100-05: Water Treatment Plant Operation and Management.

[27] Refer to the WHO website at http://www.who.int for the most recent version of the Drinking Water Guidelines.

[28] See, for example, American Water Works Association Interim Voluntary Security Guidance for Water Utilities, December 9, 2004.

Water Distribution

The water distribution system is a critical component in delivery of safe potable water. Even if water is effectively treated to remove contaminants and destroy pathogens, waterborne diseases outbreaks can occur because of deficiencies in the water distribution system. Recommended measures to prevent or minimize potential community health risks associated with the water distribution system include:

- Construct, operate, and manage the water distribution system in accordance with applicable national requirements and internationally accepted standards;[29]
- Construct and maintain the distribution system so that it acts as a barrier and prevents external contamination from entering the water system by, for example:
    - o Inspecting storage facilities regularly, and rehabilitate or replace storage facilities when needed. This may include draining and removing sediments, applying rust proofing, and repairing structures
    - o Ensuring that all installation, repair, replacement, and rehabilitation work conforms to requirements for sanitary protection and materials quality
    - o Testing material, soil, and water quality and implementing best practices to prevent corrosion, such as cathodic protection
    - o Preventing cross-connections with sewerage systems.
    - o Separating water lines and sewer pressure mains (e.g., at least 10 ft apart or in separate trenches, with the sewer line at least 18 inches below the water line)
- Maintain adequate water pressure and flow throughout the system, for example by:
    - o Implementing a leak detection and repair program (see section 1.1)
    - o Reducing residence time in pipes

[29] See, for example, American Water Works Association Standard G200-04: Distribution Systems Operation and Management.

- Maintaining positive residual pressure of at least 20 pounds per square inch (psi) [30]
- Monitoring hydraulic parameters, such as inflows, outflows, and water levels in all storage tanks, discharge flows and pressures for pumps, flows and/or pressure for regulating valves, and pressure at critical points, and using system modeling to assess the hydraulic integrity of the system

- Prevent introduction of contamination from the distribution system itself, for example by:
  - Minimizing microbial growth and biofilm development (e.g. by ensuring adequate residual disinfection levels). Collect samples from several locations throughout the distribution system, including the farthest point, and test for both free and combined chlorine residual to ensure that adequate chlorine residual is maintained
  - Choosing residual disinfectant (e.g. chlorine or chloramines) to balance control of pathogens and formation of potentially hazardous disinfection byproducts [31]
  - Using construction materials that do not contribute to release undesirable metals and other substance or interact with residual disinfectants

1.3.2 Sanitation

Measures to minimize potential community health risks can be implemented both in the collection and treatment of wastewater and sludge.

Wastewater and Septage Collection

Collection of sewage and transportation away from residential areas, while not alone sufficient to protect public health, is nevertheless generally the most important aspect of sanitation. Therefore, provision of collection services, or ensuring that collection services are available, is of primary concern. Effective design and operation of a sewerage system, as addressed in Section 1.1, can minimize the potential for community exposure and health impacts from raw wastewater and sludge collection, for example by:

- Preventing sewerage system overflows;
- Preventing buildup of potentially toxic and explosive gasses in the sewer.

Wastewater and Sludge Treatment

Potential community health and safety impacts associated with wastewater and sludge treatment facilities include:

- Liquid effluents
- Air emissions and odors
- Physical hazards

Liquid Effluents

Treated wastewater effluents are typically discharged to surface water or re-used for irrigation or other purposes. In many cases, direct or indirect human contact with treated wastewater is likely. Therefore, adequate wastewater treatment to remove contaminants and, especially, microorganisms and pathogens, as described in Section 1.1, is important not only to prevent adverse environmental impacts, but to protect public health as well.

Air Emissions and Odors

Odors from wastewater treatment facilities can be a nuisance to the neighboring community. Bioaerosols can also carry

[30] National Research Council of the National Academies, Drinking Water Distribution Systems: Assessing and Reducing Risks, The National Academies Press, 2006, p. 9.

[31] Chemical disinfectants can react with organic and inorganic precursors to form potentially harmful byproducts. Disinfection byproducts (DBP) can be controlled through DBP precursor control and removal, or through modified disinfection practice. However, the risks to health from these byproducts at the levels at which they occur in drinking-water are extremely small in comparison with the risk associated with inadequate disinfection.

disease-causing microorganisms. Furthermore, releases of hazardous gases, such as chlorine, could adversely affect nearby residents.

Air emission and odor controls are addressed in Sections 1.1 and 1.2, as well as in the **General EHS Guidelines**. In addition, the following measures are recommended to prevent, minimize, and control community exposure to dust and odors from waste management facilities:

- Provide adequate buffer area, such as trees, or fences, between processing areas and potential receptors;
- Avoid siting facilities near densely populated neighborhoods and installations with potentially sensitive receptors, such as hospitals and schools. Site facilities downwind from potential receptors, if possible.

Physical Hazards

Visitors and trespassers at wastewater treatment facilities may be subject to many of the hazards for site workers, described in Section 1.2. Recommended measures to prevent, minimize, and control physical hazards to the community include:

- Restrict access to waste management facilities by implementing security procedures, such as:
    - o Perimeter fencing of adequate height and suitable material, with lockable site access gate
    - o Security cameras at key access points, and security alarms fitted to buildings and storage areas; and
    - o Use of a site visitor register
- Light the site where necessary. As this may cause light nuisance to neighbors, the lighting installations should be selected to minimize ambient light pollution.

Land Application

Use of treated wastewater in agriculture can pose public health risks. Hazards associated with crops irrigated with treated wastewater include excreta-related pathogens and toxic chemicals that may be present in the wastewater. The following methods are recommended to protect consumers:[32]

- Treat wastewater and sludge used for land application in a manner consistent with WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater[33] and applicable national requirements;
- Stop irrigation with treated wastewater two weeks prior to harvesting;
- Limit irrigation with treated wastewater to crops that are cooked before eating;
- Restrict public access to hydraulic structures carrying wastewater and to fields irrigated with treated wastewater.

[32] WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater (2006).

[33] WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater (2006).

2.0 Performance Indicators and Industry Benchmarks

2.1 Environmental Performance

Guidelines

Drinking Water

Water quality of potable water supply systems should meet nationally legislated drinking water standards or, in their absence, the most recent World Health Organization (WHO) Guidelines for Drinking Water Quality [34] throughout the distribution network.

Sanitation

Effluent Guidelines: The choice of sanitation technology and design of wastewater treatment begin with a determination of the required level and type of treatment. Project-specific effluent guidelines for sanitation projects should be established based on a clear definition of health objectives and a comprehensive evaluation of alternatives, considering appropriate treatment technologies; quality and quantity of raw wastewater and its variability; available land area for the treatment facility; resources for capital expenditures, training, operation, maintenance, and repair; and availability of skilled operators, maintenance personnel, treatment chemicals, and replacement parts.

The selected approach should achieve effluent water quality consistent with applicable national requirements or internationally accepted standards [35] and with effluent water quality goals based on the assimilative capacity and the most sensitive end use of the receiving water.[36,37]

Treatment standards usually are either technology standards, which specify the treatment technologies or processes that must be used to meet water quality objectives, or effluent standards, which specify the physical, biological, and chemical quality of the effluent to be produced by the treatment. Effluent standards often set limits on allowable concentrations of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nitrogen, phosphorous, etc.

Treated Wastewater Re-use and Sludge Management: Treated wastewater and sludge quality for land application should be consistent with WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater [38] and applicable national requirements. Potential impact on soil, groundwater, and surface water, in the context of protection, conservation and long term sustainability of water and land resources should be assessed when land is used as part of any wastewater treatment system. Sludge from a waste treatment plant needs to be evaluated on a case-by-case basis to establish whether it constitutes a hazardous or a non-hazardous waste and managed accordingly as described in the Waste Management section of this document.

Environmental Monitoring

Environmental monitoring programs for this sector should be implemented to address all activities that have been identified to have potentially significant impacts on the environment, during normal operations and upset conditions. Environmental monitoring activities should be based on direct or indirect

[34] The 2006 version of the drinking water guidelines is available at: http://www.who.int/water_sanitation_health/dwq/guidelines/en/index.html

[35] See, for example, Brazil: Resolucao Conama No. 357, March 17, 2005; European Union: Council Directive 91/271/EEC of 21 May 1991 Concerning Urban Wastewater Treatment; United States: Environmental Protection Agency, 40 CFR Part 133 – Secondary Treatment Regulation (7-1-02 Edition); Mexico: Norma Oficial Mexicana NOM-001-SEMARNAT-1996; China: GB 18918-2002 Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant; India: National Standards for Effluents and Emission under Section 25 of the Environmental (Protection) Act, 1986, General Standards for Discharge of Environmental Pollutants, Part A – Effluents.

[36] See World Health Organization, Linking Technology Choice with Operation and Maintenance in the Context of Community Water Supply and Sanitation: A Reference Document for Planners and Project Staff, 1993.

[37] Refer to the section on "Discharge to Surface Water" of the **General EHS Guidelines.**

[38] WHO, 2006.

indicators of emissions, effluents, and resource use applicable to the particular project.

Monitoring frequency should be sufficient to provide representative data for the parameter being monitored using internationally recognized standards and procedures. Monitoring should be conducted by trained individuals following monitoring and record-keeping procedures and using properly calibrated and maintained equipment. Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Additional guidance on applicable sampling and analytical methods for emissions and effluents is provided in the General EHS Guidelines.[39]

2.2 Occupational Health and Safety Performance

Occupational Health and Safety Guidelines

Occupational health and safety performance should be evaluated against internationally published exposure guidelines, of which examples include the Threshold Limit Value (TLV®) occupational exposure guidelines and Biological Exposure Indices (BEIs®) published by American Conference of Governmental Industrial Hygienists (ACGIH),[40] the United States National Institute for Occupational Health and Safety (NIOSH),[41] Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United States (OSHA),[42] Indicative Occupational Exposure Limit Values published by European Union member states,[43] or other similar sources.

Accident and Fatality Rates

Projects should try to reduce the number of accidents among project workers (whether directly employed or subcontracted) to a rate of zero, especially accidents that could result in lost work time, different levels of disability, or even fatalities. Facility rates may be benchmarked against the performance of facilities in this sector in developed countries through consultation with published sources (e.g. US Bureau of Labor Statistics and UK Health and Safety Executive).[44]

Occupational Health and Safety Monitoring

The working environment should be monitored for occupational hazards relevant to the specific project. Monitoring should be designed and implemented by credentialed professionals experienced in water and sanitation as part of an occupational health and safety monitoring program. Facilities should also maintain a record of occupational accidents and diseases and dangerous occurrences and accidents. Additional guidance on occupational health and safety monitoring programs is provided in the General EHS Guidelines.

[39] For additional information of monitoring the performance of water and sanitation systems consult the World Bank's Water Quality Management Technical Note D.1- Water Quality: Assessment and Protection, 2003. Available at: http://web.worldbank.org/ (Water Resource Management Section; publications)

[40] Available at: http://www.acgih.org/TLV/

[41] Available at: http://www.cdc.gov/niosh/npg/

[42] Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

[43] Available at: http://europe.osha.eu.int/good_practice/risks/ds/oel/

[44] Available at: http://www.bls.gov/iif/ and http://www.hse.gov.uk/statistics/index.htm

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Annex A: General Description of Industry Activities

A.1 Drinking Water Supply

Access to water of an adequate quality is essential for public health and hygiene.[45] A drinking water supply system typically includes the following elements:

- A water source, such as a river, lake, reservoir, or groundwater aquifer where water collects, as well as the surrounding watershed or recharge area that supplies water to the source and a means of extracting and transporting water from the source to a point of treatment.
- A treatment facility for water purification.
- Treated water storage facilities and a distribution system from to deliver treated water from storage to consumption (at houses, fire hydrants, industrial use points, etc).

Water Sources

Traditional sources for potable water treatment include groundwater resources and surface water. Where surface or groundwater of adequate quality is unavailable, other sources of water including seawater, brackish water, etc. may be used to produce potable water.[46]

Groundwater: Groundwater is recharged from and flows to the surface naturally, and provides a long-term reservoir in the natural water cycle, with residence times ranging from days to millennia. Groundwater quality varies depending on the source, but generally has good clarity because of the natural filtering of groundwater as it passes through porous soil layers. In general, deep groundwater has low concentrations of pathogenic bacteria but may be rich in dissolved solids, especially carbonates and sulfates of calcium and magnesium. The bacteriological quality of shallow groundwater can be variable depending on the nature of the recharge area. A variety of soluble materials may be present including potentially toxic metals such as zinc, copper, and arsenic.

Surface Water: Surface water quality is highly dependant on the source. Upland lakes and reservoirs are typically located in the headwaters of river systems upstream of human habitation. 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 color the water. Many upland surface water sources have low pH. Rivers, canals, and low-land reservoirs generally have higher bacterial concentrations and may also contain algae, suspended solids, and a variety of dissolved constituents.

Other Water Sources: Other water sources include seawater and brackish water, which contain high concentrations of dissolved solids, which must be removed to make the water suitable for domestic, agricultural, and industrial uses.

Water Treatment

Treatment required to render water suitable for human consumption varies depending on the water source, but may include removal of suspended solids, removal of dissolved materials, and disinfection.

Removal of Suspended Solids

Suspended solids are usually removed by sedimentation and or

[45] Access to water includes the volume of water av ailable as well as the distances and time involved in water collection. The World Health Organization has defined basic access to water to include a volume of bout 20 liters per capita per day (L/c/d) available at a distance of 100m to 1000m or 5 to 30 minutes total collection time, which is generally sufficient to meet basic consumption, hand washing, and food preparation needs. Optimal access includes a volume of 100 L/c/d or more piped directly to the user, which facilitates laundry and bathing needs in addition to the basic needs. See WHO, Domestic Water Quantity, Service Level and Health, 2003, WHO/SDE/WSH/03.02.

[46] Collection of water by condensing moisture from the air is also possible, but practical applications are limited.

filtration. Coagulation, flocculation, and sedimentation may be used as pretreatment to enhance the effectiveness and minimize the cost of subsequent filtration. Coagulation involves adding chemicals to the water, such as pH buffers and coagulants, to facilitate subsequent treatment steps. The chemically treated water is sent into a basin where the suspended particles can collide and form heavier particles called floc. Gentle agitation and appropriate retention times facilitate this process. The velocity of water is then decreased so that suspended material can settle out of the water stream by gravity. The floc can also be removed directly during filtration. Common filtration methods include slow sand filters, diatomaceous earth filters, and direct filtration systems. Smaller water treatment systems might also use membrane and cartridge filtration systems.

A slow sand filter comprises a bed of fine sand approximately 3 to 4 feet deep supported by a 1-foot layer of gravel and an underdrain system. Slow sand filters are relatively inexpensive to install, are simple to operate and reliable, and are to achieve greater than 99.9 percent Giardia cyst removal. However, these filters are not suitable for water with high turbidity, and the filter surface requires maintenance. Extensive land is required due to rates of flow (0.03 to 0.10 gallons per minute per square foot [gal/min/ft2] of filter bed area). Slow sand filters do not require coagulation/flocculation and may not require sedimentation.

Diatomaceous earth filtration, also known as precoat or diatomite filtration, relies on a layer of diatomaceous earth approximately 1/8-inch thick placed on a septum or filter element. Septa may be placed in pressure vessels or operated under a vacuum in open vessels. Diatomaceous earth filters are simple to operate and are effective in removing cysts, algae, and asbestos. They have been chosen for projects with limited initial capital, and for emergency or standby capacity to service large seasonal increases in demand. Diatomaceous filters are most suitable for water with low bacterial counts and low turbidity (less than 10 nephelometric turbidity units [NTU]). Coagulant and filter aids are required for effective virus removal. Operation of diatomaceous earth filters generates spent filter cake.

Direct filtration systems are similar to conventional systems, but omit sedimentation, and some multiple-stage filtration systems can eliminate the need for chemical coagulation as well. Direct filtration may include several combinations of treatment processes. Dual- and mixed-media filters may be used to effectively process higher influent turbidities. Effective direct filtration performance ranges from 90 to 99 percent for virus removal and from 10 to 99.99 percent for Giardia removal. Direct filtration is most applicable for systems with high quality and seasonally consistent influent supplies. The influent generally should have turbidity of less than 5 to 10 NTU and color of less than 20 to 30 units.

Membrane filtration uses pressure to force water through a thin membrane. Contaminants are retained on the high-pressure side and frequently must be removed by reversing the flow and flushing the waste. The membrane technologies are relatively simple to install and, for groundwater sources that do not need pretreatment, the systems require little more than a feed pump, a cleaning pump, the membrane modules, and holding tanks. The operation of membrane systems can be highly automated. Membrane processes can be used for removal of bacteria and other microorganisms, particulate material, and natural organic material. However, membrane efficiency can be reduced by fouling. Periodic chemical cleaning may be required to remove persistent contaminants.

Cartridge filtration forces water through porous media to remove particles; pore sizes suitable for producing potable water range from 0.2 to 1.0 µm. Pretreatment with a roughing filter prior to cartridge filtration is sometimes necessary to prevent the rapid fouling of the cartridges. Cartridge filters may be suitable for removing microbes and turbidity in small systems. These systems are easy to operate and maintain. Polypropylene cartridges become fouled relatively quickly and must be replaced with new units; therefore, cartridge filtration systems are generally practical only for raw water with low turbidity. Although these filter systems are operationally simple, they are not automated and can require relatively large operating budgets. The filter media may require periodic cleaning.

Removal of Dissolved Contaminants

Some water sources must be treated to remove dissolved materials, which are not affected by coagulation and filtration, to achieve water of adequate quality. High concentrations of metals such as calcium and magnesium contribute to "hard" water, and resulting scaling problems. Dissolved metals such as iron and manganese can adversely affect the water's taste and cause stains and buildup of metal oxide particles in water tanks and pipelines. Radionuclides, nitrates, and toxic metals, such as copper and arsenic, can cause health impacts. Dissolved organic compounds can also cause adverse aesthetic and health impacts. Treatment methods include lime softening, oxidation, ion exchange, reverse osmosis, electrodialysis, aeration, and activated carbon filtration.

Lime softening involves raising the pH of the water to precipitate calcium carbonate and magnesium hydroxide using lime or hydrated lime. The resulting precipitate is removed by settling or filtration. Following filtration, the pH is lowered by addition of carbon dioxide, which is usually generated by on-site fossil fuel combustion. In addition to removing calcium and magnesium, lime softening can also remove iron and manganese, heavy metals, arsenic, radionuclides (uranium, radium 226, and radium 228), and certain organic compounds. Lime softening is best suited to groundwater sources, which have relatively stable water quality. The combination of variable source water quality and the complexity of the chemistry of lime softening generally may make lime softening too complex for small systems that use surface water sources. Excessively soft water can cause corrosion in pipes. This corrosion can shorten the service life of pipes and household appliances and can result in toxic materials, such as lead and cadmium, being dissolved in drinking water.

Oxidation can be used to remove metals such as iron and manganese by formation of insoluble species that can be then filtered from the water. Oxidation can also be used to destroy certain organic contaminants. The most common chemical oxidants used in water treatment include chlorine, chlorine dioxide, potassium permanganate, and ozone. Oxidation using chlorine or potassium permanganate is frequently applied in small groundwater systems. The dosing is relatively easy, requires simple equipment, and is relatively inexpensive. Chlorination is widely used for oxidation of divalent iron and manganese. However, the formation of trihalomethanes (THMs) may be a problem. As an oxidant, potassium permanganate (KMnO4) is normally more expensive than chlorine and ozone, but for iron and manganese removal, it has been reported to be as efficient and it requires considerably less equipment and capital investment. The dose of potassium permanganate, however, must be carefully controlled. Ozone may be used for iron and manganese oxidation, but may not be effective for oxidation in the presence of humic or fulvic materials. Oxygen can also be used as an oxidant, provided iron is not complexed with humic materials or other large organic molecules. The presence of other oxidizable species in water hinders oxidation of the desired reduced compounds.

Ion exchange can be used to remove any charged (i.e., ionic) species from water, but is usually used to remove hardness and nitrates. Removal is accomplished through adsorption of contaminant ions onto a resin exchange medium. Water is usually pretreated to reduce the suspended solids and total dissolved solids (TDS) load to the ion-exchange unit. Ion exchange can be used with fluctuating flow rates. Ion exchange waste is highly concentrated and requires careful disposal. Ion exchange units also are sensitive to the presence of competing ions. For example, influent with high levels of hardness will compete with other cations (positive ions) for space on the exchange medium, and the exchange medium must be regenerated more frequently.

Reverse osmosis (RO) removes contaminants from water using a semi-permeable membrane that permits only water, and not dissolved ions (such as sodium and chloride), to pass through its pores. Raw water is subject to a high pressure that forces pure water through the membrane, leaving contaminants behind in a brine solution. RO can effectively remove nearly all inorganic contaminants from water. It removes more than 70 percent of arsenic (III), arsenic (IV), barium, cadmium, chromium (III), chromium (VI), fluoride, lead, mercury, nitrite, selenium (IV), selenium (VI), and silver, and properly operated units can attain up to 96 percent removal rates. RO can also effectively remove radium, natural organic substances, pesticides, and microbiological contaminants. RO is particularly effective when used in series; water passing through multiple units can achieve near zero effluent contaminant concentrations. RO systems are relatively insensitive to flow and TDS concentration, and therefore are suitable for small syste ms with a high degree of seasonal fluctuation in water demand. Operational simplicity and automation allow for less operator attention and make RO suitable for small system applications. However, RO tends to have high capital and operating costs, and a high level of pretreatment is required in some cases to prevent fouling.

Reverse osmosis is also used for desalination of seawater and other water sources with high quantities of dissolved solids. Pure desalination water is usually acidic and corrosive to pipes, so it typically mixed with other sources of water that are piped onsite or else adjusted for pH, hardness, and alkalinity before being piped offsite. The product water recovery relative to input water flow is 15 to 50 percent for most seawater desalination plants (i.e., for every 100 gallons of seawater, 15 to 50 gallons of pure water would be produced along with brine water containing dissolved solids). The brine and other liquid wastes from desalination plants may contain all or some of the following constituents: high salt concentrations, chemicals used during defouling of plant equipment and pretreatment, and toxic metals (which may be present if the discharge water was in contact with metallic materials used in construction of the plant facilities). Liquid wastes may be discharged directly into the ocean, combined with other discharges (e.g., power plant cooling water or sewage treatment plant effluent) before ocean discharge, discharged into a sewer for treatment in a sewage treatment plant, or evaporated (with the remaining solids disposed of in a landfill). Desalination plants also produce a small amount of solid waste (e.g., spent pretreatment filters and solid particles that are filtered out in the pretreatment process).

Electrodialysis uses an electrical charge and a semi-permeable membrane to remove charged species. The membranes are designed to allow either positively or negatively charged ions to pass through the membrane; thus ions move from the product water stream through a membrane to the two reject water streams. The reject stream is typically 20–90 percent of feed flow. Electrodialysis can remove most dissolved ions, and is very effective in removing fluoride and nitrate, and can also remove barium, cadmium, and selenium. Electrodialysis is relatively insensitive to flow and TDS level, and low effluent concentration possible. These systems tend to have high capital and operating costs, and may require a high level of pretreatment.

Aeration (air stripping) can be used to remove volatile compounds and radon from source water. The volatilized contaminants are released to the atmosphere, with or without treatment. Aeration systems that might be suitable for drinking water systems include packed column aeration, diffused aeration, multiple-tray aeration, and mechanical aeration. A small system might be able to use a simple aerator constructed from relatively common materials instead of a specially designed aerator system.

Activated carbon removes contaminants through adsorption, primarily a physical process in which dissolved contaminants adhere to the porous surface of the carbon particles. Activated carbon removes many organic contaminants as well as taste and odor from water supplies. Organics that are not readily adsorbed by activated carbon include alcohols; low molecular weight aliphatics (including vinyl chloride), ketones, acids, and aldehydes; sugars and starches; and very high-molecular-weight or colloidal organics. Radon removal by activated carbon is not feasible at the treatment plant scale. Activated carbon is replaced periodically when the surface area is saturated and can no longer effectively adsorb contaminants. However, the adsorption process can be reversed relatively easily, allowing regeneration and re-use of the activated carbon.

Disinfection

Water systems add disinfectants to destroy microorganisms that can cause disease in humans. The most commonly used disinfection agents include chlorine, chloramines, ozone, and ultraviolet light. Other disinfection methods include chlorine dioxide, potassium permanganate, and nanofiltration. Primary disinfection achieves the desired level of microorganism kill or inactivation, while secondary disinfection maintains a disinfectant residual in the finished water that prevents the re-growth of microorganisms.

Chlorine is very effective for removing almost all microbial pathogens and is appropriate as both a primary and secondary disinfectant. Chlorine can be used in the form of chlorine gas, sodium hypochlorite, or calcium hypochlorite. Chlorine gas is usually supplied as a liquid in high-pressure cylinders, and it can also be generated onsite by electrolysis of sodium chloride solution. Sodium hypochlorite is usually stored in an aqueous solution, and diluted before use. Calcium hypochlorite is usually stored as a solid that is usually dissolved in water before use. The chlorination chemical is usually injected into the water supply line and a controlled rate. Chlorine reacts with organic material naturally present in many water sources to form harmful chemical by-products, principally trihalomethanes.

Chloramine is an effective bactericide that produces lower levels of trihalomethanes than chlorine. Chloramines are generated on site by injecting chlorine (gaseous solution or sodium hypochlorite) into the supply main followed immediately by injection of ammonia (gaseous solution or as ammonium hydroxide). Chloramine is a weak disinfectant, and is much less effective against viruses or protozoa than free chlorine. Chloramine is often used as a secondary disinfectant to prevent bacterial re-growth in a distribution system.

Ozone, an allotrope of oxygen having 3 atoms to each molecule, is a powerful oxidizing and disinfecting agent. Ozone gas is unstable and must be generated on site by passing dry air through a system of high-voltage electrodes. Ozonation requires a shorter contact time than does chlorine. Ozone does not directly produce halogenated organic materials unless a bromide ion is present. A secondary disinfectant, such as chloramine, is required because ozone does not maintain an adequate residual in water. The capital costs of ozonation systems are relatively high, and operation and maintenance are relatively complex.

Ultraviolet (UV) radiation is generated by a special lamp. When it penetrates the cell wall of an organism, the cell's genetic material is disrupted and the cell is unable to reproduce, effectively destroying bacteria and viruses. As with ozone, a secondary disinfectant must be used to prevent re-growth of microorganisms. UV radiation can be attractive as a primary disinfectant for small systems because it is readily available, it produces no known toxic residuals, it requires short contact times, and the equipment is easy to operate and maintain. However, UV radiation may not inactivate Giardia lamblia or Cryptosporidium cysts. UV radiation is unsuitable for water with high levels of suspended solids, turbidity, color, or soluble organic matter because these materials can react with or absorb the UV radiation, reducing the disinfection performance.

Water Distribution and Storage

Water distribution systems include all of the components necessary to carry drinking water from a centralized treatment plant or well supplies by means of gravity storage feed or pumps through distribution pumping networks to the consumers, including distribution and equalization storage. These systems consist of pipes, pumps, valves, storage tanks, reservoirs, meters, fittings, and other hydraulic appurtenances. Distribution systems are designed and operated to deliver water of quality acceptable for human consumption and of sufficient quantity to meet all the needs of the customers. Many distributions also provide sufficient capacity for non-potable uses, including irrigation, landscaping, and fire suppression.

Most water distribution pipes are constructed of ductile iron, pre-stressed concrete, polyvinyl chloride, reinforced plastic, and steel. In the past, unlined cast iron and asbestos cement pipes were also used, and may be important components of existing systems.

Water distribution systems may have a branch or loop network topology, or a combination of both. In a branch system, smaller pipes branch off or larger ones throughout the system such that water can take only one pathway from the source to the consumer. A loop system comprises connected pipe loops throughout the service area such that water can take several pathways from the source to the consumer. In a loop system, 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 water distribution networks include both loop and branch components. Decentralized treatment systems, which provide additional treatment near the point of use depending on the customers needs, have been implemented in trials, and may be utilized more in the future. Dual distribution systems that provide separate mains for potable and non-potable water (e.g., reclaimed water used for irrigation, fire protection, etc) are used in some communities.

Storage tanks and reservoirs are used to provide storage capacity to meet fluctuations in demand, to provide reserve supply for fire suppression and other emergency needs, to stabilize pressures in the distributions system, to increase operating convenience an provide flexibility in pumping, to provide water during source or pump failures, and to blend different water sources. Elevated tanks are used most frequently, but other types of tanks and reservoirs include in-ground tanks and open or closed reservoirs.

The water distribution system needs energy in the form of pressure to deliver the treated water. That energy can be supplied by a pump, by gravity feed from a water source (such as a reservoir or a water tower) at a higher elevation, or, in smaller systems, by compressed air. Valves are used to isolate sections of the network for maintenance and repair. Control valves are used to control the flow and pressure in the distribution system.

Ideally, the water quality should not change between the time it leaves the treatment plant and the time it is consumed. However, substantial changes can occur to finished water in the distribution system as the result of complex physical, chemical, and biological reactions. For example, tanks sized to provide adequate supply for fire suppression needs may have low turnover rates and low levels of disinfectant residual, leading to biofilm growth and other biological changes in the water such as nitrification. Design and operation of the distribution system can minimize such effects.

A.2 Sanitation

Sanitation systems protect human health and the environment by isolating, and in some manner treating, sewage waste. For rural areas, on-site sanitation systems, ranging from pit latrines to flush toilets and septic systems, are the most common. As population density increases, more complicated, centralized collection, storage, and treatment systems are needed.

Sludge Collection

On-site sanitation systems such as bucket latrines and septic systems require periodic removal of solids for proper functioning. The first stage of proper management of fecal sludge is collection and transport to a storage or treatment facility. Collection may be accomplished by manual means (e.g., with shovels and buckets), or with mechanical equipment. Mechanical equipment for septage collection include truck-mounted vacuum tanks of 3 to 6 m^3 capacity and small, hand-pushed vacuum tugs of 350 to 500 L. In houses situated close to a road, the septic tank can be emptied with the large truck and the septage can directly be hauled to the treatment site. If the house is situated in a narrow lane, a mini-vacuum-tug can be used. In that case, an intermediate storage tank (3 to 6 m^3) can be placed in the closest point accessible by truck, and the septage is transferred to the tank from the vacuum tug in several trips. This storage tank can then transferred to another emptying site or to the treatment site. One unit of equipment, either large or small, can serve 2 to 3 septic tanks per day or approximately 500 per year.

Sewerage

Sewers are closed conduits, usually circular in cross section, which carry wastewater. Sewerage refers to systems of sewers and includes pump stations, overflows, and other associated infrastructure. Most sewers are designed to carry either sewage or storm water, but many are combined sewers, which carry both sewage and storm water.

Sewers may carry wastewater from residential, commercial, and industrial users, to storage, discharge, or wastewater treatment. Because industrial liquid waste may contain a wide range of chemicals, solvents, and other contaminants that cannot be effectively removed by the centralized wastewater treatment plant, industries are often required to pre-treat their liquid wastes prior to discharging to sewer.

Design and sizing of sewerage systems considers population served, commercial and industrial flows, flow peaking characteristics, and wet weather flows. Besides the projected sewage flow, the size and characteristics of the watershed are the overriding design considerations for combined sewers. Often, combined sewers can not handle the volume of storm water runoff, resulting in combined sewer overflows, which are typically discharged to surface water with little if any treatment. Although separate sewer systems are intended to transport only sewage, all sewer systems have some degree of inflow and infiltration of surface water and groundwater. Inflow and infiltration are affected by antecedent moisture conditions, which also represent an important design consideration in separate sewer systems.

A typical method of conveyance used in sewer systems is to transport wastewater by gravity along a downward-sloping pipe gradient. These sewers, known as conventional gravity sewers, are designed so that the slope and size of the pipe is adequate to maintain flow towards the discharge point without surcharging manholes or pressurizing the pipe. Conventional gravity sewers are typically used in urban areas with consistently sloping ground because excessively hilly or flat areas result in deep excavations and drive up construction costs. Sewage pumping or lift stations may be necessary as a result of the slope requirements for conventional gravity sewers, which result in a system terminus (i.e., low spot) at the tail of the sewer, where sewage collects and must be pumped or lifted to a collection system. Pumping and lift stations substantially increase the cost of the collection system. Manholes associated with conventional gravity sewers may be a source of inflow and infiltration, increasing the volume of wastewater to be carried, as well as the size of pipes and lift/pumping stations.

Alternative wastewater collection systems can be cost effective for areas where traditional collection systems are too expensive to install and operate. For example, pressure sewers are sometimes used in sparsely populated or suburban areas in which conventional collection systems would be expensive. These systems generally use smaller diameter pipes with a slight slope or follow the surface contour of the land, reducing excavation and construction costs. Pressure sewers differ from conventional gravity collection systems because they break down large solids in the pumping station before they are transported through the collection system. Their watertight design and the absence of manholes eliminate extraneous flows into the system. Thus, alternative sewer systems may be preferred in areas that have high groundwater that could seep into the sewer, increasing the amount of wastewater to be treated. They also protect groundwater sources by keeping wastewater in the sewer. The disadvantages of alternative sewage systems include increased energy demands, higher maintenance requirements, and greater on-lot costs. In areas with varying terrain and population density, a combination of sewer types may be appropriate.

Two major types of pressure sewer systems are the septic tank effluent pump (STEP) system and the grinder pump (GP). Neither requires any modification to plumbing inside the house. In STEP systems, wastewater flows into a conventional septic or interceptor tank to capture solids. The liquid effluent flows to a holding tank containing a pump and control devices. The effluent is then pumped and transferred for treatment. Retrofitting existing septic tanks in areas served by septic tank/drain field systems would seem to present an opportunity for cost savings, but a large number (often a majority) must be replaced or expanded over the life of the system because of insufficient capacity, deterioration of concrete tanks, or leaks. In a GP system, sewage flows to a vault where a grinder pump grinds the solids and discharges the sewage into a pressurized pipe system. GP systems do not require a septic tank but may require more horsepower than STEP systems because of the grinding action. GP systems produce wastewater with higher TSS, which may not be acceptable at a downstream treatment facility.

Wastewater Treatment

Sewage treatment includes physical, chemical, and biological processes to remove physical, chemical, and biological contaminants. Its objective is to produce treated effluent and a solid waste or sludge that is suitable for discharge or reuse back into the environment. Typically, sewage treatment involves up to three stages, called primary, secondary and tertiary (or advanced) treatment.

Primary Treatment

Primary treatment is designed to remove gross, suspended and floating solids from raw sewage. This stage is sometimes referred to as mechanical treatment, although chemicals are often used to accelerate the sedimentation process.

Preliminary screening removes large suspended and floating objects. After the wastewater has been screened, it may flow into a grit chamber where sand, grit, cinders, and small stones settle to the bottom. Removing the grit and gravel that washes off streets or land during storms is very important, especially in cities with combined sewer systems. Large amounts of grit and sand entering a treatment plant can cause serious operating problems, such as excessive wear of pumps and other equipment, clogging of aeration devices, or taking up capacity in tanks that is needed for treatment. The grit and screenings removed by these processes must be periodically collected and disposed of (e.g., by landfilling or incineration).

With the screening completed and the grit removed, wastewater still contains dissolved organic and inorganic constituents along with suspended solids. Additional suspended solids may be removed by sedimentation or gravity settling, chemical coagulation, or filtration. The removed solid material is called primary sludge.

Primary treatment can reduce the BOD of the incoming wastewater by 20 – 30 percent and the total suspended solids by 50 – 60 percent. Primary treatment is usually the first stage of wastewater treatment. In some cases, treatment plants begin with primary treatment and add other treatment stages as wastewater load grows, as the need for treatment increases, and as resources become available.

Secondary Treatment

Secondary treatment uses biological processes to remove about 85 percent of the dissolved organic matter that escapes primary treatment. Secondary treatment technologies include fixed-film processes, activated sludge and other suspended growth processes, extended aeration systems, membrane biological reactors, aerated lagoons, pond and constructed wetland systems, and other forms of treatment that use biological activity to break down organic matter.

In attached growth (or fixed-film) processes, the microbial growth occurs on the surface of stone or plastic media. Wastewater passes over the media along with air to provide oxygen. Attached growth process units include trickling filters, biotowers, and rotating biological contactors. In suspended growth processes, the microbial growth is suspended in an aerated water mixture where the air (or oxygen) is pumped in, or the water is agitated sufficiently to allow oxygen transfer. Suspended growth process units include variations of activated sludge, oxidation ditches, and sequencing batch reactors. The suspended growth process speeds up the work of aerobic bacteria and other microorganisms that break down the organic matter in the sewage by providing a rich aerobic environment where the microorganisms suspended in the wastewater can work more efficiently.

From the aeration tank, the treated wastewater flows to a sedimentation tank (secondary clarifier), where the excess biomass is removed. Some of the biomass is recycled to the head end of the aeration tank, while the remainder is "wasted" from the system. The waste biomass and settled solids are treated before disposal or reuse as biosolids.

Activated sludge and related processes can be appropriate where high removal of organic pollution is required, funds and skilled personnel are available for operation and maintenance, and land is scarce or expensive. The system typically needs some form or primary treatment, such as screening and sedimentation. When properly operated and maintained, the process is generally free of flies and odors. However, most activated sludge processes are more costly to operate than attached growth processes and a steady energy supply is required. The effectiveness of the activated sludge process can be adversely affected by elevated levels of toxic compounds in wastewater. Therefore, an industrial pretreatment program may be needed to control pollutants from the industrial users that may pass through or interfere with treatment processes, contaminate sewage sludge, or create hazardous condition in the sewerage or treatment system such as formation of explosive or toxic gases.[47]

General considerations for activated sludge process design include wastewater characteristics, local environmental conditions (including temperature), possible presence of inhibitory substances (such as may be present in industrial effluents), oxygen transfer requirements and reaction kinetics (retention time in the system).

Extended aeration is a variation on the basic activated sludge process that uses a relatively low flow rate and long aeration time. The aerated sewage is formed into a brown floc-like sludge, which settles out in a separate settling tank. Thus, clear treated effluent is drawn off the top of the settling tank and sludge is drawn off the bottom of the tank. The advantage of this system is that the sludge is stable and needs no further treatment except dewatering. However, power demands are high because of the long period of aeration, thus the system is generally suitable for small plants.

Membrane biological reactors (MBR) or bio-membrane systems includes a semi-permeable membrane barrier system either submerged or in conjunction with an activated sludge process. This technology guarantees removal of all suspended and some dissolved pollutants. The limitation of MBR systems is directly proportional to nutrient reduction efficiency of the activated sludge process. MBR systems can achieve high effluent quality and use little land area. However, the MBR process is sophisticated and the cost of building and operating a MBR is usually higher than conventional wastewater treatment.

Ponds and wetlands are simple and robust wastewater treatment options with low operation and maintenance costs and demands. Ponds are classified as anaerobic (reactions take place without oxygen), facultative (in which the processes may or may not use oxygen), and maturation (in which the pond provides additional treatment in the presence of oxygen and sunlight to further reduce pollutants before discharge).

Pond and wetland systems are influenced by natural conditions, such as wind, temperature, rainfall, solar radiation, and seepage, as well as by physical factors such as surface area, water depth, short-circuiting, pH, toxic materials, and oxygen. Site-specific problems may include a high groundwater table, flooding, steep topography, and habitat for vectors such as mosquitoes.

Aerobic waste stabilization ponds are open basins in which wastewater is treated in the absence of oxygen. Solids settle to the bottom of the pond, where they are digested. Anaerobic ponds can be used as a first stage to treat wastewater prior to secondary treatment in other systems such as facultative ponds or constructed wetlands. Anaerobic ponds are normally rectangular basins with a depth of at least 3 meters and ideally 4 meters. Sludge must be removed from the ponds periodically (e.g., by draining and removal as a solid or by a float-mounted sludge pump). A well-designed anaerobic pond can remove up to about 60 percent of BOD and COD in warm conditions.

Facultative ponds are large shallow basins (about 1.5 to 1.8 meters deep) that facilitate a combination of anaerobic and aerobic processes. Treatment takes place though a combination of physical and biological processes, and can be complex. Maturation ponds are similar but smaller, and are typically placed in series after facultative ponds. Maturation ponds are more efficient than most other treatment processes at removing both bacteria and parasitic worm eggs. Facultative and maturation ponds might be considered when sufficient land is available, pathogen levels need to be reduced, and/or the inflow may occasionally include large volumes of storm water runoff.

47 See, for example, U.S. EPA Office of Wastewater Management, Permits Division, Model Pretreatment Ordinance, January 2007, EPA 833-B-06-002.

Constructed wetlands are engineered wetland systems that can treat a variety of waste effluents, including domestic wastewater, agricultural runoff, storm water, and even industrial effluents. Treatment occurs through a combination of biological and physical processes, including sedimentation, precipitation, adsorption, assimilation by the plants, and microbiological activity. The system is designed to flow by gravity, minimizing the need for pumps and electrical devices. Flow may be either vertical or horizontal, and for horizontal flow wetlands, may be either above or below the surface. Most constructed wetlands in developing countries are of the horizontal sub-surface flow type. Above-surface flow is generally avoided because it provides breeding areas for mosquitoes.

Constructed wetlands might be used when there is a need for higher effluent quality than can be achieved by anaerobic treatment alone. Constructed wetland treatment typically requires 3 – 5 m^2 per person when treating full-strength sewage; the land area requirement can be reduced by preliminary anaerobic treatment.

Tertiary Treatment

The treatment processes used to reduce the BOD of sewage waste are secondary treatment processes. Tertiary treatment is any practice beyond secondary treatment and is designed to remove nonbiodegradable organic pollutants and mineral nutrients such as nitrogen and phosphorus salts. Tertiary treatment can remove more than 99 percent of impurities from the wastewater, and is capable or producing effluent of nearly drinking water quality. An example of tertiary treatment is the modification of conventional secondary treatment to remove additional phosphorous and nitrogen. Activated carbon filters are commonly used for tertiary treatment.

Disinfection

Disinfection can be the final step before discharge of the effluent. Chlorine is the most widely used disinfectant but ozone and ultraviolet radiation are also frequently used for wastewater effluent disinfection. However, some environmental authorities are concerned that chlorine residuals in the effluent can cause adverse impacts. Dechlorination of treated wastewater may be appropriate to achieve desired water quality parameters.

Wastewater Re-Use

Wastewater is increasingly used for agriculture, especially in areas of water scarcity, population increase, and related demands for food, as wastewater provides a source of both water and nutrients. Wastewater can also be a reliable source of water throughout the year.

The wastewater is applied to the land and moves through the soil where the natural filtering action of the soil along with microbial activity and plant uptake removes most contaminants. Part of the water evaporates or is used by plants. The remainder is either collected via drains or wells for surface discharge or allowed to percolate into the groundwater. Much of the water and most of the nutrients are used by the plants, while other pollutants are transferred to the soil by adsorption, where many are mineralized or broken down over time by microbial action.

The wastewater, which is sometimes disinfected before application, depending on the end use of the crop and the irrigation method, can be applied to the land by spraying, flooding, drip irrigation, or ridge and furrow irrigation. The method selected depends on cost considerations, terrain, and the type of crops. Drip irrigation systems discharge water through small holes in pipes laid along the ground and, therefore, pretreatment to remove suspended solids is necessary for these systems so as not to clog the holes.

Sludge Treatment and Disposal

Sludge Treatment

The most common sludge treatment systems include anaerobic digestion and thermophilic anaerobic digestion.

Anaerobic digesters are large fermentation tanks which are continuously operated under anaerobic conditions. Anaerobic decomposition could be used for direct treatment of sewage, but it is economically favorable to treat the waste aerobically. Large-scale anaerobic digesters are usually used for processing of the sludge produced by primary and secondary treatments. It is also used for the treatment of industrial effluents which have very high BOD levels. The mechanisms for mechanical mixing, heating, gas collection, sludge addition and removal of stabilized sludge are incorporated into the design of large-scale anaerobic digesters. Anaerobic digestion uses a large variety of nonmethanogenic anaerobic bacteria. In the first part of the process, complex organic materials are broken down and in the next step, methane is generated. The final products of anaerobic digestion are approximately 70% methane and 30% carbon dioxide, microbial biomass, and a nonbiodegradable residue. Fully digested sludge has little readily biodegradable organic matter. It generally does not have objectionable odors, and about 50% of the solids are inorganic.

Thermophilic anaerobic digestion takes place at higher temperatures, typically 50 - 70ºC, compared with standard anaerobic digestion, which most commonly is carried out at bout 20 - 45ºC. Thermophilic anaerobic digestion can be faster, requiring only about two weeks to complete, compared with 15 to 30 days for standard anaerobic digestion. However, thermophilic digestion is more expensive, requires more energy and is less stable than the mesophilic process.

Extended aeration secondary treatment systems also serve to aerobically digest the sewage sludge. In addition, sludge from conventionally activated sludge processes can be treated aerobically by introducing air, rather than encouraging an oxygen-depleted environment as in anaerobic digestion. Because the aerobic digestion occurs much faster than anaerobic digestion, the capital costs of aerobic digestion are lower. However, the operating costs are characteristically much greater for aerobic digestion because of energy costs for aeration needed to add oxygen to the process.

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

Sludge Disposal and Use

Following stabilization (e.g. by anaerobic digestion, thermophilic anaerobic digestion, aerobic digestion, or extended aeration processes), the sludge can be dewatered and disposed of in a landfill or incinerator, or subject to further processing for beneficial uses. There are concerns about sludge incineration because of air pollutants in the emissions, along with the high cost of supplemental fuel, making this a less attractive and less commonly constructed means of sludge treatment and disposal. However, incineration may be appropriate if the composition of the sludge (e.g., because of industrial discharges to the sewer system) precludes other disposal or use option.

Both anaerobic and aerobic sludge digestion processes can result in the destruction of disease-causing microorganisms and parasites to a sufficient level to allow the resulting digested solids to be safely applied to land used as a soil amendment material (with similar benefits to peat) or used for agriculture as a fertilizer, provided that levels of toxic constituents are sufficiently low.