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General principles and guidelines for cost analysis in planning of decentralized wastewater treatment and/or reuse

Principes généraux et lignes directrices pour l'analyse des coûts lors de la planification du traitement décentralisé et/ou de la réutilisation des eaux usées

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 282, *Water reuse*, Subcommittee SC 2, *Water reuse in urban areas,* in collaboration with Technical Committee ISO/TC 224 *Drinking water, wastewater and stormwater systems and services*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

While energy consumption for water and wastewater treatment is significant, up to 80 % of it is used for conveyance. This includes pumping of wastewater to the treatment facility and pumping the effluent to its reuse site. In centralized wastewater treatment and reuse system schemes, the long-distance conveyance through piping systems and pumping stations is also associated with capital investment, which would be hard to bear for those people living in areas of low population densities.[1],[2] Thus, a network of decentralized wastewater treatment and reuse systems will potentially reduce both the capital expenses (CAPEX) and operating expenses (OPEX) in some cases, compared with conventional planning of centralized wastewater treatment and reuse systems. Another benefit of decentralized treatment is enabling local reuse, mainly for irrigation.[3],[4]

Distributed design is the concept of providing several decentralized wastewater treatment systems instead of one central plant, as outlined in other International Standards, such as ISO 23056, which defines and describes different degrees of decentralization of wastewater treatment plants and discusses considerations that should be taken in the selection of each alternative. Due to development in automation and telecommunication, as well as in biological wastewater treatment processes, the distributed design concept has become a viable option. Potential savings in using distributed design include:

— lower collection and pumping system construction costs;

— lower collection and pumping system operation and maintenance costs;

— lower energy consumption for pumping;

— local availability for reuse in agriculture or industry or landscape irrigation.

However, potential drawbacks include:

— higher specific cost of each plant compared with a centralized wastewater treatment and reuse system;

— higher operator attention required for many plants compared with one plant.

This document aims to provide guidelines for life cycle cost assessment for any degree of distribution in the planning of a network of decentralized wastewater treatment and reuse systems in order to enable the cost optimization of the design.

General principles and guidelines for cost analysis in planning of decentralized wastewater treatment and/or reuse

1 Scope

This document specifies the general principles and provides guidance on the quantitative characterization of the life cycle cost of a complete wastewater management system, including collection, treatment and, optionally, reuse. It enables the consideration of different degrees of distribution, including non-sewered systems for one or more dwellings and associated trucking operations.

The methodology provided in this document is applicable to urban or rural areas wherein several decentralized wastewater treatment and reuse systems can provide a lower cost solution than a single centralized plant. Similarly, the same methodology can be applied for industrial reuse systems, where several separate plants on a large industrial site can be considered instead of one treatment system.

The scope of this document includes the following:

a) Guidance on the determination of the degrees of distribution of decentralized wastewater treatment and reuse systems.

b) A definition of the elements and components included in the life cycle cost of the different degrees of distribution in wastewater management systems, including construction, operation and maintenance.

c) Guidance on the required steps for calculating life cycle cost indicators, including considerations of term and interest, operation and maintenance, replacement parts, equipment life expectancy, the value of water for reuse and other income from by-products.

d) A definition of the metrics for reporting results, including the cost per unit, scope, term and interest.

The following secondary costs and other considerations are not within the scope of this document:

— cost of eventual disposal of the system;

— guidance on wastewater treatment process selection and design;

— health and sustainability considerations (although health and sustainability are primary considerations in design and decisions);

— social impact factors and/or environmental risks and impacts.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20670, *Water reuse — Vocabulary*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 20670 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1.1
distributed system
two or more treatment plants in different geographical locations linked to a central system, either physically or by management

Note 1 to entry: See WEF Fact Sheet "Distributed Systems Overview" (ref. WSEC-2019-FS-012).[6]

3.1.2
degree of distribution
number of treatment plants to treat a certain population

Note 1 to entry: A high degree of distribution means many plants to treat the population, while a low degree of distribution means a number as low as one centralized plant to treat that same population.

3.1.3
non-sewered system
NSS
system that is not connected to a networked sewer and collects, conveys and fully treats the specific input to allow for safe reuse or disposal of the generated solid output and/or effluent

Note 1 to entry: A non-sewered system is also referred to as an "on-site treatment system", see ISO 24513:2019, 3.5.16.

[SOURCE: ISO 30500:2018, 3.1.1.1, modified — Note to entry replaced.]

3.1.4
total installed cost
final cost of designing, fabricating and building a capital project or industrial asset

Note 1 to entry: The total installed cost includes the cost of labour and materials.

3.2 Symbols and abbreviated terms

AOP	advanced oxidation processes
C_I	investment cost
C_M	maintenance cost
C_N	negative cost
C_O	operating cost
CAPEX	capital expenses
IFAS	integrated fixed-film activated sludge
MABR	membrane aerated biofilm reactor

MBBR	moving bed bio reactor
MBR	membrane bio reactor
NPV	net present value
OPEX	operating expenses
PE	population equivalent
PV	present value
RO	reverse osmosis
SBR	sequencing batch reactor
UASB	upflow anaerobic sludge blanket
UV	ultraviolet (irradiation, in context of disinfection)
WRRF	water resource recovery facility

4 Description of different degrees of distribution in planning and design

The difference between decentralized wastewater treatment systems (3.1.1) and distributed wastewater treatment systems (see ISO 20670) is that distributed systems are located in different geographical locations but are linked to a central system either physically or by management, whereas decentralized systems can be located in a different geographical location but are not linked physically or are not managed under the umbrella of a centralized system.

The degree of distribution (3.1.2), meaning the number of treatment units for a given population, can be as high as one system for each household (on-site systems) or as low as one single treatment plant for a city, town or village (centralized system), or many degrees in between, such as one system per street or one system for every cluster of households or drainage basin. The collection of wastewater can be via a piped network (a sewer system) or by motorized vehicles, such as vacuum trucks, in non-sewered systems. Determining the required number of systems can be challenging in the design of a wastewater treatment and reuse plan. In some cases, the means to meet this challenge can be through an economic estimation of the long-term cost.

A single large plant may benefit from the economy of scale of its equipment and from lower operation and maintenance costs compared with a distributed system made up of multiple decentralized systems. However, distributed systems can offset much of this benefit through lower CAPEX for piping and pumping as well as lower OPEX for pumping energy, on both wastewater and water for reuse. Therefore, the overall cost benefit of a distributed design or a centralized design changes from one place to another and should be calculated in order to make a decision based on costs.

A structured analysis of the total cost per unit of wastewater treatment for reuse was demonstrated by multiple computerized simulations for different types of terrain and different population densities.[9] The results show that for the lowest population density found in rural areas, the highest degree of distribution is associated with the lowest cost in flat, hilly or mountainous terrains, whereas in suburban areas it greatly depends upon the terrain. A less distributed design results in a lower cost in flat terrain, whereas a more distributed design results in a lower cost in mountainous terrain.

An example of two different degrees of distribution for a specific case is given by van Afferden et al.,[10] showing a distributed scenario of nine decentralized systems (indicated there by white triangles with a dark frame) and just one pumping station, all managed by one utility. For comparison, a centralized scenario with one wastewater treatment plant is shown (indicated there by a single dark triangle), supported by six pumping stations (indicated there by bright rectangles connected to dashed lines) and several kilometres of a trunk pipe.

NOTE There are cases in small rural communities in which the communal decentralized wastewater treatment and reuse systems are not equipped to treat sludge. In such cases, the sludge generated in these facilities is collected and brought to centralized wastewater treatment plants for treatment.

5 Generalized elements of wastewater treatment and reuse systems

5.1 General

In the planning of wastewater management systems for reuse or other purposes, there are many components and subsystems to be selected and designed, as listed in 5.2 to 5.5. All costs associated with all these elements of the system should be included in the cost comparison of different degrees of distribution of the entire plan.

The following subsections provide context, along with a brief explanation of the nature and scope of each of these elements.

5.2 Collection

The collection system is roughly divided into stages from the source towards its final destination, as shown in available publications.[11] For the purposes of this document, the following notation will be followed in order of flow, from each home in a lateral sewer up to the intercepting sewer or pressure main that reaches the wastewater treatment plant (based on EPA notation[12]): a) lateral sewer; b) branch sewer; c) trunk sewer (main sewer); d) intercepting sewer; e) pressure main.

Systems may have all or part of these collection system components for different degrees of distribution. For example, an on-site treatment system will typically only have a lateral sewer collecting from the dwelling to the treatment system.

Trucking or hauling of wastewater or sludge is sometimes an alternative to collection and conveyance systems, especially in non-sewered systems or on-site treatment systems. When any part of the wastewater is disposed of by trucking or hauling, it is accounted for as an operational cost instead of an investment cost.

5.3 Conveyance

Pumping stations and lift stations are used whenever wastewater conveyance by gravity is not possible, either as an intermediate or final run of part of the collection system. Different designs are common for a sewage pumping or lift station, with the following typical main components:[13], [14]

a) screening to protect the pumps from clogging;

b) a pit or a well to intercept the sewage and provide an operational volume and buffering;

c) pumps, including redundancy;

d) discharge pressure piping;

e) venting and optional means for odour control.

Vacuum collection systems are a recent alternative to gravity collection systems when the latter are not practicable due to area limitation. The vacuum collection sewers use suction (negative pressure) to move the sewage through the following three main stages:[15], [16]

— Vacuum valve pit: sewage collection from individual households or homes by gravity. Once the pit is full, a valve is opened and atmospheric pressure forces the wastewater to the vacuum branches.

— Vacuum mains: a network of vacuum piping collecting sewage from the collection chambers of individual housings and gradually converging towards the vacuum station. The pressure difference between the valve pit and the vacuum station pulls the wastewater through the vacuum mains.

— Vacuum station: producing the suction for the vacuum piping network connected to it and typically pumping the sewer to the wastewater treatment plant.

It is reiterated that trucking or hauling of wastewater or sludge is sometimes an alternative to collection and conveyance systems, especially in non-sewered systems or on-site treatment systems. When any part of the wastewater is disposed of by trucking or hauling, it is accounted for as an operating cost instead of an investment cost.

5.4 Treatment

The treatment plant, also referred to as a WRRF, includes all installed water treatment processes used to achieve compliance with local discharge standards or reuse requirements. These typically include the process sub-sections or categories[17] described as follows and summarized in Table C.1.

In cases where different effluent requirements are applicable for different plant sizes, such as between a decentralized plant and a centralized plant, each plant or plan may be made with the requirements for its type, as would be the eventual design for regulatory approval. For example, in some places, small wastewater treatment and reuse systems are not required to perform tertiary treatment for reuse in irrigation of tree-grown crops, whereas a large plant is required to perform tertiary treatment regardless. In such cases, the cost of tertiary treatment does not have to be included where it is not needed.

a) Pre-treatment: physical processes to remove elements that could damage downstream equipment and also remove easily removable constituents to improve downstream process efficiency. Usually, pre-treatment units are designed to handle diurnal and seasonal flow variations.

   The costing of pre-treatment shall include any aeration, mixing, chemicals, sludge treatment and disposal, whether constant, periodic or occasional over the costing period. The pre-treatment process contains some or all of the following main units:

   — Screening: removal of large particulate matter and objects that can usually be disposed of as trash. There are manual or mechanical screens and the screens openings can be coarse or fine. Screening is often installed in two stages, with a coarse screen followed by a fine screen.

   — Grit and grease removal unit: removes sand and gravel as well as fat, oil and grease.

   — Equalization tank: equalizes flowrates and organic loads in order to reduce the size and cost of downstream units and to achieve constant loads on the process units. It should be considered that smaller sewer systems have a higher ratio of peak flow to average flow than larger systems.

b) Primary treatment: partial removal of suspended solids by gravity in a sedimentation tank or pond. The quantity of sludge discharged from this operation shall be included in sludge treatment cost calculations. If chemicals are added to the primary treatment, their cost shall be included in the plant operating cost.

c) Secondary treatment: a biological treatment process, including separation between solids and liquids, such as a secondary clarifier or membrane separation. Such processes are typically based on suspended biomass, such as the activated sludge process, SBR or MBR, a biofilm process or a combination of both, such as MBBR, IFAS, MABR or trickling filters. The process can be intensive, as in the examples mentioned, or an extensive process, such as constructed wetlands, including tidal, aeration ponds or a lagoon system. OPEX items of secondary treatment include:

   — electricity for aeration with blowers or aerators or other means;

   — electricity for pumping, in circulation of sludge or tank content or other;

— electricity consumption for mixing, agitation, raking and any other similar electromechanical drives;

— chemicals added to the process for coagulation or other purposes;

— replacement parts, such as UV lamps, membranes, pumps and other items which have a shorter life expectancy (shorter period of amortization) than the period taken for life cycle cost calculation;

— labour for operation, maintenance, analysis and other;

— any other directly related specific cost item.

d) In some cases, following secondary treatment, filtration and/or disinfection is performed, mainly to reduce suspended solids, turbidity, phosphorus and microorganisms or pathogens.

The filtration could require any of the following, according to equipment selection as part of the design: pumping through the filters, backwashing, chemical dosing for coagulation or cleaning, air scouring. The corresponding OPEX items will be the power consumption of the pumps and blowers and the cost of the chemicals used for either coagulation or cleaning.

Chemical disinfection is typically performed by chlorine or chlorine derivatives, ozone or hydrogen peroxide. The associate OPEX items are the cost of the chemicals or the electricity cost of production of the oxidant. For example, disinfection with ozone could use an ozone generator from oxygen produced by a pressure swing adsorption system, in which case the electricity consumption of both units shall be included in the disinfection cost.

Alternatively, UV irradiation is selected as part of the design, in which case the power consumption is the main OPEX item.

e) Advanced treatment (sometimes referred to as quaternary treatment) is all downstream treatment processes following tertiary treatment and typically involves RO and/or AOP.

RO is originally a membrane filtration process to separate dissolved salts, but also removes viruses, bacteria and micropollutants. Its main OPEX items are the electricity for high-pressure pumping, constant dosing and periodical cleaning chemicals, membranes and other replacement parts.

AOP is currently based on enhancement of an oxidation process, such as ozonation combined with UV. OPEX items for AOP processes depend on the processes selected in design, and can be chemicals and/or power consumption, as well as replacement parts.

f) Sludge management, including sludge treatment and disposal, refers to all processes and activities carried out to handle and dispose of generated primary and/or secondary sludge. It can include stabilization and dewatering or just hauling off-site for treatment elsewhere, according to design.

Sludge processing is typically associated with a cost and is targeted at reducing the volume of remaining sludge to be disposed of at a higher cost. For example, a sludge management plan could comprise accumulation and occasional disposal by hauling off-site at a high cost or it could comprise thickening, stabilization and dewatering to a smaller volume with little additional processing requirements.

Sludge treatment is usually a multistage process, generally including thickening, stabilization and dewatering:

— Thickening can be by gravity or by mechanical thickeners.

— Stabilization can be by aerobic, anaerobic or chemical processes. Aerobic sludge digestion has a major OPEX item in power consumption for aeration, whereas anaerobic digestion typically has