DRAFT INTERNATIONAL STANDARD
ISO/DIS 24575

ISO/TC **282**/SC **2** Secretariat: **SAC**

Voting begins on: **2022-04-26** Voting terminates on: **2022-07-19**

Guidelines for cost analysis in planning of decentralized wastewater treatment and/or reuse

ICS: 13.060.01

Reference number
ISO/DIS 24575:2022(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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*.

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 treatments is significant, up to 80% 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 the 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 investment cost and operating cost in some cases, compared to conventional planning of centralized wastewater treatment and reuse system. Another benefit of decentralized treatment is enabling local reuse, mainly for irrigation[3],[4].

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

— Collection and pumping systems construction costs;

— Collection and pumping systems O&M costs;

— Pumping energy;

— Local reuse for agriculture or industry or landscape irrigation.

However, potential drawbacks might be:

— Higher specific cost of each plant compared to a centralized wastewater treatment and reuse system.

— Higher operator attention required for many plants compared to one plant.

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

Guidelines for cost analysis in planning of decentralized wastewater treatment and/or reuse

1 Scope

This document provides the general principles for, and provides guidance on, the quantitative characterization of life cycle cost of a complete wastewater management system, including collection, treatment and optionally reuse, in order to enable the consideration of different degrees of distribution. Non-sewered systems for one or more dwellings are also within the scope of this document, including any associated trucking operations.

The methodology provided in this document is applicable to any of urban and rural areas wherein several decentralized wastewater treatment and reuse systems might provide a lower cost solution than a single centralized plant. Similarly, the same methodology may be applied for industrial reuse systems, where several separate plants in a large industrial site may 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. These will include:

   — investment costs such as which part of the piping of the collection system must be included and which part may be excluded, pumping stations, wastewater treatment plants construction, reuse infrastructure and facilities;

   — operational costs such as electricity, labour, maintenance, sludge handling; water analysis etc.)

c) Guidance on the required steps for the calculation of life cycle cost indicators, including considerations of term and interest; operation and maintenance; replacement parts; life expectancy of equipment; and the value of water for reuse;

d) Definition of the metrics for reporting on the 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 the wastewater treatment process selection and design;

— health and sustainability considerations;

— the social impact factors and/or the environmental risks and impacts (See note 2).

NOTE 1 Compliance reliability of all systems is advised in view of factors such as the intended use and level of development.

NOTE 2 Engineering and planning professionals are reminded they should make health and sustainability considerations a primary factor in their proposals and decisions.

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 20670:2018, *Water reuse — Vocabulary*

ISO 24513:2019, *Service activities relating to drinking water supply, wastewater and stormwater systems — Vocabulary*

IEC 60300-3-3:2017, *Dependability management – Part 3-3: Application guide – Life cycle costing*

3 Terms, definitions and abbreviated terms

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

ISO and IEC maintain terminological 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 Terms and definitions

3.1.1
distributed systems
distributed systems are in different geographical locations, but are 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)[5].

3.1.2
degree of distribution
number of treatment plants to treat a certain population. A high degree of distribution is many plants to treat that population, and a low degree of distribution is a low 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: See ISO 30500:2018, 3.1.1.1[6].

Note 2 to entry: NSS also referred to as "onsite treatment systems", defined in ISO 24513:2019.

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

3.1.5
TNPV
Total Net Present Value
sum of the present value of all OPEX items and the total investment cost (CI)

3.2 Abbreviated Terms

AOP	advanced oxidation processes
CAPEX	capital expenses
OPEX	operating expenses
CPU	Cost per unit
CI	investment cost
CO	operating cost
CM	maintenance cost
CN	negative cost
IFAS	Integrated Fixed-film Activated Sludge
MBBR	moving bed bio reactor
MBR	membrane bio reactor
MABR	membrane aerated biofilm reactor
NPV	Net present value
PE	Population Equivalent
RO	reverse osmosis
SBR	sequencing batch reactor
TAC	total annual cost
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 (ISO 20670), is that distributed systems are 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, meaning the number of treatment units for a certain population, might be as high as one system for each household (onsite 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 for every street, or one system for every cluster of households or for each drainage basin. The collection of wastewater can be a piped network (a sewer system) or motorized vehicles such as vacuum trucks in non-sewered systems. The challenge in selecting a plan for wastewater treatment and reuse can sometimes be determining the required number of systems. In some cases, the means to meet this challenge can be through an economic estimation of the long-term cost.

A single large plant is likely to benefit from the economy of scale of its equipment and from lower operation and maintenance costs (CM) of a single site in comparison to a distributed system made up of multiple decentralized systems. However, distributed systems offset much of this benefit through lower CAPEX on piping and pumping as well as lower OPEX on pumping energy, on both wastewater and water for reuse. So 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 [7]. The results show that for the lowest population density, as 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 depended upon the terrain: centralized yielded lower cost in flat terrain and decentralized yielded a lower cost in mountainous terrain.

An example of two different degrees of distribution for a specific case are shown in Figure 1. The distributed scenario shown in the top part of Figure 1 shows nine decentralized wastewater treatment and reuse systems (white triangles with dark frame on the top map) and just one pumping station, all managed by one utility. In the centralized scenario on the bottom part of Figure 1, these are replaced by one wastewater treatment plant (single dark triangle at the bottom part of the bottom map), six pumping stations (bright rectangles connected to dashed lines on the bottom map) 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 case, the sludge generated in these facilities is collected and brought to centralized wastewater treatment plants for treatment.

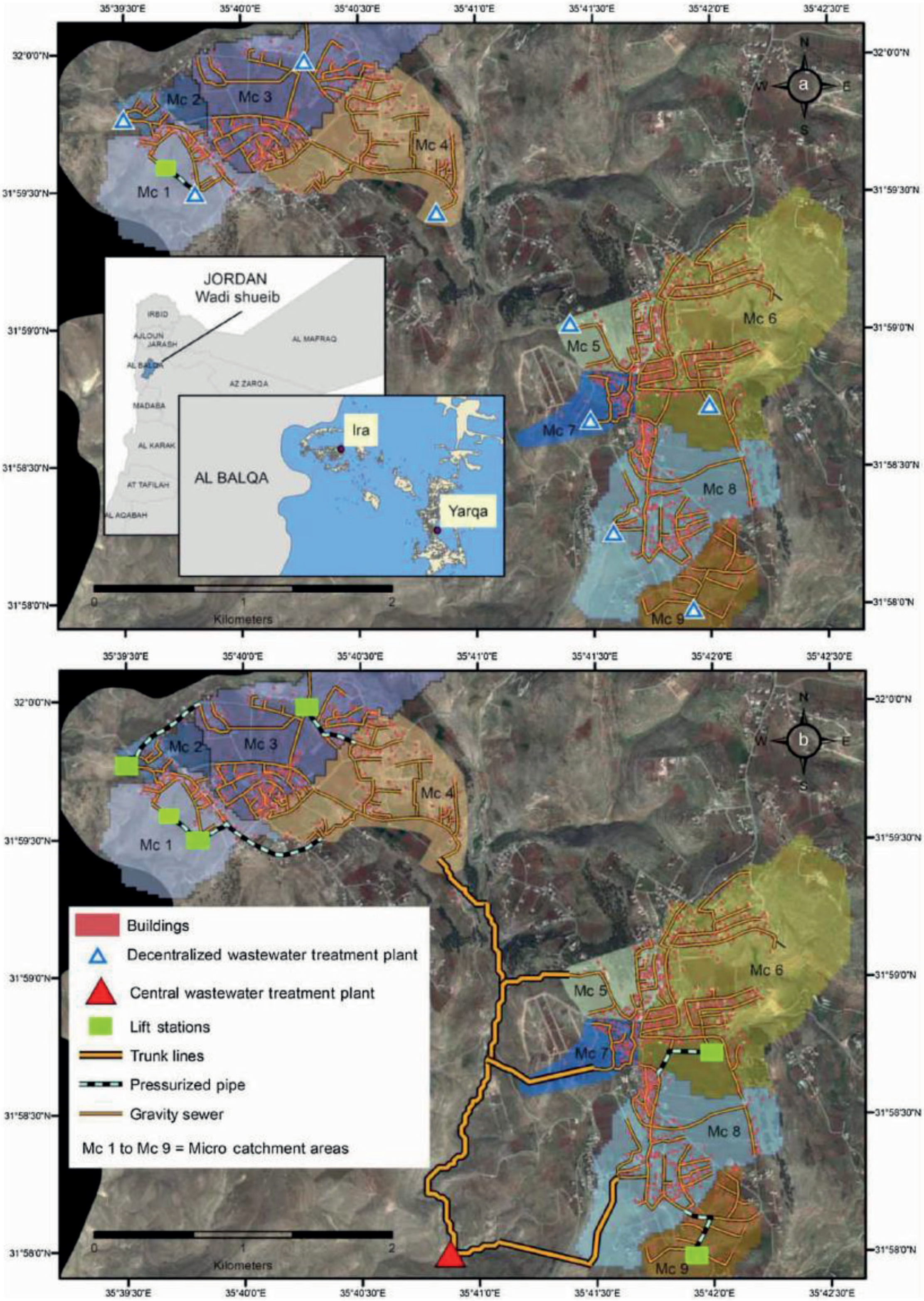

Figure 1 — Distributed (top) and central (bottom) wastewater treatment scenarios[8]

5 Generalized elements of wastewater treatment and reuse systems

5.1 General

In the planning of wastewater management systems, for reuse or another purpose, there are several tiers or subsystems to be designed, as listed in the following sections 5.2 to 5.5. These elements of the system should be included in comparison of design alternatives related to the degree of distribution of the entire system. Each element of the list below is accompanied with a brief explanation on its nature and scope.

5.2 Collection

The collection system is roughly divided into stages from the source towards its final destination as shown in Figure 2. For the purpose of this document the following notation will be followed (based on EPA notation[10]):

a) lateral sewer,

b) branch sewer,

c) trunk sewer (main sewer),

d) intercepting sewer,

e) pressure main.

Systems might have all or part of these collection system components for different degrees of distribution. For example: an onsite treatment system will usually only have lateral sewer collecting from the dwelling to the treatment system.

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

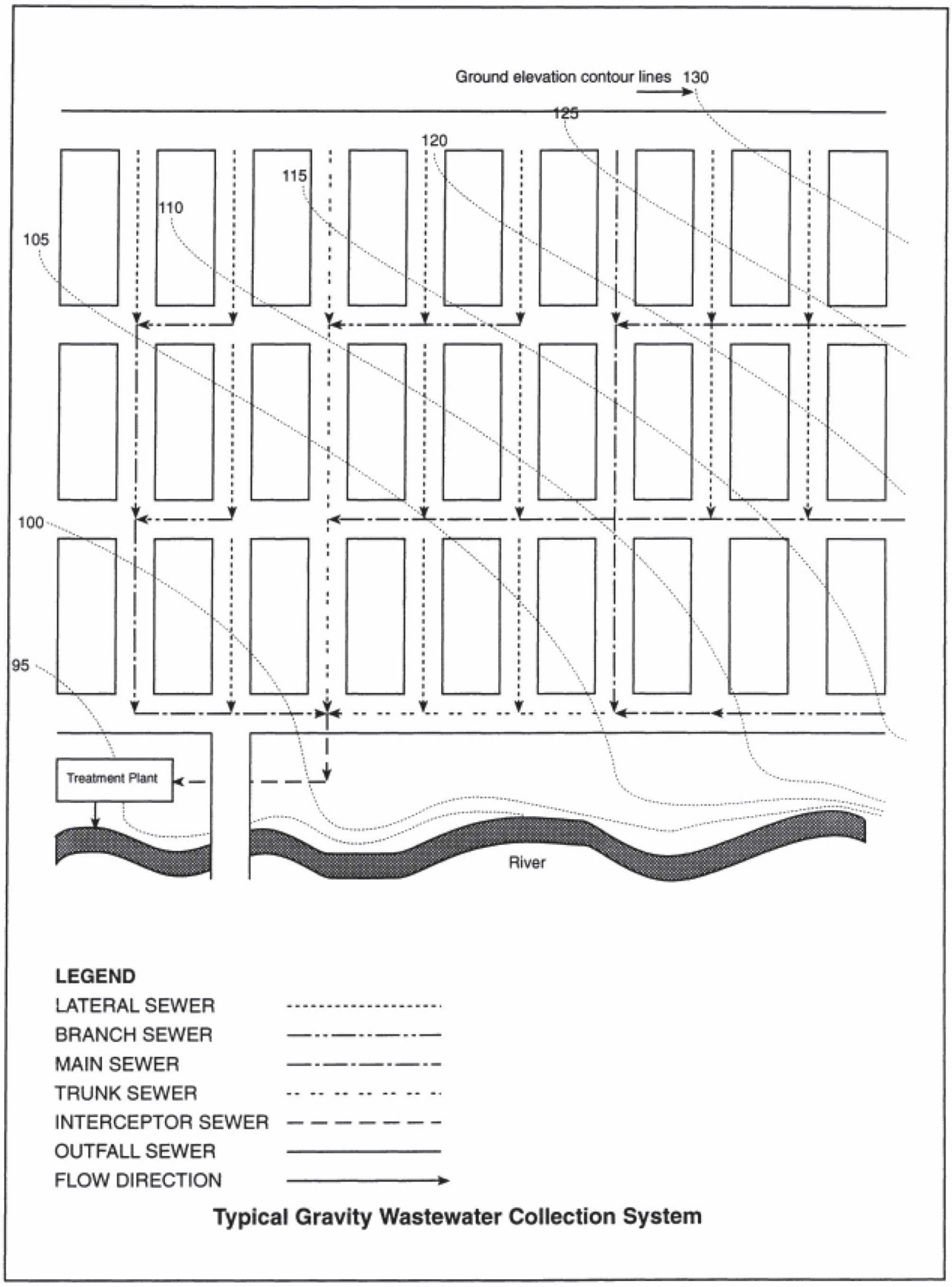

Figure 2 — Sewer line classification diagram[11]

5.3 Conveyance

Pumping stations and lift stations are used when the terrain requires pumping the wastewater in order to convey it until it can run by gravity to the wastewater treatment plant. Different designs are common for a sewage pumping or lift station. The pumping station typically consists of the main components listed below[12].

The typical main components included in the planning of each pumping station are:

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 optionally means for odor control.

Vacuum collection systems are a more recent alternative to gravity collection systems where 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[13,14]:

a) Vacuum valve pit – sewage collection from individual households or homes by gravity. Once the pit is full a valve is opened and atmospheric air force the wastewater to the vacuum branches.

b) Vacuum mains – a network of vacuum piping collecting sewage form 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.

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

5.4 Treatment

The treatment plant is also referred to as a Water Resource Recovery Facility (WRRF). It 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(15) described below and summarized in Table C.1.

a) Pre-treatment: physical processes to remove elements that might 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 pretreatment shall include any aeration, mixing, chemicals, sludge treatment and disposal, whether constant or periodic or occasional over the costing period. The pre-treatment process contains some or all the following main units:

   — Screening: removal of large particulate matter and objects that can usually be disposed as trash. There are manual or mechanical screens, and the screens openings might be coarse or fine. Many times, screening is 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 solid/liquid separation 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, or a biofilm process or a combination of both, such as MBBR, IFAS, MABR, trickling filters. The process may be an intensive process as any of the examples mentioned above or an extensive process such as constructed wetlands including tidal, aeration ponds or a lagoon system. OPEX items of secondary treatment include the following:

— 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 may be performed, mainly to reduce suspended solids, turbidity, phosphorus and microorganisms or pathogens.

The filtration might 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 cost of the chemicals used for either coagulation or cleaning.

Chemical disinfection is typically performed by chlorine or chlorine derivatives, ozone, hydrogen peroxide or other. The associate OPEX items are the cost of the chemicals or the electricity cost of production of the oxidant. For example: disinfection with ozone might 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 may be 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 following tertiary, typically involves Reverse Osmosis (RO) and/or Advanced Oxidation Processes (AOP).

RO is originally a membrane filtration process to separate dissolved salts, but also removes viruses, bacteria and micro-pollutants. Its main OPEX items are the electricity for high pressure pumping (considering energy recovery systems), constant dosing and periodical cleaning chemicals, membranes and other more frequent replacement parts.

AOP is currently based on enhancement of an oxidation process, such as ozonation combined with UV. The related OPEX items are specific to the processes selected in design, and could be chemicals and/or power consumption, as well as replacement parts.

f) Sludge management including sludge treatment and disposal:

Sludge management refers to all processes and activities to carried out to handle and dispose of generated primary and/or secondary sludges. It might include stabilization and dewatering or just hauling off site for treatment elsewhere, according to design. The typical alternatives and notes regarding the related cost items is discussed hereinunder.

It is assumed that sludge processing is associated with a cost in order to reduce the disposal cost of voluminous unprocessed sludge, which requires much processing elsewhere. For example, on one hand a sludge management plan might comprise accumulation and occasional disposal by hauling off site at a high cost, and on the other it might comprise thickening, stabilization and dewatering to a smaller volume with little additional processing requirements.

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

— Thickening might be by gravity or by mechanical thickeners.

— Stabilization might be by aerobic or anaerobic or chemical processes. Aerobic sludge digestion would have a major OPEX item in power consumption for aeration, whereas anaerobic digestion would typically have a higher OPEX item in labour and maintenance (replacement parts). Anaerobic digestion might have a negative OPEX item through sales of biogas or electricity or steam.

  Chemical stabilization uses mixing of thickened sludge with a chemical such as lime, usually with another inert powder, both of which are usually OPEX items.

— Dewatering may be carried out using different types of heavy electromechanical equipment such as a centrifuge, a belt press, a multi-disc screw or other. Dewatering usually requires a combination of electrolytes and polymers for coagulation and flocculation. Thus, the OPEX items of dewatering shall include power consumption and chemicals. In addition, it is advised that the high operator attention and maintenance (wear and tear) of this stage of the treatment relative to other parts of the wastewater treatment will be accounted for in the OPEX.

  Typically, a centrate stream, which is the filtrate from sludge dewatering, is generated from dewatering. All costs for treatment of the centrate stream (sidestream) shall be included in cost of the dewatering. For example, chemicals dosing for phosphorous or struvite removal, or a biological treatment process such as anammox or other.

— Dewatered stabilized sludge may be disposed of or treated to comply with higher requirements by means such as heating, composting or other processes. As a result, the disposal costs might be lower or even become negative (become an income). The cost of energy and chemicals to obtain this higher sludge quality (known in some places as “Class A” sludge) shall be included in the OPEX the plan. In addition, the projected cost of disposal or income from selling the sludge shall be included in accordance with chapter 6.

NOTE 1 The replacement such as UV lamps, membranes, pumps components are mentioned in chapter 6.

NOTE 2 Generally, it is required that different plans for different degrees of distributions will be estimated on the same basis. However, in some cases it will be known that the effluent quality requirements for small wastewater treatment and reuse systems are different than the requirements from a large central plant. In such a case each design may be made to the real requirement using the appropriate process or technology. For example: in some places small wastewater treatment and reuse systems might not be required to perform tertiary treatment for reuse in irrigation of tree grown crops, whereas a large plant would be required to perform tertiary treatment in any case; in such a case the cost of tertiary treatment does not have to be included where it is not needed.

NOTE 3 All components of the system have maintenance costs associated with them.

NOTE 4 See summary table of treatment process units along with their associated cost items in Table C.1.

5.5 Effluent reuse management

Reuse might involve any of transportation and storage of the treated water. This includes an operational volume, pumping stations, effluent piping (“purple” pipes) and water reservoirs such as seasonal reservoirs.

All elements of the water reuse systems within the scope of the plan will be considered for their cost, including energy consumption for pumping, chemical dosing and/or aeration in the reservoir.

6 Cost items to be considered in economic life cycle analysis calculations

Each of the components of the water network should be accounted for both their operating and maintenance cost (OPEX) and for the investment or capital costs (CAPEX).

6.1 Investment cost or CAPEX items (CI)

Primarily, the basis for the investment cost estimation of each item should be the same for every degree of distribution. For example, prices of certain items (such as pipes) are taken from price tables for all plans being compared. Alternatively, the same pricing key, such as a price per unit, is applied in all plans for a certain item, for example – in pipes it could be price per unit length and per unit diameter ($/m/mm).

The Total Investment Cost (CI): the CI is the sum of the costs of the components or items included in the plan for each degree of distribution. Each component or item of the plan listed below is noted as $C_{I,i}$, as shown in Formula (1):

$$CI = \sum_i C_{I,i} \tag{1}$$

a) Sewer collection piping – $C_{I,A}$

A complete and real cost of a plan should include all levels of the collection piping, starting with lateral sewers from the sources or household, gradually converging into larger and fewer collectors that eventually direct the sewage to treatment plants.

For the purpose of comparison between two or more plans, the common part of the sewer system may be eliminated. For example, if the two alternatives of Figure 1 are compared, the cost comparison may include only piping starting from the locations of the distributed plants, up to which both systems are identical; or in other words: the piping cost for comparison may exclude the common sections of the two plans.

The total installed cost of the collection piping should be taken for $C_{I,A}$. If no piping is installed, such as in the case of non-sewered systems or onsite treatment system, the total installed cost of the collection piping will be zero.

b) Pumping stations – $C_{I,B}$

The cost of pumping stations shall include all related civil and infrastructure such as concrete construction works, fence and electricity connection (installed cost). The cost may be obtained through specific pricing or through published correlations or even proprietary correlations. However, the same methodology should be applied to all plans being compared. For the sake of clarity: if there are no pumping stations, such as in the case of decentralized or onsite treatment system, the cost of pumping stations shall be zero.

c) The treatment plant – $C_{I,C}$

The cost of the complete treatment plant requires some level of process design in order to define the type of process and its main units. For the purpose of cost comparisons, the costs of different plant sizes may be estimated in any of the following methodologies (as long as all degrees of distribution follow the same methodology):

— offers or price lists from contractors or suppliers (usually will require some level of equipment sizing),

— scale up rules based on known prices for a similar scope, such as capacity-ratio exponents[21],

— published or proprietary correlations such as shown in example in Annex B, for which more detail can be found at the referenced source. However, The use of any published or proprietary correlations should be exercised at the discretion of a professional with understanding of their applicability to the case.

The effluent quality requirements and the intended reuse application can be different for small local plants and large centralized plant. These conditions may be considered in the design of the treatment systems for each case, so a different process and technology may be chosen for different degrees of distribution.

In some cases, landscaping or other development work is required from a local small plant located close to the source. The cost of this mandatory requirement, which may be different between local, small systems and remote larger systems, should be included as part of $C_{I,C}$.

d) Effluent distribution piping ($C_{I,D}$)

Treated water distribution might be different for different degrees of distribution. The plans should specify the reuse destinations and quantify the water distribution or discharge piping.

The distribution piping pricing $C_{I,D}$ shall be for the installed cost and should follow the same principals for the different degrees of distribution being compared, preferably based on the same sources.

In case that the treated water distribution is not part of the plan due to ownership or scope by others, it may be excluded from pricing.

e) Effluent pumping stations ($C_{I,E}$)

The cost of pumping stations shall include all related civil and infrastructure such as concrete construction works, fence and electricity connection (installed cost).

The cost may be obtained through detailed itemized pricing or through published or proprietary correlations. In any case, the same pricing methodology should be applied to all degrees of distribution being compared.

NOTE If effluent pumping is not within the scope of the plan, it does not have to be included in the cost.

f) Treated Water Reservoirs ($C_{I,F}$)

If treated water reservoirs are within the scope of the plan, their cost shall be included as part of the total CAPEX. Sizing of the reservoirs should match the reuse purpose and destination, which does not have to be the same for different degrees of distribution. Land cost consideration may be taken into account, preferably representing a real expense and not the potential value.

The basis for pricing may be according to detailed itemized costs or based on published or proprietary correlations.

6.2 Operating cost items (CO)

Operating cost correlations might be available such as in Table B.1, which generally include all of the cost items listed below in one equation. Such correlations may be used, as long as they are applied to all compared plans of different degrees of distribution. These correlations calculate CO directly.

If a correlation for CO is not applicable or available, each of the cost items $C_{O,i}$ should be accounted for as listed below, and the total operating cost is obtained by Formula (2) as follows:

$$CO = \sum_i C_{O,i} \tag{2}$$

NOTE The operating costs (CO) are expressed and directly related to unit treated (such as $/m^3), and the expenses are distributed over time, as opposed to the investment costs which are a singular event expressed per unit capacity (such as $/(m^3/d)). Guidelines for amortization of distributed expenses to present value for expression in the same terms of a singular expense, and vice versa, are provided in 7.

a) Electricity ($C_{O,A}$)

Power consumption for sewage pumping is typically estimated according to distance and elevation (head or discharge pressure) for each branch of pressure sewer.

Wastewater treatment plant energy consumption may be estimated according to published[(15)] or proprietary values for each type of process, in terms of kWh/m^3. The processes selected may vary between different plans but the methodology to attribute an energy consumption and the cost per unit energy should be the same for all plans being compared.

Distribution of water for reuse, if within the scope of the plans being compared, may be estimated according to distance and elevation (head or discharge pressure) for each branch of effluent distribution.

Calculation of the annual energy cost should typically follow the steps listed below:

— the total power consumption of a plan should be obtained in units of power, such as kW,

— a price for electricity should be assigned in terms of currency per unit energy, such as $/kWh,

— the power consumption should be multiplied by the price to obtain cost per unit time (like cash flow) such as $/h,

— the cash flow should be converted to the time scale of the amortization, such as $ per year by multiplying the cost per time (such as $/h) by time per year (such as 8700 h/y).

b) Labour – ($C_{O,B}$)

The cost of labour shall be included in the operating cost. Typically, labour is required for: sampling, analysis, measurements, data collection and documentation, reporting, changing process conditions, housekeeping and other.

NOTE Different degrees of operation and different plans typically require different levels of operator skills and attention. These might be reflected in different hourly cost and different number of hours per month for different plans. The operation of pumping stations is included in the labour cost of the plan.

Calculation of the annual cost of labour should typically follow the steps listed below:

— estimated or budgeted hours per week or per month for each of operator and technician, and calculate the hours per year,

— assign an hourly rate for each worker category or an average hourly rate for all workers categories,

— multiply the hours per year by the hourly rate to obtain the annual labour cost.

c) Chemicals ($C_{O,C}$)

The cost of all chemicals used in all operation of the entire plan are included in the operating costs. Chemicals are mostly used in the treatment plant for flocculation and coagulation, phosphorous removal, disinfection, cleaning of membranes and filters. In ponds and lagoons chemicals are sometimes used for algae control.

The calculation relating specifically to chemicals cost shall follow the steps listed below:

— estimate the annual quantity of each chemical (such as kg per year) Q_i,

— obtain the cost (price) of each chemical (such as $ per kg) c_i,

multiply the quantity by the cost to obtain the annual expense for each chemical (such as $ per year per chemical) as shown in Formula (3):

$$C_i \frac{\$}{y} = c_i \frac{\$}{kg} \cdot Q_i \frac{kg}{y} \tag{3}$$

— sum the expenses to obtain an annual chemicals cost (such as $ per year) as shown in Formula (4):

$$C_{O,C} = \sum_i C_i \tag{4}$$

NOTE Sacrificial electrodes of electrocoagulation systems can be accounted for as a chemical which is consumed continuously, and purchased periodically similarly to a batch of chemicals, in which case the cost of the electrodes will be included in $C_{O,C}$. Alternatively, the cost of the sacrificial electrodes may be considered a replacement part and included in maintenance cost.

d) Sludge disposal ($C_{O,D}$)

Any sludge and trash disposed at a cost shall be included in the operating cost under $C_{O,D}$. Sludge is typically produced in the course of water and wastewater treatment processes. The sludge can be treated to different levels to comply with a category or requirement and to reduce its quantity, all of which influence the disposal price in many places. The sludge treatment costs are included in the different cost items together with the rest of the plan, while $C_{O,D}$ only relates to the cost of the disposal, also referred to as “tipping fee”.

e) Services ($C_{O,E}$)

Regular service not included in labour or other operating cost items, are commonly provided as part of operation, such as water sampling and analysis, trash disposal, cleaning, safety inspections, consulting, software licenses. Any such budgeted expenses shall be included in $C_{O,E}$.

f) Others ($C_{O,F}$)

Generally insurance, legal and accounting cost should not be included in the OPEX (reference to be provided at a later version). However, the inclusion may be decided by the planner, although the cost of these items shall be based on the same principles for all plans.

Additional recurring costs that are budgeted within the scope of the plans and do not belong to any of the above categories ($C_{O,A}$ to $C_{O,E}$) should be included in $C_{O,F}$.

NOTE In many cases landscaping is required for decentralized systems that are located within or near residential or commercial areas. The cost of such landscaping activities are also included in $C_{O,F}$.

6.3 Maintenance cost items (CM)

Maintenance cost (CM) estimation is characterized by higher uncertainty than capital (investment) cost and operating cost, because it includes unexpected equipment failure at unexpected timing. However, long term experience with the processes involved in wastewater management for reuse enable an acceptable level of confidence. A contingency component should be included in the maintenance cost, although the same basis for contingency should be taken for all the plans of different degrees of distribution being compared.

Maintenance costs should include the following:

a) replacement or repair of equipment (mechanical, electrical, electronic) such as pumps, blowers and measuring instruments.

b) consider the cost of civil works repairs,

c) spare parts kept in stock,

d) internal personnel costs, material expenses and external services. Statutory periodic inspection costs as applicable.

Correlations for combined operation and maintenance (CO+CM) as shown in Table B.1 may be used for any of the components of the network.

Maintenance cost as a percent of equipment cost may be used, for any of the plan components. For any component this cost estimation methodology is chosen, it should be applied to that component in all plans of all degrees of distribution compared.

The most accurate methodology for maintenance cost estimation is detailed pricing based on component replacement plan and allowance for contingencies. If such information is not in hand initial calculation for maintenance costs may be derived by factoring on the investment costs such as in the following example[16]:

— civil Construction 0,5 % to 2,0 % of investment costs per year,

— renovations of Civil Construction 2,0 % to 4,0 % of investment costs per year,

— mechanical Equipment 2,0 % to 6,0 % of investment costs per year,

— electrical and Electronical Equipment 2,0% to 6,0 % of investment costs per year.

6.4 Income or revenue – Negative Cost Items (CN)

Reuse is associated with resource recovery wherein water is one of the resources recovered, but other resources such as energy or chemicals are also produced in some cases. In any case that recovered resources are planned to be sold, the outcomes should be included as an income to the net life cycle cost. The importance of accounting for this is that a plan for resource recovery facilities might be economically feasible in view of the life cycle net cost.

a) Income from selling treated water for reuse (I_W)

The income from selling treated water is calculated similarly to the costs as detailed above in section 6.2:

— estimate the annual quantity of water sold for reuse (Qw),

— estimate the sell price of water per unit volume (Pw),

— multiply the price per unit volume by volume per year to obtain annual revenue from water as shown in Formula (5):

$$I_W\left(\frac{\$}{y}\right)=P_W\left(\frac{\$}{m3}\right)\cdot Q_W\left(\frac{m3}{y}\right) \qquad (5)$$

b) Income from biogas and its products (I_G)

The income from selling biogas or electricity or heat generated from the biogas should be calculated as follows:

— estimate the annual quantity of biogas produced (Q_G),

— estimate the annual quantity of the resource produced from biogas (Q_R),

calculate the conversion factor *f* of biogas to the resource planned to be sold as shown in Formula (6):

$$f=\frac{Q_R}{Q_G} \qquad (6)$$

— estimate the sell price of the resource per unit (P_G), wherein the unit may be electricity energy units or heat energy units or biogas volume or treated biogas volume or other,

multiply the price per unit of the resource that will be sold, by the quantity of gas per year and by the factor *f* to obtain annual revenue from the biogas, as shown in Formula (7):

$$I_G\left(\frac{\$}{y}\right)=P_G\left(\frac{\$}{unit}\right)\cdot f\cdot Q_G\left(\frac{m3}{y}\right) \qquad (7)$$

c) Income from selling recovered products (I_S)

The annual income from selling stabilized sludge or other recovered nutrients such as ammonia or phosphorous or struvite or other, should be calculated as follows:

— estimate the annual quantity of each recovered product ($Q_{S,I}$),

— estimate the sell price of each of the recovered products per unit ($P_{S,I}$),

— multiply the price per unit of each of the recovered products that will be sold, by its annual,

— quantity to obtain the annual revenue from that product is calculated as shown in Formula (8):

$$I_{S,i}\left(\frac{\$}{y}\right)=P_{s,i}\left(\frac{\$}{ton}\right)\cdot Q_{S,i}\left(\frac{ton}{y}\right) \tag{8}$$

— Sum up the revenues from all the products to obtain the total income from recovered products (IS) as shown in Formula (9):

$$I_S=\sum_i I_{S,i} \tag{9}$$

— Further amortization and/or normalization is discussed in chapter 7.

d) Other income (I_O)

Any planned recurring incomes other than detailed in sections a, b and c above, should be accounted for as other income. A common example is acceptance of wastes from sources such as dairy farms or other food and beverage plants, that pay per each batch delivered to the wastewater treatment plant. The calculation should follow the general guidelines below:

— estimate the annual quantity of each source of income ($Q_{O,I}$),

— estimate the price per unit of each of the sources of income ($P_{O,I}$),

— multiply the price per unit of each of the sources of income by its annual quantity to obtain its annual revenue as shown in Formula (10):

$$I_{O,i}\left(\frac{\$}{y}\right)=P_{O,i}\left(\frac{\$}{ton}\right)\cdot Q_{O,i}\left(\frac{ton}{y}\right) \tag{10}$$

— Sum up all the revenues categorized as “other” to obtain the total income from other sources (I_O) as shown in Formula (11).

$$I_O=\sum_i I_{O,i} \tag{11}$$

7 Cost calculations, factoring and results integration

6.1 provides definitions and guidance on calculation of the total investment cost (CAPEX) while 6.2, 6.3 and 6.4 provide the same for all of the annual operating and maintenance costs as well as any recurring income. All of these values are eventually combined into a single result in this part of the document. A calculation example of the steps described hereinbelow is brought in Table A.1.

Two different ways to express the total plan cost are available to select according to relevance:

a) Net present value (NPV), based on the sum of the investment and amortization of net cost over the plan time period. The NPV is expressed in terms of currency such as $.

b) Price per unit, based on the total net annual operating cost combined with the annual amortized value of the investment, divided by the number of units per year. The result is expressed in term of cost per unit such as $/m^3 or $/PE.

7.1 Conversion of all costs to present value

The steps listed below shall be followed for the calculation of the net present value of each plan:

Express all recurring expenses (costs) and incomes (revenues) on an annual basis (per year).

a) Sum up all annual recurrences costs and revenues CO + CM + CN to obtain the net annual OPEX (CA).

b) To amortize the cash flow over the plan time period with a constant interest, apply a spreadsheet function such as "present value" (PV function in Microsoft Excel) or by using the following equivalent Formula (12)[17]:

$$CAPV = CA \cdot \left(\frac{1-(1+r)^{-n}}{r} \right) \tag{12}$$

where

CAPV is the present value of the cash flow;

CA is the Payment per year or net annual cost, equal to CO+CM+CN;

r the interest per year;

n number of years (term or time period of the plan).

c) Sum up the present value of all the OPEX (CAPV) with the total investment cost (CI) to obtain the total present value of the plan, as shown in Formula (13):

$$TNPV\,(\$) = CAPV\,(\$) + CI\,(\$) \tag{13}$$

NOTE Notations for currency are in $ but any currency may be used as long as it is consistent throughout the calculations.

These steps should be followed for every plan (every degree of distribution) in the comparison, with the same interest and over the same term (time period).

7.2 Normalization of all costs per unit

The steps listed below should be followed for the calculation of the total cost per unit:

a) select an amortization term (time period) and the interest to apply to the investment cost (CI) in order to obtain its annual value,

b) apply to the total investment cost (CI) a worksheet payment calculation function (such as PMT function in Microsoft Excel), or use the following equivalent Formula (14)[17]:

$$CIA = CI \cdot \left(\frac{r}{1-(1+r)^{-n}} \right) \tag{14}$$

where

CIA is the amortized annual value of the investment cost;

CI is the investment cost calculated in section 6.1;

r the interest per year;

n number of years (term or time period of the plan).

c) sum up the annual value of the investment cost CIA with the net annual expenses CA to obtain the total annual cost (TAC),

d) calculate the number of units for normalization of the cost (NU), most commonly annual water volume treated, or alternatively population served (PE as defined in 3.2),

e) calculate the cost per unit (CPU) by dividing the total annual cost (TAC) by the normalization unit of choice (NU) as shown in Formula (15):

$$CPU\left(\frac{\$}{unit}\right)=\frac{TAC\left(\frac{\$}{y}\right)}{NU\left(\frac{units}{year}\right)} \tag{15}$$

These steps should be followed for every plan (every degree of distribution) in the comparison, with the same interest and over the same term (time period).

8 Reporting on results of economic life cycle analysis calculations

The cost calculation results in all cases depend on the choice of term (time period) and interest selected for amortization. These values might influence the relative impact of the capital expenses and operating expenses.

Results for all degrees of distribution shall be expressed in the same manner, either as present value or as cost per unit for the same term of amortization.

The reporting on depreciation period and interest used in the depreciation or amortization calculations shall be as follows:

a) TNPV ($) or CPU ($/unit),

b) n (number of years) - term or time period taken for design, costing and amortization,

c) r – the interest used for amortization.

Annex A
(informative)

Cost calculation example

The calculations correspond to the plan presented in Figure A.1 below. All costs in US$ unless noted otherwise.

Table A.1 — Example of cost calculation

Name	scenario 1	scenario 2	scenario 3	scenario 4	Calculation basis & Remarks
No. of Plants	1	4	12	2500	-
flow per plant, m^3/d	10 000	2 500	833	4	total flow divided by plants, uniformly distributed
C_{IA} - collection sys	4 967 918	1 026 691	112 878	0	basis: 25,000 $/inch/mile, excluding gravity laterals
C_{IB} - pump stations	1 125 611	521 571	0	0	proprietary correlation for pumping station cost by pump power
C_{IC} - treatment plants	5 732 257	7 315 151	9 574 923	57 299 528	published correlation for CAS (Guo et al, 2013) presented ads table 1 in WD
C_{ID} - disch. piping	225 801	195 549	84 658	0	same as sewer pipes
C_{IE} - disch. pump	383 013	0	0	0	same as sewage pumping stations
C_{IF} - reservoirs	0	0	0	0	direct discharge to the environment
CI (present value)	12 434 600	9 058 963	9 772 459	57 299 528	sum of $C_{I,i}$ above
C_{OA} - electricity	300 853	31 612	0	0	each pump power calculated, 0.12 $/kWh
C_{OB} - labor	0	0	0	0	included in CM for all piping and pumping
C_{OC} - chemicals	0	0	0	0	included in O&M
C_{OD} - sludge disposal	0	0	0	0	included in O&M
C_{OE} - services	0	0	0	0	included in O&M
C_{OF} - other	280 793	331 390	386 117	1 223 773	published correlation for MBR (Guo et al, 2013) divided by 2
CO $/y	581 646	363 002	386 117	1 223 773	sum of $C_{O,i}$ above
CM $/y	125 266	36 141	2 469	0	4% of equipmet and 1.25% of civil per year
Total present value of annual payments	8 809 693	4 974 204	4 842 645	15 250 913	rate 5% and term 20 years
TOTAL present value of scenario	21 244 292	14 033 166	14 615 104	72 550 441	
annual value of investment	997 784	726 915	784 167	4 597 862	rate 5% and term 20 years
NOTE 1 Plan Design flow m^3/d 10 000.					
NOTE 2 All costs in US$ unless noted otherwise.					

Table A.1 *(continued)*

Name	scenario 1	scenario 2	scenario 3	scenario 4	Calculation basis & Remarks
total annual expense $/y	1 704 697	1 126 058	1 172 754	5 821 635	
specific cost per m^3	0,47	0,31	0,32	1,59	total annual cost divided by annual quantity
NOTE 1 Plan Design flow m^3/d 10 000. NOTE 2 All costs in US$ unless noted otherwise.					

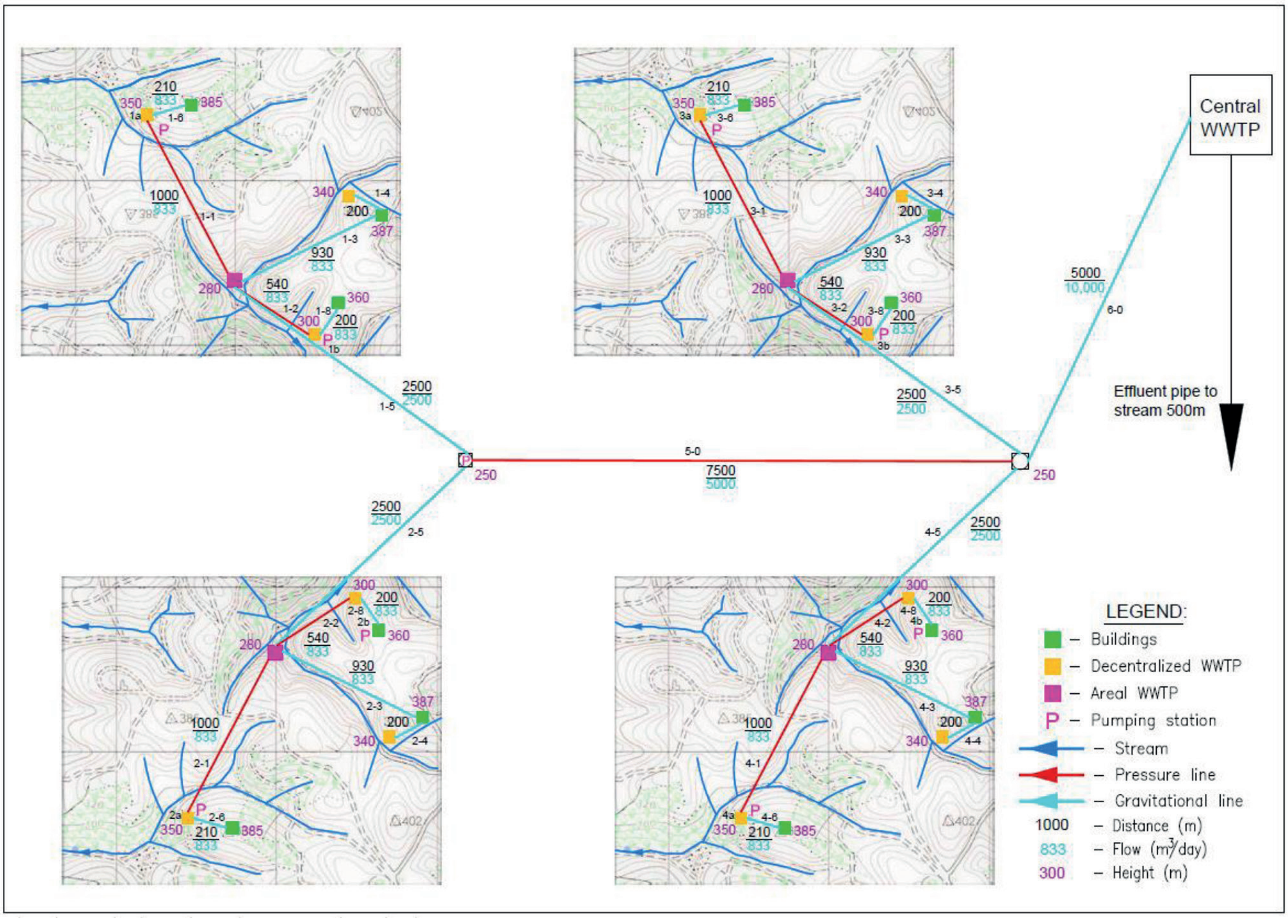

Figure A.1 — Reference plan for cost calculations

Annex B
(informative)

Correlations for CAPEX and OPEX of different process units in a treatment plant for reuse

Table B.1 — Correlations for CAPEX and OPEX of different process units in a treatment plant for reuse[16]

Water reuse technologies	Capital cost	Annual O & M
Activated sludge	$\text{Log}(y)=0{,}256 * (\log(X))^{1{,}556}+4{,}545$	-
Membrane bioreactor	$\text{Log}(y)=0.569 * (\log(X))^{1{,}135}+4{,}605$	$\text{Log}(y)=0{,}639 * (\log(X))^{1{,}143}+2{,}633$
Coagulation and flocculation	$\text{Log}(y)=0{,}222 * (\log(X))^{1{,}516}+3{,}071$	$\text{Log}(y)=0{,}347 * (\log(X))^{1{,}448}+2{,}726$
Reverse osmosis	$\text{Log}(y)=0{,}966 * (\log(X))^{0{,}929}+3{,}082$	$\text{Log}(y)=0{,}534 * (\log(X))^{1{,}253}+2{,}786$
Ultrafiltration	$\text{Log}(y)=1{,}003 * (\log(X))^{0{,}830}+3{,}832$	$\text{Log}(y)=1{,}828 * (\log(X))^{0{,}598}+1{,}876$
Peroxone (mineralization)	$\text{Log}(y)=0{,}405 * (\log(X))^{1{,}428}+4{,}528$	$\text{Log}(y)=0{,}845 * (\log(X))^{1{,}057}+2{,}606$
Granular activated carbon	$\text{Log}(y)=0{,}722 * (\log(X))^{1{,}023}+3{,}443$	$\text{Log}(y)=1{,}669 * (\log(X))^{0{,}559}+2{,}371$
y is cost in US$ and **X** is capacity in m3/d.		

Annex C
(informative)

Summary of treatment process units along with their associated cost items

Table C.1 — Summary table of treatment process units along with their associated cost items

Treatment step	Equipment	Associated O&M costs
Pre-treatment	Screen Grit chamber Grease trap Equalization tank	Electricity for mechanical equipment Disposal of waste, grit and grease Labour costs for regular cleaning
Primary treatment	Sedimentation tank, sedimentation pond, Imhoff tank Septic tank	Chemicals, Electricity Emptying costs
Secondary treatment	Suspended biomass: activated sludge, SBR, MBR Extensive processes: constructed wetlands, tidal, aeration ponds, lagoon system, stabilization pond Separation: secondary clarifier, MBR, sedimentation pond Attached biomass: MBBR, IFAS, MABR, trickling filter Anaerobic treatment: anaerobic baffled reactor, anaerobic filter, UASB, anaerobic ponds.	Electricity for aeration, pumping, mixing Chemicals Electricity for aeration, pumping Electricity, pumping Electricity Biogas treatment
Filtration and disinfection	Filtration Chemical disinfection: chlorine and derivatives, ozone, hydrogen peroxide, etc. UV irradiation	Electricity for pumping and backwashing Chemicals, Electricity, replacement parts
Advanced treatment	Reverse osmosis Advanced oxidation processes	Electricity for pumping and backwashing Chemicals, replacement parts
Sludge treatment	Thickening Sludge stabilization: anaerobic digestion, aerobic digestion, chemical conditioning Mechanical dewatering: centrifuge, band filter, press filter, multi-disc screw Side-stream (centrate) treatment Extensive dewatering : planted and unplanted drying beds, solar drying Thermal drying	Electricity for mechanical equipment Chemicals Labour costs for operation, maintenance and cleaning Energy for dryer

Bibliography

[1] Englehardt J.D., Wu T., Tchobanoglous G., Urban net-zero water treatment and mineralization: Experiments, modeling and design. Water Res. 2013, **47** (13) pp. 4680–4691

[2] Van Afferden M., Cardona J.A., Müller R.A., Lee M.Y., un A. Subah, "A new approach to implementing decentralized wastewater treatment concepts. Water Sci. Technol. 2015, **72** (11) pp. 1923–1930

[3] , T. Guo un J. D. Englehardt, "Principles for scaling of distributed direct potable water reuse systems: A modeling study. Water Res. 2015, **75** pp. 146–163

[4] T. Opher un E. Friedler, "Comparative LCA of decentralized wastewater treatment alternatives for non-potable urban reuse", J. Environ. Manage., 182, lpp. 464–476, 2016

[5] Distributed Systems Overview, Fact Sheet Series, Water Environment Federation, Water Science & Engineering Center, WSEC-2019-FS-012, (available from: https://www.wef.org/globalassets/assets-wef/3---resources/topics/a-n/distributed-systems/technical-resources/wsec-2019-fs-012-wef_wrf_distributed_sytems_overview.pdf)

[6] ISO 30500:2018, *Non-sewered sanitation systems — Prefabricated integrated treatment units — General safety and performance requirements for design and testing*

[7] Guo T., James Englehardt and Tingting Wu, Review of cost versus scale: water and wastewater treatment and reuse processes Water Science & Technology 69.2. IWA Publishing, 2014

[8] van Afferden M., Jaime A., Cardona, Mi-Yong Lee, Ali Subah and Roland A. Müller, A new approach to implementing decentralized wastewater treatment concepts. Water Sci. Technol. 2015, **72** (11)

[9] “Manual on Sewerage and Sewage Treatment Systems Part B Operation & Maintenance - 2013”, by Central Public Health & Environmental Engineering Organisation (CPHEEO) of the Ministry of Housing and Urban Affairs, Government of India (available from: http://cpheeo.gov.in/upload/uploadfiles/files/operation_chapter3.pdf).

[10] Optimizing Operation, Maintenance, and Rehabilitation of Sanitary Sewer Collection Systems, New England Interstate Water Pollution Control Commission, December 2003 (available on: https://www3.epa.gov/npdes/pubs/sso_optimizing_toc.pdf)

[11] Basic W.C.S., Minnesota Pollution Control Agency & Rick Arbor Associates, 1995 (available on https://www.pca.state.mn.us/sites/default/files/wq-wwtp8-26.pdf)

[12] Collection Systems Technology Fact Sheet Sewers, Lift Station”, EPA 832-F-00-073 September 2000

[13] Overview of a vacuum sewer system, RoeVac Vacuum Sewer System, ROEDIGER 2007 (available from: http://archive.sswm.info/category/implementation-tools/wastewater-collection/hardware/sewers/vacuum-sewers)

[14] MARIKA MÄKINEN, Operation of Vacuum Sewer System – Case Ondangwa, Namibia, Tampere University of Technology, Master of Science Thesis, May 2016 (available from: https://pdfs.semanticscholar.org/925c/4b619ffdc48744c131fb58685e72506f986d.pdf)

[15] Water and Wastewater Treatment. A Guide for the Non Engineering Professionals 1st Edition, Joanne E. Drinan and Frank Spellman, CRC press 2015

[16] Guo T., James Englehardt and Tingting Wu, Review of cost versus scale: water and wastewater treatment and reuse processes. Water Sci. Technol. 2014, **69** (2)

[17] Economic valuation of wastewater. The cost of action and the cost of no action. United nation evaluation program. 2015

[18] , Comparative Analysis of the Energy Consumption of Different Wastewater Treatment Plants (table 2), Renan Barroso Soares, Marina Santos Memelli, Regiane Pereira Roque, Ricardo Franci Gonçalves, International Journal of Architecture. Arts and Applications. 2017, **3** (6) pp. 79–86

[19] EMWATER E-LEARNING COURSE, Lesson C2 Operation Costs of wastewater Treatment Plants. Written by Arnd Wendland (also available on: https://cgi.tu-harburg.de/~awwweb/wbt/emwater/documents/lesson_c2.pdf)

[20] Baily Francis, The Doctrine of Interest and Annuities Analytically Investigated and Explained, J. Richardson, 1808; a - p. 52; b- p. 40

[21] *Perry's Handbook for Chemical Engineers*. *Chapter 9*., Seventh Edition, 1997, pp. 689

