International Standard

ISO 9111

First edition
2024-06

Water reuse in urban areas — Guidelines for benefit evaluation of reclaimed water use

Recyclage des eaux dans les zones urbaines — Lignes directrices concernant l'évaluation des avantages de l'utilisation d'eau réutilisée

Reference number
ISO 9111:2024(en)

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).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

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

Water shortages are recognized to be some of the most crucial threats to sustainable development of society. Reclaimed water is a safe, reliable and sustainable water source to help satisfy water demands, especially in many water-scarce areas. Today, reclaimed water is used in urban areas, including agricultural irrigation, ecological or environmental flow replenishment, landscape irrigation, toilet flushing, firefighting, and car washing amongst other uses. Implementation of principles of benefit evaluations can create thorough, comprehensive, systematic, and sustainable reclaimed water use. However, the intrinsic values or the benefits of reclaimed water use are not clear. There are limited guidelines or regulations currently available, specifically regarding the benefit evaluation of reclaimed water use in urban areas at a global level.

It is important to establish a systematic, scientific and holistic benefit evaluation system for reclaimed water use. Based on the different applications of reclaimed water and the varied water quality requirements linked to the intended use, it is important to evaluate the benefits of various indicators for reclaimed water use. The benefit evaluation should take into account various indicators such as the resource, ecological and environmental, social, economic and other benefits, including the reduction of global warming.

Water reuse in urban areas — Guidelines for benefit evaluation of reclaimed water use

1 Scope

This document provides guidelines to evaluate the benefits of reclaimed water for applications requiring different levels of water quality and for beneficial use in urban areas.

This document is applicable, among others, by practitioners and authorities to assist water reuse planning, design, operation and management.

This document provides evaluation indicators, procedures and examples of reclaimed water use benefits.

Design parameters and regulatory values of different reclaimed water uses as well as risk or safety evaluation of reclaimed water use are out of scope of this document.

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 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
benefit evaluation
analysis contributing to decision-making on whether to adopt a project or a plan by quantifying and comparing its benefits

3.2
ecological or environmental flow
E-flow
water flow and level that allows to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods, and well-being

3.3
avoided cost
benefits occurred as a result of avoiding unnecessary costs while meeting demand requirements and thereby avoiding the additional resources and service waste

Note 1 to entry: This concept is from least cost or integrated resource planning.

4 Abbreviated terms

COD chemical oxygen demand

CO_2-eq CO_2 equivalent

GHG greenhouse gas

IRR internal rate of return

LCC life cycle cost

LCY local currency

NCF net cash flow

NPV net present value

P phosphorous

5 General

Ensuring safety of reclaimed water is crucial to protect the environment and human health from the adverse effects of toxicants and pathogenic microorganisms. Generally, the reclaimed water safety assessment (e.g. ecological and human health risk assessment) can be conducted before implementing benefit evaluation of reclaimed water use. For detailed information on risk assessment and management, ISO 20426 and ISO 20761 can be used as references. Moreover, the supplied reclaimed water quality should also meet the requirements of local specifications and end user demands.

In principle, benefit is evaluated based on the comparison between the water reuse option and the business-as-usual or other method using alternative water resources, which are referred to as baseline. The relevant option and baseline are evaluated under the same conditions with the same indicators. The baseline can include a do-nothing scenario where no solution other than water reuse can realistically be envisioned and the baseline is to do nothing. The benefit of water reuse is expressed as the difference between the indicators for the relevant water reuse option and the baseline.

The benefit evaluation of reclaimed water use should comprehensively consider resource, ecological and environmental, social and economic benefit aspects.

The benefit evaluation of reclaimed water use includes quantitative and qualitative analyses, with corresponding indicators. The indicators should be set specifically, objectively and easily for calculation and/or comparison.

Wastewater treatment plants can be included in the boundary if necessary, as is often the case in comprehensive evaluations. The baseline scenario and the evaluation boundary including conventional wastewater treatment processes should also be determined for the benefit evaluation which is based on comparisons with the water reuse scenario.

Different water reuse projects and different utilization scenarios can be evaluated separately. Afterwards, the overall evaluation or comprehensive evaluation results can be obtained.

6 Indicators of benefit evaluation of reclaimed water use

6.1 Holistic indicator system

The indicators for benefit evaluation of reclaimed water use can be classified in four categories: resource, ecological and environmental, social and economic.

The main indicators for different benefit evaluation categories are listed in Table 1. If necessary, other indicators can be considered and incorporated for evaluation. Annex A provides examples of indicators for the evaluation of natural environment improvement by reclaimed water use in the social benefit category.

Evaluation indicators can be selected according to the evaluation needs and reclaimed water use characteristics. A comprehensive evaluation system should contain a reasonable number of indicators in terms of different aspects and avoid repetition.

Table 1 — Example of main indicators for benefit evaluation of reclaimed water use

Category	Indicators
Resource benefit	Conventional water resource savings, energy, carbon, and phosphorous resource recovery, etc.
Ecological and environmental benefit	Reduction of contaminants, electricity use, greenhouse gas (GHG) emissions, and achievement of E-flows, ecosystem protection/restoration, etc.
Social benefit	Improvement of local natural environment, improvement of regional natural environment, etc.
Economic benefit	Avoided cost, net present value (NPV), internal rate of return (IRR), etc.

6.2 Resource benefits

6.2.1 Conventional water resource savings

Reclaimed water can be an alternative water resource for many activities that do not require potable water quality. The amount of conventional water resource (i.e. surface water, rivers and lakes and groundwater that are naturally available) savings due to the substitution by reclaimed water and other water-saving activities can be calculated using Formula (1):

$$Q_t = A_1 - Q_s \tag{1}$$

where

A_1 is the amount of conventional water resource savings, expressed in m^3;

Q_t is the amount of reclaimed water use, expressed in m^3;

Q_s is the amount of water savings from water-saving activities and measures, expressed in m^3.

6.2.2 Energy resource recovery

Reclaimed water contains energy resources which can be further extracted and utilized. The amount of energy (heat or cold) resource recovery during water reclamation and reuse processes can be calculated using Formula (2):

$$\begin{aligned} A_2 &= Q_w \times \rho \times \Delta t \times C \\ A_c &= \frac{A_2 \times F}{F+1} \\ A_h &= \frac{A_2 \times H}{H-1} \end{aligned} \tag{2}$$

where

A_2 is the amount of heat or cold energy recovered during water reclamation and reuse processes, expressed in kJ;

Q_w is the amount of reclaimed water used during the process, expressed in m^3;

ρ is the density of reclaimed water, expressed in kg/m^3;

Δt is the temperature difference of extracted reclaimed water, expressed in °C;

C is the specific heat capacity of reclaimed water, 4,19 kJ/(kg·°C);

A_c is the amount of cold energy output of the reclaimed water heat pump system, expressed in kJ;

A_h is the amount of heat energy output of the reclaimed water heat pump system, expressed in kJ;

F is the performance coefficient of reclaimed water heat pump unit for cooling;

H is the performance coefficient of reclaimed water heat pump unit for heating.

6.2.3 Carbon resource recovery

Reclaimed water contains carbon resources which can be further extracted and utilized. The amount of carbon resource recovery during water reclamation and reuse processes can be calculated using Formula (3):

$$A_3 = \sum_{i=1}^{n} A_{3,i} \tag{3}$$

where

$A_{3,i}$ is the amount of carbon resource recovery during water reclamation processes (e.g. sedimentation, settling and fermentation processes) via physical separation, hydrolysis and/or fermentation approaches, expressed in kg COD;

n is the number of water reclamation processes with carbon resource extraction and recovery.

6.2.4 Phosphorous resource recovery

Reclaimed water contains phosphorous resources which can be further extracted and utilized. The amount of phosphorous resource recovery during water reclamation and reuse processes can be calculated using Formula (4):

$$A_4 = \sum_{i=1}^{n} A_{4,i} \tag{4}$$

where

$A_{4,i}$ is the amount of phosphorous resource recovery during water reclamation processes (e.g. biological treatment and anaerobic digestion processes) via the formation of struvite, hydroxyapatite, etc., expressed in kg;

n is the number of water reclamation processes with phosphorous resource extraction and recovery.

6.3 Ecological and environmental benefits

6.3.1 Reduction of contaminants

Reclaimed water use can reduce the contaminant loading that was sourced from the wastewater directly discharging into receiving water bodies. Reduction of contaminants due to the substitution of direct wastewater discharge by reclaimed water use can be calculated using Formula (5):

$$B_{1,j} = Q_t \times (C_{j,w} - C_{j,r})/1\,000 \qquad (5)$$

where

$B_{1,j}$ is the reduction in j^{th} contaminant loading, expressed in kg;

Q_t is the amount of reclaimed water use, expressed in m^3;

$C_{j,w}$ is the concentration of j^{th} contaminant of the wastewater discharge (average concentration, monthly mean or annual mean), expressed in mg/l;

$C_{j,r}$ is the concentration of j^{th} contaminant of reclaimed water (average concentration, monthly mean or annual mean), expressed in mg/l.

NOTE For other water reuse applications, other formulae or calculation methods can be applied.

6.3.2 Reduction of electricity use

Reclaimed water use can reduce the electricity use that was used to develop other alternative water resources, e.g. diverted water, desalinated water, etc. The reduction in electricity use reduction due to the substitution of other alternative water resources by reclaimed water use can be calculated using Formula (6):

$$B_2 = \sum_{i=1}^{n} Q_t \times \left(E_{i,d} - E_{i,r}\right) \qquad (6)$$

where

B_2 is the reduction in electricity use, expressed in kWh;

Q_t is the amount of reclaimed water used for each application, expressed in m^3;

$E_{i,d}$ is the amount of electricity use per cubic meter of water by other alternative water resources for each application, expressed in kWh/m^3;

$E_{i,r}$ is the amount of electricity use per cubic meter of water by reclaimed water for each application, expressed in kWh/m^3;

n is the number of different reclaimed water applications.

NOTE The value of B_2 can be negative when more electricity is used to produce reclaimed water than for other alternative water resources.

6.3.3 Reduction of greenhouse gas (GHG) emissions

Reclaimed water use can reduce GHG emissions by reducing electricity use and chemical reagent dosage without extracting extra water sources, and using biogas conserved during wastewater treatment and reuse processes. The reduction in GHG emissions can be calculated using Formula (7):

$$\begin{aligned} B_3 &= B_{3,1} + B_{3,2} + B_{3,3} \\ B_{3,1} &= B_2 \times \mathrm{f_c} \\ B_{3,2} &= C_i \times E_i + C_i \times E_t \\ B_{3,3} &= G_1 + G_2 \end{aligned} \tag{7}$$

where

- B_3 is the reduction in GHG emissions, expressed in kg CO_2-eq;
- $B_{3,1}$ is the reduction in GHG emissions due to reduced electricity use, expressed in kg CO_2-eq;
- $B_{3,2}$ is the reduction in GHG emissions due to reduced chemical reagent consumption, other consumable and wastes generated, expressed in kg CO_2-eq;
- $B_{3,3}$ is the reduction in GHG emissions due to biogas production during water reclamation and reuse processes, expressed in kg CO_2-eq;
- B_2 is the reduction in electricity use, expressed in kW·h;
- $\mathrm{f_c}$ is the conversion coefficient, expressed in kg CO_2-eq/kW·h;
- C_i is the amount of reduced chemical reagent consumption, other consumable and wastes generated due to reclaimed water use, expressed in kg chemical or other consumable and wastes;
- E_i is the carbon emission factor related to chemical reagent production, other consumable and wastes generated, expressed in kg CO_2-eq/kg chemical or other consumable and wastes;
- E_t is the carbon emission factor related to chemical reagent transmission, other consumable and wastes generated, expressed in kg CO_2-eq/kg chemical or other consumable and wastes;
- G_1 is the reduction in GHG emissions due to biogas (i.e. methane gas) collection and use during water reclamation and reuse processes, expressed in kg CO_2-eq;
- G_2 is the reduction in GHG emissions due to reduced fuel consumption as a result of biogas use, expressed in kg CO_2-eq.

GHG emissions such as CH_4 and N_2O resulting from biological treatment process can be calculated, if necessary. The calculation of detailed GHG emissions over the whole water reuse system can refer to ISO 20468-2.

Due care is suggested to be taken to prevent duplication when counting the reduction resulting from effective biogas utilization and the reduction of GHG emissions resulting from energy consumption.

6.3.4 Achievement of E-flows

Reclaimed water use can improve the ecological or environmental flow condition due to the replenishment of deficient flows. The achievement of E-flows by reclaimed water use can be calculated using Formula (8):

$$B_4 = \frac{Q_\mathrm{R}}{Q_\mathrm{D}} \tag{8}$$

where

B_4 is the degree of E-flows achievement;

Q_R is the amount of reclaimed water used for E-flows improvement, expressed in m^3;

Q_D is the amount of deficient E-flows, expressed in m^3.

6.3.5 Ecosystem protection/restoration

Reclaimed water use can facilitate ecosystem protection and restoration and promote related biodiversity by increasing species number and numbers of rare, fragile and sensitive plant, animal and microorganism communities. For detailed information regarding water-related beneficial impacts on ecosystems, ISO 14002-2 can be used as reference.

6.4 Social benefits

6.4.1 Improvement of local natural environment

The local natural environment can be improved by improving water ecological conditions through reclaimed water use. The improvement level of local natural environment can be determined by satisfaction surveys, including improvement of aesthetic pleasure, creation of landscape environments, restoration and construction of wetland ecosystems, improvement of water body recreational functions, improvement of surface water quality, recovery of ground settlements, etc. More information can be found in Table A.1.

6.4.2 Improvement of regional natural environment

The implementation of large-scale regional water reuse projects can also influence the regional natural environment, such as regional groundwater aquifer protection, local climate condition, natural amenities and biodiversity enhancement, etc.

6.5 Economic benefits

6.5.1 Avoided cost

In water utilities field, avoided cost generally refers to incremental costs associated with not having to use additional resources nor services while meeting demand requirements.

Avoided costs of reclaimed water use are generally due to the substitution of conventional water resources with reclaimed water, including savings in bills, capital investments, operating costs of energy, chemicals, and labour for water treatment, transmission and distribution. The capital and operating savings associated with reductions in wastewater collection and disposal (e.g. disposal of wastewater or treated effluent to the river, lake or sea), as well as energy charges, can also be included in avoided costs.

The total amount of avoided costs described above for each facility or item in the boundary can be obtained as the reduced costs of life cycle cost (LCC) by using reclaimed water. LCC can be calculated referring to ISO 20468-8 based on life cycle cost of treatment systems for water reuse, using Formula (9):

$$C = C_i + C_O + C_d \tag{9}$$

where

C is the avoided cost calculated as life cycle cost, expressed in LCY/year;

C_i is the capital cost, expressed in LCY;

C_O is the operating and maintenance cost, expressed in LCY/year;

C_d is the disposal cost, expressed in LCY/year.

6.5.2 Net present value (NPV)

Comparison of economic benefits and costs over a certain period to determine the project performance is important for project managers and decision makers. The net present value (NPV) is one of the commonly used indicators to assess the economic feasibility of a project. To ensure fair comparisons, all economic benefits and costs are adjusted using a discount rate. The NPV of a water reuse project can be calculated using Formula (10):

$$V=\sum_{t=1}^{T}\frac{F_t}{(1+i)^t} \tag{10}$$

$$F=B-C$$

where

V is the net present value (NPV), expressed in LCY;

F is the net cash flow (NCF) of a period, expressed in LCY;

i is the discount rate, expressed in percent (%);

t is the period in which cash flows occur;

T is the project lifespan;

B is the value of the economic benefit, expressed in LCY;

C is the value of the cost, expressed in LCY.

The value of NPV can help determine the economic viability of a water reuse project.

If the calculated NPV is positive, it suggests that the investment is profitable, and the project can be accepted, i.e. the return exceeds the predefined discount rate.

If the calculated NPV is negative, it suggests that the investment is not economically feasible, i.e. the expenses are higher or occur earlier than the returns.

A net present value of 0 indicates that the investment earns a return that equals the discount rate. In this case, the internal rate of return (IRR) can be introduced.

6.5.3 Internal rate of return (IRR)

The internal rate of return (IRR) can be used to assess the long-term economic profitability of a water reuse project. The IRR of a water reuse project can be evaluated using Formula (11):

$$\sum_{t=0}^{T}(C_I-C_O)_t(1+R)^{-t}=0 \tag{11}$$

where

R is the internal rate of return, expressed in percent (%);

C_I is the net cash inflow of a period, expressed in LCY;

C_o is the net cash outflow of a period, expressed in LCY;

t is the period in which cash flows occur;

T is the project lifespan.

If the calculated IRR is greater than the selected discount rate, the water reuse project is considered justified. Generally, for projects that last for a long time, it is recommended to use lower values of discount rate than in projects with a shorter lifespan. Furthermore, the cost analysis in planning of a decentralized wastewater treatment and/or reuse can refer to ISO 24575.

7 Procedures of benefit evaluation of reclaimed water use

7.1 Benefit evaluation flow chart

The benefit evaluation system of reclaimed water use can be performed according to the flow chart depicted in Figure 1.

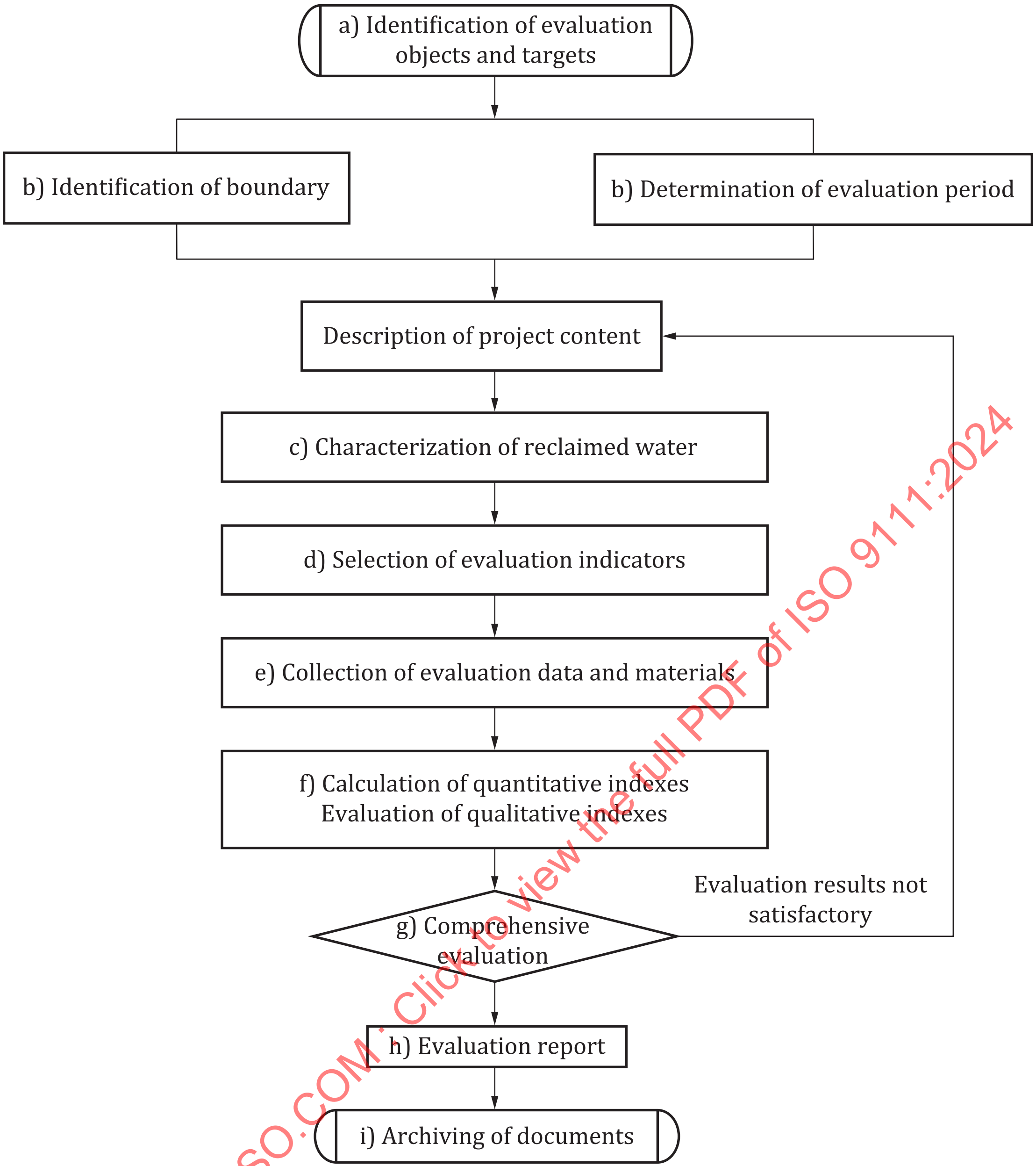

Figure 1 — Flow chart of procedures for conducting benefit evaluation of reclaimed water use

7.2 Procedures and considerations of benefit evaluation

The whole evaluation generally includes several procedures. Specifically, the first two steps of the evaluation are to identify objects and targets, and then to specify the boundary and time frame for the evaluation. The third step is to confirm the type of the project, whether it is a water reuse project or a regional water reuse system. The 4th and 5th steps are to identify whether it is a project under planning or in operation, and then to clarify the reclaimed water use quantity. The evaluation indicators should be selected by the users or practitioners. The qualitative or quantitative results should be determined or obtained via calculations. Afterwards, the evaluation report can be generated.

The following considerations should be addressed in each procedure of benefit evaluation of reclaimed water use.

a) The benefit evaluation objects and targets should be clarified at the beginning. The evaluation objects include water reuse project, and regional water reuse system. For a specific water reuse project, the reclaimed water management agencies, reclaimed water suppliers and/or reclaimed water users are mainly in charge of the evaluation. For the water reuse project in a regional area, the relevant administrative regulatory departments and/or reclaimed water management agencies are mainly responsible for the evaluation.

b) The evaluation boundary of benefit evaluation generally starts from the treated effluent of municipal wastewater treatment plants and considers the key components of water reuse systems, including reclaimed water treatment, transmission and distribution, storage and use. The evaluation boundary of a specific water reuse project normally also incorporates the end user sites. For a regional water reuse system, the source water, water reclamation plant, reclaimed water transmission and distribution pipe network, and environment buffers and storage facilities (e.g. urban water systems, environmental water bodies and wetlands) should be involved in the boundary. For detailed conditions of the boundary for evaluation, ISO 20468-2 can be used for evaluation based on GHG emissions, and ISO 20468-8 for evaluation based on LCC. The evaluation period should be calculated in multiyear basis, with the specific time period determined by the users.

c) The reclaimed water system is complicated; the benefit evaluation of reclaimed water use should consider reclaimed water users, applications, reclaimed water quality and quantity, etc.

d) Evaluation indicators should be identified according to the evaluation needs, project characteristics, regional water resources, geographical, social and economic conditions, etc. Recommended evaluation indicators are illustrated in Annex B.

e) The relevant data and material required for the evaluation can be obtained through literature review, data collection, field investigation, experimental test, questionnaire survey, etc.

f) The calculation of quantitative indicators can be performed based on different formulae. Qualitative indicators can be evaluated in a descriptive or relatively comparative manner.

g) The comprehensive benefit evaluation should include the benefits from resources, ecological improvement and environmental gains, social aesthetics, and economic savings. Various indicators can be weighted to obtain a comprehensive evaluation score. The weights can be determined by Delphi, hierarchical analysis and/or entropy method. If the evaluation results obtained from the comprehensive evaluation step are not satisfying in the light of expected outcomes by authorities or management agencies and additional information is received from suppliers, users and/or practitioners, iteration can be conducted from the description of project content step.

h) The contents of the final evaluation report generally include evaluation objects and targets, boundary, period, project content, reclaimed water use quantity, evaluation indicators, evaluation methods, evaluation results, conclusions, etc.

i) The evaluation report and relevant material should be recorded, categorized and archived.

Annex A
(informative)

Indicators for the evaluation of natural environment improvement by reclaimed water use in the social benefit category

Table A.1 summarizes several indicators for the improvement of natural environment by reclaimed water use, which falls in the social benefit category.

Table A.1 — Examples of evaluation of natural environment improvement by reclaimed water use

Aspects of the improvement of natural environment	Score				
	1	2	3	4	5
Improvement of aesthetic pleasure					
Improvement of landscape environment					
Revitalization of wetland ecological system					
Improvement of functions for recreational purposes					
Improvement of surface water quality					
Recovery of surface subsidence					
NOTE Table A.1 indicates the factors that can be evaluated and the scores that can be applied during the evaluation. The rating of the degree of improvement of natural environment in terms of different aspects is based on a scale of 1 to 5: insignificant to slight improvement (score = 1), slight to mild improvement (score = 2), mild to moderate improvement (score = 3), moderate to significant improvement (score = 4), and significant to substantial improvement (score = 5).					

Annex B
(informative)

Recommended evaluation indicators for different scenarios

B.1 Recommended evaluation indicators for different reclaimed water uses

The recommended evaluation indicators for different reclaimed water uses are shown in Table B.1.

Table B.1 — Recommended evaluation indicators for different reclaimed water uses

Indicator category	Indicators	Reclaimed water uses or applications					
		Urban miscellaneous use	Landscape use	Ecological flow replenishment	Industrial use	Agricultural irrigation	Groundwater recharge
Resource benefit	Conventional water resource savings	√	√	√	√	√	√
	Energy resource recovery				√		
	Carbon resource recovery	√	√	√	√	√	√
	Phosphorous resource recovery	√	√	√	√	√	√
Ecological and environmental benefit	Reduction of contaminants	√	√	√	√	√	√
	Reduction of electricity use	√	√	√	√	√	√
	Reduction of greenhouse gas emissions	√	√	√	√	√	√
	Achievement of E-flows			√			
	Ecosystem protection restoration		√	√			√
Social benefit	Improvement of local natural environment	√	√	√		√	
	Improvement of regional natural environment	√	√	√	√	√	√
Economic benefit	Avoided cost	√	√		√	√	
	Net present value (NPV)	√	√	√	√	√	√
	Internal rate of return (IRR)	√	√	√	√	√	√