Selecting the Treatment Technology for Wastewater Use in Agriculture Based on a Matrix Developed by the German Association for Water, Wastewater, and Waste

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Abstract Treatment of wastewater for the purpose of reuse is a complex task. In addition to the national and international regulations and standards on water quality and treatment technology, there are many other constraints that need to be taken into account, such as the financial resources and the level of training of local operating personnel. In order to methodically simplify the selection process, an assessment tool was developed by the German Association for Water, Wastewater and Waste (DWA) in 2008. This assessment tool is presented as a matrix (DWA Matrix, hereafter) that takes a variety of wastewater treatment processes into account. Within the DWA Matrix, each step in a process is assessed with regard to a diverse number of aspects, such as, discharge quality, costs, consumption of material and energy, expenses for preventative maintenance, and so forth. The assessment conducted on individual treatment methods allows them to be compared with each other and gives information about the risks of individual processes related to the water reuse. The objective of this chapter is to present background information on the process, and then to discuss how the DWA Matrix can be used for water reuse applications specifically in agriculture.

Keywords Agriculture · Assessment · Irrigation · Selection criteria
Treatment techniques · Water reuse · Wastewater treatment

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H. Hettiarachchi and R. Ardakanian (eds.), *Safe Use of Wastewater in Agriculture*,
https://doi.org/10.1007/978-3-319-74268-7_4

1 Introduction

Wastewater is a resource. Using this resource is already a common practice in some water-stressed countries. In the future, the use of treated wastewater will be an essential component for a sustained water resources management plan in many countries, and it may also become an important component of climate change adaptation. The reuse of water can address water shortage issues created by steadily rising water consumption and limited water resources very well. The needed level of treatment of wastewater, however, has to be decided based on the economics and the requirements all planned activities and potential risks related to the water. The tightening of environmental legislation in many countries (e.g., Australia, Jordan, and the USA) together with new reuse guidelines have given strong impetus to the proper reuse of water over the past 20 years (DWA 2008).

Recent research indicates an increasing trend of regulated reuse projects (Asano 2007; AQUAREC 2006; Jimenez and Asano 2008). However, there is still limited availability of data on the share of water reuse within the global water consumption. Figure 1 shows the reused volume for the largest known re-users of treated wastewater worldwide in the year 2008. The potential scope of water reuse applications is very wide: the largest water need arises from irrigation in agriculture, followed by industrial uses and other applications in urban/tourist sectors—with urban applications mostly referring to use in green areas and street cleaning (Asano 2007; Jimenez and Asano 2008). However, regulated water reuse continues to play only a marginal role in the total water demand.

Many different techniques are available nowadays for treatment of wastewater. However, information on how they should be selected and on what conditions is not readily available. The German Association for Water, Wastewater and Waste (DWA) took the lead on filling this gap by publishing a technical report on Treatment Steps for Water *Reuse* (DWA 2008). While the objective of the DWA

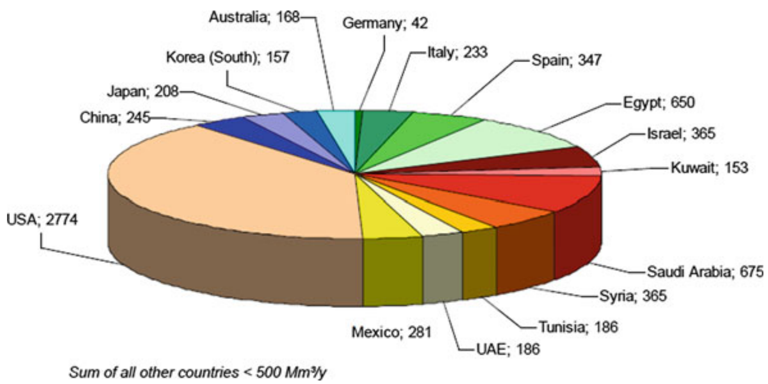

Fig. 1 Reused volume (10^6 m^3) for the largest users of treated wastewater worldwide (Kompetenzzentrum Wasser Berlin 2012, as cited in Fuhrmann et al. 2012)

report was not limited to reuse in agriculture, the objective of this present publication is to specifically address agricultural applications. The next sections aim to provide a guide on how to make a first selection of appropriate treatment technologies. In addition, they will explain how the DWA Matrix can help any organization in the field of wastewater management to get into the Safe Use of Wastewater in Agriculture (SUWA) business.

2 Water Reuse in Agriculture

Agriculture is by far the largest water consumer on a global scale, as illustrated in Table 1, and the demand is increasing. Therefore, use of wastewater to offset part of that need is logical, and it is already being practiced. Over 20 million hectares of agricultural land is currently irrigated with already used water (Hettiarachchi and Ardakanian 2016), and it continues to represent a large potential for growth.

In many developing countries and regions, use of non- or insufficiently treated wastewater in agriculture is very common. In particular in urban or peri-urban regions raw wastewater from the local population is being used for irrigation not only because it is available for free but also due to the nutrient content. In addition, the supply is relatively steady. The combination of these three factors also leads to high potential for water reuse in agricultural applications. Many developing countries and regions have introduced quality standards for the reuse of water (mainly on the basis of relevant international directives or guidelines, see Sect. 3.1). However, there is less regard on the actual implementation of these guidelines in practice.

Wastewater is the raw material needed to produce the product "adequately treated wastewater". This product should have specific qualities depending on the intended end use. For example, the permitted nutrient content depends on the vegetation, season, and the soil conditions. The hygienic aspects, on the other hand, may depend on the irrigated agricultural products and the method of cultivation. Similarly, the solid matter content should depend on the type of irrigation.

For sustainable water resources management it is essential to recognize wastewater as an important resource. However, the corresponding treatment and monitoring of the usage is indispensable in order to minimize all the risks associated with the water reuse. The objective of that treatment is to make reclaimed wastewater a secondary resource, which is fit for a specific use in agriculture.

Table 1 Competing water uses (Source of Data: United Nations 2003)

Type of Use	Global level (%)	High-income Countries (%)	Low-income Countries (%)
Agricultural	70	30	82
Industrial	22	59	10
Domestic	8	11	8

3 What Aspects to Consider in Selecting Treatment Techniques

Requirements for wastewater treatment for reuse go beyond the needs of a typical wastewater treatment facility, and the process may also require additional treatment steps. Other challenges can also emerge through the interplay of the continuous inflow of wastewater and often discontinuous consumption of the treated water. As a result, storage and plans for usage should also be taken into consideration (Fuhrmann et al. 2012). This may demand for storage capacity, which can be arranged both in surface storage tanks and also through deliberate storage in aquifers. Storage of water, however, may result in other quality demands—such as nutrient removal while using aquifer storage,—and in different quality issues such as microbial recontamination.

For the safe reuse of water, the following well-established treatment steps are typically taken into consideration (as displayed in the DWA Matrix, see Appendix B):

- Mechanical treatment, such as, sieving/screening and sedimentation,
- Biological treatment, such as, the activated sludge process, trickling filters, wastewater ponds, up-flow anaerobic sludge blanket (UASB) reactors, helophyte treatment plants or constructed wetlands,
- Combined wastewater storage- and treatment tanks,
- Filtration, sedimentation/flocculation, membrane technology, and
- Disinfection.

The technical processes of the above mentioned treatment steps are well established in general. What is less known is, how the local conditions may pose complex challenges to the implementation of water reuse infrastructure and its reliable operation. Success of a water reuse project depends on how well the treatment steps are selected and combined. There is also a need to be clear about the specific reuse-bound requirements. Beside the technological aspects, ecological, institutional, economic, and social aspects need to be taken into account. While social aspects are covered in detail in another chapter of this book, some of the mentioned key aspects to be considered in decision making are briefly discussed in the next few sections.

3.1 Health and Environmental Aspects

Municipal wastewater often contains substances that can trigger health-hazards even after conventional treatment. The most common examples are human pathogenic microorganisms in the form of bacteria, viruses, parasites, and helminth eggs and the remains of persistent chemical substances (AQUAREC 2006; WHO 2006; USEPA 2004). As a general rule, appropriate disinfection procedures should be employed to ensure the pathogens are reduced to acceptable limits through removal, destruction, or inactivation. Harmful inorganic salts and persistent anthropogenic organic substances have to be limited as well.

Similar to all other water uses, safe use of treated wastewater in agriculture also demands for a certain assurance of the water quality. However, the expected minimum requirements for the water quality may differ from application to application.

For safe agricultural irrigation applications specific water quality standards should be set by the responsible regulators. Information and recommendations from established international guidelines, such as, ISO 16075-1, 2 and 3 (ISO 2015), WHO Guideline for Water Reuse (2006), FAO Irrigation and Drainage Paper 29 on "Water quality for agriculture" (Ayers and Westcot 1985) should be taken into consideration as much as possible. Some of these international guidelines focus on risk-based and multi-barrier approaches, which requires a demanding implementation process (compared to a "simpler" definition of standards for water quality). However, at the same time, water-reuse standards should be harmonized within the national system of water and health regulations, and they should not hinder the potential of water reuse, for example, by using the containing nutrients for plant growth. National standards such as the German DIN 19650 "Irrigation—hygienic concerns on irrigation water" (DIN 1999), California Code of Regulations "Title 22" (CCR 2015), USEPA Guidelines for Water Reuse" (USEPA 2012) may serve as further references. European standards for water reuse are currently being developed.

Selected treatment technology needs to comply with the health and safety requirements to safeguard the (a) operating personnel at the treatment facility, (b) farmers who use treated wastewater, and (c) consumers of the products grown with treated wastewater. Further measures may be needed in particular with respect to health-risk awareness and epidemiological aspects. Other issues such as odor and aerosols may also have influence on health aspects.

Health aspects must be taken into consideration not only during the selection of the treatment technology and the operation of facilities but also within the complete process of water reuse in agriculture by even tracking down to the bottom of the production chain.

3.2 Financial Sustainability

Making treated wastewater available for agricultural applications is attractive; but it does come with a price tag. Water production will generate investment and operational costs. Appendix A.2 and A.3 gives a detailed tabulation. The resulting tariffs can be used as an argument in favor of such practices as long as they are lower than what is usually paid for comparable groundwater and surface water, including energy costs for delivery.

The management of water demands via appropriate prices for different types of use, such as, potable, domestic, industrial, and irrigation purposes, can contribute to a more effective use of water (Fuhrmann et al. 2012). In the same way one may encourage innovative solutions with closed water cycles for rural and urban areas. The principles of the European Water Framework Directive, therefore, demand a financial contribution from both the consumer and also from the polluter (DWA 2008). As per DWA (2008), socially acceptable and progressive tariffs set according to the ability and willingness of the user to pay are to be differentiated politically. They should also be regularly adjusted for inflation, in order to secure the necessary funding for the facility operation and customer services. In the long run, a high percentage of costs should be covered to ensure the economic sustainability of water reuse projects.

Ideally, the operation and maintenance costs should be covered by beneficiary users. Investors' own capital, state subsidies, and/or loans can be used for funding a new water reuse project. Development banks usually look at feasibility studies, which examine alternative concepts and technologies and illustrate inexpensive solutions both for the investors (low investment or operating costs) and the users (suitable tariffs) to provide funds.

There are numerous examples of well-coordinated and integrated water reuse projects that have illustrated ways for economically sustainable investments through the application of adopted frameworks, regulations, and standards—hence, ultimately through state regulation. Some examples can be found in AQUAREC (2006), EMWIS (2007), and Lazarova et al. (2013). Consumers in water-scarce countries and regions, such as Singapore, South Africa, Australia, and California, have adapted themselves, in the mid- and long-term, to the regionally available water resources with thoroughly varied water quality and different prices (DWA 2008).

3.3 Operational Aspects

Even the best technology bears considerable risks. These risks emerge when the process of water treatment, storage, distribution, and application cannot be executed as intended, for reasons beyond technological constraints. Apart from good equipment and technology, there is also a need for trained employees. Depending on the complexity of the agricultural reuse system, the water treatment processes used, as well as the operation and maintenance of the infrastructure, it also requires corresponding system management expertise.

Due to the sensitivity of the health aspects, personnel involved in the process should be able to act responsibly. Thus, the recruitment of suitable operating personnel is important. The personnel involved need to maintain the required qualifications through tailor-made training measures. Continuous follow-up trainings and examinations are recommended, especially in the early years after implementation of a water reuse project. However, in some countries and regions, these requirements are often contrary to the realities due to various reasons, such as (DWA 2008; Fuhrmann et al. 2012):

- Unclear institutional responsibilities,
- Strong hierarchical and centralized management structures with limited possibilities for decisions on-site,
- Inadequate budget for operation and maintenance,
- Lack of sufficient furnishing with operating resources, in particular equipment, spare parts, tools, energy, and chemicals,
- Personnel with insufficient qualification and limited possibilities for further training,
- Poor wages/salaries that do not motivate employees,
- Unmet demand for improvement of the image of employees (from "Sewer operator" to "Resource manager").

These conditions present enormous challenges to the project implementation and the success of investments in water reuse projects depends on how they are addressed. Appendix A.5 gives a brief overview of requirements on operating personnel.

3.4 Technological Aspects

The technologies selected for agricultural use of treated wastewater should be able to address the following (Fuhrmann et al. 2012): hygienic aspects (protection of health), biologically degradable substances (avoidance of odors), inorganic substances (protection against salinity), nutrients (protection against over-fertilization) and concentrations of solids (with regard to blockage of irrigation systems). For economic reasons, however, the selection of technology should target only the degree of treatment necessary to meet the minimum requirements applied to the expected irrigational application. Extensive reference examples on the selection of suitable water treatment and distribution technologies can be found in the literature (AQAREC 2006; Asano 2007; DWA 2008; Lazarova et al. 2013).

The treatment requirements for reuse purposes go beyond the main expectation of a typical wastewater treatment facility, which is to eliminate solids, organic matter and nutrients (see Fig. 2). The intended use of the water for irrigation may require additional treatment steps especially due to hygienic aspects (Annex A.1), the nutrients content (Annex A.6) and the concentration of solid matter (Annex A.7).

The technologies that are recommended for a controlled treatment for water reuse are already mentioned above (DWA 2008). All mentioned treatment processes are of relevance for the various purposes of reuse, and all are well established in general. Each technology has specific characteristics and functions in a treatment process; some can be seen alternating, some aid and abet further steps. At the end, in most cases it is a combination of treatment steps that achieves the desired result. But some details and characteristics may pose complex challenges to the implementation of

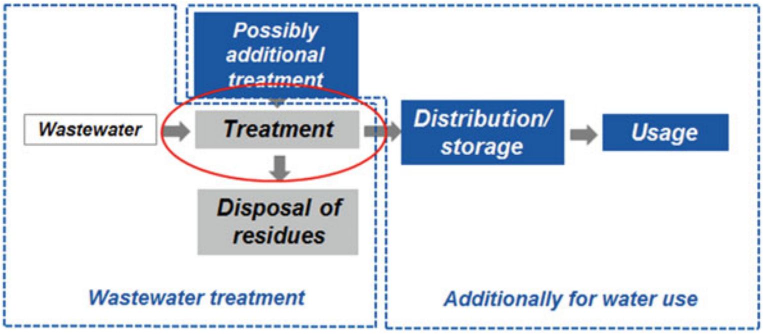

Fig. 2 System boundary of conventional wastewater treatment and additional aspects for water reuse (Firmenich et al. 2013)

water reuse infrastructure for irrigation purpose and its reliable operation. The degree of mechanization, robustness, process stability, the ability to influence the discharge quality operationally, and the accumulation of residues are only a few of these challenges (Annex A.6). The DWA Matrix in the Annex B gives important orientation and overview.

4 Selection of the Treatment Technique

Wastewater treatment with the aim of water reuse should be carried out using the technique best suited to the individual case of application. For the selection of the treatment technique, the variation of each constraint within the local conditions should be taken into consideration. In general, all aspects introduced in the previous sections should be given the due consideration. With these two sets of information in hand, the next question is what would be the best way to manage the decision-making process.

The selection process is of relevance for all stakeholders of a reuse project. It also involves financial, operational, quality and risk management aspects. Therefore, the decision-making process needs to be methodical, logical, and efficient. To organize the decision-making process, a tool was developed by the DWA Working Group on Water Reuse BIZ-11.4 (DWA 2008) in the format of an assessment matrix.

This matrix (DWA Matrix) gives a help to planers, designers, authorities, and even users in the primary decision-making phase of a project and allows a rational orientation in further improvement phases. Therefore, it essentially provides a general assessment of available options that can be used as a basis for further investigations to incorporate the local conditions. The DWA Matrix supports transparency in technologies and facilitate useful and reasonable decisions even in the case, that the expert's knowledge is limited. The Matrix explicitly will not replace engineers' assessments and tailor-made decisions.

The DWA Matrix has been developed to address water reuse needs in general, even though the present publication focuses only on agricultural irrigation. It is intended to cover a wide range of areas of application including urban uses (e.g., irrigation of parks, street cleaning, fire-protection) and non-potable domestic purposes (e.g., toilet flushing). Potable and industrial water use as well as alternative disposal concepts based on separation of sewage streams are excluded in this edition of the DWA Matrix. Indirect reuse and recharge into aquifers will be taken in account by the DWA Working Group on Water Reuse BIZ-11.4 in a further edition of the guideline expected within the next years.

The DWA Matrix presents various process steps of water treatment and provides the user an opportunity to compare/assess process steps with regard to various aspects, such as, discharge quality, costs, consumption of materials and energy, expenditure for preventative maintenance, and so on.

5 Structure of the DWA Matrix

Figure 3 below shows how the elements of the DWA assessment matrix are organized. Table 2 presents a snapshot of what is included in the first column of the DWA Matrix displayed in Appendix B. These are the criteria presented in Sect. 3 as the key aspects to be considered in decision-making. Each aspect is subdivided based on its nature and other requirements. This ultimately breaks the column 1 down to 44 lines (Table 2). All line items are clearly defined in Appendix A. The next columns of the DWA Matrix contain various technical options and process steps, one after another, of wastewater treatment. The complete assessment matrix shown in Appendix B is divided into the following five thematically grouped technologies: (a) mechanical treatment, (b) treatment ponds and tanks, (c) biological processes with higher requirements on operating personnel, (d) filtration and flocculation process steps, and (e) options for disinfection.

The assessment is facilitated in categories such as “high”, “medium”, and “low,” and is partly supplemented by specific key data, such as, energy consumption or degree of elimination of specific wastewater parameters. The details are based on evaluations of the sources given in the references as well as the expert opinion of DWA Working Group BIZ-11.4 (DWA 2008). The number(s) presented immediately next to each field indicate the relevant source(s) and the details are presented in the legend provided at the end of Appendix B.

6 Summary

Awareness of the potential of water reuse is increasing internationally. The topic represents a complex but rewarding task, which, beyond the technical questions of wastewater treatment, has to take many other different aspects and implications into

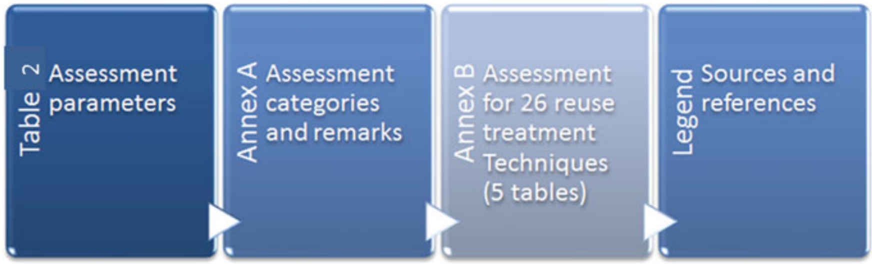

Fig. 3 Elements of the DWA assessment matrix "Treatment steps for water reuse"

account. Water scarcity has also created a growing market for water reuse, especially in agricultural irrigation. It is necessary to implement additional infrastructure and technology, not only for the treatment of wastewater, but also for the steps afterwards, such as, the intermediate storage and the creation of water-saving irrigation technologies. Although the technical processes of wastewater treatment for reuse in agricultural irrigation are more or less well known, there are many other factors that have not been well reflected yet. Some examples include unclear responsibilities, uncertainties about which water quality standards are to be applied, insufficient budgets, and a lack of trained operating personnel. These factors pose enormous challenges to the implementation of water reuse projects and their reliable and smooth operation. To ensure sustainability in water reuse projects, it is also essential to take many other aspects, including health, ecological, institutional, economic, and social aspects, into account.

The DWA Matrix presented in this manuscript offers an overview of the various possibilities for wastewater treatment for reuse purposes and is intended to be a fast and simple decision-making tool. Although it should not be considered as a perfect solution, the DWA Matrix can be applied in most cases to achieve the first rough estimate. It enables or eases the making of a sensible and well-founded decision, even when expert knowledge is not available to its fullest extent.

Acknowledgements Authors wish to offer there sincere gratitude to the DWA Working Group BIZ-11.4 for granting permission to use material developed by them in this manuscript. Authors also wish to thank leading members of the same Working Group, Prof. Peter Cornel and Dr. Tim Fuhrmann for their assistance with reviewing this manuscript.

Appendix A: Definition of Lines in Table 1

Note: Tables and explanations in Appendix A and B are direct extracts from the DWA publication *Treatments Steps for Water Reuse* (DWA 2008). There are 44 lines in the DWA Matrix. However, only 1–41 are directly applicable to the present publication. Lines 42–44 represent non-agricultural applications of water reuse.

Table 2 Line headings with assessment parameters

<table>
<tr><th colspan="4">Aspect</th><th>Line</th></tr>
<tr><td rowspan="2">Health risk</td><td colspan="3">Operating personnel water treatment facility</td><td>1</td></tr>
<tr><td colspan="3">Users of reutilized water</td><td>2</td></tr>
<tr><td rowspan="9">Economic efficiency</td><td rowspan="4">Investment costs</td><td colspan="2">Floor space required</td><td>3</td></tr>
<tr><td colspan="2">Structural engineering</td><td>4</td></tr>
<tr><td colspan="2">Mechanical engineering</td><td>5</td></tr>
<tr><td colspan="2">E+MCR technology</td><td>6</td></tr>
<tr><td rowspan="5">Operating costs</td><td colspan="2">Personnel requirement/ costs</td><td>7</td></tr>
<tr><td colspan="2">Energy requirement/costs</td><td>8</td></tr>
<tr><td colspan="2">Disposal of residues</td><td>9</td></tr>
<tr><td colspan="2">Operating resources (precipitants etc.)</td><td>10</td></tr>
<tr><td colspan="2">Preventative maintenance costs</td><td>11</td></tr>
<tr><td rowspan="5">Effects on the environment through operation of the facility</td><td colspan="3">CH_4 emission</td><td>12</td></tr>
<tr><td colspan="3">Odor nuisance</td><td>13</td></tr>
<tr><td colspan="3">Sounds/noisiness</td><td>14</td></tr>
<tr><td colspan="3">Aerosols</td><td>15</td></tr>
<tr><td colspan="3">Insects (worms, flies etc.)</td><td>16</td></tr>
<tr><td rowspan="3">Requirements on the operating personnel</td><td colspan="3">Operability/operating expenditure</td><td>17</td></tr>
<tr><td colspan="3">Expenditure for preventative maintenance</td><td>18</td></tr>
<tr><td colspan="3">Required training of operating personnel</td><td>19</td></tr>
<tr><td rowspan="17">Plant technology</td><td colspan="3">Degree of mechanisation</td><td>20</td></tr>
<tr><td colspan="3">Robustness</td><td>21</td></tr>
<tr><td colspan="3">Process stability</td><td>22</td></tr>
<tr><td colspan="3">Ability to influence the discharge quality operationally</td><td>23</td></tr>
<tr><td rowspan="12">Discharge quality (treatment performance)</td><td colspan="2">COD/BOD elimination</td><td>24</td></tr>
<tr><td colspan="2">SS reduction</td><td>25</td></tr>
<tr><td rowspan="3">Nutrient elimination</td><td>Ammonium</td><td>26</td></tr>
<tr><td>Nitrate</td><td>27</td></tr>
<tr><td>Phosphorus</td><td>28</td></tr>
<tr><td rowspan="4">Reduction of pathogens</td><td>Viruses</td><td>29</td></tr>
<tr><td>Bacteria</td><td>30</td></tr>
<tr><td>Protozoa</td><td>31</td></tr>
<tr><td>Helminths</td><td>32</td></tr>
<tr><td colspan="2">Colour/Odour</td><td>33</td></tr>
<tr><td colspan="2">Residual turbidity</td><td>34</td></tr>
<tr><td colspan="2">Salting-up due to process</td><td>35</td></tr>
<tr><td colspan="3">Accumulation of residues</td><td>36</td></tr>
<tr><td rowspan="4">Irrigation technology</td><td colspan="3">Root irrigation</td><td>37</td></tr>
<tr><td colspan="3">Trickling irrigation</td><td>38</td></tr>
<tr><td colspan="3">Sprinkler/Spray systems</td><td>39</td></tr>
<tr><td colspan="3">Flooding</td><td>40</td></tr>
</table>

(continued)

Table 2 (continued)

Aspect		Line
Types of use	Agricultural irrigation	41
	Non-potable water (toilet flushing)	42
	Urban uses (irrigation, water for fire protection)	43
	Forestry irrigation	44

A.1 Lines 1–2 "Health Risk"

The health risk associated with the operating personnel (of water treatment facilities) and the users of reused water are assessed qualitatively according to the following categories:

Category	Remarks
High	E.g., with the handling of "hazardous" chemicals
Medium	Disinfection is possibly required
Low	If employment takes place only during the pre-treatment step

A.2 Lines 3–6 "Economic Efficiency—Investment Costs"

Details on economic efficiency are of general and comparable nature. The categorization into low, medium, or high is only to allow a general comparative consideration of the process. These categories are determined and limits are set based on characteristic German values per capita (total number of inhabitants and population equivalents, PT):

Category	Remarks
High	Costs > 1000 €/PT and surface requirement >1 m^2/PT
Medium	Costs >600 to 1000 €/PT and surface requirement >0.3 to 1 m^2/PT
Low	Costs $\leq$600 €/PT and surface requirement $\leq$0.3 m^2/PT

Provision of concrete values is largely dispensed with, as these are often non-transferable. From the very beginning, the determination of investment and operating costs will be carried out attentively for each project, as economic efficiency is a decisive factor for the assessment. However, experience shows that costs can vary strongly, both from country to country and also from region to region within a country. Here, the following constraints are noted:

- Market conditions and the state of competition at the location/in the country,
- Detailed specifications of the selected technology,

- Relationship of structural engineering to mechanical engineering and/or equipment of the selected technology,
- Share of personnel costs in the investment and operating costs in countries with low wages,
- Availability and procurement costs of operating resources (energy, spare parts, expendable items, chemicals etc.),
- The need to have and/or mobilize highly qualified personnel for preventative maintenance and maintenance.

In the assessment matrix, investment costs have been divided into the areas surface requirement, structural engineering, mechanical engineering, and E+MCR (Electro-, Measurement-, Control- and Regulation technology). When numerically given, the surface requirement is specified in m^2/PT, as the basic price is extremely country-specific.

Fundamentally, for quantitative comparison, some treatment steps are designed according to load and others according to hydraulic capacity. Correspondingly, investment costs are normally set on the basis of either the number of inhabitants and population equivalents in €/PT or the hydraulic capacity in €/(m^3/h). A conversion is sensible to a limited extent only and possible only under the assumption of a specific wastewater discharge per number of inhabitants and population equivalents.

A.3 Lines 7–11 "Economic Efficiency—Operating Costs"

The general comments made about investment costs apply along the same lines for operating costs of the considered treatment processes, which are subdivided as follows:

- costs for personnel and/or personnel requirements,
- costs for energy and/or energy requirement,
- costs for the disposal of residues (presumably under German constraints),
- costs for operating resources, such as precipitants and flocculants or other chemicals,
- costs for preventative maintenance.

The numerical values refer to German conditions for newly erected facilities. The transferability to other countries, according to the comments on the investment costs, is not directly given.

For some processes the overall operating costs in euros per cubic meter (€/m^3) of treated water are given in accordance with the following categories:

Category	Remarks
High	Costs >0.4 €/m^3 and $\leq$0.8 €/m^3
Medium	Costs >0.06 to 0.4 €/m^3
Low	Costs $\leq$0.06 €/m^3

The energy requirement is given in kilowatt hours (kWh) per cubic meter of treated water. These values are largely universal and are thus directly transferable. The following categories are given for the energy requirement:

Category	Remarks
High	Energy requirement >0.02 kWh/m^3 and $\leq$0.2 kWh/m^3
Medium	Energy requirement >0.002 to 0.02 kWh/m^3
Low	Energy requirement $\leq$0.002 kWh/m^3

A.4 Lines 12–16 "Effects on the Environment through the Operation of the Facility"

Environmental loadings on the operation of the facilities for water treatment are assessed qualitatively, based on the following criteria:

- CH_4 emission (or emission of climate damaging gases),
- odour nuisance,
- sound/noisiness,
- aerosols,
- insects (worms, flies, mosquitos etc.).

Category	Remarks
High	High environmental loading
Medium	Medium environmental loading
Low	Low environmental loading

A.5 Lines 17–19 "Requirements on Operating Personnel through the Operation of the Facility"

The existing level of training of operating personnel, especially in many developing countries and emerging markets, represents a limiting factor for the selection of possible technologies for water treatment. In the assessment matrix the requirements on personnel, regarding a controlled operation, are assessed for each treatment process based on the following criteria:

- Operability and and/or operating expenditure,
- Preventative maintenance expenditure,
- Necessary training for operating personnel.

Category	Remarks
High	High requirements
Medium	Medium requirements
Low	Low requirements

A.6 Lines 20–36 “Plant Technology”

Under the umbrella term “plant technology” the technical details are gathered together about the respective processes, in particular on the treatment performance. In addition to numerical literature data, the qualitative assessment categories, given below, are used.

The quality of the treated water and/or the treatment performance is assessed based on the following wastewater parameters, in relation to the degree of elimination:

- COD and BOD_5 (organic carbon compounds),
- SS (filterable substances, solid matter, suspended solids),
- Nutrients (ammonium, nitrate, phosphorus),
- Pathogens (bacteria, viruses, protozoa, helminths).

In the matrix the degree of elimination is given in % or by the concentration in the treated water in mg/l; the reduction of pathogens is given in logarithmic steps (log-steps). The following categories are used:

Category	Remarks
High	Degree of elimination >70% or 4–6 log steps
Medium	Degree of elimination 30–70% or 2–3 log steps
Low	Degree of elimination <30% or up to 2 log steps
No influence	Degree of elimination <5%
Not relevant	E.g., if employed for post treatment only

Further parameters are drawn upon for qualitative description of the properties and condition of the treated water:

- Colour and odour,
- Residual turbidity,
- Salting-up of the water during the treatment.

Category	Remarks
High	The treated water shows a high (residual) colouring/odour/residual turbidity
Medium	The treated water shows a medium (residual) colouring/odour/residual turbidity
Low	The treated water shows a low (residual) colouring/odour/residual turbidity
No influence	–

Additional non-quantifiable parameters are drawn upon for the direct description of plant technology and qualitatively assessed in a comparative manner:

- Degree of mechanisation,
- Robustness,
- Process stability,
- Ability of influencing the discharge quality operationally.

Category	Remarks
High	Higher degree
Medium	More medium degree
Low	Lower degree

The accumulation of residues due to the treatment process is assessed as follows:

Category	Remarks
High	>80 to 110 l/(PT·a) dewatered sludge for disposal
Medium	>40 to 80 l/(PT·a) dewatered sludge for disposal
Low	Up to 40 l/(PT·a) dewatered sludge for disposal
No accumulation	–

A.7 Lines 37-40 "Irrigation Technology"

In the case of a utilization of wastewater as irrigation water, for each treatment process it is stated whether the treated water can be employed using the given irrigation technologies.

Generally, the solid matter concentration (e.g., expressed through the DS content) for irrigation facilities with very fine elements or spray nozzles (as in the case of root or trickling irrigation) has to be very small and, therefore, a filtration is recommended or is necessary.

For irrigation technologies, with which a development and distribution of fine droplets and aerosol particles occurs (e.g., through sprinkler systems), the treated water should additionally be disinfected in order to minimize health risks, e.g., for field workers and neighboring inhabitants.

Category	Remarks
Suitable	Possibly, however, limitations due to necessary filtration or disinfection
Less suitable	Requires filtration
Not suitable	–
Not relevant	E.g. if employment as pre-treatment only takes place

A.8 Lines 41–44 "Utilization Options"

These lines detail for each treatment process, in accordance with the following categories, whether the utilization of the treated water is possible and/or is worthy of recommendation for the respective purpose:

Category	Remarks
Recommended	–
Possible	–

(continued)

(continued)

Category	Remarks
Not recommended	–
Not possible	–

Appendix B: Assessment of the Treatment Technology

Note: Tables in Appendix B are direct extracts from the DWA publication on Treatments Steps for Water Reuse (DWA 2008). For download of the matrix for individual adaptation please contact the DWA costumer service (info@dwa.de).

The assessment of the treatment steps discussed is illustrated in this Appendix. Selection of the level (low, medium, and high) or the numerical values for each dimension was conducted based on different sources, which are numbered from 1-35 in the table below. The examples enclosed in the next few pages use theses reference numbers, immediately next to wherever they are applied. All 35 references are listed in a legend at the end of Appendix B.

Annex: Assessment matrix of treatment steps of water for reuse mechanical treatment

Aspect			Line no	Mechanical treatment									
				Screening						Sedimentation			
				With precipitation/ flocculation		Without precipitation/ flocculation		Micro-sieving 10 µm		With precipitation/ flocculation		Without flocculation	
Health risk	Operating personnel water treatment facility		1	High (handling of chemicals)	25	Medium	25	Low	27	High (handling of chemicals)	28	Medium	28
	Users of reused water		2	Low (only as pre-treatment stage)	25	Low (only as pre-treatment stage)	25	Low (disinfection necessary)	27	Low (only as pre-treatment stage)	28	Low (only as pre-treatment stage)	28
Economic efficiency	Investment costs	Surface requirement	3	Low	25	Low	25	Low	27	Low (0.04–0.06 m^z/PT)	6	low(0.02–0.04 m^z/PT)	6
		Structural engineering	4	Medium (400–1000 €/(m^3/h) + flocculation)	2	Low (400–1000 €/(m^3/h))	2	Low	27	Medium (250–1000 €/PT settling tank + 1–80 €/PT precipitation)	3	medium (250–1000 €/PT for settling tank)	3
		Mechanical engineering	5	Low	25	Low	25	Medium	27	Low	34	Low	34
		E+MCR technology	6	Low	25	Low	25	Low	27	Low	34	Low	34
	Operating costs	Personnel requirement/ costs	7	Low	25	Low	25	Low	27	Low	34	Low	34
		Energy requirement/costs	8	Medium (0.0117–0.017 kWh/m^3)	27	Medium (0.009–0.013 kWh/m^3)	27	low	27	Low (~0.002 kWh/m^3)	5	Low (~0.001 kWh/m^3)	5
		Disposal of residues	9	High	25	Medium	25	Low	27	High	34	Medium	34
		Operating resources (precipitant etc.)	10	High	25	Low (no operating resources)	25	Low	27	High	34	Low (no operating resources)	34
		Preventative maintenance costs	11	Low	25	Low	25	Low	27	Low	34	Low	34

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Aspect		Line no	Mechanical treatment									
			Screening						Sedimentation			
			With precipitation/ flocculation		Without precipitation/ flocculation		Micro-sieving 10 µm		With precipitation/ flocculation		Without flocculation	
Effects on the environment through operation of the facility	CH_{4-} Emission	12	None	25	None	25	None	27	Low (only with long sedimentation times slight methane formation through anaerobic degradation process possible)	30	Low (only with long sedimentation times slight methane formation through anaerobic degradation process possible)	30
	Odour nuisance	13	High	29	High	29	Low	27	Low	29	Medium	29
	Sounds/noisiness	14	Low	29	Low	29	Low	27	Low	29	Low	29
	Aerosols	15	Low	29	Low	29	Medium	27	Low	29	Low	29
	Insects (worms, flies, etc.)	16	High	29	High	29	Low	27	Medium	29	Low	29
Requirements on operating personnely	Operability/operational expenditure	17	Medium	31	Low	25	Medium	31	Medium	31	Low	31
	Preventative maintenance expenditure	18	Medium	31	Low	25	Medium	31	Medium	31	Low	31
	Required training for operating personnels	19	Medium	29	Low	29	Medium (trained personnel required)	27	Medium	29	Low	29

(continued)

(continued)

Aspect				Line no	Mechanical treatment									
					Screening						Sedimentation			
					With precipitation/ flocculation		Without precipitation/ flocculation		Micro-sieving 10 µm		With precipitation/ flocculation		Without flocculation	
Plant technology	Degree of mechanisation			20	Low/medium	25	Low	25	High	27	Medium	27	Low	27
	Robustness			21	High	25	High	25	Medium	27	Medium	27	High	27
	Process stability			22	High	25	High	25	Medium	27	High	27	High	27
	Ability to influence the discharge quality operationally			23	Medium	25	Low	31	Low	31	Medium	31	Low	31
	Discharge quality (treatment performance)	COD/BOD elimination		24	Medium (Maximum 60%)	25	Low (Maximum 25%)	25	Low (>10% or <60 mg/l)	27	Medium/high (55–75% COD; 45–80% BOD)	6	Medium (25–35% COD; 30–35% BOD)	6
		SS reduction		25	High (maximum 95%)	25	High (85%)	25	Medium (> 30% or < 10 mg/l)	27	Medium/high (60–90%)	6	Medium (55–65%)	6
		Nutrient elimination	Ammonium	26	Low (ca. 10%)	34	Low (ca. 10%)	34	Low	27	Low (<30%)	6	Low (<30%)	6
			Nitrate	27	No influence (0%)	25	No influence (0%)	25	Low	27	No influence (0%)	34	No influence (0%)	3
			Phosphorus	28	High	25	Low (<10%)	25	Low	27	High (75–90%)	6	Medium/low(< 35%)	6
		Reductions of pathogens	Viruses	29	Low	34	Low	34	No detail	27	Low (1–2 log steps)	1	Low (0–1 log steps)	1
			Bacteria	30	Low	34	Low	34	No detail	27	Low (1–2 log steps)	1	Low (0–1 log steps)	1
			Protozoa	31	Low	34	Low	34	No detail	27	Low (1–2 log steps)	1	Low (0–1 log steps)	1
			Helminths	32	Low	34	Low	34	No detail	27	Medium (1–3 log steps)	1	Low (0–<1 log steps)	1
		Colour/odour		33	No influence	25	No influence	25	No influence	27	Low (with longer sedimentation times odour through anaerobic degradation processes possible)	30	Low (with longer sedimentation times odour through anaerobic degradation processes possible)	30
		Residual turbidity		34	Low	25	Medium	25	Low	27	Low	34	Medium	34
		Salting up due to treatment		35	Medium (salting through precipitation chemicals)	25	No influence	25	No influence	27	High (salting through precipitation chemicals)	30	No influence	30

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Aspect		Line no	Mechanical treatment									
			Screening						Sedimentation			
			With precipitation/ flocculation		Without precipitation/ flocculation		Micro-sieving 10 µm		With precipitation/ flocculation		Without flocculation	
	Accumulation of residues	36	Medium (country-specific; 15–70 l/(PT.a))		Medium (country-specific; 15–60 l/(PT.a))		Low		High (730–2500 l/ (PT.a) unstabilised, liquid or 40–110 l/ (PT.a) dewatered sludge)	6	Low (330–730 l/(PT. a) unstabilised, liquid or 15–40 l/(PT.a) dewatered sludge)	6
Irrigation technology	Root irrigation	37	Not suitable	25	Not suitable	25	Suitable	27	Not suitable	10	Not suitable	10
	Trickling irrigation	38	Not suitable	25	Not suitable	25	Suitable	27	Not suitable	10	Not suitable	10
	Sprinkler/spray systems	39	Suitable (requires disinfection)	25	Not suitable	25	Suitable	27	Suitable (requires disinfection)	10	Suitable (requires disinfection)	10
	Flooding	40	Suitable	25	Suitable	25	Suitable	27	Suitable	10	Suitable	10
Types of use	Agricultural irrigation	41	Possible	29	Not recommended	29	Recommended	27	Possible	29	Possible	29
	Non-potable water (e.g. toilet flushing)	42	Not recommended	25	Not possible	25	Possible	27	Not recommended	29	Not possible	29
	Urban uses (e.g. irrigation. water for fire-protection)	43	Not recommended	25	Not possible	25	Possible	27	Not recommended	29	Not possible	29
	Forestry irrigation	44	Possible	25	Possible	25	Recommended	27	Possible	29	Possible	29

Wastewater ponds, wastewater storage and treatment tanks

Aspect			Line no	Wastewater ponds						Wastewater storage and treatment tank	
				Aerated/aerobic with sedimentation pond		Unaerated/anoxic/anaerobic		Downstream polishing pond			
Health risk	Operating personnel water treatment facility		1	Low	26.33	Low	26.33	Low	26.33	Low	26.33
	Users of reused water		2	Medium (disinfection necessary)	26.33	Medium (disinfection necessary)	26.33	Medium (disinfection necessary)	26.33	Low (with long retention time)	26.33
Economic efficiency	Investment costs	Surface requirement	3	High (0.25–0.5 m^2/PT)	6	High (1.2–3.0 m^2/PT)	6	High (3.0–5.0 m^2/PT)	6	High	6
		Structural engineering	4	Low (300–1 000 €/PT)	26.33	Low (300–1000 €/PT)	26.33	Low (300–1000 €/PT)	26.33	Medium	26.33
		Mechanical engineering	5	Low	2	Low	2	Low	26.33	Low	26.33
		E+MCR technology	6	Low	2	Low	2	Low	26.33	Low	26.33
	Operating costs	Personnel requirement/costs	7	Low	4	Low	4	Low	34	Low	26.33
		Energy requirement/costs	8	Medium	33	Low	33	Low	33	Low	26.33
		Disposal of residues	9	Medium	26.33	Medium	26.33	Low	26.33	Low	26.33
		Operating resources (precipitant etc.)	10	Low (no operating resources)	26.33	Low (no operating resources)	26.33	Low (no operating resources)	26.33	Low (no operating resources)	26.33
		Preventative maintenance costs	11	Low	26.33	Low	26.33	Low	26.33	Low	26.33
Effects on the environment through operation of the facility	CH_{4}– Emission		12	Medium (methane formation in settling areas trough anaerobic degradation process)	26.33	High (considerable methane formation through anaerobic degradation process)	26.33	Low (possible methane formation through degradation of residual loads and sludge)	26.33	High (considerable methane production through anaerobic degradation processes)	26.33
	Odour nuisance		13	Low	26.33	High (dependent on operation)	26.33	Low	26.33	Low	26.33
	Sounds/ noisiness		14	Medium (dependent on aeration)	26.33	None	26	None	26	None	26
	Aerosols		15	Medium (dependent on aeration plant)	26.33	Low	26.33	Low	26.33	Low	26.33
	Insects (worms, flies, etc.)		16	High (mosquitos)	26.33	High (mosquitos)	26.33	High (mosquitos)	26.33	High (mosquitos)	26.33

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Aspect				Line no	Wastewater ponds						Wastewater storage and treatment tank	
					Aerated/aerobic with sedimentation pond		Unaerated/anoxic/anaerobic		Downstream polishing pond			
Requirements on operating personnely	Operability/operational expenditure			17	Low	26.33	Low	26.33	Low	26.33	Low	26.33
	Preventative maintenance expenditure			18	Low	26.33	Low	26.33	Low	26.33	Low	26.33
	Required training for operating personnels			19	Low	26.33	Low	26.33	Low	26.33	Low	26.33
Plant technology	Degree of mechanisation			20	Low	26.33	Low	26.33	Low	26.33	Low	26.33
	Robustness			21	High	26.33	High	26.33	High	26.33	High	26.33
	Process stability			22	High	26.33	High	26.33	High	26.33	High	26.33
	Ability to influence the discharge quality operationally			23	Low	26.33	Low	26.33	Low	26.33	Low	26.33
	Discharge quality (treatment performance)	COD/BOD elimination		24	Medium/high (65–80% COD; 75–85% BOD)	6	Medium/high (65–80% COD; 75–85% BOD)	6	Low (reduction residual loads/ balancing of effluent peaks)	26.33	Low (reduction residual loads/ balancing of effluent peaks)	10
		SS reduction		25	High (70–80%)	6	High (70–80%)	6	Low (reduction residual loads/ balancing of effluent peaks)	26.33	Low (reduction residual loads/ balancing of effluent peaks)	10
		Nutrient elimination	Ammonium	26	Low (<30%)	6	Medium (<50%)	6	Low (reduction residual loads/ balancing of effluent peaks)	26.33	Low (reduction residual loads/ balancing of effluent peaks)	10
			Nitrate	27	Low (<30% N_{tot})	6	Medium (<60% N_{tot})	6	Low (reduction residual loads/ balancing of effluent peaks)	26.33	Low (reduction residual loads/ balancing of effluent peaks)	10
			Phosphorus	28	medium/low (<35%)	6	Medium/low (<35%)	6	Low (reduction residual loads/ balancing of effluent peaks)	26.33	Low (reduction residual loads/ balancing of effluent peaks)	10

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Aspect				Line no	Wastewater ponds						Wastewater storage and treatment tank	
					Aerated/aerobic with sedimentation pond		Unaerated/anoxic/anaerobic		Downstream polishing pond			
		Reductions of pathogens	Viruses	29	Low (1–2 log steps, dependent on retention time)	1	High (1–4 log steps, dependent on retention time)	1	High (1–4 log steps, dependent on retention time)	1	High (1–4 log steps, dependent on retention time)	1
			Bacteria	30	Low (1–2 log steps, dependent on retention time)	1	High (1–6 log steps, dependent on retention time)	1	High (1–6 log steps, dependent on retention time)	1	High (1–6 log steps, dependent on retention time)	1
			Protozoa	31	Low (0–1 log steps, dependent on retention time)	1	High (1–4 log steps, dependent on retention time)	1	High (1–4 log steps, dependent on retention time)	1	High (1–4 log steps, dependent on retention time)	1
			Helminths	32	Medium (1–3 log steps, dependent on retention time)	1	Medium (1–3 log steps, dependent on retention time)	1	Medium (1–3 log steps, dependent on retention time)	1	Medium (1–3 log steps, dependent on retention time)	1
		Colour/odour		33	Medium (colouration due to algae and bacteria)	26.33	High (colouration through algae and bacteria/odour through anaerobic degradation processes)	26.33	Medium (colouration due to algae and bacteria)	26.33	Medium (colouration due to algae formation and bacteria)	26.33
		Residual turbidity		34	Medium	26.33	Medium	26.33	Medium	26	Low	26.33
		Salting up due to treatment		35	Medium (danger of salting uo through evaporation)	26.33	Medium (danger of salting uo through evaporation)	26.33	Medium (danger of salting uo through evaporation)	26.33	Medium (danger of salting uo through evaporation)	26.33
	Accumulation of residues			36	Medium (periodic sludge clearance)	26.33	Medium (periodic sludge clearance)	26.33	Low (periodic sludge clearance)	26.33	Low (periodic sludge clearance)	26.33
Irrigation technology	Root irrigation			37	Suitable (requires filtration)	10	Suitable (requires filtration)	10	Suitable (requires filtration)	10	Suitable (requires filtration)	10
	Trickling irrigation			38	Suitable (requires filtration)	10	Suitable (requires filtration)	10	Suitable (requires filtration)	10	Suitable (requires filtration)	10
	Sprinkler/spray systems			39	Less suitable (requires disinfection)	10	Suitable	10	Suitable	10	Suitable	10
	Flooding			40	Suitable	10	Suitable	10	Suitable	10	Suitable	10

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Aspect		Line no	Wastewater ponds						Wastewater storage and treatment tank	
			Aerated/aerobic with sedimentation pond		Unaerated/anoxic/anaerobic		Downstream polishing pond			
Types of use	Agricultural irrigation	41	Possible	26.33	Possible	26.33	Possible	26.33	Possible	26.33
	Non-potable water (e.g. toilet flushing)	42	Not recommended	26.33	Not recommended	26.33	Not recommended	26.33	Not recommended	26.33
	Urban uses (e.g. irrigation, water for fire-protection)	43	Not recommended	26.33	Not recommended	26.33	Not recommended	26.33	Not recommended	26.33
	Forestry irrigation	44	Possible	26.33	Possible	26.33	Possible	26.33	Possible	26.33

UASB (Anaerobic upflow sludge blanket reactors), activated sludge processes, biological filters, reed beds

Aspect			Line no	UASB (Anaerobic upflow sludge blanket reactors)		Activated sludge process				Trickling filter		Helophyte treatment plants	
						C removal		Nutrient elimination					
Health risk	Operating personnel water treatment facility		1	Low	28	Low	28	High (handling of chemicals)	28	Low	28	Low	28
	Users of reused water		2	Low (only as pre-treatment stage)	28	Medium (disinfection required)	28	Medium (disinfection required)	28	Medium (disinfection required)	28	Medium (disinfection required)	28
Economic efficiency	Investment costs	Surface requirement	3	Low (0.03–0.1 m^2/PT)	6	Low (0.12–0.25 m^2/PT)	6	Low (0.12–0.25 m^2/PT)	6	Low (0.12–0.3 m^2/PT)	S	High (3–5 m^2/PT)	6
		Structural engineering	4	Medium	26	Medium (100–800 €/PT)	2	Medium (200–900 €/PT)	2	Medium (200–600 €/PT)	2	High (1000–2000 €/PT)	24
		Mechanical engineering	5	Medium	30	Medium (40–80 €/PT)	2	Medium (40–80 €/PT)	2	Low	2	Low	24
		E+MGR technology	6	Medium	30	High	2	High	2	Low	2	Low	24
	Operating costs	Personnel requirement/costs	7	Low	30	Medium (5–10 €/(PT.a))	8	Medium (5–10 €/(PT.a))	8	Low	4.9	Low (50–130 €/(PT.a))	24
		Energy requirement/costs	8	Low	30	High (~0.110 kWh/m^3)	5	High (~0.190 kWh/m^3)	5	Medium (~0.085 kWh/m^3)	5		
		Disposal of residues	9	Low	30	Medium (10–20 €/(PT·a))	8	Medium (10–20 €/(PT·a)	8	Low	49		
		Operating resources (precipitant etc.)	10	Low (no operating resources)	30	Medium (1–2.5 €/(PT·a))	8	Medium (1–2.5 €/(PT·a))	8	Low	4.9		
		Preventative maintenance costs	11	Low	32	Medium (2.5–5 €/(PT·a))	8	Medium (2.5-5 €/(PT·al)	8	Low	4.9		

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Aspect		Line no	UASB (Anaerobic upflow sludge blanket reactors)		Activated sludge process				Trickling filter		Helophyte treatment plants	
					C removal		Nutrient elimination					
Effects en the environment through operation of the facility	CH_4– Emission	12	High (the methane load dissolved in the treated water (the more the higher the temp.) evaporates)	30	None	30	None	30	None (only if air flow insufficient possible formation of anaerobic zones with methane development)	30	Low (formation of anaerobic zones with methane development possible)	26
	Odour nuisance	13	Low	30	Medium	29	low	29	medium	30	low	30
	Sounds/noisiness	14	Low	30	Medium/high (dependent on plant technology)	29	Medium/high (dependent on plant technology)	29	None	26	None	26
	Aerosols	15	Low	30	Low/high (dependent on plant technology)	29	Low/high (dependent on plant technology)	29	Low	30	Low	30
	Insects (worms flies, etc.)	16	Low	30	Low	29	Low	29	High	30	High	30
Requirements on operating personnely	Operability/operational expenditure	17	Medium	30	Medium	31	High	31	Medium	30	Low	30
	Preventative maintenance expenditure	18	Medium	30	Medium	31	High	31	Medium	30	Low (periodic cutting of the plants)	30
	Required training for operating personnels	19	Medium	30	Medium	29	High	29	Medium	30	Low	30
Plant technology	Degree of mechanisation	20	Low	27	High	27	High	27	Medium	30	Low	27
	Robustness	21	Low	27	High	27	High	27	High	27	Low/medium	27
	Process stability	22	Low	27	High	27	High	27	High	27	High	27
	Ability to influence the discharge quality operationally	23	Medium	30	High	30	High	30	Medium	30	Low	30

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Aspect			Line no	UASB (Anaerobic upflow sludge blanket reactors)		Activated sludge process				Trickling filter		Helophyte treatment plants	
						C removal		Nutrient elimination					
Discharge quality (treatment	COD/BOD elimination		24	Medium/high (50 to 85–95%)		High (80–90% COD; 85–93% BOD)	6	High (80–90% COD; 85–93% BOD)	6	High (70–80% COD; 80–83% BOD)	6	High (75–85% COD; 80–90% BOD)	6
	SS reduction		25	Medium/high (65–80%)	6	High (87–93%)	6	High (87–93%)	6	High (87–93%)	6	High (87–93%)	6
	Nutrient elimination	Ammonium	26	Medium (<50%)	6	Low (ca. 20%)	3	High (>80%)	6	Medium/high (50–85%)	6	Medium/high (40–98% with seasonal variations)	29
		Nitrate	27	Medium (<60% N_{tot})	6	No effect (0%)	3	High (ca. 80%)	34	Medium (<60% N_{tot})	6	Low (0–17%)	24
		Phosphorus	28	Medium/low (<35%)	6	Low (0% wo. precipitation)/ high (ca. 90% with precipitation)	3	Low/ (30% wo. Precipitation)/ high (ca. 90% with precipitation)	3	Medium/Low (<35%) (only with precipitation)	35	medium/high (30–95% depending on age)	29
	Reductions of pathogens	Viruses	29	Low (0–1 log steps)	1	Low (0–2 log steps)	1	Low (0–2 log steps)	1	Low (0–2 log steps)	1	Low (1–2 log steps)	1
		Bacteria	30	low (0.5–1.5 log steps)	1	Low (1–2 log steps)	1	Low (1–2 log steps)	1	Low (1–2 log steps)	1	Medium/low (0.5–3 log steps)	1
		Protozoa	31	Low/(0–1 log steps)	1	Low (0–1 log steps)	1	Low (0–1 log steps)	1	Low (0–1 log steps)	1	Low (0.5–2 log steps)	1
		Helminths	32	Low (0.5–1 log steps)	1	low (1–<2 log steps)	1	Low (1– <2 log steps)	1	Low (1–2 log steps)	1	Medium (1–3 log steps)	1
	Colour/odour		33	High (formation of odour substances due to anaerobic degradation)	30	Low (with correct operation)	30	Low (with correct operation)	30	Low (possible formation of odour substances under anaerobic conditions)	30	Low (possible formation of odour substances under anaerobic conditions)	30

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Aspect		Line no	UASB (Anaerobic upflow sludge blanket reactors)		Activated sludge process: C removal		Activated sludge process: Nutrient elimination		Trickling filter		Helophyte treatment plants	
	Residual turbidity	34	Medium		Medium		Medium		Medium	30	Medium	30
	Salting up due to treatment	35	No effect	30	Low	30	Medium (salting up due to precipitation chemicals for P removal)	30	Low (danger of salting up through precipitant or water evaporation only with higher recirculation rate strong sunrays, lower air humidity)	30.34	low (danger of salting up through evapo-transpiration via the plants)	30
	Accumulation of residues	36	Low (70–220 l/(PT·a) unstabilised, liquid or 10–35 l/(PT·a) dewatered sludge)	8	High (1100–3000 l/(PT·a) unstabilised. liquid or 35–90l/(PT.a) dewatered sludge)	6	High (1100–3000 l/PT·a) unstabilised, liquid or 35–90 l/(PT.a) dewatered sludge)	6	Medium (360–1800 l/(PT·a) unstabilised. liquid sludge or 35–80 l/(PT·a) dewatered sludge)	6	Medium/high (plant cutting)	30
Irrigation technology	Root irrigation	37	Not relevant (pre-treatment only)	10	Suitable (requires filtration)	10	Suitable (requires filtration)	10	Less suitable (necessary filtration)	10	Less suitable (necessary filtration)	10
	Trickling irrigation	38	Not relevant (pre-treatment only)	10	Suitable (requires filtration)	10	Suitable (requires filtration)	10	Less suitable (necessary filtration)	10	Less suitable (necessary filtration)	10
	Sprinkle/spray systems	39	Not relevant (pre-treatment only)	10	Suitable (requires disinfection)	10	Suitable (requires disinfection)	10	Suitable (requires disinfection)	10	Suitable (requires disinfection)	10
	Flooding	40	Not relevant (pre-treatment only)	10	Suitable	10	Suitable	10	Suitable	10	Suitable	10
Types of use	Agricultural irrigation	41	Not recommended	30	Recommended	29	Recommended	20	Possible	30	Possible	30
	Non-potable water (e g flushing of toilets)	42	Not possible	30	Not recommended	29	Possible	29	Not recommended	30	Not recommended	30
	Urban uses (e.g. irrigation, water for fire-protection)	43	Not possible	30	Not recommended	29	Possible	29	Not recommended	30	Not recommended	30
	Forestry irrigation	44	Possible	30	Recommended	29	Recommended	29	Possible	30	Possible	30

Filtration (downstream), precipitation/flocculation (downstream), membrane technology

Aspect			Line no	Filtration (downstream)						Precipitation/ flocculation (downstream)		Membrane technology			
				Quick filtration (coarse)		Slow sand filtration		Double layer filtration				UF/MF		NF/RO	
Health risk	Operating personnel water treatment facility		1	Filtration (downstream)	28	Low	28	Low	28	High (handling of chemicals)	28	High (handling of chemicals)	28	High (handling of chemicals)	28
	Users of reused water		2	Medium (disinfection necessary)	28	Medium (disinfection necessary)	28	Medium (disinfection necessary)	28	Medium (disinfection necessary)	28	Low	28	Low	28
Economic efficiency	Investment costs	Surface requirement	3	Low	30	Low	30	Low	30	Low	30	Low	30	Low	30
		Structural engineering	4	Low (25–60 €/ PT)	11	Low (25–60 €/ PT)	11	Low	32	Low	32	High (4000–8000 €/(m^3/h))	12, 13, 14, 15	High	34
		Mechanical engineering	5					Low	34	Low	32			High	34
		E+MCR technology	6					Low	34	Low	32			High	34
	Operating costs	Personnel requirement/costs	7	Low	11	Low	11	Low	34	Low	32	Medium (0.26–0.4 €/m^3)	12, 13, 14, 15	High	34
		Energy requirement/costs	8	Low	33	Low	33	Low	33	Low (~0.001 kWh/m^3)	5			High (0.45–0.70 \$/m^3 desalination)	10
		Disposal of residues	9	Low	11	Low	11	Low	34	Medium	32			High	34
		Operating resources (precipitant etc.)	10	Low	11	Low	11	Low	34	Medium	32			High	34
		Preventative maintenance costs	11	Medium	11	Medium	11	Medium	34	Medium	32			High	32
Effects on the environment through operation of the facility	CH_4- Emission		12	None	30	None	30	None	30	None	30	None	30	None	30
	Odour nuisance		13	Low	27	Low	27	Low	27	Low	30	Low	30	Low	30
	Sounds/noisiness		14	Low	27	Low	27	Low	27	Low	30	Low	30	Low	30
	Aerosols		15	Low	27	Low	27	Low	27	Low	30	None	30	None	30
	Insects (worms, flies, etc.)		16	Medium	27	Medium	27	Medium	27	Low	30	None	30	None	30
Requirements on operating personnely	Operability/operational expenditure		17	Medium	31	Medium	31	Medium	31	Medium	30	High	30	High	30
	Preventative maintenance expenditure		18	High	31	High	31	High	31	Medium	30	High	30	High	30
	Required training for operating personnels		19	High (trained personnel necessary)	27	High (trained personnel necessary)	27	High (trained personnel necessary)	27	High (trained personnel necessary)	30	High (trained personnel necessary)	30	High (trained personnel necessary)	30

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Aspect				Line no	Filtration (downstream)						Precipitation/ flocculation (downstream)		Membrane technology			
					Quick filtration (coarse)		Slow sand filtration		Double layer filtration				UF/MF		NF/RO	
Plant technology	Degree of mechanisation			20	Low	27	Medium	27	Medium	27	Low	27	High	27	High	27
	Robustness			21	Medium	27	Medium	27	High	27	High	27	Medium	26	Medium	27
	Process stability			22	High	27	High	27	High	27	High	27	High	27	High	27
	Ability to influence the discharge quality operationally			23	High	30	High	30	High	30	High	30	High	30	High	30
	Discharge quality (treatment performance)	COD/BOD elimination		24	Low (>20% or <40 mg/l)	11	Low (>20% or <40 mg/l)	11	Low (>20% or <40 mg/l)	11	Low	30	High (with aeration ca. 89–96% or COD <30 mg/l, BOD <5 mg/l)	12, 13, 14, 15	Not relevant (post-treatment only)	30
		SS reduction		25	Medium/high (>50% or <5 mg/l)	11	Medium/high (>50% or <5 mg/l)	11	Medium/high (>50% or <5 mg/l)	11	High	30	High (almost 100%)	12, 13, 14, 15	High	26
		Nutrient elimination	Ammonium	26	Medium (<5 mg/l)	11	Medium (<5 mg/l)	11	Medium (<5 mg/l)	11	Low (ca. 10%)	3	High (with aeration ca. 90% or 0.1–2 mg/l)	12, 13, 14, 15	Not relevant (post-treatment only)	30
			Nitrate	27	High (<10 mg/l)	11	High (<10 mg/l)	11	High (<10 mg/l)	11	No influence (0%)	3	Medium/high (4.5 mg/l)	12, 13, 14, 15	Not relevant (post-treatment only)	30
			Phosphorus	28	Medium (30% without flocculation)/ high (ca. 70% or <0.3 mg/l with flocculation)	11	Medium (30% without flocculation)/ high (ca. 70% or <0.3 mg/l with flocculation)	11	Medium (30% without flocculation)/ high (ca. 70% or <0.3 mg/l with flocculation)	11	High	3	High (with precipitation ca. 90% or 0.5–0.7 mg/l)	12, 13, 14, 15	Not relevant (post-treatment only)	30
		Reductions of pathogens	Viruses	29	Medium (1–3 log steps)	1	Medium (1–3 log steps)		Medium (1–3 log steps)	1	Medium (1–3 log steps)	1	High (2.5 – >6 log steps)	1	High (2.5– >6 log steps)	1
			Bacteria	30	Medium (0–3 log steps)	1	Medium (0–3 log steps)		Medium (0–3 log steps)	1	Low (0–1 log steps)	1	High (3.5– >6 log steps)	1	High (3.5– >6 log steps)	1

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Aspect		Line no	Filtration (downstream)						Precipitation/ flocculation (downstream)		Membrane technology			
			Quick filtration (coarse)		Slow sand filtration		Double layer filtration				UF/MF		NF/RO	
	Protozoa	31	Medium (0–3 log steps)	1	Medium (0–3 log steps)		Medium (0–3 log steps)	1	Medium (1–3 log steps)	1	High (>6 log steps)	1	High (>6 log steps)	1
	Helminths	32	Medium (1–3 log steps)	1	Medium (1–3 log steps)		Medium (1–3 log steps)	1	Low (2 log steps)	1	High (>3 log steps)	1	High (>3 log steps)	1
	Colour/odour	33	No influence	30	No influence	30	No influence	30	No influence	30	No influence	30	No influence	30
	Residual turbidity	34	Low	11	Low	11	Low	11	Low	3	Low	34	Low	30
	Salting-updue to the treatment	35	No influence	30	No influence	30	No influence	30	Medium (salting-up due to precipitant chemicals)	30	Medium (salting-up due to precipitant chemicals)	34	No influence (but heavily salted concentrate for disposal)	30
	Accumulation of residues	36	Low	30	Low	30	Low	30	Low	30	Low (550–1100 l/(PT·a) stabilised, fluid or 17–34 l/(PT·a) dewatered sludge)	3	Medium (heavily salted concentrate for disposal)	30
Irrigation technology	Root irrigation	37	Suitable	10	Suitable	10	Suitable	10	Suitable	10	Suitable	10	Suitable	10
	Trickling irrigation	38	Suitable	10	Suitable	10	Suitable	10	Suitable	10	Suitable	10	Suitable	10
	Sprinkler/spray systems	39	Suitable	10	Suitable	10	Suitable	10	Suitable	10	Suitable	10	Suitable	10
	Flooding	40	Suitable	10	Suitable	10	Suitable	10	Suitable	10	Suitable	10	Suitable	10
Types of use	Agricultural irrigation	41	Recommended	27	Recommended	27	Recommended	27	Recommended	30	Recommended	30	Recommended	30
	Non-potable water (e.g. toilet flushing)	42	Possible	27	Possible	27	Possible	27	Possible	30	Recommended	30	Recommended	30
	Urban uses (e.g. irrigation, water for fire-protection)	43	Possible	27	Possible	27	Possible	27	Possible	30	Recommended	30	Recommended	30
	Forestry irrigation	44	Recommended	27	Recommended	27	Recommended	27	Recommended	30	Recommended	30	Recommended	30

Desinfection

Aspect			Line no	Disinfection											
				Membrane (UF)		UV		Ozone		Soil filter		Polishing pond		Chlorine	
Health risk	Operating personnel water treatment facility		1	High (handling of chemicals)	28	Medium	26	High (handling of chemicals)	28	Low	28	Low	28	High (handling of chemicals)	28
	Users of reused water		2	Low	28	Low	28	Low	28	Low	28	Medium (post-disinfection necessary)	26	Low (only with over-chlorination)	26
Economic efficiency	Investment costs	Surface requirement	3	Low	30	Low	30	Low	30	High	30	High	30	Low	30
		Structural engineering	4	High	34	Low (7–41 €/PT)	16	High (0.52 €/m^3)	17	High	18.19.20.21	Low	22.23	Low	34
		Mechanical engineering	5	High	34	Medium	26	High	32	Low	18.19.20.21	Low	22.23	Medium (Safety technology)	26
		E+MCR technology	6	High	34	Medium	26	High	17	Low	18,19,20,21	Low	22.23	Low	34
	Operating costs	Personnel requirement/costs	7	High (0.2–0.8 €/m^3)	7	Low (0.03–0.05 €/m^3)	7	Medium (0.05–0.2 €/m^3)	7	Low	18,19,20,21	Low	22.23	Low (0.04–0.06 €/m^3)	7
		Energy requirement/costs	8							Low	18,19,20,21	Low	22.23		
		Disposal of residues	9							Low	18,19,20,21	Low	22.23		
		Operating resources (precipitants etc.)	10							Low	18,19,20,21	Low	22.23		
		Preventative maintenance costs	11							Low	18,19,20,21	Low	22.23		
Effects on the environment due to operation of the facility	CH_4 emission		12	None	26	None	26	None	26	None	26	Small (possible methane formation with anaerobic degradation of residual loads and sludge)	30	None	26
	Odour nuisance		13	Low	30	Low	30	Low	30	Low	30	Low	30	Low	30
	Sound/noisiness		14	Low	30	None	26	Low	30	None	26	None	26	None	26
	Aerosols		15	None	30	None	30	None	30	Low	30	Low	30	None	30
	Insects(worms, flies etc.)		16	None	30	None	30	None	30	Medium	30	High (mosquitos)	30	None	30

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Aspect				Line no	Disinfection											
					Membrane (UF)		UV		Ozone		Soil filter		Polishing pond		Chlorine	
Requirements son operating personnel	Operability/operating expenditure			17	High	30	Low	30	High	30	Low	30	Low	30	High	30
	Maintenance expense			18	High	30	Medium	26	High	30	Low	30	Low	30	High	30
	Necessary training of operating personnel			19	High (trained personnel required)	30	Medium	26	High (trained personnel required)	30	Low	30	Low	30	High (trained personnel required)	30
Plant technology	Degree of mechanisation			20	High	27	Medium	27	Medium	27	Low	27	Low	27	Low	27
	Robustness			21	Medium	27	High	27	Medium	27	Medium	26	Low/medium	27	Medium	26
	Process stability			22	High	27	High	27	High	27	High	27	Medium/high	26	High	27
	Ability to influence the discharge quality operationally			23	High	30	High	30	High	30	Low	30	Low	30	High	30
	Discharge quality (treatment performance)	COD/BOD elimination		24	Not relevant (for post treatment only)	30	No influence	34	Not relevant (for post treatment only)	30	High (ca. 85%)	18,19,20,21	Low (reduction residual loads/balancing of effluent peaks)	26	No influence	34
		SS reduction		25	High	26	No influence	34	Not relevant (for post treatment only)	30	High (ca. 90%)	18,19,20,21	Low (reduction residual loads/balancing of effluent peaks)	26	No influence	34
		Nutrient elimination	Ammonium	26	Not relevant (for post treatment only)	26	No influence	34	Not relevant (for post treatment only)	30	High (ca. 80%)	18,19,20,21	Low (reduction residual loads/balancing of effluent peaks)	26	No influence	34
			Nitrate	27	Not relevant (for post treatment only)	26	No influence	34	Not relevant (for post treatment only)	30	Low (10% unplanted)/ high (70% unplanted)	18,19,20,21	Low (reduction residual loads/balancing of effluent peaks)	26	No influence	34

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Aspect				Line no	Disinfection											
					Membrane (UF)		UV		Ozone		Soil filter		Polishing pond		Chlorine	
			Phosphorus	28	Not relevant (for post treatment only)		No influence		Not relevant (for post treatment only)		Medium (ca. 30% unplanted)/high (ca. 80% unplanted) performance sinks however with operating time		Low (reduction residual loads/balancing of effluent peaks)	26	No influence	34
		Reduction of pathogens	Viruses	29	High (2.5– >6 log step)	1	Medium (1– >3 log steps)	1	High (3–6 log steps)	1	Medium/low (1.5–2.5 log steps)	18.19.20,21	High (1–4 log steps)	1	Medium (1–3 log steps)	1
			Bacteria	30	High (3.5– >6 log step)	1	High (2– >4 log steps)	1	High (2–6 log steps)	1	Medium/low (1.5–2.5 log steps)	18,19,20,21	High (1–6 log steps)	1	High (2–6 log steps)	1
			Protozoa	31	High (>6 log step)	1	High (>3 log steps)	1	Low (1–2 log steps)	1	Medium/low (1.5–2.5 log steps)	18,19,20,21	High (1–4 log steps)	1	Low (0–1.5 log steps)	1
			Helminths	32	High (>3 log step)	1	No influence	1	Low (0–2 log steps)	1	Medium	26	Medium (1–3 log steps)	1	Low (0– <1 log steps)	1
		Colour/odour		33	No influence	30	Low (decolouration possible)	30	Low (removal of colour and odour substances)	30	Medium (repossible formation of odour substances with anaerobic conditions)	30	Medium (possible colouration due to algae; odour formation with anaerobic conditions)	30	Medium (aggravation of odour and taste if residual chlorine contained in water)	30
		Residual turbidity		34	Low	34	No influence	34	No influence	34	Low	18,19,20,21	Medium	30	No influence	34
		Salting up due to treatment		35	No influence	30	No influence	30	No influence	30	No influence	30	Small (danger of salting up through water evaporation with longer retention times, stronger sunrays, larger water surface)	30	Low	26
	Accumulation of residues			36	Low (concentrate for disposal)	30	None	30	None	30	Low	26	Low (periodic sludge clearance)	30	None	30

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Aspect		Line no	Disinfection						
			Membrane (UF)	UV	Ozone	Soil filter	Polishing pond	Chlorine	
Irrigation technology	Root irrigation	37	Suitable						10
	Trickling irrigation	38	Suitable						10
	Sprinkler/spray systems	39	Suitable						10
	Flooding	40	Suitable						10
Type of use	Agricultural irrigation	41	Recommended						30
	Non-potable water (e.g. For flushing toilets)	42	Recommended						30
	Urban uses (e.g. irrigation, water for fire-protection)	43	Recommended						30
	Forestry irrigation	44	Recommended						30

Legend of information sources

No.	Source
1	WHO, 2006a
2	Günthert and Reicherter, 2001
3	ATV-DVWK, 2000
4	DWA-Landesverband [Federal State Association] Bayern, 2005
5	MURL, 1999
6	Von Sperling and Chernicharo, 2006
7	ATV, 1998
8	Grünebaum and Weyand, 1995
9	Lenz, 2004
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12	Wedi, 2005
13	Engelhardt, 2006
14	Günder, 2001
15	Frechen, 2006
16	Schleypen, 2005
17	Cornel, 2006
18	Laber, 2001
19	Novak, 2005
20	DWA, 2006
21	Lützner, 2002
22	IRC, 2004
23	Ruhrverband, 1992
24	Barjenbruch and Al Jiroudi, 2005
25	Working Group (joint assessment)
26	Tim Fuhrmann (personal assessment)
27	Hans Huber (personal assessment)
28	Volker Karl (personal assessment)
29	Roland Knitschky (personal assessment)
30	Alessandro Meda and Peter Cornel (personal assessment)
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32	Holger Scheer (personal assessment)
33	Florian Schmidtlein (personal assessment)
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