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Cost effectiveness analysis of alternative technologies for the mobilisation of additional water

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Content

1 Introduction

The application and adaptation of non-conventional alternatives of water supply is a viable option for a save and secure provision of water in Jordan [Mohsen and Al-Jayyousi, 1999]. To ensure this, i.e. to supply more water, save the existing water resources, and meet the growing demand for water in the Lower Jordan Basin, different decentralised technologies have been designed that particularly suit the conditions in rural communities in Jordan. These technologies are meant to recharge existing water resources and make new sources (like treated brackish or wastewater) accessible. Their design, development, and testing is carried through by the work packages 3.1 to 3.3 (see http://www.iwrm-smart2.org/). They include:

- decentralised wastewater treatment
- managed aquifer recharge
- brackish water treatment

The aim of different water treatment systems is to provide water quality A, suitable for reuse in agricultural irrigation. This water quality is defined by the Jordanian Standard 893-2006 for reclaimed domestic wastewater [JS 893-2006, 2006]. Water quality A ensures use of treated water for irrigation of cooked vegetables and playgrounds.

In order to assess the economic feasibility of the three water treatment technologies (wastewater treatment, managed aquifer recharge and brackish water treatment) in terms of the costs for generating water quality A, we applied a cost-effectiveness analysis (CEA). This is done by ranking the costs of the different technologies to achieve a certain output water quality. The analysis does not focus on certain communities in the Lower Jordan River Basin. Instead, it offers an ex-ante decision tool for any location in the study region. Clearly not all water treatment technologies can be applied in every location, i.e. brackish water is not available in highland areas. This means, communities only select and compare the technologies relevant to them. Specific local conditions and existing facilities may vary between locations and have to be considered when applying these results to one location. The cost-effectiveness analysis focuses on water treatment technologies designed for 5000 person equivalents (pe) in line with the SMART project's aim to serve villages and semi-urban settlements with about 5000 inhabitants.

The report consists of three main parts:

1) A detailed description of the three technologies under consideration.
2) Cost data collection for a set of categories, including construction costs and operational costs. This ensures comparability of cost data between the different technologies.
3) The implementation of the cost-effectiveness analysis, including sensitivity analysis.

2 Technologies

The following sections give an overview of the considered technologies. They are to be applied locally in towns and villages in the rural parts of the Lower Jordan River Basin where centralised wastewater treatment and water supply are not feasible and thus decentralised systems are crucial. In particular, a geographically diverse and uneven terrain hampers the connection of towns and villages to large central treatment plants [Wolf et al., 2008]. To close the local water cycle, it is intended to address treated brackish and wastewater for irrigation as well as groundwater recharge.

2.1 Decentralised wastewater treatment (DWWT)

There are two DWWT systems considered in this case: sequencing batch reactor (SBR) and constructed wetlands (CW). Both are suitable approaches to sufficiently treat wastewater. In (this case) In the following analysis, SBR consists of a preliminary treatment, a primary septic tank, a buffer tank, and a sequencing batch reactor (SBR). Constructed wetlands are artificial wetlands or swamps, which operate like biofilters and hence remove pollutants from the wastewater.

2.1.1 Seque

The first step, the preliminary treatment, removes coarse material. After this the primary septic tank serves as a first cleaning stage of the wastewater. Scum flows on the surface of the water, solids settle and are digested anaerobically. Septic tanks are comparatively simple treatment systems and maintained preventively. The following buffer tank serves as a flow buffer and compensates very high or very low water flows and, in addition to that, more solids settle on the bottom of the buffer tank. In a SBR system, air is bubbled through the wastewater to reduce the biological and chemical oxygen demand (BOD and COD). Aerobic bacteria remove the organic load and thus clean the wastewater. As a variation of the activated sludge treatment, the SBR technology has several advantages to other treatment systems. It is highly flexible considering fluctuant input flows, has a high removal capacity, a high sedimentation rate because of the lack of flow, and needs very little space [Eckstädt, 2004]. The basic procedure of a SBR-system contains a discontinuously emptied and charged reactor with varying water levels and predefined process steps with a fixed timing [Schreff, 2004]. Figure 1 shows the SBR system used in this CEA [BDZ, 2012].

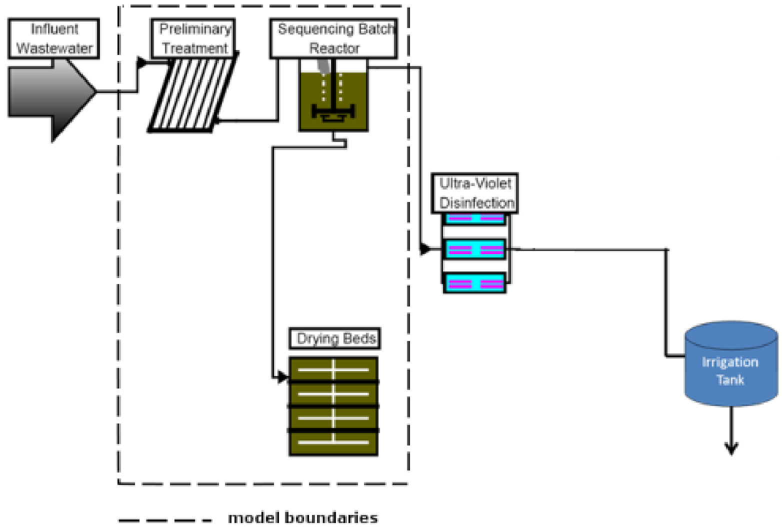

Figure 1: Sequencing batch reactor with model boundaries for CEA [BDZ, 2012]

2.1.2 *Vertical flow constructed wetlands (VFCW)*

Another approach is realised with constructed wetlands (CW) where an artificial swamp or marsh, commonly vegetated with reed, acts as a biofilter to remove pollutants from the wastewater.

The term wetlands encompasses a wide range of different ecosystems, which do not necessarily need to be flooded. Saturated soil conditions are sufficient to define a system as a wetland. They lie between dry land and aquatic systems. Constructed wetlands imitate natural ones, the cleaning processes being the same. The removal mechanisms are based on macrophytic plants, microbial (algal), and physical processes, where a mixture of water, substrate, plants, litter, invertebrates, and microorganisms form the total wetland system [Kadlec et al., 2000].

The mechanisms that improve the water quality include [Kadlec et al., 2000]:

- sedimentation
- filtration and chemical precipitation
- chemical transformation
- adsorption and ion exchange
- breakdown and transformation

Generally there are two different types of CW: free water and surface flow wetlands. Free water wetlands simulate hydrological regimes of natural systems. In opposition to that, surface flow wetlands have an input and an output point, between which the water is cleaned through different processes. Surface flow wetlands can be further categorised into surface- and subsurface-flow wetlands [Kadlec et al., 2000].

The system considered in SMART is a subsurface-flow wetland with vertical flow. These are usually beds vegetated with common reed, sometimes with cattails or bulrush, too.

The wetland bed is discontinuously flooded with a large amount of wastewater, which then infiltrates into the soil and percolates through the ground to a drainage system at the bottom of the wetland, where the cleaned water is collected. The bed drains free of the water and is aerated in this way to supply a sufficient amount of oxygen for the cleaning of the next wastewater batch [Vyzamal and Kröpfelová, 2008].

Figure 2 shows the VFCW system applied in this analysis.

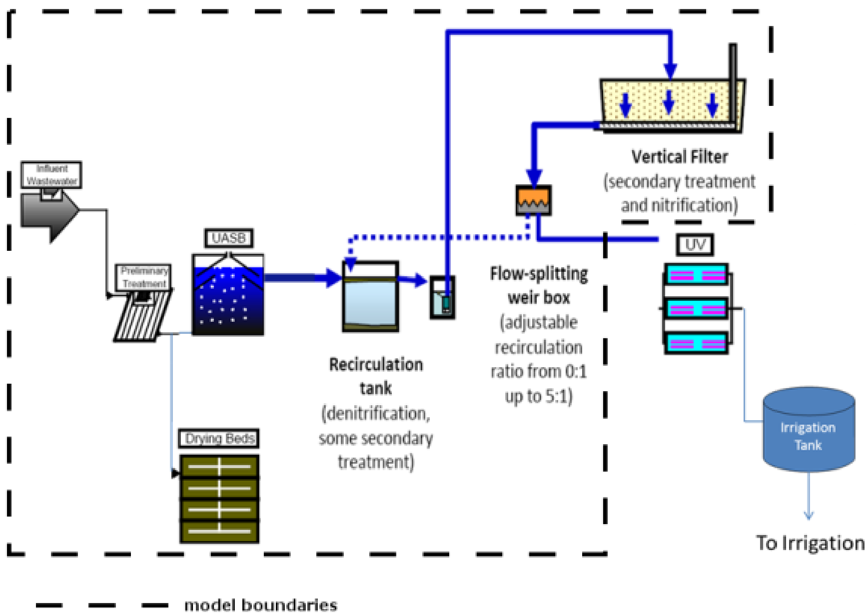

Figure 2: Vertical flow constructed wetland with model boundaries for CEA [BDZ, 2012]

2.2 Managed aquifer recharge (MAR)

Groundwater is naturally refilled by infiltration from precipitation and streams. Managed aquifer recharge is therefore the intentional replenishing of the groundwater level via planned and designed use of infiltration basins and injection wells [Dillon et al., 2010]. However, not only a controlled raise of the groundwater level is intended, but also further treatment of the infiltrated water [Wolf et al., 2008]. In this study, the input water is treated wastewater with a water quality not suited for irrigation (i.e. water qualities B or C).

However, other types of input water, such as freshwater, river water, treated brackish water, are possible.

Infiltration reservoirs are simple basins with unobstructed access to the underlying soil or rock. The treated wastewater is discharged into the reservoir where it percolates through a sand and gravel filter layer into the ground and sorption and degradation processes enhance the water quality. The water then reaches the saturated aquifer zone and elevates the groundwater table. Figure 3 shows the schematic principle of the recharge via infiltration basins.

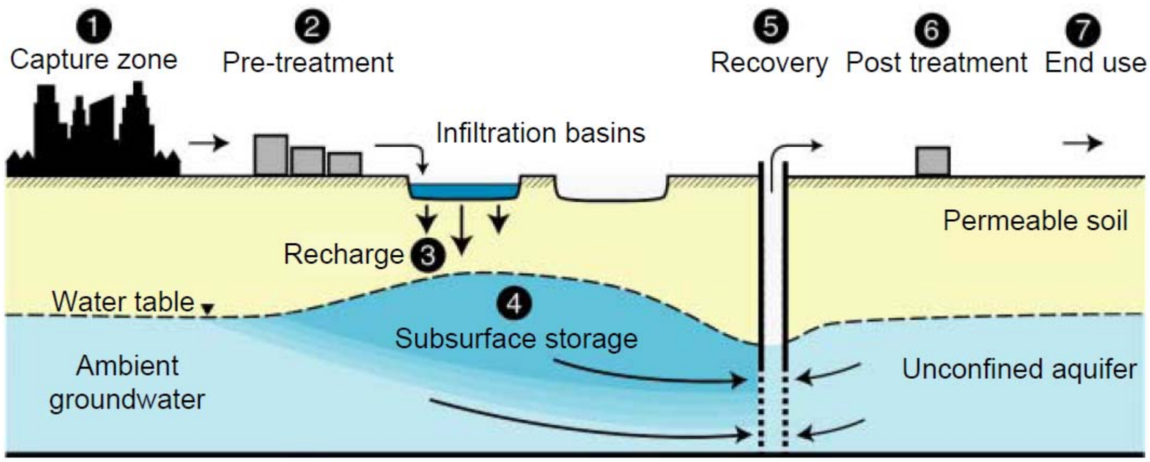

Figure 3: Scheme of managed aquifer recharge [Dillon et al., 2010]

Absorbing wells are underground structures, where the water infiltrates into the soil via wells or subterranean blind ditches. Because of the subsurface inflow of the water, evaporation has not as high an influence on the infiltrated water amount as on infiltration via reservoir.

Another alternative is infiltration without any building structure directly into Wadis. But not every village or town has its own Wadi to infiltrate water into the soil. In addition, the Wadi surface is sometimes clogged with very small soil particles from sedimentation that reduce the hydraulic conductivity and thus hamper a reliable infiltration [Wolf et al., 2008].

When planning a groundwater recharge site, it is necessary to consider the geology and hydrogeology of the underlying soil and rock, the amount of people that have to be supplied by that specific aquifer, and the source of the input water [Hochstrat et al., 2010]. There are considerable differences between an infiltration in clayey or silty soil, and sandy or pebbly soil with respect to the percolation velocity into the ground. The necessary hydraulic conductivity k_f for infiltration lies between $k_f=10^{-3}$ m/s (coarse gravel, coarse sand) and $k_f=10^{-5}$ m/s (sand and finer, more binding aggregates). A lower hydraulic conductivity, i.e.

an insufficient permeable soil causes very low infiltration rates, which means that aquifer recharge is not an efficient solution to reduce the groundwater salt concentration or to mitigate water scarcity [Mutschmann and Stimmelmayr, 1999; Tholen, 2006].

The amount of people that use this groundwater on a daily basis defines the size of the infiltration reservoirs and the volume of infiltrated water. The input water quality has an influence on the output quality of the groundwater after a minimum passage through the unsaturated soil, where different processes ameliorate the water. The aquifer can be considered as a bioreactor, too, where microorganisms remove contaminants and enhance its quality [Dillon et al., 2010].

It is illegal to infiltrate treated wastewater in Jordan [JS 893-2006]. However, it could be a realistic option for the foreseeable future. If the quality of the infiltrated water has a specific standard, the concentration of contaminants is low and the retention time within the aquifer is long enough, infiltration of treated wastewater can be an important source to reduce the water scarcity in countries like Jordan.

In any case, wastewater has to be treated before infiltration. In this case the treatment includes a screen, an equalisation tank, a trickling filter, aeration tanks, a clarifier, and UV disinfection right before the distribution to the users. The treated wastewater is then infiltrated into the soil, which necessitates a reservoir or well to drain the water.

Figure 4 depicts the scheme of the wastewater treatment plant in Deir Alla. For MAR it is crucial to use treated wastewater (or else), otherwise the groundwater would be contaminated with a very high load of organic pollutants. The WWT procedure in Deir Alla is solely an example for a treatment solution and is exchangeable with other technologies or treatment methods. It is important that the wastewater is treated to a specific water quality, so that the infiltration is harmless to the already endangered aquifer.

The output quality of the treated wastewater (= effluent) is assumed to be in the range of quality B or C [JS 893-2006]. After the seepage and the following soil passage, the infiltrated water is supposed to have water quality A. This is not comparable to drinking water quality but qualifies the water as usable for irrigation purposes, especially for cooked vegetables and playgrounds [JS 893-2006].

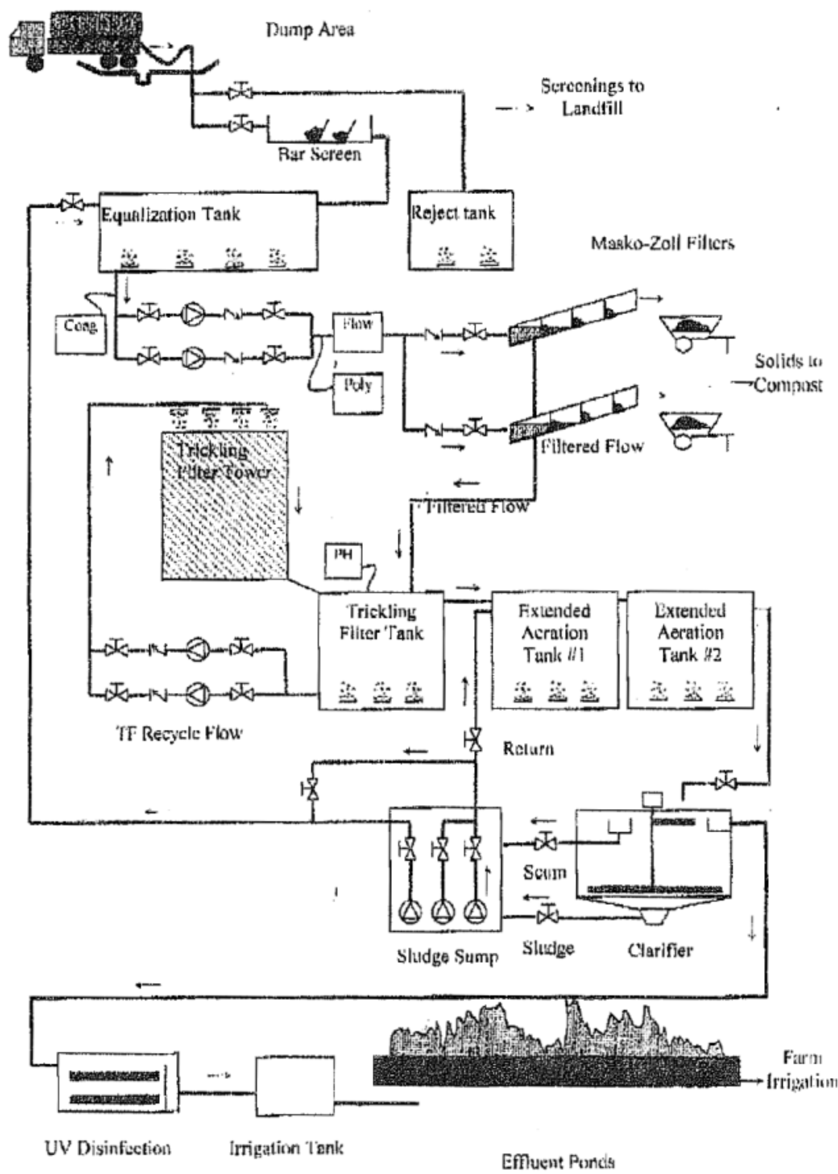

Figure 4: Scheme WWTP Deir Alla

2.3 Brackish water treatment (BRA)

Desalination of brackish water in general and brackish groundwater in this case is increasingly becoming an important water source and serves as a resource for irrigation water for agricultural needs [Birnack et al., 2010].

A decreasing groundwater table is not the sole problem concerning aquifers. In Jordan, not only is the existing amount insufficient to supply people with enough water, the salt concentration of the groundwater, too is a pressing problem. Brackish irrigation water leads

to high salt concentrations in the soils and hence to reduced productivity on agricultural land.
To use the brackish groundwater, a treatment to reduce the concentration is necessary. This is done with reverse osmosis by pressing the water through membranes. The salt molecules are too big to pass the membrane and thus the water is purified. The high energy demand causes high costs for the desalination technologies. Until now, the application of brackish and seawater desalination does not have as big a role in Jordan as it could have because of its expensive practice [Saghir and Schiffler, 1999].

3 Cost categories

In order to collect cost data for the three technology options DWWT, BRA, and MAR, relevant cost categories had to be identified that enable subsequential cost comparisons between the three technologies. This identification was based on the German DWA specifications for wastewater treatment plants and have been adapted to the according technology [DWA, 2003]. Furthermore, Tan-Torres Edejer et al. (2003) provided useful information on different cost classification options, e.g. classification by input category, like salaries or supplies, or intervention activity, like design and planning or construction. The compilation of cost categories has been done with respect to the subsequent cost-effectiveness analysis (CEA) and therefore supplementary items such as life-time have been added as outlined in the respective literature [Schmidt and Ross, 1975]. The final preparatory step for the CEA was the classification of all costs into the main categories investment costs and operation and maintenance costs (see chapter 5.2) [LAWA, 2005].

In general, there are two main cost categories to define, analyse, and evaluate the costs of a technology: capital costs as well as operational and maintenance (O&M) costs, where O&M costs are divided in fixed and variable. Capital costs encompass non-recurring costs, mostly buildings, structures, land, and fences, whereas O&M represent current costs or cost progressions, like energy costs and salaries (fixed O&M costs), and operational goods, spare parts or maintenance of the machinery (variable O&M costs). The fixed O&M costs arise even if the plant is not operated. Additionally, there are other costs that contain items like fees, capacity building, transport and shipping.
Table 1 displays the cost categories which formed the basis for the collection of the cost data. Discrepancies that arise between these categories and the actual data set (see Appendix A, page 35ff.) as well as between the data sets for the individual technologies are due to the different sources. Engineering models may be based on other categories than

plant concepts of actual treatment plants in Jordan and economic evaluations use other classifications as well. Additionally, different firms have different perceptions of the organisation and operation of their plants and thus use their own cost data categories.
Thus Table 1 serves as a basis for data collection and was developed during the collection process to fit the given data.

Table 1: Cost categories for cost analysis

general information		plant's capacity
		quantity of water
		intended use of generated water
		minimum quality standard achieved
		date of construction (investment)
		time of construction (investment)
		life-time
		duration of commissioning
capital costs		overall investment costs
		material for civil works (machinery, building materials)
		buildings
		land purchase costs
		various (fences around the plant, etc.)
O&M	variable	operational goods (chemicals, other materials, etc.)
		spare parts and maintenance
		advanced salary
	fixed	energy costs (variable cost)
		diesel, water, oil (variable cost)
		salary
further costs		capacity development costs (training)
		costs to deliver components to Jordan
		extra fees such as customs, handling
		transaction costs
		other charges, fees, insurances, etc.

4 Collection of cost data

In the process of data collection, different sources were used. These include technology providers, Jordanian plants, and literature. A major effort was undertaken to collect viable data. In March 2011 a field trip to Jordan was undertaken to collect cost data from different plant operators. Between June and September 2011, German technology providers were interviewed. Meetings and interviews in 2009 with Jordanian responsibilities resulted in a detailed set of cost data for material prices to calculate construction costs of the technologies. Relevant literature was consulted to complete the data set (see Appendix A, page 35ff.).

4.1 Data sources

4.1.1 Germa

Within the work packages 3.1 to 3.3 of the SMART II project, German technology providers develop technological solutions to mitigate the progressing water scarcity in the Lower Jordan River Basin. As mentioned before, these technologies include decentralised wastewater treatment and reuse (DWWT&R), managed aquifer recharge (MAR), and brackish water treatment (BRA).

In order to create robust data for the subsequent analysis, one major data basis for the CEA is the cost data provided by developers. These developers produce pilot plants for the different technologies that are tested in Germany as well as in Jordan at representative sites. These tests are conducted to monitor the plants in every-day use, their robustness, and reliability. The advantages of using the data from the technology providers are that the operation of the plants verifies the cost estimates.

Managed aquifer recharge

Huber SE, responsible for MAR in work package 3.2 of the SMART II project, was contacted to collect cost data for the MAR technology. In the course of extensive communication via email and telephone, pilot plant data for pre-treatment for MAR was made accessible by representatives of Huber SE, namely Dr. Stephania Paris and Celine Schlapp.

Brackish water treatment

BRA technology in work package 3.3 lies within the responsibility of Stulz-Planaqua. After extensive communication with Christine Klockow of Stulz-Planaqua, data for a membrane pilot plant was provided.

Decentralised wastewater treatment

Data for decentralised wastewater treatment was already collected by BDZ in SMART 1.

Data from Jordanian plants 4.1.2

A second important source of cost data are treatment plants currently operating in Jordan. Therefore several interviews with Jordanian experts and employees of the Water Authority Jordan (WAJ) were carried out in Jordan in March 2011. The data was gathered based on the previously identified categories and describe infiltration of treated wastewater and brackish water treatment. The sources and specifications of this data are described in the following chapters.

Managed aquifer recharge

The data for the MAR is to be ascribed to an interview on March 6th 2011 with Abdel-Majeed Al-Dayyat, manager of the Deir Alla Wastewater Treatment Plant located in the Balqa Govenorate. The data of the treatment plant show the cost of the pre-treatment step in infiltration. This technology is exchangeable, i.e. crucial is a treatment to a specific water quality before the water can be infiltrated. However, the data for especially the infiltration basin could not be provided. But the costs of the other categories were made available, including construction, O&M, and other costs.

The supplied number of population by the WWTP is about 100,000 person equivalents (pe). The input into the plant is lower than the plant's actual capacity with 300…350 m^3/day to 400 m^3/day. Hence it may be considered that the number of person equivalents supplied by aquifer recharge could be about 3500 to 7000 for a daily water usage of 0.05 to 0.1 m^3d/cap.

Brackish water treatment

The data for the brackish water treatment was collected in an interview with Rateb Al-Adwan, director of Water Quality at the WAJ on March 8th 2011. In Jordan, there are 23 desalination plants for drinking water in small communities (between 9,000 and 11,000 person equivalents). Brackish water with a concentration between 1,500 and 9000 mg salt per litre is treated accordingly. Multiple technologies can be found: nano-, ultra- or microfiltration. The cost for the plant that given by the WAJ is an example and encompasses the treatment of 1,680 m^3 per day.

Other data 4.1.3

Further data sources were consulted to supplement the data gathered above. These sources are briefly mentioned as follows.

Discussion with Jordanian engineers

The basis for the data is a meeting with co-workers of Nabil Ayoub Wakileh & Co. on April 21st 2009. Rami Abu-Arqoub, Ziad Wakileh, Sawsan Zaater, and Sabine Sorge participated. Material costs to calculate construction costs for the technologies were gathered.

Models

The conception and dimensioning of the constructed wetlands were conducted by engineers at UFZ and is based on models for intermittent sand filtration [Crites et al., 1998]. The design for SBR was provided by ATB (2009) and is discussed in Sorge et al., 2009 and Cardona, 2011, pers. comm.. The data for SBR and VFCW were provided in collaboration with work package 3.1 of the SMART II project.

Literature

The laboratory costs for all technologies in the category "other costs" listed in the appendix (see page 35) are calculated as follows [UN, 2003; Cardona, 2011, pers. comm.]:

$$cc = 1438 \cdot Q^{0.847} \qquad (4.1)$$

with

cc construction costs in JD

Q wastewater input in m^3/a

Equation 4.1 [UN, 2003] calculates the construction costs in denpendance on the yearly wastewater throughput of the respective plant.

A literature research to determine the necessary infiltration basin for MAR of 400 m^3/d resulted in different approaches to assess the costs of the basin. A detailed empirical equation to calculate the needed volume of an infiltration basin for rainwater infiltration provides an approach to dimension the size of the basin for a certain precipitation event [DWA, 2002; Schneider, 2006]. This is not applicable for the infiltration of treated wastewater, because there is no precipitation intensity, duration, or yield factor. Another approach uses physical details and experienced data. It describes four phases of infiltration via a basin: a filling phase, normal operation, basin depletion and cleaning. During the phase of normal operation the infiltration rate is supposed to be between 2 and 5 $m^3/(m^2\ d)$. The optimal storage depth is between 1 and 2 m and the bottom of the basin should include a constructed filter layer of sand and gravel of 0.5 m [Mutschmann and Stimmelmayr, 1999].

Assuming an infiltration rate of 2 $m^3/(m^2\ d)$ and a storage depth of minimum 1 m, an infiltration area of at least 200 m^2 is necessary. Thus, two basins with 100 m^2 each would be sufficient if solely volume is considered. But to secure a safe and robust operation of the aquifer recharge, more than two basins are advisable for back-up, because sedimentation, clogging, and vegetal invasion may reduce or stop infiltration. Three basins with 100 m^2 each are recommended to fulfil these requirements. Still, such a design contains considerable uncertainties since the achievable infiltration performance will significantly depend on local soil and geological properties.

Other data

The missing data for the category "other costs" in MAR and BRA were calculated on the basis of assumptions in SBR and VFCW. These involve costs for installation, construction management, and contingency. The calculated installation costs (see appendix, page 35), with 40 % of the construction costs, is an assumption based on BDZ experience [Cardona, 2011, pers. comm.].

4.2 Data selection

After careful exploration and comparison of the different data sources, it turned out that the cost data from the technology providers are solely for the pilot plants they install in Jordan, however these are not designed for an every-day use in little towns and villages to treat brackish and wastewater to a specific quality but rather to research additional aspects, like removal of medicine residues and the maximum possible degree of purification.

Hence, the data provided by the technology providers does not reflect the intended standard use of the plants in Jordanian villages. Thus, the comparison between collected data from Jordanian plants and data from German technology providers would be distorted and this would result in disadvantages for some of the technologies in terms of cost-effectiveness.

The data collected in Jordan in March 2011 is considered to be much more viable, because it reflects real, operated local plants. Especially the O&M costs are derived from long-term experiences with the every-day use of the surveyed plants. This means that they can be applied to assess and compare different technological solutions.

The cost data that is based on modelled plants and collected material prices is sufficient to simulate the different treatment options, because it is derived from experience value. This data can be calibrated with actual values of plants in operation and pilot plants after a certain operation time. With such an assessment, the cost data can be evaluated in retrospect [Cardona, 2011, pers. comm.].

Literature data in this case is also based on experience value and serves as an additional backup for the collected data set. Groundwater recharge via infiltration basins is a technologically simple but robust solution. Information about size and design was collected via literature research, the required costs to build an infiltration plant were identified in expert interviews in Jordan and Germany.

Considering these arguments, the final data set is composed as listed in Table 2.

Table 2: Data sources for collected cost data

Technology	Specification	Part	Source
DWWT&R	SBR	material prices	interview with Nabil Ayoub Wakileh & Co., April 21st 2009
		design	[ATB, 2009] [BDZ, 2012]
	VFCW	material prices	interview with Nabil Ayoub Wakileh & Co., April 21st 2009
		design	[Crites et al., 1998] [BDZ, 2012]
MAR		treatment step	interview with Abdel-Majeed Al-Dayyat, manager of the Deir Alla Wastewater Treatment Plant, March 6th 2011
		infiltration step	[Mutschmann and Stimmelmayr, 1999] interview with Nabil Ayoub Wakileh & Co., April 21st 2009 interview with Engicon, May 13st 2009
BRA			interview with Rateb Al-Adwan, director of Water Quality at the Water Authority of Jordan, March 8th 2011

5 Methodology of cost-effectiveness analysis

5.1 General

Economic evaluations of interventions that ameliorate water quality or mitigate water scarcity are an important tool for planners and decision makers. There is a chance that bad choices concerning projects are made if costs, benefits, and the environmental impact of projects are not accounted and evaluated in a proper way (in practice, costs and the impacts are always accounted). Hence suitable economic evaluation techniques to appraise measures are more than necessary [Winpenny, 1995]. Cost-effectiveness is fundamental for efficient and sensible decision-making, thus the CEA is one of the main decision making methods. It is able to rank alternative projects or plans and thus serves as a decision tool, but it cannot decide if an option should be implemented or not, or in other words if an alternative is acceptable [Bateman et al., 2002; Pearce et al., 2006].

In comparison to cost-benefit analysis (CBA), cost-effectiveness analyses have certain advantages. E.g. if it is not possible to describe the effectiveness or outcome in monetary terms, environmental or physical criteria are used, which are easier to determine [Aulong et al., 2009]. These criteria can be water quantities per time unit, reduction in pollution or improvements in human health or the environment [EPA, 2000]. Hence CEA, in general, compare the relation of an indicator of effectiveness (E) with the related costs (C). In the simplest form, the cost-effectiveness ratio (CER), a criterion for the evaluation, is calculated as follows [Pearce et al., 2006]:

$$CER = \frac{C}{E} \tag{5.1}$$

In contrast to the CBA, the process of data collection and processing is by far easier.

The main steps of a CEA of water management issues can be summarised as follows [Aulong et al., 2009; Schmidt and Ross, 1975; Winpenny, 1995]:

1. Stating the problem

   Specification of issues to solve, their cause, and possibly their development, e.g. water scarcity or a poor water quality.

2. Defining the objective

Description of objective of the project or plan, i.e. the goal that is to be achieved by implementing and operating the project.

3. Identifying and characterising water management measures

    After the identification of suitable measures to achieve the specified goal, a characterisation and description of these options follows.

4. Cost analysis of selected alternatives

    To evaluate the different measures, an extensive cost analysis is necessary to calculate the cost-effectiveness of each option. This analysis involves collecting cost data primarily for construction as well as operation and maintenance.

5. Discounting of costs

    A certain amount of money has a higher value now than in the future because of interest. In other words, a certain amount of cost that incur later in the future rather than in the present is preferable as interest can be saved or earned before paying. Discounting calculates the present value of a future payment or sum, in this case the costs of a project or plan.

6. Calculating CEA criterion

    To rank the measures, some kind of value or criterion is necessary. In the case of CEA this value can be annualised costs or cost-effectiveness ratio.

7. Sensitivity analysis

    A simple sensitivity analysis calculates how much the result changes if one process parameter is varied. It estimates the impact of the change of this parameter and the impact of uncertainties and errors respectively. More complicated sensitivity analyses vary more than one parameter at a time.

The literature distinguishes between two types of CEA: overall and incremental cost-effectiveness analysis. Overall CEA is the ratio of the annual or total cost of the option to the effect or outcome, respectively. Incremental cost effectiveness calculates the difference in costs if water quality or another criterion will be changed, and can be used as a benchmark measure [Wheeler, 1998].

In this study, the desired outcome is clear, because irrigation water has to have water quality A [JS 893-2006], and thus the overall CEA was considered to be the appropriate method. The comparison between the options is made over the whole life-time of the measures. Although the goal is the same (water quality A), the initial situation differs with respect to the water source being treated (treatment of wastewater vs. treatment of brackish water vs. aquifer recharge). Hence there is no uniform baseline scenario that can be used as a benchmark measure.

Cost-effectiveness is defined as the relation between costs and one unit of effect produced by an intervention [Sijbesma and Christoffers, 2009]. It is measured with different decision criteria, mainly [Aulong et al., 2009; LAWA, 2005]:

- Effectiveness-cost ratio (E/C)

  The effectiveness-cost ratio displays the quotient of effectiveness, i.e. a certain outcome, and the costs to achieve this outcome. This is reasonable for e.g. different measures with diverging results.
- Cost-effectiveness ratio (CER)

  The cost-effectiveness ratio is the inverse quotient of the effectiveness-cost ratio. The value derived from it serves as a basis for different conclusions than the ones derived from the effectiveness-cost ratio. It is useful if the goal to be achieved is comparable but the costs of the different measures vary.
- Net present value of cost

  The net present value (NPV) approach is used to evaluate long-term plans or projects. Net present values are calculated by abstracting the economic benefits (e.g. cost savings) from the costs at each year within a planning period (often the life-time of a construction); the differences are discounted to its present values. The sum of the discounted values adds up to the net present cost value of a measure.
- Annualised costs

  Annualised costs arise at regular intervals, i.e. annually. They are based on the calculation of the present value of the cost and further on an annuity factor (determined by the rate of interest and the time horizon) accounting for distribution of the costs over the whole project period.

In this CEA we decided to calculate annualised costs to evaluate the different technology options, in order to be in line with calculations undertaken in WP 3.1 and WP 7 of the SMART II research project. In relation to the annual throughput of the respective plants, a unit cost of treated water can be calculated. These results are comparable since the outcome quality (A) is defined and equal for all technologies.

The equations used to calculate annualised costs are described in the following section, the actual implementation of the analysis can be found in chapter 6.5.

5.2 Applied procedure

The first step in calculating annualised costs of a project is to sum up all investment (IC) and operation and maintenance (O&M) costs. Regarding the difference between single and regular payments, and the differing periods in which the costs arise, there are different factors for IC and O&M to calculate the total project costs (TPC).

The discount factor for single payments (DFS) is

$$DFS = \frac{1}{(1+i)^n} \quad (6.1)$$

where DFS discount factor for single payments
i interest rate
n evaluation period.

This factor multiplied with a certain amount of cost incurred at a specific year in the future renders the present value of this cost.

For recurring costs with constant values, the discount factor for uniform cost progression is calculated with

$$DFU = \frac{(1+i)^n - 1}{i \cdot (1+i)^n} \quad (6.2)$$

where DFU discount factor for uniform cost progression.

This factor multiplied with a certain amount of yearly cost (annuity) within the planning period of 1-n years renders the present value of these yearly cost arising in the future.

The total project costs then are

$$TPC = IC + O\&M \cdot DFU \quad (6.3)$$

where TPC total project costs [JD]

IC investment costs [JD]

O&M operation and maintenance costs [JD/a].

TPC represents the sum of the initial investment cost and the present value of the annual costs arising in the future (annuities).

To distribute the total project costs over the whole project period, an annuity factor (AF) is necessary:

$$AF = \frac{(1+i)^n \cdot i}{(1+i)^n - 1}, \quad (6.4)$$

This leads to the annualised costs (AC)

$$AC = TPC \cdot AF, \quad (6.5)$$

and, relating to the annual flow rate, to the specific treatment costs

$$STC = \frac{AC}{Q_a} \quad (6.6)$$

where UTC unit treatment costs

Q_a annual flow rate [m^3/a].

Note, that the computation of annualised cost can address the investment cost only (i.e. the O&M costs are not discounted and added simply to the annualised capital cost).

6 Implementation of the CEA

In this section we follow the seven steps of CEA (see chapter 5) in order to rank the alternative technology options: DWWT&R, MAR, and BRA.

6.1 Stating the problem

In the Middle East and North Africa (MENA) region in general and in the Lower Jordan River Basin in particular, there is an urgent need to exploit all available water resources in order to mitigate water scarcity. Because of brackish surface and groundwater, limited natural groundwater recharge, and the depletion of natural water resources with only marginal reuse of treated wastewater (even though there are regions with extensive water reuse), the water situation has become a serious problem in the study region. The overuse of freshwater and the discharge of wastewater into the environment without treatment add to the issue as well as the constant salinisation of surface and groundwater [Wolf and Hoetzl, 2011].

The cost-effectiveness analysis (CEA) presented here intends to compare the various technological solutions DWWT&R, MAR, and BRA to mobilise additional water resources. Although there is no one-fits-all solution for all locations within the study region, there are boundary conditions and other constraints that leave some decision margin and help to decide between the presented alternatives on a case-to-case basis. The CEA displays cost data that are general costs for the Lower Jordan River Basin. If decision-makers use the CEA for a particular location, adjustments regarding the cost data may be necessary. The main cost variations occur due to difference in bedrock, and thus differences in installation costs.

6.2 Defining the objective

The overall aim of the CEA is to assess the costs of treating one unit of water to a certain water quality for each of the three technology options. Since water demand is particularly urgent in agricultural irrigation, we focus on the costs of producing one cubic meter of water in water quality A as defined by Jordanian standard for irrigation water [JS 893-2006].

6.3 Identifying / selecting alternatives

The selection of the applicable technologies was part of SMART I. A short introduction to the different alternatives is given in chapter 2.

6.4 Cost analysis

The cost analysis encompasses the collection of cost data of the different options, the subsequent selection of applicable data (see chapter 4.2), and the concluding summary of the selected data (see Appendix A).

6.5 Assessment of annualised costs

The calculation procedure of the evaluation criterion *annualised costs* has been conducted as depicted in chapter 4. Note that the resulting total project (TPC) and unit treatment costs (UTC) in JD/m^3 only serve as comparison values. They have no absolute validity but merely facilitate the decision between the given alternatives [Sander, 2003]. This is due to changes within the relatively long project periods, and uncertainty about costs that might arise in the future.

The application of the cost comparison method to calculate UTC requires equality in the envisaged output. This is assured by determining the output quality according to the water quality for irrigation purposes defined by Jordanian standard [JS 893-2006].

6.5.1 Life-times

The different plants have differing life-times and different periods until purchasing of spare parts is necessary. Thus the evaluation periods in this CEA are set equal to the individual life-times of the different plants. The selected life-times are assumptions based on literature and empirical data. Therefore, the life-time of SBR is about 25 years [LAWA, 2005], of VFCW about 20 years [SMUL, 2004], the assumed life-time for MAR is about 30 years and for BRA about 15 years [LAWA, 2005].

Comparing all options, the higher life-time of MAR is owed to the long durability of simple infiltration basins and of large treatment plants like the one used to assess the treatment costs for MAR. If another pre-treatment option is used before percolation, life-time and reinvestment points have to be adjusted accordingly.

6.5.2 Input data

The input data for the calculation of the CEA criterion *annualised costs* is shown in Table 5 to Table 8, in Appendix A. The costs are categorised into investment (IC) and operation and maintenance costs (O&M), as required for the application of the calculation scheme. Sources and background are presented in chapter 4.

6.5.3 Discounting

In the process of calculating UTC for a comparative evaluation, all costs are discounted. Here, a difference is made between single payments and cost progressions (see equations 6.1 and 6.2). Since interest rates are uncertain, it was decided to use three discount rates (0.03;0.05;0.07).

6.5.4 Total project costs

Input for the calculation of the total present cost value (TPC) are the resulting data of the cost analysis (see Appendix A). They are categorised into investment costs (consisting of construction and other costs such as construction management and installation) and operation and maintenance costs (see equation 6.3).

The results in Table 4 are rounded to three digits. Since CEA is an ex-ante decision-making tool, the calculated costs are best possible estimates of costs.

Table 3: Total project costs (TPC) in JD

Rate of interest	0.03	0.05	0.07
SBR	1,250,000	1,140,000	1,060,000
VFCW	1,260,000	1,180,000	1,120,000
MAR, infiltration, three basins	91,800	86,700	83,200
MAR, infiltration+treatment, three basins	3,420,000	3,170,000	2,990,000
BRA	1,030,000	931,000	851,000

6.5.5 Unit treatment costs

To determine UTC for the analysed treatment plants, the total project costs are annualised, considering the individual evaluation periods. This is done by using an annuity factor (see equation 6.5). Unit treatment costs are then calculated by dividing the annualised costs by the annual flow rate Q_a of the plant. The result of the CEA thus represents annualised costs over the life-time, standardised to one cubic meter of water throughput. All resulting values are summarised in Table 3 and Table 4.

The results shown in Table 4 incorporate the results of the analysis for SBR and VFCW, the three basin MAR solution with pre-treatment in a central plant and brackish water treatment. All treatment options are designed to supply 5000 p.e.

Table 4: Unit treatment costs (UTC) in JD/m³

Rate of interest	0.03	0.05	0.07
SBR	0.53	0.60	0.68
VFCW	0.62	0.70	0.79
MAR, infiltration, three basins	0.03	0.04	0.05
MAR, infiltration+treatment, three basins	1.19	1.41	1.65
BRA	0.59	0.61	0.64

6.6 Sensitivity analysis

As a last step, a sensitivity analysis was undertaken. For this CEA the basic parameter interest rate i is varied in order to examine the influence of its alteration. Figure 5 depicts the results for UTC in JD per m^3. As expected there is a positive correlation between the increasing interest rate and rising UTC, though the incline is not the same for every technological option. With a rising interest rate, the factors DFS and DFU decrease, as does the value of future payments (Formulae 6.1 and 6.2). But the annuity factor (AF) and hence the annualised costs rise, which accounts for the incline in UTC (Formula 6.4).

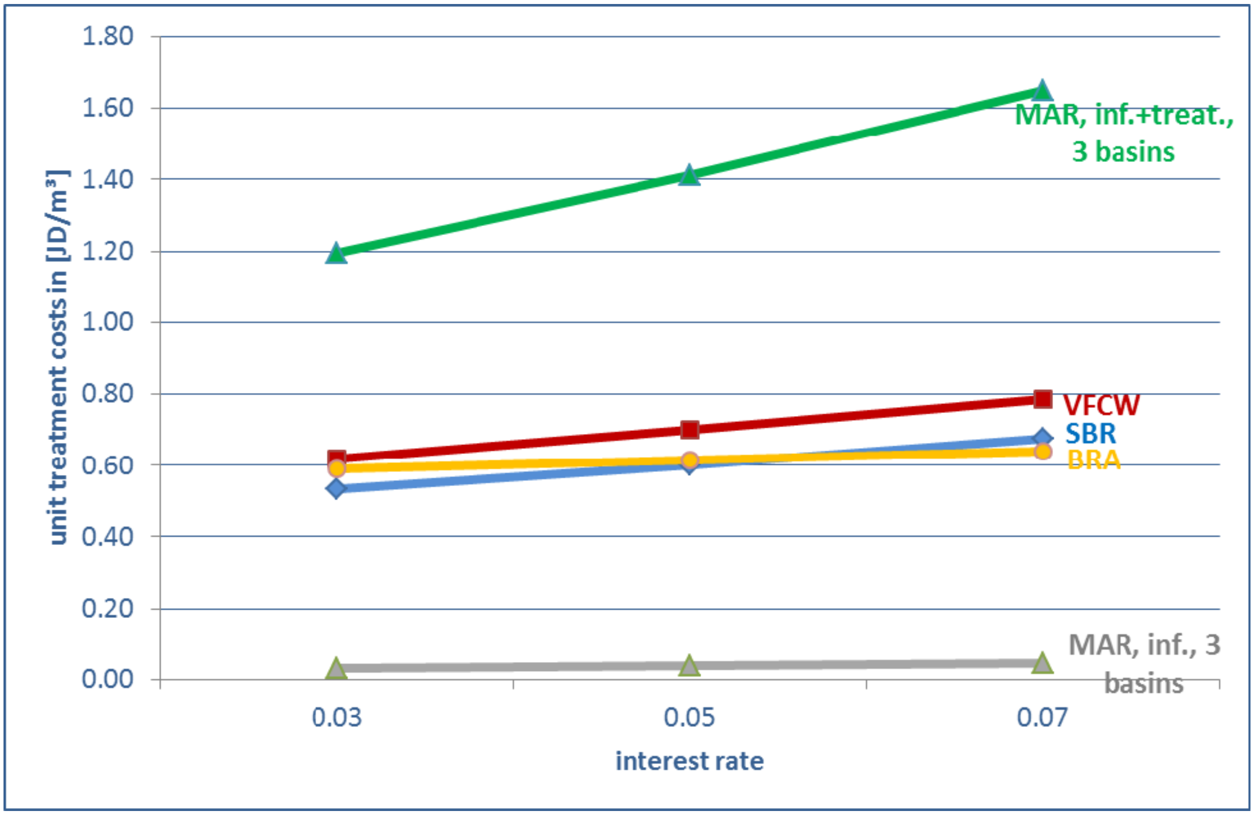

Figure 5: Unit treatment costs for all technologies in JD/m³

7 Discussion and conclusion

After extensive cost collection and analysis for the designated technology options DWWT, MAR and BRA, all data was categorised into investment and operation and maintenance costs. These categories function as input for the subsequent cost-effectiveness analysis which was conducted using a cost comparison method. The differences in construction and operation and maintenance were taken into account not only in terms of costs, but also by assessing and determining different life-times for the plants. Unit treatment costs (UTC) were chosen as cost-effectiveness criterion, which are calculated by normalising annualised costs to 1 m³ water throughput.

Our findings show that the decentralised technologies VFCW, SBR and BRA do not differ significantly in terms of their cost-effectiveness of producing one cubic meter of water quality A, with specific treatment costs ranging from 0.53 JD/m³ (SBR) and 0.59 JD/m³ (BRA) to 0.62 JD/m³ (VFCW). The two MAR options differ considerably from the other technologies and show up as in Figure 4. The least cost-effective option is MAR (treatment+infiltration) with 1.19 JD/m³ and the most cost-effective option is MAR (infiltration) with 0.03 JD/m³.

The high specific treatment costs for MAR (treatment + infiltration) can be ascribed to the treatment costs of the central wastewater treatment plant Deir Alla that was selected as an example for providing a water quality that would be suitable for infiltration purposes (see chapter 4.1.2). Note that pre-treatment in a centralised treatment plant before infiltration can be substituted by smaller decentralised low-tech treatment plants that generate water quality below standard A. Combining such plants with infiltration basins would result in water quality A at a lower cost. MAR (infiltration) turns out as the most cost-effective option because it assumes that a treatment plant is already in place. Thus, solely an addition of the infiltration basins is necessary and the additional costs arise from the infiltration step.

A closer look at the core technologies SBR, BRA and VFCW shows that treatment with SBR systems have a slightly lower treatment costs per cubic meter than BRA and VFCW. This can be explained by the comparatively simple treatment systems with a high removal capacity and sedimentation rate when processing wastewater (see chapter 1). Surprisingly, VFCW turn out to be the least cost-effective option of the decentralised technologies, although the distance between the specific treatment costs for constructed wetlands and the other technologies is only marginal. The higher costs are mostly due to substantial land requirements and the amount of filter medium needed for the wetland. However, we refrain from condemning VFCW as too expensive since different constructional alternatives and adjustment to in-situ conditions might result in another picture. Critics claim that VFCW is generally less cost-effective for large villages with 5,000 pe, and may be more viable for smaller pe values. However, a comparison of investment and O&M costs for small treatment plants (4 to 50 pe) shows a similar pattern as the results presented here, where constructed wetlands are listed as comparatively expensive, even though only used as finishing treatment [BDZ, 2011].

As expected, costs increase with rising interest rates, hence there is a positive incline from an interest rate of 3% to 7%. For plants with high investment costs and moderate O&M costs, the incline is steeper (see MAR infiltration+treatment, Figure 5) than for technologies with moderate investment costs and relatively higher O&M costs (see e.g. SBR and BRA, Figure 5).

The cost-effectiveness analysis can be used in decision processes that involve the determination of the most cost-effective or in other terms beneficial technological option to mitigate water scarcity. In order to make the analysis applicable to different locations in the Lower Jordan River Basin, we decided not to focus the analysis on one or two specific locations. Instead, our analysis presents general cost estimates that are generally applicable to the entire region. This point is very important when using the CEA results in single villages or specific locations, because construction costs are likely to vary according to the bedrock conditions. Decision-makers should therefore check, whether our assumptions for construction costs of the technology options are applicable to the village under considerations and make adjustments if necessary. The technology options under investigation were optimized to suit 5,000 p e and thus we cannot guarantee similar or equal results for smaller or larger villages. Our results can therefore only accurately guide decisions for villages or communities with about 5,000 p e.

Depending on the location, not all technology options might be feasible. For example, BRA is only an option if brackish water is available in sufficient quantities. Furthermore, MAR are only feasible if the hydraulic conductivity of the underlying soil is within useful parameters. If the resulting infiltration rate is too low, this option should not be considered in a water resources management plan for a specific location. Thus, when a decision is to be reached between different technology options only the results for the relevant technologies that are suitable to the local conditions should be considered. It is also important to keep in mind that until now, infiltration of treated wastewater for groundwater recharge is illegal in Jordan. Thus decision-makers should note that the inclusion of MAR can only serve as decision aid for possible future plans.

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Appendix

A. Cost data – input for CEA

Table 5: Cost data DWWT - SBR

parameter			unit	
population			pe	5,000
flow rate			m³/d	370
flow rate			m³/a	135,050
investment costs IC	treatment plant	preliminary treat	JD	25,300
		primary sep tank	JD	23,200
		buffer tank	JD	24,800
		SBR system	JD	238,00
		total cc SBR	JD	311,300
	sludge treatment	sludge dry bed	JD	89,900
	total cc		JD	401,000
	other costs	fence	JD	2,750
		installation costs	JD	160,000
		office and laboratory	JD	41,100
		construction management	JD	40,100
		contingency	JD	40,100
		total other costs	JD	284,000
	total investment costs		**JD**	**685,250**
O&M costs	Energy		JD/a	6,830
	Salary		JD/a	25,700
	total O&M		**JD/a**	**32,530**

Table 6: Cost data DWWT - VFCW

parameter			unit	
population			pe	5,000
flow rate			m^3/d	370
flow rate			m^3/a	135,050
investment costs IC	treatment plant	preliminary treat	JD	25,300
		primary sep tank	JD	23,200
		pumping well 1	JD	19,300
		pumping well 2	JD	11,800
		vertical flow wetland	JD	331,000
		recirculating tank	JD	54,400
		total cc CW	JD	465,000
	sludge treatment	sludge dry bed	JD	21,800
	total cc		JD	487,000
	other costs	fence	JD	2,750
		installation costs	JD	195,000
		office and laboratory	JD	41,100
		construction management	JD	48,700
		contingency	JD	48,700
		total other costs	JD	336,250
	total investment costs		**JD**	**823,050**
O&M costs	Energy		JD/a	2,080
	Salary		JD/a	26,300
	total O&M		**JD/a**	**28,380**

Table 7: Cost data MAR

parameter			unit	
population			pe	5,000
flow rate			m^3/d	400
flow rate			m^3/a	146,000
INFILTRATION				
realisation with three basins (recommended)				
investment costs IC	construction costs	excavation	JD	5,250.00
		sand and gravel filter	JD	3,000.00
		concrete walls	JD	7,540
	other costs	fence	JD	232
		installation costs	JD	6,316
		office and laboratory	JD	43,000
		construction management	JD	1,579
		contingency	JD	1,579
O&M costs	exchange/cleaning sand filter		JD/a	1,200.00
TREATMENT				
investment costs IC				
	construction costs	overall investment costs	JD	1,250,000
		material for civil works	JD	100,000.00
		buildings	JD	15,000.00
	other costs	installation costs	JD	546,000.00
		construction management	JD	136,500.00
		contingency	JD	136,500.00
O&M costs	Fixed	energy	JD/a	9,400.00
		diesel, water, oil	JD/a	1,355.00
		salary	JD/a	42,000.00
	Variable	operational goods, spare parts and maintenance, advanced salary	JD/a	5,511.00
	total O&M costs		JD/a	58,266.00
total IC MAR			JD	2,250,000
total O&M costs MAR			JD/a	59,500.00

Table 8: Cost data BRA

Parameter			unit	
Population			pe	5,000
flow rate			m³/d	400
flow rate			m³/a	146,000
investment costs IC	construction costs	overall investment costs*	JD	240,000.00
		total construction costs	JD	240,000.00
	other costs	installation costs	JD	96,000.00
		office and laboratory	JD	43,000
		construction management	JD	24,000.00
		contingency	JD	24,000.00
		total other costs	JD	187,000
	total investment costs		**JD**	**283,000**
reinvestment costs RIC	construction costs	overall investment costs	JD	240,000.00
	total reinvestment costs		**JD**	**240,000.00**
O&M costs	Fixed	energy	JD/a	5,000.00
		salary (engineer and operator)	JD/a	22,000.00
		management costs	JD/a	2,000.00
	Variable	operational goods, spare parts and maintenance	JD/a	33,400.00
	total O&M costs		**JD/a**	**62,400.00**

* includes brackish water treatment as well as brine disposal