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Benefits and Costs of Managed Aquifer Recharge: Further Evidence

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Abstract: Managed Aquifer Recharge (MAR) provides an integrated solution that allows aquifer storage to complement surface water storage. Cost–benefit analysis provides a systematic method for comparing alternative water infrastructure options. When market valuations of water infrastructure are unavailable, levelised cost is a widely accepted method of comparing MAR with alternative solutions. Benefits of MAR can be estimated by the cost of the cheapest alternative source of supply or the value of production using MAR. This article presents quantitative analysis of levelised costs and benefit cost ratios of 21 MAR schemes from 15 countries, and qualitative assessment of additional social and environmental benefits. MAR schemes recharging aquifers with natural water using infiltration basins or riverbank filtration are relatively cheap with high BCRs. Schemes using recycled water and/or requiring wells with substantial drilling infrastructure and or water treatment are more expensive, while offering positive BCRs. Most MAR schemes have positive or neutral effects on aquifer storage and condition, water quality, and environmental flows. Energy requirements are competitive with alternatives. This paper demonstrates strong returns to investment in the reported MAR schemes. MAR provides valuable social benefits and contributes to sustaining groundwater resources where extraction is managed.

Keywords: managed aquifer recharge; groundwater; water storage; water infrastructure; costs; benefits; cost benefit analysis; levelised cost; benefit cost ratio

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Citation: Ross, A. Benefits and Costs of Managed Aquifer Recharge: Further Evidence. *Water* **2022**, *14*, 3257. https://doi.org/10.3390/w14203257

Academic Editors: Enrique Fernández Escalante, Christopher J. Brown, June Mirecki and Catalin Stefan

Received: 24 August 2022
Accepted: 13 October 2022
Published: 15 October 2022

1. Introduction

There are many perspectives on the value of water. The 2021 World Water Development Report [1] identified five interrelated perspectives; in situ values of water resources and ecosystems, water infrastructure for storage and supply, water services including drinking water and sanitation, water as an input to production, and cultural values. Water holds different values for different people and stakeholder groups, and there are different ways to calculate and express these values. It is difficult to quantitatively compare the value of water for domestic use, environmental flows and cultural beliefs. Ward [2] observes that this has resulted in a high degree of public intervention in water management. As a result Young [3] notes that water allocation and management decisions are often guided by synthetic estimates and cost recovery objectives.

Ward [2] identifies special biophysical, socio-economic and institutional characteristics of water resources including spatial and temporal variability and uncertainty of flows, and difficulties in measuring supply or use, establishing ownership and regulating extraction. Reservoirs and aquifers store and release water for diverse uses and purposes including urban use, irrigation, power production, recreation, drought and flood risk reduction and flows for key ecological assets. In a given river or aquifer, upstream uses often reduce the quantity and quality of downstream flows. The diversity of water resource uses, purposes and impacts leads to a requirement for complex allocation institutions to optimise the benefits.

Groundwater resources have unique characteristics and play a special role in the environment and society. Groundwater accounts for about 99% of liquid freshwater on

Earth [4]. Quantities are relatively stable, but many groundwater resources recover slowly from depletion or are non-renewable. The 2022 World Water Development Report [4] finds that groundwater provides about half of the volume of water withdrawn for domestic use by the global population, and around 25% of all water withdrawn for irrigation serving 38% of the world's irrigated land. Yet, the Global Groundwater Governance Project [5] found that groundwater resources and their importance are often poorly understood and undervalued. Globally there has been substantial depletion of stored groundwater, estimated at between 100 and 200 km^3 a year from the beginning of the present century. In addition groundwater pollution reduces the suitability of ground water for drinking purposes and adversely affects groundwater dependent ecosystems [4].

Managed Aquifer Recharge (MAR) is an integrated approach that allows aquifer storage and replenishment needed to complement reservoirs and other surface water storages [4]. A review of sixty years of global progress in MAR by Dillon et al. [6] found that MAR provides cost-effective storage in aquifers that minimises evaporation and environmental impacts. MAR can also be used to retain unharvested urban stormwater and recycled water to be made available for productive use when needed. At the watershed scale MAR can be used to maintain environmental water flows. The application of MAR has increased by a factor of 10 over the last 60 years.

Water resources including groundwater acquire an economic value when their supply is scarce relative to demand for their uses. Growth of population and the economy increase the scarcity of water. There are usually a number of alternative ways of meeting demands for scarce water resources and storage and supplying water for domestic consumption, agricultural and industrial uses and the environment. It is important to establish a consistent methodology for comparing and evaluating the impacts of alternative water resource management options including MAR. Economic principles that can inform water policy rest on the concepts of benefit and cost. Cost–benefit analysis provides a systematic approach for evaluating the impacts of alternative water infrastructure options from the perspective of society as a whole [2].

Using the standard of economic efficiency an action or project is desirable if it results in an increase in total net value produced by the use of scarce resources. According to this standard an action or project should be undertaken if the added benefit is more than or equal to the added cost [2], or if the ratio of the benefit to the cost—the benefit cost ratio (BCR) is more than 1. The BCR is an indicator of the relationship between benefits and costs of a proposed action or project which can be used to compare and inform choices between alternative actions and projects.

Although benefits and costs are key determinants of the global uptake of MAR, there are few studies of the benefits and costs of different kinds of MAR, or of the performance of MAR compared to other water resource management options. Existing studies focus on small regions or individual cases and do not provide cross scheme synthesis at cross-continental scales.

The International Association of Hydrogeologists' (IAH) Commission on Managing Aquifer Recharge has established an economics of MAR working group to clarify and document the financial cost and economics of MAR. The following analysis draws on methodology developed by Ross and Hasnain [7] in collaboration with the IAH MAR economics working group, as explained below.

MAR schemes show a great diversity of type and scale. Pyne [8] illustrates how this diversity leads to a wide range of costs and benefits of different schemes, which are influenced by hydrogeological, environmental, socio-economic and institutional factors at various scales. Hydrogeology, soil and vegetation characteristics affect water recharge and recovery rates, socio-economic conditions affect the demand, availability and cost of labour and capital, and regulatory arrangements influence project set up and implementation costs [8,9].

This article contains five components:

1. Quantitative analysis of cost data from 21 MAR schemes from 15 countries, including capital and operating costs combined with data on volumes of water recharged and recovered, to estimate levelised costs per cubic metre of water recharged and/or recovered. A separate method for costing of three schemes that bank water for drought and emergency supplies is based on capital costs of daily supply capacity;
2. Analysis of the effect of selected factors on levelised costs, and sensitivity of levelised cost estimates to changes in project discount rates and length of life;
3. Quantitative estimates of benefits and benefit cost ratios (BCRs) and analysis of the effect of selected factors on BCRs. Benefits have been estimated using several approaches notably the costs of the next best alternative source of water supply or water treatment, the value of production using recharged water, and market-based valuations of MAR water;
4. Qualitative analysis of "unpriced" environmental and social benefits including aquifer integrity and groundwater levels, groundwater quality, environmental flows and energy requirements;
5. Conclusions.

2. Methodology and Data for Assessing the Costs and Benefits of MAR Schemes

Qureshi et al. [10] explain that efficient allocation of a groundwater resource requires that the marginal benefit (or value) of extracting an additional unit of groundwater equals the full marginal opportunity cost of extracting that unit of groundwater. The marginal opportunity cost consists of the actual marginal costs of extracting a unit of groundwater, plus the present value of the increase in future marginal costs which results from the future absence of that unit of groundwater. Nonrenewable groundwater resources are a special case in which exploitation reduces the stock of the resource, and the cost of extraction rises due to declining water levels. In this case, the benefits of current abstraction and future abstraction have to be balanced and should account for the scarcity rent of exploiting a nonrenewable resource.

Boardman et al. [11] provide details about how cost–benefit analysis provides a systematic approach for valuing and evaluating alternative water supply and management options by quantifying their impacts on society as a whole. A distinction should be made between financial and economic values. Whereas a private investor is interested in actual money costs and returns of a water project, governments need to consider the overall effects of the project on the economy in terms of the "opportunity costs" or the next best alternative use for the groundwater resources.

A distinction can be made between extractive and non-extractive values of groundwater [10]. The extractive value of groundwater includes municipal, agricultural, industrial, mining and some environmental uses. Non-extractive values of groundwater can be divided into in situ benefits, natural discharge benefits and option values. In situ benefits include protection of groundwater quality, avoidance of land subsidence and prevention of seawater intrusion. Natural discharge benefits include maintenance of springs and wetlands, their associated biodiversity and their recreational and cultural values. Option values include maintaining aquifers and connected ecosystems for use by future generations.

Market prices can be a good measure of the benefits of water projects when there are no major externalities or unpriced rationing of water. In practice market prices are hard to observe because of the physical, institutional and economic characteristics of many water services markets. Where water prices can be observed they are often set in an administered price system which may understate the marginal benefits of water [2,3]. Drinking water and irrigation water prices often reflect what people can afford to pay and what is politically acceptable rather than water scarcity.

An alternative method for estimating benefits of a public water supply program comes from the principle of alternative cost [2,12]. This principle is applied by recognising that the upper bound of willingness to pay for a publicly supplied service is the costs saved by not supplying the service from the least costly economically feasible alternative. Zekri [12] illustrates that this method must be used carefully because there are usually many possible alternatives including private alternatives to public projects and public alternatives to each component of multiple purpose programs. Higher cost alternatives should only be used to value the benefits of a water supply proposal if they would be built in the absence of the proposal [2].

The direct costs and benefits of intentional aquifer recharge such as water storage and recovery and additional water supplies (extractive values) are easier to account for and measure in monetary terms than indirect costs and benefits to third parties and the environment (non-extractive and option values). This study focuses on quantitative analysis of extractive values of MAR schemes because of lack of data available to measure non-extractive values. A brief qualitative analysis of non-extractive benefits and costs of MAR schemes is included in Section 4 of this article. The range of valuation techniques used in the analysis of benefits of MAR schemes is limited by data availability and the need to make consistent analysis across a diverse set of MAR schemes.

Time is an important dimension when comparing projects. Discounting costs and benefits provides a framework to compare different flows of costs and benefits over periods of time. Some projects may have a large flow of benefits early in their life whereas others might have long delayed benefits. Estimating the life of the program or project is difficult and some projects involve multiple stages including adaptation to factors such as to climate change and population growth. Sensitivity analysis provides a mechanism to estimate the effects of different assumptions about discount rates and project length of life, and more generally address change and uncertainty [2].

2.1. Costs of MAR Schemes

Levelised cost is the preferred method to estimate and present the capital and operating costs of MAR schemes following the methodology established by Ross and Hasnain [7]. Levelised costs of water recharged and/or recovered per cubic meter provide a widely accepted and effective method of comparing the costs of water from MAR and alternative water storage and supply solutions [9]. Levelised cost of a water supply project is defined as the constant level of revenue necessary each year to recover all the capital, operating and maintenance expenses over the life of the project divided by the annual volume of water supply.

Levelised costs per cubic meter of water recharged were estimated for schemes with the primary objective of aquifer recharge. Levelised costs per cubic meter of recovered water were estimated for schemes that were established primarily to provide additional water for domestic water supply or agriculture, or water security during droughts or at times of exceptional demand. The costs of recovered water include the costs of both recharge and recovery, in some of these cases a separate estimate of water recharge is provided. The cost of recovery capacity in cubic metres per day was used in the case of three schemes that were established to provide short-term or emergency supplies during periods of exceptionally high demand or drought.

Levelised costs were processed and standardized in three steps:

1. Financial cost data (capital and operating costs) were collected for each scheme in local currency units. Data was collected for each scheme on capital and annual operating costs. Some schemes were built in several stages and where the levelised cost for the entire scheme could not be estimated, levelised cost was estimated for a selected stage or stages of the scheme. In a few cases, capital costs were estimated by scaling up the costs of components of infrastructure such as wells.
2. The capital costs of MAR schemes apply to different years and periods of time, depending on when the scheme is assumed to start. The capital cost of each scheme was standardized to year 2016 values in local currency units by multiplying costs by a gross domestic product (GDP) deflator, which measures changes in prices of all domestically produced goods and services. A GDP deflator was used instead of a consumer price index because it was assumed that the inflation of MAR construction

costs is related more closely to changes in GDP than to consumer price changes. Local Currency Costs were then standardized by converting them to 2016 US dollars.

3. A standardised estimate of the levelised cost of each scheme was estimated assuming an operating life of 30 years, a discount rate of 5.0% and hence a capital recovery factor of 0.0650. Further details of this calculation are shown in an example in Appendix A at the end of this article. This standardised approach has the crucial advantage of enabling comparison between heterogeneous MAR schemes across different regions and scales. The standardised assumptions of 5% discount rate and 30 year project life are a reasonable approximation for most cases, although discount rates range from 3% in a few European countries to more than 10% in some developing countries, and operating life can range from 10 to 50 years or more.

Some MAR schemes are established to provide reserve supply capacity that ensures water security during emergencies such as extreme water shortages or short periods of exceptionally high demand. Ross and Hasnain [7] describe the relevant cost as capital cost divided by supply capacity ($/m^3/day) rather than levelised cost of supply. Supply capacity in m^3 per day is estimated by dividing the capital cost by the daily amount recoverable from storage in m^3. Operational costs are not assessed in these cases because facilities only operate occasionally, during emergencies or periods of exceptional demand, for durations that are unknown in advance.

2.2. Sensitivity Analysis

Sensitivity analysis was carried out to allow for variations in national discount rates and project lengths of life.

2.2.1. Discount Rates

A high discount rate reduces the weight given to future costs in relation to current costs. Capital costs make up the major upfront costs of projects, future costs are mainly operating and maintenance expenses. Therefore, low discount rates favour projects with a relatively high share of capital costs compared to operating costs, whereas high discount rates favour projects with a relatively low share of capital costs.

There is no consensus on the appropriate method for estimating the social discount rate (SDR) for social infrastructure projects. Freeman et al. [13] explains that two commonly used alternatives are the social time preference rate (SRTP) and the social opportunity cost of capital (SOC). The SRTP is the rate at which society is willing to postpone a unit of current consumption in exchange for more future consumption. Using this approach recent UK estimates of the SDR have been in the range 3.5–3.75% [13]. Zhuang et al. [14] argue that the SOC can be approximated by the marginal pre-tax rate of return on private investments which are displaced by public investments. Harrison [15] and Warusawithrana [16] present estimates of the social opportunity of capital varying between about 7% and 9%. In response to varying methods and estimates of the SDR the US Council of Economic Advisers and Harrison propose sensitivity testing social infrastructure proposals using alternative discount rates. The US Council of Economic Advisers [17] suggests using rates of 3% and 7%. Harrison [15] suggests using real rates of 3, 8 and 10%, representing the weighted average riskless rate of return, the weighted average rate of return and a rate of return for a riskier asset that reflects the marginal productivity of capital during the 2000s. In this paper the sensitivity of costs and benefits of MAR to variations in the discount rate is tested using rates of 3%, 5% and 8%.

2.2.2. Project Length of Life

Increasing the length of the life of a project reduces the levelised costs. Schemes with a longer life have a lower levelised costs than equivalent schemes with a shorter life, therefore schemes with a high capital cost and a long life may have lower levelised costs than schemes with a low capital cost and a short life.

The intended length of life of MAR projects is variable ranging from less than 20 to over 50 years. The OECD [18] finds that many water infrastructure projects remain in operation beyond 50 years. In this paper the sensitivity of costs and benefits of MAR schemes to variations in the length of life is calculated assuming a project life of 30 and 50 years. Some projects have been increased in size during the life of the original project. In these cases costs and benefits have been calculated for the project as originally specified.

2.3. Benefits of MAR Schemes

Studies by Marsden Jacob and Associates [19] and the National Academies of Sciences, Engineering and Medicine [20] found that in the absence of market prices, a range of techniques have been established to value the benefits of MAR schemes. These include the avoided cost of the cheapest alternative supply or treatment, or the net value of production using recharged water (e.g., farm production). In situ groundwater values are estimated by the costs avoided because groundwater resources are protected by MAR—avoided costs include costs of pumping, saltwater intrusion and subsidence. Brief details of the approach used to value the benefits of individual MAR schemes in this publication are included in Section 3.3 below. There are also various methods to value unpriced social and environmental benefits and to estimate the price people are willing to pay for services from MAR [10,21]. An example of the application of the analysis of willingness to pay for benefits from a MAR scheme can be found in Ruperez et al. [22].

The choice of valuation techniques depends on the context and objectives and scope of MAR and the availability of information. If the main benefit of a MAR scheme is additional water supply, the monetary value of additional supply (either annual supply or reserve supply for drought years) may be estimated by one of the following methods:

1. Volume of water recovered or supplied multiplied by the price of water produced by the scheme. Theoretically this is the best and most direct way to estimate the value of MAR water, but it is often not feasible because of absence of water markets and/or data on transactions. The cost of water for recharge provides an alternative market-based valuation, but water is often supplied at rates that do not reflect its full economic value;
2. The cost of recovering or supplying an equivalent amount of water of similar quality by the next cheapest economically feasible supply option. This may be described as the alternative cost of production or the avoided cost of production. If the main benefit is an improvement in water quality to meet a specified standard, as might be the case in a MAR scheme using recycled stormwater or wastewater, the benefit can be valued by the costs of the next cheapest water treatment facility. The benefit of water reserve supply schemes can be estimated by the avoided cost of an alternative that will provide the equivalent supply capacity. The next cheapest supply option is used for estimating benefits of the majority of schemes included in this article;
3. In the case of water for agricultural or industrial use additional supply can be valued by the net benefit (revenue minus cost) of additional production made possible by the additional water supply owing to MAR.

2.4. Qualitative Estimates of Non-Extractive Environmental and Social Benefits

MAR schemes have non extractive environmental and social benefits and costs that cannot be easily measured or quantified. This paper includes a brief qualitative assessment of the effects of MAR schemes on groundwater quantity and aquifer integrity, groundwater quality, environmental flows and energy costs. Intentional aquifer recharge increases groundwater stocks and water levels, and enables aquifer integrity and well water levels to be maintained when groundwater extractions do not exceed recharge minus outflows. Aquifer storage and recovery can improve water quality by diluting and treating pollutants. In connected groundwater and surface water systems MAR can enable base flow and environmental flows to be maintained in dry times. Finally, while MAR schemes have significant energy requirements for groundwater pumping and treatment, these can be less than alternative sources of water supply.

2.5. Data

The data for this paper was compiled as part of a study of 28 global MAR schemes edited by Zheng et al. in collaboration with members of the International Association of Hydrogeologist's Commission on Managing Aquifer Recharge (IAH-MAR), UNESCO and the Groundwater Solutions Initiative for Policy and Practice (GRIPP) and published by UNESCO in 2021 [23]. The assessment in this paper refers to the analysis of 21 of the 28 case studies included in the UNESCO publication supplemented by additional analysis of individual cases. These case studies were selected because they included quantitative estimates of both benefits and costs using standardised methodology.

3. Results and Discussion

3.1. Costs of MAR Schemes

An overview of the costs of 21 MAR schemes from 15 countries is presented in Table 1. This table shows the average annual volumes of water recharged and recovered under each scheme and the levelised cost per cubic meter recharged and/or recovered, standardised to USD 2016 values, using a discount rate of 5% and assuming a project life of 30 years. Levelised costs for recovered water are included if data is available, in other cases levelised costs of recharge are shown. The table also shows the sensitivity of levelised costs to changing the discount rate to 3% and 8%, and increasing the project life to 50 years.

Table 1. MAR case studies: volumes of water recharged (Rch) and recovered (Rcv) per year (Yr), and levelised costs (LC) of water (costs are in USD at year 2016 values).

	Case Study Location	MAR Type [i]	Water Source [ii]	End Use [iii]	Vol Rch Yr (10^3 m^3) [iv]	Vol Rcv Yr (10^3 m^3) [v]	LC m^3 Rch (USD) [vi]	LC m^3 Rcv (USD) [vii]	LC with 3% & 8% DR [viii]	LC with 50 yr PL [ix]
1	Khulna Bangladesh	W	N	HC	0.677	0.225	1.752	5.252	4.502 6.580	4.711
2	Turku, Finland	IB	N	HC	22,800	22,300	0.892	0.912	0.775 1.144	0.813
3	San Luis Rio, Mexico	IB	R	AG	11,000	11,000	0.020	ne	0.019 0.023	0.019
4	Dharta basin, Rajasthan, India	ICM	N	AG	779	779	0.007	ne	0.006 0.009	0.006
5	Genevois France-Switz	IB	N	HC	6320	6320	0.754	ne	0.650 0.931	0.678
7	El Carracillo, Spain	IB	N	AG	2400	2400	0.207	ne	0.168 0.279	0.179
9	Perth Australia	W	R	HC	14,000	14,000	ne	1.292	1.206 1.437	1.230
10	Orange Co, USA	IB	N	HC	148,000	148,000	0.450 [x]	ne	0.430 0.490	0.436
12	North London UK	W	N	HC	60 per day [xi]	66,000	ne	USD 730 m^3 day	ne	ne
13	Windhoek Namibia	W	N	HC	30 per day	11,000	ne	USD 860 m^3 day	ne	ne
14	Salisbury S. Australia	W	R	NPU	3500	2500	ne	0.986	0.837 1.162	0.911
15	Uttar Pradesh India	IB	N	AG	45	45	0.048	ne	0.046 0.055	0.047
17	Central Platte Nebraska USA	ICM	N	AG	11,110	2340	0.044	0.212 [xii]	0.168 0.287	0.180
18	Hilton Head USA	W	N	HC	8 per day	950	ne	USD 490 m^3 day	ne	ne

Table 1. *Cont.*

	Case Study Location	MAR Type [i]	Water Source [ii]	End Use [iii]	Vol Rch Yr (10^3 m^3) [iv]	Vol Rcv Yr (10^3 m^3) [v]	LC m^3 Rch (USD) [vi]	LC m^3 Rcv (USD) [vii]	LC with 3% & 8% DR [viii]	LC with 50 yr PL [ix]
19	Serchio R Lucca Italy	RBF	N	HC	13,600	13,600	ne	0.162	0.153 0.178	0.156
20	Haridwar India	RBF	N	HC	15,400	15,400	ne	0.107	0.102 0.112	0.105
21	Arizona Water Bank USA	IB	N	HC& AG	342,000 [xiii]	ne	0.092	ne	ne	ne
22	Sidfa Egypt	RBF	N		2190	2190	ne	0.038	0.036 0.042	0.037
25	Koksjide Belgium	IB	R	HC	1959	1292	0.500	ne	0.433 0.614	0.451
27	Wala Wala Jordan	IB	N	HC	6739	11,734	ne	0.388	0.334 0.472	0.353
28	Dinteloord The Netherlands	W	R	AG	125	125	ne	0.760	0.635 0.973	0.669

[i] MAR Type: W = wells, IB = infiltration—basins, ICM= infiltration—in channel modifications. [ii] Water source: N = natural water and R = recycled water including wastewater & urban stormwater. ne = not evaluated. [iii] End use: HC = human consumption, NPU human non-potable use, AG = agricultural use. [iv] Volume of water recharged per year, thousand cubic metres (Vol Rch Yr). Daily recharge capacity for 3 schemes established to provide reserve supply capacity. [v] Volume of water recovered per year (Vol Rcv Yr): thousand cubic metres. [vi] Levelised cost per cubic metre recharged (LC m^3 Rch) with discount rate (DR) of 5% & project life (PL) 30 years. [vii] Levelised cost per cubic metre recovered (LC m^3 Rcv) with 5% DR & 30 year PL. [viii] Levelised cost per cubic metre recovered or recharged (if recovered not available) assuming DR of 3% (top number) & 8% (bottom number) & 30 year PL. [ix] Levelised cost per cubic metre recovered or recharged (if recovered not available) assuming 5% DR & 50 year PL. [x] Orange County is a large multipurpose project. This analysis considers one part of the Orange County project the Santa Anna River (SAR) recharge. Cost is met by a Replenishment Assessment Fee of USD 0.45 and other sources of revenue. [xi] In the case of the North London, Windhoek and Hilton Head schemes daily recharge and maximum daily recoverable volumes are shown instead of annual amounts recharged and recovered. [xii] Cost per m^3 of increased flow to the river from groundwater. [xiii] Average annual recharge 2000–2009.

A previous study by Ross and Hasnain [7] estimated the costs of a different set of 21 MAR schemes and included a breakdown of capital costs and operating costs. That analysis indicated that schemes with the lowest costs use in channel or basin infiltration coupled with natural water sources that do not require expensive treatment. Schemes with the highest costs involve recharge or injection wells and recovery of recycled stormwater or wastewater. These schemes may require relatively costly treatment to meet standards for drinking water or non-potable use (NRMMC, EPHC, NHMRC) [24]. Data collected for this paper includes a wider range of MAR schemes and countries than in previous analyses, which enables more representative analysis of factors that affect scheme costs and benefits. While the data does not include breakdowns of capital and operating costs the results are broadly consistent with the previous findings by Ross and Hasnain.

3.2. Factors That Influence Levelised Costs

The results presented in Table 1 are consistent with findings of previous research that the main factors affecting differences in annual average levelised costs of MAR schemes are the source of recharge water, end use of recovered water and MAR type and technology. Costs are also influenced by project size and economies of scale, and the level of income in host countries. Factors that affect the levelized costs of 18 of the 21 MAR schemes are summarised in the following paragraphs. Costs of three reserve supply schemes are not included because these costs are measured by daily supply capacity instead of annual average levelised costs.

3.2.1. Source of Water

Generally MAR schemes that recharge natural water are cheaper than schemes using recycled water. Schemes using natural water and in channel modification or basin infiltration methods offer relatively cheap water supplies. Examples include Dharta Basin and Uttar Pradesh in India, El Carracillo in Spain and Central Platte in the USA. MAR schemes using infiltration and recovery of natural water for drinking water can be very cheap compared to alternatives because natural treatment during underground storage reduces the costs of treatment of recovered water prior to human consumption. Examples include the Arizona Water Bank and the three riverbank filtration schemes.

Schemes using recycled water such as stormwater and especially wastewater are more expensive than schemes using natural water because they require more expensive treatment before recharge and after recovery in order to avoid soil and water contamination, and to meet national standards for water in specific uses. Examples include Perth and Salisbury in Australia and Dinteloord in The Netherlands. However, MAR using recycled water can still be substantially cheaper than alternative water supplies. This is confirmed by other studies. Cooley et al. [25] report that the median levelised cost of water from stormwater capture and recharge projects averaged between USD 0.48 m^3 for large projects (8–10 Mm^3), and USD 1.28 m^3 for small projects (less than 1.85 Mm^3). Levelised costs for small projects (less than 12 Mm^3) using recycled wastewater for indirect potable reuse were USD 1.50 m^3. This compares with a median cost of USD 2.13 m^3 for water produced by small desalination facilities (less than 20 Mm^3). Diringer et al. [26] found a median levelised cost of USD 0.67 m^3 for 50 stormwater capture projects—USD 0.96 m^3 for urban stormwater and USD 0.43 m^3 for non-urban stormwater. Recycled wastewater schemes have the advantage that they can generally be used continuously at full capacity whereas stormwater schemes lie idle during dry periods.

In the case of water banking to provide groundwater reserves that maintain supplies in drought conditions or buffer against climate change, there may be no viable alternative supply, or the costs of such a supply would greatly exceed the average marginal cost of additional supplies from conventional sources. The three schemes established to provide emergency reserve supplies, North London, Hilton Head, and Windhoek are not directly comparable with other schemes in Table 1 because their costs are measured in terms of daily supply capacity. The average cost of daily supply for these schemes is USD 744 per m^3/day.

3.2.2. End Use

Schemes that recharge water for agricultural and non-potable end uses are cheaper than schemes producing water for human consumption because less expensive treatment is required to achieve standards for agricultural water use than for human consumption. The average levelised cost for six schemes producing water for agriculture and one scheme for non-potable use was USD 0.23 m^3 compared to USD 0.63 m^3 for nine schemes producing water for human consumption. Two exceptionally large schemes, Orange County and the Arizona Water Bank produced water for human consumption at the relatively low average levelised costs of USD 0.45 m^3 and USD 0.09 m^3, respectively.

3.2.3. MAR Type and Technology

Infiltration methods usually offer cheaper infiltration than wells and well fields. The average levelised cost of water from 11 schemes using infiltration methods was USD 0.24 per m^3 compared to USD 1.24 per m^3 for water from four schemes using wells. The levelised cost for water from nine schemes using infiltration methods was USD 0.50 m^3 excluding the very large Orange County and the Arizona Water Bank schemes. Riverbank filtration schemes such as Serchio in Italy, Haridwar in India and Sidfa in Egypt provide a low-cost alternative method of infiltration when feasible. Wells installed in the bank next to a river draw water from the river through the bank. Bank filtration partially purifies river water reducing costs of water treatment although some treatment, e.g., for iron removal, is required. The cost of the three riverbank filtration schemes averaged 0.11 US cents m^3.

3.2.4. Project Size

Large projects benefit from economies of scale that can result in lower levelised costs than smaller projects, although this advantage is sometimes offset by the greater range of objectives and functions that larger projects have to meet. The economies of project size are illustrated by the relatively low cost of water supplied by the Orange County and Arizona Water Bank projects.

3.2.5. Country Incomes

MAR schemes in low income countries have lower costs than schemes in high income countries, for example the average levelised cost of eight schemes using natural water in high income countries was USD 0.23 m^3 compared to an average of USD 0.10 m^3 for five schemes using natural water in low and middle income countries.

Table 2 shows average annual levelised costs of 18 of the 21 schemes in Table 1 excluding the three reserve supply capacity schemes whose costs are measured differently. These schemes are divided into three categories, recycled water wells and infiltration, natural water wells and infiltration and riverbank filtration. The average levelised cost of five schemes using recycled water—USD 0.74 per m^3—is much higher than the average levelised cost of 10 schemes using natural water—USD 0.24 per m^3 for wells and infiltration, and USD 0.11 for three schemes using riverbank filtration.

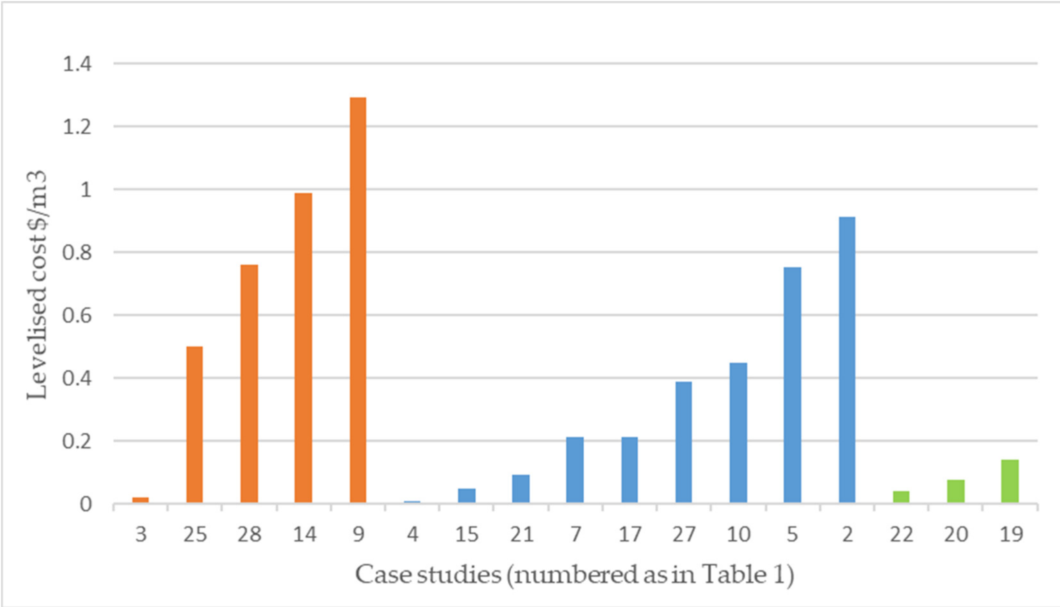
Table 2. Average (AV) levelised costs of MAR schemes in USD per m^3 and standard deviations (STDEV) (in year 2016 values), by water source (number of schemes in brackets).

Recycled Water Wells and Infiltration	Natural Water Wells and Infiltration	Riverbank Filtration (RBF)
0.74 (AV) (5) 0.58 (STDEV)	0.24 (AV) (11) 0.16 (STDEV)	0.11 (AV) (3) 0.03 (STDEV)

The levelised cost of 17 of the MAR schemes in Table 2 is shown in Figure 1. The Khulna scheme is excluded because it has an exceptionally high recovery cost of USD 5.292 that cannot be displayed at a comparable scale to the other schemes. There are significant variations among the schemes in each of the three categories but most of the schemes using natural water shown in blue (wells and infiltration) and green (RBF) are much cheaper than schemes using recycled water shown in orange. Two schemes using natural water, Turku and Genevois are more expensive than the San Luis scheme using recycled water, because water for these schemes requires expensive treatment to meet standards for human consumption, whereas the San Luis scheme supplies water for agriculture which requires less expensive treatment.

3.3. *Benefits and Benefit Cost Ratios of MAR Schemes*

The following section presents BCRs for 21 MAR schemes. As discussed earlier market prices can be a good measure of the benefits of water projects but in practice market prices are hard to observe, and where they can be observed they are often set in an administered price system which understates the marginal benefits of water. In this study benefits for 13 of the 21 MAR schemes are estimated by the cost of the next cheapest alternative to MAR. Market based valuations of water are used to estimate benefits for four schemes and the value of agricultural production produced by MAR water is used to estimate benefits for three schemes. Estimated BCRs for each of the 21 schemes together with brief explanatory comments about the methods and sources for estimates are presented in Table 3. Most of the data is sourced from case studies in Zheng et al. [23], references to additional sources are shown in column 7 of Table 3.



Legend: recycled water schemes: [orange], natural water schemes: [blue], riverbank filtration schemes: [green].

Figure 1. Average levelised costs of MAR schemes in USD per m^3.

Table 3. MAR case studies: levelised costs (LC) of water and benefit cost ratios of MAR schemes.

	Case Study Location	LCm^3 Rch (USD)	LC m^3 Rcv (USD) [i]	BCR	EST [ii]	Explanatory Comments about Benefits and BCR
1	Khulna Bangladesh	1.752	5.272	1.5	AC	Cost of MAR compared with next best alternative, reverse osmosis
2	Turku Finland	0.892	0.912	1.4	AC	Cost of MAR compared with renovation & use of 2 local surface water plants
3	San Luis Mexico	0.020	Ne	3.0	AC	Cost of MAR compared with water treatment in surface-based facility
4	Dharta basin India	0.007	Ne	5.3	AgV	Benefit measured by increase in net profit owing to extra crops grown with additional irrigation enabled by MAR
5	Genevois France-Swiss	0.754	Ne	5.8	AC	Cost of MAR compared with new water treatment plant
7	El Carracillo Spain	0.207	Ne	2.2	P	Ratio of shadow price of irrigation water estimated from willingness to pay surveys (USD 0.45), to levelised cost of additional water available owing to MAR ($US 0.21) [27]
9	Perth Australia	ne	1.292	1.5	AC	Cost of MAR is about 2/3 of cost of new seawater desalination plant providing equivalent volume of water
10	Orange Co California USA	0.450	Ne	1.8	MV	Ratio of price paid by OCWD for MWD treated water (USD 0.82) to the required pumping fee to support the Groundwater Replenishment System (USD 0.45)
12	North London UK	ne	USD 730 m^3 day	5.5	AC	Cost of the cheapest alternative supply option without accounting for the costs of water transfers
13	Windhoek Namibia	ne	USD 860 m^3 day	>2	AC	Unit cost of water from MAR is substantially less than alternative options that require expensive water transfers
14	Salisbury S. Australia	ne	0.99	2.5	AC	Cost of MAR treatment of stormwater used for public open space irrigation compared with lowest cost alternative—mains water supply

Table 3. *Cont.*

	Case Study Location	LCm^3 Rch (USD)	LC m^3 Rcv (USD) [i]	BCR	EST [ii]	Explanatory Comments about Benefits and BCR
15	Uttar Pradesh India	0.048	ne	1.3	AgV	Net returns from additional agricultural production
17	Central Platte Nebraska USA	0.044	0.212 [iii]	6.7	AgV	Ratio of unit value of agricultural production to levelised cost of recovered water
18	Hilton Head USA	ne	USD 980 m^3 day	2	AC	Cost of MAR compared to alternative treatment and transmission facilities sized to meet peak day demands
19	Serchio R Lucca Italy	ne	0.162	>10	MV	Financial benefits derived from 0.18/m^3 unit charge for water result in estimated BCR of 1.59. Addition of human health and aquifer conservation benefits raise estimated BCA to >10 [27]
20	Haridwar India	ne	0.105	5.1	AC	No estimate of economically feasible alternative supply in Haridwar. Estimate based on similar RBF scheme in neighbouring Srinagar—produces water at less than 20% of cost of surface water treatment [28]
21	Arizona water bank USA	0.092	ne	2.2	MV	Ratio between average purchase price of AWB stored water and AWB's average cost of purchasing water
22	Sidfa Egypt	ne	0.038	4.7	AC	No estimate of economically feasible alternative supply in Sidfa. BCA estimated by comparing similar RBF scheme in Aswan region with surface water treatment plant [29]
25	Koksjide Belgium	0.500	ne	2.2	AC	Cost of MAR compared to cost of purchasing drinking water from neighbouring area
27	Wala Wala Jordan	ne	0.388	~7	MV	Ratio of current average water tariff to estimated unit cost of recovered water
28	Dinteloord The Netherlands	ne	0.760	I.4	AC	Cost of MAR compared with cost of buying agricultural land for surface water storage

[i] Cost of water supply capacity per cubic meter per day is reported for three schemes (North London, Hilton Head and Windhoek); [ii] Column 6 shows the method of estimation (EST). AC represents estimates based on alternative cost, MV represents estimates based on market valuations of recharged or recovered water, AgV represents value of agricultural production using MAR water; [iii] Cost per m^3 of increased flow to the river from groundwater.

3.4. Factors Affecting Benefits and Benefit Cost Ratios of MAR Schemes

The major factors influencing differences in benefits and BCRs of MAR schemes are the same as the main factors that influence scheme costs, i.e., the source of water, end use and MAR type and technology. This is not surprising since cost of the next cheapest alternative source of supply is used to estimate benefits for the majority of the schemes. Volume weighted average BCRs for different types of source water, end use and MAR type and technology are summarised in Table 4. In this relatively small sample of global MAR schemes volume weighted average BCRs are highly sensitive to the inclusion or exclusion of large schemes. Table 4 shows average BCRs including and excluding three schemes with exceptionally large recharge volumes; Orange County, Arizona Water Bank and North London.

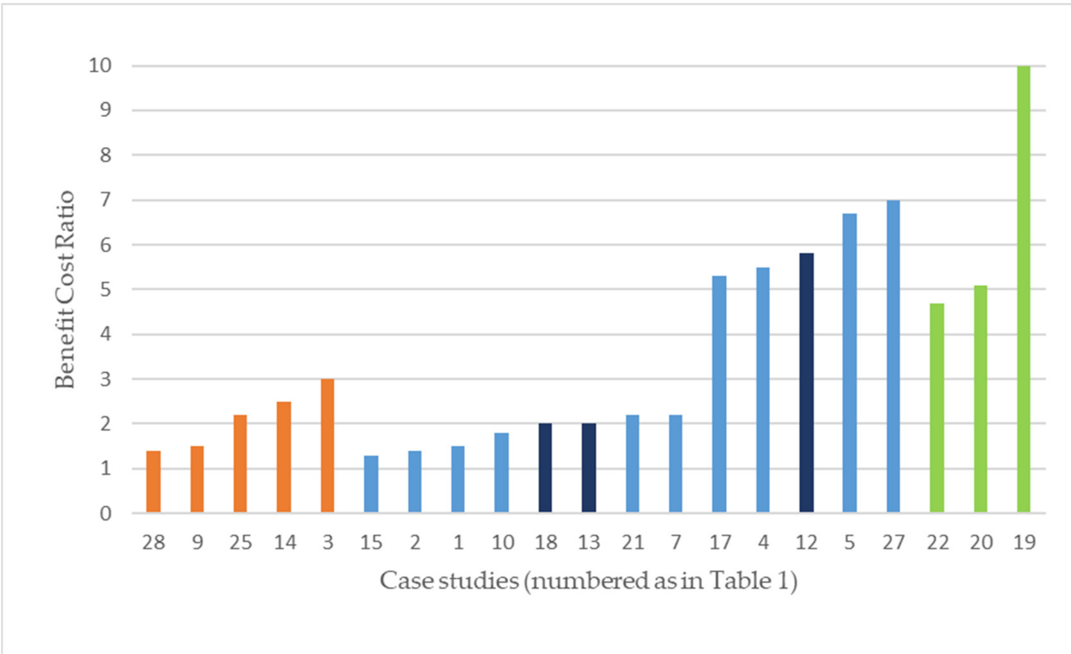
Schemes using natural water are cheaper and have higher BCRs than schemes using recycled water although schemes using recycled water often have higher BCRs than alternative sources of water. The volume weighted average BCRs for 16 schemes using natural water averaged 2.8 and BCR's for five schemes using recycled water averaged 2.20. The 16 schemes using natural water include the Orange County, Arizona Water Bank and North London schemes which are unusually large, with high capital costs and BCRs of 1.8 and 2.2 and 5.5, respectively. Without these large schemes the average BCR for schemes using natural water is 4.8.

Table 4. Benefit cost ratios for different MAR types, source water and end uses.

Factor	**Including Large Schemes**		**Excluding Large Schemes**		
Source water	2.8 (16) Natural water	2.2 (5) Recycled water	4.8 (13) Natural water	2.2 (5) Recycled water	
End use	2.8 (14) Human consumption	4.3 (7) Non-potable use & agriculture	4.6 (11) Human consumption	4.3 (7) Non-potable use & agriculture	
MAR type and technology	Injection Wells 4.4 (7)	Infiltration methods 2.3 (11)	Injection Wells 1.8 (6)	Infiltration methods 3.8 (9)	Riverbank Filtration 7.2 (3)

Schemes producing water for human consumption are more expensive and have lower BCR's than schemes producing water for non-potable uses including agriculture because water for human consumption requires additional, more expensive treatment. The volume weighted BCRs for 14 schemes producing water for human consumption averaged 2.8, when the large Orange County, Arizona Water Bank and North London schemes are included, and 4.6 for 11 schemes when the three large schemes are excluded. The BCR for seven schemes producing water for agricultural and non-potable use averaged 4.3.

Generally, schemes that use wells for injecting water into aquifers are more expensive and have lower BCRs than schemes that use infiltration basins or in channel modifications. Riverbank filtration schemes are relatively inexpensive and have the highest BCRs. When the Orange County, Arizona Water Bank and North London Schemes are excluded, the average weighted BCR is 1.8 for six schemes using well injection, 3.8 for nine schemes using infiltration methods and 7.2 for three schemes using riverbank filtration. When the three large schemes are included the average weighted BCR is 4.4 for seven schemes using wells and 2.3 for 11 schemes using infiltration. The BCRs for each of the 21 MAR schemes is shown in Figure 2.



Legend: recycled water: ; natural water: ; reserve supply: ; riverbank filtration: .

Figure 2. Benefit cost ratios for twenty-one MAR schemes.

3.5. Relationship between BCR's and Levelised Costs

The relationship between BCRs and levelised costs for 17 MAR schemes excluding the three reserve supply schemes and the Khulna scheme is shown in Figure 3. The top left quadrant includes schemes with low levelised costs and high BCRs; the three riverbank filtration schemes and the Dharta, Central Platte and Wala Wala schemes. There is one case in the top right quadrant the transboundary MAR project in the Genevois aquifer, where MAR has enabled highly beneficial management of transboundary resource despite relatively high costs. The bottom left-hand quadrant includes examples from the diverse range of projects with low levelised costs and low BCRs. This category includes two very large projects, Orange County and the Arizona Water Bank, and the San Luis, El Carracillo and Uttar Pradesh schemes. The bottom right-hand quadrant, low BCRs and high levelised costs is populated by four schemes using recycled water, Perth, Salisbury, Koksjide and Dinteloord, and the Turku scheme. The results shown in Figure 3 underline earlier findings that schemes using riverbank filtration have relatively high BCRs and relatively low-costs and that schemes using recycled water are relatively expensive with low BCRs. Schemes using natural water have a large range of BCRs and costs depending on scheme end use and size, and the country where the scheme is located.

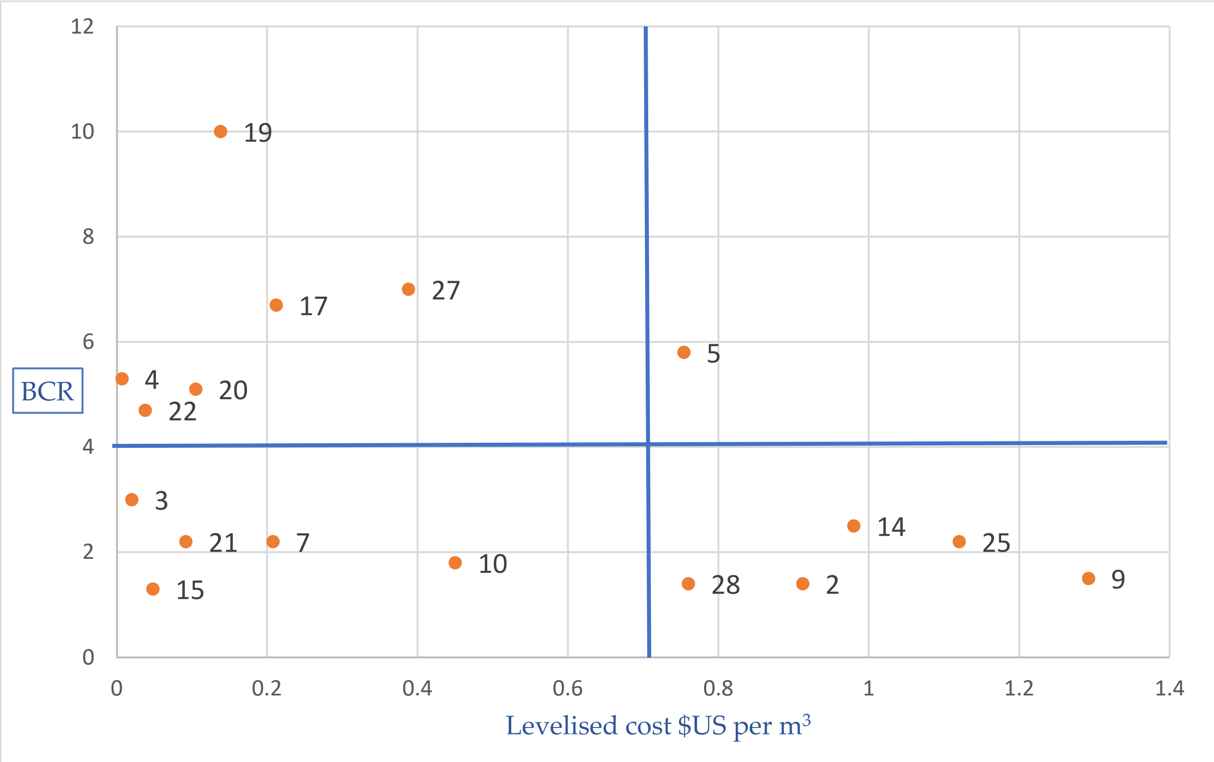


Figure 3. Benefit cost ratios and levelised costs for seventeen MAR schemes.

4. Additional Qualitative Environmental and Social Benefits of MAR Schemes

In addition to economic benefits measured by the costs of alternative water supply or the value of production using MAR water, MAR schemes often have additional environmental and social benefits [1]. These benefits are often significant and can be assessed qualitatively although they are difficult to quantify. Selected benefits are summarised below:

1. Groundwater quantity: maintenance of aquifer integrity and well water levels;
2. Groundwater quality: achievement of national water quality standards and removal of specific pollutants;
3. Environmental flow benefits: maintenance of environmental flow requirements;
4. Energy intensity of public water and wastewater services measured in kilowatts-hours of electricity, normalised by water volume to express energy intensity in kilowatts-hours per cubic metre (kWh/m^3) recharged and/or recovered.

Table 5 contains a classification of each of the 21 MAR schemes as having a positive (+), neutral (N), negative (-) or not estimated (ne) impact on groundwater quantity (GWQN), groundwater quality (GWQL) and environmental flows (ENV). Table 5 also includes estimates of average energy requirements (ENR) for each scheme per m^3 of water recharged (RECD) and/or recovered (RECV). The classifications in Table 5 are based on information provided in case studies in the UNESCO book on managing aquifer recharge [23]. They are broadly consistent with sustainability rankings included in Chapter 3 of the book.

Table 5. Environmental and social benefits of MAR schemes.

Scheme	GWQN	GWQL	ENV	ENR KWH/m^3	Additional Information on Specific Benefits
1 Khulna, Bangadesh	N	+	ne	0.27 RECV	Reduced groundwater salinity
2 Turku, Finland	+	N	N	0.64 RECV	
3 San Luis, Mexico	N	-	ne	0.08 RECD	
4 Dharta basin, Rajasthan, India	+	-	ne	Negligible	
5 Genevois, France-Switzerland	+	+	N	0.61 RECD 0.14 RECV	
7 El Carracillo, Spain	+	-	N	0.17 RECV	
9 Perth, Australia	N	N	N	ne	
10 Orange County, USA	+	N	N	0.3–0.6 RECV	Management of saltwater intrusion, flood control
12 North London, UK	+	N	ne	0.25 RECV	
13 Windhoek, Namibia	N	N	ne	3.9 RECV	Energy costs are relatively high but cheaper with MAR than alternatives
14 Salisbury, S. Australia	+	+	+	0.2 RECV	Recreational benefits, reduced GHG emissions
15 Uttar Pradesh, India	+	-	N	ne	Beneficial dilution of pollutants
17 Central Platte, Nebraska USA	+	N	+	Negligible	
18 Hilton Head, USA	N	N	N	0.3 RECV	Management of saltwater intrusion, carbon sequestration
19 Serchio R, Italy	N	N	N	0.67 RECV	Emerging pollutants managed using strong monitoring
20 Haridwar, India	+	N	ne	0.16 RECV	Well water levels maintained in project wells, falling in other wells
21 Arizona water bank USA	+	N	N	0.48–0.91 RECV	Stored water assists settlement of American indian claims
22 Sidfa, Egypt	N	N	ne	Very low energy use	
25 Koksjide, Belgium	+	+	+	0.85 RECV	Development of wet grasslands
27 Wala Wala, Jordan	N	-	N	1.18 RECV	Seasonal pollution managed using monitoring
28 Dinteloord, The Netherlands	N	N	ne	1.13 RECD 0.29 RECV	Prevention of groundwater salinisation

Twelve of the 21 schemes are assessed to have a positive effect on aquifer integrity and well water levels. The other nine have a neutral effect. The positive effects are distributed relatively evenly across different MAR types and end uses and are not strongly related to low levelised costs or high BCRs. Schemes using natural water are more likely to have a positive impact on aquifer integrity and groundwater levels (10 out of 14) than schemes using recycled water (two out of seven) although schemes using recycled water do not have negative effects on groundwater levels.

Sixteen schemes including 13 out of the 14 schemes that produce water for human consumption are assessed to have a positive (four schemes) or neutral (12 schemes) impact on water quality. Water recovered from these schemes meets all or most national standards for the end use for which it is intended. Four agricultural MAR schemes (three using natural water and one using recycled water) and one scheme producing water for human consumption do not meet national water quality standards. The four agricultural MAR schemes are located in low and middle income countries and have low levelised costs. Three schemes that fail to meet national standards have established additional monitoring or management to manage water quality problems.

There is limited information about the impact of MAR schemes on environmental flows. Ten schemes are assessed to have a neutral impact on environmental flows and three are assessed to have positive impacts. Twelve schemes provide additional project specific social and environmental benefits, three schemes provide benefits in managing groundwater salinity or saltwater intrusion, three manage other sources of groundwater pollution and specific pollutants and the other six all schemes provide a range of additional benefits.

There does not appear to be a strong correlation between the level of quantitative extractive benefits and BCRs and the extent of qualitative social and environmental benefits. Most schemes have some additional social and environmental benefits that supplement their quantitative BCR. The Salisbury and Kokside schemes which use recycled water and have high levelised costs and low BCRs are the only schemes which are assessed to have positive impacts on aquifer integrity, water quality and environmental flows. Qualitative benefits add strong additional value to the schemes.

Jones and Sowby [30] report that energy used in water supply can be divided into sourcing, treatment and distribution. Energy requirements of water supply vary with climate, topography, source characteristics, end uses, proximity of water sources and end users and other factors. The measured energy requirements of MAR schemes vary substantially ranging from 0.16–3.9 kWh/m^3.

The energy requirements (ER) of five of the seven schemes storing and recovering water for agriculture and non-potable use, and the Haridwar and Sidfa RBF schemes are very low, ranging from negligible to 0.17 kWh/m^3. These schemes use natural infiltration and low-cost recovery methods and do not need expensive treatment to meet water quality standards. The Dinteloord scheme which infiltrates recycled water for agricultural use requires expensive water treatment with relatively high ER, and the Sidfa RBF scheme requires energy intensive pumping to transport water from abstraction wells to customers.

The ER for 14 schemes producing water for human consumption are increased by requirements for water treatment to meet water quality standards. These requirements are influenced by source water characteristics, treatment requirements and distribution costs. The ER for these schemes range from a low of 0.25 kWh/m^3 in North London to 3.9 kWh/m^3 in Windhoek with most schemes falling in the range 0.3–0.85 kWh/m^3. The Windhoek scheme is relatively energy intensive because of high ER of infiltration and abstraction in the hard fractured rock aquifer, but still has lower energy requirements than transferring water from the Okavango delta (4.9 kWh/m^3) or a coastal desalination plant (11.3 kWh/m^3).

These ER can be compared with the ER of public water supply in the USA using treated groundwater, surface water, wastewater and desalination. The US Electric Power Research Institute (2013) [31] report an average ER of public water supply using groundwater in the USA of 0.46 kWh/m^3. The average ER of public water supply using surface water was 0.35 kWh/m^3, the ER of treated water from wastewater plants was 0.65 kWh/m^3 and the ER of water from desalination plants was 2.64 kWh/m^3.

5. Conclusions

MAR schemes are highly heterogeneous with a wide range of types, objectives and sizes which can be matched with local hydrology, hydrogeology and demand for water storage and supply. The results reported in this article confirm previous findings that the main factors that influence differences in costs and benefits of MAR schemes are source of water, end use and MAR type and technology. Costs are also influenced by project size and economies of scale, and levels of income in different countries.

Schemes using natural water have a large range of BCRs and costs depending on scheme end use and size, and the country where the scheme is located. Schemes recharging unconfined aquifers with natural water requiring small amounts of treatment, using infiltration basins or riverbank filtration are relatively cheap with high measured BCRs. Schemes using recycled water and/or requiring wells with substantial drilling infrastructure and or water treatment are relatively expensive, but even when water requires costly treatment before recharge and recovery, MAR schemes using recycled storm water and wastewater can offer substantial benefits that exceed costs.

MAR has a wide range of social and environmental benefits that are difficult to quantify. MAR schemes examined in this article have positive effects on aquifer storage and condition, positive or neutral effects on water quality and significant environmental benefits. The energy costs of these MAR projects are competitive compared to alternatives.

The analysis of levelised costs and BCRs in this paper indicates the strong returns to investment in the reported MAR schemes. These are examples of well designed and executed MAR projects that are the most economically viable alternative for water resources development, enhancing resilience and/or water quality. Dillon et al. [6] show that in 2015, the global volume of MAR was 1% of groundwater extraction, and that since the 1960s implementation of MAR has accelerated at a rate of 5% per year but is not keeping pace with increasing groundwater extraction.

MAR can provide valuable social benefits and contribute to sustaining groundwater resources where extraction is also managed. Further analysis and benchmarking of these benefits would provide additional evidence to guide investment in MAR and water resources management policies that seek to buffer against shortfalls, and give incentives for MAR and water banking, and protections for banked water.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data on 21 MAR schemes in this article refers to data on these schemes in the UNESCO publication "Managing aquifer recharge: a showcase for resilience and sustainability".

Acknowledgments: The analysis of 21 MAR schemes in this article builds on and extends the analysis of these schemes in the UNESCO publication "Managing aquifer recharge: a showcase for resilience and sustainability".

Conflicts of Interest: The author declares no conflict of interest.

Appendix A

Table A1. Example of method of estimating levelised cost.

1	METADATA	
2	Country	Finland
3	Name/location	Virttaankangas
4	Coordinates	60°58′54″ N 22°37′54″ E
5	Year commenced operation	2013
6	MAR type	Infiltration Basins
7	Source Water	Treated River water
8	Correspondent	Aki Artimo
9	Notes, exceptional features	None
10	COSTS	
11	Capital costs (LCU in year scheme commenced operation)	190,000,000
12	Index in year scheme commenced operation	108.309
13	Index in 2016	112.139
14	Row 15/14	1.035361789
15	Indexed capital cost (LCU 13 × 16)	196,718,739.9
16	Exchange rate LCU/USD 2016	0.904

Table A1. *Cont.*

17	Indexed capital cost USD (17/18)	217,609,225.6
18	Annual operating cost in LCU	5,600,000
19	Annual operating cost in USD (20/18)	6,194,690.265
20	Water recharged per year (m^3)	22,800,000
21	Water recovered per year (m^3)	22,300,000
22	Operating life	30
23	Capital recovery factor at 5% discount rate = 0.0650	0.065
24	Levelised cost = (19 × 25) + 21	20,339,289.93
25	Levelised cost per m^3 recharged (26/22)	0.89207412
26	Levelised cost per m^3 recovered (26/23)	0.912075781

LCU = Local currency Units, USD = US dollars.

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