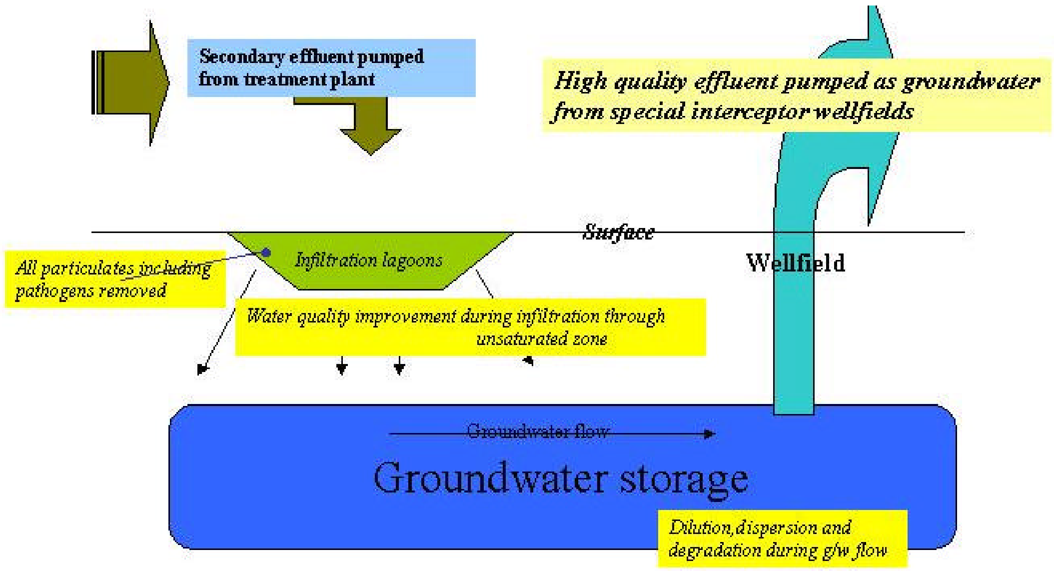
MINISTRY OF WATER AND IRRIGATION

Water Resource Policy Support
Water Reuse Component



OPTIONS FOR ARTIFICIAL GROUNDWATER RECHARGE WITH RECLAIMED WATER IN THE AMMAN-ZARQA BASIN & JORDAN VALLEY

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Abbreviations

ARD	Associates in Rural Development
AZB	Amman-Zarqa Basin
BMP	Best Management Practices
BOD_5	Biochemical Oxygen Demand, Five Day
COD	Chemical Oxygen Demand
DA	Development Area
DO	Dissolved Oxygen
ECC	Economic Consultative Council
FCC	Fecal Coliform Count
GAP	Good Agricultural Practices
GIS	Geographic Information System
GPS	Global Positioning System
GTZ	German Technical Cooperation
HL	Highlands
HRZ	Hashemite-Rusefieh-Zarqa area
IAS	Irrigation Advisory Service
IRG	International Resources Group
JICA	Japanese International Cooperation Agency
JV	Jordan Valley
JVA	Jordan Valley Authority
Km^2	Square Kilometers
KTR	King Talal Reservoir
LEMA	Lyonaise des Eaux Management-Amman
LIMS	Laboratory Information Management System
m^3	Cubic meter
M&I	Municipal and Industrial
MCM	Million cubic meters
MOA	Ministry of Agriculture
MOH	Ministry of Health
MWI	Ministry of Water and Irrigation
NCARTT	National Center for Agriculture Research and Technology Transfer
NIR	Net Irrigation Requirements
NPW	Net Present Worth
NRA	Natural Resources Authority
RA	Rapid Appraisal
RS	Remote Sensing
SAT	Soil Aquifer Treatment
SO	Stage Office
SS	Suspended Solids
TDS	Total Dissolved Solids
TO	Task Order
UFW	Unaccounted for Water
USAID	United States Agency for International Development
WAJ	Water Authority of Jordan
WRPS	Water Resources Policy Support
WSP	Waste Stabilization Ponds
WWTP	Wastewater Treatment Plant

Executive Summary

Opportunities for the use of artificial recharge techniques in the use of reclaimed water have been examined for the Amman-Zarqa Basin and the Jordan Valley area. The study has involved the review of the current knowledge of the aquifers and groundwater resources, and of desk studies and other work on artificial recharge completed to-date. The previous artificial recharge work done has been mainly for use with wadi run-off.

Recharge using surface infiltration, or soil-aquifer treatment (SAT), is the most robust technique and is suitable for use with secondary effluent with no special requirements for pre-treatment. Possible locations where this could be utilized in the basin include two areas to the east of As Samra, and within the alluvial areas along the margin of the Jordan Valley.

Well recharge could in principal be applied widely as there are several potential aquifers into which recharge could be done but artificial recharge through wells demands comprehensive pre-treatment and is technically more complex to manage

Simple cost comparisons show that the cost of surface and well recharge facilities are likely to be of the same order (0.5 – 1.1 million JD), but the additional costs of the essential comprehensive pre-treatment, at an estimated 0.4 JD/m^3, make well recharge expensive. Together with the comparative complexity of using the technique, well recharge is unattractive at present.

SAT systems or infiltration lagoons, though considered technically feasible in the highlands, appear unlikely to meet with official or public acceptance at present because public water supplies are drawn from the same areas. In contrast, similar schemes in the Jordan Valley appear likely to gain ready acceptance as a clearly useful approach, making best use of resources. It is recommended that a detailed feasibility study, including pilot scheme, be promoted in this area.

Acknowledgments

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Our colleagues in the Ministry of Water and Irrigation were active partners in these investigations. We would specifically like to acknowledge the valuable participation of Eng. Edward Qunqar, Director of the Water Resources Directorate and Mohammed Al Momnaei, Head of Groundwater Studies Department.
meeting with Dr Elias Salameh, University of Jordan; meeting with senior MWI staff

In addition, the cooperation and enthusiasm of the staff of the Water Authority of Jordan (WAJ), the Jordan Valley Authority (JVA), Dr. Elias Salameh of the University of Jordan and the many others who worked with our team greatly facilitated the work.

Finally, the support of the United States Agency for International Development (USAID) Mission in Jordan, and the Associates in Rural Development (ARD, Inc.) team, in Jordan and Vermont, is highly appreciated.

I. Introduction

I.1 General Context

This report has been prepared under the terms of the Water Policy Support project of the Ministry of Water and Irrigation, which is being undertaken by ARD Inc. with funding from the United States AID. The consultancy forms part of the Water Re-Use component and deals specifically with the Groundwater Recharge sub-activity.

This study, carried out between March 12th and April 2nd 2001, looks into the possibility of using artificial recharge techniques to the use of reclaimed water under the Water Reuse component of the Water Policy Support project. The report looks at prospects for the recharge of reclaimed water in the Amman-Zarqa Basin and the Jordan Valley.

I.2 Terms of Reference

The full ToR are shown in Annex 1

I.3 Methodology

Prior to this project, the application of artificial recharge has been considered on several previous occasions, but in the context of enhancing natural recharge. This study has been based upon an initial review of this earlier work and on current knowledge of the hydrogeology of the basin and the Jordan Valley area. Based upon the above work it has then focussed on the identification of areas where artificial recharge using reclaimed water would be at the same time, both feasible and also offer wider opportunities for the utilization of water resources on a potentially useful scale.

I.4 Work Done

The work carried out has included the following main components;

- The review of the reports of previous relevant Ministry and predecessor agency documents, consulting studies, and hydrogeological reports and data,

- field visits, one to selected areas of the main Amman-Zarqa basin, including As Samra oxidation ponds and Wadi Zarqa, and a second to the Jordan Valley focussing on the area to the south of Wadi Zarqa, to JVA and Wadi Khafrein Dam,

- discussions with senior technical staff of the MWI to benefit from their especially relevant local experience

- meetings with other Jordanian experts and academics to ensure that all other national expertise has been consulted, and

- consultation with other team members to integrate results with the project at large.

II. Previous Artificial Recharge in the Amman-Zarqa Basin and Jordan Valley

II.1 General

One of the earliest known examples of artificial recharge occurred following the construction of the Khafrein and Shuaib dams on the margins of the Rift Valley starting in 1968 (Hirzalla 1973). Although the subject of artificial recharge appears to have been reviewed on several occasions in the past, the next reports were those of the MWI Working Group on Artificial Recharge (1994,1995,1996) prepared within the Water Quality Improvement and Conservation Project. Bajjali (1991) discussed the various factors affecting groundwater quality in Wadi Dhuleil area and examines the effects of the specially constructed 1 million m3 capacity Khalideyah recharge dam for the enhancement of recharge from Wadi Dhuleil, with a series of abstraction wells downstream to intercept the recharged water. Few other specific proposals have been carried forward and little practical work has yet been done except for another similar scheme, which lies outside the Amman –Zarqa catchment but is nevertheless highly relevant, at Suwaqa Dam. Here, infiltration from the dam, also specially constructed to enhance natural recharge, has also been found to be very limited (Rayyan 1996).

Bajjali (op cit) discusses the effects of the groundwater contamination from the unrecognized but significant artificial groundwater recharge which has also taken place from the As Samra Reclaimed water Treatment plant oxidation ponds, comparing present conditions with those observed in the 1965 study (CWA 1965). He shows that this is an important existing local source of artificial recharge that is not normally recognized.

Some additional information concerning some of the above examples are given below.

II.2 Case history outlines

Wadi Dhuleil/Khaleydia

A dam was specially constructed in 1983 to hold run-off and enhance infiltration from the reservoir and which would benefit groundwater resources locally. A recharge well and a series of observation boreholes was drilled immediately downstream of the dam with the intention of carrying out experimental recharge. It is understood that this was not in fact done and that the dam proved unsuccessful in enhancing recharge in the long term because of rapid siltation and the loss of water storage. This arrangement of recharge well and wadi dam with observation boreholes was followed at the Wadi Siwaqa scheme referred to above.

Khafrein and Shuaib Dams

Reference is made by Hirzalla (op cit), to the unexpected high leakage losses from these reservoirs, which are founded on over 20m of alluvial sands and gravels, overlying fractured and jointed limestones. He quotes losses from Shuaib during its initial 3 months of operation of over 30,000 m3/d. These dams, constructed in 1969, currently continue lose a high proportion of their inflow as artificial recharge. Inflow to the reservoirs is a mixture of natural run-off and reclaimed water from upstream wastewater treatment plants (As Salt and Fuheis, and Wadi As Sir respectively). Data from Khafrein indicate that average daily artificial recharge “losses”, at water levels of up to 67.5m above datum, are about 14000 m3/d. The losses, which will be largely a function of water level, take place partly through ‘sink holes’, which have been observed in the exposed in the bed of the dry reservoir during the summer.

The effects of the dam losses on groundwater levels near to Shuaib Dam were reported by Hirzalla to be substantial, immediately following construction. Recharged groundwater from both dams appears to move directly into the limestones, beneath the dam structure and from here into the alluvial aquifer at the margin of the Valley.

As Samra WWTP oxidation ponds

The WWTP was constructed in 1985 and is now severely overloaded, such that the quality of the effluent fails by a substantial margin, to achieve any of the basic quality criteria for Jordanian effluent discharge. Since commissioning, losses from the ponds, which are estimated to average about 17% of total flow, have added continuously to groundwater.

The migration of the recharged reclaimed water has been uncontrolled such that it has migrated in the direction of prevailing groundwater flow towards the east, carrying greatly increased levels of nitrogen (up to 50 mg/l NO_3-N) and increased salinity. In this area, development of water resources commenced in the 1960’s at which time the salinity of the groundwater ranged typically between 300-400 mg/l as total dissolved solids (CWA 1965); in 1989, at the same locations, the salinities had risen to between 1300-4000 mg/l (Bajjali op.cit), the higher salinities being the result presumably of irrigation return contamination, as the As Samra sewage has a salinity of only 1200 mg/l.

II.3 Other work

The main result of the MWI Working Group deliberations and the support of USAID work so far has been the development of the detailed designs for a project in the catchments of the Wadis Madoneh & Butum. The project would involve the use of a series of wadi dams and water harvesting measures for the optimization of natural recharge (MWI, 1997a and b).

III. Opportunities for artificial recharge

III.1 Review of technology

The field of artificial recharge is broad and covers a whole spectrum of proven techniques for enhancing natural groundwater recharge. The fund of experience is now substantial and artificial recharge should no longer be regarded as an exotic technique for water management.

TABLE III-1

Artificial recharge techniques

(See also annexes 3 & 4)

Facility	**Purpose proposed**	**Source Water Quality Constraints** *Nutrients*	*SS*
Surface Methods			
Lagoons, dams basins, pits	Storage augmentation	Minimize	Minimize
	Quality Improvement	None	Minimize
Subsurface Methods			
Wells, boreholes	Storage	Minimize	Extremely low
	Quality Improvement (not suitable other than for dilution)	n/a	n/a

In the Jordanian context, and in the Amman-Zarqa basin where source water would be a secondary effluent, the range of appropriate techniques is limited, as shown. Hydrogeologically, there are many transmissive aquifers which also have good unconfined storage coefficients and capable of accepting artificial recharge. A table summarizing the geology and hydrogeology and indicating aquifers, which might be used for artificial recharge, is shown below as Table III-2.

Table III-2 Summary table showing geology, & main aquifers for artificial recharge

Era	*Period*	*Group*	*Formation*	*Symbol*	*Lithology*	*Hydrogeological significance*	*Thickness (m)*
Cenozoic	*Quaternary*		Alluvium		Unconsolidated deposits		10-15m?
			Basalts		Volcanics & clays		
	Tertiary		Basalts		Volcanics & clays		
		Belqa	Umm Rijan	B4	Chalky lst & cherts		
Mesozoic	*Upper Cret.*		Muwaqqar	B3	Bituminous shale,lst., chert	Aquitard	
			Amman	B2	Marly lst with phosphate&chert		
			Umm Ghadran	B1	Marl &shale	(Aquitard)	220
		Ajlum	Wadi Sir	A7	Marly lst.		
			Shuaib	A5-6	Clayey dolomitic lst	Aquitard	
			Hummar	A4	Lst, dolomitic lst		
			Fuheis	A3	Sanstone and shale		
			Na'ur	A1-2	Dolomitic limestone		
	Lower Cret.		Kurnub	K	Consolidated sandstone		280
			Huni	Z2	Sandstone & shale		

Notes

- [dark grey shading] Aquifer suitable for application of surface recharge , normally in hydraulic connection with bedrock aquifer
- [light grey shading] Surface recharge of aquifer possible where exposed , or well recharge also possible
- [very light shading] Recharge of aquifer by well possible

Surface Methods

In the table, any of the surface techniques could in principal, be applied to make use of underground storage and also to provide a stage of treatment to all or part of the secondary effluent in the basin, provided the source water quality is adequate and the necessary geological conditions are met. Essentially granular aquifers exposed at the surface are needed to provide the infiltration conditions required.

Highly fractured and jointed limestones of relatively high transmissivity are unfavorable in that recharged water can move rapidly away from the site of recharge and be difficult or costly to recover. Furthermore, with secondary effluent, fractured aquifers are capable of transmitting particulates, including microbes. For this reason surface recharge demands at least superficial granular materials. The process of recharge of effluents for treatment is often known as soil-aquifer treatment or SAT. A schematic diagram of the process is given in Figure III-1.

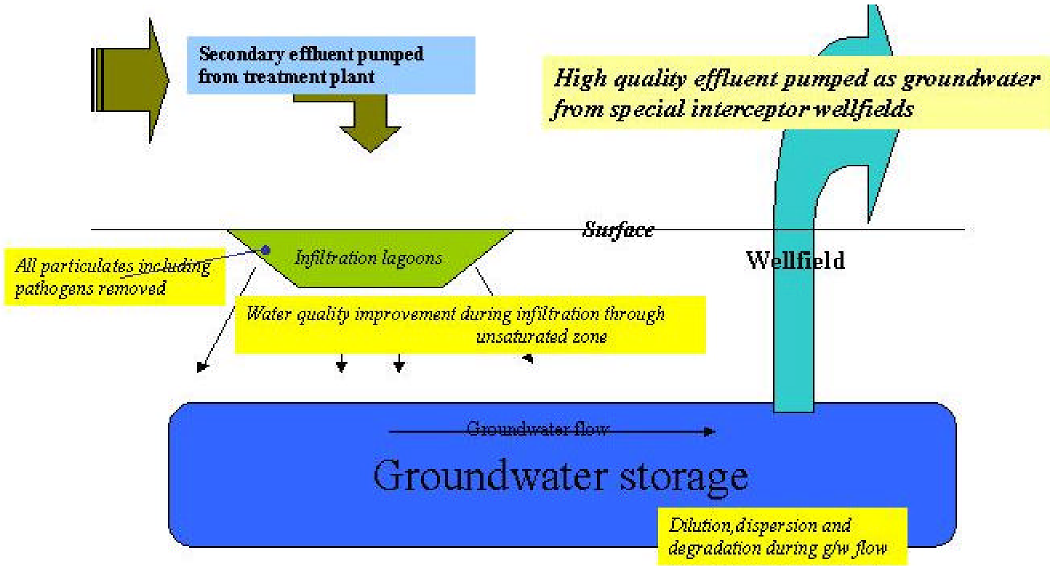

Figure III.1. Soil-Aquifer-Treatment (SAT) process for water reuse

Subsurface

Well recharge could only be envisaged using highly treated water so microbial contamination would not be an issue. The same problems of managing water storage in a highly transmissive aquifer, which are rapid migration and costly recovery, would also apply however.

The constraints on nutrients and suspended solids in particular are specially listed in the table as the critical constituents. The quality of the reclaimed water is generally very low at present and As Samra treatment plant, the main source, produces an effluent which does not comply with Jordanian Standards, and it would not be possible to envisage an artificial recharge scheme being built around such an effluent. This means that any recharge will have to await commissioning of the proposed new plant in 2007.

III.2 Recharge water sources

This report deals exclusively with the use of that reclaimed water as a recharge water source, so the opportunities for applications of artificial recharge are limited. This limitation is both in terms of the amount of recharge water available (determined by volume of reclaimed water generated by treatment plants), and also on the locations where artificial recharge might be done as determined by the geology. Reclaimed water arises at specific points and so has to be conveyed and delivered to the recharge site. As indicated in Section II, there is effectively already artificial recharge in progress by default, from the large area of existing stabilization ponds, and the result has been severe groundwater contamination as discussed.

The discharged treated effluent from the other WWTP's at Abu Nuseir, Al Baq'a and Jerash are currently of acceptable quality with respect to Jordanian standards, with some specific exceptions. Compared with As Samra, the current flows at the smaller WWTP's are small, as shown in the table below.

TABLE III-3
Reclaimed water Recharge Sources
(1000's m^3/d)

Year	As Samra	Others	Total
2000	45.9	4.9	50.8
2005	65.4	7.1	72.5
2010	104.7	12.9	117.6
2015	120.7	14.9	135.6
2020	137.9	16.6	154.5
2025	157.6	19	176.6

Commissioning of proposed new water supplies to Amman Basin in the period 2005 and 2010 accounts for the steep indicated increase in reclaimed water availability in that period. Within the 'Others' value for 2025, the flow from Al Baq'a accounts for over 65% of the total.

In the present plans for water use, irrigation and possible forestry areas have been defined in the vicinity of As Samra for some of these resources. Artificial recharge of all, or part, of this treated secondary effluent (after 2007), is a further option. It is understood that this effluent will comply with limits for TSS (total suspended solids) and BOD (biochemical oxygen demand) of 30 and 30 respectively. The application of SAT recharge effectively adds a tertiary treatment stage. Interception of the artificially recharged resources by a specially designed wellfield, would produce a water supply suitable for a range of agricultural or industrial use (such as refinery cooling water for example) for local wide agricultural use or export elsewhere in the basin (see below).

The costs of treatment to appropriate standards either before or after recharge, and also of interception and recovery of the recharged water also have to be included.

The 3 smaller WWTP's discharge directly into wadis, which are in the King Talal Reservoir catchment. At Jerash, WWTP effluent is fully committed for agriculture already. At and around these smaller sites, the geological conditions do not appear favorable for artificial recharge and recovery, and they are not considered further.

III.3 Possible recharge sites

The possible locations for artificial recharge are shown in Figure III-2.

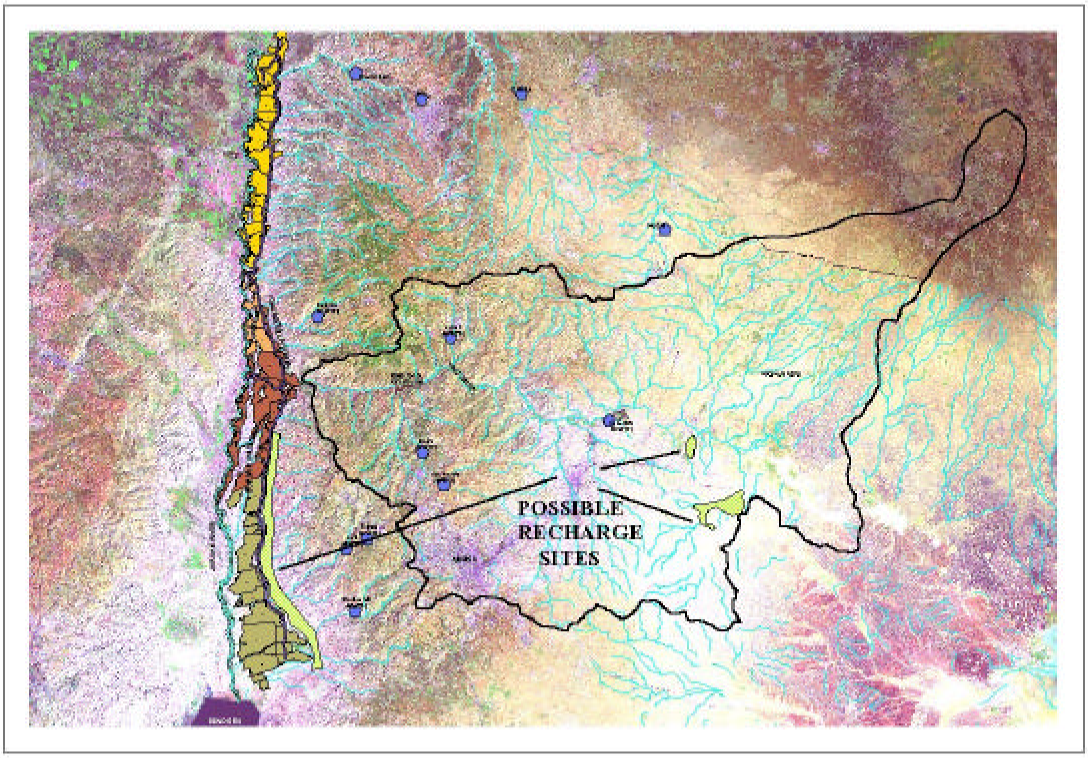

Figure III.2. Locations of possible artificial recharge sites in the Amman-Zarqa Basin & Jordan Valley

As Samra- Al Halabat and Sharkiyah/Wadi Rukban area

Within 10 to 15 km ESE of the present As Samra plant there appears, from the soils and geological maps, to be some areas within which SAT areas could be accommodated, subject to suitable detailed geological examination. All potential sites would require pumping to the SAT facility, and further pumping after infiltration, as groundwater, for further use. The depth to groundwater is too great to be ideal and further investigation will need to be done to establish viability.

Jordan Valley

The main treated reclaimed water resources for any recharge in the Jordan Valley would arise locally and mainly from releases from King Talal reservoir. In addition, there are WWTPs (As Salt, Fuheis, and Wadi as Sir) discharging to wadis which flow into the valley and which already are, or would be available for local recharge, given suitable geological conditions. It is probable that infiltration of the bulk of the flows, except at times of high flow, already takes place along the course of the wadis.

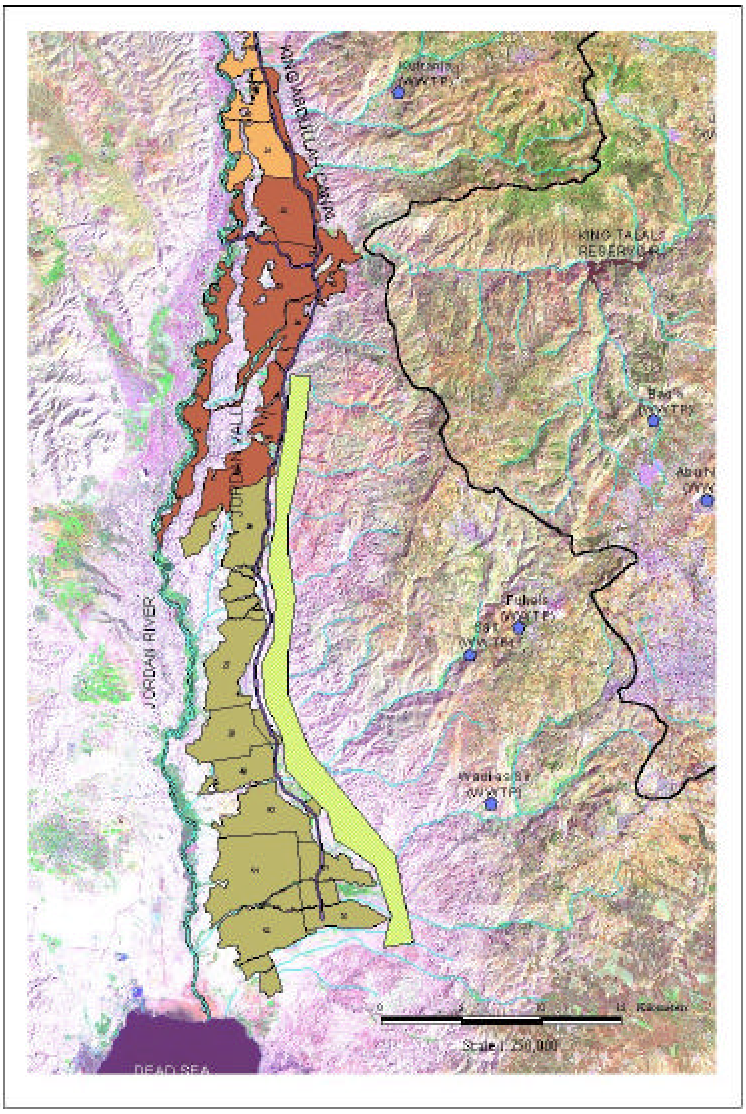

Figure III.3. General locations of possible artificial recharge sites in the Jordan Valley

The King Abdullah Canal contains input from the Yarmouk river, local resources and in the lower reaches, King Talal Reservoir. Quality is inevitably variable but it is a large resource, and any surplus flows which could be deployed seasonally for recharge and storage in the alluvial fans of the Valley margin through the use of artificial recharge, could have high value. The geology of the alluvial fans has been studied in detail by Dr Salameh of the University of Jordan, and a report is in preparation for submission to the High Council for Science & Technology (pers.comm). It is also understood that a research thesis concerning the Khafrein dam has been completed by Mr Stefan Lenz from Karlsruher University (Dr E Salameh, pers comm.), which should throw valuable light on the hydrology of the valley margin.

Judging from the experience with Shuaib and Khafrein dams (Hirzalla 1973) and the information held by Dr E Salameh, it appears highly likely that other suitable sites might be identified at the valley margin where basins dedicated to recharge could be constructed (see Figure III.3). Identification of specific location will require review of the detailed mapping and some fieldwork. It is probable that recharge of the alluvial aquifer from the margin of the Valley as proposed, could be further enhanced at several location in the Southern and Middle areas and possibly even more widely.

Well Recharge

Given water of high and consistent water quality in terms of suspended solids and nutrients, well recharge would be possible in the relatively transmissive aquifer conditions, which can be found widely in the basin. The relatively permeable B2-A7 limestone, and deeper arenaceous aquifers as well, would otherwise offer good opportunities for application. However, using reclaimed water as the source, it is difficult to envisage a feasible economic context within the planning period, which might encourage the application of well recharge, principally on account of the expense of treating the reclaimed water to a sufficiently high standard. Costly treatment would be essential simply to avoid rapid clogging of the formation, irrespective of the water quality constraints for further use. As well as comprehensive suspended solids removal, it would be necessary to reduce nutrient and organics concentrations.

The technology of well recharge is also substantially more complex than required for surface methods, and a short outline setting out the main features is given in Annex 4 for completeness.

III.4 Constraints on application

Physical

To make reclaimed water infiltration and recovery practically feasible, it is essential to find the appropriate hydrogeological conditions. These include

- a thick, chemically inert, unconsolidated and permeable aquifer
- a sufficient depth to the water table, to allow storage & quality improvement
- no significant clayey or silty beds within the unsaturated zone

The above conditions are believed to apply to potential sites in the highlands or the Jordan Valley, although in the Valley it will also be important to avoid areas with severe salinity problems and also for the alluvial strata to be in contact with a good bedrock aquifer. The higher the vertical infiltration rate, the higher the potential throughput (compatible with adequate natural treatment), and the smaller the amount of land needed.

Social & Cultural

The above notional schemes are set out to be “self-contained” so that good secondary effluent is the source and a highly treated effluent/groundwater mixture is pumped. The dedicated wellfield would ensure that migration of any recharged effluent from the site is minimized so that in areas where groundwater is not already contaminated, any degradation is small.

Nevertheless, this kind of use of an aquifer in combination with an effluent, even though it will be of relatively high quality, is a sensitive issue where groundwater is used as a drinking water supply, as it is in the Highlands area. In addition, there are fundamental religious reservations on the part of many people, which would be difficult to overcome without long-term evidence of reliability and wholesomeness.

IV. Potential Recharge Areas

IV.1 Introduction

The limitations on possible use of reclaimed water for artificial recharge have been discussed above. Arising from these considerations some possible areas have been identified but all are subject to further detailed appraisal to establish their validity. The last option of well recharge is included mainly to establish a comparison, as the costs of pre-treatment of any recharge water are likely to be prohibitive.

IV.2 As Samra - Wadi Dhuleil- Al Halabat Areas

Locations

Proximity to the source of the secondary effluent is clearly a cost advantage in any scheme, and in this case areas, which might contain suitable ground conditions, on the lines discussed above, have been sought. From the soils map, there appears to be some areas within which an SAT scheme of the size envisaged might be accommodated. Two possible areas within about 15km have been located on the 1:50,000 soils maps (Ministry of Agriculture 1994). These are at or near Ad Dhuleil, and in the Al Halabat as Sharkiyah areas (Figure IV-1). These range from about 10 km to 15km from As Samra Reclaimed water Treatment Plant. Without measured infiltration rate values it is difficult to assess the precise sizes of the area which would

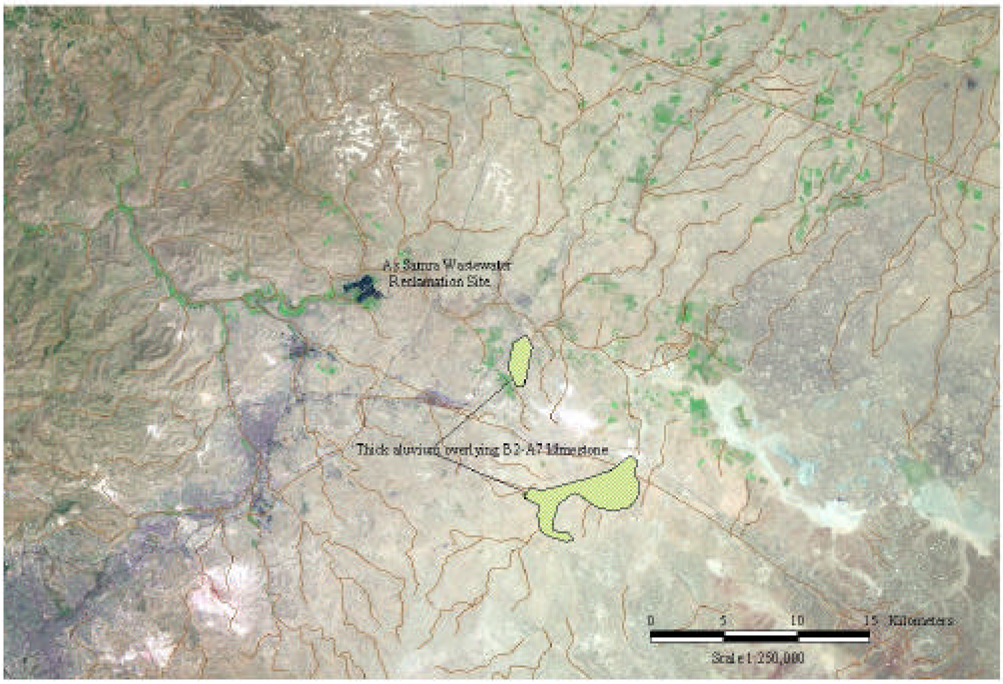

Figure IV.1. Locations of possible artificial recharge sites in the As Samra area

be needed at this stage, but for a 10,000m3/d scheme, it is probable that the area would be less than 25 ha.

Typical site details

The site should be selected (possibly using surface resistivity survey in combination with hand augering) in the area with the maximum thickness of superficial strata in which the shallow lagoons would be excavated and which would comprise at least part of the unsaturated zone. It is clear that the alluvial strata are everywhere relatively thin 10-15m, but this is sufficient for SAT purposes. The underlying bedrock over most of this area is the Amman-Wadi Sir limestones, which are of moderate transmissivity and possess good storage properties, and the site should be chosen to overlie these strata, specifically avoiding the basalt areas. Depth to groundwater in the area exceeds 75m but the specific nature of the unsaturated zone is not known.

The infiltration lagoon design envisaged the use of long (500m) and narrow (20m) lagoons to make good use of the horizontal as well as vertical permeability of the superficial strata. Lagoons would be separated at the surface by 10m and each would be excavated to 1.5m depth to allow a depth of 1.0m or more of recharge water depth during operation, and the excavated spoil used to embank the margins of each lagoon. Each lagoon would be capable of holding one day's delivery of treated effluent (though distribution on-site might be necessary if infiltration rate is low and many lagoons are needed). In estimating costs, several infiltration rates have been used. Water would be delivered from the WWTP through a conveyor pipeline through a lift of up to about 50m; after infiltration, reclaimed water would be intercepted by means of a specially constructed wellfield designed to optimize recovery. These wells would be drilled to about 250m depth to abstract from the Amman-Wadi Sir limestone succession. Mixed groundwater and reclaimed high quality effluent would be pumped to the surface for agricultural or industrial use. For the purposes of this report, the configuration at any SAT site would be similar. An extra settling/balancing storage lagoon has been included in each notional scheme, from which water would be distributed to the infiltration lagoons, ideally by gravity.

IV.3 Rift valley sites

Khafrein & Shuaib

These two sites already operate very successfully as recharge facilities. There is also, below Khafrein, pumping plant installed which allows surplus water, additional to irrigation needs, to be transferred back to the reservoir. It is recommended that this approach be extended to Shuaib and, when the additional and improved effluent flow becomes available to augment King Abdullah Canal baseflow, that these facilities be upgraded to make best use of the available storage in the reservoir throughout the year. It is clear from the reservoir water budget for Khafrein that the losses from the reservoir are predictably, head-dependent. By maintaining the head as high as possible, the rate of recharge can be optimized.

Need for investigation

The precise circumstances in hydrogeological terms, which give rise to the favorable recharge conditions at the above sites need to be documented. The sites are said to be built on alluvium, but widely distributed sinkholes have been reported in the dried out bed of Khafrein reservoir. While it is not impossible for superficial deposits to reflect the locations of such features in underlying limestones, it suggests an unstable situation where the bedrock is at very shallow depth. It is understood that there was no pattern observed in the distribution of these features. A review of the PhD thesis on Khafrein dam and reservoir (Lenz, University of Karlsruher, pers comm. Dr Salameh) should be an initial priority in any investigation.

The relationship between reservoir stage and downstream groundwater level at the existing recharge dams should be studied in advance of any planning to develop recharge in the region. The study should take into both water level/piezometric effects in alluvium and bedrock into consideration and also the water quality changes which occur during the process of artificial recharge. Even at present, the reservoirs are presumably subject to wide variation in quality at certain times of the year in addition to those caused by pumping surplus water from downstream. To characterize the recharge water and the effects on groundwater downstream, continuous solid-state recorders would be needed. Some new observation well drilling might be needed.

Once the reasons for the success of the above sites have been established, the establishment of infiltration areas at other locations could offer considerable benefits.

Other sites

Subject to the above thorough investigation additional similar sites might be considered elsewhere along the rift valley margin. Where the above existing reservoirs are constructed on locally major wadis, any other similar facilities for recharge would have to built in minor wadi sites to the north as far as Wadi Zarqa, although recharge water from could be delivered farther north but would need a special delivery arrangements.

No specific sites have been visited but it appears that similar storage sites could be found, in hydro geologically analogous situations, into which surplus King Abdullah Canal water could be pumped when available. A proper survey needs to be carried out to identify suitable sites, in areas where the additional recharge into the alluvial strata could be put to best use. It appears from discussion with Dr Salameh (University of Jordan) that the geological mapping of the alluvial fans that might be used, is soon to be published.

For the purposes of this report it is assumed that any new recharge facility would be a lagoon system similar to the SAT scheme put forward for the As Samra area, and needing regular cleaning, as being economically attractive. Such a system would probably not differ significantly in terms of land requirement for SAT and would probably be easier to accommodate to the land areas available, and the prevailing topography (see Annex 5). Such installations, which are relatively inexpensive, could be distributes most widely and gain access to the aquifer storage space available most efficiently.

Unless it can be shown that recharge of alluvium/limestone, on the lines of the Khafrein/Shuaib dams can safely replicated, it is difficult to see how the cost of a fully engineered dam could be justified for artificial recharge, even if a site could be found.

IV.4 Well recharge

Although the technology of well recharge does not lend itself to the use of a reclaimed secondary effluent as a source water, for reasons which are listed in Annex 4, it is possible to treat effluent to sufficiently high standards that recharge might be feasible.

In general terms, water with high suspended solids concentrations can only be recharged into highly transmissive aquifers and this is done in some countries as a means of disposal rather than management or to attempt to benefit groundwater users at all points down-gradient. Secondary effluents have been recharged in the Barcelona area of Spain into clean very coarse conglomeratic alluvium but even here, periodic backwashing is needed. In the Amman-Zarqa Basin, there are many several aquifers into which recharge could be attempted, but all are fractured and jointed and in Unless effluent is sterilized by chlorination or UV treatment prior to recharge, there is the danger, in these aquifers, of causing widespread microbial contamination. In addition, nutrients N and P should be removed as far as possible, so that the likelihood of any microbial activity in the well, which is likely to encourage, clogging, is minimized.

V. Outline Design & Costs

V.1 Soil aquifer treatment scheme

Recharge supply

Pumping arrangements for treated reclaimed water already form part of the plans to pump effluent eastwards for irrigation and forestry. Calculated unit costs (MWI, 2000) for the effluent delivered to 112m above As Samra are used as indicative only in Annex 5.

Settling/balancing storage

On-site settling and effluent storage would use a single additional lagoon which could be split into sub-divisions with baffles, and could reduce suspended solids prior to distribution to the infiltration lagoon. On sloping sites, gravity distribution could offer settlement benefit (see below)

Infiltration lagoons

For reasons discussed in Section 4, lagoons should be long and narrow (500m X 20m). As the possible SAT recharge areas are fairly level, lagoons could be straight but in other areas, in the Jordan Valley, where the available sites are not necessarily level, lagoons could be curved to follow contours. Delivery of recharge water by gravity across sloping sites would offer a settlement treatment benefit.

As the infiltration capacity is not known, three simple options have been looked at ranging from 0.1 m/d to 1.0 m/d as the average recharge (or infiltration) rate over a two-week recharge period. Actual rates will vary during the period as bed clogging occurs. To achieve a total rate of recharge of 10,000 m3/d, different numbers of lagoons are needed depending on the average infiltration rate possible. It is further assumed that one half of the number of operational lagoons would be draining for cleaning at any time, so the number of lagoons for each option is twice the number needed to recharge at the required rate. The numbers of operating lagoons for the three infiltration rates considered are therefore 2, 4 and 10 plus the intake settling/balancing lagoon, making a total number of 3, 5 or 11.

Service area and roads

An area at one end of the infiltration lagoons has been allocated to services, which would include the inlet for the effluent, valves and meters together with access track and an on-site office building.

Wellfield & observation drilling

Four production wells are envisaged as being sufficient, if properly located, to scavenge the recharged water and minimize loss of recharged water from the recharge facility area. Four observation wells at 10,000 JD each are also included. It is assumed that arrangements for use of the pumped water for agriculture or industry would allow continuous operation.

Operation & maintenance

Two-week (say) cycles of infiltration, draining & cleaning would be a typical schedule of use. Drained lagoons would be allowed to dry prior to manual or mechanized cleaning (scraping) of the beds. Bed-cleaning wastes would be given to farmers for soil conditioning. It is estimated that 2 operatives would be needed for each lagoon, employed continuously at a cost of 3 JD per hour.

The overall capital cost of SAT installations would range between 0.55 & 1.13 million JD using the unit costs listed in Annex 5.

V.2 Jordan Valley - Recharge options

Infiltration lagoons

It is thought that the design, construction and operation, and hence costs of lagoons would be similar to those which apply for the SAT systems mooted for the highlands area. The main differences are as follows;

- water quality differs so the mode of operation and cleaning would differ, and
- terrain is less level so lagoons would probably need to be contoured.

To protect the infiltration lagoons against rapid clogging at times of high turbidity in the Canal, additional settlement could be built in, and pumping from the Canal could also be controlled by turbidity.

Recharge water supply

At this stage it is not known how supplies would be developed. Direct abstraction from the mixed water of the King Abdullah Canal including the reclaimed water from King Talal reservoir could be taken from canal-side pumping stations. Alternatively, if many facilities were developed along the valley margin and a large total supply (say 40-50,000 m3/d) were needed, a special supply could be diverted from Wadi Zarqa and pumping minimized. No costs have been developed for this.

Dam storage

The cost of Khafrein dam was about 600,000 JD in 1968 when it was built. Modern costs would be many times this possibly as much as 10 fold. A special pumping station for each dam would be needed pumping from the King Abdullah canal and involving as lift of the order of 50m at least.

V.3 Well recharge

Advanced water treatment costs

Effluent would need extra clarification, and nutrient and organics removal. This would require sand filtration, carbon adsorption, and RO treatment. The estimated cost of the additional treatment either before or after delivery to the recharge site, is 0.4 JD/m3. The annual costs for a 10,000-m3/d facility would over 1.46 million JD. To this would be added the cost of delivering water to the site and this has been assumed the same as for the infiltration lagoons so that total cost is about 2.8 million JD.

Recharge well costs

The costs of a recharge are deemed greater than for a comparable production well, as there is a need for additional diameter to accommodate a thicker gravel pack (to protect the formation and possible contain a backwashing system). There may also be a recharge main and a pumping main, additional valves and controls in the well, and the highest quality screen, possibly over a greater depth. Reverse circulation should be used for drilling if possible to minimize danger of formation damage.

Where the estimated costs of a production well including all screen, casing, pumps, power supply, headworks, and controls to 250m, is about 60,000 JD; on this basis, the comparable recharge well cost is 100,000 JD/well.

If production of recharged water was undertaken on a seasonal basis, water would be pumped by other users or could be abstracted from a special wellfield. The costs produced here assume that 4 production wells would be needed. On this basis, capital cost is 0.7 million JD, so comparable to surface infiltration.

Operation and maintenance

The water supply would be costly but would be of a quality, which ensures the longest period of recharge before needing backwashing. Recharge rate would gradually decline as clogging took place, needing rehabilitation to recover the performance. It is typical for the achievable average rate of recharge to decline over time so that economic well lifetime may be considerably shorter than a production well. Ten years rather than 15 years may be a realistic period for planning.

VI. Conclusions & Recommendations

VI.1 In general, there are wide opportunities for artificial recharge in the Amman-Zarqa Basin and the Jordan Valley. However, recharge using reclaimed water as the source would limit the scope greatly. Only two areas have been identified in which artificial recharge using surface infiltration techniques are considered to be applicable. The areas are the Halabat and Sharkiyah area in the highlands, and along the eastern margin of the Jordan Valley.

VI.2 Both soil-aquifer treatment (SAT) with dedicated wellfields for recovery, and recharge well systems have been roughly costed, based on 10,000 m^3/day modules.
The capital costs of both types of recharge are similar, but the unit costs of water for well recharge are very high on account of the comprehensive additional treatment needed, making the use of the technique unattractive at present.

VI.3 Indications are that the recharge of reclaimed water into aquifers that are used at any point for potable supply would be wholly unacceptable at present, even with comprehensive treatment and well recharge. Given this, acceptance of SAT is highly unlikely at present.

VI.4 Artificial recharge of reclaimed water from King Talal Reservoir (KTR) in the Jordan Valley appears to have a high chance of acceptance. Storage of any additional water in the alluvial deposits can be seen to offer clear potential benefits, and any risks are small. A pilot recharge scheme using infiltration lagoons should be promoted.

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ANNEX I

Terms of Reference

Scope of Work–Jordan Water Resource Policy Support Project
Short Term Technical Assistance– Groundwater Recharge Specialist

Background

This project is to support the implementation of Jordan's water policies, and one of its main components is water reuse planning.

The consultant's assignment will be to complete the groundwater recharge sub-activity of the water reuse component.

Scope of Work

Recycling water by injecting reclaimed water into the ground and/or allowing groundwater recharge by surface application of reclaimed water may a have high benefit. As confidence is gained in the ability to monitor and control the quality of recycled water, public perception has changed in some countries and recycling to groundwater has become acceptable. Given that the planning period is twenty-five to thirty year, this option should be investigated even if the decision is to defer implementation until a much later date.

- Seek and assess opportunities for artificial recharge of groundwater with recycled water in the Amman-Zarqa basin and Jordan Valley. Emphasis is to be placed on areas where groundwater depletion is advancing. Consideration needs to be given to the soils and stratigraphy, the receiving aquifers, and the practicalities of recovering the recharged water.
- Assess the technical feasibility of groundwater recharge, considering both injection and surface application of recycled water. Determine the level of treatment necessary and possible methods.
- For the most attractive options, determine the mode of artificial recharge, the infrastructure required, and the capital and operating costs of these facilities. Assess the public acceptability of groundwater recharge with recycled water, both in the Amman-Zarqa highlands and the Jordan Valley, if technically viable.
- Assist with determining the economic feasibility of recharge options in view of planned uses of the water.

Outputs

The primary output of this activity is the Groundwater Recharge Options report, which should address the items detailed in the scope of work above and other relevant aspects of planning groundwater recharge with treated reclaimed water in the Amman-Zarqa basin and the Jordan Valley. The format of the report will follow that of the other technical reports produced under the water reuse component of this project.

Roles and Responsibilities

The consultant will report to the ARD Home Office Project Management team at ARD headquarters concerning all US-based arrangements and activities (contractual issues, international travel, travel advance, payment for services).

In Jordan, the consultant will work directly with the Water Reuse Planning Component leader on all technical issues, report to ARD's Chief of Party on all logistical issues.

Level of Effort

The in-country activities of the consultant will be in one visit in which the above scope of work will be completed. A total of 20 working days are allocated for this consultancy between January ?? and February ??. These days comprise 17 working days in country plus three days for travel.

Travel Schedule

To be determined.

ANNEX 2
Travel Itinerary & Work Schedule

March 12th	Departure home 0730 for London Heathrow. Depart LHR 1600
13th	Arrive Marriott Hotel Amman 0230 am, by taxi; arrive project office 0930.
14- 15th	Report review at ARD Project office.
16th	Work at Hotel
17-18th	Discussion with counterparts & report review at proj. office.
19th	Field work – visit to highlands area, As Samra oxidation ponds and King Talal reservoir site
20th	Meeting with MWI staff and work at office.
21st	Field visit to Jordan Valley and meetings with Mr Shafiq Habash, JVA, the Director of Karameh Dam, and Dr Andreas Kuck, GTZ, concerning salinity in groundwater in the valley. Also visited Khafrein dam and local area.
22nd	Work at project office; meeting with W Bajjali, ex WAJ groundwater expert with special experience in Wadi Dhuleil.
23rd	Recreation
24th	Work at Project Office
25th	Meeting with Dr Nadir Al Ansari, University of Al al-Bait concerning reclaimed water re-use. Work in office p.m.
26-28th	Office closed due to Arab Summit Mtg; report writing at hotel.
29th	Work at ARD Project office.
30th	Work at hotel.
31st	At ARD Office; meeting with Dr Elias Salameh, University of Jordan; meeting with senior MWI staff
April 1st	Completing report at ARD Office.
2nd	Depart Amman on BA 6706 at 0735; arrive at home 1800

ANNEX 3

Artificial Recharge of Treated Sewage Effluent through infiltration lagoons

1. Introduction

1.1 Basic concept

The re-use of sewage effluent and sludges to irrigate and fertilise, has been used throughout recorded history though mainly on an informal basis. Often the underlying main objective has been one of disposal but the use of 'night soil' in China, for example, has been an important part of their system of conservation and agriculture for centuries. From the mid 19th Century, the collection of large volumes of sewage in sewers from urban centres, provided a new resource for agriculture in some areas, and sewage 'farming', using primary effluent, was practiced in many European countries from this time. It was used essentially as a means of disposal of sewage from the large and then rapidly growing conurbations. The more modern re-use of treated sewage effluent by rapid infiltration, has been applied on a large scale in some parts of the world, and particularly in the US where large amounts of water have been conserved for re-use, mainly for unrestricted irrigation (Bouwer 1985,1991).

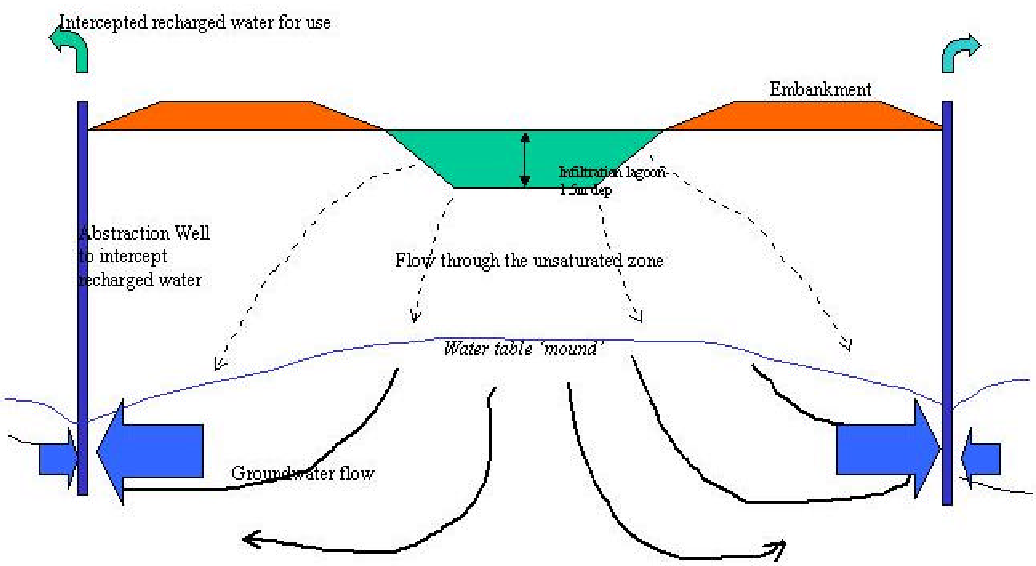
Through the use of a system of artificial recharge lagoons, polluted river water has been used as a source for public water supply for many decades in Europe. River water has been collected from contiguous alluvium either by directly induced recharge, or by the use special infiltration lagoons from which the infiltrated river water is abstracted through specially located interceptor wells. In Holland for example, the River Maas is used for water supply after thorough pre-treatment, artificial recharge, abstraction and final treatment. The river is polluted and of variable salinity; through recharge, variability in the source water quality is attenuated, and much valuable additional treatment effected. This is only one of many schemes operating in the Netherlands (Peters 1988). Also, in many areas in Germany, similar artificial recharge schemes make use of industrially polluted river water, also for public supply. Partial oxidation and pathogen removal during the infiltration process, between surface and water-table in alluvium, is an important element of the overall treatment process. In each case, the capacity of the natural strata as treatment media, rather than for storage, has been used to advantage (Kussmaul 1977). Nevertheless, the storage capacity of the formation does play an important part in the process, in allowing retention and dispersion so that water quality variation is further attenuated.

In arid regions, where natural renewable water resources are severely limited, the re-use of reclaimed water becomes an important option when new resources have to be found. The infiltration process has a considerable capacity to improve the quality of the recharged water as indicated above. Dilution of recharged water with natural groundwater improves quality and further infiltration and dispersion within the saturated aquifer allows further oxidation, and other processes, to take place (see below). The recovered reclaimed water resources thus recovered can be stored in an aquifer, where hydrogeological conditions are suitable.

1.2 Previous international experience

Some of the most comprehensive reclaimed water recharge research has been carried out since the late 60’s, in Arizona USA (Bouwer op. cit). The literature is extensive but much work has been focussed on varied and sometimes complex case studies, while the basic technology is relatively simple. The basic principle is illustrated in Figure 3.1.

Figure 3.1. - Section across single lagoon showing water flow directions



One recent and relevant successful application has been in western South Africa, where the water resources options are extremely limited because of the lack of natural water resources. Here, the artificial recharge of treated domestic and industrial sewage effluent (with storm drainage when available) is an integral part of the water supply system, which is based on the re-abstraction of the recharged reclaimed water as groundwater (Wright & Parsons 1994). This application would offer some parallels for Jordan.

Highly treated reclaimed water has also been used experimentally for recharge through wells, much of the research having been done on Long Island in the USA in the 70’s and early 80’s (Faust & Vecchioli 1974, Vecchioli 1975, Roberts 1985). The feasibility of recharge through wells is technically more difficult because of susceptibility of the aquifer to clogging and these problems are particularly acute with reclaimed water. In the Long Island example referred to, the difficulties of operation related to the problems of rehabilitation of the arenaceous alluvial aquifer after clogging by suspended solids, even though the recharge water was of very low turbidity. This, together with the costs of the very highly treated water, made the scheme completely uneconomic. High injection (recharge) rates and lesser problems with clogging have been encountered using fissured aquifers. However, because of the more rapid and less predictable movement of groundwater in such aquifers, the management of recharged groundwater resources for re-use tends to be difficult. As a result, limestones and other fissured aquifers have more frequently been used for disposal rather than resources management.

1.3 Applications in the Amman-Zarqa/Jordan Valley areas

Clearly a pre-requisite is the availability of a source of treated reclaimed water and in the above areas, the only major current sources are those discharged from the As Samra Plant and the smaller plants at Baq'a, Abu Nuseir and Jarash (East). Additional plants are planned for Zarqa and Jerash(West). New treated effluent resources will therefore become available from these new developments which could be applied in this way, but which are currently destined for direct agricultural re-use. The most appropriate methods in these areas would be infiltration lagoons, which, suitably landscaped, can also offer some benefits in terms of amenity and wildlife.

The application of treated reclaimed water recharge in Jordan could therefore be seen as involving typically, a system of specially designed and located infiltration lagoons. The unsaturated zone is used to effect additional treatment, and the saturated zone for storage, detention, dilution and mixing prior to withdrawal for re-use from the dedicated wellfield. At the point of withdrawal, the recharged water will form only a proportion of the pumped water and, in addition to dispersion and mixing with natural groundwater, the degradation of any organics in the recharged water also would be well-advanced. Furthermore, the abstraction of the recharge water/groundwater mixture from the dedicated wellfield would serves to protect local groundwater (if of superior quality) and the aquifer at large, from possible degradation. It must be added however, that the quality of the water that could be produced is likely to be of higher quality than already exists over large areas of the country.

2. Criteria for design of a reclaimed water recharge scheme

2.1 Introduction

The various schemes, which have been studied and operated around the world, have been based upon many considerations including the local hydrogeological setting, source water quality and specific needs for the additional water. The most important of these are

- the hydrogeology (infiltration rate and unsaturated zone thickness and properties, and volume of aquifer storage available),
- the quality of the effluent (effect on infiltration rate and operating regime)
- the land area available (the capacity of the recharge facility)
- location of the water source and point of abstraction (to minimise cost and maximise mixing and dispersion),
- availability of other resources for blending, if necessary, and
- proposed manner of re-use.

The above topics are explored further below

2.2 Hydrogeology

The volume of aquifer used to receive and store the recharged water has to be readily accessible and provide adequate operating storage. There also has to be sufficient opportunity for infiltration treatment in the unsaturated zone between the surface and the water table. Basic requirements are therefore for a thickness of unsaturated zone (ideally >30m), and a vertical permeability which enables high rates of recharge without overloading the treatment capacity of the unsaturated zone. There also has to be sufficient space in the aquifer where the recharged water can be retained and not lost through evaporation, or through springs. Alluvial aquifers would be ideal in the, but because of the need to avoid areas of low permeability and high anisotropy, special site investigation would be needed. Piedmont areas may be most suitable, where average grain size is comparatively large so vertical permeability relatively high. Alternatively sites within wadi spreads may be suitable, though there may need to be special provision for diversion works on the upstream side.

The infiltration rates which can be achieved, will depend on the vertical permeability of the formation. These will be high at the start of a recharge period and tend to decline as the bed of the lagoon clogs progressively with suspended solids and biological debris. The duration of a recharge period will ultimately be optimised to maximise throughput compatible with good recharged water quality. There is little information on possible natural infiltration rates but experience elsewhere indicates that rates of 1.0 m/d may a typical value. (Mohsin et al 1995, Bradford 1995). In practice, infiltration takes place through the bottom and sides of a lagoon when the sides are left uncovered and simply constructed with a batter of say, 1:2. For present purposes, assuming a 'good' site, whether in a wadi course or elsewhere is selected, a 'design' starting infiltration rate of at least 1.0 m/d appears realistic. If it is further assumed that the average infiltration rate over the infiltration/draining/cleaning and re-aeration cycle is 0.5m/d, about 0.2 Ha of recharge lagoon area per megalitre of effluent, would be required, or about 2 Ha for 10,000 m3/d

2.3 Lagoon Design

Shape

In a piedmont area whether in a wadi or on the edge of an interfluve, an elongate shape parallel to groundwater level contours would be most efficient, in terms both of maintaining a similar depth-to-water beneath the infiltration facility, and for interception of the recharged water immediately down the hydraulic gradient. This could be done using existing, or specially drilled, wells for interception of the recharged groundwater.

Bed area/depth

Best advantage can be taken of typically higher horizontal permeability if lagoons are long, thin and deep. At locations where the vertical permeability is high this is not be such an important consideration. However, to minimise the surface area and maximise the depth is also beneficial in reducing losses to evaporation during the hottest time of the year when evaporative losses may exceed 5 mm/d. Because infiltration should be continuous to maximise throughput, at least two lagoons would be needed for any facility, so that one could be draining for re-aerating, and cleaning, while the other was in operation. In practice it would probably be desirable to include a special additional lagoon into which supplied effluent could be further settled prior to recharge, and which would serve as a balancing storage.

Cleaning

Mechanical cleaning is possible using specially adapted equipment which would require an access ramp, and a level bed. If water supply practice was followed, then 300-500mm of filter sand might be laid on the bed of lagoons; the clogged layer can be removed, cleaned and replaced. The use of mechanical cleaning methods is however, geared specially to the cleaning of lagoons which have fully engineered concrete, or otherwise stabilised, sides (such schemes are used in Germany and the Netherlands). This tends to severely reduce infiltration by blocking off the horizontal infiltration of recharge water for reasons described above. For applications in Jordan, mechanised cleaning has not been considered at the moment.

2.4 Treated effluent quality and pre-treatment

It is preferable for the main oxygen demand and the bulk of the suspended solids and nutrients to be removed prior to entry into the aquifer. The biological and chemical oxygen demands are still relatively high for artificial recharge, and the further aeration in the lagoons prior to recharge would help to satisfy these demands and to oxidise ammonia. This would therefore occur to some extent prior to infiltration, within the recharge lagoons, though without some mechanical aeration, may not be very efficient. The simplest method of doing this, would be for the effluent to be discharged through an aeration cascade at the point of discharge into the lagoon system, to enhance dissolved oxygen content as much as possible. Other processes, which would occur in lagoons, is the assimilation of nitrogen and phosphorus by algae, under the influence of high temperatures, and solar radiation. The removal of these nutrients is beneficial provided the vegetation produced does not sink and decompose, otherwise anoxic conditions may occur on the bed of the lagoon.

If this is not possible, anoxic conditions may become quickly established leading to undesirable water quality changes such as mobilisation of iron and production of hydrogen sulphide. However, it must be added that beneficial changes, such as reduction of nitrate, may also occur.

The recharge operation therefore has to scheduled carefully, not only to enable the lagoon beds to be cleaned, but also to provide opportunity for some re-aeration of the unsaturated zone and at the same time, maintain recharge rates at the optimum.

3. Recharged water quality improvement.

3.1 Unsaturated zone

During infiltration to the water table, through the unsaturated strata, many water quality changes are possible as the result of interaction between the infiltrating water, the pore gases, and the strata. At the point of entry into the aquifer (the lagoon bed), the particulate matter would be strained out, including most of the bacteria and viruses; some of these can penetrate through the pores or fractures of the strata, but tend to be adsorbed within metres of entry (typically, in unfissured strata, much less). From that point, the interactions which take place, are between the dissolved substances and gases in the water. There is also heat exchange between the water and the mass of the strata, so that the variations in input water temperature are greatly reduced or virtually eliminated.

The main changes, which occur during infiltration, are the result of

- *Chemical and physico-chemical reactions*

- Adsorption/desorption
- Acid-base reactions
- Oxidation –reduction
- Precipitation-solution

- *Biochemical reactions*

- Degradation by microbes
- Cell synthesis

Charged particles and ions, and colloidal particles are held or at least retarded, by adsorption onto the surfaces of the finer particles (clay and silt) in the strata. Desorption can occur if salinity declines for example. The solubility and mobility of constituents increases with decreasing pH. Acid-Base reactions can be influenced by the break down of organics in infiltrating water. Oxidation of the organics requires pore oxygen and also the oxygen in nitrate and, in some cases, the sulphate also. The opportunity for the regeneration of pore gas during aeration periods is vital for the long-term provision of as much pore oxygen as possible. Depending on the pH and the concentrations of various constituents in the water, there can be either precipitation or solution.

The most important range of changes is that concerning the degradation of organic compounds which are major contaminants in recharged effluent. These biochemical reactions break the compounds down into smaller more stable molecules, water and carbon dioxide. The improvement in water quality will be best where the unsaturated zone is thickest.

Results from the US example operating at Phoenix, Arizona, point to remarkable efficient treatment in passing through the natural media, as illustrated in the table below.

Constituent	**Recharged Effluent**	**Recovered groundwater**
TDS	750	790
Suspended solids	11	1
NH4-N	16	0.1

NO3-N	0.5	5.3
Organic- N	1.5	0.1
Phosphate as P	5.5	0.4
Fluorine	1.2	0.7
BOD	12	0
TOC	12	1.9
Zn	0.19	0.03
Cu	0.12	0.016
Cd	0.008	0.006
Pb	0.082	0.006
Faecal coliforms/100ml	3500	0.3
Viruses, pfu/100ml	2118	0

(all values in mg/l unless otherwise stated; from Bouwer 1985,1990)

3.2 Saturated Zone

At the water table, oxidation of all ammonia and part of the organics would, ideally, have occurred. On reaching the water table, recharged water will migrate towards discharge, whether natural or artificial (pumped). In the course of migration through the saturated aquifer, the dissolved constituents in the water are subject to dispersion and dilution, and the degradable constituents to continued decay. The rate and effectiveness of these processes are directly related to the properties, physical and chemical, of the aquifer. Under saturated conditions, with no gaseous oxygen, the availability of oxygen is less, so oxidation of organics takes longer. However, the process still occurs and water quality can be expected to improve in the direction of groundwater flow. In due course, quality will improve to the point of being suitable for any use, including use as drinking water.

Clearly the arrangements for interception of recharged water for re-use, depend on the above processes and the plans for re-use.

4. Recharged groundwater interception.

The dimensions of the groundwater ‘mound’ which would build up beneath the recharge facility, is a function of the rate of recharge and the properties of the aquifer. The mound would ‘decay’ continuously down the groundwater gradient with dispersion and concomitant dilution taking place. Further water quality improvement would also take place including the removal of any organics, and bacteria or viruses, if any of the later reached the water table.

Mathematical modelling would be helpful in assessing the way in which the recharged water body would move. If complete interception of the recharged water was required, then results of modelling would enable the optimum depths, designs and spacings for the appropriate production wells to be determined (provided the appropriate local data were available). There would be quality benefits in allowing the longest possible travel time but if quality only had to satisfy agricultural/irrigation standards, long travel/residence time in the aquifer would not be an important objective. Recharge would be a continuous operation so to achieve maximum scheme efficiency, wellfield abstraction would also have to be more or less continuous.

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ANNEX 4

Well Recharge

1.Introduction

General

A well use for recharge of surplus water is seen as an ‘ordinary’ well in reverse and assumed to operate and respond in much the same way with the rise in water level caused being analogous to drawdown. Drainage wells and soakaways are common for the disposal of water but the technology of constructing and operating recharge wells as a useful water resources management technique is more recent, although many pilot studies have been carried out in the past (Edworthy & Downing 1981). The constraints and limitations of the technique are now better understood and the high quality water typically needed for well recharge, is less expensive to produce.

Well recharge facilities are small in size, need little land and cause little disturbance to the environment; water resources can be augmented in specific areas where there is a deficit or where there is room in an aquifer for additional storage. Special recharge wells dedicated to the one activity are typical but there has been increasing interest in the use of a single well for both recharge and production or ASR (artificial storage and recovery).

Applications

Where space is limited and water quality is high, well recharge has great potential as one technical option for the augmentation of groundwater storage. Its ultimate suitability for any application depends on cost.

2.Selection of recharge well sites

For well recharge, the availability of storage space in the aquifer is the main pre-requisite to allow suitable sites to be defined. Beyond that there are many varied reasons for considering groundwater recharge.

Regional use

Recharge wells are often seen as a way of focussing additional water resources where there are clear and well defined areas of deficit, but this is only of value when there is easily accessible aquifer storage and there is a large supply to fill it. It is sometimes used as a way of using a winter surplus from a treatment plant which can be recharged to augment storage ready for higher rate use in the summer.

Specific problems

If saline intrusion is being caused by too much fresh groundwater pumping near the coast, a recharge barrier can in principle be set up using a line of recharge wells between the coast and the production wellfield (Bruin & Seares 1965, Aberbach & Sellinger 1967). Similarly, groundwater flow can be 'managed' to divert contaminated groundwater flow by means of recharge.

3.Water quality considerations

The major problem which afflicts all recharge well operations, is the process of well clogging. This is most conspicuously caused by the particulates, both organic and inorganic but can also be caused by a range of other factors. Susceptibility to clogging also depends on the nature of the aquifer. Where fracturing is important, the impact of clogging is least, but for unconsolidated alluvial types of aquifer, clogging can occur rapidly and rehabilitation can be difficult if not impossible.

Suspended solids

In a pumping well, after proper development, fine materials are removed from the aquifer closest to the well so that hydraulic losses are minimised. If the rate of pumping is excessive, fine solids can be mobilised during operation. During recharge, even with good quality water, suspended solids are strained out from the recharged water and accumulate on the face of the aquifer inside the well. The finer solids can penetrate the aquifer to a degree which is a function of the pore, or fracture, size. The cumulative effect is for the recharge rate to diminish so that 'backwashing' has to be done to remove as much of the added solids as possible. In practice, a proportion of the solids which enter the aquifer usually cannot be removed by the inflow velocities which can be imposed by pumping. The effect of this is a progressive underlying decline in recharge rate, even though partial renovation is possible at each 'cleaning' operation (Marshall et al, 1968)

Microbes and nutrients

Microbes are part of the suspended solids load but the main problem comes from 'resident' microbes which are able to use substances in the recharge water as a nutrient, whether it may be iron, nitrogen, or phosphorus, for example. Growth of the local microbes can eventually occlude the screen or pack and cause severe clogging which can be very difficult to break down. Sterilisation, or other chemical treatment with energetic backwashing, is usually needed.

Encrustation

Compatibility of the recharge water with the ambient groundwater needs to taken into account. Changes in pH or redox potential when the hydraulic regime in the well changes (from recharge to pumping for example), and when mixing in the well takes place, can lead to the build up of encrustation. Precipitation of lime is one of the most likely potential problems.

Gas clogging

Bubble formation in the recharge supply within the well can happen when there is a fall in pressure as water leaves the recharge inlet pipe. If bubbles are produced faster than they can be re-absorbed into the water, the residual small bubbles can block the interstices of the aquifer and reduce the transmissivity greatly. To avoid this problem, the recharge pipe can be equipped with a remotely operated control valve which enables the recharge inlet pipe to be kept full all the time.

Storage & recovery changes

Recharged water is subject to dispersion when it is injected or gravitated into an aquifer, so that mixing with the native groundwater takes place across the interface between the two. The mixing can be accompanied by density stratification where there is a large difference in salinity. During recovery, the recharged water is recovered with little or no quality change initially, but as the time progresses, mixed groundwater is pumped and quality changes gradually to that of the native groundwater. To recover all of the recharged water, it may be necessary, because of dispersion and mixing, to pump many times that volume. The effect of this phenomenon, if the native groundwater is saline or otherwise of low quality, is to contaminate a proportion of the recharged water so that there are 'losses' in terms of usable resources as a result of recovery after storage. The longer water is stored in the aquifer the farther will tend to migrate in the direction of natural groundwater flow and the longer will be the time needed to recover it; in time stored water will move beyond the point where recovery is possible unless there are interceptor wells down gradient. For single ASR wells (Artificial Storage and Recovery wells) this can be a serious drawback.

4.Well construction

The dangers of clogging by drilling mud during drilling need to be avoided and it is desirable to use organic drilling fluid rather than bentonite. The dangers of exposing the aquifer to suspended solids can be further minimised by applying reverse-circulation drilling, a technique particularly useful for drilling large diameter boreholes.

Dimensions & materials

Depth and diameter need not differ greatly from production wells, but there is sometimes the need to accommodate separate recharge and pumping mains, and possibly additional valves. Furthermore, it is essential in aquifers which are especially susceptible to clogging, to include a thick gravel pack so that suspended solids introduced into the well during recharge, can be accommodated before they reach the formation (Edworthy 1978, O'Shea 1984).

Screen, pack and backwashing

A thick gravel pack can be good protection for the aquifer against invasion by suspended solids during recharge when flow into the aquifer is continuous, and pressure (or head is highest. Under unconfined conditions where the screen extends downwards from the water table, there is a danger, during pumping, that part of the screened section of the hole will be above groundwater level, and there will be no flow through it. This can be dealt with by installing back-washing pipes behind the screen within the gravel pack from which water can be jetted to clean the 'dry' section.

In a confined aquifer, the same problem need not occur, but there will still be a basic limitation on the rate at which water can be drawn back through the well by pumping. To dislodge clogging materials from the pack and aquifer, special surging, jetting and possibly back-washing with chemicals might be necessary.

It is highly desirable for the screen to have as high an open area as possible so that 'access' to the pack is easiest, either for recharged or pumped water, or for special washing activities from within the well.

5.Operation and maintenance

The rate of recharge declines over time at a rate which depends on the extent of any clogging problems. Experience show that partial or even near-complete recovery of performance is possible by regular backwashing, but that there is a gradual decline towards a 'sustainable' rate which may be a fraction of the initial rate. Regular cleaning at an interval which has to be set on the basis of experience, is essential to long life, but even more important is the demand for the highest possible water supply from the outset

Figures

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Annex 5

COST ESTIMATES

Table 5.1 -Re-use of As Samra effluent by artificial recharge

Cost of facility to recharge 10000 m3/d

Option	*Inf Rate m/d*	*Inf Area* m2*	*Service** area (m2)*	*Total area m2*	*Excavation (m3) to 1.5m*
1	1.00	30000 .00	2800 .00	32800	43335 .00
2	0.50	50000 .00	4400 .00	54400	72225 .00
3	0.10	110000 .00	8800 .00	118800	158895 .00

* - Includes for duplicate recharge basins, plus settling/buffer storage lagoon
** - Additional space at site for settlement lagoon, access, services etc.

Option	*Cost of land JD*	*Cost of Excavation JD*	*Cost of Wellfield JD*	*Local site minor works JD*	*Capital cost of site JD*
1	16400	195007 .5	280000	54400	**545807.5**
2	27200	325012 .5	280000	64400	**696612.5**
3	59400	715027 .5	280000	79600	**1134027.5**

Cost of Recharge Water

Assume 0.378 JD/m3(see reference) and 3.65 MCM/a (10000 m3/d)

~~Total = 1,379,700 JD/a~~

Lagoon Operation & Cleaning

Option	*Staff No*	*Unit cost* JD*	*Ann cost JD/a*	*Water source JD/a*	*Total Ann cost (JD/a)*
1	4	7488	29952	1379700	**1409652**
2	10	7488	74880	1379700	**1454580**
3	22	7488	164736	1379700	**1544436**

* Full time 6-day week, 8h day & 3JD/hr

(Ref-MWI 2000 WRPS Project; Pre-feasibility study,Water Re-use for Ag & Forestry)

Figure 5.2 Estimate of Well Recharge Costs

(for scheme to recharge 10000 m3/d)

Capital Costs

	Unit	Rate	No	Total
		JD		JD
Land	ha	5000	4	20000
Recharge wells	ea	100,000	4	400000
Production wells	ea	60,000	4	240000
Monitoring wells	ea	10000	4	40000
Total JD				**700000**

Annual Cost of Recharge water

Water delivery and costs (value taken from MWI, 2000)	m3	0.38	3650000	1387000
Addition effluent treatment (Value adapted from estimated figure in Asano**)	m3	0.4	3650000	1460000
Total JD				**2847000**

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