Pathways to Water Resource Sustainability Using Managed Aquifer Recharge (MAR)

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ABSTRACT

Managed Aquifer Recharge (MAR) is a powerful water resource management tool that can be used to stretch limited water resources for seasonal or long term use. Many projects have demonstrated the maintenance or improvement of water quality that is a key benefit of MAR.

Storage of low cost surplus water during periods of high supply and recovery of that water during periods of high demand equate to significant cost and resource savings. Storage of MAR can be done at scales and durations not possible with surface storage approaches. Stretching limited water and capital resources is a key factor in the sustainability of industry and communities.

The paper and presentation layout steps to development of a MAR programme. Examples of successful projects in USA, UAE, KSA and AU are used to demonstrate significant points in the process. Also covered are the significant cost and resource benefits of storage in aquifers over traditional surface storage approaches or development of additional resources.

KEYWORDS

Managed Aquifer Recharge, Water Resource Management, Sustainability

1. INTRODUCTION

Managed Aquifer Recharge (MAR) is the intentional increase in the amount of recharge to an aquifer for water resource management and/or environmental purposes. The author presents the benefits of MAR along with some of the key objectives, and challenges, that may be met in successfully planning and executing a MAR project. Examples of projects, many of which the author has been involved, are used for demonstration of important points.

2. GOAL SETTING

An understanding of the opportunities and limitations related to MAR projects is critical to identification of appropriate goals. Identification of pursued benefits and potential challenges is important to the goal setting process.

Among the demonstrated benefits MAR offers include the storage of water to meet short term, seasonal or long term demands. The quantity of water that can be stored may be small to very large. High storage capacity can be utilised to hold surface water which may otherwise be lost or not put to beneficial use. The water quality of the stored water is maintained during the storage period and is in some cases improved during storage. Indirect potable reuse has been successfully incorporated into MAR projects with strong public support. Operational requirements for the maintenance of water quality and the need for treatment of the recovered water is typically less than surface storage options (tanks or reservoirs). The surface footprint and land requirements of a MAR system are generally less than surface water storage options. The security of the stored water underground is significant advantage over surface water storage.

Some of the factors critical to success of MAR include the need to understand the hydrogeology of the receiving aquifer and groundwater systems affecting the receiving aquifer. The aquifer must have sufficient capacity for storage. The hydraulic characteristics of the aquifer must be appropriate to retain the water in storage without unacceptable loss to down gradient flow or mixing with undesirable water quality present in the aquifer. Treatment of water pre and post storage is needed in some cases. MAR does not work in all hydrogeological environments.

Careful consideration of the water resource availability, the hydrogeology and conditions of recovery of the stored water is needed to set worthy and attainable goals. There are many successful projects that demonstrate the resource, societal and cost benefits of MAR. Setting appropriate goals including resource management, water treatment, basin replenishment, saline water intrusion barriers, etc. or a combination of goals is important to focusing efforts of study, design and execution.

Combining MAR with other water resource strategies can provide significant savings. Construction of a seawater desalination plant in an area with seasonal variation in demand requires that the plant is sized to meet maximum day demands. An oversized desalination plant does not operate at a consistent rate, resulting in increased O&M., Storing water in a MAR scheme of sufficient capacity can allow for reduction of the size of the seawater desalination plant and operation of the plant at a constant rate.

Improper setting of goals can lead to difficulties in programme implementation and failure of the MAR project. Setting goals that are outside the capabilities of MAR, failure to consider resource availability and disregard for hydrogeological conditions are some of the most common stumbling blocks in MAR projects.

3. PLANNING

Planning of a successful MAR programme requires understanding of the physical and regulatory conditions that will affect the various aspects of the project. Failure to plan properly for source water cycle and quantity can result in under sizing of the scheme and loss of opportunity for storage/loss of resources. Water quality of the source and receiving aquifer must be considered with respect to hydrogeochemical reactions during storage.

Quantity and timing of availability of recharge water must be considered early on in the planning process. In many cases source water is available seasonally such as during high flows in the spring due to snowmelt or during the rainy season. Short term flows at high rates require different strategies and infrastructure than sources available on a continuous basis such as seawater desalination. If treatment is required prior to storage then facilities sized to purpose must be planned for.

Characterisation of the hydrogeological system is a critical element in the planning process and should be started early. Building understanding from historic records including bore logs, hydrogeological investigations and long term water level and quality monitoring is of great advantage to developing an understanding of the system and where extra effort may be needed for characterisation.

Hydrogeochemical mixing of recharge and receiving waters should be predicted early on. Undesirable effects in water quality during storage have resulted in increased cost, reduced benefit and failure of MAR systems. Mobilisation of arsenic and development of regulated disinfection by products are two examples of undesirable water quality effects that have been encountered during MAR projects, Oftentimes, these effects can be mitigated or avoided through low cost measures including pH adjustment of the recharge water or a change in design of recharge/recovery well construction. Identifying the potential for problems early improves the likelihood that the programme can progress on time and within budget.

The Orange County Water District determined that recharge with recycled water would result in mobilisation of arsenic from the aquifer geologic materials. Studies conducted with Stanford University determined that addition of standard water treatment chemicals (lime) balanced the recharge water and reduced arsenic mobilisation.

4. DESIGN AND EXECUTION

Based on understanding of the factors affecting the basic elements of the programme a design process can be undertaken that addresses any difficulties and takes advantage of opportunities.

Budgeting and programming of water availability and timing of recharge should be considered along with the civil engineering needed to get the water from source to recharge facility and ultimately into the receiving aquifer. In many cases, recharge water is available on a seasonal basis. The recharge water can therefore be of high volume over a short duration requiring facilities to handle and recharge the water at a rate that the aquifer can accept.

Seasonal availability of recharge water can take advantage of low demands and existing distribution system capacity. The Las Vegas Valley Water District's Artificial Recharge program, for instance, stores Colorado River Water during the cooler winter months. The river intake and distribution system have available capacity because water demands are lower in the winter months This water is stored to meet long term gaps in supply and potential shortages.

Timing and end use of the recovered water are important to consider early on. Design of recovery and treatment facilities needs to consider future system capacity and timing of recovery. Ensuring that the water is where it is needed, when it is needed is the goal of a successful MAR programme particularly in the case of public water supply.

Design of recharge and recovery facilities is important to the success of the project and manageable O&M. Surface recharge through infiltration basins can recharge large amounts of water in a short amount of time if the hydrogeological conditions are correct. Shallow water levels and the presence of low permeability sediments can reduce the effectiveness or surface recharge and make the project unmanageable.

Injection through dedicated or dual use (recharge/recovery) wells is the preferred method in areas where the aquifer is confined. Recharge through wells can be successful in aquifers with deep or shallow water levels. Method of injection and potential for geochemical reactions must be considered to avoid plugging of the recharge well or dissolution of aquifer materials.

In Saudi Arabia, investigations of the recharge schemes at Al Alb and Ghatt were used as the basis for a nationwide approach at over 200 dams. The Al Alb and Ghatt recharge schemes were constructed using passive recharge wells constructed in the upstream impoundments behind the large dams on these wadis (dry river beds). In theory, the impoundment would fill up during infrequent heavy rains and flow into the open recharge wells, recharging the channel gravels for downstream agricultural users. Storing the water underground would reduce the loss of water to high evaporation rates in the region. Investigations revealed that the impoundments were effectively sealed with fine grain silt and during heavy rain the silt was mobilised plugging the recharge wells. Potential solutions were passive filtration at the recharge well head (rock filled gabion baskets) and siphoning the water downstream for filtration and injection.

Groundwater flow modelling is used to predict effects to the groundwater system into the future, aquifer conditions when water will be recovered and effects of recovery. Prediction of water level rise and migration of the recharge water away from the recharge area are critical to long term success of the project. Water that migrates out of the recovery area prior to the need for the recovered water is lost. These simulations are needed to plan recovery facilities capacity and location.

Solute transport modelling is used to simulate water quality change due to recharge and recovery over time. Recharged water of a different quality then the water in the receiving aquifer will mix and migrate during storage. Water quality requirements and recovered quantity targets may not be met if design does not consider the effects of mixing.

Collier County, Florida stores fresh water in deep brackish water aquifers of the Suwannee Limestone. Early testing indicated that recovery of freshwater would only be 50% of that injected. Modelling and continued cycling of recharge/recovery indicated that recoveries would increase to nearly 100% as a freshwater buffer in the aquifer was developed around the recharge/recovery wells.

Regulatory requirements for monitoring of recharged water, water in storage and recovered water are becoming increasingly sophisticated. Monitoring programmes should be established to meet these requirements and foreseeable developments in regulatory compliance. As laboratory analyses improve, constituents of concern can be detected at increasingly lower concentrations. Oftentimes, regulatory conditions change based on these precision analytical methods.

The Las Vegas Valley Water District’s Artificial Recharge Program recharges chlorinated drinking water into an artesian aquifer. Improved laboratory analytical techniques revealed that disinfection by-products (DBPs) were being formed and were present at levels above recently enacted standards in the recovered water meant for addition to the public water supply. Detailed sampling and monitoring of effects in the aquifer showed that these DBPs were not present in water stored in the aquifer short distances away from the recharge/recovery well. Pumping several well volumes to waste resulted in water of acceptable quality. It was determined that bacteria in the aquifer resulted in natural attenuation of the DBPs during storage and only the recently recharged water in the bore and nearby aquifer zones contained unacceptable levels of DBPs.

5. COST BENEFIT

The determination of cost benefit to establish a MAR programme should of course consider capital and operating costs and the benefit of resource availability when needed. Other benefits that are less readily defined include environmental benefits, societal benefits and the benefit to other users of the groundwater system.

Capital costs include, but are not limited to:

- Land;
- Testing costs, feasibility analyses;
- Consulting services for the design, permitting, and supervision of the construction;
- Construction costs (e.g., roads, piping, instrumentation, controls, and pretreatment systems); and
- Regulatory testing requirements during construction and operational testing.

Operation and maintenance costs include the following:

- Labour (system operation, regulatory requirements, administration);
- Electricity;
- Consulting services;
- Regulatory testing requirements (e.g., water quality testing);
- Maintenance costs (e.g., parts replacement, well and basin rehabilitation);
- Pre-treatment costs (additional treatment prior to recharge);
- Post-treatment costs (e.g., chlorination); and
- Raw water costs. (Maliva, 2014)

Benefit of a MAR project relate back to the goals of the project. Benefits to consider in developing cost benefit may include the damage cost of the water not being available during a drought, the value of maintaining a safe and reliable water supply in an uncertain resource situation, the value as compared to other water resource options (dams, seawater desalination, etc.), the value of the water for economic purposes if it were not otherwise available (industrial or agriculture) and the value of water being stored in the aquifer for other groundwater users (reduced pumping costs and improved groundwater quality).

In the United Arab Emirates the Liwa Aquifer Storage and Recovery (ASR) scheme is being constructed and recharged with enough water to meet the capital city of Abu Dhabi's emergency water supply needs for 90 days. Prior to the project the city had enough storage capacity to meet emergency water supply needs for only 3 days. The next best alternative to MAR considered was construction of above ground storage tanks. Cost for the above ground storage solution was estimated at $4 Billon USD for 600, 45,000 m^3 storage tanks and required ancillary equipment. The MAR solution was budgeted at $500 Million USD. Management of water quality in long term, above ground storage also came out as a key O&M issue compared to recovered water that could go direct to the public water supply from the MAR scheme.

In Perth, Western Australia the Water Corporation is developing a Groundwater Replenishment Scheme (GRS) at Beenyup. This project included a 3 year trial and is now under construction to recharge tertiary treated recycled water to the groundwater system used for drinking water supply. Comparison of CAPEX/OPEX indicates that the GRS is 70% the cost of seawater desalination. Other benefits noted include reduction in carbon emissions and elimination in loss of the resource represented by wastewater disposal to the sea. (Vanderzalm, J.L. et al., 2015)

6. CONCLUSION

Managed Aquifer Recharge is a water resource management tool that should be considered early on in planning efforts. MAR holds many benefits, including cost, that weigh favourably when considered against other storage strategies. MAR can take advantage of seasonal surplus (cheap water) and deliver the water during seasonal or long term shortages (expensive water). By capturing surplus water that might otherwise be lost, more expensive/less desirable resource development options (seawater desalination) can be reduced in scale or in some cases be avoided. The increasing value of recycled water in arid regions and the demonstrated success of recycled water MAR for indirect potable reuse results in significant benefit in situations that may have few other options.

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Bio

Mike is a Senior Associate Hydrogeologist with Beca in Auckland, NZ. Mike has nearly 30 years of experience in water resource development and management with significant experience in Aquifer Storage and Recovery (ASR) and Managed Aquifer Recharge (MAR). Mike has worked in Florida, California and Nevada in the USA, Abu Dhabi, UAE and Riyadh, KSA prior to joining Beca in Auckland, NZ early in 2014. Of particular relevance to his presentation topic, Mike was technical manager of the Las Vegas Valley Water District Artificial Recharge program which was the largest direct injection ASR program in the world at the time. Mike has worked on other MAR projects during his career in California and Florida, USA and also while in the Middle East.