Water Resources - Drought Management, Conservation and Protection of the Quality of Source Water

Outlining the Case for an Artificial Groundwater Recharge System - Jamaica Experience

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Abstract

Climate change, and its effects, is a phenomenon that can no longer be ignored, especially in the Caribbean region. Climate change has been having negative effects on Jamaica's water resources, making it very challenging for the country to meet all its water needs. In the last four years, Jamaica has experienced drought of a severity that has been unseen for decades. Therefore, the country's public water utility provider, the National Water Commission, with financial assistance from the Inter-American Development Bank and Japan International Cooperation Agency, developed a project that is aimed at alleviating the effects of drought through replenishing and sustaining the groundwater potential in the country's metropolitan area.

This project comprised the development of an artificial groundwater recharge system and satisfies the classic purposes for pursuing aquifer recharge viz.; increasing the bank of useable groundwater for continued and improved abstraction; improving and increasing the buffer zone between freshwater/saltwater so that current production rates

can be sustained; and providing storage for unused surface water in a regime that minimizes the effects of evaporation.

The design of the system considered key issues such as native groundwater quality, aquifer storage capacity, location and quality of source water, treatment options, possibility of groundwater quality derogation, clogging of aquifer, etc. One of the major challenges to this project was to develop a recharge and abstraction scheme that maximizes the recovery of recharge water. For this reason, detailed investigations were carried out to identify a suitable aquifer and a suitable water source, as well as to assess the recharge rates, abstraction rates, and available storage capacity. To ensure that the recharge water would not contaminate the native groundwater, the design included a treatment facility consisting of primary and secondary treatment systems. Furthermore, an extensive water quality monitoring exercise was carried out on the source to obtain a baseline for monitoring the performance of the scheme during operation, which commenced in March 2016.

Introduction

Groundwater is a valuable resource throughout the world and supplies many of the hydrologic needs of people everywhere, especially in places where surface water, such as lakes and rivers, are scarce or inaccessible.Groundwater accounts for more than thirty per cent (30%) of the world’s sustainable stock of freshwater, and with the consistent increase in population and development, there is now an increased demand on groundwater resources as a more dependable source for potable and irrigation water needs. However, the sustainability of groundwater resources is being severely threatened by urbanisation and climate change. Urban development inhibits groundwater recharge since, often-times, precipitation cannot penetrate the impervious surfaces. As a result, groundwater supply is being depleted, as the amount of discharge water (output) exceeds the amount of recharge water (input). Urbanization also increases the amount of pollution in our environment. If soil is contaminated or surface runoff is polluted, the quality of the groundwater will be compromised. Polluted groundwater and/or a diminished supply of groundwater are of particular concern, where groundwater is a major source for drinking and irrigation.

Furthermore, as global temperatures are predicted to rise annually, it is expected that water scarcity will become an increasing problem in the future, owing to the significant relationship between water resources and climate change. The variation in climatic conditions has an adverse effect on the water balance, due to a decrease in average annual precipitation while average annual evaporation increases. If not managed, groundwater supplies and other fresh water sources will become limited; impacting not only your residential, commercial, industrial and agricultural activities, but also the environment, human heath, food security.

In Jamaica, groundwater resources accounts for approximately fifty per cent (50%) of the potable water that serves the approximate 2.8 million citizens, and more than forty per cent (40%) of the irrigation water that serves the farmers. Analysis however, has indicated that the accessible volume of groundwater resource in Jamaica have reduced by more than five per cent (5%) in the last decade. Therefore it is imperative that

Jamaica, and other similarly affected countries, devise solutions to this serious problem, and find ways to effectively conserve, manage, and distribute water resources.

It is for the above reasons that one of the Government of Jamaica's main objectives is to improve the country's water resources and supply system to make them more resilient and less susceptible to climate change and the impact of drought. Under this initiative, one selected project was the development of an artificial groundwater recharge system.

Background

The National Water Commission (the water utility service provider), through the Government of Jamaica, with financial assistance from the Inter-American Development Bank (IDB), has embarked on a programme aimed at improving the reliability of the existing water supply systems island-wide. One component is the establishment of an artificial ground water recharge system to augment aquifer resources in the Kingston Metropolitan Area (KMA).

The design for the artificial groundwater recharge system (AGRS) was firstly prepared by consulting firm Nippon Koei Limited (and their sub-consultants) on behalf of the NWC under a loan agreement with the Japan International Co-operation Agency (JICA). The design consisted of the development of a recharge facility capable of handling eight million imperial gallons of water per day (8 migd). During the preliminary design stage, it was agreed that the recharge water would be made available by the National Irrigation

Commission (Jamaica), owners/ operators of the country's Irrigation System. The design was later updated by a Jamaican Government engineering company, Rural Water Supply Limited, who also were the Engineers during construction.

Construction activities were carried out by a local construction firm, M&M Jamaica Limited. The construction phase was allotted a timeline of fifteen (15) months with works completely tested and commissioned in March 2016.

The operations of the Facility, to be carried out by the Water Resources Authority, Jamaica, involve monitoring of its performance to ascertain the impact of the system on the water quality and recharge potential of the affected aquifer.

Purpose

Assessment of an aquifer within the hydrological basin that serves sections of the KMA suggested that water was being abstracted (via wells) in excess of the reliable yield of the aquifer, resulting in upconing and the intrusion of saline water into the aquifer. Consequently, the development of the artificial groundwater recharge system is aimed at flushing back the saline intrusion, replenishing/increasing the groundwater potential within the aquifer and sustaining the necessary abstraction rate(s) to meet the demands.

Sufficient data is currently not available to demonstrate the performance of the Recharge System. Therefore, this paper will endeavor to present the benefits of an artificial groundwater recharge system, as well as outline the processes and intricacies that were involved in developing a similar system in Jamaica.

Design Considerations

The two most important aspects to consider when developing an aquifer recharge system are the identification of a suitable aquifer and a suitable water source. For the Artificial Groundwater Recharge System (AGRS) developed in Jamaica, a detail data collection and investigation exercise was conducted to identify a suitable water source. The suitable aquifer was determined based on the need; however the investigation considered identification of suitable recharge points for the recharge water. The main criteria used to select the project area (water source and recharge points) were as follows:

- Recharge & Abstraction Rates- In order to achieve the required recharge and abstraction rates, the project area needs to be located where the aquifer is known to be highly permeable.
- Recovery of Recharge Water- In order to maximise recovery of recharged water, the project area needs to be located where there is existing & future (continued) abstraction of a similar magnitude to the proposed recharge.
- Lifecycle Cost - In order to minimise capital and operating costs, the project area needs to be located near to an irrigation canal, where there is the possibility of gravity flow from the canal to the recharge point, and the aquifer is close to or outcrops at the land surface.

- Risk of Pollution - In order to minimise potential aquifer pollution, the project area needs remote, away from urbanised or industrialised areas.

Secondly, aquifer investigations must be conducted to assess the recharge rates, the abstraction rates, and the amount of storage available in the aquifer, as well as to determine the quality of the source water. Thorough analysis of the source water for the AGRS was done to set the baseline for the raw water that would be entering the aquifer. Water resource modeling was also conducted using the Integrated Global System Model (IGSM) to confirm aquifer properties, sustainable yield and water balance. The IGSM also calculated the potential groundwater level impacts due to the recharge, abstraction and net mound elevation/migration, recharge rate, and the recovery of recharge water.

Thirdly, potential risks that may constrain the operation of the aquifer recharge scheme such as derogation of existing groundwater or surface water abstractions, clogging of the aquifer from the recharge water or water quality issues should be considered and assessed. Analysis of the source identified for the AGRS indicated higher than normal levels of pesticides and coliform bacteria as well as turbidity. Therefore, a primary and secondary treatment system was necessary in order to mitigate against clogging of the aquifer and contamination of the native groundwater.

Design Solution and Construction

The final design consisted of the development of a direct sub-surface recharge system, whereby the recharge water is directly introduced into the aquifer through sinkholes and disused wells. However, for this project is source water was treated prior to recharging the aquifer. The important considerations were:

- A treatment facility, capable of removing suspended solids, pathogens and nutrients,
- Intake structure, to divert raw water from the irrigation canal,
- Conveyance/distribution system, to transport raw water from the canal to the treatment facility, and treated water to the recharge points, and
- Development of recharge points for discharge of the treated water into the aquifer.

The treatment facility with a foot print of 58 acres was designed to handle maximum eight (8) migd, with an average capacity of five (5) migd. The facility included for four (4) sedimentation basins to remove suspended solid and eight (8) wetland beds to remove bacteria and nutrients. A bar screen was also installed at the intake structure to prevent coarser materials (trash, etc.) from entering the conveyance system.

The intake structure was equipped with a measuring device, and regulators to control the volume of water diverted from the canal. Approximately, two (2) kilometers of 800 mm nominal diameter ductile iron pipes was selected as the preferred conveyance system for the raw and treated water. Furthermore, a splitter chamber and inlet/outlet channels were also considered for even distribution of the water within the treatment system.

The system was also designed as a full gravity system with zero energy being utilized for operation. The operation station is equipped with photovoltaic system for internal power needs and with a rain water harvesting structure.

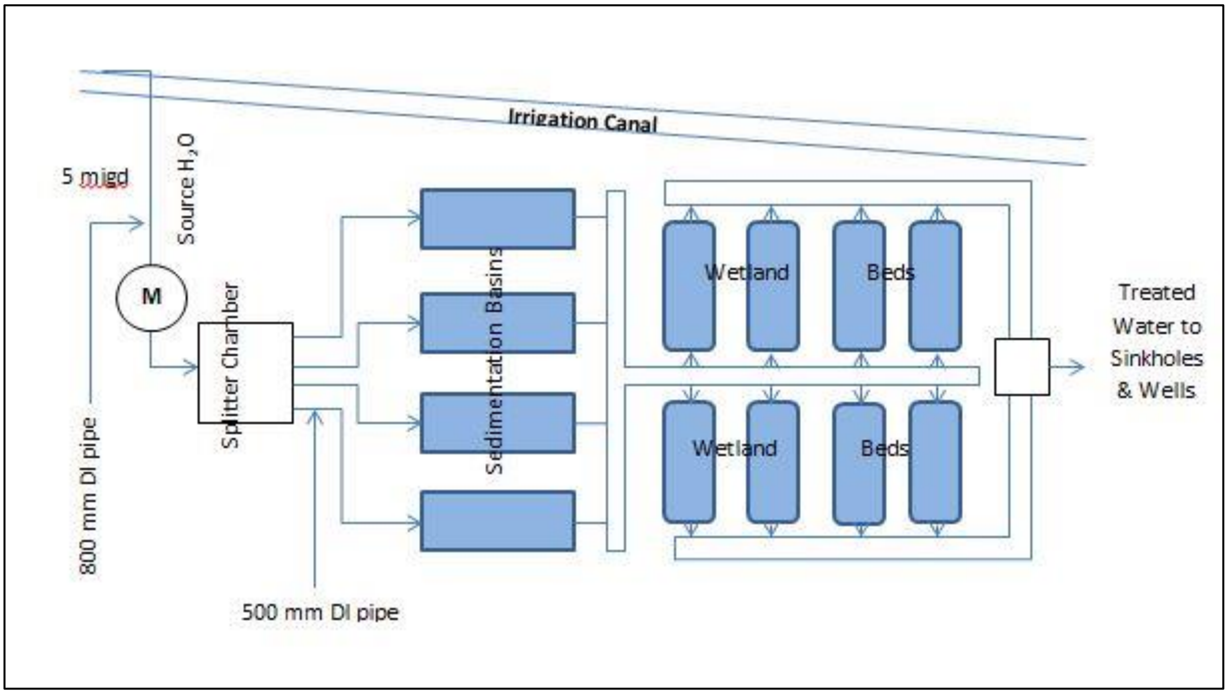

Figure 1 - Design Layout

Operation & Maintenance

An important deliverable of the constructed system is the Operation and Maintenance Manual, which provided relatively simple and user friendly guidelines. Generally, the operations and maintenance procedures are:

- Daily, or as needed, operation of the control structures & recording of flows
- Sediment removal from the Settling Basins annually, or as needed
- Control of invasive vegetation/algae annually, or as needed
- Harvesting of Wetland Bed reeds annually, or as needed

- Regular monitoring of water for suspended solids, and periodic monitoring for chemical and bacterial contamination

Challenges faced during Implementation

One major challenge faced during implementation was the identification of a suitable project location that would satisfy the requirements for maximizing recovery of recharge water. The recommended practice for maximizing recovery of recharge water is to have abstraction wells locating close to the area of the centre of the recharge mound and operating at the same time recharge in occurring.

With the source water being owned by one government entity, the responsibility for construction by another, the project engineering management by a third, and finally, the operations, maintenance and monitoring by a fourth, it is reasonable to assume that differences of opinion would arise. In some cases resolution had to be arrived at tactfully, with due compromise being exercised

Conclusions / Recommendations

Even though the primary objective of a groundwater recharge system is to preserve and/or enhance groundwater resources, artificial aquifer recharge has been used for many other beneficial purposes. Some of these purposes include conservation or disposal of floodwaters, control of saltwater intrusion, storage of water to reduce pumping and piping costs, temporary regulation of groundwater abstraction, and water quality improvement by removal of suspended solids by filtration through the ground or by dilution by mixing with native water.

The Jamaica Artificial Groundwater Recharge System satisfies all the major purposes for developing a groundwater recharge system, such as increasing the bank of useable groundwater for continued and improved abstraction, and increasing the buffer zone between freshwater/saltwater, among other beneficial purposes. Furthermore, some of the uniqueness of this Artificial Recharge System are:

1. The ARGS utilizes the natural topography of the land to establish a fully gravity and energy-free system.
2. This system allows for direct discharge into aquifer by utilizing existing sinkholes and deep wells.
3. The treatment facility ensures that recharge water of equal or better quality enters the native aquifer water.
4. The system utilizes excess irrigation water that would otherwise flow directly to the sea, to replenish and augment the vast underground reservoir for future use.

Generally, the prospects of storing surplus surface water underground, and abstracting it whenever and wherever necessary, appears to be a more effective technology when compared to other surface water augmentation methods, such as dams and diversions, which have become more expensive and less promising in terms of environmental considerations. Also, in urban areas, artificial recharge can maintain groundwater levels in situations where natural recharge has become severely reduced.

The recharge process is extremely complex, and, due to the numerous factors affecting the process, it is only partly understood. The studies on artificial recharge techniques are mostly site-specific and descriptive in nature, which gives little insight into the potential success of implementing this technology in other locations. Thus, with a carefully developed monitoring and testing programme, this project can give meaningful insight into the dynamics of groundwater response to unnatural intervention. Also, while the system is a discrete structure, a more definitive statement on the global applicability of similar systems may then be forthcoming.

Given the care to incorporate design methodology for protecting the integrity of the aquifer, and that underground storage is less susceptible to evaporation, this technology can assist with water resource management that responds as a positive adaptation need to climate change.

Biographies

Derian Jackson, PE, PMP, MBA

Derian Jackson is a professional engineer with a bachelor of engineering degree in Chemical Engineering, from the University of Technology, Jamaica. He is also the holder of master's degree in Business Administration from the University of the West Indies. Mr. Jackson is a Project Manager with more than eight years of experience administering water and wastewater infrastructures, including overseeing multimillion dollar sewer and potable water design and construction projects involving national and international partners. His experience also includes working with multilateral funding agencies such as the Inter-American Development Bank and the European Union.

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Peter Clarke, J.P.; PE; PMCert,; MSc NRM; MSc BE; BSc CEM.

Peter Clarke has 32 years of experience in the area of water supply where he has been responsible for the construction of pumping stations, reservoirs, wells, treatment plants, water mains, intakes, pipeline bridges, pipeline tunnels, and river training works.

Currently, he is employed to the Water Resources Authority in the capacity of Deputy Managing Director. His most recent past employment has been to Rural Water Supply Ltd, where, in his capacity as Engineering Manager, he coordinated:

- the design/project management team for the Groundwater (Aquifer) Recharge Project for part of S.E.St.Catherine (Innswood).[IDB Funded]. Estimated value J$1+B.

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