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Successful application of Managed Aquifer Recharge in the improvement of the water resources management of semi-arid regions: Examples from Arizona and the Southwestern U.S.A.

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ABSTRACT

Artificial recharge of groundwater is a technique nowadays fully integrated in the water resources planning in the State of Arizona. First experiences were carried out by the University of Arizona, and their main target was the study of water quality changes after passing through the soil to be purified. Afterwards, a very wet period suffered in Arizona made all stakeholders became aware of the necessity of storing surface water surpluses by means of artificially recharging drafted aquifers. 1980 and 1986 laws established the legal framework for all MAR aspects, including the ownership of the recharged water. So, the most important artificial recharge projects in Arizona were developed, i.e. Salt River Project, Granite Reef Underground Storage Project, Central Arizona Project, among others. They have contributed to a very important development of this technique and have provided excellent results. In this paper, the main characteristics of some of these large projects are shown.

Key words: Arizona, artificial recharge, Central Arizona Project, MAR, Salt River project

Aplicación con éxito de la recarga artificial en la mejora de la gestión de los recursos hídricos en regiones semi-áridas: ejemplos de Arizona y el Suroeste de Estados Unidos

RESUMEN

La recarga artificial es actualmente un mecanismo plenamente integrado en la gestión de los recursos hídricos en el estado de Arizona. Las primeras experiencias fueron llevadas a cabo por la Universidad y su objetivo fue el estudio de los cambios de calidad en el agua tras su paso por el suelo. Posteriormente, épocas de grandes lluvias concienciaron a todos los estamentos implicados sobre la necesidad de almacenar los excedentes de escorrentía superficial utilizando la recarga artificial de acuíferos. Las leyes de 1980 y 1986 establecieron un marco legal que regula todo el proceso de la recarga, así como la propiedad del agua recargada. Así se desarrollaron los grandes proyectos de recarga artificial en el estado: Salt River Project, Granite Reef Underground Storage Project, Central Arizona Project, y otros, que han permitido desarrollar esta técnica con excelentes resultados en Arizona. En el presente artículo se muestran las principales características de algunos de estos grandes proyectos.

Palabras clave: Arizona, Central Arizona Project, MAR, recarga artificial, Salt River project

Summary

Before 1980, the use of Managed Aquifer Recharge (MAR) in Arizona was limited to very small tests carried out by the University of Arizona and the U.S. Water Conservation Laboratory. All these tests were performed as part of research activities for applications to agriculture. The largest of these pilot tests was the Flushing Meadows Project constructed in 1967 to obtain information on the changes in the water quality of municipal effluent after its infiltration from surface basins. The renovated water was for use in crop irrigation. This project was a pioneer in the development of soil aquifer treatment (SAT) now extensively used throughout the world. Two major events impulsed the rapid spread of the use of MAR in Arizona. The first was based on the influence of public opinion on water management. In the last few years of the decade of 1970 and the early ones of the decade of 1980, Arizona and the entire desert region of the southwestern United States was subjected to a very wet climatic period. The very few surface water reservoirs were incapable of storing the very large volume of runoff. Flooding was extensive and visible to the population of the two largest cities of Phoenix and Tucson. Public opinion expressed by the communication media made inquiries about possible ways of storing the excess water such as by replenishing the over drafted aquifers. Why not save this water underground for use during dry periods and at the same time correct some of the problems created by the intensive use of groundwater, such as land subsidence and groundwater quality deterioration. The other event that contributed to an accelerated pace in the use of MAR, was the completion of the Central Arizona Project, Aqueduct to the cities of Phoenix (population: 4 million) and Tucson (population: 1.5 million), and the need to store the unused portion of the Colorado River water allocated to Arizona by the U.S. Supreme Court (Arizona vs. California, 1963). The needed legal framework to carry out groundwater recharge was also completed at this time with the passing of two state laws: The Groundwater Management Act of 1980, and the Groundwater Recharge and Underground Storage and Recovery Act of 1986. These laws guarantee the ownership of the surface water stored in the aquifer and defined and regulated all aspects of MAR. The addition of MAR as a component of the water resources management system of this semi-arid area provided immediate benefits to the more efficient use of its limited water resources. At this time a rapid transition from a predominantly agricultural economy to an urban/industrial economy was taking place in Arizona. The introduction of MAR provided the needed water factor to sustain the rapid population growth. Direct surface and direct subsurface recharge methods have been successfully used to store water in many aquifers of the state. Water spreading methods using in-channel and off-channel basins are used to store large volumes of surplus surface water. In 1986 the Salt River Project (SRP) Phoenix's largest water purveyor in partnership with six municipalities of the metropolitan area planned, designed, permitted constructed and operates the state's largest underground storage facility. The Granite Reef Underground Storage Project (GRUSP) is a surface water spreading operation located in the east of Phoenix consisting of seven basins and occupying an area of 150 hectares. It is built in a secondary dry channel of the Salt River isolated from normal river flows approximately five kilometers downstream from SRP's Granite Reef Diversion Dam. This facility has a capacity to store in the aquifer 250 million cubic meters of water per year. It recharges imported water from the Salt, Verde and Colorado Rivers and a very small volume of reclaimed water. Since 1994 this project has stored in the aquifer in excess of 1,200 million cubic meters of water. In 2007 the SRP completed and is operating the New River-Agua Fria Underground Storage Project (NAUSP). This facility also uses surface basins for recharge and has an annual storage capacity of 100 million cubic meters. The water sources for this project are similar to those for the GRUSP. This operation serves the needs of the municipalities of the western part of Phoenix. Both the GRUSP and the NAUSP are connected to the extensive canal and pipeline water distribution system of SRP and are a component of the very large water resources management system of the Phoenix metropolitan area. The Central Arizona Project (CAP), the steward of the 2,700 million cubic meters per year Arizona's Colorado River water entitlement, and operator of the 550 kilometers long CAP Aqueduct has water spreading recharge facilities with an aquifer storage capacity of 460 million cubic meters per year. These facilities consist of three projects near Phoenix, three near Tucson and one between the Colorado River water diversion point of the CAP Aqueduct and the city of Phoenix. The latter facility, called the Tonopah Recharge Project (TRP) has a capacity of 185 million cubic meters per year and is utilized predominantly for the recharge of water credits for the states of Nevada and California in accordance with a three state agreement. In this agreement Arizona stores water allocations of Colorado River water of Nevada and California in wet years in exchange of Arizona's Colorado River water allocations in drought years. In dry periods Arizona recovers from underground storage at TRP its water allocation from the Colorado River. The city of Tucson has two large water spreading recharge projects with a total capacity of 185 million cubic meters per year. It also has a 36 million cubic meter per year water spreading recharge operation, the Sweetwater Recharge Project, which stores only reclaimed water underground. The Viddler Water Company, a private corporation, operates a 123 million cubic meters per year water spreading facility near Phoenix to bank water for sale in the future. The recharge units are basins developed in abandoned agriculture fields with a slow infiltration rate. The only water source for this facility is CAP water delivered from the nearby CAP Aqueduct via a small concrete lined canal. There are many smaller water spreading recharge facilities in Arizona. They are mostly used for disposal and aquifer storage of reclaimed water in small communities. Although the use of direct surface recharge of reclaimed water in Arizona is limited by law to municipal effluent that has undergone at least an advanced secondary treatment the effect of soil infiltration/percolation adds additional treatment of the water (SAT) before it blends with the native groundwater. Single purpose recharge wells (recharge only) and dual purpose (recharge/recovery) wells are extensively used throughout Arizona. They are used when sufficient space for water spreading is not available or the cost of the land is too high. The water quality requirements for the recharge water are that its chemical composition has to be equal to or better than that of the groundwater of the receiving aquifer. It also has to be subjected to severe disinfection at the wellhead. Aquifer Storage Recovery (ASR) wells are used by some municipalities to store potable water from their drinking water treatment plants as a convenience when surface storage is not available or is too expensive. This occurs during peak low demand periods and to avoid expensive reduction in the water treatment train production of the potable water plants.

Another use of recharge wells is for contamination control and attenuation. This is commonly referred to as “plume management”. In Arizona the use of recharge wells for this purpose is extensive. Both Phoenix and Tucson are important centers of the electronics/semi-conductor industries. Phoenix is frequently called the second “Silicon Valley”. In the near past these industries used volatile organic compounds (VOCs) to degrease circuit boards and other components. Compounds like carbon tetrachloride, chloroform, trichloroethylene (TCE), tetrachloroethylene (PCE), and dichloroethylene (DCA) extensively used have been determined to be carcinogens. They have a considerable half life and are resistant to biodegradation in the natural environment such as in the alluvial aquifers of the basins of Arizona. Permitted disposal of these compounds after their use consisted in years past of infiltration/percolation via dry wells or ponds which resulted in considerable contamination of the groundwater. Many drinking water wells had to be abandoned and new water sources found. This occurrence in a semiarid region with limited water resources caused severe economic impacts that were followed by litigation. The U.S. Environmental Protection Agency (USEPA) declared large portions of urban aquifers zones of control and remediation (Superfund Sites). For the VOCs contamination sites the use of contaminated groundwater extraction and treatment by air stripping columns is common. The treated water is then injected by a distant well in a strategic location that mitigates the contamination plume. The Indian Bend Wash Superfund Site case in the city of Scottsdale, within the Phoenix metropolitan area has been a classic case of a TCE plume where the three components of the aquifer system where contaminated. These required treatment of the three plumes moving in different directions at different depths. In Tucson a missile fabrication plant produced a groundwater TCE and a chromium contamination plume. This has been successfully controlled by an extraction-treatment-recharge procedure very similar to that used for seawater intrusion control. The extracted treated water is re-injected by a well field that produces a hydraulic barrier, isolates the plume and avoids its spreading.

Vadose zone wells were developed for the first time in Arizona to recharge large volumes of municipal effluent that is treated by advanced waste water treatment methods to drinking water standards. The Water Campus facility is the largest MAR facility in the USA using this methodology. It utilizes 27 vadose zone wells. Each well is 60 meters deep and penetrates a section of alluvial sediments that adds SAT to the recharged water. The Water Campus has successfully operated its vadose zone well field for ten years. A recently completed study indicated that the overall recharge capacity has decreased with time due to clogging, from particle rearrangement in the aquifer but principally from the precipitation of calcium carbonate from the use of lime for pH control of the processed water at the treatment plant. Mild acidification of the recharge water appears to improve the well performance but more testing is required to develop a control procedure. The City of Las Vegas, Nevada has a population of 1.5 million and along with Phoenix is the fastest growing urban center in the U.S.A. Nevada’s entitlement of Colorado River water, its closest water source, is very limited. Groundwater used intensively for decades was declining rapidly. Groundwater recharge was considered as the higher priority solution and was implemented starting in the decade of 1980. Thick calcified beds in the alluvial sediments near the surface restricted the use of direct surface recharge. Dual purpose wells are now used to inject treated Colorado River water in periods of low water demand, mostly during the short winter and recovery during peak demand periods. Las Vegas has the largest aquifer recharge volume ASR well system in the U.S.A. at this time. In the State of New Mexico there are several pilot projects in different stages of development. Some of these are limited to the collection and infiltration of storm runoff. The closest water source for its largest city, Albuquerque, is the Rio Grande. The very tight water rights situation of this river, which includes claims from several states and Mexico, makes it difficult to obtain large volumes of water for surface spreading facilities and long term banking. Four hundred kilometers downstream from Albuquerque on the Rio Grande is the City of El Paso, Texas. Since the late 1980s this municipality has been treating and recharging 14 million cubic meters per year of its effluent into the Hueco Bolson aquifer its principal water source for decades. The tertiary treated grade reclaimed water is injected by wells to a depth of 200 meters and recovered by down gradient wells. The distance between the recharge and the recovery wells is such that the residence time of the reclaimed water in the aquifer ranges between 2 and 6 years. This was considered sufficient for blending and dilution with the native groundwater and to receive additional physical chemical treatment in the aquifer with such processes as adsorption, ion exchange and oxidation-reduction. The Arizona and southwestern U.S.A. MAR experience has contributed to the adaptation and improvement of groundwater recharge methodology, and of water resources management procedures, and could serve as a guide and model for its application in other semiarid areas of the world.

Introduction

The City of Phoenix planned to store its excess allocation of Colorado River (CAP) water in the aquifer as soon as the Central Arizona Project Aqueduct was completed and CAP water delivered to its water treatment plants. Two methods were considered. Using direct surface recharge by means of in-channel or off-channel basins untreated CAP water could be recharged in one or several of the ephemeral streams that traverse the City. The water would infiltrate into the upper aquifer of the large underlying alluvial aquifer system and either be pumped from shallow wells or slowly percolate deeper to augment the groundwater of the two lower aquifers. The shallow aquifer designated the upper alluvial unit (UAU) is very permeable attaining a maximum thickness of one hundred meters. Pumping for agriculture before the urban encroachment had dried this unit in many areas of the City. The other method considered was to recharge the CAP water once treated to potable standards using injection. The City has many high capacity wells that are connected to their potable water distribution system. These could be converted to dual purpose (recharge-recovery) by adding to each one a recharge unit. One well, City of Phoenix well number 17, was equipped with two recharge pipes that extended 25 meters below the groundwater level leaving intact its turbine pump. A twin, small diameter monitor well was constructed 30 meters from the production well and recharge and recovery tests ran to evaluate the technical and economic feasibility of creating a large capacity well field. The injection using this well, 500 meters deep, demonstrated that recharge into the deep semi-confined aquifer was feasible (Lluria, 1985). This pilot recharge well was the first ASR (Aquifer Storage Recovery) well in Arizona. The City of Tucson carried out an extensive study on the use of well recharge utilizing their central well field where aquifer over drafting had occurred. In the early 1990's they converted several of these wells to dual purpose wells for banking CAP water from their new CAP water treatment plant. Both the pilot tests in the City of Phoenix well number 17 and those in the City of Tucson central well field demonstrated that ASR was applicable in banking treated CAP water. However, this methodology was more costly than surface water spreading using recharge basins or modified river channel methods when large volumes of raw water such as that diverted directly from the CAP Aqueduct, were available. Both large urban communities decided on developing large direct surface recharge facilities for banking their unused CAP water.

In the late 1980's the Central Arizona Project Aqueduct conveying water from the Colorado River was completed to Phoenix. There was insufficient surface storage capacity at that time in the Salt River Valley for any unused portion of the Central Arizona Project (CAP) water. Storage in the distant reservoirs of the Salt and Verde Rivers would have been very costly. This prompted the Salt River Project (SRP) and several municipalities to work together in developing a large underground water storage facility. A study completed in 1986 and funded by the Arizona Municipal Water Users Association (AMWUA) had selected favorable sites in the Salt and Agua Fria Rivers for in-channel groundwater recharge. This methodology had been successfully used for many years in the Los Angeles Basin and in the San Francisco Bay Area to store water from various sources in the underlying alluvial aquifer and appeared to be the most applicable for the underground storage of large volumes of water in the Salt River Valley.

Direct surface recharge: Case Histories

The Granite Reef Underground Storage Project

In 1986 the City of Mesa and the SRP initiated discussion on the possibility of developing a large water spreading recharge facility in the East Salt River Valley. Based on the preliminary selection of potential river channel sites study, a team of professionals from SRP carried out an assessment of the upper most reach of the lower Salt River immediately downstream of the Granite Reef Dam. The evaluation of this seven mile long area indicated very favorable hydrogeologic conditions for direct surface recharge and the absence of any environmental constraints. Four potential sites were selected to locate a large underground storage project. All these sites were located near the SRP water delivery system and nearby its large capacity wells. This provided the necessary supporting infrastructure without the need for additional capital costs. In 1987 planning commenced in a joint effort with SRP and six municipalities to select the site, acquire the land, design, permit, construct and operate a regional water underground storage facility. It was named the Granite Reef Underground Storage Project (GRUSP) because of its proximity to the SRP's Granite Reef Dam (Figure 1). More than ninety percent of the site for the emplacement of the facility is located within the Salt River Pima-Maricopa Indian Reservation. This required negotiations with the Indian community that were concluded in 1992. A parcel of land with an area of 150 hectares was leased for a period of twenty years. Every five years the land is appraised and the rent adjusted according to its current value. The main determinant of the land value for this parcel is sand and gravel that because of its high demand in the rapid growing Phoenix area has caused a progressive and considerable increase in the rent that has affected the unit cost of recharge at GRUSP.

The permit process for GRUSP commenced in 1987 and was completed in 1992. Two federal and two state permits were required. The federal permits needed were from the application of two sections of the Clean Water Act. Section 401 is under the jurisdiction of the U.S. Environmental Protection Agency. Section 404 is the responsibility of the U.S. Army Corps of Engineers. These permits were issued in 1992. The two state permits, also obtained in 1992, were the Underground Storage Facility Permit issued by the Arizona Department of Water Resources and the Aquifer Protection Permit issued by the Arizona Department of Environmental Quality. These two permits were the result of two laws passed in 1986 by the State of Arizona Legislature: The Recharge and Underground Storage and Recovery Act and the Environmental Quality Act.

Figure 1. Panoramic view of the Granite Reef Underground Storage Project, a surface water-spreading facility located in Phoenix, Arizona

Figura 1. Vista panorámica del Proyecto de almacenamiento subterráneo de Granite Reef, una instalación superficial tipo balsa situada en Phoenix, Arizona

One of the most important factors that have contributed to the successful operation of the GRUSP is the very favorable hydrogeologic characteristic of the site. It is located in the periphery of the large Salt River Valley tectonic basin where high energy sediments were deposited as a thick alluvial fan. These coarse grained unconsolidated sands and gravels have high permeability and water storage capacity. This allows rapid recharge rates of large volumes of water with limited impacts to groundwater mounding. The storage capacity of the area of hydrologic impact of GRUSP exceeds 7,000 million cubic meters. The quality of the native groundwater in the aquifer underlying the site is very good as a result of natural recharge during flood events of the Salt River for hundreds of years. The original water sources for recharge at GRUSP were CAP water and Salt and Verde Rivers water. In 2007 reclaimed water was added.

Construction and Operation of GRUSP

In 1993 large storm water releases in the Salt River postponed the construction of the GRUSP facility for one year. Four recharge basins with a total area of 70 hectares were built in 1994 (Lluria and Fisk, 1995b). In 1999 two more basins were added increasing the recharge surface to 90 hectares. Water is delivered to the basins from SRP's South Canal by a 3.5 kilometers long delivery channel. All the delivery units and recharge units are constructed in the channel of the Salt River of river bed material and are subjected to damage or destruction during storm water released from Granite Reef Dam. The very coarse sediments at the site provide recharge rates that range from 0.6 to 2 meters per day. Inflows to the facility are measured at a dedicated turnout structure in the South Canal and those of the reclaimed water at the end of the pipeline which conveys them from the City of Mesa Northwest Water Reclamation Facility. Water from the SRP canal and the water reclamation mixes before being delivered to the recharge basins (Figure 2).

Some Challenges and Solutions

The GRUSP has operated successfully for 15 years having stored in the aquifer in excess of 1,200 million cubic meters (Lluria, 1998). The owners have used the facility for both short term and long term storage. Other entities have also used GRUSP for water storage. Of these, the Arizona Water Banking Authority has been the entity accumulating the larger water storage credits. Although the facility has operated efficiently and with cost-effectiveness there have been some issues that required attention. Of these the damages caused by storm water releases in the channel of the Salt River are of concern because of the cost of reconstruction. Only four flood events have partially damaged the facility. These were in the winters of 1995, 2005, 2008 and 2009. Measures that have been successful in mitigating damage consists of breaching some of the structures to route the flows and minimize erosion. In 1994 a sanitary landfill was completed one mile north of the GRUSP site. Groundwater mounding under this landfill is controlled by regulating inflow, rotating the operating recharge basins and increasing the hydraulic gradient away from the landfill by pumping some of the SRP's high capacity wells. Surface seeps to nearby gravel mining pits are suppressed by decreasing the water depth in the closer recharge basins and by eliminating the use of portions of the basins that have preferential flow pathways connecting with the gravel pits. Evapo-transpiration losses are minimized by a systematic control of the vegetation in the delivery and recharge units of the facility. Monitoring of hydraulic impacts is carried out by 15 proximal wells and ten distal wells. Geophysical methods are being considered for further monitoring (Lluria, 2002).

Figure 2. Recharge basin of the Granite Reef Underground Storage Project. This basin has a surface area of 25 hectares and an infiltration rate of one meter per day
Figura 2. Balsa de recarga del Proyecto de Almacenamiento subterráneo Granite Reef. Esta balsa tiene una superficie de 25 ha y una tasa de infiltración de 1 m/día

Benefits Resulting from the Operation of GRUSP

The principal benefit of the operation of GRUSP has been its contribution to the replenishment of the aquifer of the East Salt River Valley sub-basin. A volume of water equivalent to 40 percent of the total water storage capacity of the SRP's reservoir system of the Salt and Verde Rivers has been added to the aquifer for further recovery. The recharge operation has produced favorable changes in the quality of the groundwater in the proximity of the site with considerable reduction in its content of arsenic and nitrate (Lluria, 1999). Being the first project in the Phoenix area it was able to store a large volume of CAP water which otherwise would have been lost to Arizona. The addition of GRUSP as a component of the large SRP water resource system has improved its operational flexibility and also resulted in better water management practices for several municipalities. GRUSP is an excellent example of close interagency cooperation including a Native American Community. The very small construction, operation and maintenance costs coupled with the accessibility via the proximal SRP water delivery systems of several sources and the nearby recovery SRP large capacity well field, results in a very cost-effective recharge operation.

The New River Agua Fria Underground Storage Project

To provide aquifer storage services to its customers on the west side of the Phoenix metropolitan area the SRP constructed the New River Agua Fria Underground Storage Project (NAUSP). Four other municipalities joined the SRP as partners. Land was purchased on the eastern bank of the Agua Fria River. This land had been in use for agriculture for many years. The site is located within the ancestral fluvial system of the Agua Fria River and has very favorable hydrogeologic characteristics for the emplacement of a direct surface groundwater recharge facility (Paski and Lluria, 2005). It is located on the periphery of the large Luke cone of depression where considerable land subsidence has occurred and aquifer replenishment is urgently needed (Lluria, 1995a). The NAUSP was completed in March 2007 and during that year it stored 26 million cubic meters of water. The water-spreading facility consists of six off-channel basins with an infiltration area of 55 hectares. A seventh in-channel basin of 35 hectares will be added in 2010. CAP and Salt and Verde Rivers water is delivered to the facility from two water treatment plants by pipelines. All three water types are blended before they are recharged. The NAUSP facility is permitted for a maximum volume of 93 million cubic meters per year which is forty percent of the permit capacity of GRUSP.

During the development of the NAUSP a few difficulties were encountered that had to be resolved. The original site selected in the channel of the Aqua Fria River had to be abandoned because of proximity to future gravel mining operations. This was resolved satisfactorily with the transfer to the present site. The top soil from the agriculture fields had to be removed for the construction of the of-channel basins to assure adequate infiltration rates and eliminate any potential agriculture contaminants contained in the rich organic soil horizon. The purchase of land for the present site was high because of its proximity to the recently completed City of Glendale sports center. The NAUSP will provide a much needed underground storage facility for the West Valley region of Phoenix in particular for the temporary storage of reclaimed water. It will capture flows in the tail end of the SRP system that may otherwise be unused. The recharge operation will improve the quality of the groundwater in the vicinity of the site especially in lowering its high nitrate content caused by decades of crop fertilization and irrigation. Having two recharge facilities, one located near the head of the water delivery system (GRUSP), the other near its terminus (NAUSP) increases considerably the operational flexibility of the SRP's water resources management system (Lluria, 2008).

Direct subsurface recharge: Case Histories

The Salt River Project Well Recharge and Recovery System

The SRP has evaluated the potential to develop a well recharge and recovery system by retrofitting some of its 250 large production wells for dual purpose. These wells have a yield that ranges from 180 to 300 liters per second. They range in depth from 100 to 500 meters and penetrate the very permeable alluvium of Pliocene to Holocene age that constitute the fill of Salt River sedimentary basin. The wells selected for conversion to recharge/recovery wells have a transmissivity that exceed 1,200 cubic meters per meter per day, and the quality of the groundwater in their area of hydrologic impact is of acceptable quality and devoid of any contamination. The water used for recharge will be SRP raw canal water which is a blend of Salt, Verde and Colorado River water. The canal water will be treated at the wellhead using a mobile filtration and disinfection unit before it is recharge by gravity into the well. The wellhead treatment units has been developed and tested in four phases (Macia and Lluria, 2001). It consists of a filtration component capable of filtering down to 10 microns using a durable and exchangeable fabric and a back-wash system. Filtration rates are up to 100 liters per second. The filtered water is then disinfected using hydrogen peroxide (30% H2 02). The disinfection component pumps the H2 02 solution into the filtered effluent and regulates the concentration based on the particulate load. The wellhead treatment unit is mounted in a trailer. If the well is needed for groundwater production the treatment unit can be easily moved and rapidly connected to another well. The treatment unit is fully automated using a PLC and the filtration, back-wash and disinfection operations governed by remote control from the water dispatch center of SRP. The low total particulate content and excellent bacteriological quality of the treated water safeguards the integrity of the well from clogging and damage to the well screens (Lluria et al., 1991). The recharge unit of the well consists of four PVC eductor pipes of different diameters strapped to the pump column. All these pipes are sufficiently submersed below the groundwater level and sealed at the surface to avoid any air penetration. To prevent cavitation the appropriate diameter eductor pipe is used and vacuum gages monitor positive negative pressure. If that occurs the recharge operation is discontinued for correction.

The Water Campus Facility Vadose Zone Recharge Wells

The City of Scottsdale Water Campus facility consists of a water reclamation plant to treat sewage from the northern part of the city and a potable water treatment plant to treat CAP water (Figure 3).

Figure 3. The city of Scottsdale Water Campus facility. A water reclamation and potable water treatment plant performing aquifer storage using vadose zone recharge wells and ASR wells

Figura 3. La instalación del Campus del Agua en la ciudad de Scottsdale. Es una planta depuradora y potabilizadora que posibilita el almacenamiento en el acuífero mediante pozos de recarga en la zona no saturada y pozos ASR

The reclamation plant uses microfiltration (MF) and reverse osmosis (RO). The treated water is recharged by 27 vadose zone wells that have a depth of 55 meters and penetrate the upper alluvial unit consisting of very permeable sands, silts and very minor clay. The recharge operation commenced in 1999. The average recharge capacity of each well was 53 liters per second. This gave a total aquifer recharge capacity of approximately 45 million cubic meters per year. After 10 years of reclaimed water recharge at the Water Campus, the recharge capacity has decreased by 48 percent due to clogging. By 2010 the capacity of the reclamation plant will double and new vadose zone wells will be drilled and equipped to accommodate the increase in flow. New rehabilitation procedures are being implemented to increase the diminished capacity of the original vadose zone wells.

The surplus potable water from the CAP water treatment plant is recharged by the vadose zone well field if there is available capacity. Normally, the potable water is recharged by the ASR wells that are located within the Water Campus facility. The operation of the vadose zone recharge wells during the past 10 years at the Water Campus have demonstrated that it is a very cost effective way to store the excess reclaimed water of a municipality. The cost of constructing, operating and maintaining these types of wells is very low compared to an ASR well. Compared to aquifer storage basins they occupy little space and can be placed in underground vaults where they are not visible (Gastelum et al., 2009).

References

Gastelum,J., Lluria, M.R. and Small,G.G., 2009. Vadose zone recharge wells: Ten years at the City of Scottsdale's Water Campus Facility: Arizona Hydrological Society Proceedings of the 2009 Annual Meeting, Phoenix.

Lluria, M.R., 1985., City of Phoenix Cave Creek Recharge Project: Technical Aspects. In Marsh, F., ed., Second Symposium on Artificial Recharge of Groundwater: University of Arizona, pp. 82-111.

Lluria, M.R., Gorey, T.L. and Mack, R.B., 1991. Hydro-geochemistry and chemical compositional changes of groundwater from a deep well recharge operation using river water subjected to limited on-site treatment. Proceedings of the Fifth Biennial Symposium on Artificial Recharge of Groundwater: University of Arizona, pp. 155-168.

Lluria, M.R. 1995a., Site selection for aquifer storage projects in the Lower Agua Fria Basin. Proceeding of the Seventh Biennial Symposium on Artificial Groundwater Recharge, pp. 47-57.

Lluria, M.R. and Fisk, M., 1995b. A large aquifer facility for the Phoenix area. In Artificial Recharge of Ground Water, II: American Society of Civil Engineers, pp. 129-138.

Lluria, M.R., 1998. Successful operation of a large aquifer storage facility for a desert community. In Artificial Recharge of Groundwater; A.A. Balkema, Rotterdam, pp. 41-45.

Lluria, M.R., 1999. Hydro-geochemitry and quality changes to the groundwater of the receiving aquifer of a large water-spreading facility. In Proceedings of the Ninth Biennial Symposium on Artificial Recharge of Groundwater: Arizona Hydrological Society, pp. 225-236.

Lluria, M.R. 2002., Geophysics for site selection, monitoring and operation of ground-water recharge projects. In Dillon, P. ed., Management of Aquifer Recharge for Sustainability: A.A. Balkema Publishers, pp. 547-552.

Lluria, M.R., 2008. Water spreading in the desert: Southwest Hydrology volume 7 number 3. pp. 28-29.

Macia, N.F. and Lluria, M.R., 2001. Development of an extensive well recharge and recovery system for a large

utility. In Proceedings of the Tenth Biennial Symposium on Artificial Recharge of Groundwater: Arizona Hydrological Society, pp. 81-88.
Paski, M.P. and Lluria, M.R. 2005. Hydrogeologic and geologic considerations for site selection of a large water spreading facility in the West Salt River Valley. In Proceedings of the Twelfth Biennial Symposium on Groundwater Recharge, pp. 81-91.

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