The Role of Decentralized Artificial Recharge Systems in Water Resources Management

Daniel B. Stephens, Daniel B. Stephens & Associates, Inc.

Dan is Principal Hydrologist and Chairman of the Board of Daniel B. Stephens & Associates, Inc., founded in 1984. It has become an employee-owned firm of over 100 employees providing water resources and environmental engineering consulting services with offices in New Mexico, Texas, and California. Dan received his PhD in hydrology from the University of Arizona; his MS in hydrology from Stanford University; and his BS in geological science (with honors) at Pennsylvania State University. He was on the faculty, and a former department chair, of the geoscience department at New Mexico Tech from 1979 to 1989, and he continues as an adjunct faculty there as well as at UNM. Dan currently serves on the Board of Directors of the National Ground Water Association.

The following is a transcript of an oral presentation given by Dan Stephens.

I would like to acknowledge a coauthor, Stephanie Moore who also helped co-organize this conference, but couldn't be here due to a vacation commitment, as well as coauthors Mark Miller, Todd Umstot, and Deb Salvato. In putting this talk together, the topic I was invited to speak about evolved over time and what I am going to present is actually somewhat similar to the presentation of the previous speaker, Vaikko Allen, although I had no prior knowledge of what he was going to discuss. The coincidence of our themes suggests that there really is something to this concept, which I call decentralized artificial recharge. I think this is an appropriate topic for this conference because of its futuristic view.

I want to spend a minute looking at how "hardscaping" in our urban environment has affected the hydrologic cycle. We have done a great deal to install curb and gutter systems and other impervious pavements. At our company's Albuquerque office site, we put in a back driveway and the water that comes off of this lot goes into a concrete-lined flume that discharges into the Rio Grande. Figure 1 is a sketch that is relevant to a Floridian aquifer, but it has the same importance practically everywhere urbanization has taken place to modify the hydrologic balance. Whereas in Florida you might have 40 percent of precipitation evapotranspiring, 10 percent runoff, and 50 percent going to infiltration, the percentages elsewhere change to 30 percent evapotranspiration, 55 percent runoff, and 15 percent infiltration. Urbanization has led to a significant reduction in deep percolation or recharge.

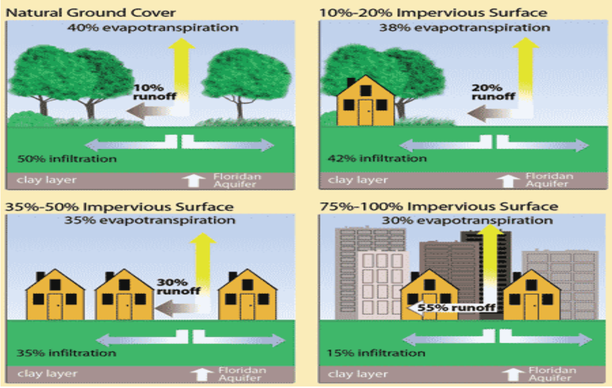
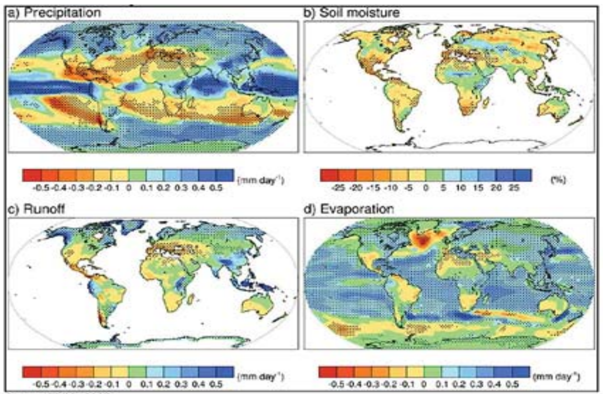


Figure 1. Urbanization decreases ET, reduces runoff

Another factor that is becoming more well established, at least through computer simulations, is the importance of climate change altering the hydrologic balance in certain parts of the world. For example, as you can see from Figure 2, global climate models predict much lower precipitation over the next century, and that is going to lead to much less recharge. In fact, recent research published in *Water Resources Research* showed that the incremental reduction in precipitation leads to a much larger reduction in recharge; it is not simply proportional.



Source: IPCC, 2007

Figure 2. Global climate model predictions: less precipitation, less recharge

So what have people done over the years to augment recharge? Artificial recharge is a technique to get water under the ground artificially. For example, traditional methods use spreading basins like the one pictured in the top left photo of Figure 3. The photo was taken near Anaheim California. The basin fills with water, the water percolates over some period of time, and infiltration occurs. Also pictured in the figure is a typical infiltration gallery, and a vadose zone or dry well by Hydrosystems Inc. in the Scottsdale area. The bottom right photo shows an ASR well in the Las Vegas valley.

Figure 3. Artificial recharge supplements loss

For millennia, sources of water used for artificial recharge have including capturing runoff. In Biblical times, water was captured from streams and stored for agriculture. In the United States, the first artificial recharge project that I can find information on took place in Iowa in 1871. In 1895, artificial recharge projects began in California, followed by Long Island in 1935 with a program to take stormwater and other water from air conditioning systems and infiltrate that water into the Long Island aquifer. Today there are about 3,000 artificial recharge basins. Figure 4 is an inflatable dam diverting water from the Santa Ana River in California. Figure 5 shows spreading basins in India, very similar to what you might have seen in biblical times.

Figure 4. Inflatable dam diverting water from the Santa Ana River

Figure 5. Spreading basins in India

Centralized artificial recharge projects typically are conducted by agencies, cities, counties, and water agencies. Figure 6 is an example of in-channel recharge with levees on the Santa Ana River in Los Angeles that slows down the runoff. When a storm comes in, it wipes out these dirt-filled levees and they are then rebuilt.

Figure 6. Artificial recharge project with levees on the Santa Ana River

Recently, the main driver for capturing stormwater has been the Clean Water Act. The Act requires that the water discharged to receiving bodies should be improved; it is very simple and straightforward. To bring home the importance of this stormwater capture and recharge, we recently conducted a project in an industrial area with a lot of hardscape parking lots and some buildings. This is in an area of New Mexico that sees very little rainfall, is a sandy site, and under natural conditions, most if not all of the water evaporates, leaving almost no measureable runoff. Figure 7 illustrates the monitoring wells that were installed (black circles). After about 20 or so years, the monitor wells started to fill with water where previously no water had been found. We could see groundwater mounds developing in the vicinity of the retention ponds that were used to capture the runoff from hardscape. We conducted computer simulations to show how much water would be needed to simulate the buildup of the groundwater. Using the computer simulator ModFlow, we found that 40 percent of rain that fell in that little watershed became recharge. We used another type of model based on infiltration through the individual basins and surface water runoff modeling and found about 60 percent of the rainfall was necessary to produce those conditions. So how much water was that? If a subdivision were developed, there would be enough water to provide 25 percent of its needs given a 5-home per acre density; so it probably is significant.

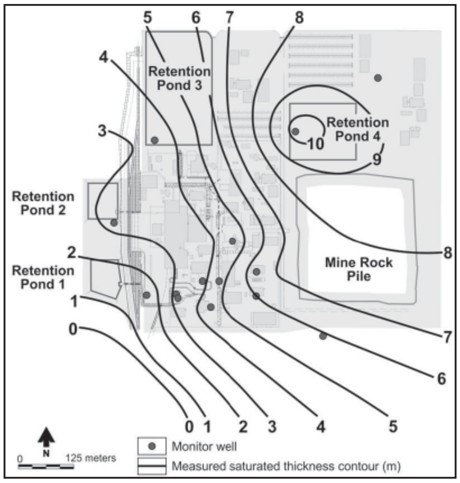


Figure 7. Groundwater mound beneath retention ponds (black dots are monitoring wells)

Figure 8 shows a graph of harvestable stormwater for the City of Tucson, taken from a recent planning document from the county. The graph shows that the amount of harvestable rainwater coming into the watershed is a function of the area where the water is being captured. In a developed urban area, the red line shows the predicted amount of capture; as you get to the lot scale or neighborhood scale, you are in the vicinity of about 50 percent capture of the water that falls or more. As the area gets smaller and smaller, you get more efficient at capturing rainfall. If you were trying to capture rainfall, you'd like to capture it close to the source before it has time to be intercepted or otherwise detained. This type of lot-scale rainwater harvesting is catching on as a green technology (Fig. 9).

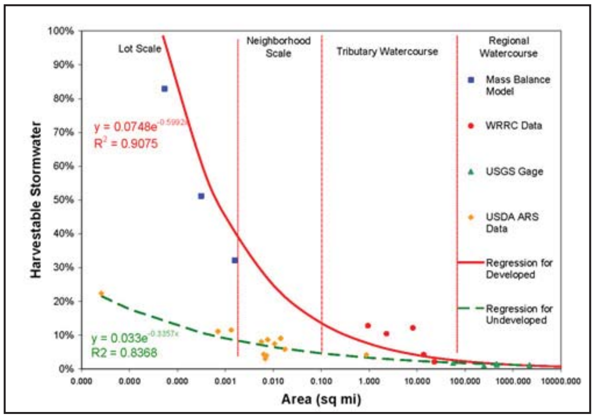


Figure 8. Potential stormwater recovery, City of Tucson

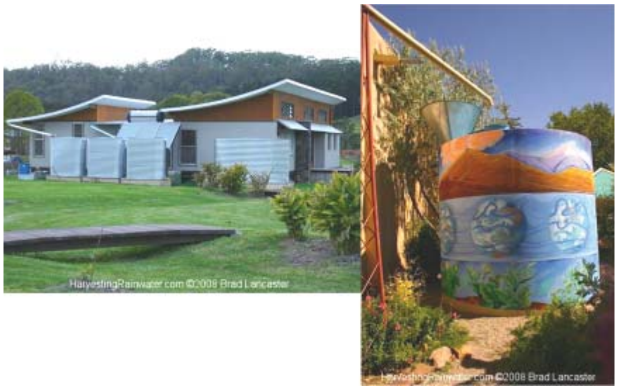


Figure 9. Lot scale rainwater harvesting

Low impact development (LID) is a technology that has evolved since the 1990s. The concept started in Maryland and has now taken off. LID is a means of compliance with the Clean Water Act on a local scale. Figure 10 shows a couple illustrations of how water from a hardscape street can be diverted into a vegetation lined channel, and where water is diverted into "rain gardens" used to beautify with plants. In the process of getting water onto lawns or gardens, the peak discharge from floods is reduced and the water that runs off is spread over a longer period of time so flood potential is minimized.

Figure 10. Water from a hardscape street diverted into a vegetation lined channel or "rain garden"

Green roofs are part of LID technology, and Figure 11 shows two examples. The first is a home being constructed in the Albuquerque area. The second shows the roof of the EPA building in downtown Denver; you can see the green roof is very well vegetated. This trend in LID and stormwater management helps improve habitat and recreation and affords some improvement in the water quality of the runoff, which is what was intended. Some of these designs are appropriate to recharge groundwater as shown in Figure 12 where an infiltration basin in a landscape lot leads water into a dry well.

Figure 11. Green (ET) roofs

Figure 12. Infiltration basin leads water into a dry well

Figure 13 shows permeable pavers, Figure 14 shows underground infiltration basins, and Figure 15 is a photo of an infiltration gallery. All these LID technologies are once again modifying the landscape and the hydrologic cycle and the local hydrologic balance as shown in Figure 16. It is an example of a plan to take a shopping mall in Maryland and put green roofs on top of it so that more of the water can be captured onsite and runoff prevented. This is in compliance with the Clean Water Act to minimize urban runoff. The green roofs and rain gardens, however, do not promote recharge. As a groundwater hydrologist, my interest is not so much in stormwater, but in recharge. Perhaps Mr. Allen, our prior speaker, and the LID people are focusing on stormwater control; I want to twist this around and see how it can be used primarily for groundwater recharge.

Figure 13. Permeable pavers promote recharge

Figure 14. Underground infiltration basins

Figure 15. Infiltration gallery

Figure 16. Emerging trends in water and land use again are modifying hydrologic balance

A recent investigation that I came across in the Los Angeles area is called the Water Augmentation Study. This investigation used modeling, field experiments, and instrumentation around LID sites and commercial and residential areas in the Los Angeles and San Gabriel River basins. Their simulations show that if you were to capture the first ¾ of an inch of runoff, that would amount to about 384,000 acre-feet per year of water in the Los Angeles and San Gabriel River areas, enough for 1.5 million people and with a water value of $311 million; that is not small change.

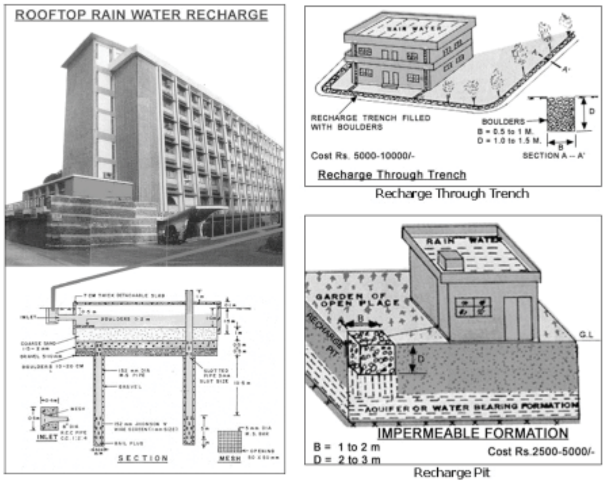
As you heard earlier today, a recent federal driver may lead to increased recharge opportunities. The 2009 U.S. EPA Guidance for Federal Facilities interprets the 2007 Energy Independence and Security Act for redeveloped and new facilities to maintain predevelopment hydrology. They do that by retaining up to the 95th percentile storm onsite and I think this will be a model for states and municipalities in the future.

Local mandates for recharge began in the early 1970s. The local governments in Maricopa County, Arizona, have been using stormwater retention basins and dry wells to keep recharge in the basin as high as practical. Very recently, the Santa Ana Water Quality Control Board issued orders for the NPDES permits in a three-county area for new residential, commercial, and industrial developments and redevelopments to implement LID with infiltration as the first priority. I think that is going to be a significant trend as we move forward.

In 2004, the state of New Jersey implemented stormwater management rules for new developments where you either have to maintain all the pre-construction recharge volume or you must infiltrate the increase in post-development runoff volume for the two-year storm. That is a mandate example that comes from a state initiative. From an international perspective, in some provinces in

India, rainwater harvesting is mandated and in some places the rainwater harvesting is used for artificial recharge such as shown in Figure 17. Figure 18 shows sketches from guidance documents that municipalities and states give to developers to instruct them as to how to use rooftop rainwater for recharge. The hotel pictured takes water down into a subsurface vadose zone well and an infiltration basin combination. Other designs are provided to show developers how to build so that recharge is enhanced in India.

Figure 17. Artificial recharge with roof water is mandated in some provinces in India



Recharge Through Trench

Recharge Pit

Figure 18. Guidance documents for developers on using rooftop rainwater for recharge

Try to extend this concept to an urban watershed, recognizing that we don't want to impair downstream surface-water users. We would like to be able to capture the runoff above the pre-development flow and the lost evapotranspiration (ET). I think this is a concept that is simple but probably not commonly recognized. The regulatory focus has been on stormwater runoff control, and every time we put down an urban hardscape, what really happens is that we are cutting off evapotranspiration. We take water that soaked into the soil and was retained, and recover that water so it can percolate on down. Thus, there will be some decrease in evapotranspiration every time we put more hardscape down and don't do anything else with that water. Evapotranspiration is typically the largest natural output of the water balance in an area.

Figure 19 is a graphic of how this concept works. Let's say we had 20 inches of rainfall, and about 4 inches of that runs off, and about 12 inches is taken up by the native plants. That leaves about 4 inches for recharge. Figure 20 shows a home set in an area with a lot of hardscape. So the runoff increases to 8 inches and, because I've used hardscape, the recharge decreases. Figure 21 shows a LID rain barrel installed and there is some overflow into a basin and some vegetation; as a result, the runoff has returned to 4 inches. I've increased my ET a little bit for onsite vegetation use, but my recharge has increased a couple inches, even though we kept the runoff about the same.

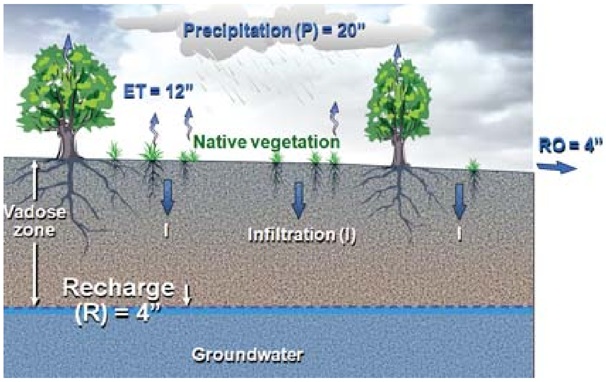


Figure 19. Capture evapotranspiration (ET) and restore runoff (RO) for improved sustainability: baseline condition

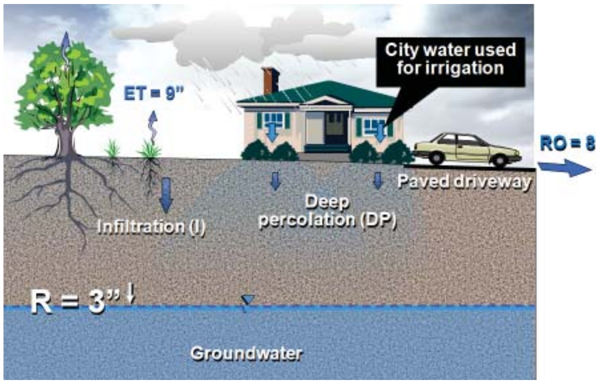


Figure 20. Home set in area

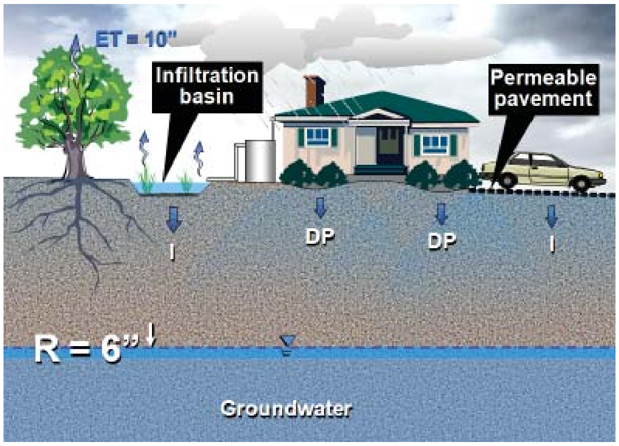


Figure 21. Home with LID rainbarrel installed

The question is how significant this is on a regional scale in a basin. Let's look at, for example Figure 22. Consider a 10-mi-wide aquifer and a river—it could be the Rio Grande 10 miles away—where the water table is represented by the red line. If the recharge rate were 2 percent of precipitation, we aren't taking any water out, so that would represent a natural condition. A recharge rate of 20 percent of precipitation is represented by the green line and a 50 percent is represented by the blue line. You see a difference of over 130 feet or so in increased water level that would result from raising the recharge rate from 2 percent to 50 percent. Similarly, if you had a well pumping a couple thousand gallons a minute in the center of the system, the effect of recharge on water levels is certainly significant (Fig. 23)

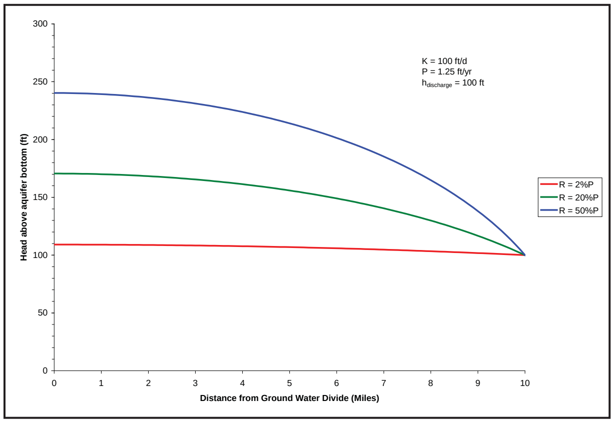


Figure 22. Benefits of decentralized artificial recharge

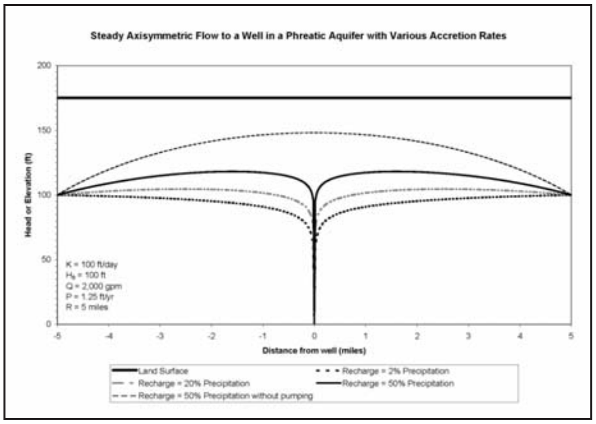


Figure 23. Steady axisymmetric flow to a well in a phreatic aquifer with various accretion rates

Figure 24 shows how roof water harvesting could be done on a local level. The system would include a storage tank and some type of underground infiltration structure that would use a soil treatment natural process to cleanse and filter the water so that the cleaner water goes down into an impaired aquifer. This would raise the water table and allow more and fresher water to be pumped from the well.

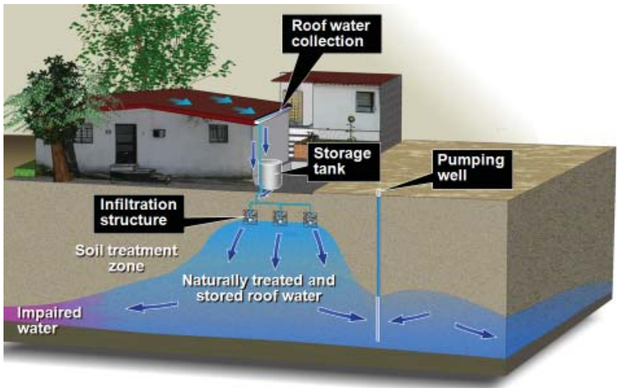


Figure 24. Roof water harvesting done on the local level

I did some calculations to determine the value of increased runoff. Assuming a 40-acre subdivision with five homes per acre, if we were able to capture 2 inches of precipitation as increased recharge, we get over 10,000 gallons for every 1/5-acre lot for a total of 2.17 million gallons per 40 acres, which is 6.7 acre-feet per year. If that water has a value of $5,000 per acre-foot, the resulting value is $33,500. That does not sound like a whole lot; the infrastructure to enhance the recharge for these homes may cost more than $33,500. We would need more incentives.

Let's look at scaling up to a larger area of 400 square miles, about the size of Los Angeles or half the size of Orange County. Assume precipitation of 15 inches, and 50 percent of precipitation becomes recharge through a decentralized system using LID methods. The potential new recharge would be 76,500 acre-feet per year. So is that a big deal? The Orange County Water District and the Orange County Sanitation District teamed to create the OCWD (Centralized) Groundwater Replenishment Project (Fig. 25), and I am on the advisory board of the Orange County Water District for this project. It is no coincidence that the Orange County Sanitation District and the Water District are located next to one another, because the Sanitation District’s water goes into the Water District's water. Some of the water is used for seawater intrusion; some gets pumped into spreading basins where the water percolates down and into the wells; and after a significant amount of water treatment is done at a treatment plant, it flows into homes. This project uses advanced procedures to treat the water.

Remember the 76,500 acre-feet of water we calculated for a 400 square mile area? Orange County Water District built their treatment plant at a cost of $481 million, it operates at a $30 million annual rate, and it produces 72,000 acre-feet of water per year. That is about the same amount as what results from an increase in the recharge rate to 50 percent using LID. And these costs include taking treated wastewater, pumping it uphill into the Anaheim area, spreading it in the basins, moving it down, pumping it back out, treating it again, and then providing it to the customers.

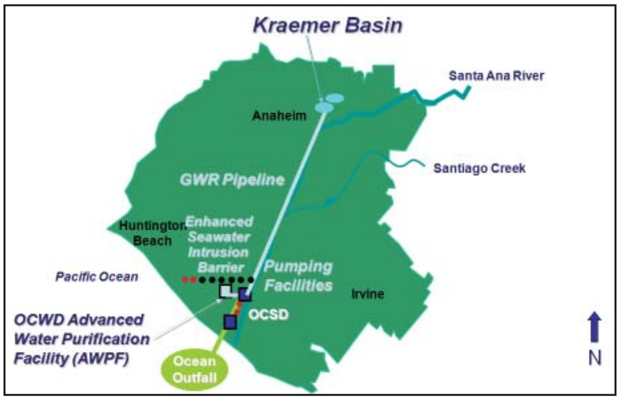


Figure 25. Orange County Water District (centralized) groundwater replenishment project

In Tucson, about 40 percent of municipal water is used for home irrigation and landscaping. That amount is probably typical for New Mexico and other areas in the Southwest. Why use treated and pumped (expensive) municipal water for lawn and garden? A combination of roof water harvesting with local artificial recharge could be used as a local conjunctive use approach. Rain barrels could be used during the summer for gardens and outdoor use. In the winter when we don’t need to water gardens, we could recharge the excess winter precipitation. When we have intense thunderstorms in the summer and the rain barrels fill, we can put that water back into the aquifer and use the existing municipal well system for indoor/potable use. These decentralized lot and neighborhood artificial recharge systems make sense to me: they increase the recharge to the well fields; increase base flow to streams; support springs, wetlands, and riparian habitat; and diminish surface runoff volume to the background pre-development condition.

How would this apply in New Mexico if we did a combination roof water harvesting or LID? The Office of the State Engineer (OSE) supports the harvesting of rainwater for onsite domestic uses. OSE states, "The collection of water harvested in this manner should not reduce the amount of runoff that would have occurred from the site in its natural, pre-development state." I think that is a fine objective, but OSE does not give any guidance on how to calculate natural runoff or how to obtain any sort of approval. OSE also says that rainwater harvested cannot be used for any other use; it is not appropriate for anything other than onsite purposes. What about using that water for artificial recharge? No, according to OSE, because they have concerns. Those concerns most likely relate to downstream surface-water right holders. By holding back rainwater on your site, it may prevent the runoff from flowing into the Rio Grande or other tributaries, thereby impinging on some other surface water right. Also, it would significantly reduce the amount of water that goes into Elephant Butte Reservoir and leave less water available to meet our Rio Grande Compact obligations. But if we divert surface runoff and tried to capture it in our neighborhood, the same kinds of issues emerge. In addition, the State Engineer is likely to be concerned that we would want to claim some water right to any of the water we captured. The salvaged ET could be viewed as a claim to some right to that water. Another concern is that if we incentivize local scale artificial recharge, we may be setting a precedent for septic system users to request credit for their water returns to the aquifer.

A decentralized approach to groundwater sustainability and runoff control is consistent with sound water conservation practices. It supports Clean Water Act requirements, off-sets the need for additional water supplies, utilizes existing potable supply infrastructure, and avoids land purchases for large scale, centralized basins as seen in Los Angeles, California. The concept affords many water quality benefits by catching water at the local level with home roof or office building systems, or at the subdivision scale. If you capture the runoff before it flows far from the property, you avoid the industrial chemicals and petroleum hydrocarbons on the land surface. Keeping the water from mixing with other wastewater discharge in streams allows the use of natural soil-aquifer treatment processes in the soil that come with LID such as filtration through lawns and gardens, biodegradation, volatilization, and absorption of metals.

A number of studies have shown no significant impact to groundwater quality from stormwater infiltration. The USGS has studied 2,100 stormwater ponds in the Long Island area. The U.S. Department of Agriculture investigated 100 stormwater ponds in industrial residential and commercial areas in Fresno, California. The University of Arizona has looked at dry wells in the Phoenix area, and more recently, the Los Angeles River and San Gabriel River Watershed Council has conducted very detailed investigations on catching poor-quality water and looking at monitor well quality underneath six well-instrumented LID sites in the Los Angeles area. Even early EPA documents say that runoff from residential areas is the largest component of urban runoff in most cities and is usually the least polluted urban runoff flow and should be considered for infiltration.

Some concerns with enhancing recharge on a local scale include the situation where fast flowing gravels and karst sites provide little chemical attenuation; perched conditions on impervious soil horizons can create difficult conditions; shallow water tables offer little storage and afford lower treatment potential; and in some areas of Albuquerque, for instance, collapsible soils produce technical instability.

A challenge to local scale recharge implementation in New Mexico is the fact that a property owner or developer receives no benefit for adding to the groundwater recharge by salvaging ET or capturing the excess runoff through a new or retro-fitted construction. In essence, as I see it, in a fully appropriated basin, a party who adds water to the basin would have to purchase the water rights, thus paying for water rights as well as for all the infrastructure costs incurred to recharge the aquifer.

In conclusion, I think decentralized artificial recharge systems are in the future and may be decades out, but they can significantly add to the groundwater reserves without depleting the pre-development runoff. Nationally, local artificial recharge with roof water and runoff is likely to be increasingly considered in water management planning. In New Mexico, clarity and consistency are needed in regulations to encourage a decentralized artificial recharge approach to augment groundwater supplies.

Thank you.