Comparing Methods of Estimating Stream Depletions Due to Pumping

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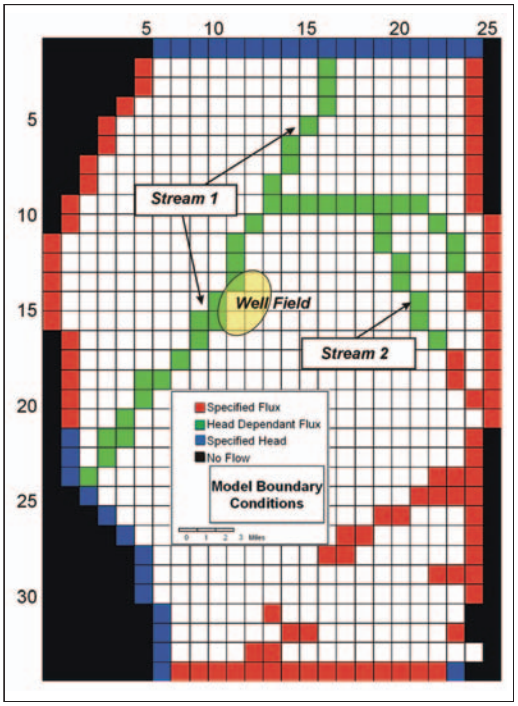
In arid western states, older or more senior surface water rights exist along with younger or junior rights to pump groundwater. Regulatory and water management agencies in many of these states use an analytical model to help administer the surface and groundwater rights in connected stream-aquifer systems. In several states, the model used is based on equations developed by Glover and Balmer (1954) to estimate stream depletions due to groundwater pumping from a connected alluvial aquifer. CDM studied the effect of the simplifying assumptions contained in the analytical model on predicted stream depletions. This was accomplished by developing a detailed numerical groundwater flow model, computing stream depletions for two streams affected by pumping, and comparing the results to the analytical model.

In New Mexico, a site with an alluvial basin-fill aquifer connected to nearby shallow streams was selected for the analysis. The study area contains a regional heterogeneous aquifer located in a deep fault-block basin, with a groundwater system that discharges into the streams, and streams that penetrate a very small portion of the aquifer. A wellfield is located very near one stream, and another stream located approximately 10 miles away is also thought to be affected by the well pumping.

Evaluation Approach Used

The Glover and Balmer analytical model is a generalized solution to the equations developed by Theis (1941). The Glover-Balmer model assumes the river fully penetrates a homogenous, isotropic aquifer that has a flat water table surface. All water pumped is assumed to come from the stream system, which is in full hydraulic connection to the adjacent aquifer.

A numerical flow model was developed and calibrated for the study area using MODFLOW (Harbaugh and MacDonald, 1996). The numerical model consists of 4 layers, 33 rows by 25 columns, with spatially varying aquifer hydraulic conductivity and storage coefficient, constant head and constant flux boundary conditions, and areal recharge. The streams in the study area were simulated with the RIVER package (shown above).



Model boundary conditions for the numerical (MODFLOW) model.

A series of simulations were made with the MODFLOW model in order to approximate the conceptual setting of the analytical model (one layer, constant aquifer properties, fully penetrating stream, no ambient hydraulic gradient). The pumped wells are located near one of the streams. The wells were operated until 1989. Analytical results were computed for the 20-year period from 1990 to 2010.

Matching MODFLOW and Analytical Model

Many intermediate MODFLOW simulations were conducted, but the following key changes were made to try to replicate the analytical model:

Run 1 - Convert model from 4 layers to 1 layer

Run 2 - Aquifer properties (transmissivity and specific yield) made constant

Run 3 - River bottom set to base of aquifer

Run 4 - Initial water table made flat and equal to stream stage

The figure on page 31 shows the predicted stream depletion for the nearby and distant streams for each of the MODFLOW simulations described above. The difference in timing and amount of stream depletions

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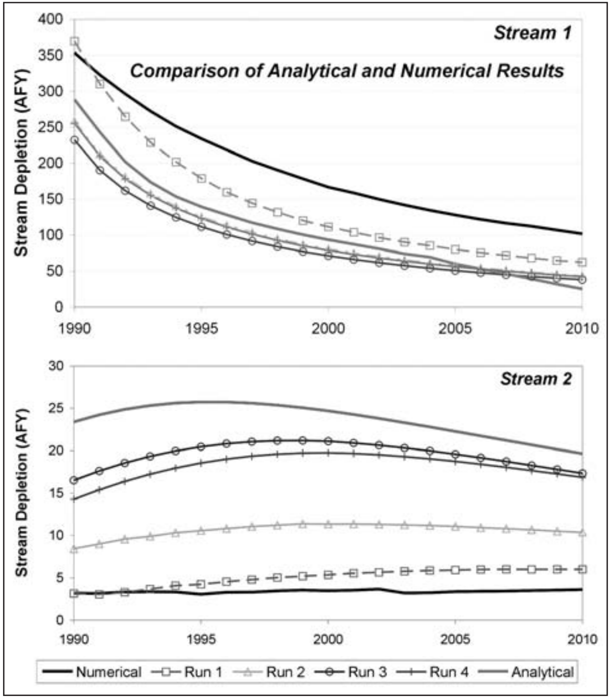
are due to different distances and lag times of pumping effects between the wells and each stream, with the larger and more immediate depletion effects being associated with the stream adjacent to the pumping wells.

Significant Differences in Results

Of the factors that were modified in the numerical model to more closely approximate the analytical model, converting the model from four layers to one, holding transmissivity and specific yield constant, and making the river fully penetrating (Runs 1-3) caused the greatest change in the predicted stream depletion. Stream depletions differed by a factor of two to five between the modified numerical model and the original numerical model. In contrast, changes in riverbed conductance and the shape of the initial water table surface had no significant effect on stream depletions.

Under the simplifying assumptions made, the numerical model could not reproduce the pattern of stream depletions calculated by the analytical model for either stream. Removing model boundary conditions and eliminating portions of the model beyond the rivers may result in closer correlation.



Predicted stream depletion for nearby well (top) and distant well (bottom) under different model runs. The solid grey and black lines represent stream depletion computed by the analytical and full numerical models, respectively. The patterned lines represent stream depletion results from the numerical model as it was simplified sequentially.

Uses of the Analytical Model

The numerical model results provide useful insights into the effect of individual assumptions implicit with the analytical method. In cases where a stream-aquifer setting is similar physically to the setting upon which an analytical method is developed, the analytical model results should depict actual effects very closely. The information presented in this evaluation may help water managers decide when and how to apply the analytical stream depletion method in the future.

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References..

Glover, R.E., and G.G. Balmer, 1954. River depletion resulting from pumping a well near a river, Transactions of the American Geophysical Union, 35(3): 468-470.

Harbaugh, A.W., and M.G. McDonald, 1996. Programmer's documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite-difference ground-water flow model, U.S. Geological Survey Open File Report 96-486, 220 p.

Theis, C.V., 1941. The effect of a well on the flow of a nearby stream, Transactions of the American Geophysical Union, 22(3): 734-738.

Arsenic Removal from Drinking Water: El Paso's Experience

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On Feb. 28, 2002, the U.S. Environmental Protection Agency (EPA) promulgated the new Arsenic Rule and set the maximum contaminant level (MCL) for arsenic (As) at 10 micrograms per liter (µg/L). Compliance with this lower arsenic MCL will require many groundwater systems to treat their water supplies. The EPA has identified several Best Available Technologies for arsenic removal, including ion exchange, activated alumina, reverse osmosis, and electrodialysis reversal. In addition, the EPA has recognized an emerging technology developed by CH2M Hill in 1993 for arsenic removal, known as the coagulation/microfiltration (C/MF) process that uses the Pall microfiltration membrane.

This summary presents the results of a two-year pilot test carried out in El Paso, Texas. The objective of the study was to evaluate treatment technologies suitable to the groundwater in El Paso. The study also helped determine the feasibility of the technologies for applications of variable scale, ranging from well-head treatment to full-scale water treatment operation. Technologies tested included three adsorption media (granular ferric hydroxide, Alcan FS50, and SORB 33TM) and CH2M Hill's C/MF process. An alternative technology, the Aqua Disk® coagulation/filtration process, was also tested.

In all of the tests, the groundwater was pretreated with carbon dioxide (CO_2) to adjust the pH from 8.3 to 6.8 to facilitate arsenic removal. For several of the adsorption media tests, sodium hypochlorite (NaOCl) was also added to the water to oxidize As(III) into As(V), a form more easily removed. The two filtration tests were pretreated with ferric chloride, $FeCl_3$, to enhance coagulation.

Testing times and durations, pretreatment, bed volumes treated (representing the life of the media), and highlights of the tests are summarized in the table above.

TECHNOLOGY	RUN	PRETREATMENT	BED VOLUMES TREATED*	HIGHLIGHTS
GFH	*02/06/02 – 08/05/02*	pH adjustment (CO_2)	29,500	- Significant media loss during pre-washing - No backwashes - Removed As(III) and As(V) - Short media life - Media is shipped wet and has to remain wet
	11/11/02 – to date	pH adjustment (CO_2) As(III) oxidation (NaOCl)	> 75,000	- Five backwashes - Removed As(V) - Prolonged media life
Alcan FS50	*02/06/02 – 04/19/02*	pH adjustment (CO_2)	< 400	- Not capable of removing As(III) - Very short media life
	06/10/02 – 08/05/02	pH adjustment (CO_2)	< 750	- Not capable of removing As(III) - Very short media life
SORB 33™	*12/17/02 – to date*	pH adjustment (CO_2) As(III) oxidation (NaOCl)	> 95,000	- No media loss during pre-washing - No backwashes necessary - Removed As(V) - Prolonged media life - Media is shipped dry
	12/19/02 – to date	pH adjustment (CO_2) As(III) oxidation (NaOCl)	> 95,000	- No backwashes necessary - Removed As(V) - Prolonged media life
C/MF	*02/28/02 – 08/05/02*	pH adjustment (CO_2) $FeCl_3$ – 10 mg/L	NA	- Not capable of removing As(III) - Cleaning frequency greater than 100 days - High flux rate, 90 gfd
Aqua Disk®	*08/15/02 – 11/05/02*	pH adjustment (CO_2) $FeCl_3$ – 10 mg/L Anionic polymer – 0.25 mg/L	NA	- High hydraulic loading rates - Effective but not reliable for arsenic removal - Difficult to establish optimal operating conditions

* Bed volumes treated before arsenic leakage exceeded 10.0 µg/L.

Granular Ferric Hydroxide (GFH): The GFH adsorption media removed both As(III) and As(V) to less than detection limits, even without sodium hypochlorite pretreatment. Pretreatment approximately tripled the life of the media. Some oxidation of As(III) may occur on the GFH media, as has been reported by the German GFH manufacturers.

Iron-coated Activated Alumina (Alcan FS50): Alcan FS50 adsorption media without sodium hypochlorite pretreatment did not remove As(III), and the bed life was short compared to other adsorption media. Theoretically, the life of the FS50 media could be improved with the addition of sodium hypochlorite. However, this was

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not attempted during the pilot test.

Bayoxide® E33 (SORB 33TM): The SORB 33 media with sodium hypochlorite pretreatment successfully removed both As(III) and As(V) to less than detection limits, and had the longest life of the three absorption media tested.

Coagulation/Microfiltration Process: The C/MF process with sodium hypochlorite pretreatment effectively removed arsenic to less than 10 µg/L from the groundwater. Adjusting the pH prior to treatment significantly reduced the dose of coagulant (ferric chloride) required to remove arsenic from groundwater.

Coagulation/Filtration Process (Aqua Disk®): The AquaDisk filter technology with preoxidation and coagulation effectively removed arsenic from groundwater, but the unit was very sensitive to chemical dosages of ferric chloride and anionic polymer, and thus was not deemed reliable. Because of this sensitivity, it was difficult to maintain optimal operational conditions to maximize arsenic removal from groundwater, extend backwash intervals, and reliably produce low-turbidity finished water.

Conclusions

With the addition of carbon dioxide for pH adjustment and sodium hypochlorite for oxidation, the granular iron media (GIM) technologies – which included GFH, Alcan FS50, and SORB 33TM – effectively removed arsenic from groundwater. The sodium hypochlorite pretreatment also greatly increased media life. GIM technologies are good solutions for small and isolated systems because of their low operational and maintenance requirements.

The coagulation/(micro)filtration technologies with preoxidation and coagulation were also effective in removing arsenic, and were able to accommodate relatively high flow rates. These processes are better suited to larger applications, as the systems are more complex to operate and maintain and may incur higher energy costs. Optimal operating conditions were difficult to maintain with the AquaDisk, however.

As a result of the pilot tests and the performance of other treatment plants, conventional treatment (including groundwater collection, preoxidation, rapid mix with $FeCl_3$ as coagulant, flocculation, lamella plate sedimentation, filtration and disinfection) was selected for the largest full-scale water treatment operation (60 million gallons per day blended capacity) at the Upper Valley Water Treatment Plant in El Paso. The plant will remove arsenic from groundwater from the Mesilla Bolson to serve the west side of the city. Wellhead treatment using adsorption media was selected for a number of wells located on the east side.

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Aquascape Solutions for Stormwater Treatment

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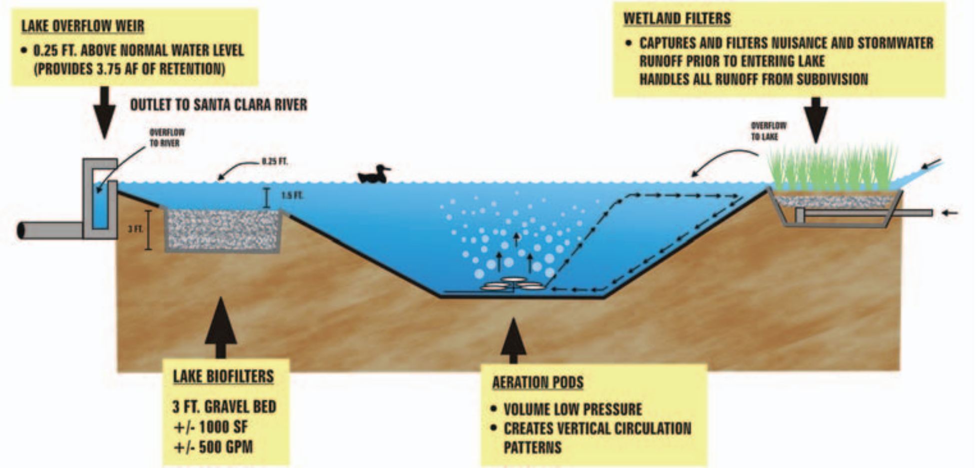
Residents admiring the views across a pristine lake located within a planned community in Southern California are unaware of the important function the lake fulfills as the area's primary stormwater quality treatment facility. In operation since February 2000, the 15-acre manmade lake, designed by PACE (Pacific Advanced Civil Engineering Inc.) of Fountain Valley, California, is the centerpiece of the Bridgeport development in Santa Clarita, 38 miles north of Los Angeles. The developer, Newhall Land, focused on proactively addressing impending federal stormwater regulations and simultaneously added value to the project. The resulting aquascape system integrates an ecosystem into an urban environment that maintains exceptional water quality through natural biological processes. Important elements of the Bridgeport Lake system include: pretreatment wetland filters, lake biofilter beds, aeration, wetland plantings, and a substantial stormwater retention volume/capacity.



Design of the Bridgeport Lake system.

Wetland Filters

The lake's water quality system pretreats all stormwater runoff entering the lake by means of wetland filters along the perimeter that function somewhat like a "kidney" for the lake system. To intercept runoff, nuisance flows, and peak storm flows before they discharge into the lake, water quality filters are located at all 18 inflow points. Each filter has an average surface area of 250 square feet and is approximately three feet deep. The bottom six inches is filled with gravel, and wetland vegetation is planted above the gravel. Low flows discharge into the lower gravel layer through an inverted pipe at the bottom, while peak flows during larger storm events enter through the upper end of the pipe into the vegetation without damaging the wetland. The filters can trap and treat up to one-half inch of runoff inflow. Any inflow in excess of

that amount flows into the lake system by dissipating through the filtration box, and is subsequently treated through aeration, the biofilter treatment system, and wetland vegetation.

Debris entering the wetland filters is cleaned out periodically. However, the limited amount of sediment in runoff flows is typically captured and treated by the filtration system, which has not experienced a major loss of void volume since it has been in operation. Nevertheless, the system is designed so that entire gravel-filled planters could be replaced if they became filled with sediment.

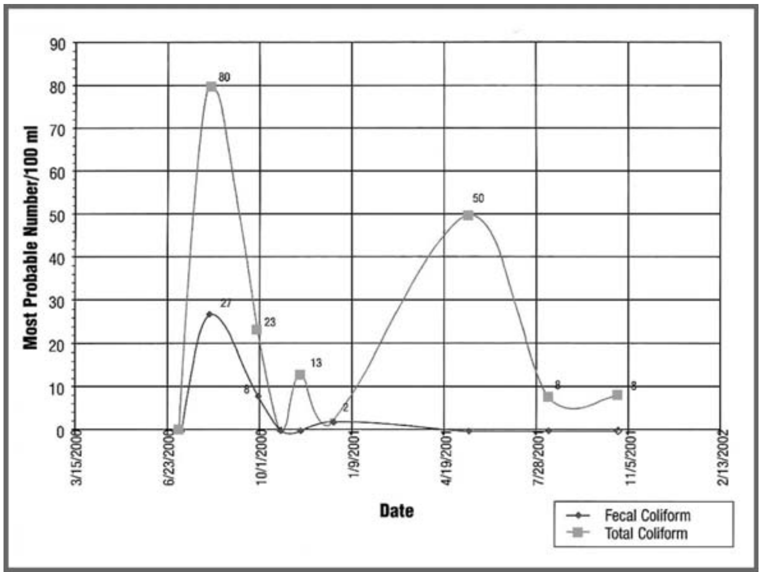
Stormwater inflow into the lake system has reduced by approximately 50 percent the amount of onsite well water that must be added to replace the 60 acre-feet per year lost to evaporation. Makeup water is obtained from a single pump supplied and maintained by Valencia Water Company.

Lake Biofilters

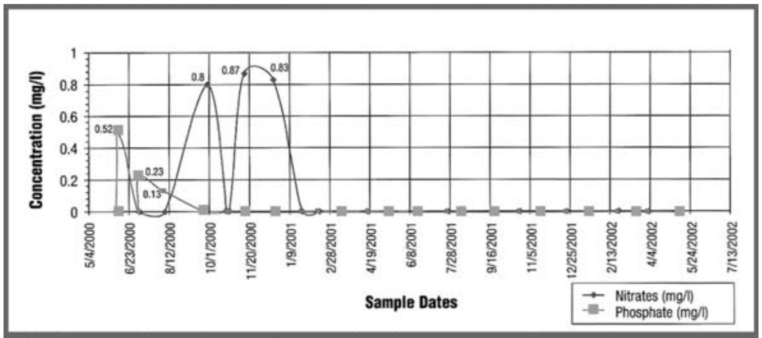
The Bridgeport Lake system incorporates 15 biofilters placed at the end of each lake finger to promote the overall circulation of the lake system. Operated by a single pump, the biofilters consist of self-contained, submerged gravel beds adjacent to the perimeter of the lake through which lake water is circulated and distributed underneath through a slotted pipe system. Naturally occurring microorganisms coat the gravel and filter out nutrients such as nitrogen and phosphorous that would promote the growth of algae in the lake. Recirculation pumping also introduces additional oxygen into the lake system to counteract depletion from algae and other organisms and the effects of high surface temperatures. Recirculation continues 24 hours a day through the biofilters; complete filtration of the lake is accomplished approximately every three days. Because of its biofilters and a turnover rate that exceeds the industry average, the Bridgeport Lake system has achieved a water quality that is significantly higher and more stable than conventional man-made lake systems.

Aeration

A stabilized biological lake system requires maintenance of the dissolved oxygen levels in order to eliminate the potential for odor problems and to deal with other operational issues such as eutrophication and stratification, which can lead to algae blooms. Aeration for Bridgeport Lake is provided through a fine bubble diffusion system located at the bottom of the lake to maximize dissolved oxygen efficiency. The aeration system incorporates technology typically employed in the wastewater field for sewage treatment applications. The key element is an "aeration disk" rather than a conventional perforated air diffuser pipe system. The aeration disks are constructed with flexible rubber skins that precisely control the size of the bubbles, enabling extremely fine bubbles to be produced. Fine bubbles increase the contact area, enhancing oxygen transfer. Run by a few small compressors, the aeration system at Bridgeport Lake operates 24 hours per day and is sufficient to turn over the lake every 3 to 4 hours, a common lake design guideline.



Total and Fecal Coliform Concentrations versus Time
Concentration spikes in July 2000 and May 2001 are likely due to nuisance irrigation runoff and water fowl excretions typical of dry summer periods.



Nitrate and Phosphate Concentrations versus Time
Neither have been detected over a 16-month period. The limits for nutrient concentrations that potentially cause eutrophication (excessive and detrimental aquatic growth) are N greater than 1.0 mg/l and P greater than 0.1 mg/l.

Bridgeport Lake arguably has the best circulation system possible in a manmade lake. However, a factor at any residential lake is wind circulation. The homes on the east side of the lake block the wind and to some extent prevent surface aeration, leaving the water at that end of the lake more susceptible to stagnancy and lowered water quality. This issue was mitigated with additional regular filter maintenance at that end of the lake.

Summary

Bridgeport Lake represents the successful application of a constructed aquascape system that provides stormwater treatment. Various lake parameters have been tested and monitored as part of the routine maintenance program (see charts above). The results demonstrate that exceptional water quality can be achieved far beyond what results from traditional stormwater treatment methods, while providing many additional benefits to the surrounding community. However, the absence of operational problems with the lake may be the greatest testimony to the system's effectiveness.

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