Predicting Groundwater Recharge Rates in Small Urbanized Watersheds

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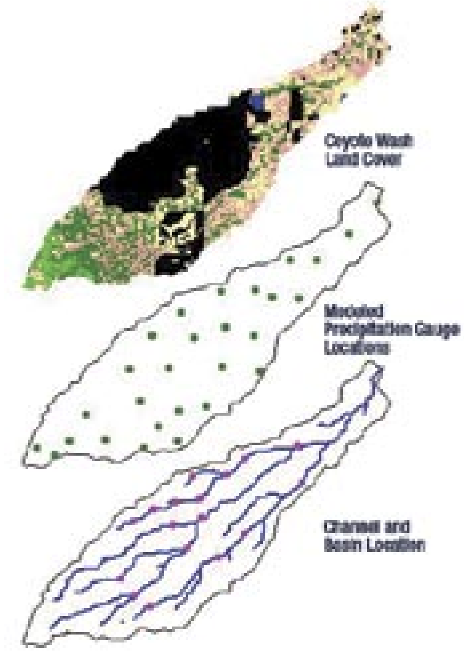
Surface water modeling and groundwater recharge estimations were used to evaluate whether natural groundwater recharge rates are increased by urbanization and can be further increased by capturing stormwater runoff in flood control retention/detention basins. Coyote Wash, an 11,461-acre urban subwatershed in the Sierra Vista area of southeastern Arizona, was selected for evaluation. Construction of 17 stormwater detention basins has been proposed in this subwatershed for flood control. The design and location of those basins were used for recharge analysis.

Increases from Urbanization

A large body of research and data was reviewed to quantify the amount of groundwater recharge that likely occurred under natural conditions, and how much may be occurring under current urbanization. Groundwater recharge in semi-arid watersheds occurs primarily by mountain front recharge and within ephemeral stream channels, with the majority occurring during abnormally wet years. Several different estimation methods used elsewhere in the Southwest were applied to the Coyote Wash subwatershed to estimate pre-development recharge rates. Average pre-development recharge estimates ranged from 75 to 220 acre-feet per year (0.5 to 1.5 percent of annual precipitation) over the basin. Point measurements from two channel and two stormwater basin monitoring sites in Sierra Vista from August 2000 through August 2003 showed recharge rates of one to five feet per year in the basins and five to 12 feet per year in the channels. In-situ rates were typically higher in channels because sediment accumulation has reduced surface infiltration rates in the basins. The precipitation totals during the years monitored approximated historical wet, dry, and average precipitation years. The estimated average channel recharge rates scaled to the total channel area of the Coyote Wash watershed suggest that urbanization may have increased recharge rates by 200 to 300 acre-feet per year above pre-development rates.



Increases from Basins

A three-part modeling approach was used to project increases in recharge resulting from construction of the proposed stormwater flood control basins. First, historical data from the high-density precipitation gauge network at nearby Walnut Gulch Experimental Watershed were used to create a synthetic precipitation record that approximated the wet, dry, and average years measured in the Sierra Vista area. The Walnut Gulch data provided rainfall intensity and spatial variability information required for modeling. AGWA/KINEROS2, an event-oriented, physically based surface water model, was then run with the synthetic precipitation data to predict changes in stormwater runoff and channel or basin infiltration resulting from complete build-out and the construction of retention/detention basins in Coyote Wash. Finally, using data from monitoring points in Sierra Vista, recharge "factors" representing the fraction of infiltration resulting in recharge to the aquifer were estimated for wet, dry, and average precipitation years for channels and basins. These factors were then applied to the infiltration volumes predicted from the AGWA/KINEROS2 model to estimate the increased groundwater recharge to the aquifer that would result from flood control basin construction.

Six AGWA/KINEROS2 model scenarios were evaluated for infiltration under wet, dry, and average precipitation years:

- Pre-development conditions;
- Post-development conditions (build-out within Coyote Wash);
- Post-development with 17 high-permeability stormwater detention basins;
- Post-development with 17 low-permeability stormwater detention basins;
- Post-development with 17 high-permeability stormwater detention basins with two-foot retention depths;
- Post-development with 17 low-permeability stormwater detention basins with two-foot retention depths.

Depending on the precipitation year, between 40 and 88 precipitation events were simulated for each annual scenario. Modeled stormwater channel infiltration volumes predicted five times as much infiltration would occur under the post-development scenario than under the pre-development scenario (see table above). Predicted increased recharge rates ranged from less than zero to nearly 700 acre-feet per year, depending on the scenario and precipitation year. The greatest increase occurred with post-development, high permeability retention basins with two-foot depths, whereas the least increase occurred under the same scenario but with low-permeability basins.

The considerable range in recharge estimates in this analysis results from the use of uncalibrated models and uncertainties and assumptions used in the calculations. Additional field monitoring and calibration modeling are recommended to improve the confidence in predicted recharge rates. If maximizing groundwater recharge rates is desired, the design and siting of stormwater basins solely for stormwater capture merits further investigation.

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Estimated Channel and Pond Recharge Volumes

Model Scenario	Precipitation Year	Estimated High Channel Recharge[1] Acre-feet	Estimated Low Channel Recharge[2] Acre-feet	Estimated High Pond Recharge[1] Acre-feet	Estimated Low Pond Recharge[2] Acre-feet	Enhanced High Recharge Rate[1] Acre-feet	Enhanced Low Recharge Rate[1] Acre-feet	Enhanced Average Recharge Rate[3] Acre-feet
Pre-Development	Wet	627	298	0	0	0	0	
	Avg	257	101	0	0	0	0	
	Dry	101	46	0	0	0	0	
Post-Development	Wet	2684	1277	0	0	0	0	
	Avg	1321	519	0	0	0	0	
	Dry	445	202	0	0	0	0	
Post-Development w/Ponds (Ksat = 2 ft/day)	Wet	2207	1050	1419	568	942	341	642
	Avg	1087	427	552	269	318	178	248
	Dry	375	171	200	23	130	-8	61
Post-Development w/Ponds (Ks = 6 in/day)	Wet	2621	1246	728	291	665	261	463
	Avg	1306	513	295	144	280	138	209
	Dry	453	206	100	12	109	15	62
Post-Development w/2ft Ponds (Ks = 2 ft/day)	Wet	1780	847	1941	776	1037	347	692
	Avg	852	335	820	400	350	216	283
	Dry	288	131	301	35	144	-37	54
Post-Development w/Ponds (Ks = 6 in/day)	Wet	1817	864	1135	454	268	42	155
	Avg	864	339	487	238	30	58	44
	Dry	294	134	167	19	16	-49	-17

[1] Estimated recharge by applying "High" recharge factors of 0.9, 0.63, 0.48; and "Low" recharge factors of 0.24, 0.09 and 0.04 to wet, average and dry year AGWA channel infiltration. Recharge factors based on estimated in-situ recharge rates at monitoring sites

[2] Estimated recharge by applying "High" recharge factors of 0.6, 0.3, 0.15; and "Low" recharge factors of 0.32, 0.16 and 0.02 to wet, average and dry year AGWA pond infiltration. Recharge factors based on estimated in-situ recharge rates at monitoring sites

[3] Estimated recharge by applying recharge factors of 0.57, 0.36, 0.26 to wet, average and dry year AGWA channel infiltration; and applying recharge factors of 0.46, 0.23 and 0.09 to wet, average and dry year AGWA pond infiltration.

The Flea Who Cried "Wolf!"

***Tim Moore** – Risk Sciences*

Compliance with the Clean Water Act is based on an enormous honor system. Permitted dischargers must self-report the results of periodic water quality analyses. Federal and state laws require that all monitoring data be certified as "true, accurate, and complete." The system works well if everyone tells the truth. Unfortunately, *Ceriodaphnia dubia*, a tiny aquatic flea used to evaluate the potential for toxicity in freshwater, routinely commits perjury.

The U.S. Environmental Protection Agency is well aware of the propensity for deceit by this pint-sized Pinocchio; the EPA protocol manual warns that the whole effluent toxicity (WET) test that uses this insect is only accurate "plus or minus 100 percent." When WET test procedures were added to EPA's standard methods, the agency acknowledged that "accuracy cannot be ascertained." This is a startling admission, considering that each discharger must affirm under oath that the results of WET tests recorded on the EPA Discharge Monitoring Report are "true and accurate"!

EPA developed this short-term chronic toxicity test to identify situations where pollutants, acting synergistically or below chemical detection limits, were harmful to the environment. WET tests are performed by exposing 50 water fleas to various concentrations of effluent and counting the number of offspring produced in a week. Results are compared to the number of offspring produced by a group of ten organisms exposed only to nontoxic control water. The control water is carefully prepared by the laboratory according to an old family recipe published by EPA. Statistically significant reductions in reproduction are deemed to be evidence of toxicity and, in most cases, constitute permit violations.

The test method does not directly identify the chemical cause of toxicity when a test fails. That requires sophisticated and expensive follow-on analyses. Moreover, each test failure does not necessarily have a chemical "cause." EPA admits that the WET procedures report false toxicity in approximately one in every 20 tests performed. Not bad odds, unless one considers the long-term implications.

Evaluating survival and reproduction in quarterly samples for the normal permit term of five years requires the performance of 40 statistical analyses. Therefore, the average discharger should expect to report at least two false failures during each permit cycle, and more if sampling must be performed monthly or on multiple test species.

EPA acknowledges there is no way to distinguish a true test failure from a false positive. The agency asserts, however, that the precision of WET methods is within the range of analytical variability observed for traditional chemical tests. This may be true, but with chemical methods, accuracy can be verified and EPA has established Method Detection Levels (MDLs) for each method to insulate permittees from the adverse effects of test variability. Not so for WET testing.

Based on large-scale interlaboratory studies, EPA determined that the coefficient of variation (CV) for the *Ceriodaphnia dubia* reproduction test was approximately 0.34. To put this in perspective, if an ATM machine had a CV of 0.34, two-thirds of the time it would dispense between $66 and $134 when $100 was requested. One out of six people would get less than $66, although their account would still be debited for the full $100. Viewed from the perspective of our everyday tolerance for error, a CV of 0.34 is not trivial.

During the same comprehensive interlaboratory study, EPA submitted to several dozen laboratories samples that were spiked with a toxic concentration of potassium chloride. Two-thirds of the labs reported their sample was not toxic. In a similar study by the Western Coalition of Arid States (Westcas), plain nontoxic water was reported to be toxic by laboratories analyzing the blind sample. These real-world investigations clearly demonstrate what EPA means when they say the test is accurate “plus or minus 100 percent.”

Permittees in the arid West are even more at risk of false toxicity results because higher levels of hardness, alkalinity, and total dissolved solids in western water supplies tend to inhibit *Ceriodaphnia dubia* reproduction. Elevated conductivity is frequently mistaken for chronic toxicity because EPA’s toxicity identification evaluation protocol lacks a procedure to account for natural ionic interference.

Permit writers are now expanding the use of WET testing to evaluate water quality in groundwater remediation projects, stormwater runoff, and man-made conveyance structures. This will dramatically increase the number of false permit violations throughout the arid West. To forestall that outcome, Westcas has joined with other municipal and industrial stakeholders to challenge EPA’s WET methods in federal court. A final decision is expected this fall.

Visit www.toxicity.com for more information or contact Tim Moore at Tim_Moore@risk-sciences.org.