Verde River Basin PARTNERSHIP

Informing the community about our water

Verde River Basin Water-Resource Notes no.3

The Northern Arizona Regional Groundwater-Flow Model: A Powerful Scientific Tool to Guide Our Water-Management Decisions

This is the third of a series of Verde Water-Resource Notes prepared by the Verde River Basin Partnership. The Partnership's goal is to help citizens and their elected and appointed officials to (1) understand the science of our interconnected groundwater and surface water that together maintain the Verde River; (2) appreciate the fragility of the system; and (3) promote the value of the river, and the life and lifestyles it supports.

Supporting material and references can be found in the Verde River Basin Partnership Water-Resources Primer at www.vrbp.org.

Numerical groundwater-flow models are, without question, the best tools available to help us evaluate the consequences of human-induced changes on the movement and storage of water in groundwater systems and the changes in the rates and locations of groundwater discharge from them. Numerical groundwater-flow models, many of which are based on software developed by the U.S. Geological Survey (USGS), are used effectively throughout Arizona, the nation, and the world. The USGS is highly experienced in numerical groundwater-flow modeling and is highly regarded for its scientific rigor and credibility.

An Essential Scientific Tool to Guide Our Water-Management Decisions

In order to make well-founded long-term water-management decisions that support a sustainable supply of groundwater for our grandchildren and their grandchildren and that ensure the year-round flow of a healthy Verde River, we need to have the best available scientific tools.

Upper Verde River & its lush riparian zone. Courtesy: Gary Beverly.

The Northern Arizona Regional Groundwater-Flow Model (NARGFM) is such a tool. It can be used to guide our elected officials and resource managers in developing water-management strategies that will protect the long-term health of our groundwater, springs, and perennially-flowing streams.

Predicted effects of particular interest for long-term water management include changes in the depth to the groundwater and the rates and locations of discharge of groundwater to springs and streams. These predicted effects may be displayed by graphs, tables, or maps.

The NARGFM is a computer model of our groundwater system that can represent recharge (the addition of water to the system), the movement of groundwater through the system, and discharge (the release of groundwater from the system). The model's power is its ability to predict the effects of natural changes such as changes in recharge owing to long-term climate variation or human-induced changes such as groundwater pumping (a form of discharge) or the engineered return of treated wastewater to the groundwater system (a form of recharge).

The NARGFM was developed specifically for our region by the U.S. Geological Survey (USGS). It incorporates scientific information from the results of multiple USGS hydrologic studies underway in north-central Arizona since 1999.

These fundamental hydrologic studies and the development of the model were supported by taxpayers through the Arizona Department of Water Resources, the USGS, and additionally, for development of the NARGFM and studies in the Verde River watershed, Yavapai County.

Although the areas of primary focus were the Big Chino, Little Chino, Upper Agua Fria, and Verde Valley sub-basins, the model covers most of northern Arizona. This is because groundwater flow is continuous across some boundaries between adjacent administratively defined basins or sub-basins in northern Arizona. Thus groundwater withdrawals in one basin may potentially capture groundwater flow from an immediately adjacent basin.

Aquifers and Groundwater Flow

All rocks and unconsolidated sediments (for example, sand, gravel, silt) in the outermost part of the earth contain void spaces. At some depth below the land surface these voids are completely filled (saturated) with groundwater. The upper boundary of the saturated rocks or sediments is the water table, and bodies of water-saturated rock or sediment are aquifers.

A numerical groundwater-flow model is a computerized simulation (representation) of a groundwater system. The model's predictive capability depends upon the degree to which the model accurately simulates the groundwater system being modeled, i.e., the processes of recharge and discharge, and the hydraulic properties that control the rate and direction of water movement as well as the storage of water within the groundwater system.

The volume of void spaces in aquifers may range from one percent or less to as much as about 20 percent. When these voids are filled with water, an aquifer can store a great amount of groundwater. Gravity drives the groundwater to flow continuously through the interconnected voids from points of recharge to points of discharge, (from high areas to low areas). Ground water is always in motion. However, the rate of flow is slow by comparison with the flow rates we observe in streams. A velocity of one foot per day or greater is a high rate of flow for groundwater, and groundwater velocities can be as low as one foot per year or one foot per decade. In contrast, velocities of streamflow are generally measured in feet per second; a streamflow velocity of one foot per second is approximately 16 miles per day.

The percentage of void space, the efficiency of movement of groundwater through the interconnected voids, and lateral variation in the elevation of the water table are important hydraulic properties that control the rate at which an aquifer transmits groundwater.

Thus, they are simulated in a numerical groundwater-flow model.

Groundwater Recharge

The natural source of groundwater is rain and meltwater from snow. Rainwater or snowmelt initially either infiltrates (seeps) below the land surface or is evaporated. If the intensity of rainfall or the production of snowmelt exceeds these two processes, the surplus water begins to flow overland into streams and rivers, forming runoff.

Water that infiltrates into the ground is used by plants (transpiration) during the growing season, and is also subject to evaporation by the sun to depths of about 3 feet or so. Infiltrated water that is not consumed by these two processes (together, evapotranspiration) continues to move downward under the pull of gravity to become natural groundwater recharge. This source of recharge is simulated in a numerical groundwater-flow model.

Runoff always flows downhill, becoming channeled into gullies and streams. Larger runoff events may deliver water onto and sometimes across the valley floors in stream channels to reach our major rivers such as the Verde River. In ephemeral channels, some of this channelized runoff also infiltrates into the ground becoming natural groundwater recharge. Infiltration along ephemeral stream channels can be very effective and is often capable of consuming all of an ephemeral stream's water before it reaches a major river. Infiltration of runoff is also simulated in a numerical groundwater-flow model.

In our dry climate, most of the precipitation we receive is consumed by evapotranspiration. The USGS has estimated that, on long-term average, only 1 to 2 percent of total annual precipitation enters the groundwater system as natural recharge in the Little Chino and Big Chino sub-basins. In the Verde Valley sub-basin, about 4 percent of the annual precipitation enters the groundwater system as natural recharge. The difference reflects the relatively great precipitation, including abundant snowfall, in the high Mogollon Rim country along the northeast margin of the Verde Valley sub-basin.

Human-induced recharge can occur from various processes, the most common in our area resulting from irrigation of crops. Some of the irrigation water infiltrates below the land surface and becomes groundwater recharge. This process and other human-induced sources of recharge, such as the engineered return of treated wastewater to the groundwater system from infiltration basins, are also simulated by a numerical groundwater-flow model.

Groundwater Discharge

Groundwater naturally discharges from aquifers at springs and into streams as well as to evapotranspiration in areas in which riparian vegetation is rooted in shallow groundwater.

Pumpage from wells is an additional form of groundwater discharge. A numerical groundwater-flow model simulates both natural discharge and human-induced discharge from pumped wells.

It's All Connected

Recharge, groundwater flow, and discharge are individual but interdependent components of a groundwater system. A change in one of these components affects the others. Changes in recharge or discharge will be reflected in changes to the movement of water through and discharge from the groundwater body. For example, under natural conditions, the long-term rate of recharge to the aquifer equals the long-term rate of discharge from it. However, the addition of discharge from pumping dewaters part of the aquifer around the well, lowering the water table. Eventually the amount of natural discharge to springs, streams, or riparian zones will be reduced in an amount equal to the pumpage.

Predictive Capability of a Numerical Groundwater-Flow Model

Models such as the NARGFM are commonly intended to allow us to understand the hydrologic consequences of human impacts (for example, pumping or engineered recharge) on the groundwater system being modeled. For our water-management concerns, model predictions about water-level changes and changes in the amount and location of groundwater discharge are of most interest.

The predictive capability of a numerical groundwater-flow model depends upon the accuracy with which it simulates the groundwater system being modeled, i.e., the processes of recharge and discharge, and the hydraulic properties that control the rate and direction of groundwater movement as well as the storage and release of water within the groundwater system. Most numerical groundwater-flow models are first constructed to simulate natural conditions prior, insofar as possible, to the earliest groundwater pumping. This process, which creates an initial baseline, is referred to as steady-state model calibration.

Next, in the so-called transient model calibration, the model is progressively adjusted in a series of time steps—in the NARGFM, 9 steps, mostly decadal, for the period between 1910 and 2006.

Best estimates from historic records are applied, within each time step, throughout the model area for average quantity and location of such elements as natural recharge, human-induced recharge, pumpage, and evapotranspiration. Simulated model results are then compared for each time step to observed (measured) water levels in wells and also to groundwater discharge to streams and springs.

Hydraulic properties of the aquifers that govern the storage and flow of groundwater are adjusted within reasonable limits to perfect as well as possible the agreement of the simulated and observed values. The degree of success of this calibration provides the modeler with an indication of the predictive capability of the model.

When the model's conceptual design appropriately simulates the groundwater system being modeled, the calibration process can be used to establish reasonable limits on the model's predictive capability. When these constraints are considered, a numerical groundwater-flow model is, without question, the most effective tool available to evaluate the consequences of human-induced changes on the movement and storage of water in a groundwater system and the changes in the rates and locations of groundwater discharge from it.

As with many kinds of computer models, some information necessary to fully calibrate a groundwater-flow model is nearly always lacking. Thus, educated estimates by experienced hydrologists are required during model construction. These estimates are constrained by good geologic information, well records, pumping tests, and experience gleaned from hydrologic and modeling experience in other areas. Importantly, the laws of physics that regulate infiltration, recharge, groundwater flow within aquifers, and discharge are well-founded, well-understood, and universally accepted.

Why Does It Matter?

Groundwater pumping and stream diversions have eliminated perennial flow along many of Arizona's streams and rivers, turning them into dry washes that flow only after storm or snowmelt events.

The Verde is one of Arizona's few remaining rivers that is still perennial and largely free-flowing. It supports lush riparian habitat, vibrant aquatic and terrestrial life, human recreation, and a growing river-based economy that thrives on tourism. Like many other parts of the southwest, the Verde watershed is pressed by an expanding population and ever-increasing water demand.

Numerical groundwater-flow models are used worldwide to move from guesswork to science-based water-resource planning and management. For the first time we have a robust publicly-available groundwater-flow model—the USGS NARGFM—as a critical tool to guide our water-resource management in the Verde River Basin. We can't wait! We need to use this powerful science-based tool now to guide policy that assures both an adequate water supply and a flowing river for our grandchildren and their grandchildren.

Santa Cruz River north of Nogales, Arizona--once perennial, but now a dry wash. Mt. Wrightson is in the background. Courtesy: Dan Campbell.

The NARGFM now provides a powerful tool to guide elected officials and resource managers in addressing water-management policy that can avert the loss of this vital resource and in planning the sustainable use of our groundwater for the long term.

What Can We Citizens Do?

Conservation of water by citizens, businesses and municipalities will help. It's important, though, to understand that conservation alone will not assure the long-term future of our groundwater supply and the river.

Numerical groundwater-flow models are used effectively throughout the world; the USGS pioneered them and represents the global gold standard in numerical groundwater-flow modeling.

Learn about and understand where your water comes from and how our groundwater and the river work together.

Encourage decision makers to begin applying the Northern Arizona Regional Groundwater-Flow Model as a valuable scientific guide to long-term management of our water resources.

FOR MORE INFORMATION ABOUT THE VERDE RIVER BASIN PARTNERSHIP AND WATER RESOURCES OF THE VERDE RIVER BASIN, PLEASE VISIT: www.vrbp.org.