Preliminary Model Development of the Ground- and Surface-Water System in Pinal Creek Basin, Arizona

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ABSTRACT

Ongoing studies of surface water and ground water contaminated by acidic-mine wastes in the Pinal Creek Basin near Globe, Arizona, include the development of a ground-water flow model. The flow system is being simulated with the U.S. Geological Survey's updated three-dimensional, finite-difference, ground-water flow model, MODFLOW-96. The model has been vertically discretized into five layers and horizontally discretized into 62.5-meter by 125-meter cells. Simulation of the hydrologic processes in the basin will provide information on the effects of streamflow infiltration, ground-water discharge to a perennial stream reach, ground-water pumping, and an unlined surface-water impoundment. The model also will be used to test the value of various types of data for calibrating ground-water flow models. The aquifer is bounded by impermeable crystalline rocks and is composed of a thick conglomerate and, near major drainages, unconsolidated alluvium where the bulk of the contamination is present.

INTRODUCTION

A plume of acidic-mine wastes have contaminated ground and surface waters in the Pinal Creek Basin near Globe, Arizona. A number of studies are underway at the U.S. Geological Survey (USGS) Pinal Creek Toxic-Substances Hydrology Research site to identify the processes that control the migration and transformation of contaminants in ground water and surface water. The major source of contamination is mine-process water that was stored in an unlined surface-water impoundment, referred to as Webster Lake, for 43 years. In 1986, the lake was ordered drained by the U.S. Environmental Protection Agency (USEPA), and by May 1988, the lake was dry. Because of the complex patterns and dynamics of ground-water flow, a model capable of simulating these effects is needed. One of the uses of the model is to test the value of alternative forms of data in estimation of model parameters. MODFLOW-96 will be used to simulate the aquifer and flows in Pinal Creek and its tributaries. This paper describes the preliminary design of a ground-water and surface-water flow model that will be used for these studies.

GEOHYDROLOGIC SETTING

Pinal Creek Basin is a broad alluvial valley bounded by mountain ranges that were formed by block faulting. The mountain ranges are composed of igneous, metamorphic, and sedimentary rocks. The geology and structure of the Pinal Creek Basin has been documented in several publications and will be summarized here.

Basin Structure

Pinal Creek Basin has been divided into two structural compartments—the southern and northern blocks, which are connected by a structurally complicated area termed the “bottleneck” (fig. 1) by Neaville and Brown (1993). The southern block is bounded on the west by the Miami Fault and is bounded on the south by the Pinal Mountains (fig. 1). Miami Fault is a northeastward-trending normal fault that has a dip that ranges from 35° to vertical and a vertical displacement of more than 500 m (Neaville and Brown, 1993, p. 7). The eastern boundary of the block is the Pinal Creek fault zone that is covered

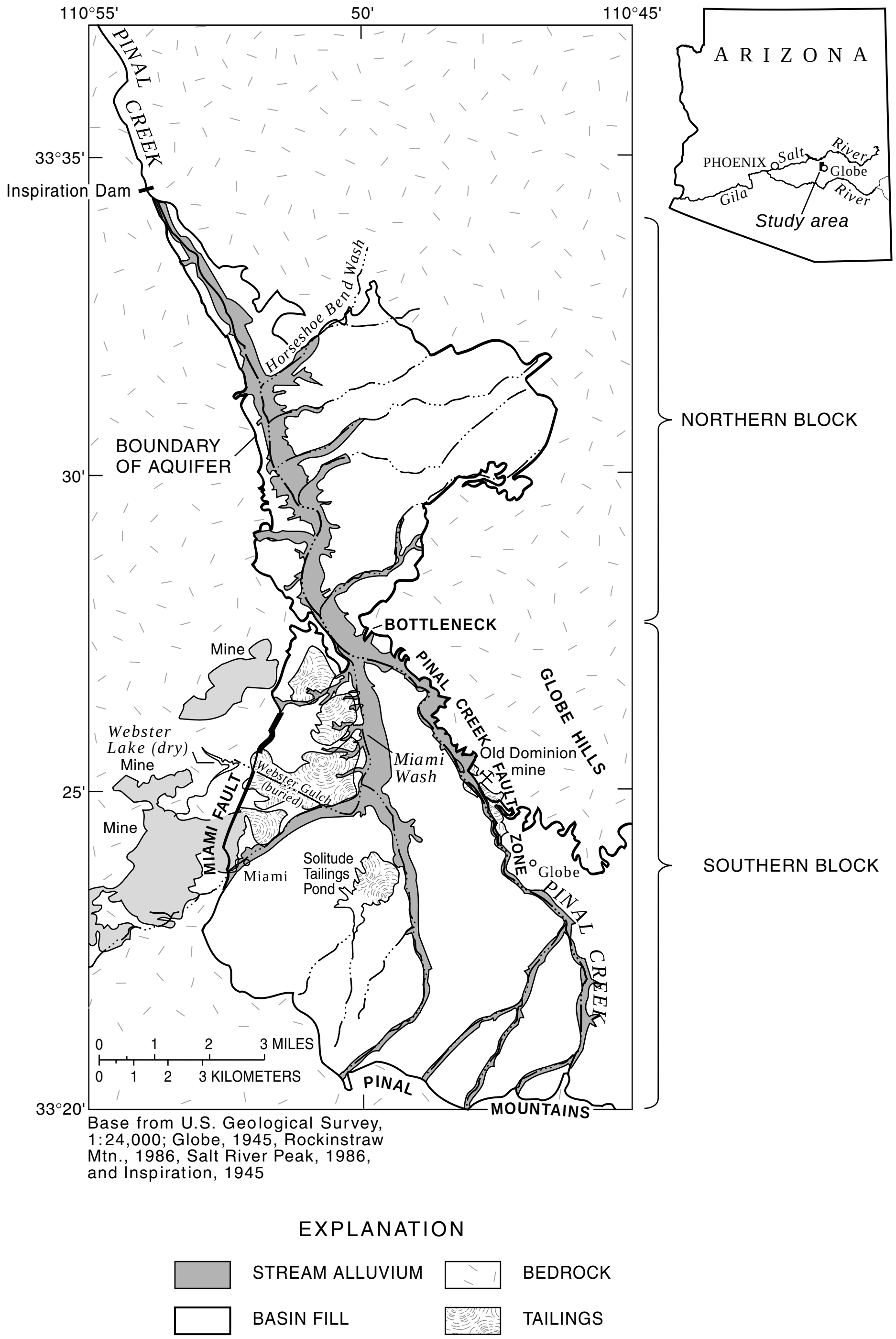

Figure 1. Geologic setting and tributary streams, Pinal Creek Basin, Arizona.

on the surface in most places by a detritus mantle but is more than 1.5 km wide in the underground workings of the Old Dominion mine. The fault zone has a vertical displacement that is probably less than 200 m and consists of a series of southwestward-dipping step faults (Peterson, 1962, p. 46). The Miami Fault and the Pinal Creek fault zone intersect at the bottleneck to form the northern boundary of the southern block.

The northern block is subdivided into two areas. The northern area is north of Horseshoe Bend Wash (fig. 1). Alluvial material in this area thins to the north and overlies igneous rock. The southern area is south of Horseshoe Bend Wash and is bounded by steep-angled normal faults along which the basin block has been down-dropped (D.R. Pool, hydrologist, USGS, written commun., 1984). Drillers' logs of wells in the area indicate a vertical displacement of about 300 m. The southern boundary of the northern block is the intersection of the Miami Fault and the Pinal Creek fault zone at the bottleneck.

Hydrogeologic Units

Ransome (1903) and Peterson (1962) mapped the geology of most of the basin. On the basis of their hydrologic properties, the geologic units in the basin are grouped into three major categories—bedrock, basin fill, and unconsolidated stream alluvium. A Precambrian-age basement complex of schist that has been intruded by large bodies of igneous rocks makes up most of the bedrock group (Neaville and Brown, 1993, p. 8). The bedrock group is much older than the basin fill that uncomformably overlies it. Bedrock also makes up the mountains and basement complex that bound the study area. This group has low permeability, and most ground-water flow occurs through fractures and faults.

The basin fill is alluvial material of Pliocene and Pleistocene ages that filled structural troughs. This unit is faulted in areas because of mild volcanic activity (Peterson, 1962, p. 8). The hydraulic-conductivity values of this unit range from 0.1 to 0.2 m/d (Neaville and Brown, 1993, p. 11). The degree of cementation plays a large role in determining the hydraulic properties of this unit. Thickness of this unit varies from as much as 1,000 m in the southern part of the basin to 0 at the lateral bedrock boundary.

Unconsolidated stream alluvium is Quaternary to recent in age and is incised in the basin fill along the active channels in the basin (fig. 1). The unit can be divided into two distinct zones, a basal boulder zone and an overlying sandy zone. The boulder zone is only a couple of meters thick, and the hydraulic conductivity for the zone is greater than 400 m/d. The remainder of the unit is the sandy zone, and the hydraulic conductivity ranges from about 50 to 150 m/d. Most of the unit consists of gravel; however, material size ranges from clay to boulders (Neaville and Brown, 1993, p. 12). The unit is about 50 m thick near the confluence of Miami Wash and Pinal Creek and thins to 0 along the upper reaches of the drainage basin and at Inspiration Dam. This unit is hydraulically connected to the basin fill, which bounds the stream alluvium laterally and at depth.

OCCURRENCE AND MOVEMENT OF SURFACE WATER

Most of the stream channels within the study area are dry during most of the year. Peren- nial flow exists only in the lower 6 km of Pinal Creek and at a few springs in the Pinal Mountains, Globe Hills, and the hills north of Miami (Neaville and Brown, 1993, p. 13). Streamflow losses in the Pinal Mountains have been measured by Hazen and Turner (1946), Neaville and Brown (1993), and in the spring of 1998, as a part of this study. The measurements allow a characterization of the distribution of infiltration in the southern part of the basin. Streamflow lost through infiltration has the potential to recharge ground water in the stream alluvium and basin fill.

Pinal Creek upstream from Inspiration Dam is perennial because the shallow bedrock forces ground water toward the land surface. The head of flow of the perennial reach moves upstream and downstream depending on ground-water levels in the unconsolidated deposits (stream alluvium and basin fill).

The ground-water system also is recharged by surface water stored in unlined impoundments. Webster Lake was the largest unlined impoundment in the basin and was used to store mine-process water. The surface elevation of the lake varied and, on several occasions, the lake overflowed into Webster Gulch. The maximum capacity of the lake, estimated from topographic maps, was 7,150,000 m^3 (Neaville and Brown, 1993, p. 14). Seepage of lake water into the aquifer may have contributed large amounts of contaminants to the ground-water system before the lake was drained in 1988. The lake may partially fill after large rainstorms but any standing water is expeditiously removed.

OCCURRENCE AND MOVEMENT OF GROUND WATER

Ground water occurs almost exclusively within the basin fill and stream alluvium. Flow in the bedrock units probably is restricted to intensely fractured or faulted areas, and flow is considered insignificant compared with flow in the unconsolidated deposits (Neaville and Brown, 1993, p. 15). Most ground-water recharge originates as infiltration into the streambed in the headwaters of Pinal Creek and tributaries and flows northward in the same direction as Pinal Creek.

In the area near the confluence of Pinal Creek and Miami Wash, the alluvial aquifer is constricted, horizontally and vertically, by bedrock. This constriction forces ground water toward the land surface, and at times, flow in the creek can result if the water table is above land surface. This surface-water flow, however, usually is short lived as the water infiltrates the channel of Pinal Creek and recharges the aquifer in the northern block. As the ground water flows northward, the aquifer again thins and narrows until it is truncated by bedrock near Inspiration Dam. This truncation causes all ground-water flow to discharge to the surface at Inspiration Dam. Surface-water measurements from above and below the dam confirm that all flow goes over the dam.

MODEL DESIGN

MODFLOW-96 (Harbaugh and McDonald, 1996) will be used to simulate steady-state and transient surface-water and ground-water flow in the basin. The model is an update of the modular three-dimensional finite-difference ground-water flow model of McDonald and Harbaugh (1988). The model will include a modified stream package that allows ground-water recharge to the uppermost active layer. A steady-state simulation will be done using average annual conditions that are based on estimated inflows and outflows. Transient flow will be modeled using stress periods that will allow for simulation of major hydrologic events in the basin after September 1984.

The model will simulate ground-water flow in the basin fill and stream alluvium, which are bounded by relatively impermeable bedrock. The contact between the basin fill and bedrock will form the boundary of the active-flow area (fig. 1). The model grid has been rotated 20° west of north. This orientation places the model columns nearly parallel to the long axis of the stream alluvium. The aquifer has been uniformly discretized horizontally into cells that are 125 m wide along the 231 rows and 62.5 m wide along the 242 columns. These grid dimensions were selected to allow adequate representation of the thin stream alluvium in the upper reaches of the streams. The aquifer has been discretized vertically into five layers (fig. 2). The uppermost layer will represent stream alluvium and will vary in thickness from 0 at the periphery of the model to a maximum of 100 m in the central part. The second layer will represent the boulder zone at the base of the stream alluvium. This layer is a couple of meters thick and will have a higher hydraulic conductivity than the upper layer of the model. Layers 3 through 5 will represent basin fill. Layer 3 will be used to simulate the shallow basin fill and will be 100 m thick except in the far northern part of the basin where the aquifer thins and is truncated by bedrock. The fourth layer will simulate the basin fill to an intermediate depth, and north of the bottleneck, will extend to the bedrock contact. South of the bottleneck, the bottom of the fourth layer has been assigned a constant elevation of 640 m, and the layer is underlain by a fifth layer that extends to the bedrock contact at depth.

The bedrock and basin-fill contact is represented as a no-flow boundary, and all model cells outside this contact are inactive. A no-flow boundary also will be used to simulate the ground-water divide that corresponds to the surface-water divide in the southeastern part of the model area. The stream package will be modified to allow for recharge to the uppermost active layer. This modification will be standard in the new version of the stream package that is currently being developed (David E. Prudic, hydrologist, USGS, oral commun., 1998). Allowing recharge to the uppermost active layer provides for a better simulation of the system because the water level in the stream alluvium rises and declines in response to changes in amounts of precipitation. The draining of Webster Lake in the 1980’s will be simulated using the general-head boundary package.

The model will be run in the steady-state and transient modes. Head data from the

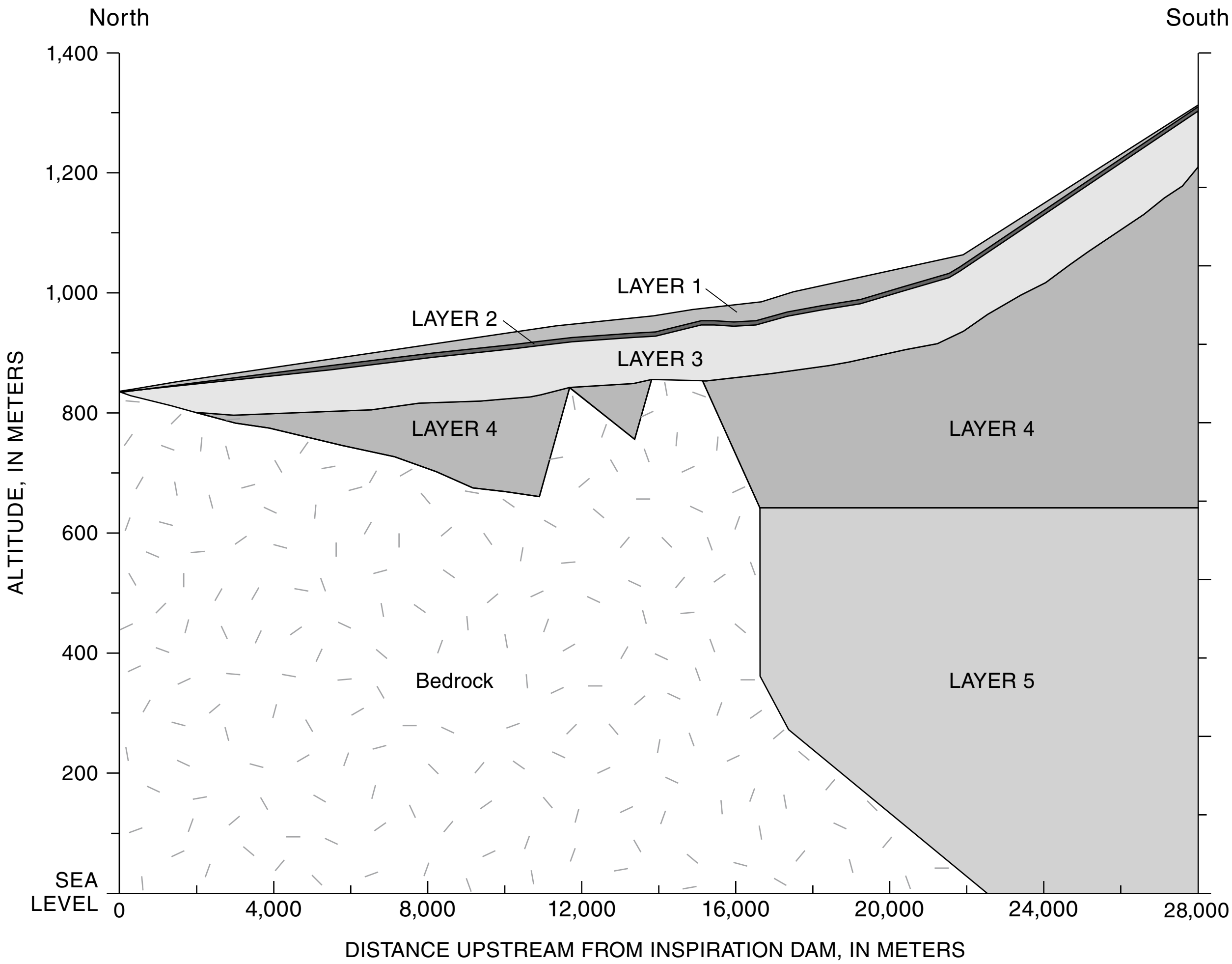

Figure 2. Generalized vertical discretization for ground-water flow model.

steady-state simulation will be used as the starting head for the transient simulation. The steady-state model will be calibrated using water levels measured before large-scale remedial pumping began in the late 1980's, before Webster Lake was drained in the late 1980's, and using discharge data for Pinal Creek at Inspiration Dam that have been collected since July 1980. Transient simulations will be calibrated using water levels and discharge data from Inspiration Dam and the location of the head of flow in Pinal Creek.

The model will be used to test the value of alternative forms of data in estimation of model parameters. In particular, the suitability of using available time-of-travel data in the model-calibration process will be tested. Results of chemical-tracer tests also will be incorporated into the calibration process. Another use of the model will be to apply the monitoring-network-design model developed by Wagner (1995) to evaluate the information and cost tradeoff between ground-water head and age data.

SUMMARY

Ground water and surface water in Pinal Creek Basin near Globe, Arizona, have been contaminated by acidic-mine wastes. The USGS is using the model package, MODFLOW-96, with a modified stream package to simulate the ground water in the aquifer in order to study the movement of contaminants in the aquifer system. Information provided by the model will be used to better understand the hydrologic processes in the aquifer. The aquifer has been vertically discretized into five layers and horizontally discretized into

cells that are 62.5 m by 125 m. Pinal Creek Basin presents a unique opportunity to analyze the value of using alternative types of data for calibrating ground-water flow models. The model will incorporate age data (and chemical-tracer data in general) and also will be used in conjunction with another model to evaluate the information and cost tradeoff between the use of ground-water head and age data.

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