Executive Summary of
Review of the Reports "C.V./C.F. Ranch Acquisition, Hydrology Report" (2004)
and
"Big Chino Ranch Hydrology Study" (2005)
(both prepared for the City of Prescott by Southwest Ground-water Consultants, Inc.)

by
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ABSTRACT

In December, 2004 the City of Prescott (COP) purchased the Big Chino Ranch in the Upper Big Chino Valley for the purpose of withdrawing and transporting 8,717 acre-feet per year (af/yr) of ground water from the valley for the cities use. Prescott had initially considered purchasing the C.V./C.F. Ranch immediately adjacent to the Big Chino Ranch for the same purpose, but for several reasons decided to purchase the Big Chino ranch instead. The physical availability of 8,717 af/yr of ground water from both ranches under the state's Assured Water Supply rules was evaluated by Southwest Ground-water Consultants (SGWC), a consulting firm under contract to COP.

In order to make their evaluation, SGWC constructed a numeric ground-water model of the Upper Big Chino Valley. Based on their model results, SGWC reported that the desired amount of ground water could be withdrawn from either ranch while still meeting the requirements of the Assured Water Supply rules. SGWC also concluded that COP could withdraw up to 12,704 af/yr from the Big Chino Ranch, the full amount legally available, and still meet the requirements of the Assured Water Supply rules. Two reports prepared by SGWC *"C.V./C.F. Ranch Acquisition, Hydrology Report"* (2004) and *"Big Chino Ranch Hydrology Study"* (2005) discuss construction of the numeric model and model predictions. Both reports also discuss the data available for model construction and the methodology used to calibrate and verify the model. The latter two steps are necessary for demonstrating that the model acceptably simulates the natural ground-water flow system in the upper Big Chino Valley and is therefore capable of predicting physical availability and hydrologic consequences of the COP's proposed ground-water withdrawal.

Eighty to eighty-six percent of the flow of the Verde River above the Paulden gage is derived from Big Chino Valley. The COP's proposed withdrawal will ultimately reduce natural discharge of ground water from the valley to the river by an amount that equals or nearly equals the proposed rate of withdrawal. A major conclusion reached by SGWC based on their numeric model is that more than 1,000 years is required for this to occur following the initiation of pumping.

Although SGWC state that their numeric ground water model is both calibrated and verified this is not the case. Knowledge of the essential features of the ground-water flow system of the Upper Big Chino Valley is not sufficient to permit construction, calibration, and verification of a model that can be shown to acceptably simulate the system. Essential features for which information is lacking include the geologic framework underlying the valley, the hydraulic properties of this framework, water levels, and the spatial-temporal movement of water into, through, and from the valley. Failure

to successfully calibrate and verify the model renders it incapable of acceptably predicting the consequences of COP's proposed ground-water withdrawal.

The model's southeastern boundary fails to replicate the essential features of the area from which ground water discharges from the Big Chino Valley, i.e., the Upper Verde River. Instead, it creates a flow system in the model that is different from the natural system that it is intended to simulate. As a result, the model is not predicting the consequences of pumping from the Upper Big Chino Valley; rather it is predicting the consequences of pumping from a ground-water system created by the model itself.

The model's irrelevance as a predictive tool is most evident when one compares the most basic assumption used by SGWC for calibration and verification of their model, i.e. that only 52 years was required for the ground-water system to reach steady state following the initiation of substantial pumpage in about 1940, with the model's prediction that more than 1,000 years are required for the system to reach a new steady state with Prescott's proposed pumpage. Steady state in this case refers to the condition in which the withdrawal of ground water has reduced the natural flow of ground water from the Big Chino Valley into the upper Verde River by an amount equal to pumpage. The model's prediction is obviously in direct contrast and wholly inconsistent with the basic assumption made by SGWC for calibration and verification of the model.

SGWC calculate a value for ground-water recharge to the Big Chino Valley equal to 28,000 af/yr in their 2004 report and a value equal to 25,725 af/yr in their 2005 report. They also calculate a range from 7,200 to 21,600 af/yr for evapotranspiration from the Big Chino Valley ground-water system. This range effectively removes the Big Chino Valley as a source of water to the Upper Verde River for the upper value of evapotranspiration and substantially reduces it for the lower value. In order to account for the flow actually observed in the Upper Verde River, SGWC also conclude that somewhere between 30 and 90 percent of the base flow at the Paulden streamgage is derived from the regional limestone aquifer east of the Big Chino Valley and north of the Upper Verde River. The methods used by SGWC to calculate recharge and evapotranspiration lack scientific merit, however, as does their logic for estimating the potential contribution of ground water to the Upper Verde River from the regional limestone aquifer east of the Big Chino Valley and north of the Upper Verde River.

INTRODUCTON

The City of Prescott (COP) has the right to withdraw up to 14,000 acre-feet/year (af/yr) of ground water from the Big Chino Valley ground-water system (the Big Chino Valley ground-water system as used in this report includes Big Chino Valley and Williamson Valley) and transport this water to Prescott for the city's use under A.R.S. 45-555. A supplementary advisory opinion from the Arizona Department of Water Resources (ADWR, 2003) stated that, owing to Prescott's sale of its CAP allocation and participation in the Yavapai-Prescott Indian Water Settlement, the COP is entitled to withdraw and transport only 8, 717 af/yr of ground water from the Big Chino sub-basin without retirement of historically irrigated acres within the sub-basin.

In pursuit of this water, the COP initially decided to purchase the C.V./C.F. Ranch in Big Chino Valley, but for several reasons, decided instead to purchase land from the JWK Ranch—later identified as Big Chino Ranch—immediately west of the C.V./C.F. Ranch. Purchase of the Big Chino Ranch by the COP, in partnership with the Town of Prescott Valley, was completed in December, 2004.

While still in the process of purchasing the C.V./C.F. Ranch, the COP contracted with Southwest Ground-water Consultants (SGWC) to determine the feasibility of developing 8,717 af/yr from it. In order to make this evaluation, SGWC constructed a numeric ground-water model of the Upper Big Chino Valley that was used to evaluate the physical availability of groundwater from the C.V./C.F Ranch under the Assured Water Supply rules. SGWC reported their results in a report (SGWC, 2004) submitted to the COP in June 2004. With the imminent purchase of Big Chino Ranch, the COP contracted with SGWC to evaluate the physical availability of groundwater from this ranch under the Assured Water Supply rules. Because Big Chino Ranch is also in the Upper Big Chino Valley, SGWC was able to utilize the same numeric model they had constructed for the C.V./C.F. Ranch evaluation. Results of the Big Chino Ranch evaluation were reported (SGWC, 2005) to the COP in a report dated August 2005.

In addition to the withdrawal of the 8,717 af/yr allowance, the purchase of Big Chino Ranch also allows the COP, under A.R.S. 45-555, to develop and import approximately 3,987 af/yr of additional ground water representing retired irrigation rights on historically irrigated land on the ranch. Thus, the potential legally available amount of ground water that can be developed and imported from the Big Chino Ranch by the COP is estimated to be 12,704 af/yr.

The use of the same numeric ground-water model for both studies causes the two reports to be similar in many regards, although the 2004 report provides some information on the modeling effort and results that the 2005 report does not. The latter report also has changes from the 2004 report with regard to water quality, natural recharge, and the assessment of the COP's planned withdrawals, in this case, from Big Chino Ranch. A complete review of SGWC'S work for the COP, therefore, required a review of both reports.

The principal objective of SGWC's 2004 report is to evaluate the physical availability of the COP's planned withdrawal of 8,717 af/yr from the C.V./C.F. Ranch under the State's Assured Water Supply rules. The purpose of the 2005 study is also to assess the physical availability of ground water from the Big Chino Ranch under the Assured Water Supply rules. In this case, the physical availability of both 12,704 af/yr and 17,987 af/yr were evaluated. The latter withdrawal rate is obtained by assuming that all 14,000 af/yr allocated to Prescott under A.R.S. 45-555(E) is withdrawn plus the 3,987 af/yr of additional ground water representing estimated retired irrigation rights from historically irrigated land on the Big Chino Ranch.

Major conclusions and predictions of the 2004 report are:

1) The maximum decline in water level at three new wells withdrawing 2,000 gallons per minute (9,678 af/yr) at the C.V./C.F. Ranch for 100 years would be 49 feet at a depth of 150 feet below land surface; this is much less than that allowed under the Assured Water Supply rules.

2) With the exception of arsenic, ground-water quality is generally good. Arsenic in two wells in the Upper Big Chino Sub-basin exceeds the MCL for 2006.

3) Past use of pesticides could create the potential for localized areas of contamination.

4) Prescott's proposed ground-water withdrawal would cause a decline in ground-water flow out of the model's southern boundary of 3,185 af/yr (37 % of pumpage) after 100 years. Therefore, any effect on the Upper Verde River would be less than this amount as perennial flow in the river begins many miles below the model's southern boundary.

5) A reduction in flow at the southern boundary equal to pumpage (8,717 af/yr) will require about 1,000 years. Thus, an even greater time period would be required before natural discharge from the Big Chino Valley into the Upper Verde River is reduced by an amount equal to Prescott's proposed pumpage.

Major conclusions and predictions in the 2005 report in addition to those above are:

1) The maximum decline in water level after withdrawing 17,987 af/yr for 100 years from the well field proposed at the Big Chino Ranch would be 77 feet at a depth of 121 feet below land surface; this is much less than that allowed under the Assured Water Supply rules.

2) Prescott's proposed ground-water withdrawal of 12,704 af/yr results in a decline in ground-water flow out of the model's southern boundary of 4,601 af/yr (36 % of pumpage) after 100 years.

The maximum decline in water level at the Big Chino Ranch proposed well field after withdrawing 12,704 af/yr for 100 years is not stated.

The 2005 report does not address the time required for the reduction in flow at the southeastern boundary of the model to equal COP's proposed withdrawal rates, but based on conclusion 5 above for the 2004 report, this time would be approximately 1,000 years. As also stated in conclusion 5, an even greater time period would be required before natural discharge from the Big Chino Valley into the Upper Verde River is reduced by an amount equal to Prescott's proposed pumpage from Big Chino Ranch.

The time required for COP's proposed withdrawal to reduce natural discharge into the Upper Verde River by an amount equal to the withdrawal is a major conclusion of SGWC's work and a major concern for many residents of Yavapai County, in which the Upper Verde River and the Verde Valley occur.

In addition to construction of a numeric ground-water model, the 2004 report also estimates: 1) a range from 7,200 to 21,600 af/yr for evapotranspiration from the Big Chino Valley ground-water system, 2) a range from 30 to 90 percent of the base flow at the Paulden streamgage for the potential contribution of ground water to the Upper Verde River from the regional limestone aquifer east of the Big Chino Valley and north of the Upper Verde River 3) ground-water recharge to the Big Chino Valley equal to 28,000 af/yr. The 2005 report accepts the conclusions of the 2004 report for the first two items, but calculates a new value for ground-water recharge to the big Chino Valley equal to 25,725 af/yr.

ANALYSIS

The use of a numeric ground-water model for predictive purposes requires that the model acceptably simulates the essential features of the natural system being modeled. Ground-water systems are bounded in space—from above, below, and on the sides. Water may enter or discharge from some or all of these boundaries, and this movement must be acceptably simulated with respect to water levels and the spatial-temporal distribution and rate of water movement into the system as natural and artificial recharge and from the system as ground-water discharge. Ground-water systems are also defined internally by their geologic framework and the spatial distribution of the hydraulic properties of this framework that control the movement and storage of water. These properties as well as the spatial-temporal distribution and rate of water movement through the framework are also essential features. Finally, in order to predict changes within the natural system over time due to pumping, water levels and the spatial-temporal distribution and rate of movement of water into, through, and from the system must be specified prior to initiation of the pumpage.

Assuming that knowledge of the essential features of a ground-water system is sufficient for model construction, proof that each feature has been acceptably simulated in the model is provided by a model process known as calibration and verification. Calibration is accomplished for steady-state conditions (a time when nothing is changing in the ground-water system, i.e., ground-water recharge equals ground-water discharge and water levels are constant through time). Verification is accomplished for a time period when the ground-water system has responded to a hydrologic stress, such as pumping. Once properly constructed, calibrated and verified, a model is assumed to be capable of predicting the hydrologic response of the natural ground-water system to a stress. For a pumping stress, the response is expressed in terms of water level declines and changes in flows (generally reduction in natural discharge) resulting from ground-water withdrawal by wells.

Although SGWC state that their model is both calibrated and verified, available data on the internal geologic framework, the hydraulic properties of this framework, and the spatial-temporal distribution of flows and water levels within the model and at the model's boundaries are not sufficient to constrain the construction, calibration, and verification of the model. In addition, the treatment of the southeastern boundary in the model, in and of itself, makes calibration and verification of the model impossible. The inability of SGWC to calibrate and verify their model means that the model is incapable of predicting the hydrologic consequences of Prescott's proposed ground-water withdrawal from the Upper Big Chino Valley.

The Geologic Framework of the Upper Big Chino Valley

The model has six layers that extend vertically from the land surface downward to the inferred top of the Tapeats Sandstone or Precambrian granitic rock, both of which are considered to be virtually impermeable. The uppermost layer (layer 1) simulates alluvium or basin-fill deposits above a unit of basalt flows (layer 2), that underlie the valley center in the modeled area. Layers 3 and 4 simulate basin-fill deposits underlying the basalt. Layer 5 represents the Martin Formation over most of the area, and layer 6 represents the Martin Formation in the most deeply down-faulted part of the area. The movement of water in the model and in the natural system is three-dimensional. In order for the model to be predictive, these layers must exist, their thickness and spatial distribution must be accurately portrayed, and the natural movement of water within each layer and between layers must be acceptably simulated. Interpretations of the subsurface geology therefore need to be geologically reasonable. Some of SGWC's interpretations do not meet that test.

Geologic control for the assignment of the layers and estimation of their hydraulic properties in the ground-water model in the Upper Big Chino Valley is weak at best. The reason is that the basin-fill deposits are mostly buried, and geologic details must be inferred from well logs. However, the wells were mostly drilled as water wells; most are no more than a few hundred feet deep, and what logs exist are mostly drillers' logs. The deepest well (744 feet) with a useful descriptive log that we were able to locate in the modeled area is CVM-1, drilled by Water Research Associates (WRA, 1990, Phase II, Volume III, p. 8-9 and Fig. II-2). Contours at the base of the basin-fill deposits (Ostenaa and others, 1993a, plate 8) indicate that the basin-fill deposits, resting on the Martin Formation, are approximately 1,900 feet thick at the location of CVM-1; at the southeastern boundary of the model, the thickness in the deepest part of the basin is at least 2,300 feet—roughly 3 times the depth of the deepest well with a useful log in the model area. Thus, explicit information about the lower part of the basin-fill deposits within the model area is virtually nonexistent. As a consequence, the distribution and character of the basin-fill deposits in the model are, to a substantial degree, conjectural.

Not only are the available geologic data insufficient to adequately constrain the model in general, but SGWC almost certainly failed to acceptably represent the up-valley extent of the clay or clay-rich deposits in their model. Thus, the model's predictions cannot be considered as unique, even if the model were calibrated and verified, since calibration and verification are completely tied to the geologic framework that the model simulates. Other interpretations of the framework, as well as a more accurate simulation of the distribution of the clay or clay rich deposits would result in different calibration and verification results, and, hence, different predictions of the effect of ground-water extraction

Model Simulation of Hydraulic Properties

In order for a model to predict the effects of pumping it must acceptably simulate the hydraulic properties that control the movement and storage of water within an aquifer. Because the model's representation of the internal geologic setting of the natural system is unconstrained by field data, knowledge of the spatial variation in the hydraulic properties of these deposits is similarly limited.

Despite the fact that SGWC's reports list 16 wells for which information on various hydraulic properties is available, in fact, none of the data for the basin-fill aquifer can hold up to scrutiny. Even if hydraulic-property values for the 16 wells are taken at face value, the report recognizes that "*the limited number and distribution of aquifer parameter data in the Big Chino Valley* (and the modeled area) *requires that estimates of aquifer parameters* (for model construction) *be based, in significant part, on lithologic data from local driller's logs and extrapolation of parameters with similar lithology and greater aquifer test data, particularly from the Little Chino Valley to the south*"

The weakness of this approach can be seen from several viewpoints. First, as discussed, there are no driller's logs available for much of the modeled area and those that are available penetrate at most only about 40 percent of the basin-fill deposits. These two facts combined mean that the lithologic nature of an extremely large part of the modeled area is simply unknown. Second, interpretation of hydraulic properties from lithologic data is highly subjective and introduces a large potential error into the model analysis. Third, we are not aware of any established relationship between the lithologic and hydraulic characteristics of the unconsolidated deposits in the Little Chino Valley or the basis on which this information can be transferred to Big Chino Valley, even if such a relationship does exist. Extrapolation of hydraulic properties from scarce or nonexistent lithologic information simply piles speculation upon speculation and has the potential to introduce substantial unknown error into the model.

In addition to the lack of data for the hydraulic properties of the basin-fill deposits of the modeled area, there is little knowledge about the thickness, extent, and hydraulic properties of the Martin Formation. As stated in the report, "*aquifer parameter data on the limestone aquifer* (the Martin Formation) *is non-existent in the Big Chino Valley*." This fact required SGWC to assume values for the hydraulic properties of the Martin Formation as well as its thickness and extent, thereby subjecting the model to another potentially large unknown error from these assumptions alone. Thus, the model constructed by SGWC is a geohydrologic representation of the Upper Big Chino Valley that is virtually unconstrained due to a lack of information for the hydraulic properties of area being modeled.

Spatial-Temporal Distribution of Water Levels

The spatial-temporal distribution of water levels is one of the two parameters used to evaluate a model's successful reproduction of the actual ground-water system being simulated. Information regarding water levels is extremely limited however, and this limitation further precludes calibration and verification of the model.

Water moves vertically between the six layers of the Upper Big Chino Valley model as well as horizontally through each layer, and the model must acceptably simulate this movement and water levels in these layers for it to be considered to be calibrated and verified. Although substantial ground-water withdrawal from the Big Chino Valley began in the 1940's, an extensive set of water-level measurements throughout the valley was not conducted until 1975 (Wallace and Laney, 1976, plate 1), some 35 years or so after this withdrawal began. These measurements were only obtained for the uppermost geologic unit simulated by the model. At the time of the 1975 measurement, continuous water-level measurements dating back to 1955 were available from only four wells and none of these were in the modeled area (Schwab, 1995). Information on pre-development water levels is completely lacking as a result. This lack makes it impossible for SGWC to calibrate the model to pre-development conditions based on field data for this time period.

There is no information for water levels below the uppermost model layer for any time period. This means that the vertical and horizontal movement of water simulated by the model is totally unconstrained by either the hydraulic properties of the geologic units simulated by the model or by water levels in these units.

Although insufficient water-level data compromises calibration and verification of a model, the absence of water-level data, such as the case for the Upper Big Chino Valley model, makes calibration and verification of the model impossible.

In summary, SGWC's inability to constrain the essential features of the natural system being simulated means that their model's representation of the Upper Big Chino Valley cannot be considered as unique in any manner. Given the available information, the model's representation of the Upper Big Chino Valley is simply one of an infinite number of representations. Calibration and verification of the model ~~is~~ are not possible under these circumstances. Other interpretations of the framework, hydraulic properties, and water levels, as well as a more geologically reasonable simulation of the distribution of the clay or clay-rich deposits would result in different calibration and verification results, and, hence, different predictions of the effect of ground-water extraction.

The Model's Southeastern Boundary

Even though the model simulates only the Upper Big Chino Valley, it must acceptably simulate the natural discharge boundary of the Big Chino Valley ground-water system, i.e., the Upper Verde River, in terms of location, flow, hydraulic properties, and water levels. In place of this boundary, the model simulates an artificial boundary (the model's southeastern boundary) located approximately 15 miles northwest of the Upper Verde River. The nature of this boundary is such that it defines or creates a flow system in the model, for both pre-development and stressed conditions, that is different from that of the natural system the model is intended to simulate.

For simulation of pre-development conditions, water levels were specified and arbitrarily held constant at the model's southeastern boundary. Because this was the only boundary from which water could discharge from the model, water levels within the model's interior were arbitrarily forced to rise above those at the boundary in order to allow discharge to occur. This occurred regardless of the hydraulic characteristics and recharge value simulated on the model. This would not occur under natural conditions.

Water levels at the location of this artificial boundary would normally change in response to pumping, but the treatment of this boundary in the model prevented any such change other than that arbitrarily induced by the modeler. During simulation of Prescott's proposed pumpage, water levels at the artificial southeastern boundary were arbitrarily lowered by about five to ten feet. As a result, water-level declines induced by simulated pumpage could cause no more than five to ten feet of decline at the boundary, regardless of what the natural response would have been. This treatment caused the boundary to artificially supply water to the model in response to simulated pumpage in an amount that ultimately equaled the rate of pumpage simulated in the interior of the model. Such a source of water does not exist in nature at the boundary.

The southeastern boundary, therefore, causes water levels and flows in the model to be different from those that would exist in the natural system for both pre-development and pumping conditions. Different boundary conditions define different ground-water systems, even if the geometry and hydraulic properties of the two systems are identical, and the failure of the model's southeastern boundary to acceptably simulate the discharge boundary of the natural system makes model calibration and verification impossible. Simulation of a ground-water system with an incorrect boundary condition means that the simulation exercise is solving the wrong problem and by definition will provide the wrong answer. Because of this failing alone, the model is incapable of predicting the response of the Upper Big Chino Valley ground-water system to Prescott's proposed pumpage.

The Inconsistency between the Most Basic Assumptions Made to Calibrate and Verify the Model and Model Prediction

The model's irrelevance as a predictive tool is most evident when one compares the most basic assumption used by SGWC for calibration and verification of their model, i.e. that only 52 years was required for the ground-water system to reach steady state following the initiation of substantial pumpage in about 1940, with the model's prediction that about 1,000 years are required for the system to reach a new steady state with Prescott's proposed pumpage. The model's prediction is obviously in direct contrast and wholly inconsistent with the basic assumption made by SGWC for calibration and verification of the model.

In addition to SGWC's contradictory assertions that the ground-water system had reached steady state in 52 years or less from substantial pumpage that began in about 1940 but that 1,000 years would required for steady state to be reached with Prescott's proposed pumpage, other evidence indicates that the system was not in steady state in 1992. Pumpage slowly reduces the natural rate of discharge from a ground-water system by an amount that ultimately equals the rate of pumpage, creating a new steady state. Therefore, if pumpage exists, steady state implies that the reduction in the rate of natural discharge caused by pumping equals the rate of pumping. The assumption that the ground-water system was in steady state in 1992 directly implies then, that the reduction in ground-water discharge to the Upper Verde River resulting from the initiation of substantial pumping beginning in about 1940 was fully manifested after only 52 years or less of pumpage.

A similar time period would be expected before steady state was reached with new pumpage of similar magnitude. Prescott's proposed withdrawals that were simulated on the model are greater than the average net withdrawal (3,163 af/yr; allowing for 50 percent irrigation return flow) for the Upper Big Chino Valley that was simulated on the model over the 52-year calibration period. Accordingly, the time to reach steady state for Prescott's modeled new pumpage would be expected to be somewhat greater than fifty years but not anywhere near an additional 950 years.

Either the assumption that the system was in steady state with ground-water pumpage in 1992 is wrong, or the effort to calibrate and verify the model based on the assumption was not successful. In either case, the discrepancy between the assumption that only 52 years or less were required for the ground-water system to reach steady-state conditions with pumpage between 1940 and 1992 and the model's prediction that 1,000 years are required for Prescott's proposed pumpage to reach steady state indicates that the model is not an acceptable instrument for predictive purposes.

Recharge

The Big Chino Valley ground-water system is part of the Big Chino Sub-basin and is naturally recharged by ground water moving into the valley from the larger part of the sub-basin that surrounds it and by the infiltration into the valley floor of intermittent streamflow originating in the uplands of the sub-basin as streams cross from the uplands onto the valley floor. Precipitation falling directly on the valley floor may or may not be a source of recharge and has been ignored by most investigators, including SGWC. Although overlooked by SGWC, underflow from the Little Chino Sub-basin also recharges the Big Chino Valley ground-water system near Paulden.

The 2004 SGWC report states a value for recharge to the Big Chino Valley ground-water system equal to 28,000 af/yr, whereas the 2005 report states a revised value equal to 25,725 af/yr. Both calculations are based on the assumption that the only source of recharge is from infiltration into the valley floor of intermittent streamflow originating in the uplands of the sub-basin as streams cross from the uplands onto the valley. Oddly, however, Big Chino Wash itself is not considered to be such a source. Other sources of recharge are not included in their values, including underflow from the Little Chino Sub-basin. Both calculations are also based on the assumption that average annual runoff from intermittent streams becomes recharge, an assumption that, among other things, overlooks the observed, but unquantified fact that some intermittent flow exits the valley to the Verde River.

Numerous problems exist with SGWC's methods for calculating their 2004 and 2005 values for recharge that extend beyond the sources they failed to consider. These problems transfer over into their calculation of recharge for the upper valley and therefore into calibration and verification of their model. Given their assumption for the source of recharge, SGWC needed to be able to estimate average annual flow of streams entering Big Chino Valley. The only streams for which flow data exist, however, are Walnut Creek and Williamson Valley Wash, and the period of time represented by these data is insufficient for determining long-term average annual flow at either gage. Nevertheless, SGWC used these data in their 2004 report as the basis for calculating average annual flow of these two streams as a percentage of annual precipitation. They then applied that percentage to estimate average annual flow of all of the ungaged intermittent streams entering the valley.   Their basic erroneous assumption that the data at Walnut Creek and Williamson Valley Wash were of sufficient duration to establish average annual discharge at these two locations introduces an unknown, but potentially significant error in their overall calculation of recharge. Another error of unknown magnitude stems from SGWC's assumption that the interplay between those factors that control runoff in a given watershed, such as Walnut Creek, is constant from one watershed to the next. However, this interplay, which includes the depth and permeability of soils and the distribution and intensity of precipitation, would be expected to vary among the watersheds draining into Big Chino Valley.

In their 2004 use of the flow data collected for Williamson Valley Wash, SGWC failed to recognize that the streamgage is located near the mouth of the valley and that flow at the gage is a combination of ground-water discharge above the gage and intermittent flow from streams draining the watershed also above the gage. Owing to the location of the streamgage and the ground-water inflow component of the discharge that it measures, the data from the gage do not represent intermittent flow at the point where Williamson Valley Wash enters the floor of Williamson Valley as assumed by SGWC. Further, there is substantial ground-water discharge from Williamson Valley Wash into Big Chino Valley proper that is not measured by the gage and that could be derived only from precipitation falling on the watershed behind it. SGWC failed to include this water in their 2004 calculation of recharge. Ground water in Williamson Valley either discharges directly into Big Chino Valley proper or discharges into Williamson Valley Wash above the streamgage. Some water is also discharged by evapotranspiration, but this is considered to be negligible (Navarro, 2002). All of this water must be included in any calculation of recharge to Williamson Valley, a requirement that was not met at all by SGWC in 2004 and only partially met in 2005.

A major unjustified assumption used by SGWC in calculating their 2004 and 2005 recharge values is that only the lower one-third of the Partridge Creek drainage area contributes to runoff in the creek and, therefore, to recharge to Big Chino Valley. This is an incredible assumption inasmuch as the otherwise universal belief in hydrology is that a stream's entire watershed contributes to its flow. The apparent need to make this assumption, however, is that had the entire Partridge Creek watershed been used, recharge from Partridge Creek alone, given the methodology used by SGWC to calculate recharge, would have equaled about 24,000 af/yr using their 2004 methodology and about 22,400 af/yr using their 2005 methodology. Such values for recharge from Partridge Creek are, of course, absurdly large. They should have indicated to SGWC that their methodology for estimating recharge was seriously flawed.

For the 2005 estimate of recharge, SGWC recognized that the Williamson Valley streamgage is located near the mouth of the valley. Accordingly, they disregarded the discharge measured there as a source of recharge. This water, they assumed, becomes recharge between the gaging station and Sullivan Lake, but they did not include it in their final 2005 recharge value in any case. Needing a value for average annual runoff to Williamson Valley from the surrounding uplands, SGWC used a value of 9,800 af/yr, which they attributed to Navarro (2002) without further comment. We note, however, that Navarro (2002, Table 12) estimated recharge of 73,000 af/yr to Williamson Valley. SGWC averaged the value of 9,800 af/yr with the one-year value for runoff from Walnut Creek. As in their 2004 report, they used this average, expressed as a percentage of precipitation to estimate intermittent runoff from the remaining watersheds draining into Big Chino Valley.

The 2005 method for calculating recharge to the Big Chino Valley ground-water system carries with it all of the errors inherent in the 2004 calculation of recharge plus some of its own. A basic conceptual error in SGWC's 2005 calculation is the assumption that Navarro's (2002) recharge value for Williamson Valley is derived solely from intermittent runoff into the valley. However, Navarro's value represents infiltration of precipitation on the watershed and not intermittent runoff. Of even greater concern is that the value for Williamson Valley runoff chosen by SGWC and attributed to Navarro is different by nearly an order of magnitude from Navarro's estimate of recharge.

Evapotranspiration

Without scientifically supportive data, and in direct contrast to previous work, SGWC concluded that evapotranspiration from the Big Chino Valley ground-water system is between 7,200 and 21,600 af/yr. They based this conclusion on an assumption that evapotranspiration occurs in those areas where depth to ground water is 20 feet or less and that the rate of evapotranspiration is somewhere between 25 to 75 percent of the potential rate at the surface. However, they provide no technical support for these assertions. In contrast, evaporation from a ground-water body is generally considered to be negligible for depth to the water-table greater than about three feet. Of course, evapotranspiration can occur from greater depths, assuming that plants exist that actually tap the water table as a source of water. Riparian vegetation consisting of plants that tap the water table exists locally within Williamson Valley Wash, but Navarro (2002) concluded that their water demand is negligible.

Although the SGWC state an absolute range for evapotranspiration from the Big Chino Valley ground-water system, they qualify their conclusion with the statement that, "*detailed studies of the type and density of vegetation in the areas of shallow ground water have not been conducted and would be required to accurately access the amount of evapotranspiration in the Big Chino Valley*." Given the work by Navarro in Williamson Valley, the general lack of riparian vegetation elsewhere, and the modeling approach used by the USBR, this statement is not correct. Given this and the fact that the method used in the SGWC report to estimate evapotranspiration lacks scientific credibility, SGWC's estimate of the amount of water lost by evapotranspiration should be viewed as substantially overstated.

Regardless of their qualification and the conclusions reached by other studies, SGWC state that the loss of water from evapotranspiration reduces the contribution of ground water to the Upper Verde River by an equal amount, essentially removing ground water from the Big Chino Valley ground-water system as a source of water to the Upper Verde River if the higher values for evapotranspiration are accepted, and substantially reducing the contribution if the lower values are accepted.

Ground water lost to evapotranspiration must originate from recharge to the ground-water system. Given their methodology to calculate recharge, SGWC should have included their assumed values for evapotranspiration in their recharge calculations before subtracting them from ground-water discharge to the Upper Verde River. This SGWC did not do.

Incorporating SGWC's assumed range for evapotranspiration into their methodology for calculating recharge, while still ignoring other errors, results in a range in values for recharge to Big Chino Valley from 45,100 to 80,290 af/yr for their 2004 methodology and a range from 38,320 af/yr to 63,510 af/yr for their 2005 methodology. Subtracting evapotranspiration losses from the 2004 range for recharge results in a range of values for natural pre-development discharge from Big Chino Valley to the Upper Verde River from 37,900 to 58,690 af/yr. Subtracting SGWC's inferred evapotranspiration losses from their 2005 range for recharge results in a range of values for natural pre-development discharge from Big Chino Valley to the Upper Verde River from 31,120 to 41,910 af/yr. Other corrections to SGWC's calculation of recharge, such as the addition of omitted sources of recharge including the entire Partridge Creek drainage area as well as recharge from Big Chino Wash and the Little Chino Sub-basin would increase even further pre-development discharge from Big Chino Valley to the Upper Verde River. Thus, rather than reducing the contribution of ground-water to the Upper Verde River, the relatively large loss of water from evapotranspiration assumed by SGWC for the Big Chino Valley actually substantially increases this contribution to rates far above the 18,000 ac-ft/yr reported by Wirt and Hjalmarson (2002) based on streamflow measurements made in the Upper Verde River from 1963 to 1997.

Imposition of Recharge on the Ground-Water Model

Although SGWC's basic assumption is that recharge occurs by seepage from intermittent streams as they move across the Big Chino Valley floor, their simulation of this recharge in their model fails to adequately represent this source. Flow from intermittent streams has been observed to move across the valley floor to Big Chino Wash causing it to flow also. For smaller storms, this water seeps through the Big Chino Wash streambed to become ground-water recharge. In major storms, a substantial volume of flow exits to the Upper Verde River and thus, does not constitute a source of recharge. Neither event is represented by SGWC's modeling approach or in their calculation of recharge.

In accord with SGWC's basic assumption, natural recharge should have been imposed only along intermittent stream courses within the valley floor, including Big Chino Wash. Instead, recharge was continuously simulated along and just inside, the entire length of three of the four model boundaries and was not extended from the model boundaries to Big Chino Wash. Simulated recharge from Partridge Creek and Pine Creek was terminated prior to their confluences with Big Chino Wash, and no recharge is simulated in Big Chino Wash.

The manner in which recharge is simulated assumes that unnamed intermittent streams enter Upper Big Chino Valley continuously at an average spacing (based on nodal distance in the model) of 2,000 feet, and that their contribution to recharge is identical over long distances of the Upper Big Chino Valley. Neither assumption is completely reasonable. Total simulated recharge from the unnamed intermittent streams equals 5,292 ac-ft/yr, a relatively large amount of water from such streams assuming they exist in the manner in which they were simulated.

SGWC's calculated value for recharge to the model from Partridge Creek equals 7,190 af/yr or about 58 percent of the total recharge to the model. Simulated recharge from the area of the stream however is only about 10.5 percent of the total simulated recharge.

The greatest amount of recharge simulated on the model extends from Partridge Creek for a distance of about 3 miles immediately north of the creek. Collectively, this recharge equals 58 percent of the recharge in the model and presumably it represents recharge from the creek. The reason for moving the major part of discharge from Partridge Creek north of the stream, however, is not discussed by SGWC and is inconsistent with their basic assumption of the manner in which recharge occurs.

Overall, it is clear that serious problems exist in SGWC's methods for estimating recharge as well as in their assumed values for loss of ground water by evapotranspiration. These problems extend to the entire Big Chino Sub-basin and compromise the integrity of SGWC's ground-water model. SGWC also failed to distribute recharge on their model in a manner consistent with their basic assumption for the manner in which recharge occurs. This further comprises the integrity of the model.

Ground-Water Inflow to the Upper Verde River
From the Regional Limestone Aquifer North of the Verde River

SGWC's assumption that evapotranspiration eliminates or substantially reduces natural discharge from the Big Chino Valley to the Upper Verde River requires some other source of discharge to maintain the base flow. Accordingly, SGWC suggest that water from the regional limestone aquifer east of Big Chino Valley and north of the Verde River potentially provides between 30 and 90 percent of the annual base flow at the Paulden gaging station. This conclusion is based on a range in estimated values for recharge to the regional aquifer made in the reports, and on the fact that water levels in wells in the regional aquifer are higher than the level of the Verde River.

The regional limestone aquifer immediately east of Big Chino Valley and north of the Verde River underlies the Big Black Mesa and Hell Canyon drainage areas. The Hell Canyon drainage, including Limestone Canyon, which drains most of the southeastern part of Big Black Mesa, enters the Verde River below the Paulden streamgage—i.e., below the Upper Verde River. As a result, the Hell Canyon drainage area has been considered by ADWR (Owen-Joyce and Bell, 1983) to be part of the Middle Verde River ground-water Sub-basin and would not be expected to contribute ground-water to the upper reach of the river. The areas that drain the regional limestone aquifer north of Hell Canyon enter the Verde River below the canyon and also would not be expected to contribute ground-water to the Upper Verde River. Thus, the only contribution that ground-water from the regional limestone aquifer north of the Upper Verde River would that part of Big Black Mesa that drains to it. Under this assumption, Ford (2002) estimated the ground-water contribution from the Big Black Mesa to the Upper Verde River to be far less than 1,264 af/yr.

The fact that water levels in the regional limestone aquifer north of the Upper Verde River are higher than the river does not indicate (as assumed by SGWC) that a substantial amount, or any amount, of water flows from the regional aquifer to the river above the Paulden gage. The general movement of ground water is perpendicular to water-level contours rather than directly between any two points, such as a well and the river, with differing water levels. A contour map of water levels in the regional limestone aquifer north of the Upper Verde River and east of the drainage area for the Paulden gage indicates a general southeastward movement of water away from the Upper Verde

River and toward the Middle Verde River below the Paulden gage. This conclusion matches that previously reached by the Arizona Department of Water Resources.

Further, recent geochemical modeling by Wirt (2005) indicates that the combined Big Chino basin-fill aquifer and the limestone that underlies it provide between 80 and 86 percent of the base flow measured an the Paulden gage; the regional aquifer north of the Verde River contributes between 0 and 6 percent; and the balance, 14 percent, originates in the Little Chino basin-fill aquifer.

SUMMARY

Overall, owing to erroneous assumptions, spurious reasoning, insufficient constraining data, and the inappropriate treatment of the southeastern boundary of the model, SGWC's model is incapable of predicting the effects of the City of Prescott's proposed extraction of ground water from the upper part of Big Chino Valley. The model's irrelevance as a predictive tool is most evident when one compares the most basic assumption used by SGWC for calibration and verification of their model—i.e. that only 52 years was required for the ground-water system to reach steady state following the initiation of substantial pumpage in about 1940—with the model's prediction that about 1,000 years are required for the system to reach a new steady state with Prescott's proposed pumpage. The model's prediction is obviously in direct contrast and wholly inconsistent with the basic assumption made by SGWC for calibration and verification of the model.

SGWC's methods for calculating their 2004 and 2005 recharge values for Big Chino Valley are subject to numerous conceptual errors and their values for recharge lack scientific credibility as a result. In addition, their method for distributing recharge on the model is highly questionable. SGWC's method for estimating evapotranspiration also lacks scientific credibility, and the reports' estimate of evapotranspiration should be viewed as substantially overstated. Their unsubstantiated suggestions that evapotranspiration removes a significant part, if not nearly all, of the contribution of the Big Chino Valley ground-water system to the base flow of the Upper Verde River and that the regional limestone aquifer east of the valley and north of the river contributes between 30 to 90 percent of the base flow at the Paulden streamgage also lack scientific merit.

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