IN THE SUPERIOR COURT OF THE STATE OF ARIZONA
IN AND FOR THE COUNTY OF MARICOPA

IN RE THE GENERAL ADJUDICATION OF ALL RIGHTS TO USE WATER IN THE GILA RIVER SYSTEM AND SOURCE	W-1 (Salt) W-2 (Verde) W-3 (Upper Gila) W-4 (San Pedro) (Consolidated) Contested Case No. W1-103 REPORT OF THE SPECIAL MASTER ON METHODOLOGY FOR DETERMINATION OF CONE OF DEPRESSION

CONTESTED CASE NAME: *In re San Pedro Subflow Technical Report*

HSR INVOLVED: San Pedro River Watershed Hydrographic Survey Report

DESCRIPTIVE SUMMARY: Report of the Special Master regarding Cone of Depression Test filed pursuant to Rule 53(f), Ariz. R. Civ. Pro. Objections to the Report must be filed with the Clerk of the Superior Court of Maricopa County on or before January 14, 2019. Responses to objections are due on or before February 22, 2019. A hearing on any objections will be held at a time and place to be set by the Court.

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At issue in this proceeding is the appropriate methodology to be used in the San Pedro River watershed to determine whether the cone of depression created by a well pumping in a steady-state condition will cause a drawdown at the boundary of the subflow zone equal to or greater than 0.10 foot. Drawdown is the reduction in the hydraulic head or water table in an aquifer due to pumping.

Under state law, the court has jurisdiction over wells that pump subflow. The purpose of the Cone of Depression Test developed by the Arizona Department of Water Resources (ADWR) addressed in this case is to identify the wells in the San Pedro River watershed subject to the court's jurisdiction to determine and enforce rights to appropriable water under state law by reason of pumping subflow. The court also has jurisdiction over all wells in the San Pedro watershed that withdraw water subject to claims based on federal law. *See* A.R.S. §45-251(7). The discussion, findings of fact, and conclusion of law contained in this Report are limited to an assessment of a test to determine the court's jurisdiction over wells for purposes of state law water rights.

I. Background

This consolidated general adjudication provides the forum to determine the extent and priority of the rights of all persons to use water in the Gila River system and source, which may include the water rights of well owners. *In re Gen. Adjudication of All Rights to Use Water in Gila River Sys. & Source*, 175 Ariz. 382, 391, 857 P.2d 1236, 1245 (1993) ("*Gila II*"). Due to Arizona's differentiated water rights for appropriable water and percolating groundwater, a determination must be made whether a well withdraws appropriable water or pumps percolating groundwater. Consequently, wells located within the subflow zone as well as those wells located outside the lateral boundaries of the subflow zone with cones of depression that intercept the subflow zone and affect "the volume of surface and subflow in such an appreciable amount that it is capable of measurement" must be included within the adjudication. *In re the General Adjudication of All Rights to Use Water in the Gila River System and Source*, 198 Ariz. 330, ¶48, 9 P.3d 1069, 1083 (2000), *cert. denied sub nom. Phelps Dodge Corp. v. U.S.*, 533

U.S. 941 (2001) ("*Gila IV*"). As the boundaries of the subflow zone in the San Pedro River watershed have been determined, the wells located in the subflow zone have now been identified. This proceeding concerns on the appropriate test to identify wells located outside the subflow zone but impact the subflow zone due to their cones of depression.

In 2002, ADWR submitted the *Subflow Technical Report, San Pedro River Watershed* (2002) detailing a proposed cone of depression test that would simulate a well's cone of depression to ascertain whether the cone of depression would intersect the boundary of the subflow zone and cause a drawdown at that point greater than or equal to 0.10 foot.[1] In 2003, Special Master Schade held an evidentiary hearing on the objections filed to ADWR's proposed cone of depression test. The Special Master subsequently approved the 0.10 foot of drawdown as the "appreciable amount capable of measurement" as well as the use of groundwater modeling to quantify the drawdown. *Report of the Special Master on the Arizona Department of Water Resources' Subflow Technical Report*, San Pedro River Watershed (July 16, 2004).

In 2005, Judge Ballinger issued an order that approved a modified Subflow Technical Report, adopted the 0.10 foot quantity as the amount capable of measurement and confirmed the use of groundwater modeling for cone of depression testing. *Minute Entry*, filed September 28, 2005. He also defined the court's jurisdictional limits to "fairly protect the rights of both surface and groundwater users" by adopting the "temporal parameters" applicable to cones of depression for purposes of adjudicating water rights under state law. *Id.* at 7, 32. The court has the power to define and exercise its jurisdiction over the wells in the San Pedro basin to accomplish the purpose of this adjudication. *See In re Marriage of Flores & Martinez*, 231 Ariz. 18, 20–21, 289 P.3d 946, 948–49 (Ct. App. 2012).

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[1] The proposed test also included a second condition requiring the water level in the well to be lower than the water level in the subflow zone during pumping. The second condition was not adopted. *Minute Entry,* 32, filed September 28, 2005.

The two temporal parameters that Judge Ballinger considered for use in the groundwater model were steady-state and transient state. A cone of depression reaches a steady-state condition when pumping causes no change in storage in the aquifer because the cone of depression has expanded to cause an increase in the flow of water into the aquifer and/or a decrease in the flow of water out of the aquifer equal to the well's pumping rate. The determination of the size and shape of a cone of depression formed by a well pumping at a steady-state condition is not a function of time. A cone of depression simulated by transient-state modeling, in contrast, involves a defined time period.

Judge Ballinger focused on "the fact that a well's cone of depression is dynamic . . . . a well's cone of depression generally stabilizes gradually, expanding or decreasing". *Minute Entry* at 32. To avoid excluding those wells that could impact the subflow zone in the future from the court's jurisdiction, the court found that "future consequences of existing well characteristics" must be considered when setting the adjudication court's jurisdiction. *Id.* at 36. He held that "a well with a cone of depression reaching the subflow zone will be subject to adjudication if the extent of the well's current or prospective depletive effect on the stream is measurable by reasonably accurate means." *Id.* The court concluded that a groundwater model that simulates a well's cone of depression at steady-state adequately addresses "the need to consider the future consequences of existing well characteristics." *Id.* In response to this decision, ADWR developed the Cone of Depression Test to identify those wells located outside the subflow zone that have or will develop cones of depression that cause or will cause a drawdown at the subflow zone boundary equal to or greater than 0.10 foot. *Id.* at 32.

ADWR Demonstration Project

On January 27, 2017, the Arizona Department of Water Resources ("ADWR") submitted the Demonstration Project Report: *De Minimis* Assessment & Cone of Depression Methodology ("Demonstration Report") that evaluated two groundwater models, Aquifer^{Win32}, a commercial software program, and MODFLOW, a software program developed by the United States Geological Survey (USGS), for use as the Cone of Depression Test. It presented the proposed models in a demonstration format that generated results for a sample population of wells representing a spectrum of pumping rates and locations within the San Pedro River watershed.

Mr. Jeffrey Trembly, the Adjudications Program Director for ADWR, described the population of wells in the San Pedro watershed. He classified more than half of the wells as small volume wells, 2,000 to 3,000 as medium volume wells and the remainder as large volume wells. From its registry of 10,000 - 11,000 wells in the San Pedro River basin, ADWR selected 41 wells located in townships 23 and 24 of the Sierra Vista subwatershed, exclusive of Fort Huachuca to be included in the Demonstration Project.

The specific wells used in the Demonstration Project ranged in capacity from wells pumping 0.5 gallons per minute (gpm) to 399.9 gpm. The median rate was 12.2 gpm because 24 of the selected wells reportedly pumped less than 35 gpm. The average pumping rate of the group increased to 67.3 gpm due to the inclusion of eight wells pumping over 150 gpm. The pumping rate for an irrigation well was set as the maximum observed amount attributed to that well in the 1991 San Pedro Hydrographic Survey Report (HSR). The pumping rate of a municipal well was based on the highest pumping rate reported in the last five years for the individual well or for the water company as a whole.

The physical locations of the wells chosen by ADWR for the Demonstration Project across the watershed covered a large area. Sites were selected near the boundaries of the subflow zone and along the mountain front west of the river. The sample set also included a group of wells to the southeast of the San Pedro River. The locations of the wells with respect to the lateral boundaries of the subflow zone varied from 19 feet to more than 10 miles. Maps prepared for the 1991 San Pedro HSR provided the location of each well. Based on the mapped location, ADWR determined the GIS coordinates for each well that it used to measure the relevant distances needed for the modelling.

The Demonstration Project proved to be a particularly useful method to develop a Cone of Depression Test in this adjudication. It enabled the parties to understand the proposed groundwater models, the underlying limitations of the models, and the available data for wells with different spatial and pumping characteristics. The use of a clearly identified group of wells also allowed the parties and their experts to analyze the competing models using the same data. In addition, the Demonstration Project allowed for valid comparisons of results submitted by experts who proposed revisions to existing methodologies or developed new methodologies. Finally, it enabled ADWR to engage in the iterative process commonly used in scientific research to test information provided by the parties and produce results using the groundwater models under review.

II. Groundwater Models

The primary groundwater models considered in this proceeding were: Aquifer^{Win32}, MODFLOW, and the Jacob Non-equilibrium Equation with an Image Well developed by Mr. Jon Ford, a hydrologist and geologist called by Salt River Project. The models forecast the extent of the drawdown at the subflow zone boundary caused by a well's theoretical cone of depression at a steady-state condition. They forecast the future hydrologic condition based on assumptions, quantitative data about a physical setting, and mathematical relationships that relate drawdown to pumping rates and soil conditions including the following:

1. Drawdown at any point is directly proportional to the pumping rate and inversely proportional to transmissivity, which is the rate of the flow of water through a defined width of the aquifer.
2. Transmissivity equals the product of the hydraulic conductivity of the soil and the thickness of the aquifer.

The models also take into account the distance between the well and the subflow boundary because distance affects the development of a cone of depression.

To generate their forecasts, the models simplify reality because a set of mathematical equations cannot fully capture the complexity of the natural world. Physical complexity exists because aquifers and groundwater flow are three-dimensional. Different types of soils, rock and geological features can co-exist within the same aquifer. Aquifers can also have multiple sources and sinks of water, recharge and discharge, respectively. Thus, a groundwater model's capacity to incorporate the level of complexity present in the watershed affects the accuracy of the model's results.

Initially, ADWR considered using the Theim equation,[2] an analytical method, to quantify drawdown for a well at steady-state. *Arizona Department of Water Resources Initial Progress Report Concerning Implementation of Cone of Depression Tests*, filed April 23, 2015. The Theim equation calculated drawdown at a given location based on the pumping rate of the well (Q), the transmissivity of the aquifer surrounding the well in the aquifer (T), and two different

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[2] The basic Theim equation is:

$$Drawdown = \frac{Q}{2\pi T}\, ln\frac{R_2}{R_1}$$

The variable R_2 is the distance between the well and the location where the well has no impact. The variable R_1 represents the distance between the well and the point where drawdown is to be measured.

distances: (1) the distance between the well and the selected site where drawdown is to be measured; and (2) the distance between the well and a location where the well has no impact. After fully evaluating the Theim equation and reviewing the parties' submitted comments, ADWR rejected the Theim equation as an appropriate groundwater model.

In place of the Theim equation, ADWR selected Aquifer^{Win32}, a more sophisticated groundwater model known as an analytical element method[3] that uses the Theim equation as one of its elements. The data required for this model includes the well's location relative to the subflow zone and the aquifer parameters, which includes transmissivity discussed in greater detail below. In addition to data, Aquifer^{Win32} requires the modeler to add appropriate image wells. Image wells are actually mathematical equations that represent imaginary flows of recharge to or discharge from an aquifer that pump simultaneously with and at the same rate as the actual wells to reflect the hydrological boundaries of the location studied.

Dr. Mark Cross, a hydrogeologist retained by Arizona Public Service and BHP Copper, Inc., evaluated the operation of Aquifer^{Win32}. He opined that a large number of image wells must be added to the model created for each well to generate accurate boundary conditions due to the very low drawdown criterion of 0.10 foot. The addition of multiple image wells increases the complexity of the model and the amount of time needed to analyze each well. Dr. Cross concluded that once "24 or so" image wells were added to the model, the boundary conditions no longer presented a major issue.

Aquifer^{Win32} also depends upon the modeler properly determining a reference head for each well at a location where drawdown will always be zero. Mr. Ford and Dr. Cross agreed that the Aquifer^{Win32} model's reliance on the use of a reference head set by the modeler created

[3] Analytical solutions can be applied to more complex problems using an analytical element method.

uncertainty. It also inserted subjectivity into the process because no physical basis exists for selection of the correct location of the reference head.

As shown in *Figure 1* below, the amount of drawdown at steady-state as determined by Aquifer^{Win32} is sensitive to: (1) the number of image wells; (2) whether the number of image wells added was even or odd; and (3) the distance between the well and the reference head. Dr. Cross characterized the range of results as a "large error relative to the 0.10 foot criterion."

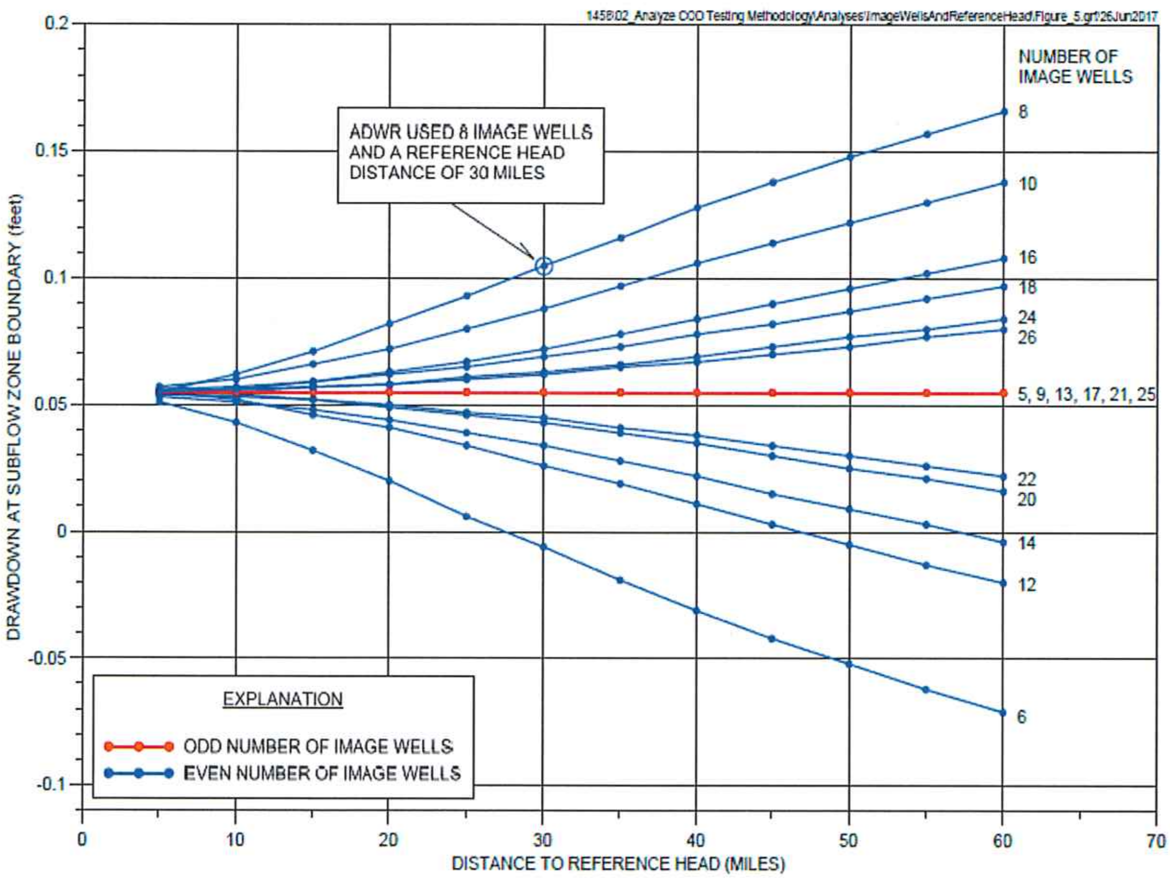

Figure 1. The drawdown results shown on the y-axis for a single well depend on the number of image wells and the distance to the reference head shown on the x-axis.
Source. Figure 5 from Analysis of Cone of Depression Test Methodology Proposed by Arizona Department of Water Resources, Exh. SRP 30.

Depending upon the number of image wells and the location of the reference head, Aquifer^{Win32} could forecast drawdown results for the same well as less than 0.10 or greater than 0.10 foot.

Finding of Fact No. 1. Aquifer^{Win32} requires a reference head to be set at a location which requires subjective judgment and lacks objective physical standards. This feature contributes additional uncertainty into the groundwater model and can introduce significant error given the 0.10 foot criterion.

The Jacob Non-equilibrium Equation with an Image Well[4] (Jacob Equation) used an analytical approach to determine drawdown at the subflow boundary. According to Mr. Ford's testimony, the Jacob Equation is equivalent to the Theim equation with one image well. Ms. Jean Moran, a hydrogeologist testifying for the United States, confirmed that the Jacob Equation was mathematically sound and recommended that it be used in conjunction with Aquifer^{Win32} to determine drawdown. The issue was raised that the model had not been located in a scientific journal and subject to peer review. Publication, however, does not always correlate with reliability and innovative theories may not be published despite solid methodology. *Daubert v. Merrell Dow Pharmaceuticals*, 509 U.S. 579 (1993).

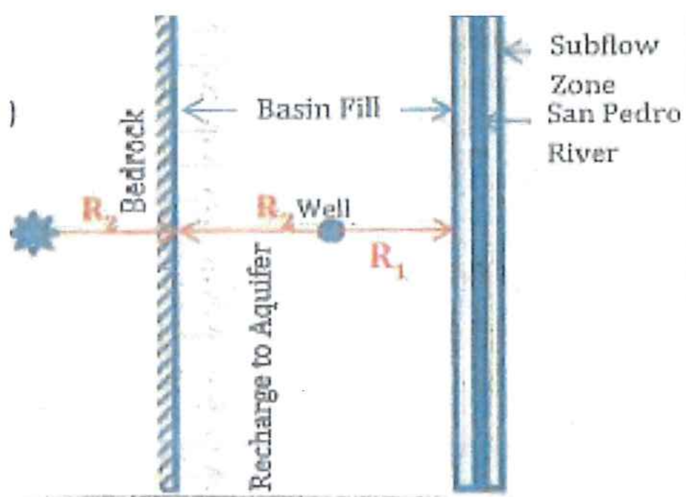

Figure 2. The conceptual model shows the mountain front as the source of recharge. Mathematically, the recharge is created by an image well marked by a large asterisk.
Source. Jon R. Ford Expert Report at 20 Exh. FMC 14.

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[4] $Drawdown = \frac{264Q}{T} \log \frac{(2R_2+R_1)^2}{R_1^2}$.

Mr. Ford's conceptual model uses mountain front recharge as the source of recharge to the watershed as shown in *Figure 2.* The mountain front labeled as "Bedrock" provides the source of recharge and the relevant distances measured are the distance from the tested well to the mountain front (R_2) and the distance from the well to the subflow boundary (R_1). The Image Well in this model refers to a single well on the opposite side of the recharge boundary from the well being tested that is recharging the aquifer at the same rate as the tested well is discharging it. The determination of drawdown using the Jacob Equation also depends upon the pumping rate of the well and the transmissivity of the aquifer between the well and the source of recharge and the drawdown measurement site.

Finding of Fact No. 2. Aquifer^{Win32} and Jacob Non-equilibrium Equation with an Image Well calculate drawdown based on a single value for transmissivity to account for the aquifer conditions proximate to the well and for the area between the well and the subflow zone boundary.

In addition to the analytical model, ADWR also considered MODFLOW, a computer program that numerically approximates the solution to the groundwater flow equation[5] that uses a three dimensional approach to calculate flow through an aquifer. MODFLOW operates using a grid of distinct cells each of which is coded with available data that defines the aquifer characteristics at relative locations.

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[5] The groundwater flow equation mathematically describes the flow of groundwater through aquifers. at steady-state, as follows:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=0$$

Arlen Harbaugh, Edward R. Banta, Mary C. Hill and Michael G. McDonald, *MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model.*

Three dimensional flow is represented by the variables, x, y, and z (to differing degrees groundwater flows through the ground vertically, horizontally and laterally). The different soils through which the water flows create different hydraulic conductivities, which are represented by K. Each K has a subscript tied to the direction of flow. The hydraulic head, the combined measure of the elevation and water pressure, is represented by the variable h. The amount of recharge to and discharge from the aquifer is represented by W. *Id.*

Finding of Fact No. 3. Due to its structure, MODFLOW can incorporate different values for transmissivity at different locations within the aquifer, complex boundary conditions, and multiple sources of recharge in its simulation of a well's cone of depression at steady state conditions.

Mr. Edwin Corkhill, the chief hydrologist for ADWR, opined that for reasons of consistency the selected model should cover the entire watershed, i.e., different groundwater models should not be applied to different section of the San Pedro River watershed. He also testified that no constraints limit the use of MODFLOW other than the fact that there is not a single MODFLOW model currently available that models the entire watershed. In 2007, the USGS completed a MODFLOW model for the Upper San Pedro which covers approximately 1,400 to 1,800 square miles. Mr. Corkhill stated that a modified version of the USGS model could be used for the cone of depression testing. Mr. Ford described the necessary modification of the existing USGS model, if used, should be based on collection and input of additional data or by simplifying the model. Dr. Amy Hudson, a hydrogeologist and geochemist, who appeared for Freeport Minerals Corporation, testified the USGS has also completed the hydrogeologic study for the Middle San Pedro basin which provides data for the development of a MODFLOW model for that location.

III. Specific Elements of the Models

a. Source of Recharge

No dispute exists that runoff from the mountains surrounding the San Pedro watershed provides the primary source of recharge to the San Pedro aquifer. Estimates of the contribution of mountain front recharge to the aquifer ranged from 50% to 80%. The remainder of the recharge comes from the San Pedro River, artificial recharge sources and ephemeral streams.

Ms. Moran demonstrated the importance of correctly locating recharge at the mountain front rather than at the river by focusing on Well 11 from the Demonstration Project. Well 11 pumped at the rate of 7.7 gpm and was located 1,228 feet from the subflow zone boundary. When the Aquifer^{Win32} program used the river as the source of recharge, it calculated that Well 11 caused a 0.089 foot drawdown at the subflow boundary. In contrast, when the Aquifer^{Win32} program evaluated Well 11 using mountain front recharge, the drawdown at the subflow boundary increased to 0.1092 feet. Ms. Moran explained that a drawdown of less than 0.10 foot occurred in the first calculation because the river, as the source of recharge in the model, provided water to the area of the cone of depression sufficient to raise the hydraulic head at the subflow zone boundary and reduce the drawdown level. Mr. Ford agreed with Ms. Moran's explanation of the importance of correctly identifying the source of recharge in designing the conceptual model. Dr. Hudson and Mr. Ford also demonstrated the impact of the choice of source of recharge on wells located near the mountain front using the data from the Demonstration Project. When the Aquifer^{Win32} model was configured to use the river as the source of recharge, it calculated the drawdown at the subflow boundary caused by several wells located near the mountain front as greater than 0.10 foot, but when reconfigured to use mountain front recharge as the source of recharge, the resulting drawdown dropped below the 0.10 foot limit.

Finding of Fact No. 4. The conceptual groundwater model for the Cone of Depression Test must designate mountain front recharge as the primary source of recharge to the San Pedro River watershed.

b. Transmissivity

Ms. Moran prepared maps based on ADWR's drawdown calculation for each well in the Demonstration Project using the MODFLOW and Aquifer^{Win32} programs adjusted for mountain front recharge. These maps are replicated as *Figure 3.* Based on her review of the data and the results, she concluded that wells close to the river will cause drawdown greater than 0.10 foot at the subflow boundary and that the extent of the drawdown caused by the remaining wells farther from the river will depend upon pumping rates and transmissivity.

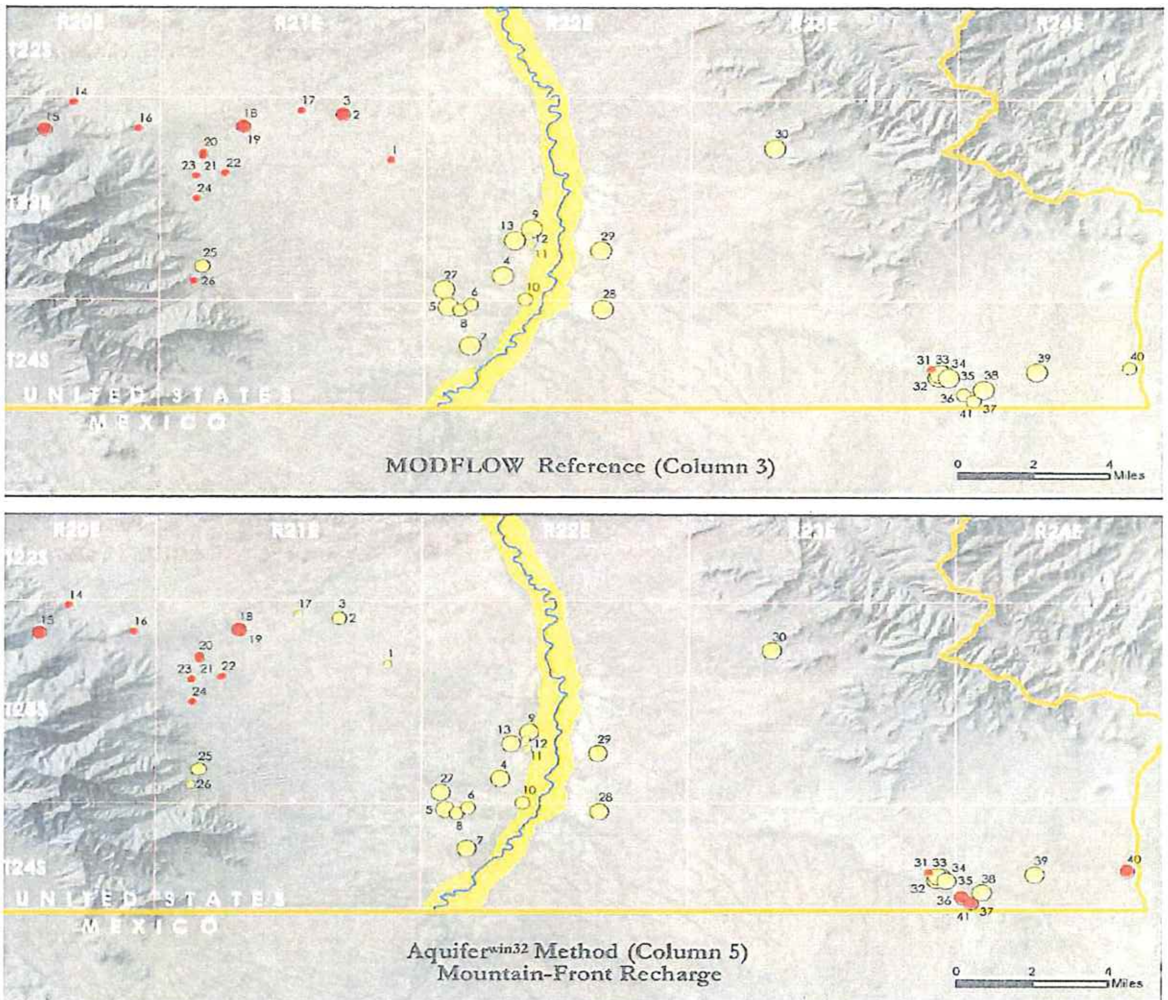

Figure 3. Wells are represented by circles that are proportionate to their determined pumping rates (large circles indicate high pumping rates and small circles indicate low pumping rates). Light colored wells have calculated future drawdowns > 0.10 foot. Dark wells have forecasted drawdowns < 0.10 foot. The top map shows the drawdown for 41 wells using MODFLOW. The bottom map depicts the same wells with drawdown calculated using Aquifer$^{Win\ 32}$.
Source: Stetson Engineers, Inc., *Review of ADWR Demonstration Project and Addendum,* figure A-2. Exh. FMC 12.

One of the primary disputes in this case concerns the proper method to model transmissivity, i.e., should it be determined at the site of the well or should it be determined over a larger area. Transmissivity is a function of the thickness of the aquifer and the hydraulic conductivity of the soil.

As soil composition changes, hydraulic conductivity changes which in turn affects transmissivity. Similarly, changes in the thickness of the aquifer cause changes in transmissivity.

Mr. Trembly testified that for the Demonstration Project, the saturated thickness of the aquifer at a well location was determined from several sources including an estimation of the water level in a well, the recorded water level in the well, and pre-development levels projected by the MODFLOW model. Hydraulic conductivity at the well site was derived from ADWR's Driller's Log Program that converts the driller's descriptions of the lithology to the related hydraulic conductivity values for the saturated interval and then calculates the weighted average of the hydraulic conductivities as the single hydraulic conductivity for the well. In some cases, Mr. Trembly stated that ADWR may also have based the hydraulic conductivity attributable to one well on other well logs in the area or on general knowledge of the hydraulic conductivity in the area.

Dr. Peter Mock, a hydrologist called by the Gila Indian Community, and Dr. Hudson testified that transmissivity affects the formation of the cone of depression at the well, between the well and the river, and also in all the directions to which the drawdown cone reaches. Dr. Cross testified that the cones of depression tested under steady-state pumping conditions will be very large. As shown on *Figure 3,* both groundwater models forecast wells having cones of depression with radii exceeding 10 miles that impact the subflow zone boundary. The extent of the area encompassing the simulated cone of depression, the site of the drawdown measurement, and the sources of recharge is important to the choice of type of groundwater model because the selected model must be able to accurately incorporate the transmissivity values found in the relevant portion of the aquifer.

Analytical models, which attribute a single value to transmissivity, are appropriate for aquifers or areas of aquifers consisting of homogenous porous materials. By definition, a homogenous aquifer will have a relatively constant hydraulic conductivity and, therefore, should have relatively constant transmissivity. Heterogeneous aquifers have different types of soil and therefore different hydraulic conductivities. As a result, transmissivity within an aquifer consisting of differing types of soils will vary. Numeric models should be used when aquifers are heterogeneous.

Mr. Ford defined heterogeneity as occurring in an aquifer when there are multiple types of lithologies, such as sand, gravel, silt, clay or limestone. The San Pedro aquifer was described by Mr. Corkhill as having basin fill deposits that range from highly permeable sand and gravel units to silt and clay units that are less permeable, and areas of interbedding of these units. Mr. Trembly explained that a bright line distinction does not exist between a homogenous and a heterogeneous aquifer; instead, a gradation exists between the classifications depending on the types of lithology, how often they occur, and where they occur. In addition, determinations must be made as to whether all soils found in the aquifer are significant, e.g., the presence of clay stringers through sand can be ignored.

Dr. Cross testified that based on his observations of work done in the San Pedro basin, the sediments in the aquifer include sand and gravel in some area and silt and clay in other area with lenses of sand and gravel. He gave as his opinion that the aquifer is very heterogeneous. Dr. Cross specifically referenced the thick sequences of poorly permeable sediments of silt and clay in the central part of the ADWR Demonstration Project which he stated can substantially influence drawdown. Similarly, Dr. Hudson opined that the Upper San Pedro aquifer is heterogeneous in general based on the fact that the hydraulic conductivity values vary over several orders of magnitude. Mr. Trembly agreed that it is very likely that significant heterogeneity exists in the aquifer in the area east of San Pedro River between the river and the location of Well 40. Dr. Mock states that there is heterogeneity in the basin, citing to his review of wells logs showing "all different amounts of sand, gravel, silts, and clays." Ms. Moran concurred that the aquifer is not homogenous.

Mr. Ford believes there is less heterogeneity in the aquifer than shown in the USGS model created using MODFLOW. He does not believe there is a "distinct thick, laterally continuous basin centered clay layer" in the basin fill in the Upper San Pedro Basin. Rather, Mr. Ford is of the opinion that the basin fill is a series of discontinuous layers of sand, gravel, silt and clay. Mr. Ford concluded by stating that the USGS model needs to either be significantly simplified or more data added to the model so that it accurately represent the heterogeneity in the San Pedro aquifer.

Finding of Fact No. 5. The San Pedro aquifer contains differing soil types that result in hydraulic conductivities calculated at different locations within the aquifer to vary by several orders of magnitude. Transmissivity is not constant throughout the aquifer.

Important to the decision of which model to choose is an examination of the experts' opinions as to whether ADWR's methodology of calculating transmissivity at the well site appropriately encompasses the transmissivity of the entire relevant area. With respect to the Demonstration Project in particular, Dr. Hudson noted that the clay zone west of the San Pedro River creates sufficient heterogeneity in the aquifer that the resulting complexity cannot be captured in an analytical solution or analytical element model. Ms. Moran stated that a single transmissivity value calculated at the well may not account for transmissivity between the well and the subflow zone because this approach relies on the assumption that the aquifer is homogenous between the well and the subflow zone. Dr. Mock testified that he has some concern with basing transmissivity solely on the results from a driller's log and proposed examining multiple drillers' logs from an entire area around a well to determine hydraulic conductivity. He specifically emphasized the need to take into account the hydraulic conductivities of the floodplain Holocene alluvium and the basin fill between the well and the river.

As can be seen from the data provided from the Demonstration Project and the wells shown on *Figure 3,* all three proposed groundwater models forecast that the cones of depression for the 13 wells generally located within a mile of the river will impact the subflow zone by more than 0.10 foot at steady-state. Once away from the immediate vicinity of the river and as the relevant distances and areas expand, the models no longer exhibit the same agreement. Disagreement exists with respect to eight wells, more than one-third of the remaining 28 wells, as to whether the calculated drawdown exceeds the 0.10 foot criterion.

Finding of Fact No. 6. The use of a single transmissivity value based on the lithology surrounding the well does not adequately reflect the transmissivity affecting the formation of a cone of depression where there are longer distances between the wells and the relevant boundaries in the San Pedro River Basin.

IV. Choice of Model

Based on the evidence presented, the universe of groundwater models appropriate to simulate a cone of depression at steady-state are: the Theim equation, Aquifer^{win32}, MODFLOW and the Jacob Non-equilibrium Equation with an Image Well.[6] As stated above, ADWR rejected the Theim equation. The decision among the three remaining models from a technical standpoint should be determined based on the purpose of the test, the scale of the project, and whether the aquifer or the portion of the aquifer under study is relatively homogenous or non-homogenous. From a legal standpoint, the groundwater model selected for the Cone of Depression Test must be "'the least

[6] Dr. Mock testified about a software program known as AnAqSim, but little evidence was presented about it other than the representation that it had a better capacity than Aquifer^{Win32} to accurately calculate transmissivity. Dr. Hudson offered the opinion that the AnAqSim is not as well vetted as MODFLOW.

expensive and delay-causing' efficient method that provide a 'high degree of reliability.'" *Minute Entry* at 29, *quoting Gila IV* at 343, 9 P.3d at 1082.[7]

a. Technical Standards

The technical purpose of this test is to determine whether a well located within the San Pedro basin and outside the subflow zone boundary of the San Pedro River may cause a drawdown of 0.10 foot at the subflow zone boundary due its cone of depression at a steady-state condition. The precision of the 0.10 foot drawdown criterion requires a model that does not include attributes that contribute to the uncertainty already inherent in any groundwater model covering large sections of or an entire aquifer projected over a long period of time. The sensitivity of the results generated by Aquifer^{Win32} to the location of the reference head for which no objective standards exist contributes an element of additional uncertainty in that model not found in Modflow or the Jacob Equation.

The large areas encompassed by the cones of depression simulated at steady-state and the distances involved between the well and the drawdown measurement and the recharge sites require a model that can incorporate multiple transmissivity values. While disagreement exists as to the degree of heterogeneity in the aquifer, the evidence demonstrates that the aquifer is sufficiently heterogeneous that groundwater models relying on a single transmissivity value generate drawdown values for wells at longer distances from the subflow zone boundaries that materially differ from those generated by MODFLOW, which can incorporate multiple transmissivity values. As shown in Table 1 below, MODFLOW reports only about 10% of the drawdown for Wells 1, 2, and 3 that the analytical methods calculate. As to Well 40 on the opposite of the river, MODFLOW calculates a drawdown that exceeds the analytical results by more than 60%. Admittedly, the absolute differences in drawdown are small, but the consequences of an increase or decrease in the drawdown by a fraction of an inch are material.

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[7] The courts have also referred to a requirement that a test be "realistically adaptable to the field". *Id.* Judge Ballinger found that computer modelling, at least for purposes of the test at issue, satisfied that requirement. *Minute Entry* at 29. No party introduced evidence on this element during the hearing.

Well No.	Distance from Well to Boundary (ft)	MODFLOW Drawdown (ft)	$Aquifer^{Win32}$ Drawdown (ft)	Jacob Equation Drawdown (ft)
1	17,148	0.02	0.27	0.29
2	21,416	0.052	0.322	0.32
3	21,181	0.033	0.322	0.32
40	67,285	0.112	0.069	0.07

Table 1.

The concept of developing an "effective transmissivity" was offered as a possible solution to the analytical models' use of a single transmissivity value. Mr. Ford defined effective transmissivity as "an attempt to represent the impact of change in lithology in a horizontal or . . . vertical distance between the well and the subflow zone." Ms. Moran proposed a broad examination of drillers' logs to determine the transmissivities of the basin and then the transmissivity values for each well would be calibrated against the values of the basin. The use of effective transmissivity means that a transmissivity value would not be determined solely at the well site as initially proposed by ADWR, but would also be determined using Driller's Logs and other hydrological data from the area surrounding the well and the area between the well and the subflow boundary. No clear methodology appears in the record describing when an effective transmissivity value should be substituted for a transmissivity value determined at the well site or how such a computation should be accomplished for the $Aquifer^{Win32}$ and Jacob Equation models. In MODFLOW, transmissivity data can be input into each section or cell in the model. Thus, given the precision demanded by the 0.10 foot standard, MODFLOW is the appropriate groundwater model to use from a technical standpoint for the Cone of Depression test because it uses an accepted methodology to calculate transmissivity over extended distances and because of its capacity to utilize multiple transmissivity values to more accurately reflect aquifer conditions.

b. *Gila IV* Standards

The chosen groundwater model must have a high degree of reliability because of the need to protect the rights of groundwater users who are entitled to a strong initial presumption that a well is pumping percolating groundwater and the rights of surface water users who are entitled to protection for their water rights based on a priority system. *Gila IV* at 342, 9 P.3d at 1082. Due to the temporal parameters adopted in 2005, reliability of the selected Cone of Depression Test cannot be verified by field testing because the drawdown caused by the simulated cones of depression cannot be physically measured. The simulated of cones of depression that will be generated by these models are cones of depression that will exist at steady state conditions, and in all probability, do not actually exist at the time of the test. Consequently, the determination of whether a model has a high degree of reliability must be based on the demonstrated capacity of the model and the methodology of the model.

MODFLOW is a groundwater model that has been in use and vetted for more than 30 years. Mr. Corkhill agreed that MODFLOW is perceived as the "gold standard". The developer of $\text{Aquifer}^{\text{Win32}}$ used MODFLOW as the standard against which to validate the results of its analytical element model. MODFLOW is designed precisely to analyze groundwater flow through porous medium in aquifers composed of changing combinations of clay, silt, sand and gravel resulting in different transmissivities at different locations in and levels of the aquifer. MODFLOW can be calibrated against physical measurements, which gives it an advantage over analytical approaches.

Finding of Fact No. 7. MODFLOW is the standard in the industry for modelling groundwater flow in aquifers.

Finding of Fact No. 8. A properly designed and populated MODFLOW model is a highly reliable test to determine and measure the drawdown of a well's maximum cone of depression at the boundary of the subflow zone.

The *Gila IV* court affirmed the trial court's decision that any test must also be the least expensive and least apt to cause delay. *Gila IV* at 342, 9 P.3d at 1082. Mr. Trembly testified that ADWR recommended Aquifer^{Win32} due to considerations of cost, time and efficiency. Mr. Corkhill confirmed that ADWR took into account scheduling and cost in choosing Aquifer^{Win32}. Mr. Ford also reached the opinion that the cost and time of acquiring the additional data he believes necessary to create an acceptable MODFLOW model that addresses the uncertainty question are not warranted by the improvement of the results in MODFLOW over the Jacob Equation. Thus, a key question in this case is whether the estimated costs and time associated with MODFLOW as compared to either Aquifer^{Win32} or the Jacob Equation outweigh the benefits of MODFLOW's increased capacity to accommodate the complexity of large areas of an aquifer with multiple hydraulic conductivities in which the theoretical maximum cone of depression must be simulated at steady state conditions.

In the case of the San Pedro River basin, the cost and time necessary for the development of a MODFLOW model for the San Pedro River basin may be less than in other basins because portions of the basin already have been modelled and the necessary data collected for other portions. As discussed above, the USGS has created a model for the Upper San River basin and it has completed a hydrogeologic study for the Middle San Pedro basin. Models exist for the San Pedro Riparian Conservation Area. Mr. Corkhill estimated that he expected that ADWR would require three to five years to create a MODFLOW model for the entire basin. Mr. Trembly estimated that completion of the testing using Aquifer^{Win32} would occur in one to two years. Dr. Hudson commented that, in her opinion, the amount of effort necessary to develop a large regional MODFLOW model that can evaluate a number of wells will be similar to the amount of time required to individually parameterize each well in Aquifer^{Win32} and run separate simulations and perform separate evaluations. Thus, the estimates in terms of time to prepare models for the entire San Pedro River basis range from no difference to one year to as much as four years (the difference between the minimum time estimated by Mr. Trembly to run Aquifer^{Win32} and the maximum amount of time estimated by Mr. Corkhill).

The implicit assumption in these estimates of time, cost and delay is that the chosen model must analyze every well in the basin. One reason for this assumption is that the Cone of Depression test has been regarded by some as a screening tool to eliminate wells from the adjudication. A conclusion that a well's maximum cone of depression will not cause a 0.10 foot drawdown in the subflow zone may not, however, exclude the well from the adjudication because it may still be subject to the adjudication for purposes of federal law. The well may also remain included in the adjudication as the result of the cumulative analysis referenced in Judge Ballinger's decision. *Minute Entry* at 37. Other parties have expected the test to include wells in the adjudication and require their owners to assume the evidentiary burden of establishing that their wells will not deplete the baseflow of the river as a result of their well's simulated cones of depression in the future. *San Carlos Apache Tribe's Notice of Joining the Salt River Project's Brief on the Proposed Subflow Approaches and Separate Comments on Proposed Procedures*, filed August 6, 2018, at 3. The *Gila IV* court held:

> When DWR determines and establishes that a well is in the subflow zone by using the pertinent criteria or that it is pumping subflow by reason of its cone of depression, DWR provides clear and convincing evidence of that fact. *See Gila River II,* 175 Ariz. at 392, 857 P.2d at 1246. The burden then shifts to the well owner to show that a well is either outside the subflow zone or is not pumping subflow. *Id.*

Gila IV at 343, ¶41, 9 P.3d at 1082.

Due to its steady-state requirement, the Cone of Depression test does not simulate a cone of depression at any specific point in time; instead it simulates a potential maximum cone of depression. *Gila IV* decision does not shift the burden of proof until ADWR provides evidence that due to the formation of an actual cone of depression, a well is currently depleting the subflow. Thus, in both instances, the assumed purposes of the Cone of Depression test are too broad. The limited purpose of this test with its reliance on steady-state modeling is simply to assure that "that a well with a cone of depression reaching the subflow zone [will] be subject to the adjudication if the extent of the well's current or prospective depletive effect on the stream is measurable by reasonably accurate means". *Minute Entry* at 36.

Conclusion of Law. The results generated by the Cone of Depression Test do not cause the evidentiary burden to shift to the well owner to show that owner's well will not pump subflow due to the well's cone of depression determined at a steady state condition.

In a general adjudication where considerations of time and money do not weigh heavily, the ideal approach would be to test all wells using a steady-state model to identify the complete class of currently operating wells that could potentially deplete the subflow zone. Here, however, as forcefully argued by several parties, resources are limited. Thus, the better approach is to apply the test to wells where the facts and circumstances warrant the additional testing necessary to assess a simulated cone of depression. Taking a more focused approach means that as the scope of the task contracts so that testing is applied to only groups of wells or areas of the aquifer, the absolute difference in time and resources needed for the creation of the appropriate MODFLOW model as compared to an analytical model also contracts.

An examination of the clear language of *Gila IV* establishes that not all wells must be subjected to the Cone of Depression Test. A well will be subject to this court's jurisdiction when ADWR shows that "the well's cone of depression <u>extends</u> into the subflow zone and <u>is</u> depleting the stream." *Gila IV* at 342, 9 P.3d at 1082 (emphasis added). Although the Cone of Depression Test will identify all well owners subject to this court's jurisdiction, i.e., those well owners who are currently pumping subflow as well as those well owners who may pump subflow in the future, the court unquestionably has jurisdiction over that subclass of well owners currently depleting the stream by virtue of the cones of depression developed around their wells. Consequently, once a subflow depletion test determines that a well is pumping subflow and the amount of the subflow depletion, no additional testing to prove that the cone of depression may have a future impact on the subflow zone is necessary to establish the court's jurisdiction over that well.

In contrast to some of the parties, ADWR has not shared the assumption that all wells should be subject to the Cone of Depression test. It has consistently taken the position that some wells should be excluded from the testing. During the proceedings, ADWR proposed that small wells should be excluded from the process. Following the conclusion of the hearing, ADWR submitted a formal analysis of small wells and proposed buffer zones of 5,000 and 15,000 feet from the subflow zone in most locations for wells pumping at steady-state rates of 0.62 gpm and 1.86 gpm, respectively. The general purpose of the buffer zones would be to delineate those wells that should be tested, i.e., wells within the buffer zones, and to create presumptions with respect to wells pumping at these lower rates located outside the buffer zones. Although the merits of ADWR's proposal will not be addressed in this Report, it is clear that hydrological data, tools, analysis and professional judgment can target those portions of the basin that warrant testing using a steady-state model.

A decision that the Cone of Depression test need not be done on all wells will not invalidate any of the suggested models. None of the proposed models must be applied to the entire basin to be effective. As demonstrated by Dr. Hudson's testimony that she created a MODFLOW program for approximately 213 square miles of the San Pedro basin, a MODFLOW model need not cover the entire basin. Similarly on point, the record contains no testimony that the USGS's MODFLOW program for the Upper San Pedro basin is flawed or invalid because it covers a part of, and not all of, the basin.

Finally, it is necessary to address the issue of whether the adoption of MODFLOW would create unnecessary delay. When circumstances warrant the use of both a Cone of Depression and a subflow depletion test, instead of the testing procedures proceeding *seriatim,* the tests could be conducted simultaneously, which would reduce delay in the continued adjudication of water rights that could occur if no subflow depletion test could be formulated and applied until the completion and application of a highly reliable groundwater model for the Cone of Depression test.

Finding of Fact No. 9. The high degree of reliability of a properly designed and populated MODFLOW model is not outweighed by potential delay or differences of cost and time necessary to implement an analytical method or analytical element model.

Accordingly, based on the foregoing,

IT IS RECOMMENDED that the MODFLOW program shall be used to create the groundwater model for the Cone of Depression Test.

V. Time to File Objections to the Report

Written objections to this Report may be filed on or before **January 14, 2019.** Responses to objections must be filed on or before **February 22, 2019.** All objections and responses must be filed with the Clerk of the Maricopa County Superior Court. A copy of all papers filed with objections and responses shall be served on all persons listed on the Court approved mailing list for this case.

Susan Ward Harris
Special Master

On November 14, 2018, the original of the foregoing was delivered to the Clerk of the Maricopa County Superior Court for filing and distributing a copy to all persons listed on the Court approved mailing list for the for Contested Case No. W1-103.

Barbara Brown

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