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 DRAFT REPORT ON THE ARIZONA DEPARTMENT OF WATER RESOURCES' DEMONSTRATION PROJECT REPORT: CONE OF DEPRESSION TEST METHODOLOGY

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

HSR INVOLVED: San Pedro River Watershed Hydrographic Survey Report.

DESCRIPTIVE SUMMARY: Draft Report on ADWR's Proposed Cone of Depression Test Methodology filed pursuant to Rule 53(f), Ariz. R. Civ. Pro.

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At issue in this proceeding is the appropriate methodology to determine whether a well's cone of depression at steady-state flow will cause a drawdown at the boundary of the subflow zone equal to or greater than 0.1 foot. Drawdown is the reduction in the hydraulic head or water table in an aquifer due to pumping.

I. Background

This consolidated general adjudication provides the forum in which 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 pumped from wells. *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*"). The relevant class of wells to be considered in this adjudication are those wells located within the subflow zone that pump subflow and 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". *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*").

In 2002, Arizona Department of Water Resources (ADWR) submitted the *Subflow Technical Report, San Pedro River Watershed* (2002) detailing a proposed cone of depression test that would include a well in the adjudication if its simulated cone of depression had reached the edge of the jurisdictional subflow zone and drawdown at that point was greater than or equal to 0.1 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 0.1 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*

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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 jurisdictional subflow zone during pumping. The second condition was not adopted. *Minute Entry*, 32, filed September 28, 2005.

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 0.1 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 undertook the task in that 2005 decision of defining the court's jurisdictional limits to "fairly protect the rights of both surface and groundwater users". *Id.* at 7. 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).

In the context of the cone of depression test, 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". *Id.* at 32. To avoid excluding from the court's jurisdiction those wells that could impact the subflow zone at a later date, the court found that "future consequences of existing well characteristics" must be considered when setting the adjudication court's jurisdiction. *Id.* at 36. Judge Ballinger 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.* at 36. The court ultimately determined that steady-state modeling adequately addresses "the need to consider the future consequences of existing well characteristics." *Minute Entry* at 36.

The 2005 decision led to ADWR's development of a second Cone of Depression Test to identify those wells located outside the subflow zone, which when assumed to be pumping at steady-state, will develop cones of depression that cause drawdown at the subflow zone boundary equal to or greater than 0.1 foot. [030518:15 (Trembly)] A steady-state condition occurs when pumping causes no change in storage in the aquifer and 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. [030618:47 (Corkhill); 030818:59, 186 (Moran)]

II. ADWR Demonstration Project

On January 27, 2017, the Arizona Department of Water Resources ("ADWR") submitted its Demonstration Project Report: *De Minimis* Assessment & Cone of Depression Methodology ("Demonstration Report") that evaluated two groundwater models, Aquifer$^{\text{Win32}}$, 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 elected to present the proposed models in a demonstration format that provided results for a sample population of wells representing a wide spectrum of pumping rates and locations. [030518:26 (Trembly)]

Mr. Jeffrey Trembly, the Adjudications Program Director for ADWR, testified that wells in the San Pedro watershed predominately pump relatively small amounts of water with more than half of the wells classified as small volume wells. [030518:40 (Trembly)] Of the remaining wells, 2,000 to 3,000 are considered medium volume wells and a couple thousand are large volume wells. *Id.* From its registry of 10,000 - 11,000 wells in the San Pedro basin, ADWR selected 41 wells located in townships 23 and 24 of the Sierra Vista subwatershed, exclusive of Fort Huachuca. [030518:27 (Trembly); Demonstration Report at 26, Figure 3-1]

The wells ranged in size from wells pumping 0.5 gallons per minute (gpm) to 399.9 gpm. [Demonstration Report at Table 3-1] The median rate was 12.2 gpm due to 24 of the selected wells reportedly pumping 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). [030518:20 (Trembly)] The pumping rate of a municipal well was based on the highest of the last five years of the pumping rates for the individual well or for the water company as a whole. [030518:20 (Trembly)]

The physical locations of the wells chosen by ADWR for the Demonstration Project covered a wide area. In addition to a large set of wells along the boundaries of the subflow zone, ADWR selected wells near the mountain front west of the river and another 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 widely from 19 feet to more than 10 miles. [Demonstration Report at Table 3-1] 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. [030518:20 (Trembly)].

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 obtain a good understanding of the proposed groundwater models, their underlying limitations and the available data from an examination of the test results for wells with different spatial and pumping characteristics. The use of a clearly identified group of wells also caused all of the parties and their experts to focus on the competing models in the context of the same data. In addition, the Demonstration Project allowed for valid comparisons of results submitted by experts who proposed revisions to existing 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 the results from six different approaches. [ADWR Demonstration Project Report: Response to Cone of Depression Test Comments, May 12, 2017]

III. Groundwater Models

Groundwater models can forecast a future hydrologic condition using assumptions, quantitative data about a physical setting and one or more mathematical equations. [Applied Groundwater Modeling at 9, Exh. FMC 146] In the process, groundwater models simplify reality and do not uniquely represent the complexity of the natural world. [030718:156 (Hudson); Mary P. Anderson, William W. Woessner & Randall J. Hunt, *Applied Groundwater Modeling* 11-12 (2d ed. 2015), Exh.146] Physical complexity exists because aquifers and groundwater flow are three-dimensional. Aquifers can consist of different types of soils, rock and geological feature and they may have multiple sources and sinks of water, recharge and discharge, respectively. 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, are the primary groundwater models presented in this case for the purpose of forecasting the extent of the drawdown at the subflow zone boundary caused by a well's theoretical cone of depression at steady-state conditions.

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

[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.

(Q) and the hydraulic conductivity of the soil surrounding the well in the aquifer (K). (The product of K and the thickness of the aquifer equals the transmissivity of the aquifer (T). [030918:224 (Ford)]) Drawdown at any point is directly proportional to the pumping rate [030918:28 (Cross)] and inversely proportional to transmissivity. Distance also plays a part in the development of a cone of depression requiring that the location of the well and the source of recharge be carefully established.

After fully evaluating the Theim equation and reviewing the parties' submitted comments, ADWR replaced the Theim equation with Aquifer^{Win32}, a more sophisticated groundwater model known as an analytical element method[3] that uses the Theim equation as one of its elements. [030618:125 (Mock)] The necessary information for this model, as in the case of the Theim equation, included data to be collected about the well's location relative to the subflow zone and the aquifer parameters. [030518:19-20 (Trembly)] Aquifer^{Win32} also requires the modeler to input appropriate image wells, which are 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 real wells, to establish the hydrological boundaries of the location studied. [030518:29 (Trembly), Jon R. Ford Expert Report at 18, Exh. FMC 14] In this case, ADWR used image wells to create a constant head boundary at the river and an impermeable boundary. *Id.* Finally, Aquifer^{Win32} relies upon a reference head established for each well at a location where drawdown will always be zero. [3rd Progress Report at 14; 030518:30 (Trembly)]

Dr. Mark Cross, a hydrogeologist retained by Arizona Public Service and BHP Copper, Inc., evaluated the operation of Aquifer^{Win32} . [030818:189 (Cross)] He opined that a large

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[3] Analytical solutions can be applied to more complex problems using an analytical element method. [030718:153 (Hudson)]

number of image wells must be added to the model created for each well due to the very low drawdown criterion, adding to the complexity of the model. [030918:60 (Cross)] Dr. Cross concluded that once "24 or so" image wells were added to the model, the boundary conditions no longer presented a major issue. [030918:61 (Cross)] Mr. Ford and Dr. Cross agreed that the reliance of Aquifer$^{\text{Win32}}$ on the use of a reference head created uncertainty and inserted subjectivity into the process because no physical basis exists for selection of the correct location of the reference head. [030918:61 (Cross); 030918:214, 217 (Ford)] As shown in *figure 1*, the amount of drawdown at steady-state 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. Consequently, depending upon the number of image wells and the location of the reference head, Aquifer$^{\text{Win32}}$ could forecast drawdown results for the same well as < 0.1 or > 0.1 foot. Dr. Cross characterized the range of results as a "large error relative to the 0.1 foot criterion." [030918:64 (Cross)]

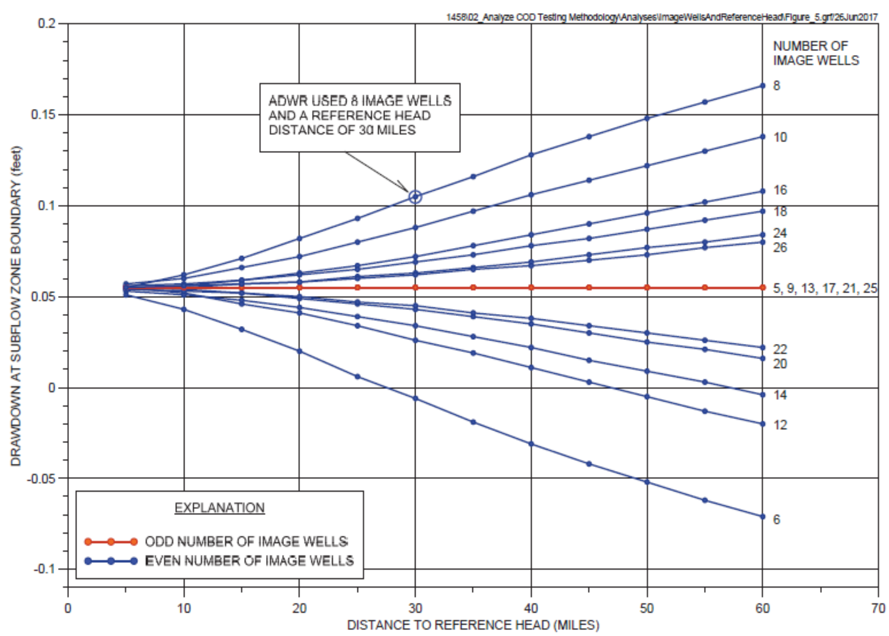

Figure 1. The drawdown results shown on the y-axis for a single well depend on the number of image wells and the distance to the reference head shown on the x-axis. **Source.** Figure 5 from Analysis of Cone of Depression Test Methodology Proposed by Arizona Department of Water Resources, Exh. SRP 30.

The Jacob Non-equilibrium Equation with an Image Well[4] (Jacob Equation) was a second analytical approach considered in this case. 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). 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 the relevant cone of depression. [030818:60-61 (Moran)]

According to Mr. Ford's testimony, the Theim equation with one image well is equivalent to the Jacob Equation. [030918:218-219 (Ford)] As was true under the Theim equation, drawdown increases as pumping increases and decreases when pumping decreases. Drawdown decreases as transmissivity increases and increases when transmissivity decreases. Further, holding pumping and transmissivity steady, drawdown will increase as the distance of the well from the source of recharge increases.

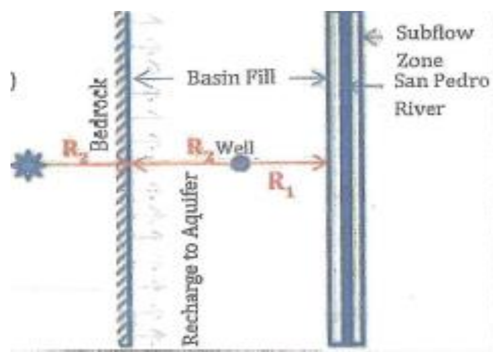

Figure 2. The conceptual model shows the mountain front as the source of recharge. Mathematically, the recharge is created by an image well marked by a large asterisk.
Source. Jon R. Ford Expert Report at 20 Exh. FMC 14.

Figure 2 illustrates Mr. Ford's conceptual model. 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).

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

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.

In addition to the analytical model, ADWR also considered MODFLOW, a computer program that numerically approximates the solution to the groundwater flow equation.[5] [Arlen Harbaugh, Edward R. Banta, Mary C. Hill and Michael G. McDonald, *MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model*, Exh. FMC 141] MODFLOW operates using a grid of distinct cells each of which is coded with data that defines the aquifer parameters at relative locations. [*Id.* at 2] 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. [Evaluation of Cone of Depression Testing and Recommendation for Use of Transient Numeric Modeling at 3, Exh. 65] Mr. Edwin Corkhill, the chief hydrologist for ADWR, testified that no constraints limited the use of MODFLOW other than the fact that there is not a single MODFLOW model available to cover the entire area. [030518:189 (Corkhill)] He 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 watershed. [030618:31 (Corkhill)]

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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*, at 10-11, Exh. FMC 141 at 10-11]

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 is represented by W. *Id.*

In 2007, the USGS completed a MODFLOW model for the Upper San Pedro which covers approximately 1,400 to 1,800 square miles. [030718:82, 117 (Hudson)]. 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. [030718:6,117 (Hudson)] Mr. Corkhill testified that a modified version of the USGS model could be used for the cone of depression testing. [030518:18 (Corkhill)] Mr. Ford also testified that the existing USGS model, if used, should be modified based on collection and input of additional data or by simplifying the model. [031218:71 (Ford)]

IV. Specific Elements of the Models

a. Source of Recharge

Based on ADWR's understanding of the court's request for information about the drawdown at the subflow boundary, ADWR designated the San Pedro River as the source of recharge to the aquifer in the original Aquifer^{Win32} model. [030518:28-29 (Trembly)] In the past, the courts have been criticized for water right decisions that relied on hydrologic concepts not generally accepted by the current scientific community.[6] In these proceedings, every effort will be made to meet the standard imposed by the Arizona Supreme Court in *Gila IV* that requires a decision to comport "with hydrological reality as it is currently understood". *Gila IV* at 334, 9 P.3d at 1073.

No dispute exists that runoff from the mountains surrounding the San Pedro watershed provides the primary source of recharge to the San Pedro aquifer. [030618:18, 20 (Corkhill); 030718:29 (Moran); 030918:123 (Cross); 030918:191,197 (Ford)] Estimates of the contribution of mountain front recharge to the aquifer ranged from 50% to 80%. [030618:53

[6] *See, e.g.*, Robert J. Glennon and Thomas Maddock, *In Search of Subflow: Arizona's Futile Effort to Separate Groundwater from Surface Water*, 36 Ariz. L. Rev. 567 (1994).

(Corkhill); 030718:26 (Hudson)] The remainder of the recharge comes from the San Pedro River, artificial recharge sources and ephemeral streams. [030718:30, 107 (Hudson)]

Ms. Moran testified to the importance of locating recharge at the mountain front rather than at the river by focusing on Well 11 from the Demonstration Project, a well pumping 7.7 gpm located 1,228 feet from the subflow zone boundary. [0300818: 40, 59 (Moran)] The original Aquifer^{Win32} program calculated that Well 11 caused a 0.089 foot drawdown at the boundary. [ADWR Filing Response to Comments, Table 1, filed May 12, 2018] When the Aquifer^{Win32} program evaluated Well 11 using the mountain front as the source of recharge, the drawdown increased to 0.192 feet. *Id.* Ms. Moran explained that the initial drawdown of less than 0.1 foot occurred in the original modelling because the river, as source of recharge in the model, provided sufficient water to the cone of depression to raise the hydraulic head at the subflow zone boundary and thereby reduce the drawdown. [030818:40, 59 (Moran)] Mr. Ford agreed with Ms. Moran's explanation and concurred that Well 11 would be included in the adjudication. [031218:207-208 (Ford); 031218:153 (Ford)] Dr. Hudson and Mr. Ford also highlighted the impact of the choice of source of recharge on wells located near the mountain front. [031218:61 (Ford)] Wells located near the mountain front were included under the Aquifer^{Win32} test as originally configured, which when reconfigured to use the mountain front as the primary source of recharge, were excluded.

While it must be accepted that a groundwater model will use simplifying assumptions, the conceptual model for the groundwater model for the Cone of Depression Test must accurately reflect the sources of recharge. Based on the testimony received at the hearing, the conceptual groundwater model for the Cone of Depression Test must designate mountain flow recharge as the primary source of recharge to the basin.

b. Transmissivity

Ms. Moran prepared maps based on ADWR's drawdown calculation for each well in the Demonstration Project using MODFLOW and Aquifer^{Win32} adjusted for mountain front recharge. These maps are replicated as *figure 3*. Based on her review of all of the data and her own analysis, she concluded that wells close to the river will be included in the adjudication and the status of the remaining wells will depend upon transmissivity and pumping rates. [030818: (Moran)]

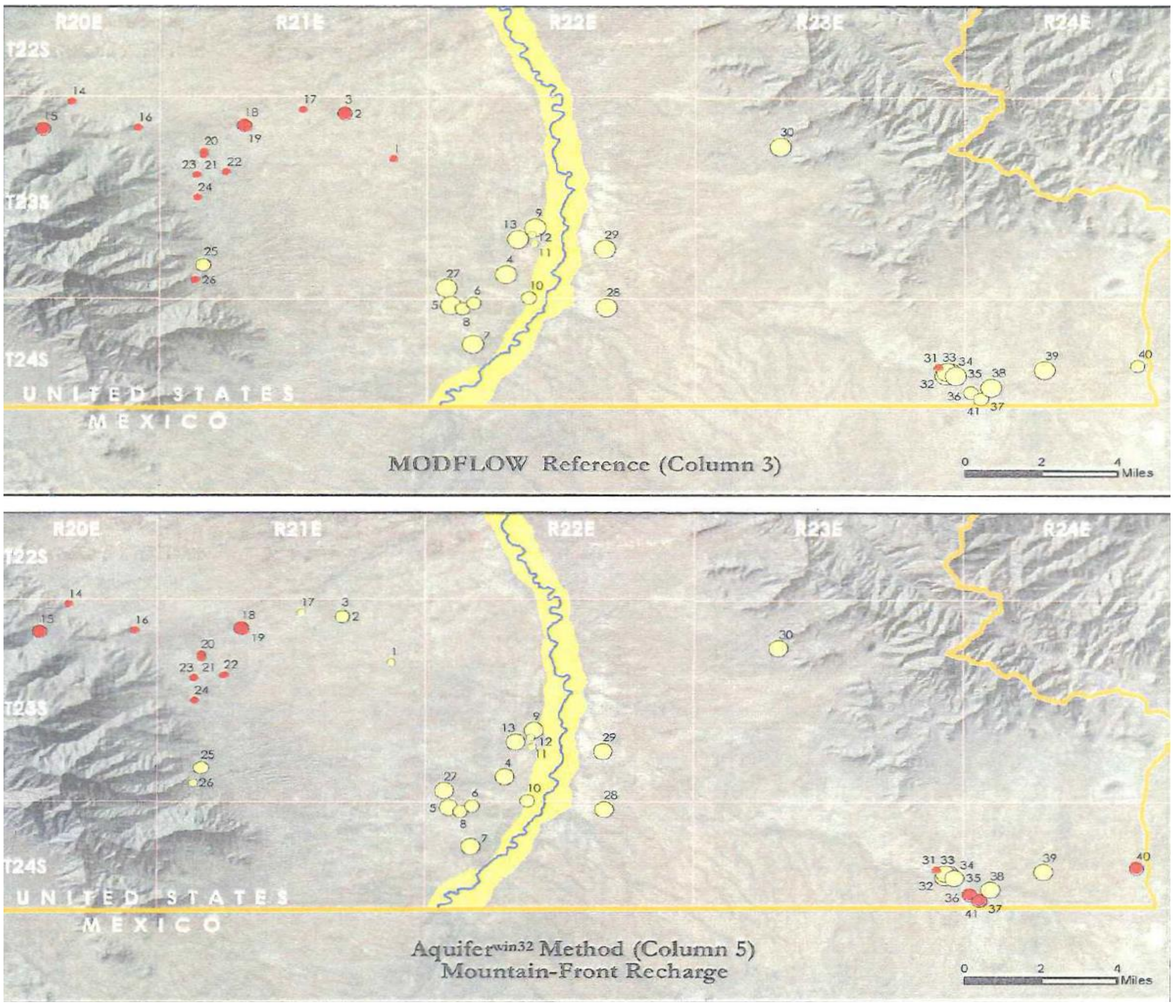

Figure 3. Wells are represented by circles that are proportionate to their determined pumping rates (large circles indicate high pumping rates and small circles indicate low pumping rates). Yellow wells have calculated future drawdowns > 0.1 foot. Red wells have forecasted drawdowns < 0.1 foot. The top map shows the drawdown for 41 wells using MODFLOW. The bottom map depicts the same wells with drawdown calculated using Aquifer$^{\text{Win 32}}$.
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, which is a function of the thickness of the aquifer and hydraulic conductivity. Mr. Trembly testified that for the Demonstration Project, the saturated thickness of the aquifer was determined from several sources including an estimation of the water level in a well, recorded water level in the well, and pre-development levels projected by the MODFLOW model. [030518:21 (Trembly)] Hydraulic conductivity 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. [030518:23 (Trembly)] 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 [030518:23, 57 (Trembly)] or on general knowledge of the hydraulic conductivity in the area. [030518:59 (Trembly)]

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. [030618:123 (Mock); 030718:53 (Hudson)]. Dr. Cross testified that the cones of depression tested under the chosen model will be very large. [030818:202 (Cross)] As shown on *figure 2*, both types of groundwater models forecast wells having cones of depression with radii exceeding 10 miles that impact the subflow zone boundary. The extent of the area of the simulated cone of depression is important to the choice of type of groundwater model because the selected model must be able to accurately model the transmissivity values found in that portion of the aquifer.

Analytical models are appropriate for aquifers or areas of aquifers consisting of homogenous porous materials. [030718:47 (Hudson)] A homogenous aquifer will have a relatively constant hydraulic conductivity, one of the elements used to calculate transmissivity. In contrast, numerical models should be used when aquifers are heterogeneous. [*Id.* at 127]

Mr. Ford defined heterogeneity as occurring in an aquifer when there are multiple types of lithologies, such as sand, gravel, silt, clay or limestone, that affect hydraulic conductivity. [031218:11 (Ford)] 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. [030618:141 (Corkhill)] 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. [030518:177 (Trembly)]

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. [030918:34-35 (Cross)] 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 [030918:37 (Cross)] 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. [030718:26 (Hudson)] 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. [030718:128-129 (Hudson)] 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. [030518:62 (Trembly)] 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.” [030818: 114 (Mock)]. Ms. Moran concurred that the aquifer is not homogenous. [030818:128 (Moran)]

Mr. Ford believes there is less heterogeneity in the aquifer than shown in the USGS model created using MODFLOW. [031218:53 (Ford)] 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. [Rebuttal Expert Report at 40, Exh. FMC 34] 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. [031218: 11, 26, 53-54 (Ford)]

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 appropriately encompasses the transmissivity of the entire relevant area. Ms. Moran stated that a single transmissivity value calculated at the well does not account for transmissivity between the well and the subflow zone because this approach effectively assumes that the aquifer is homogenous between the well and the subflow zone. [030818:128 (Moran)] 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. [030618:144 (Mock)] Mr. Ford also testified about effective transmissivity, which he defined as “an attempt to represent the impact of change in lithology in a horizontal or …vertical distance between the well and the subflow zone.” [031218:63 (Ford); Rebuttal Report at 32] 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. [030818:127-129 (Moran)] Dr. Mock specifically focused on the need to take into account the hydraulic conductivities of the floodplain Holocene alluvium and the basin fill between the well and the river. [030618:159 (Mock)]

Thus, the evidence does not support the use of a single transmissivity value based on the lithology surrounding the well because it would effectively transform the forecasted cone of depression from one developing in a heterogeneous aquifer to a greater or lesser degree to one that is developing in a homogeneous aquifer. As can be seen from the Demonstration Project and on *figure 3,* all three proposed groundwater models forecast that the cones of depression for the 13 wells located within the same section as the river will impact the subflow zone by more 0.1 foot at steady-state. Once away from the immediate vicinity of the river, however, the models no longer exhibit the same agreement. Disagreement exists with respect to eight wells or more than one-third of the remaining 28 wells concerning whether the calculated drawdown exceeds the 0.1 foot criterion. Thus, a logical conclusion is that at longer distances from the boundaries, the heterogeneity of the aquifer cannot be adequately quantified by transmissivity values determined at the well site.

V. 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.[7] [030518:187 (Corkhill); Jon R. Ford Expert Report, Exh. FMC 14 (Ford)] As reported above, ADWR rejected the Theim equation. The decision among the three models from a technical standpoint should be determined based on the

[7] 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.[030618:116 (Mock)] Dr. Hudson offered the opinion that the AnAqSim is not as well vetted as MODFLOW. [030718:169 (Hudson)]

purpose of the test, the scale of the project, and whether the aquifer or the portion of the aquifer under study is homogenous or non-homogenous. [030818:202 (Cross); Anderson et al., *supra*, Exh. 146]. From a legal standpoint, the appropriate model that will effectively become the Cone of Depression Test must provide a high degree of reliability while also being the least expensive and least apt to cause delay. *Gila IV* at 343, 9 P.3d at 1082.

a. Technical Standards

The technical purpose of this test is to determine the entire class of wells located within the San Pedro basin and outside the subflow zone boundary of the San Pedro River that may create a 0.1 foot drawdown at the subflow zone boundary while pumping at steady-state. The court has already found and ADWR has confirmed that the required level of precision demanded may not be achievable under any groundwater model. Thus, the more appropriate question is not which groundwater model can accurately model a 0.1 drawdown, but which model can generate results with less uncertainty. [*Minute Entry* at 28; 030618:32 (Corkhill)] Also as Dr. Cross testified, the reliability of the methodology becomes very important due to the level of required precision. [030918:84 (Cross)] The precision of the 0.1 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. As discussed above, the sensitivity of the results generated by Aquifer^{Win32} to the location of the reference head for which no objective standards exist contributes additional uncertainty into the groundwater model that is not acceptable given the 0.1 foot standard.

The large area encompassed by the cones of depression simulated at steady-state requires 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 that rely on a single transmissivity value can generate drawdown values materially differ from those generated by MODFLOW. As can be seen 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 exceed the analytical results by more than 60%. Admittedly, the absolute differences in drawdown are small, but the consequence of an increase or decrease by a fraction of an inch can mean the difference between inclusion of a well within this court's jurisdiction or its exclusion. Thus, due to the precision demanded by the 0.1 foot standard, MODFLOW is the appropriate groundwater model to use from a technical standpoint for the Cone of Depression test.

Well No.	Distance from Well to Boundary (ft)	MODFLOW Drawdown (ft)	Aquifer^{Win32} Drawdown (ft)	Jacob Equation Drawdown (ft)
1	17,148	0.02	0.22	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.

b. *Gila IV* Standards

The chosen groundwater model must have a high degree of reliability because of the need to establish the court's jurisdiction and appropriately protect the rights of groundwater users who are entitled to strong initial presumption that a well is pumping percolating groundwater and the rights of surface water users. *Gila IV* at 342, 9 P.3d at 1082.

MODFLOW is a groundwater model that has been in use and vetted for more than 30 years. [030718:66 (Hudson)] It is the standard in the industry for modelling groundwater flow in aquifers. *Id.* Mr. Corkhill agreed that MODFLOW is perceived as the "gold standard". [030618:172 (Corkhill)] The developer of Aquifer^{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. [030618:5 (Corkhill)] A properly designed and populated MODFLOW model has the best capacity of the three models under consideration to calculate drawdown based on accurate boundary conditions, sources of recharge and varying transmissivity values that affect the development of a cone of depression under steady-state conditions.

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 consideration of cost, time and efficiency. [030518:42 (Trembley)] Mr. Corkhill confirmed that ADWR took into account scheduling and cost in choosing Aquifer^{Win32}. [030618:44 (Corkhill)] 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 an analytical model. [031218:148-149 (Ford)] 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 the development of a theoretical maximum cone of depression for a well in a heterogeneous aquifer.

In terms of cost, which in this case equates with the amount of employee hours that ADWR would have to devote to the project, Mr. Trembly estimated that completion of the testing using Aquifer^{Win32} would occur in one to two years. [030518:83 (Trembly)] Mr. Corkhill estimated that he expected that ADWR would require three to five years to create a MODFLOW model for the entire basin. [030618:40 (Corkhill)] Dr. Hudson testified that she spent about one month to create a MODFLOW program that covered approximately 213 square miles or 5% of the San Pedro basin. [030718:82 (Hudson)] She also 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. [030718:40-41 (Hudson)]

While normally the court would defer to ADWR in terms of its estimates of the amount of time necessary to complete a project, in this case it is not clear if ADWR contemplated that an equal number of wells would be analyzed using each groundwater model. Mr. Trembly estimated that approximately two hours would be required to input the necessary data and aquifer parameters into the Aquifer^{Win32} program for each well. [030518:84 (Trembly)] Assuming 11,000 wells in the basin, the modelling effort for the entire basin using Aquifer^{Win32} would require 22,000 hours of work. During the course of these proceedings, ADWR has, however, proposed excluding small-volume wells and not without requiring a well-by-well analysis of those wells because of the likelihood that their cones of depression will not cause the requisite amount of drawdown. The 1991 San Pedro HSR includes 2,595 potential water rights for domestic wells that have pumping rates less than four gallons per minute. [031218:157] Clearly, the exclusion of thousands of wells would dramatically reduce the amount of time needed to complete testing using Aquifer^{Win32}.

At the conclusion of the hearing, having had the benefit of hearing all the evidence, the parties were given the opportunity to respond to ADWR's proposal to exclude wells located outside the subflow boundaries pumping 0.62, 2 or 4 gpm from this adjudication. Without exception, all parties opposed the exclusion of any wells from the adjudication at this time for a number of different reasons. At this point, there is not sufficient evidence to make a determination to exclude a class of wells as *de minimis* or because they pump such low volumes that they would likely be excluded under the Cone of Depression Test. Such a determination will have to be the subject of a separate evidentiary proceeding.

Based on the evidence presented, the amount of additional time that may be needed to complete a MODFLOW model, as compared to the time needed to analysis all of the wells in the basin using an analytical model, does not outweigh the importance of using a highly reliable model to conduct the Cone of Depression Test. Moreover, any time gained in the adjudication by creating a model that does not adequately account for the complexities of the aquifer and requires subjective judgments could be lost in increased litigation over the results generated by that model.

The final *Gila IV* standard that must be considered is whether the groundwater model chosen for the Cone of Depression Test is the least delay-causing. The specific question of which model will allow ADWR to complete the project more quickly has been addressed above with the conclusion that there is not a material difference in time required assuming projects of similar size and scope, or at least not sufficiently material to override the determination that MODFLOW is the more reliable model. The more general question that deserves consideration is whether the Cone of Depression Test selected in the course of this evidentiary proceeding should delay the adjudication of wells located outside the subflow zone boundaries that now have cones of depression that are currently depleting subflow.

These proceedings concerning wells located outside the boundaries of the subflow zone have moved forward based on an explicit assumption that no adjudication of water rights can be undertaken with respect to any well located outside the subflow zone boundary until all wells that may come within the court's jurisdiction have been identified using the Cone of Depression Test. [030718:95-96] The reason that the completion of testing under the Cone of Depression Test has become a *de facto* condition precedent to the determination of whether a particular well is pumping subflow by reason of its existing cone of depression is not clear. Salt River Project has taken the position that "all well owners in the Gila River System and Source are parties to this proceeding." Salt River Project's Proposals Regarding Subflow Depletion Analysis filed August 25, 2017, p. 3. Assuming the truth of this statement, it does not appear that the basis for this approach arises out of due process concerns.[8]

Pursuant to the clear language of *Gila IV*, a well will be subject to this court's jurisdiction when ADWR shows that "the well's cone of depression extends into the subflow zone and is 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. Thus, the implementation of a test that determines that a well is pumping subflow and the amount of the subflow depletion should not be dependent upon the determination of the entire class of well owners subject to this court's jurisdiction. Instead of the testing procedures proceeding *seriatim* they could proceed simultaneously thereby reducing delay in the adjudication of water rights necessitated by the time necessary to create a highly reliable groundwater model for the Cone of Depression Test.

Accordingly, based on the foregoing, the following findings are made:

Conclusions of Law

1. A well located outside the boundaries of the subflow zone is subject to the adjudication when the well's cone of depression extends into the subflow zone and depletes the stream. *Gila IV* at 342, 9 P.3d at 1082.

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[8] This statement does not negate future consideration of whether it would be prudent to provide additional notice to those well owners who have not filed a statement of claimant when warranted by the circumstances.

2. A well located outside the boundaries of the subflow zone with a cone of depression reaching the subflow zone at steady-state flow will be subject to adjudication if the well's prospective depletive effect on the stream will cause a drawdown at the boundary of the subflow zone equal to or greater than 0.1 foot as measured by reasonably accurate means. *Minute Entry*, filed September 28, 2005

3. The test approved by the court to be used by ADWR to determine and measure the drawdown of a well's cone of depression at the boundary of the subflow zone must comport "with hydrological reality as it is currently understood". *Gila IV* at 334, 9 P.3d at 1073.

4. The test used by ADWR to determine and measure the drawdown of a well's cone of depression at the boundary of the subflow zone must have a high degree of reliability. *Gila IV* at 1082.

5. The test used by ADWR that the court has determined to have a high degree of reliability must be the least expensive and delay-causing. *Gila IV* at 342, 9 P.3d at 1082.

Findings of Fact

1. Three viable groundwater models exist to measure the drawdown of a well's cone of depression at the boundary of the subflow zone at steady-state conditions: Aquifer$^{\text{Win32}}$, MODFLOW, and the Jacob Non-equilibrium Equation with an Image Well.

2. Aquifer$^{\text{Win32}}$ is an analytical element model, Jacob Non-equilibrium Equation with an Image Well is an analytical model, and MODFLOW is a numerical model.

3. Analytical element models and analytical models are appropriate for homogenous aquifers. Numerical groundwater models can be used to model aquifers that are heterogeneous, with complex boundary conditions and have multiple sources of recharge.

4. A conceptual model of the San Pedro River watershed that comports with hydrological reality as it is currently understood must have mountain system recharge as its primary source of recharge.

5. The porous materials in the San Pedro aquifer include highly permeable sand and gravel units to silt and clay units that are less permeable, and areas of interbedding of these units.

6. The San Pedro aquifer is a heterogeneous aquifer.

7. All three models require data regarding the hydraulic conductivity of the soils surrounding the wells to be tested in the aquifer and their cones of depression, the thickness of the aquifer, the pumping rate of the wells, and the sources of recharge.

8. 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 0.1 foot criterion.

9. 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.

10. The use of a single value for transmissivity will not accurately define the transmissivity controlling the development of the maximum cone of depression for all wells in the San Pedro basin.

11. Groundwater models that generate a drawdown calculation based on a cone of depression simulated using a single transmissivity value not reflective of the entire area affected by the maximum cone of depression at steady-state are not highly reliable.

12. MODFLOW is the groundwater model standard in the industry that has been vetted for decades.

13. MODFLOW can incorporate multiple transmissivity values, boundary conditions and sources of recharge in its calculation of the drawdown caused by a well's cone of depression at the subflow zone.

14. MODFLOW 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.

15. The high degree of reliability of MODFLOW is not outweighed by the differences of cost and time necessary to implement an analytical method or analytical element model.

VI. Deadline for Submitting Proposed Corrections and Objections

The parties shall file proposed corrections and objections to this draft report on or before May 31, 2018. Oral Argument on the corrections and objections will be held at 1:30 p.m. on June 14, 2018, in the Superior Court of Arizona, Central Court Building, Courtroom 301, 201 West Jefferson Street, Phoenix, AZ, 85003-2202.

Instructions for telephonic participation:

Dial: 602-506-9695 (local)

1-855-506-9695 (toll free long distance)

Dial Participant Pass Code 163622#

Susan Ward Harris
Special Master

On May 11, 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.