Workplan to Collect Geophysical Data for an Improved Hydrogeologic Conceptual Model of the Big Chino Sub-basin, Central Arizona

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Problem

Water users and managers who rely on the Verde River system and its aquifers for water supplies have an intrinsic interest in developing the best possible tools for assessing the effects of groundwater withdrawals. A group of these managers and their technical staff (hence termed the "Cooperators") have requested this workplan from the USGS to aid in the understanding and effective management of water resources in the Big Chino sub-basin (fig. 1; use of "sub-basin" consistent with Arizona Department of Water Resources nomenclature). Specifically, better knowledge is needed regarding how past, present, and future groundwater withdrawals from the Big Chino sub-basin will affect groundwater levels in the study area and future discharge at the headwaters of the Verde River, specifically at the Upper Verde Springs (UVS), which is believed to be a major discharge zone of groundwater from the sub-basin. The relation of increased withdrawals to reduced base flow is largely a function of connections between hydrogeologic (aquifer) units, aquifer storage properties and transmissivity, and proximity of withdrawal locations to discharge areas. The theoretical ultimate impact on base flow will be a reduction equivalent to the increase in groundwater withdrawal rate minus any reduction in evapotranspiration assuming no variations in inflow (recharge).

Communities upstream of the Verde River headwaters, including Prescott and Prescott Valley, are currently considering augmenting their water supplies by using groundwater withdrawals from the Big Chino sub-basin. Downstream users of Verde River flows, including greater Phoenix water provider Salt River Project, are concerned that Big Chino sub-basin groundwater withdrawals will eventually reduce the flow in the Verde River and their water availability. The timing of the effect of withdrawals on the Verde River flows depends on the location of the withdrawals and aquifer properties including connectivity between aquifer units, aquifer-storage properties, and transmissivity. Given the current understanding of aquifer properties, the period of time to affect the Verde River flows could be on the order of years to a century or more. In addition, variable recharge rates result from infiltration of periodic flows in major ephemeral stream channels in the region. Decreases in recharge rates could exacerbate the effects of groundwater withdrawals on Verde River flow, while increases in recharge rates could help counter the effects of the withdrawals. Further data collection and monitoring of the hydrologic system in the Big Chino sub-basin are proposed here for the purpose of improving definition of the important aquifer properties and understanding variations and locations of ephemeral channel recharge.

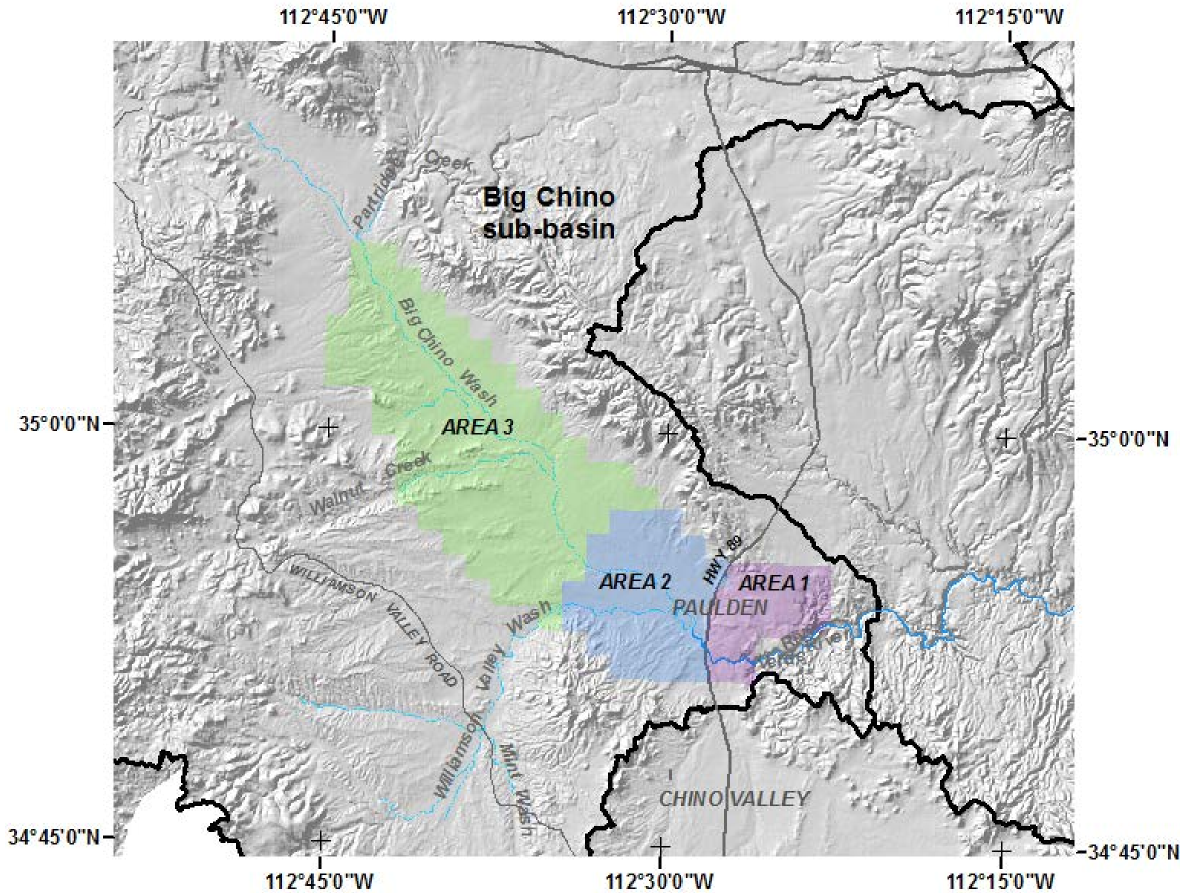

Figure 1. Approximate location of Big Chino study area and areas of interest for geophysical surveys.

Objectives

The objective of this project is to develop information for the Big Chino sub-basin that will improve understanding of the hydrogeologic system and how features of the hydrologic system affect the timing of variations in groundwater discharge to the Verde River including the response of the hydrologic system to variable groundwater withdrawals and recharge. Information will be developed through field data collection including monitoring of aquifer storage and water levels in wells and geophysical surveys Groundwater monitoring will include aquifer-storage monitoring to estimate storage change and aquifer-storage properties at several locations. Most of the storage monitoring stations will be co-located at wells where co-incident water-level data will be collected. Some of the storage monitoring will help assess recharge in major ephemeral channels. Geophysical surveys will target improving definition of aquifer structure, i.e. lateral extent and depth, and distributions of major aquitards (silt and clay layers and basalt flows) relative to major sand and gravel intervals, and underlying extents of limestone aquifers and non-aquifer crystalline rock. Borehole surveys of porosity and hydraulic conductivity will also be made in available wells. In addition, recharge in major ephemeral channels distributions will be monitored in a parallel investigation coordinated by area stakeholders. All of this information will be used to inform site selection for several new deep wells that are planned for installation by the Cooperators outside this project.

Relevance and Benefits

The results of this study will provide improved knowledge of the hydrogeologic system of the Big Chino sub-basin. Stakeholders will have a better understanding of hydrologic data needs through estimates of aquifer-storage properties and recharge in major ephemeral channels, and improved resolution of aquifer dimensions and lithology from geophysical surveys. Accordingly, the water-resource planning capabilities of federal, state, and local governmental agencies and offices with a stake in the upper and middle Verde area will benefit. The content of the work is consistent with and supports USGS Bureau Science Strategy *A Water Census of the United States: Quantifying, Forecasting, and Securing Freshwater for America's Future* in USGS Circular 1309: Facing Tomorrow's Challenges—U.S. Geological Survey Science in the Decade 2007-2017.

Approach

Improved understanding of the response of the Big Chino aquifer system to groundwater withdrawals and variations in ephemeral channel recharge will be accomplished by: hydrologic monitoring and geophysical surveys. Ongoing water-level monitoring in wells (ADWR and USGS) will be augmented with aquifer-storage monitoring to quantify changes in groundwater storage, estimate aquifer-storage properties, and estimate recharge in reaches of major ephemeral channels. Alluvial aquifer thickness and extent and the distribution of major alluvial lithologies will be mapped using surface geophysical methods in key areas. Borehole surveys of porosity and hydraulic conductivity will be conducted using Nuclear Magnetic Resonance (NMR) methods in available boreholes.

Task 1. Monitor aquifer-storage change and estimate aquifer-storage properties

Gravity methods will be used to monitor aquifer-storage change for two purposes. The method will be used to estimate aquifer-storage properties at several well sites. Aquifer-storage properties are a poorly constrained, but highly important variable that have a direct effect on the predicted timing of changes in stream base flow due to groundwater pumping. The method will also be used to estimate streamflow infiltration along reaches of Big Chino Wash, Walnut Creek, and Williamson Valley Wash.

Repeated measurements of changes in gravity at wells and corresponding measurement of water levels provide a means to calculate aquifer-storage properties. There are currently 9 wells within the study area being monitored by USGS for seasonal groundwater storage and water-levels as part of Yavapai WAC monitoring activities. The existing network will be augmented with as many as 30 additional storage-monitoring stations (Table 1, Fig. 2). Most of the new stations will be co-located with observation wells, some of which are monitored for water levels by ADWR at annual to hourly rates. Tapedowns of depth to water will also be made with each gravity observation at available wells. Other stations will be located in areas where storage-change information would be helpful but no observation wells are available. Potential new stations shown on Table 1 and in Fig. 2 are generalized locations for planning purposes and may be modified after reconnaissance of the sites. USGS will contact land owners and acquire written permission for installation of aquifer-storage stations and measuring water levels in co-located wells.

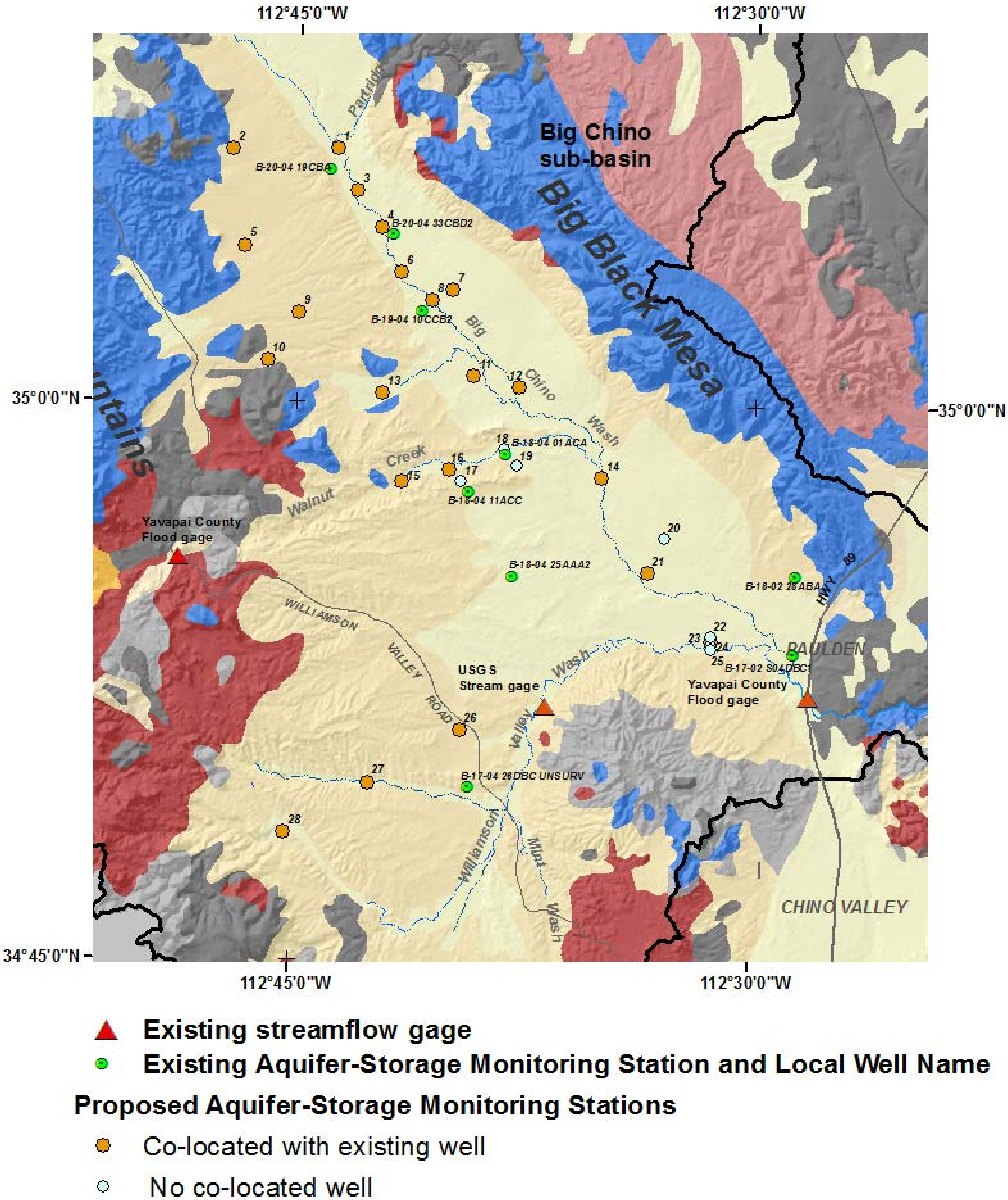

Figure 2. Locations of proposed aquifer-storage monitoring sites, existing aquifer-storage monitoring sites, and existing stream gages.

Table 1. Proposed and existing aquifer-storage monitoring stations in the Big Chino basin area. Existing stations are cooperatively funded by Yavapai County Water Advisory Committee and USGS.

Station Label on Fig. 2	Local Well Identifier	Purpose	Area
1	B-20-04 18CDC	Recharge and aquifer-storage properties	Big Chino Water Ranch
2	B-20-05 15CCC	Recharge and aquifer-storage properties	Juniper Mountain-Front
3	B-20-04 30AAD	Recharge and aquifer-storage properties	Big Chino Water Ranch
4	B-20-04 32ACA	Recharge and aquifer-storage properties	Big Chino Water Ranch
5	B-20-05 34CDD	Recharge and aquifer-storage properties	Juniper Mountain-Front
6	B-19-04 04CAC	Recharge and aquifer-storage properties	Big Chino Water Ranch
7	B-19-04 10ADA	Recharge and aquifer-storage properties	Big Chino Water Ranch
8	B-19-04 10CAB	Recharge and aquifer-storage properties	Big Chino Water Ranch
9	B-19-05 13BBA	Recharge and aquifer-storage properties	Juniper Mountain Front
10	B-19-05 23CBA	Recharge and aquifer-storage properties	Pine Creek
11	B-19-04 23DCB	Recharge and aquifer-storage properties	Pine Creek
12	B-19-03 30BCB1	Recharge and aquifer-storage properties	Pine Creek-Big Chino Wash
13	B-19-04 29DAB	Recharge and aquifer-storage properties	Pine Creek
14	B-18-03 09ABB	Recharge and aquifer-storage properties	Lower Big Chino Wash
15	B-18-04 09BAD	Recharge and aquifer-storage properties	Walnut Creek
16	B-18-04 03DDB	Recharge and aquifer-storage properties	Walnut Creek
17	No co-incident well	Recharge	Walnut Creek
18	No co-incident well	Recharge	Walnut Creek
19	No co-incident well	Recharge	Walnut Creek
20	No co-incident well	Recharge	Playa
21	B-18-03 23CCC	Recharge and aquifer-storage properties	Playa
22	No co-incident well	Recharge	Lower Williamson V. Wash
23	B-17-02 06BBB	Recharge and aquifer-storage properties	Lower Williamson V. Wash
24	No co-incident well	Recharge	Lower Williamson V. Wash
25	No co-incident well	Recharge	Lower Williamson V. Wash
26	B-17-04 14CDA	Recharge and aquifer-storage properties	Williamson Valley
27	B-17-04 29BDD	Recharge and aquifer-storage properties	Hitt Wash
28	B-17-05 35DDD	Recharge and aquifer-storage properties	Upper Williamson V. Wash
Existing	B-20-04 33CBD2	Recharge and aquifer-storage properties	Big Chino Water Ranch
Existing	B-20-04 19CBA	Recharge and aquifer-storage properties	Big Chino Water Ranch
Existing	B-19-04 10CCB2	Recharge and aquifer-storage properties	Big Chino Water Ranch
Existing	B-18-04 25AAA2	Recharge and aquifer-storage properties	Juniper Mountain Front
Existing	B-18-04 11ACC	Recharge and aquifer-storage properties	Walnut Creek
Existing	B-18-04 01ACA	Recharge and aquifer-storage properties	Walnut Creek
Existing	B-18-02 28ABA	Recharge and aquifer-storage properties	Paulden
Existing	B-17-04 26DBC	Recharge and aquifer-storage properties	Williamson Valley
Existing	B-17-02S04DBC1	Recharge and aquifer-storage properties	Paulden

Previous investigations have demonstrated the utility of gravity methods for monitoring the dissipation and expansion of the groundwater storage mound that develops as a result of periodic infiltration in ephemeral channels (Pool and Schmidt, 1997, and Pool, 2005). Similar methods will be applied in the study area by establishing gravity stations that will be paired with existing and proposed stream flow monitoring in Big Chino Wash, Walnut Creek, and Williamson Valley Wash (Fig. 3). Groundwater storage change near Big Chino Wash in the area of the Big Chino Water Ranch will monitor storage change in response to recharge at the wash. Where possible, the stations will be co-located at wells where coincident water levels can be observed. Two existing storage monitoring stations near Walnut Creek will be augmented with 6 additional stations to monitor storage change along profiles perpendicular to the channel. Aquifer-storage change near Williamson Valley Wash will be monitored with three stations between the channel and ADWR Index Well B-17-02 06BBB, the record for which clearly displays water-level recovery and drainage from recharge events (Blasch and others, 2005) in 1993 and 2005 (Fig. 3). The water-level monitoring in the Index Well will also be upgraded to include continuous data using a transducer. The stations designed to monitor ephemeral channel recharge will be surveyed 3 times per year as long as changes are observed. The frequency of observations will be decreased to once per year in the case where changes are not observed and no significant streamflow occurs. More frequent observations may be made following major streamflow events for the purpose of monitoring changes in the recharge mound.

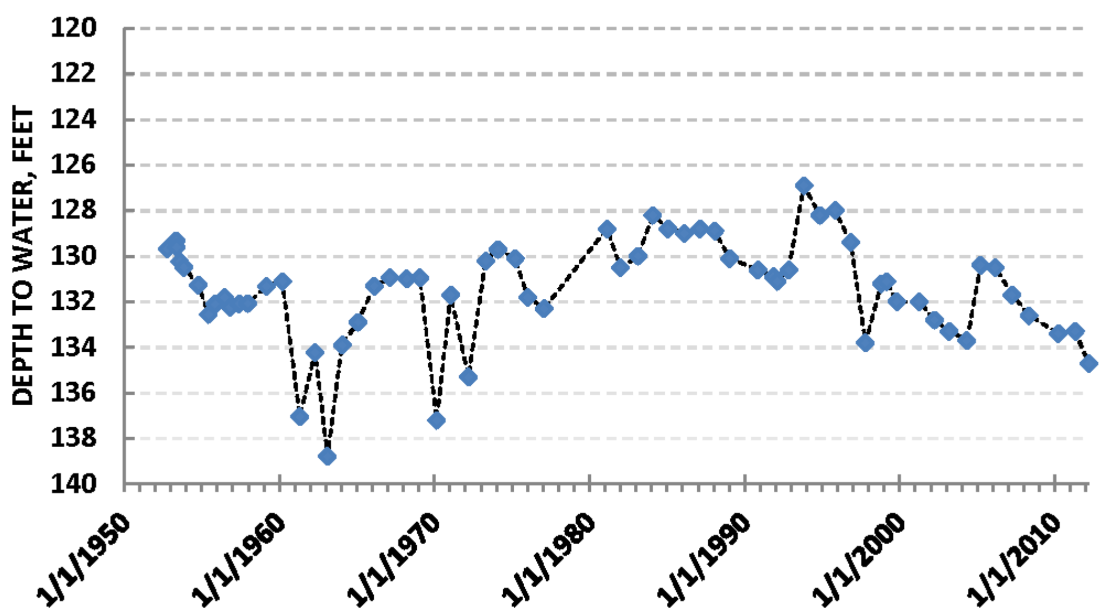

Figure 3. Hydrograph of ADWR Index Well B-17-02 06BBB.

Task 2. Geophysical surveys including electro-magnetic methods, borehole porosity and hydraulic conductivity surveys and evaluation of passive seismic methods for the area.

Geophysical methods will be employed to gather data regarding the subsurface environment in locations, with a distribution, and at a budget not possible using monitor wells. The geophysical surveys will also aid in site selection of planned deep monitoring wells. Methods will include electro-magnetic geophysical methods (ground-based transient electromagnetic (TEM) and controlled source audio-magnetotelluric (CSAMT)) methods). Passive seismic methods will be evaluated for their utility in the area. Borehole surveys of porosity and hydraulic conductivity will also be completed in available boreholes that are suitable for Nuclear Magnetic Resonance (NMR) methods. Electro-magnetic methods are minimally invasive field techniques that require sufficient space to lay out transmitter and receiver wires and coils on the land surface. Extensive undeveloped areas and farm-lands of the region are ideal for these methods. TEM methods are generally best for mapping lithologic variations within depths of a few hundred feet. CSAMT methods are better for mapping alluvial deposits at greater depths and offsets along faults. Passive seismic methods rely on monitoring of ground motion caused by local sources such as road traffic and farm machinery and distant sources including thunderstorms, ocean swells, and earthquakes. Monitoring of ground motion for periods of days or longer may require several post-hole size installations, but the passive seismic method is otherwise non-invasive. NMR methods in boreholes require 4-inch or larger diameter plastic cased holes with a minimum of annular space between the outside of the casing and the drill hole diameter. The USGS Arizona Water Science Center will use Center equipment for the electro-magnetic surveys and equipment rented from the USGS office of Groundwater for the passive seismic methods and borehole NMR surveys. Experienced USGS staff will carry out all of the surveys.

Geophysical methods will be applied in 3 general areas that are of interest to the cooperators (figs. 1 and 4) to address specific lithologic questions in Big Chino sub-basin. The 3 areas of interest include:

1. Paleozoic carbonate aquifer that lies to the north of the Verde River above the Paulden gage T18N R2W sec 26 to T18N R1W sec 30, T18N R2W sec 35 to T18N R1W sec 32, T17N R2W sec 2 to T17N R1W sec 5.
2. The purpose of geophysical surveys in area 2, the Paulden area, is to obtain structural and lithologic information. USGS proposes mapping the entire Paulden area rather than focusing on the area of the Big Chino fault.
3. The central and northern parts of the basin including the region of steep hydraulic gradients near Walnut Creek that appears to hydraulically compartmentalize the upper and lower parts of the alluvial basin. USGS plans a thorough mapping of the region.

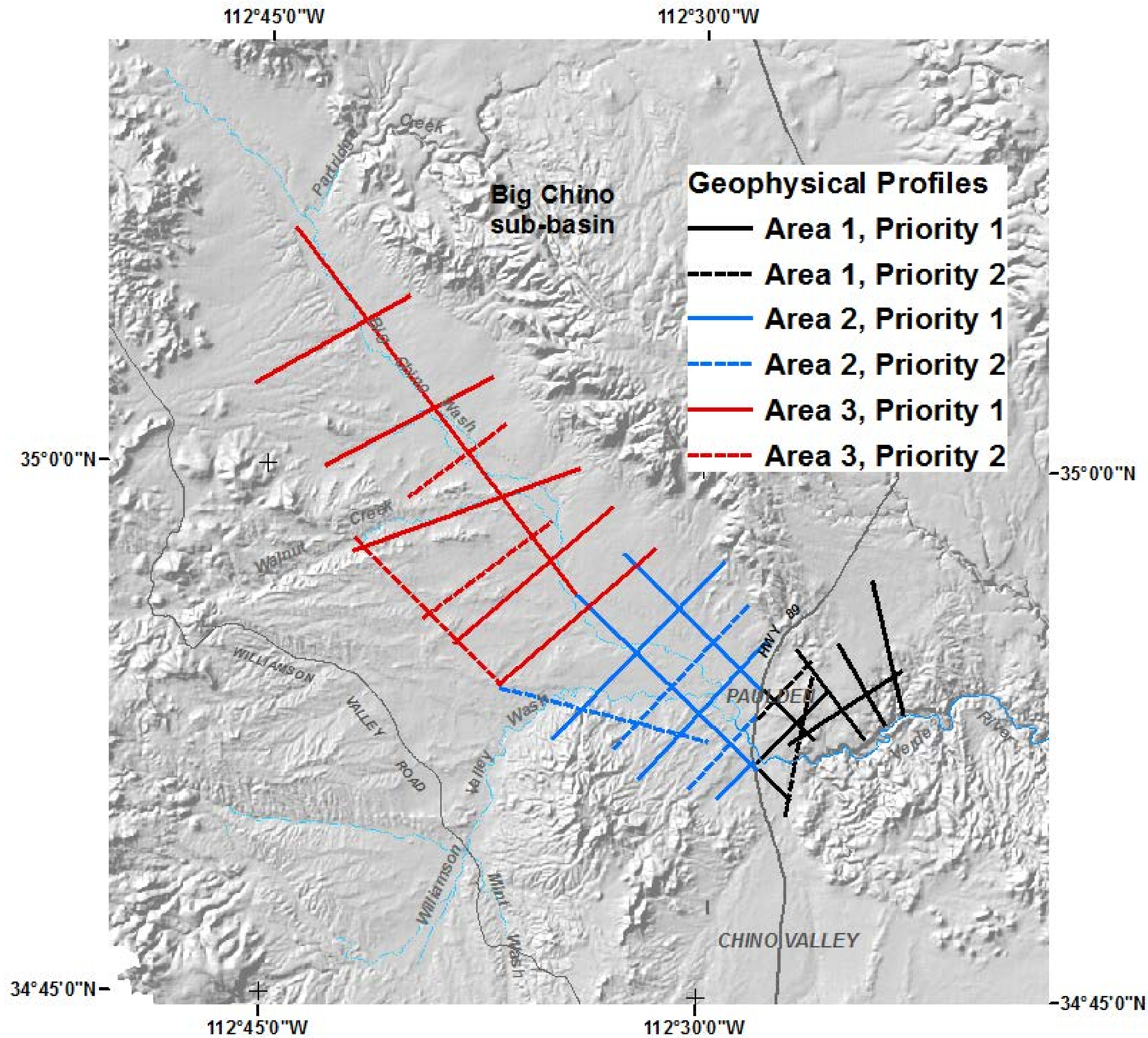

Figure 4. Proposed geophysical surveys including prioritized surveys (Priority 1 or 2) within Areas 1, 2 and 3.

Geophysical surveys will be completed using a 3-step process. Initial reconnaissance surveys of each area will be used to evaluate which method or combination of methods is best suited for the area. Data from the initial survey will be modeled and discussed with the cooperators before finalizing the types of methods and surveys to be used for each area. The bulk of the data collection for each area will occur during a second more intensive data collection phase that will include the Priority 1 profiles shown on Figure 4. A final data collection phase will include the proposed Priority 2 profiles or any other area that the Parties feel needs further data collection.

Targets of the surveys will include the aquifer extent and lithology, and geologic structures such as major vertical offsets along faults. In particular, the distributions of productive aquifer lithology (coarse-grained sediments and limestone), and poor aquifer materials (fine-grained sediments and crystalline rock), will be mapped. Depths of investigation will range from a few tens of meters to several hundred meters dependent on the expected depths of subsurface targets. Data processing will include subsurface electrical and seismic velocity models including identification of depth to bedrock and major zones of aquifer and aquitard materials.

Targets of surveys in Area 1 (fig. 4) include the thickness and extents of the alluvial deposits and Paleozoic carbonate aquifer and structural targets including offsets along the Mesa Butte and Big Chino Fault systems that may limit or transmit groundwater flow. Detailed data collected along profiles will be needed to map geologic structure in sufficiently useful detail. The specific location of profiles will be determined after evaluating available geologic information, drill logs, other geophysical data), and access to lands in the region. Six Priority 1 profiles are planned, 4 are aligned approximately NW-SE and 2 are aligned approximately NE-SW. Other lower priority profiles may be considered for densification of data sets provided time, funds, and cooperator needs require those data. The distribution of data collection sites along profiles may be as small 500 ft or as great as 1 mi between stations along multiple profiles. Geophysical methods for the area may include CSAMT for the mapping of offsets near any possible faults. TEM methods may be more appropriate for mapping major alluvial intervals of silt and clay, sand and gravel, and interbedded basalt flows, and the contact with underlying bedrock of siltstone, limestone, and volcanic rock.

The targets of surveys in Area 2 include the thickness and extent of the alluvial deposits, major intervals of silt and clay, interbedded basalt flows, and extent of the Paleozoic limestone. Data will be collected along detailed profiles will be using CSAMT or TEM methods. Five high-priority geophysical profiles are proposed in the area including 3 oriented in NE-SW directions and 2 perpendicular profiles than lie along NW-SE directions. Other lower priority profiles may be considered for densification provided time, funds, and cooperator needs require those data. The specific location of profiles will be determined after evaluating available geologic information including drill logs, other geophysical data, and access to lands in the region.

The targets of surveys in Area 3 include the thickness, extent, and continuity of the alluvial and Paleozoic carbonate aquifers including offsetting faults, the extent and thickness of the silt and clay layers, and the thickness and extent of interbedded basalt flows. CSAMT is likely a more appropriate method for this area; there are more than several hundred feet of alluvium in Area 3 and likely structural features. Five high priority profiles are proposed including 4 profiles that cross the basin axis in a NE-SW orientation and 1 profile along the basin axis in a NW-SE orientation. Other lower priority profiles may be considered for densification of data sets provided time, funds, and cooperator needs require those data. It is anticipated that densification of the surveys may be needed in the area of steep hydraulic gradients. The specific location of profiles will be determined after evaluating available geologic information including drill logs, other geophysical data, and access to lands in the region.

Borehole Porosity and Hydraulic Conductivity Surveys

Nuclear Magnetic Resonance (NMR) methods are proposed to help determine aquifer properties in uncased or plastic cased boreholes. NMR applied as a borehole method measures the amount of water molecules that are free to move through porous aquifer materials relative to the molecules that are bound in minerals or on mineral surfaces. The primary results of the surveys produce a log of free water in the unsaturated zone and effective porosity for the saturated interval. Hydraulic conductivity of the aquifer materials in the logged interval can be estimated in many cases. USGS operates an NMR borehole tool that can be scheduled for surveys. At least two observation wells in the Big Chino have PVC casing and could potentially be surveyed with the instrument. Both wells, Local IDs B-19-04 10CCB2 (about 650 ft deep) and B-20-04 33CBD2 (about 420 ft deep) were installed by the City of Prescott in the Water Ranch area. Other boreholes are also likely available including several new shallow monitor wells that are planned by the cooperators.

Communications and Deliverables

Communications between the cooperators and USGS will be accomplished through informal and formal communications. Informal communications will be via telephone and email and will include exchange of data, clarification of previous work products, discussion of details regarding data collection methods and siting, and other similar topics as necessary. Informal cooperator interaction will be welcomed throughout the project. Formal communications will include progress updates and reports for each task, as described below.

- **Project progress updates**

The USGS will hold meetings with the cooperators as needed, up to quarterly in frequency, and in person or via remote-communication technology in order to regularly update progress made, and just as importantly, to seek input and guidance from the cooperators. Anticipated information exchanged in update meetings includes:

  - Status of aquifer-storage monitoring station installation
  - Status and issues regarding planning of USGS-conducted field-data collection
  - Collected data
  - Results of geophysical surveys
  - Plans for next phase of geophysical surveys
  - Progress on final report publication
  - Feedback from USGS to the cooperators regarding the planning and implementation of cooperator-conducted field-data collection

When feasible, material to be presented at update meetings will be furnished to the cooperators at least one week in advance of the meeting.

- **Reports publication**

Publication of peer-reviewed and publicly released reports documenting methods and results will play an essential role in building confidence in project results for the cooperators and for the public as a whole. Study results will be formally released in USGS-series reports and become publically available upon release; however, through the quarterly meetings described previously, the cooperators will be engaged in the process throughout the investigation and will be aware of findings. In addition to cooperator reviews, report products will have two independent colleague reviews. Until final USGS approval of reports, results cannot be publically released. Groundwater (well data) will be published annually on NWISWeb including relevant data collected by ADWR. All gravity data will be archived in the AzWSC Temporal Gravity Database. All data collected will follow applicable USGS standard field methods, be subject to QA/QC procedures, and be archived in appropriate databases.

Two USGS-series reports will be published as part of this project. The first will document aquifer-storage monitoring sites and early monitoring results. The second report will discuss the results of the geophysical surveys including the borehole surveys of porosity and hydraulic conductivity. A web page for the project will be maintained for the duration of the project. At the discretion of project staff, scientific journal articles may also result from this work. Such articles, although not a requirement of this project, would serve to strengthen the scientific integrity of the work. Cooperators will be given the opportunity to review and comment on articles prior to submission to peer review.

Schedule

The proposed work will be carried out in stages by task. Gantt charts (Tables 2-3) show the proposed project timeline by task. Monitoring of aquifer-storage change, Task 1, is recommended to occur over at least a 2-year period and preferably longer in order to monitor a range of hydrologic conditions. This task could be continued in later years to increase the period of record (lightly shaded cells in tables). Task 2, geophysical surveys, is scheduled by Area (1, 2, and 3) and by stages of the surveys including land owner contacts and permissions, reconnaissance of the area to determine precise areas to be surveyed, initial surveys to determine best geophysical methods to be applied for each area, Priority 1 survey lines, and Priority 2 survey lines. Area 1 is the highest priority area because results of the surveys could help the cooperators site the drilling of several shallow wells, which is tentatively planned to begin in the fall of 2014. All of the Area 1 surveys will be completed in the first year of the project and all but Priority 2 surveys in Area 1 will be completed within before the 4th quarter of the first project year. Borehole surveys of porosity and hydraulic conductivity are planned for the middle quarters of project year 2 to allow for the possible use of the method in the new shallow wells.

Table 2. Proposed project timeline for TASK 1 “Monitor aquifer-storage change and estimate aquifer-storage properties” by annual quarter starting with beginning quarter of Task funding. Lightly shaded cells designate possible continued monitoring.

TASK 1 - Monitor aquifer-storage change and estimate aquifer-storage properties	YEAR 1				YEAR 2				YEAR 3	
	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	1st Qtr	2nd Qtr
Locate new aquifer-storage monitoring stations										
Install new aquifer-storage monitoring stations										
Aquifer-storage monitoring										
Communications with cooperators										
Report 1 – Aquifer-storage monitoring										

Table 3. Proposed project timeline for TASK 2 “Geophysical and borehole porosity and hydraulic conductivity surveys” by annual quarter starting with beginning quarter of task funding

TASK 2 - Geophysical and borehole porosity and hydraulic conductivity surveys	YEAR 1				YEAR 2				YEAR 3	
	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	1st Qtr	2nd Qtr
Land owner contact and permission	■	■								
Area 1	■									
Area 2		■								
Area 3		■								
Reconnaissance for geophysical surveys	■	■	■							
Area 1	■	■								
Area 2		■	■							
Area 3		■	■							
Initial geophysical surveys	■	■	■	■						
Area 1	■	■								
Area 2			■	■						
Area 3			■	■						
Initial geophysical survey analysis	■	■	■	■						
Area 1	■	■	■							
Area 2			■	■						
Area 3			■	■						
Complete Priority 1 geophysical surveys		■	■	■	■	■				
Area 1		■	■							
Area 2				■	■	■				
Area 3				■	■	■				
Complete Priority 2 geophysical surveys			■	■	■	■	■			
Area 1			■	■						
Area 2					■	■	■			
Area 3					■	■	■			
Complete geophysical survey analysis						■	■			
Borehole porosity and hydraulic conductivity Surveys						■	■			
Communications with cooperators	■	■	■	■	■	■	■	■		
Report 2 - Geophysical surveys						■	■	■	■	

Budget, Personnel, and Billing

The project budget for each task is presented by year of funding in Tables 4a-c. The proposed project requires a wide variety of skillsets for successful implementation. USGS will assemble a project team that reflects expertise in the hydrogeology of the area and in geophysical field data collection and analysis. Workplan budgeting included a project chief plus field support from students, hydrologic technicians, and hydrologists.

Geophysics and aquifer storage-change monitoring, will be performed by USGS personnel and are specifically budgeted in this workplan. In addition, data used by the USGS in the analysis, regardless of source, will be archived in the USGS National Water Information System database.

The cooperators will be billed for station installations and monitoring described in TASK 1 on the basis of work completed. Billing occurs quarterly in March, June, August, and December, and will reflect the number of installations or monitoring observations completed in each quarter. Aquifer-storage monitoring will be billed as a cost for each installation, $900, and a cost for each observation, also at a rate of $900 per observation. Installation of as many as 30 sites is planned and as many as 180 observations at 30 sites are planned over a two-year period following site installation during the first 2 quarters of year 1. Total yearly costs shown in Table 4a are the maximum costs assuming all 180 possible observations are made. The actual schedule of observations and costs and will be determined by agreement with the cooperators. It is anticipated that all installed sites will be observed twice during the first year. Any trends in the first 2 observations will be evaluated and future monitoring schedules for each site may be modified thereafter. The TASK 2 geophysics will be billed in four equal amounts in each federal fiscal year (December, March, June, and August) based on the year’s funding.

Table 4a. Budget for Task 1 “Monitor aquifer-storage change and estimate aquifer-storage properties” and associated report task by funding year. Two complete years of monitoring are needed, therefore, the full task including installation, monitoring, and a report requires a partial third year. Costs reflect year totals assuming 2 observations at each of 30 stations during year 1, 3 observations at each of 30 stations during year 2, and 1 observation at each of 30 stations during year 3. Actual costs will be determined on the basis of total observations made at $900 per observation

Task	Cost per Site Installation or Observation	Project Year		
		1	2	3
Install as many as 30 new aquifer-storage monitoring stations including 1 water-level transducer	$900	$27,000		
Aquifer-storage monitoring at 30 sites, 2 surveys in first year and 3 surveys per year thereafter. Actual number observations each year will vary.	$900	$54,000	$81,000	$27,000
Report including publication				$25,000
Total		$81,000	$81,000	$52,000

Table 4b. Budget for Task 2 “Geophysical surveys including borehole porosity and hydraulic conductivity surveys and assessment of passive seismic methods” and associated report task by funding year.

Task	Project Year		
	1	2	3
Geophysical surveys and data analysis including evaluation of passive seismic methods for the area	$132,000	$130,000	
Borehole porosity and hydraulic conductivity surveys	$25,000		
Report including publication		$54,000	$10,400
Total	$157,000	$184,000	

Table 4c. Total budget and funding split between the Cooperators and USGS. Cooperative Match Funding in years 2 and 3 is subject to congressional appropriations

Funding Entity	**Project Year**		
	1	**2**	**3**
The Cooperators	$188,000	$215,000	$52,000
USGS Cooperative Match Program	$50,000	$50,000	$10,400
Total	$238,000	$265,000	$62,400

Selected References

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