BOARD OF SUPERVISORS AGENDA ITEM REPORT
CONTRACTS / AWARDS / GRANTS

Requested Board Meeting Date: June 6, 2017

or Procurement Director Award ☐

Contractor/Vendor Name (DBA): U.S. Geological Survey (USGS), Department of the Interior

Project Title/Description:
Joint Funding Agreement (JFA) for Aquifer Storage Change and Land-Surface Elevation Change Monitoring in the Tucson Active Management Area Aquifer (Aquifer)

Purpose:
This JFA is a funding contribution from the Pima County Regional Flood Control District to this USGS project The purpose of this JFA between the USGS, Department of the Interior is to monitor changes in water stored in the Aquifer and evaluate land surface change, which may impact infrastructure, cause subsidence and land fissures.

Procurement Method:
Exempt from Procurement Code - JFA with the USGS, Department of the Interior

Program Goals/Predicted Outcomes:
Improve our knowledge of existing water resources and threats to infrastructure from loss of water in the Aquifer and subsequent land-surface elevation change.

Public Benefit:
Obtain a better capacity to estimate risks from land-surface changes to roads, sewer lines, and foundations, as well as knowledge of changes in water resource volume availability and physical location.

Metrics Available to Measure Performance:
Annually, the USGS, Department of the Interior will provide us with interpretive maps, a presentation on the updated data, and periodic technical reports.

Retroactive:
No

To: CoB 5-17-17 (3)
Ver. - 1
pgs. 18

Original Information

Document Type: ____________ Department Code: __________ Contract Number (i.e.,15-123): CT-FC-17*230

Effective Date: 07/01/2017 Termination Date: 06/30/2020 Prior Contract Number (Synergen/CMS): ____________

☒ Expense Amount: $ 69,000 ☐ Revenue Amount: $ ____________

Funding Source(s): Flood Control Tax Levy

Cost to Pima County General Fund: 0

Contract is fully or partially funded with Federal Funds? ☒ Yes ☐ No ☐ Not Applicable to Grant Awards

Were insurance or indemnity clauses modified? ☒ Yes ☐ No ☐ Not Applicable to Grant Awards

Vendor is using a Social Security Number? ☐ Yes ☒ No ☐ Not Applicable to Grant Awards

If Yes, attach the required form per Administrative Procedure 22-73.

Amendment Information

Document Type: ____________ Department Code: __________ Contract Number (i.e.,15-123): ____________

Amendment No.: ____________ AMS Version No.: ____________

Effective Date: ____________ New Termination Date: ____________

☐ Expense ☐ Revenue ☐ Increase ☐ Decrease Amount This Amendment: $ ____________

Funding Source(s):

Cost to Pima County General Fund: ____________

Contact: Evan Canfield, Civil Engineering Manager

Department: Regional Flood Control District Telephone: 724-4636

Department Director Signature/Date: [signature] 5/3/17

Deputy County Administrator Signature/Date: [signature] 5/5/17

County Administrator Signature/Date: [signature] 5/5/17

(Required for Board Agenda/Addendum Items)

Form 9-1366
(April 2015)

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

JOINT FUNDING AGREEMENT

Customer #:	6000000793/AZ012
Agreement #:	17CMAZ00600
Project #:	ZF009EF
TIN #:	86-6000543
Fixed Cost Agreement	YES

FOR

WATER RESOURCES INVESTIGATIONS

THIS AGREEMENT is entered into as of the, 7th day of April, 2017 by the U.S. GEOLOGICAL SURVEY, UNITED STATES DEPARTMENT OF THE INTERIOR, party of the first part, and the PIMA COUNTY REGIONAL FLOOD CONTROL DISTRICT, party of the second part.

1. The parties hereto agree that subject to availability of appropriations and in accordance with their respective authorities there shall be maintained in cooperation an investigation of aquifer storage change and land subsidence in the Tucson Basin and Avra Valley as described in the attached workplan herein called the program. The USGS legal authority is 43 USC 36C; 43 USC 50; and 43 USC 50b.

2. The following amounts shall be contributed to cover all of the cost of the necessary field and analytical work directly related to this program. 2(b) includes In-Kind Services in the amount of $0.00 .

   (a) by the party of the first part during the period

Amount	Date	to	Date
$51,000.00	July 1, 2017		June 30, 2020

   (b) by the party of the second part during the period

Amount	Date	to	Date
$69,000.00	July 1, 2017		June 30, 2020

   Total=$120,000.00

   (c) Contributions are provided by the party of the first part through other USGS regional or national programs, in the amount of: $0.00

   Description of the USGS regional/national program:

   (d) Additional or reduced amounts by each party during the above period or succeeding periods as may be determined by mutual agreement and set forth in an exchange of letters between the parties.

   (e) The performance period may be changed by mutual agreement and set forth in an exchange of letters between the parties.

3. The costs of this program may be paid by either party in conformity with the laws and regulations respectively governing each party.

4. The field and analytical work pertaining to this program shall be under the direction of or subject to periodic review by an authorized representative of the party of the first part.

5. The areas to be included in the program shall be determined by mutual agreement between the parties hereto or their authorized representatives. The methods employed in the field and office shall be those adopted by the party of the first part to insure the required standards of accuracy subject to modification by mutual agreement.

6. During the course of this program, all field and analytical work of either party pertaining to this program shall be open to the inspection of the other party, and if the work is not being carried on in a mutually satisfactory manner, either party may terminate this agreement upon 60 days written notice to the other party.

Contract No: CT-FC-17-230 Amendment No: ______
This number must appear on all correspondence and documents pertaining to this contract

7. The original records resulting from this program will be deposited in the office of origin of those records. Upon request, copies of the original records will be provided to the office of the other party.

8. The maps, records, or reports resulting from this program shall be made available to the public as promptly as possible. The maps, records, or reports normally will be published by the party of the first part. However, the party of the second part reserves the right to publish the results of this program and, if already published by the party of the first part shall, upon request, be furnished by the party of the first part, at costs, impressions suitable for purposes of reproduction similar to that for which the original copy was prepared. The maps, records, or reports published by either party shall contain a statement of the cooperative relations between the parties.

9. USGS will issue billings utilizing Department of the Interior Bill for Collection (form DI-1040). Billing documents are to be rendered quarterly. Payments of bills are due within 60 days after the billing date. If not paid by the due date, interest will be charged at the current Treasury rate for each 30 day period, or portion thereof, that the payment is delayed beyond the due date. (31 USC 3717; Comptroller General File B-212222, August 23, 1983).

U.S. Geological Survey United States Department of the Interior		Suzanne Shields	
USGS Point of Contact		**Customer Point of Contact**	
Name:	James M. Leenhouts	Name:	97 E. Congress, 3rd Floor
Address:	520 N. Park Ave., Suite 221 Tucson, AZ 85719	Address:	Tucson, AZ 85701
Telephone:	520-670-6671 x278	Telephone:	520-243-1800
Email:	leenhout@usgs.gov	Email:	suzanne.shields@rfcd.pima.gov

Signatures and Date

Signature:	Jam M. Leenhouts	Date: 04/07/17	Signature:	S Shields	Date: 5/3/17
Name:	James M. Leenhouts		Name:		
Title:	Director		Title:		

APPROVED AS TO FORM: & within the powers & authority granted under the laws of this state

Deputy County Attorney

ANDREW FLAGG

PIMA COUNTY
BOARD OF DIRECTORS

Chairman

ATTEST:

Clerk of the Board

Aquifer-Storage Change and Land-Surface Elevation Change Monitoring in the Tucson Active Management Area

2017-2020

Introduction and Results

Aquifer-storage change has been monitored by the U.S. Geological Survey (USGS) within the Tucson Active Management Area (AMA) since 1996. The USGS began a cooperative study with Metropolitan Domestic Water Improvement District and the town of Oro Valley in 1996 to monitor aquifer-storage change in the Lower Cañada del Oro sub-basin. In 1998, the USGS began a cooperative study with the Arizona Department of Water Resources (ADWR), Pima County, and the City of Tucson to monitor land-surface elevation change and aquifer-storage change in the Tucson AMA. In 2003, these two monitoring studies were combined, and the town of Marana joined the study.

Results of the monitoring period from 2014 to 2016 indicate that basin-wide positive aquifer storage change occurred for the first time in the Tucson Basin and continues to occur in Avra Valley (figures 1 and 2). Estimated aquifer storage increased by 350,000 acre-ft in the Tucson Basin and by 280,000 acre-ft in Avra Valley from 2014-2016. Additionally, results from the extensometer network show that water levels continue to recover in both basins and rates of compaction are beginning to decrease or cease in some areas. In other areas, latent compaction from previous maximum water-level declines continues to occur (figures 3 and 4).

This proposal outlines a scope of work for continued and expanded monitoring of both aquifer-storage change and land-surface elevation change in the Tucson AMA for the period of July 1, 2017 through June 30, 2020.

Aquifer-Storage Change

Aquifer-storage can be monitored by measuring changes in gravity. As water is added or removed from the aquifer, there is a change in mass and a corresponding measurable change in gravity. Gravity also is affected by changes in land-surface elevation, so monitoring of land-surface elevation change is essential for accurate measurement of aquifer-storage change.

Water levels in wells commonly are monitored to estimate aquifer-storage changes. However, use of water-level variations entails significant assumptions about the hydraulic properties of the aquifer system. One difficulty is the heterogeneity of hydrologic properties of the aquifer; the alluvial sediments of the aquifer vary in lithology and texture, both laterally and with depth. Thus, data from individual wells may not represent aquifer characteristics some distance away from the well. A second difficulty is monitor-well design; in Tucson Basin, most water levels are measured in deep wells that tap multiple aquifer layers, most of which are confined and have accordingly low storage properties. Water levels in these deep wells are a composite of water levels from several aquifer units. When these composite water levels are used to estimate storage changes, the hydrologic properties used in the calculation typically do not reflect the range of aquifer materials over which the well is screened. Because of these complexities and requisite assumptions, use of water-level variations as the only indicators of storage change can be uncertain, and cannot be reliably extrapolated beyond the well location.

Monitoring of gravity and water levels in Tucson Basin has shown that large changes in groundwater storage, as much as several feet of water, have occurred that were not reflected in comparable water-level changes. The extent to which water levels are influenced by storage changes are directly related to the proximity of the well to the recharge area. Closer proximity yields an earlier and more discernible water-level response. Water-level responses also depend on the geometry and lithology of the sedimentary layers in the aquifer system that wells sample. This information often is incomplete, or uncertain. All of this points to the need for a combination of storage-change and water-level data, which together enable defensible estimates of aquifer specific yield distribution.

Land-Surface Elevation Change

Permanent land subsidence can occur in alluvial basins when water is removed from aquifer systems (Galloway and others, 1999). Aquifer systems in unconsolidated rocks such as those in the Tucson AMA are supported by the granular skeleton and the pore-fluid pressure. When groundwater is withdrawn and the pore-fluid pressure is reduced, the granular skeleton is compressed, causing some lowering of the land surface. Both the aquifers (sand and gravel) and aquitards (clay and silt) of aquifer systems are deformed as a result of changes to the pore-fluid pressure and skeleton, but to different degrees. Most permanent subsidence occurs due to the irreversible compression of aquitards during the slow process of aquitard drainage (over a number of years).

Permanent subsidence, seasonal elastic deformation, and uplift have been observed in Tucson Basin and Avra Valley. Rates of compaction in Tucson Basin in relation to water-level decline have been less than 0.5 foot per 100 feet of water-level decline. Comparison with the Eloy and Phoenix areas (greater than 1 foot per 100 feet of decline) suggests that compaction to date in the Tucson region has been largely elastic and recoverable. Compaction and land subsidence can be slowed or stopped, and in areas having appropriate geologic conditions, reversed to some extent by eliminating groundwater withdrawals or through artificial recharge.

The City of Tucson has increased delivery of recharged, recovered, and blended Central Arizona Project (CAP) water, while reducing pumping from the Central Well Field. This appears to have reduced or stopped water-level declines an induced recovery in most areas. However, subsidence due to previous levels of pumping and maximum water-level declines will continue in some areas into the future. Continued monitoring of areas having the greatest potential for subsidence will provide information that resource managers can use in the development and implementation of mitigation efforts.

Objectives

The objectives of this project are to monitor aquifer-storage change and land-surface elevation change within the Tucson AMA.

Approach

Land-surface elevation change is monitored at a network of benchmarks (figure 1) throughout the Tucson AMA by measuring changes in land surface elevation over time (approximately annually) with Interferometric Synthetic Aperture Radar (InSAR) and targeted GPS surveys. The Arizona Department of Water Resources (ADWR) has an InSAR program in the Tucson AMA. InSAR is a technique that utilizes interferometric processing to compare the amplitude and phase signals received during one pass of the satellite-based SAR platform over the AMA with the amplitude and phase signals received during a second pass of the platform over the same area but at a different time.

The InSAR data are used by ADWR to produce a land-surface elevation-change map over the same time period as the targeted GPS surveys conducted by the USGS in the Tucson AMA. The ADWR provides the elevation-change maps to the USGS as an in-kind contribution to the project in exchange for absolute gravity data collection in the other state AMA's. The GPS data are then used to compare with and constrain the InSAR deformation information. The annual combined InSAR/GPS product provides a much broader coverage of land-surface deformation information than could be feasibly obtained with GPS alone.

Aquifer-storage change is monitored by measuring changes in gravity over time at the same network of benchmarks (figure 1). Gravity is affected by mass and distance; a change in mass or a change in elevation will cause a change in gravity. Groundwater depletion is a mass change and land-surface elevation change is a distance change. By removing the effect of change in distance, changes in gravity are used to determine changes in aquifer-storage.

Temporal-gravity surveys are used in the Tucson AMA to detect local changes in the gravitational field of the Earth attributed to water mass change. The method is readily applied to measurement of aquifer-storage change in the AMA because of the occurrence of significant variations in pore-space storage that result from ground-water withdrawal, periodic natural recharge events, and focused artificial recharge. Two instruments are used at the network of benchmarks: the relative gravity meter and the absolute gravity meter. The relative meter is the primary instrument by which differences in gravity are monitored at stable monuments. Much as control benchmarks are used in conventional land surveying, repeated relative gravity surveys for ground-water storage monitoring should include reference stations where the absolute acceleration of gravity is monitored. The USGS uses a Micro-g LaCoste A-10 field-portable absolute gravity meter to establish these reference stations as needed. This is particularly valuable in a hydrologic context where a number of absolute stations may be located throughout a basin, thereby serving to constrain and adjust the gravity differences from relative gravity surveys.

Gravity surveys are conducted approximately annually at the entire network of benchmarks in order to estimate aquifer-storage change (figure 2). GPS surveys also are conducted annually at the portion of the network that previous surveys have shown to be the most active areas of land-surface elevation change. The network of benchmarks may be modified and/or expanded in areas of poor coverage to improve resolution. These areas include Avra Valley, Sahuarita, and central Tucson. Gravity measurements will increasingly be made using the A10 portable absolute gravimeter; this will allow for fewer relative gravity measurements, thus improving the efficiency of data collection.

Benefits

Aquifer-storage monitoring

Microgravity surveys are an efficient, noninvasive means of measuring changes in the amount of groundwater in Southwestern alluvial basins. Monitoring changes in groundwater storage in the Tucson AMA is a means to monitor the status of the basin aquifers and to track the progress toward the statutory goals of the 1980 Groundwater Management Act. This will be of value as water-supply entities in eastern Pima County address needs to manage and augment groundwater resources. The most significant value would accrue as the city further implements aquifer storage and recovery efforts in Avra Valley and the Tucson Basin. As the storage and recovery projects reach anticipated capacity, pumping from the Central Well Field and Sahuarita areas will continue to be reduced. This decreased demand will, if withdrawals do not increase, enable water levels in the aquifer to recover.

Water-level data entail assumptions about aquifer and well properties; thus, monitoring of gravity changes as pumping decreases in the basin currently is the only way to measure attendant changes in the amount of water in the aquifer and determine if and when aquifer recovery is occurring. This information conceivably will serve as part of a basis for decisions regarding distribution of groundwater withdrawals to help in mitigating land subsidence or aquifer storage losses in particular areas.

Aquifer-storage change is one of the three components of the groundwater budget. The other two are inflow to and outflow from the aquifer system. Measurement of aquifer-storage change and measures and estimates of outflow enable better estimation of recharge and development of a more reliable groundwater budget for the basin. Measures of aquifer-storage change increase the reliability and utility of groundwater flow and management models. Use of storage-change data to improve model calibration enables additional reduction in the uncertainty of model results. The improved understanding of the movement, distribution, volume, and availability of ground water, to which storage monitoring contributes, enables more effective water management in the Tucson AMA and in other areas of the State.

Surveys in the Tucson AMA since 1998 have provided previously unavailable data quantifying recharge and storage changes. For example, the results of aquifer-storage change monitoring in the Tucson Basin between 1998 and 2012 indicate that storage change and recharge can vary considerably from year to year. It is possible that just a few years may account for the majority of recharge to southwestern aquifers for an entire decade or more. These data are being used to improve the understanding of the aquifer systems and to improve groundwater flow models that will be used in resource planning.

Land-surface elevation change monitoring

Some types of infrastructure are more sensitive to changes in land slope than other types. Sewer systems are largely gravity driven, and are designed and constructed at slopes of about 2 feet per 1,000 feet. Small slope changes can cause operational problems under some conditions. Accurate determination of the rates, amounts, and distribution of land subsidence, together with delineation of higher-risk areas, will provide data upon which mitigation and protection plans can be based.

Subsidence rates will increase when the stress threshold between elastic and inelastic compaction is exceeded. Because it is not possible to reliably estimate when the threshold might be exceeded in the Tucson AMA, and infrastructure damage becomes more likely, subsidence monitoring also provides a means to identify the type of compaction that is occurring.

Groundwater withdrawals from the city's Central Well Field has been substantially decreased as CAP recharge and recovery reaches full capacity. However, regional subsidence in response to previous pumping is unlikely to end in the near future. It will continue until the aquifer system reaches pressure equilibrium. Observation of the timing and magnitude of aquifer responses will further improve the understanding of land subsidence and of how the aquifer systems function. Monitoring data also will contribute to a better understanding of the responses of the aquifer systems to withdrawals, and will provide additional insight in future plans for well-site selection, recharge efforts, and water-management programs. Additionally, monitoring data will continue to augment and serve as ground truth for satellite-based information that the ADWR is acquiring to enable broad-scale assessments of regional subsidence in the Tucson Basin.

Differential subsidence refers to a relatively large amount of subsidence over a relatively short distance, and can cause focused effects. For example, localized subsidence of as little as one-half inch can necessitate rebuilding a highway overpass. Differential subsidence has the potential to separate pipe joints of sewer and water lines—this can lead to system disruptions and roadway damage. Also vulnerable are the concrete lining sections of engineered channels that rely on the integrity of expansion joints to prevent flood damage. Costs to address such infrastructure failures are high. Awareness of the distribution and magnitude of differential subsidence can help to guide the design and implementation of maintenance and monitoring schedules, selection of monitoring methods, and the design and construction of future infrastructure.

Relevance and Benefits

This study addresses the science of aquifer-storage change and land-surface elevation change within the Tucson Active Management Area, specifically related to groundwater withdrawal and natural and artificial recharge. The study contributes to the goals of the USGS strategic science direction "A Water Census of the United States," as identified and described in the Strategic Science Plan of the USGS (U.S. Geological Survey, 2007).

Data Management Plan

USGS Fundamental Science Practices require that data collected for publication in databases or information products, regardless of the manner in which they are published (such as USGS reports, journal articles, and Web pages), must be documented to describe 1) the methods or techniques used to collect, process, and analyze data, 2) the structure of the output, 3) a description of accuracy and precision, 4) standards for metadata, and 5) the methods of quality assurance.

The gravity data for the project will be collected with a Microg Lacoste A-10 absolute gravimeter and relative gravimeters made by Lacoste and Romberg and ZLS Corporation. The gravity data will be collected using techniques consistent with published methodologies for using microgravity to investigate and monitor aquifer-storage change and land subsidence (Pool and Schmidt, 1997; Carruth and others, 2007; Pool and Anderson, 2007; Carruth and others, 2017 (in prep.)). The data will be added to datasets previously collected by Carruth and others (2007) and Pool and Anderson (2007) for the Tucson AMA aquifer-storage change and land-surface elevation change monitoring project (http://az.water.usgs.gov/projects/9671-9EF/). All data collected will be published on a publicly available database to be kept in perpetuity. The USGS ScienceBase (sciencebase.gov) database is a likely publication outlet. A digital object identifier (DOI) will be generated for the published database. Data collected from previous years will be stored and served on the database, and newly collected data will be published on the database as they are reviewed, checked, and approved.

All gravity data for the project will be collected, processed, reviewed, approved, and published following QA/QC protocols established by the USGS Southwest Gravity Program (USGS, in prep.). All gravity data will be collected by trained USGS personnel—absolute gravity data will be collected approximately every 6 months and relative gravity data will be collected approximately annually. Gravity data will be processed by USGS personnel in the office within 3 months of data collection. An experienced reviewer will review and check the data for accuracy, then the project chief will release the data as a published ScienceBase data release. All metadata will be documented in the ScienceBase data release as well as in Carruth and others, (2017 in prep). Once published, the data will be fully accessible to anyone inside or outside the USGS.

Products

1) Annual interpretive maps of aquifer-storage change and land-surface elevation change in the Tucson AMA (available to all cooperators and to the public on http://az.water.usgs.gov/).

2) Oral presentation of findings to all cooperators each year.

3) Oral presentation of findings at a state or national professional society meeting each year or as funding permits.

Work Schedule and Budget

Fixed-cost funding information for this project is provided in tables 1 and 2. Table 1 presents the schedule of work activities over the project life. Table 2 presents the summary of funding by agency. It is understood that all agency funds in future years are subject to appropriation.

Table 1—Schedule of work activities.

Work Tasks	Year 1				Year 2				Year 3			
1. GPS and InSAR surveys												
2. Gravity surveys												
3. Data post processing, analysis, and interpretation												
4. Preparation of annual digital maps of aquifer-storage change and land-surface elevation change												
5. Oral Report to project cooperators												
6. Oral Presentation at state or national professional meeting												
7. Review, revision and approval of annual maps of aquifer-storage change and land-surface elevation change												
8. Posting of annual maps to http://az.water.usgs.gov/ and distribution to project cooperators												

Table 2—Summary of funding by agency.

Note: Funding distributions shown are proposed for the July 1, 2017 through June 30, 2020 project period. A table reflecting the final distribution will be provided to all participants following completion of funding agreements.

Table 2. Summary of funding by agency

Agency	Year 1	Year 2	Year 3	Total Share
USGS	26,000	26,000	26,000	78,000
ADWR	35,000	35,000	35,000	105,000
USGS	17,000	17,000	17,000	51,000
Pima County	23,000	23,000	23,000	69,000
USGS	8,000	8,000	8,000	24,000
Town of Oro Valley	10,000	10,000	10,000	30,000
USGS	4,000	4,000	4,000	12,000
Town of Marana	5,000	5,000	5,000	15,000
USGS	4,000	4,000	4,000	12,000
Metro Water	5,000	5,000	5,000	15,000
Total Annual Cooperators	78,000	78,000	78,000	234,000
Total Annual USGS	59,000	59,000	59,000	177,000
Totals	**137,000**	**137,000**	**137,000**	**411,000**

References

Carruth, R.L., Pool, D.R., Anderson, C.E., 2007, Land subsidence and aquifer-system compaction in the Tucson Active Management Area, south-central Arizona, 1987–2005: U.S. Geological Survey Scientific Investigations Report 2007-5190, 27 p.

Pool, D.R., and Schmidt, W., 1997, Measurements of ground-water storage change and specific yield using the temporal-gravity method near Rillito Creek, Tucson, Arizona: U.S. Geological Survey Water-Resources Investigations Report 97–4125, 30 p.

Pool, Donald R., and Anderson, Mark T., 2008, Ground-water storage change and land subsidence in Tucson Basin and Avra Valley, southeastern Arizona, 1998-2002: U.S. Geological Survey Scientific Investigations Report 2007-5275, 34 p.

U.S. Geological Survey, 2007, Facing tomorrow's challenges—U.S. Geological Survey Science in the Decade 2007-2017: U.S. Geological Survey Circular 1309, 69 p.

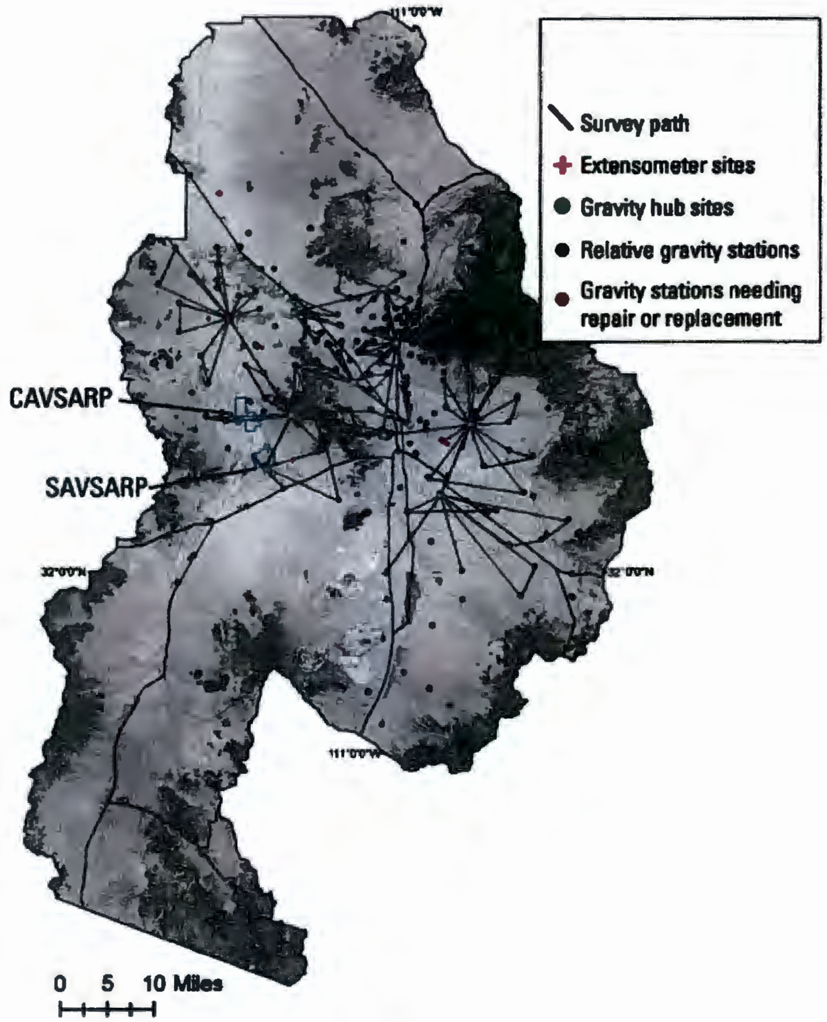

Figure 1. Map of gravity network in the Tucson Active Management Area.

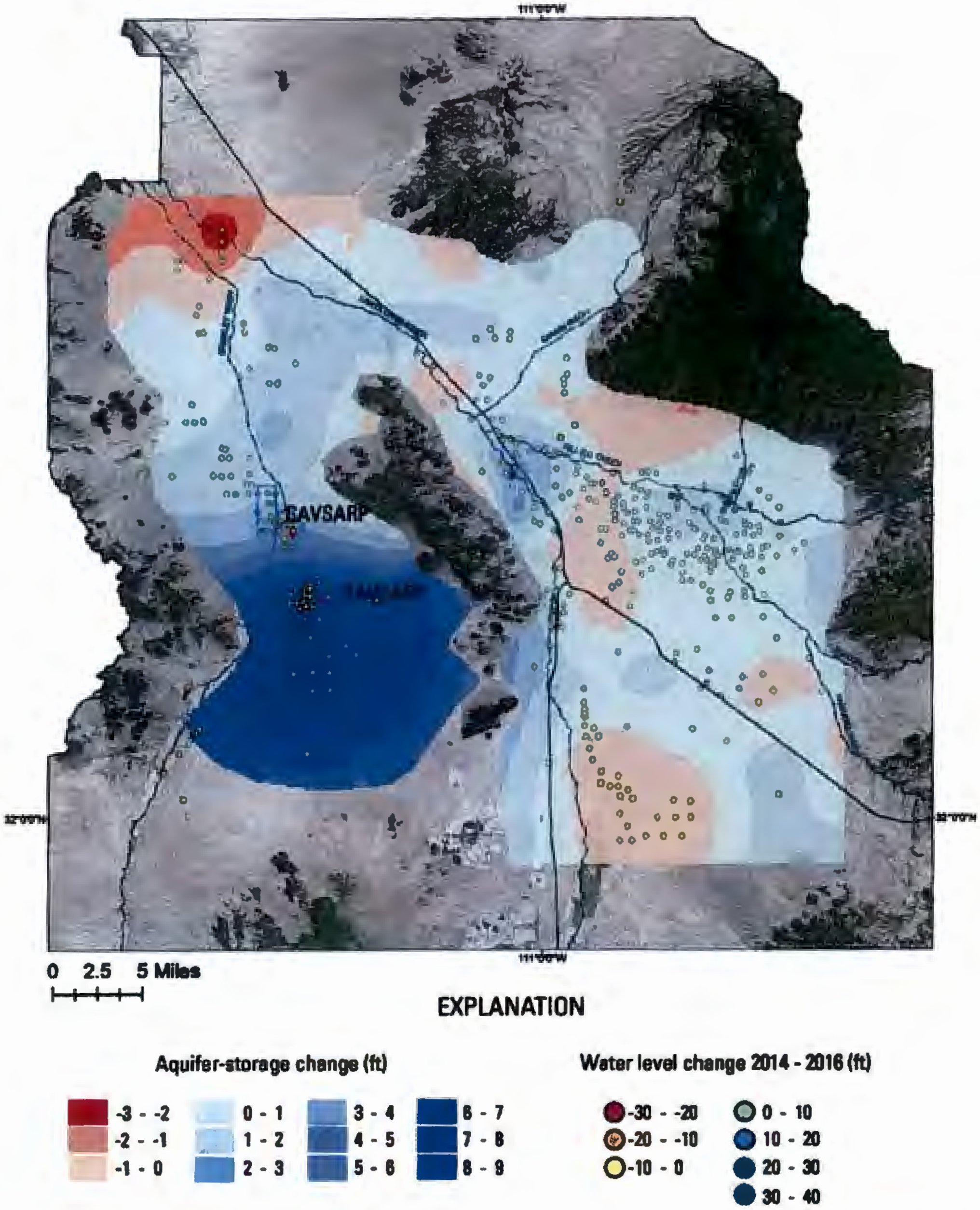

Figure 2. Map of aquifer-storage and water-level change in the Tucson Active Management Area, 2014-2016.

Analysis is preliminary and subject to revision.

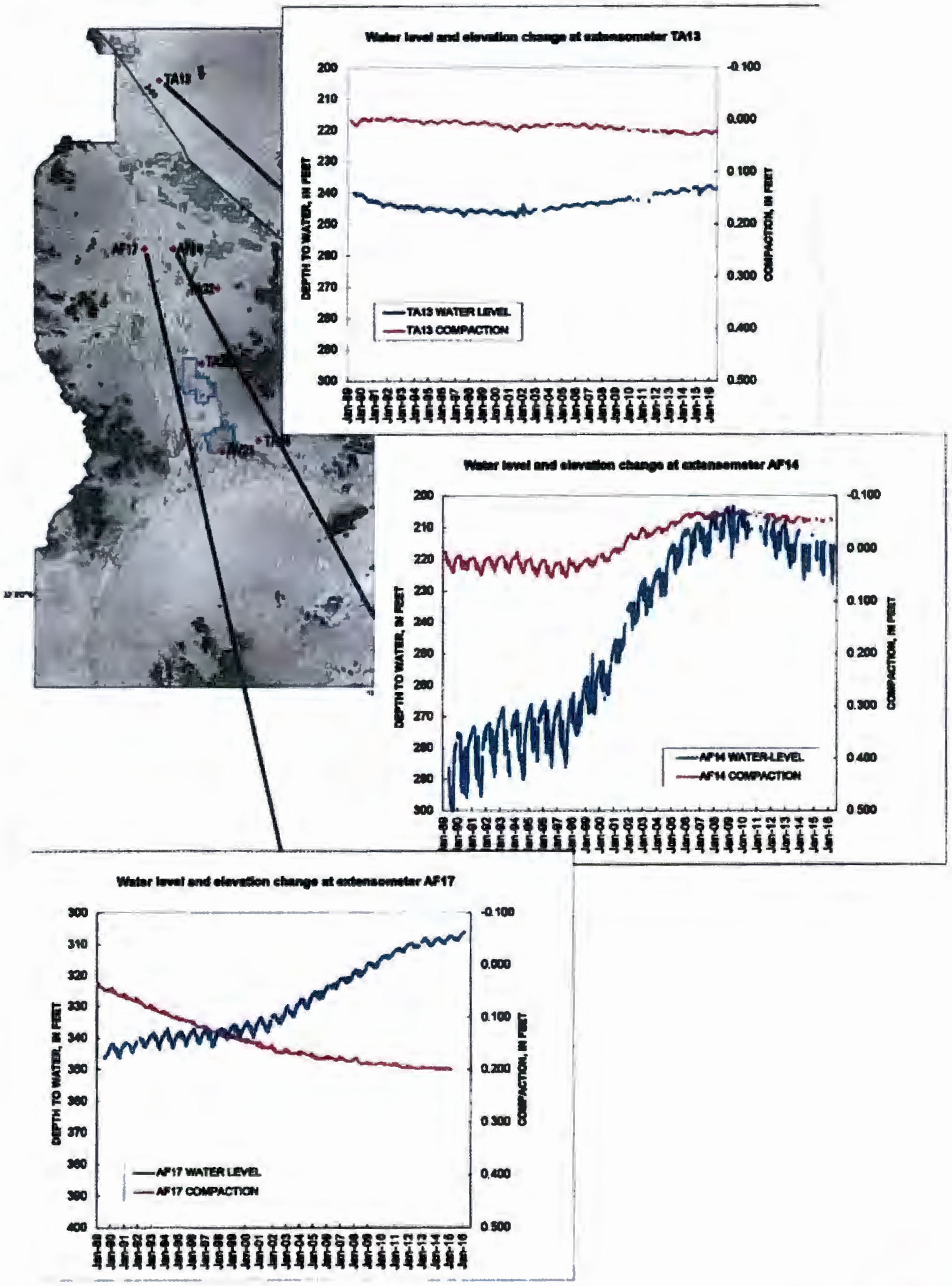

Figure 3a. Water level and land-surface elevation change at northern Avra Valley extensometers.

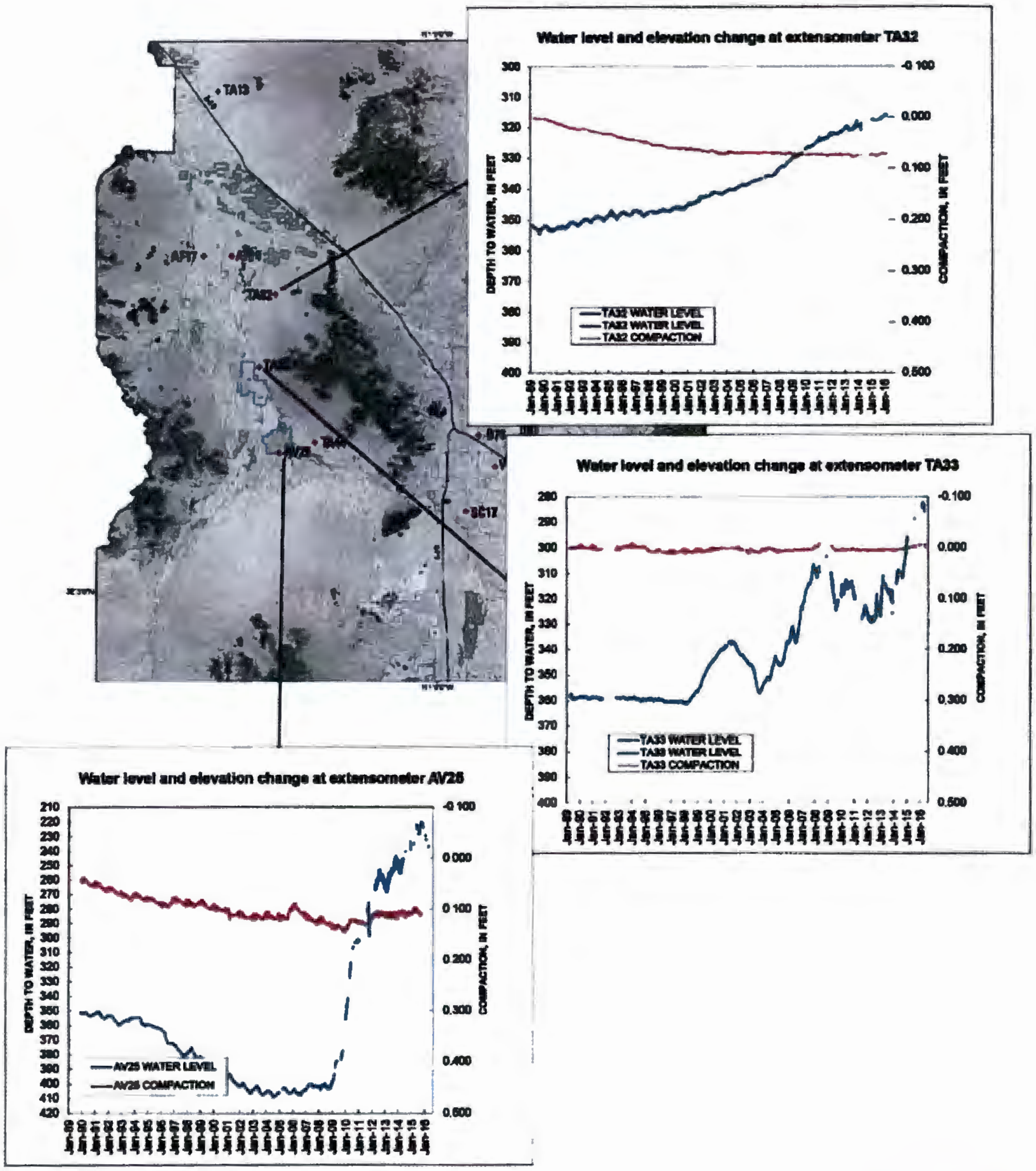

Figure 3b. Water level and land-surface elevation change at central Avra Valley extensometers.

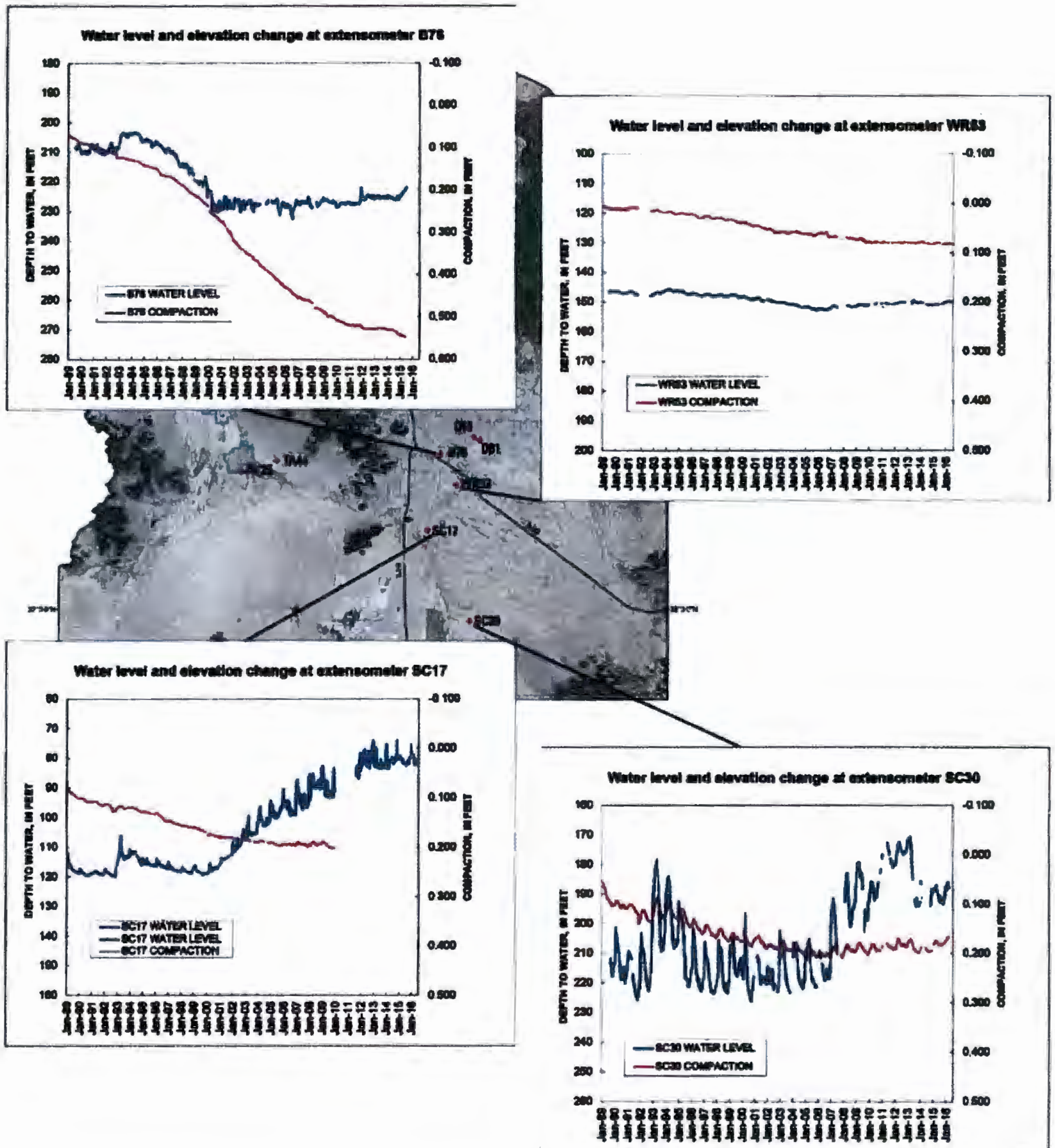

Figure 4a. Water level and land-surface elevation change at Tucson Basin extensometers.

USGS
science for a changing world

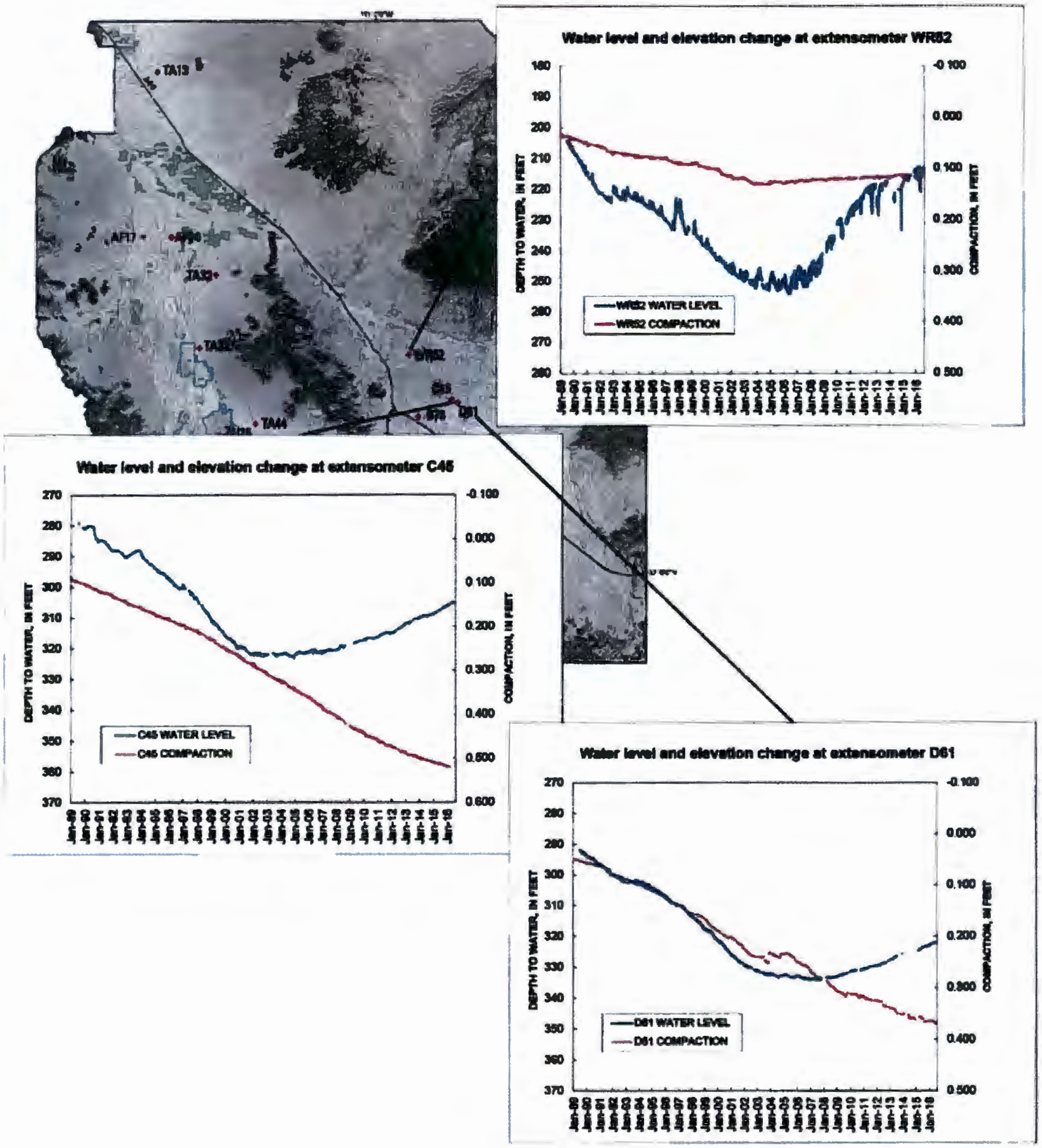

Figure 4b. Water level and land-surface elevation change at Tucson Basin extensometers.