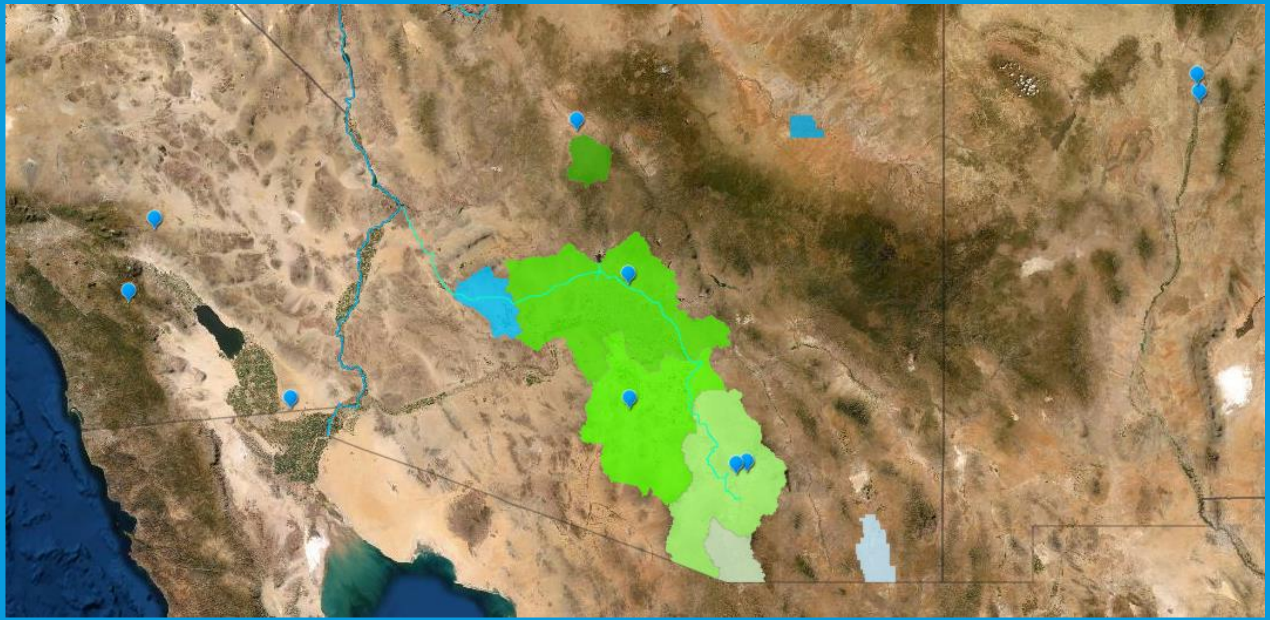
REVIEW OF GRAVITY DATA COLLECTED IN THE SAN PEDRO AREA, 2008 -2015

USGS SOUTHWEST GRAVITY PROGRAM:



- Method (repeat microgravity) first developed at Univ. of Arizona, then USGS
- Joint effort by Arizona, New Mexico, and California Water Science Centers, USGS Cooperative Water Program, Cooperators
- Quantitative geophysics:
  - Data review and archival
  - **Online-accessible database:**
    https://go.usa.gov/x7buN
  - Techniques and Methods Report
  - Office software and mobile app for reproducible science

USGS

What is repeat microgravity?

A very small change in gravity can be measured by sensitive instruments at the microGal level (1 microGal = 10 nm/s^2)

This small change in gravity is directly proportional to mass change (once other influences are removed).

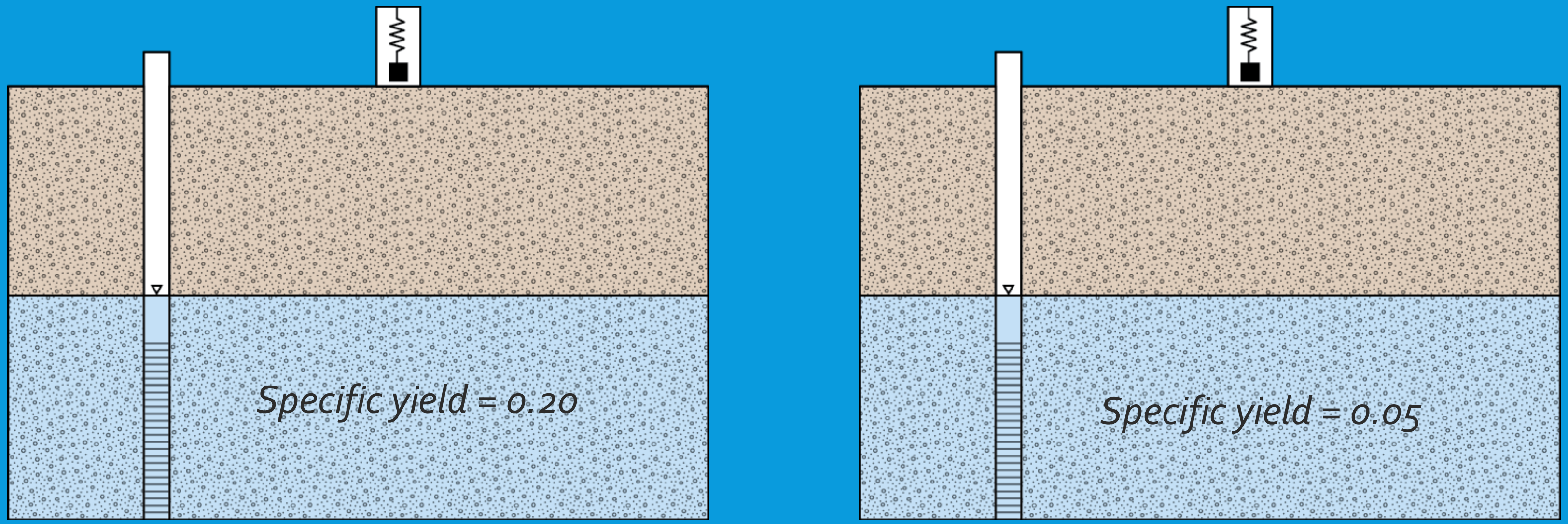
A change in the amount of water stored underground causes a mass change and a corresponding gravity change.

The relationship between the observed change in gravity and the amount of storage change (as the change in the thickness of a slab of free-standing water) is:

$$41.9\ \text{microGal} = 1\ \text{m of water}$$

Why repeat microgravity?

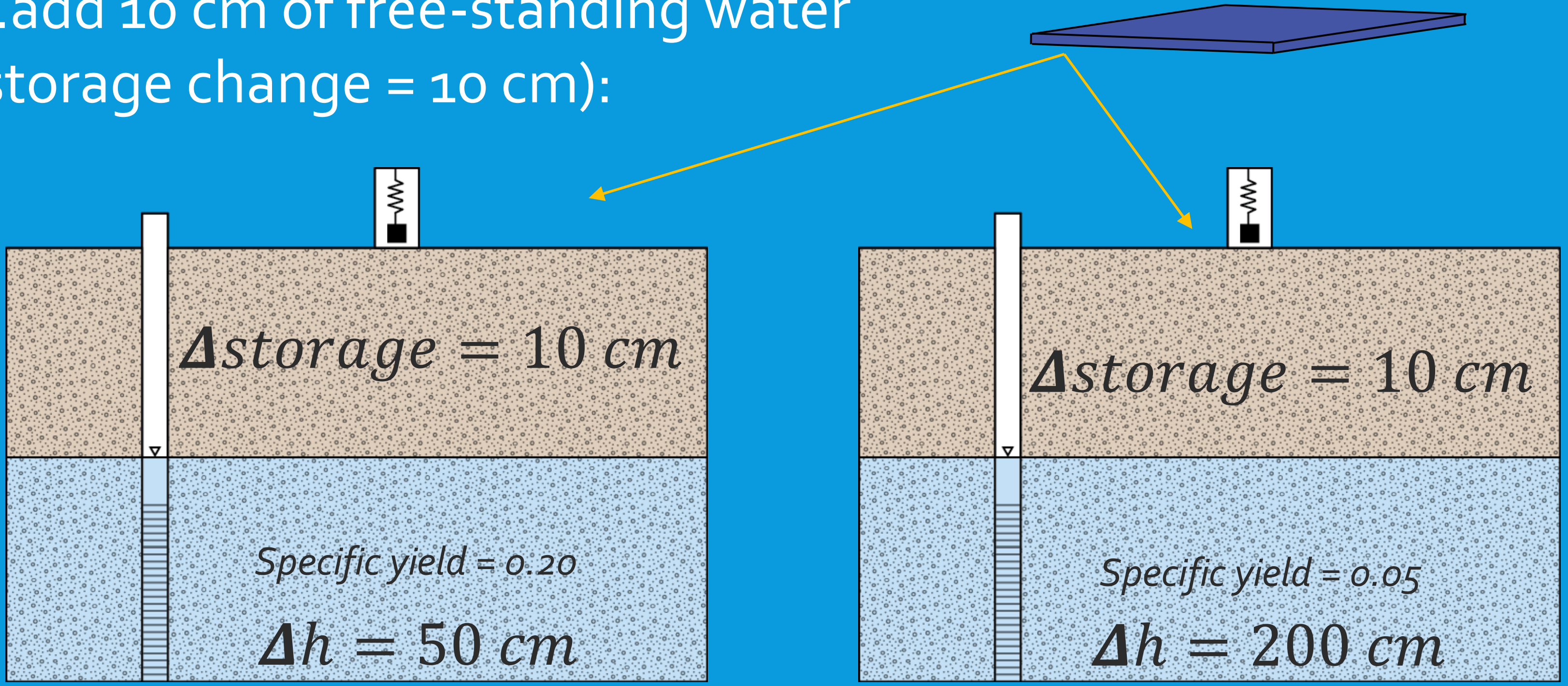
- A quantitative measurement
  - Gravity change is linear with mass change – not dependent on estimates of aquifer properties like specific yield (specific yield is required in order to estimate storage change from water level changes alone).



Why repeat microgravity?

- A quantitative measurement
  - Gravity change is linear with mass change – not dependent on estimates of aquifer properties like specific yield (specific yield is required in order to estimate storage change from water level changes alone).

...add 10 cm of free-standing water (storage change = 10 cm):



$$S_y * \Delta h = \Delta Storage$$

$\Delta h = change\ in\ water\ level$

Why repeat microgravity?

- Water levels may, or may not, represent the aquifer
- Identify confined vs unconfined conditions
- Measure a water budget component that must usually be estimated as the residual of other components (inflows – outflows = storage change).

Selected well construction scenarios in a multiple aquifer system

A. Well screened in shallow unconfined aquifer with lower hydraulic head than in the deep confined aquifer. Water level in the well represents hydraulic head in the shallow aquifer and approximates regional aquifer water table.

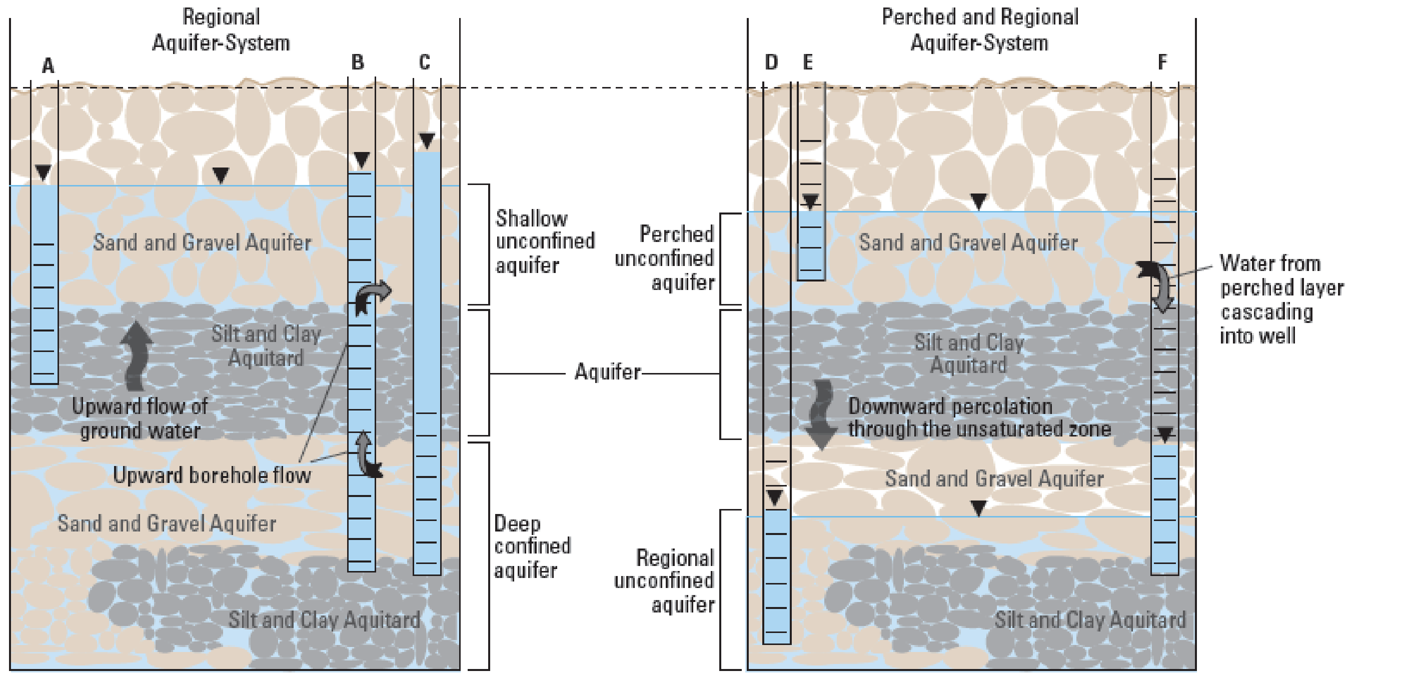
B. Well screened in shallow unconfined aquifer and deep confined aquifer with higher hydraulic head than in the shallow aquifer. Upward flow occurs in borehole. Water level in the well represents a hydraulic head that is a composite of the two aquifers and does not approximate the shallow aquifer water table.

C. Well screened in deep confined aquifer with higher hydraulic head than shallow unconfined aquifer. Water level in the well represents hydraulic head in deep confined aquifer and does not approximate water table.

D. Well screened in regional unconfined aquifer. Water level in the well represents hydraulic head in the regional aquifer and approximates regional aquifer water table.

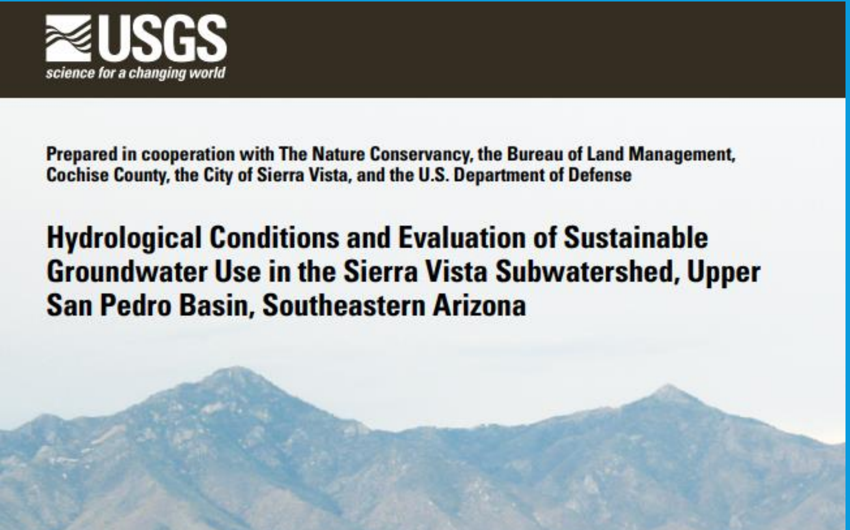
E. Well screened in perched unconfined aquifer. Water level in the well represents hydraulic head in the perched aquifer and approximates perched aquifer water table.

F. Well screened in perched and regional aquifers with water cascading into well from the perched aquifer through screened intervals. Water level in the well represents hydraulic head that is greater than the hydraulic head in the regional aquifer and does not approximate the regional or perched aquifer water table.

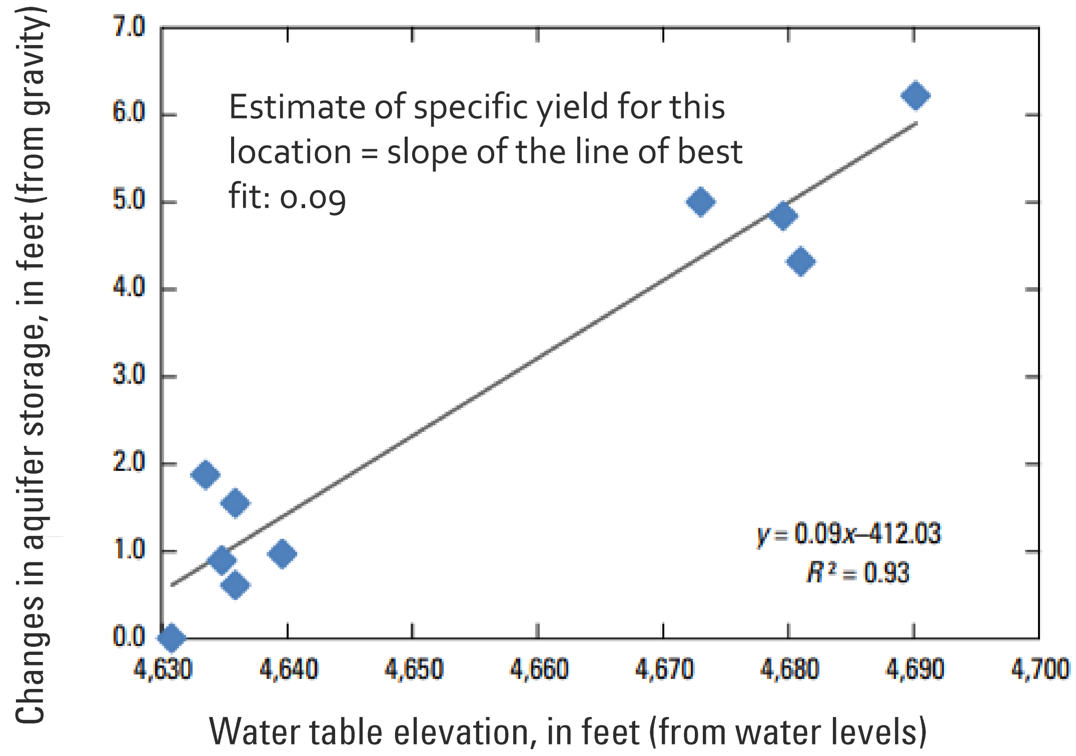


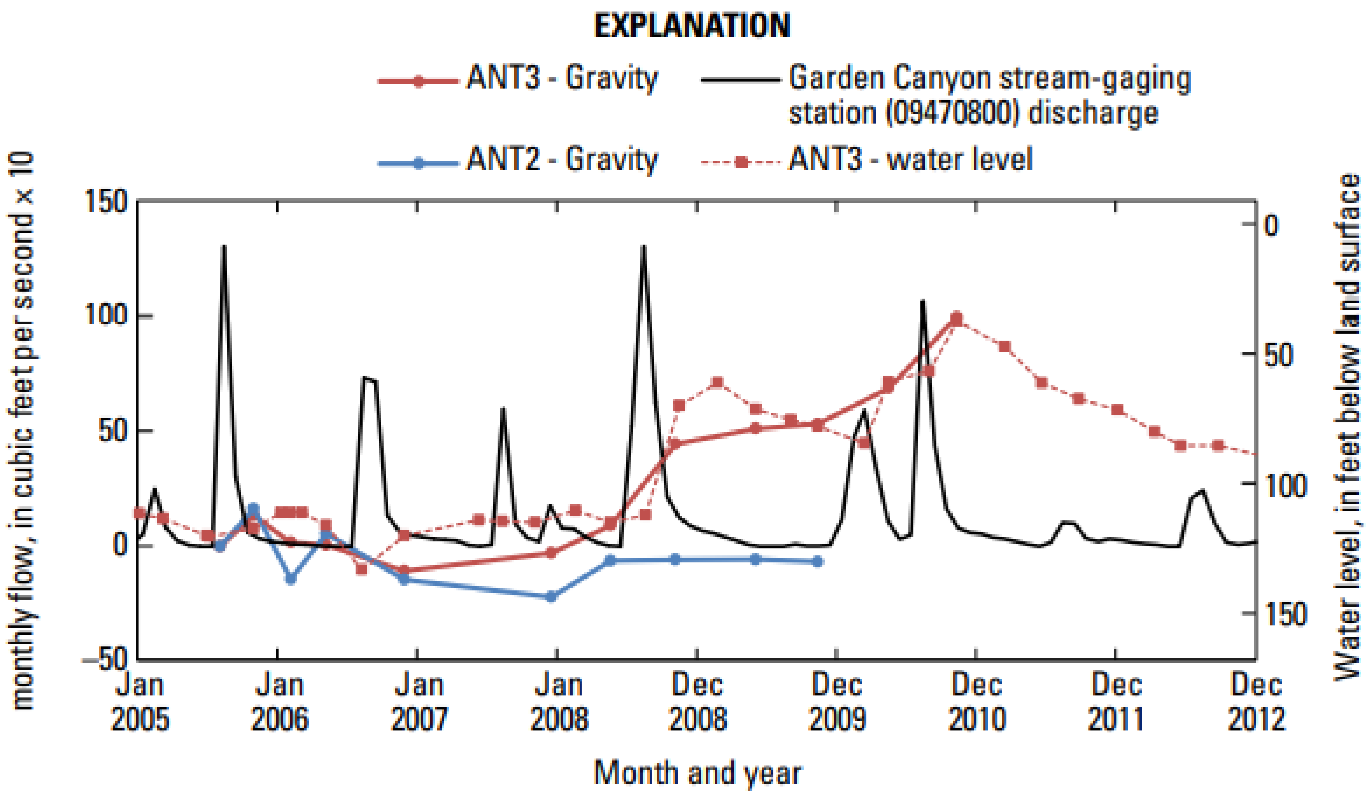
Pool and Anderson, USGS Scientific Investigations Report 2007-5275
https://pubs.usgs.gov/sir/2007/5275/

SAN PEDRO GRAVITY DATA



Report (SIR 2016-5114) available here:
https://go.usa.gov/x7bPf





ıre 16. Graph showing water-level, streamflow, and gravity change near Garden Canyon Wash and the ıntain front of the Huachuca Mountains in the Sierra Vista Subwatershed, southeastern Arizona.

SAN PEDRO GRAVITY DATA

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Prepared in cooperation with The Nature Conservancy

Gravity Data from the Sierra Vista Subwatershed, Upper San Pedro Basin, Arizona

Report available here: https://go.usa.gov/x7bPs

Open-File Report 2015–1086

U.S. Department of the Interior
U.S. Geological Survey

- Revised previous network to better estimate ephemeral channel recharge and effects of pumping.
- Change between 2014 and 2015 reflected increases in storage due to above-average rainfall in summer 2014.

ScienceBase Catalog → USGS Data Release Products → Gravity Change from 2014 to...

Gravity Change from 2014 to 2015, Sierra Vista Subwatershed, Upper San Pedro Basin, Arizona

View

Dates

Publication Date : 2016-09-16
Date Collected : 2015-05

Citation

Kennedy, J.R., 2016, Gravity change from 2014 to 2015, Sierra Vista Subwatershed, Upper San Pedro Basin, Arizona: U.S. Geological Survey data release, http://dx.doi.org/10.5066/F7SQ8XHX.

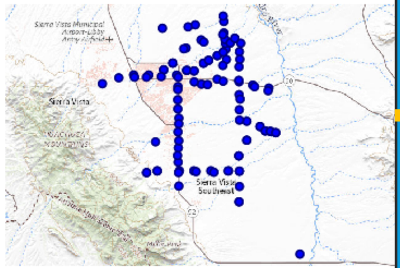
Summary

Relative-gravity data and absolute-gravity data were collected in the Sierra Vista Subwatershed, Upper San Pedro Basin, Arizona, in May–June 2014 and 2015. Data from 2014 and a description of the survey network were published in USGS Open-File Report 2015–1086. Data presented in the shapefile here are the following:
(1) Network-adjusted values from 2015,
(2) Gravity change from 2014 to 2015, and
(3) Survey-grade coordinates obtained from a Global Positioning System (GPS) survey in 2015.

2015 data and network adjustment results are presented in
Kennedy, J.R., 2016, Gravity change from 2014 to 2015, Sierra Vista Subwatershed, Upper San Pedro Basin, Arizona: U.S. Geological Survey Open–File Report 2016–1155, 15 p., http://dx.doi.org/10.3133/ofr20161155

2014 data and network adjustment results are presented in
Kennedy, J.R., 2015, Gravity data from the Sierra Vista Subwatershed, Upper San Pedro Basin, Arizona: U.S. Geological Survey Open–File Report 2015–1086, 26 p., http://dx.doi.org/10.3133/ofr20151086

Map »



Spatial Services

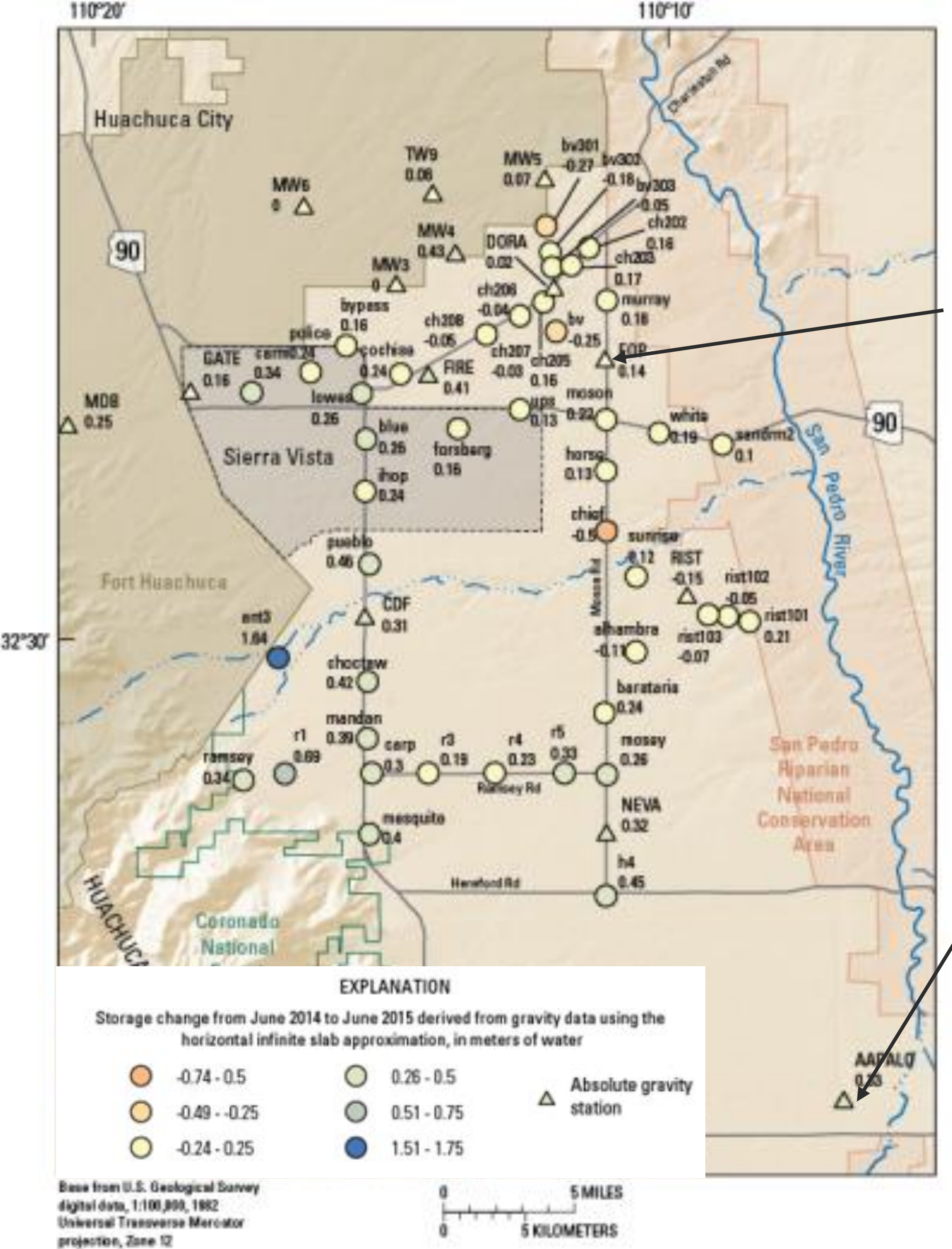
ScienceBase WMS : https://www.sciencebase.gov/catal
ScienceBase WFS : https://www.sciencebase.gov/catal

Communities

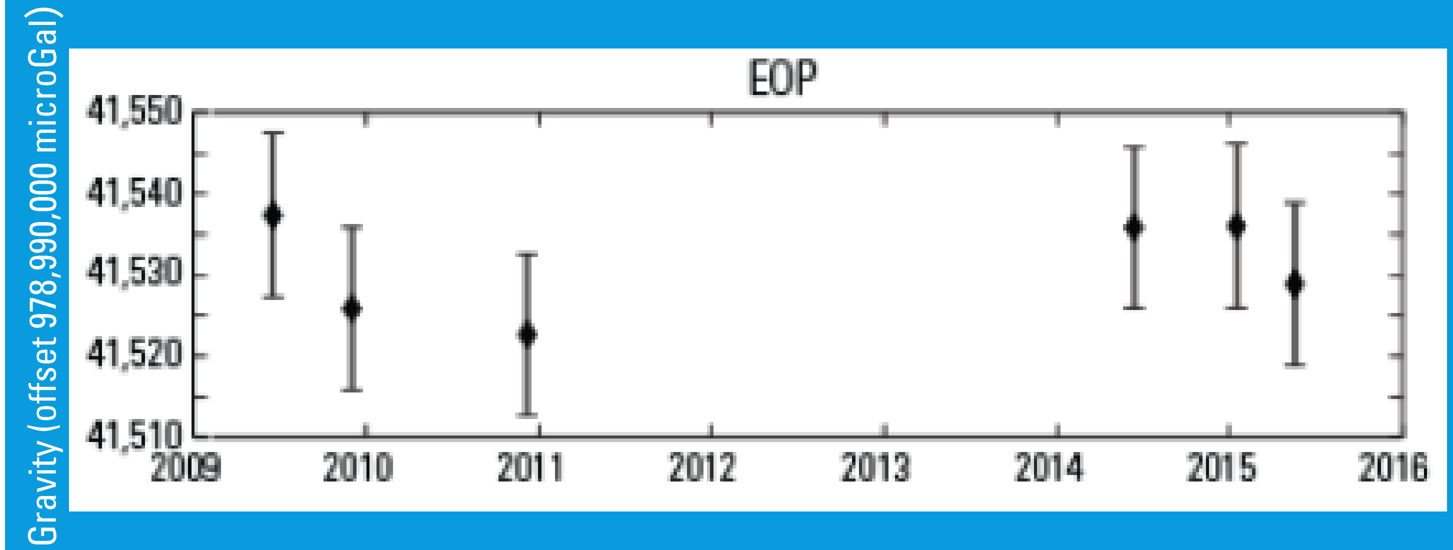
- USGS Data Release Products

Data available here:
https://go.usa.gov/x7bPv

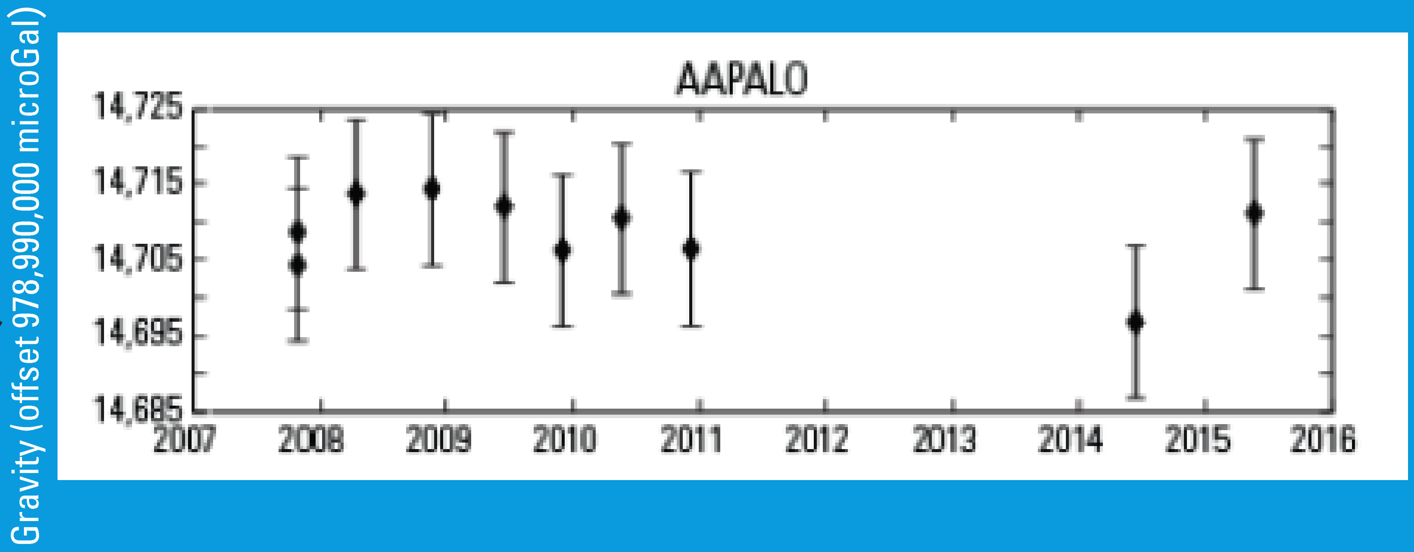
USGS



110°20'
110°10'
32°30'
Huachuca City
Sierra Vista
Fort Huachuca
San Pedro River
San Pedro Riparian National Conservation Area
Coronado National
HUACHUCA
90
Charleston Rd
Moson Rd
Ramsey Rd
Hereford Rd
MW6 0
TW9 0.06
MW5 0.07
bv301 -0.27
bv302 -0.18
bv303 -0.05
ch202 0.16
ch203 0.17
MW4 0.43
DORA 0.02
MW3 0
ch206 -0.04
murray 0.18
bypass 0.16
ch208 -0.05
bv -0.25
police
ch207 -0.03
ch205 0.16
EOP 0.14
GATE 0.16
carmel 0.34
cochise 0.24
FIRE 0.41
lowell 0.26
ups 0.13
moson 0.22
MDB 0.25
blue 0.26
forsberg 0.16
whria 0.19
sandrm2 0.1
horse 0.13
ihop 0.24
chief -0.5
sunrise 0.12
RIST -0.15
rist102 -0.05
pueblo 0.46
CDF 0.31
rist101 0.21
rist103 -0.07
ant3 1.64
alhambra -0.11
choctaw 0.42
barataria 0.24
mandan 0.39
r1 0.69
carp 0.3
r3 0.19
r4 0.23
r5 0.33
mosey 0.26
ramsey 0.34
NEVA 0.32
mesquite 0.4
h4 0.45
AAPALO
EXPLANATION
Storage change from June 2014 to June 2015 derived from gravity data using the horizontal infinite slab approximation, in meters of water
-0.74 - 0.5
-0.49 - -0.25
-0.24 - 0.25
0.26 - 0.5
0.51 - 0.75
1.51 - 1.75
Absolute gravity station
Base from U.S. Geological Survey digital data, 1:100,000, 1982
Universal Transverse Mercator projection, Zone 12
0 5 MILES
0 5 KILOMETERS



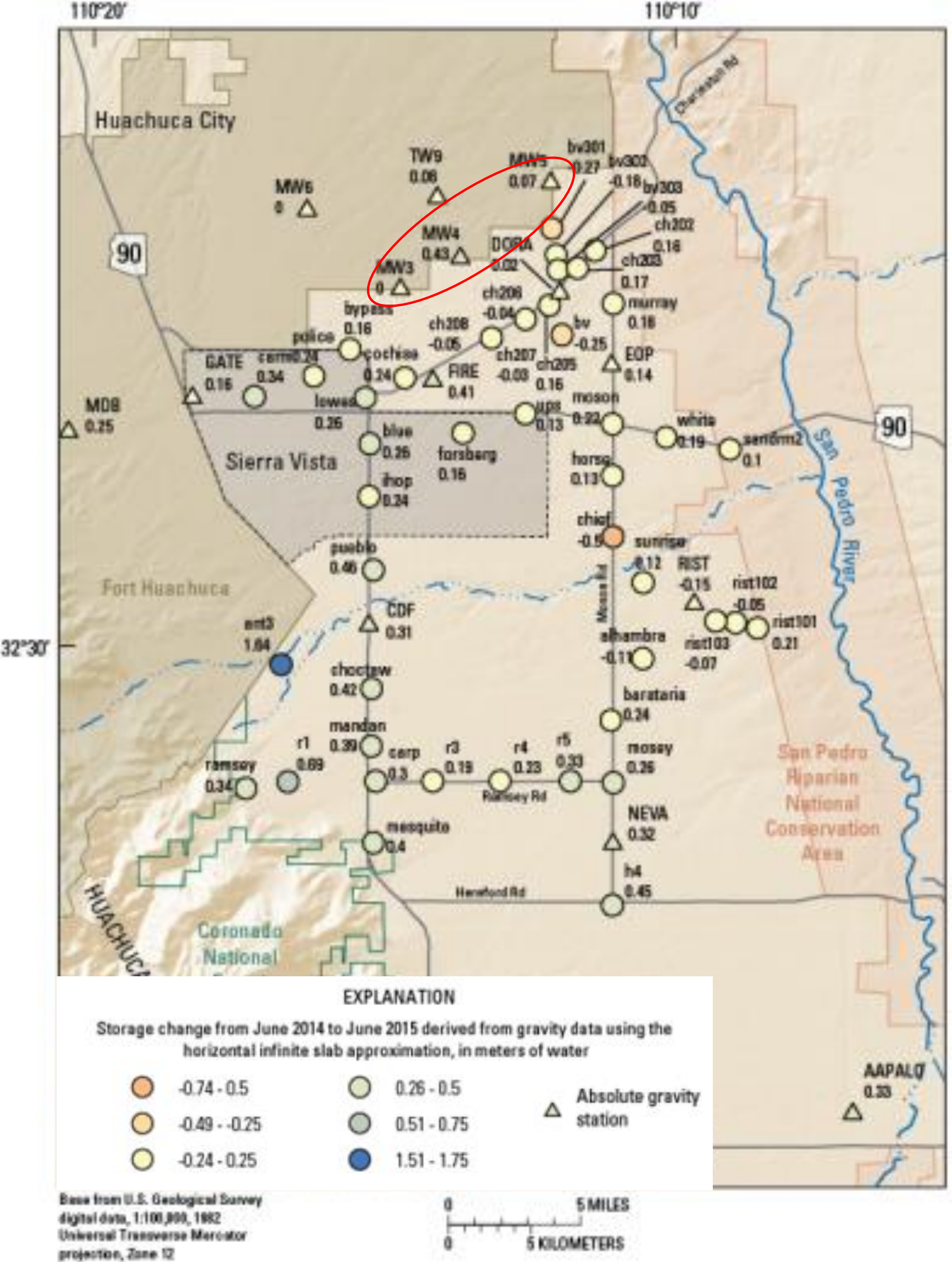
EOP
Gravity (offset 978,990,000 microGal)
41,550
41,540
41,530
41,520
41,510
2009
2010
2011
2012
2013
2014
2015
2016

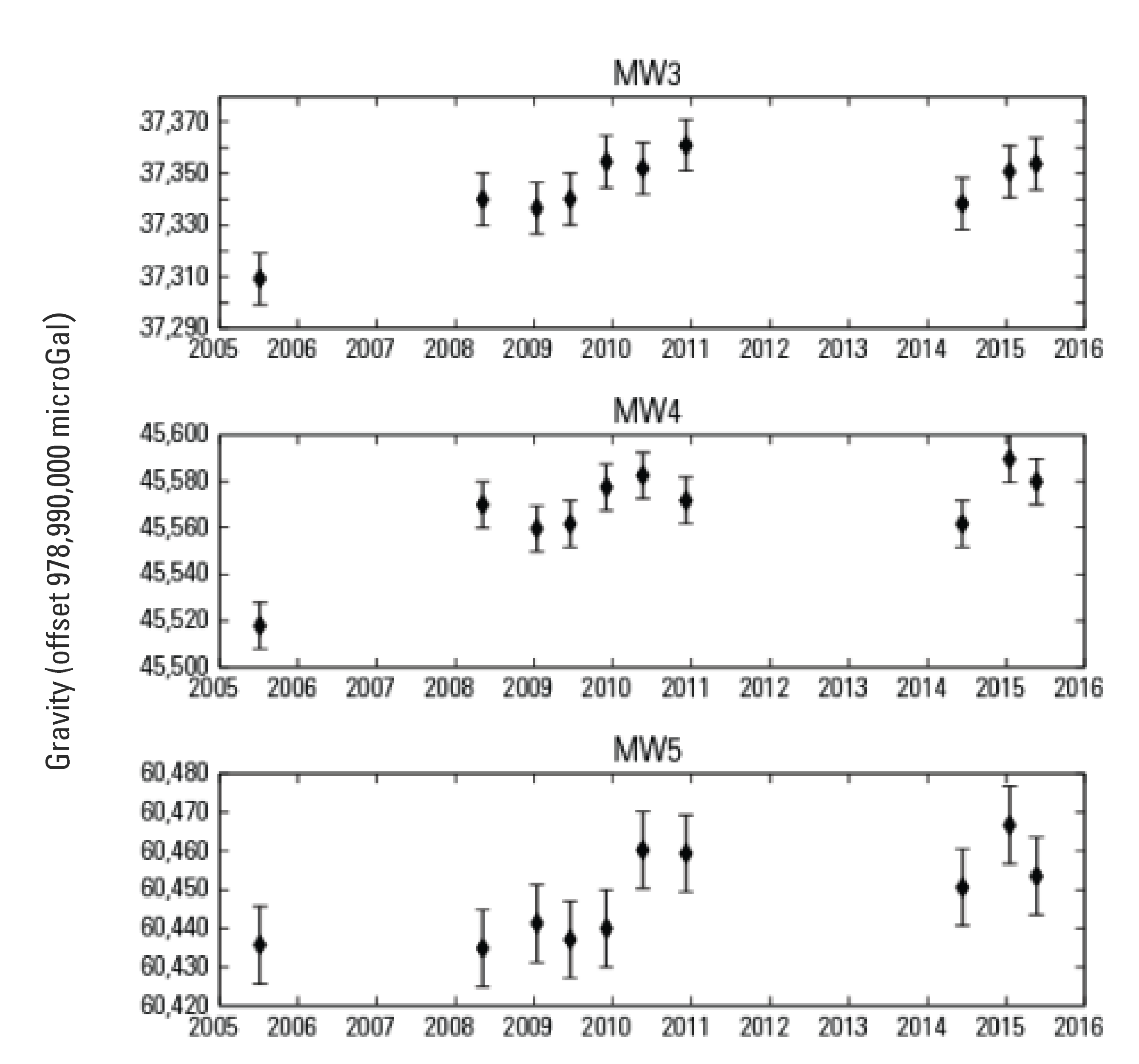


AAPALO
Gravity (offset 978,990,000 microGal)
14,725
14,715
14,705
14,695
14,685
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

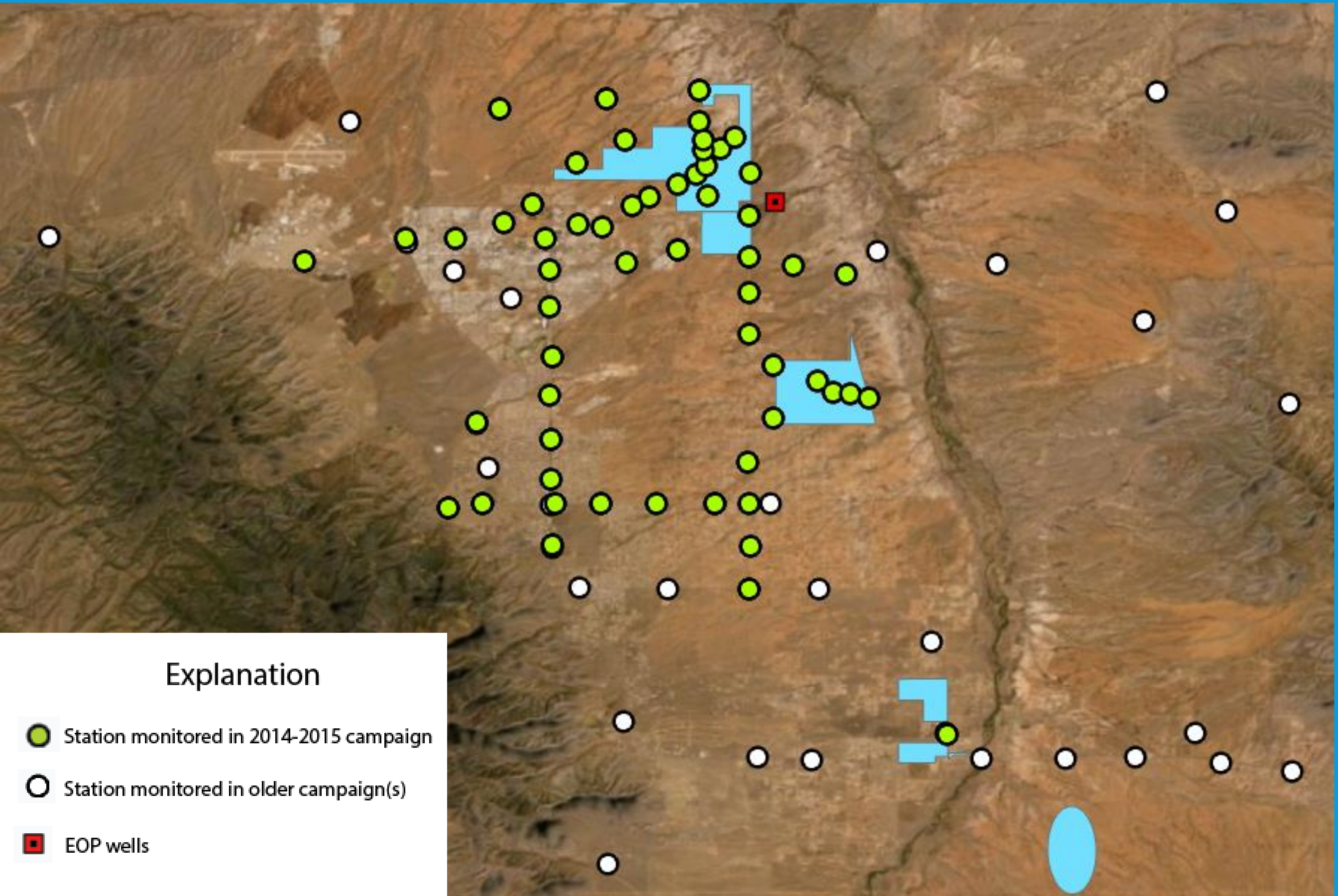
USGS

Gravity minus 978,990,000 microGal, with time





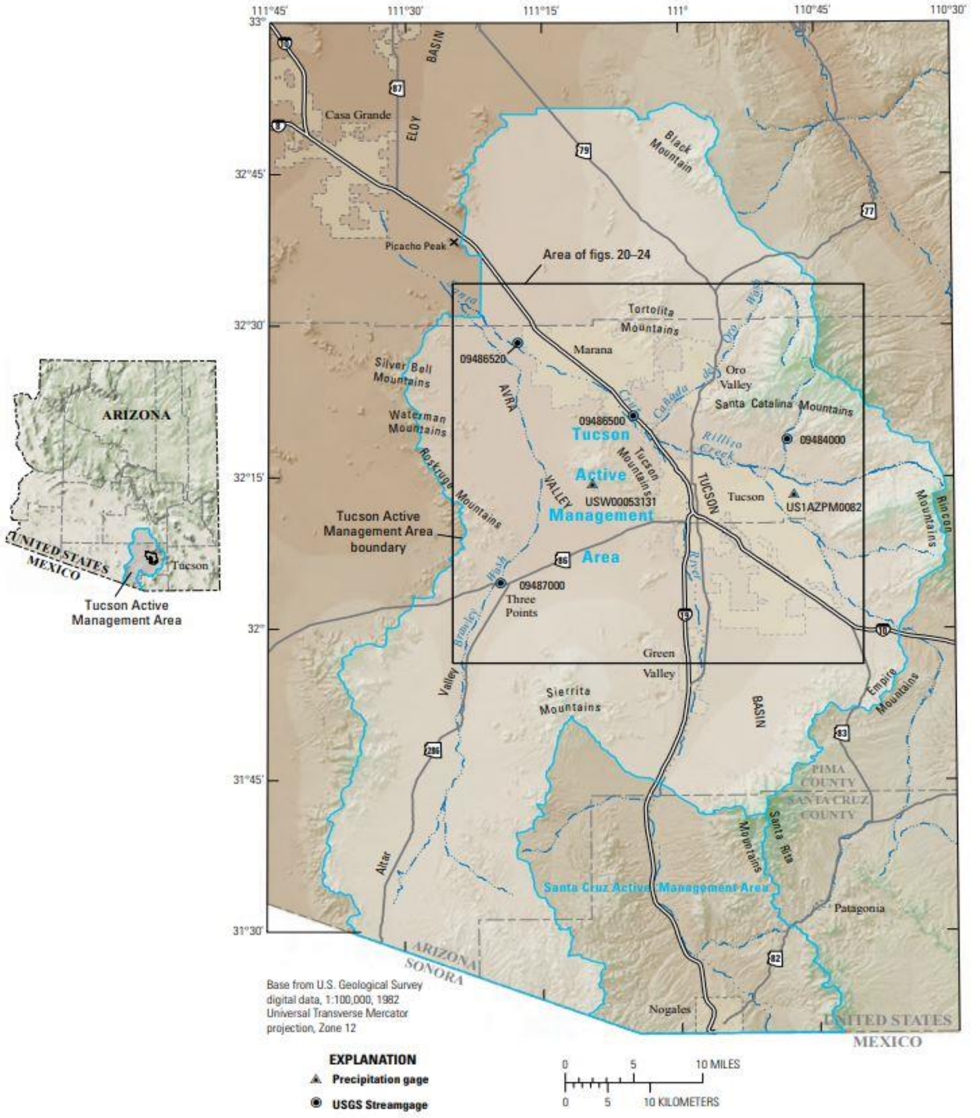
Network as of 2015:



2014-2015 set up new stations to better identify long-term storage changes at key locations

No monitoring since 2015

Tucson AMA gravity project, 1998 - 2024+



- USGS Cooperative Water Program
- ~140 stations in a network spanning greater Tucson, Marana, and Avra Valley
- Shows long-term early storage declines followed by increasing storage with increasing artificial recharge
- Shows effect of variable precipitation and resulting natural recharge on the amount and pattern of resulting storage change.

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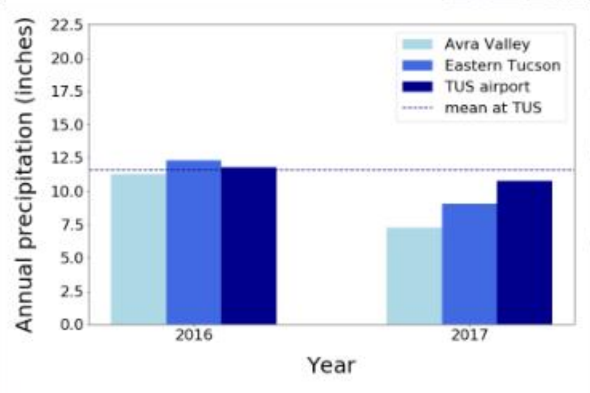
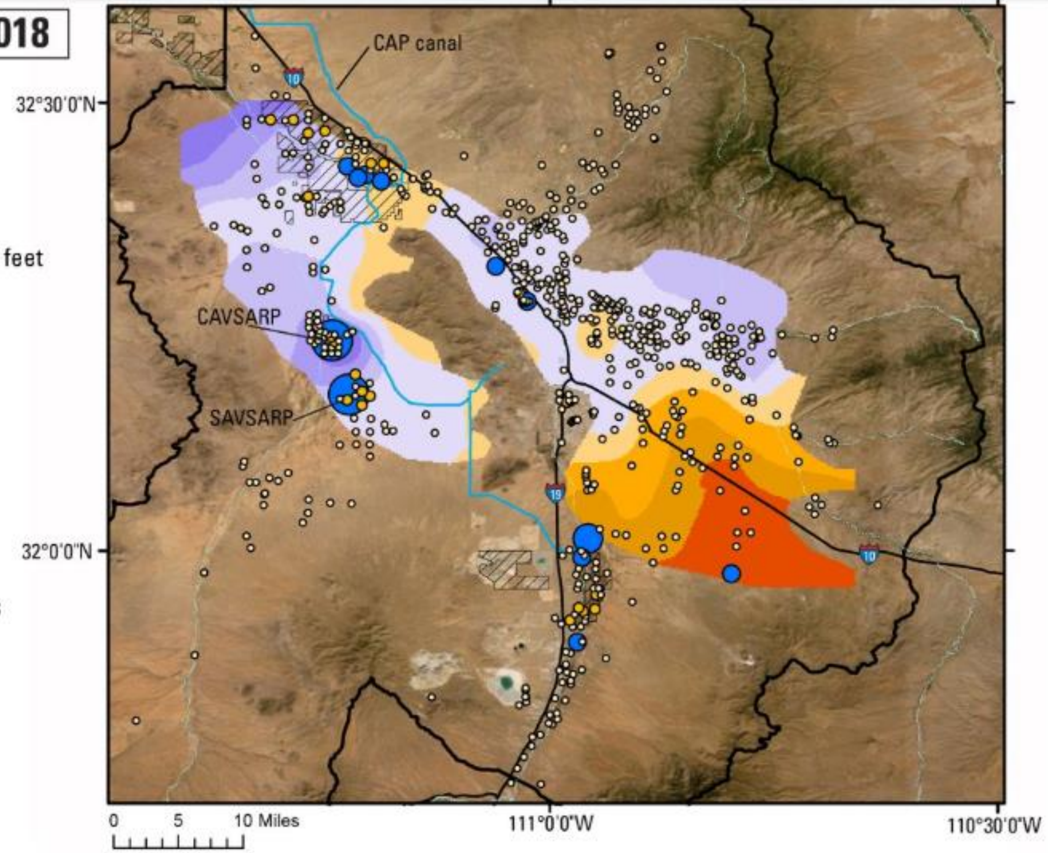
Changes in Gravity used to Quantify Groundwater-Storage Change in the Tucson AMA

Background | Results | More information

Results of gravity monitoring in the Tucson AMA, 2003 to 2019

some positive storage change is shown near the foothills of the Catalina mountains. This may be due to the timing of the 2018 survey, which likely included the effects of precipitation received in the early spring of 2018.





Approximate locations of recharge facilities and non-exempt pumping wells in the Tucson AMA, with gravity-based groundwater storage change.

Explore the Story Map here: https://wim.usgs.gov/geonarrative/tucsongravity/

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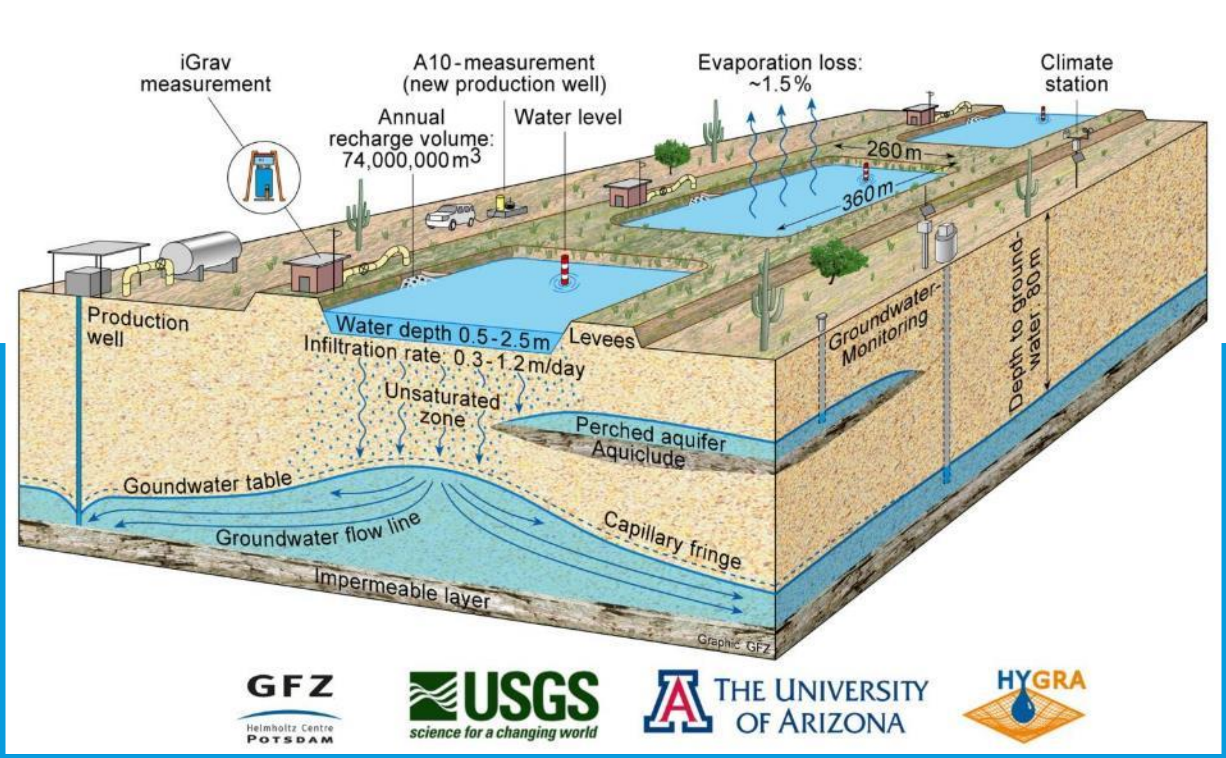
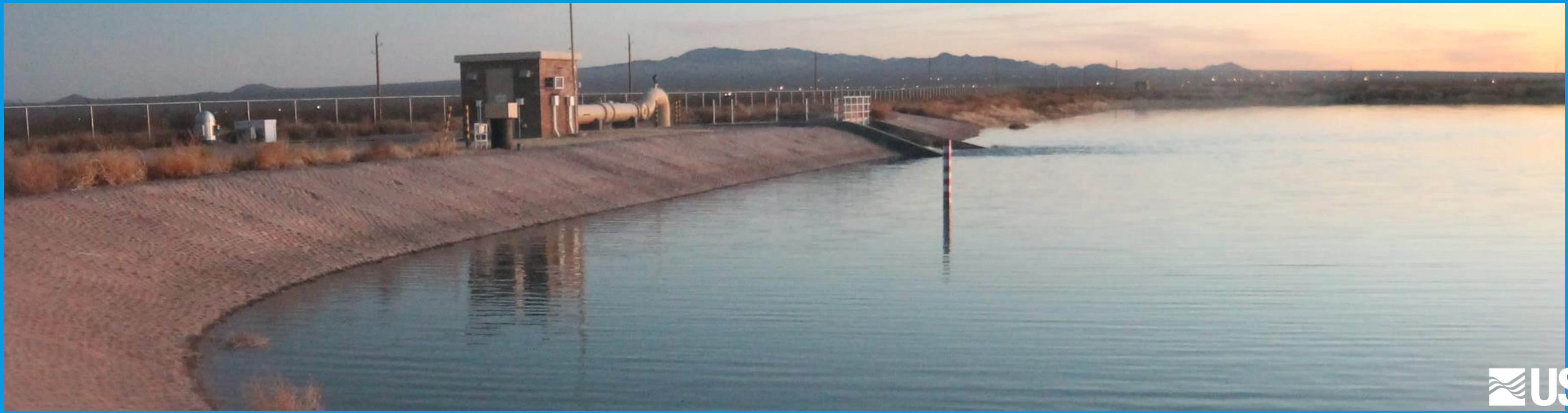
Other Tucson studies

Tucson Water's SAVSARP facility:

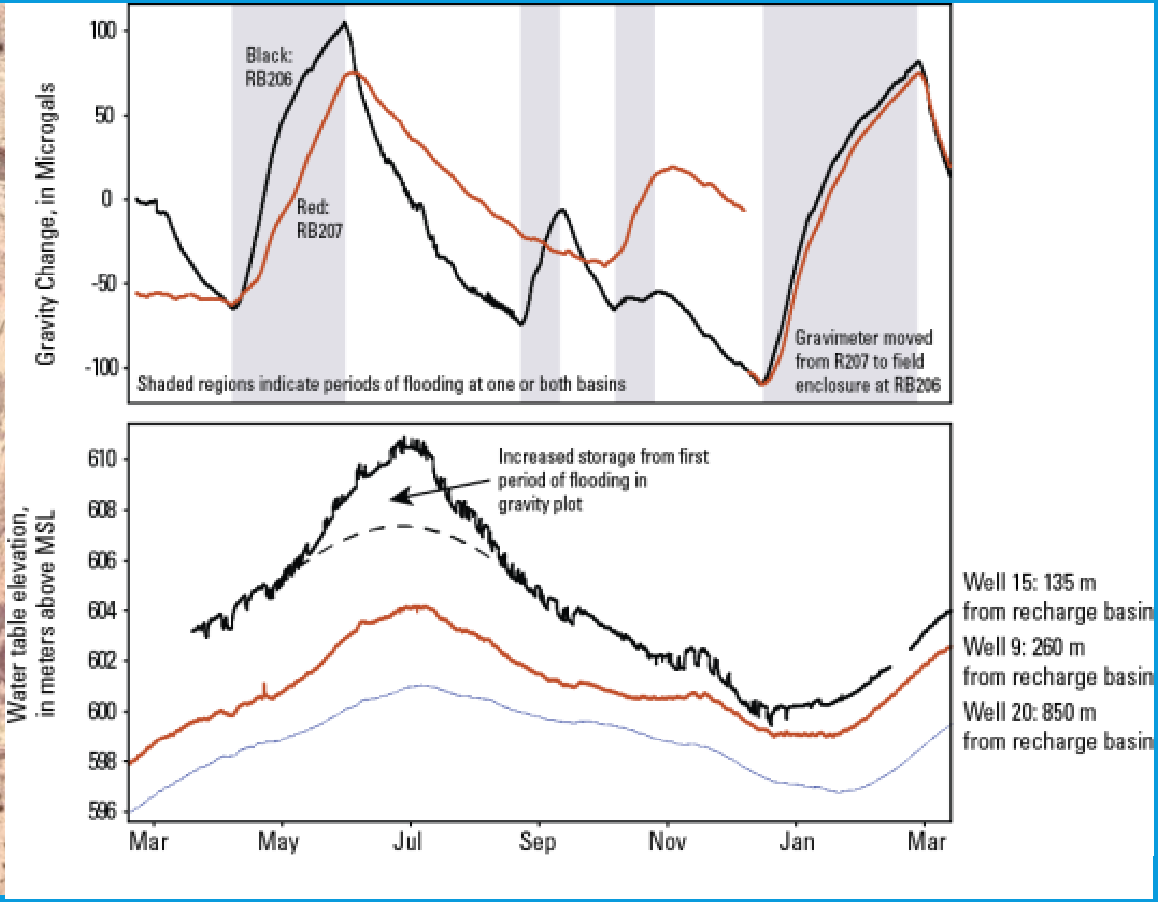
- Recharges ~50,000-80,000 acre-feet/year of CAP water





Other Tucson studies: SAVSARP

Continuous gravity observations demonstrate fast response to storage changes



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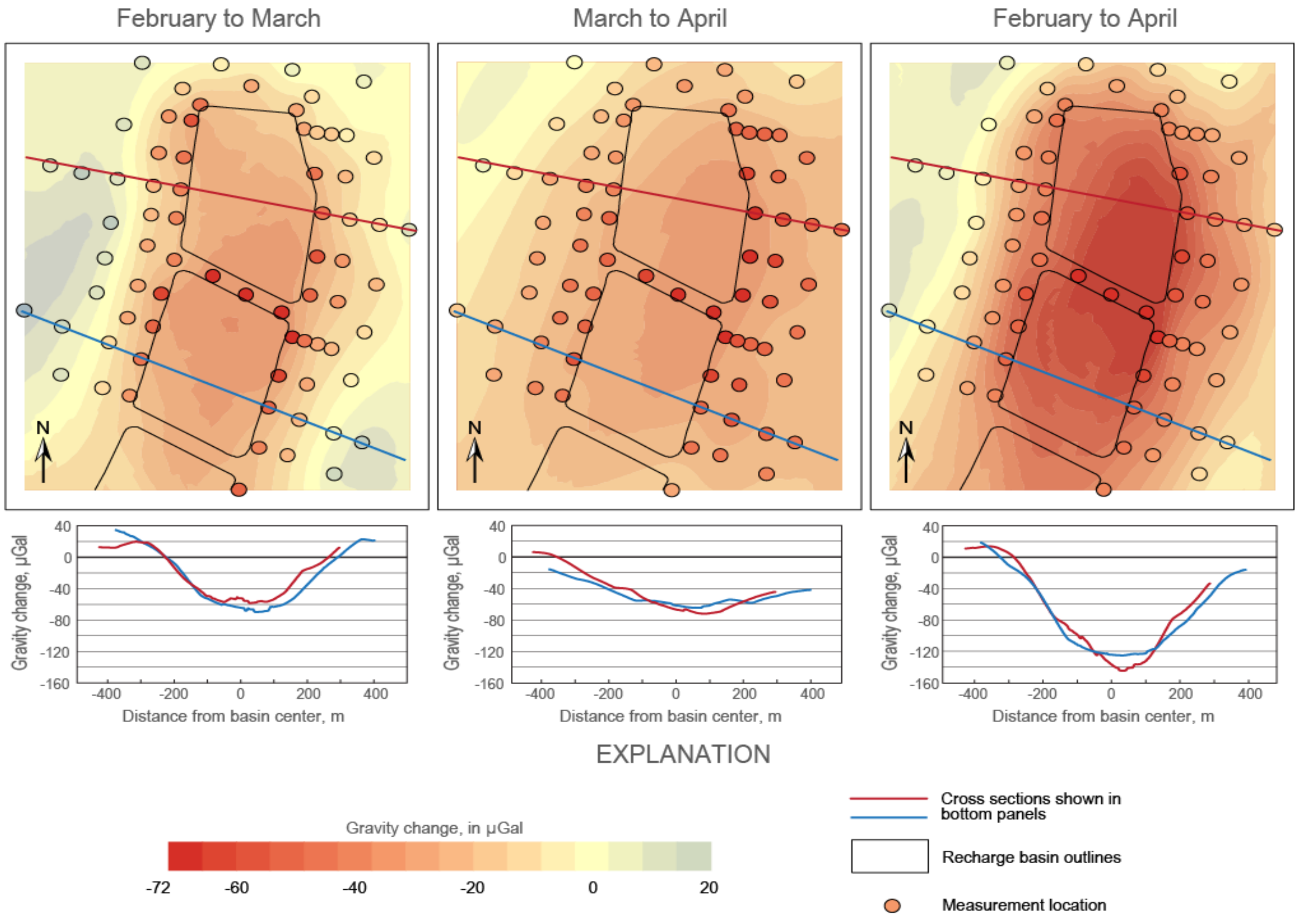
Other Tucson studies: SAVSARP

Dense network of observation locations provides detailed storage change map between discrete measurements



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Other Tucson studies: Heritage Project

- ~3,150 acre-feet/year of reclaimed water
- Released into the Santa Cruz River channel near downtown Tucson
- Objective includes monitoring storage changes near WQARF sites
- Requires LIDAR drone flights to account for mass changes resulting from sediment redistribution

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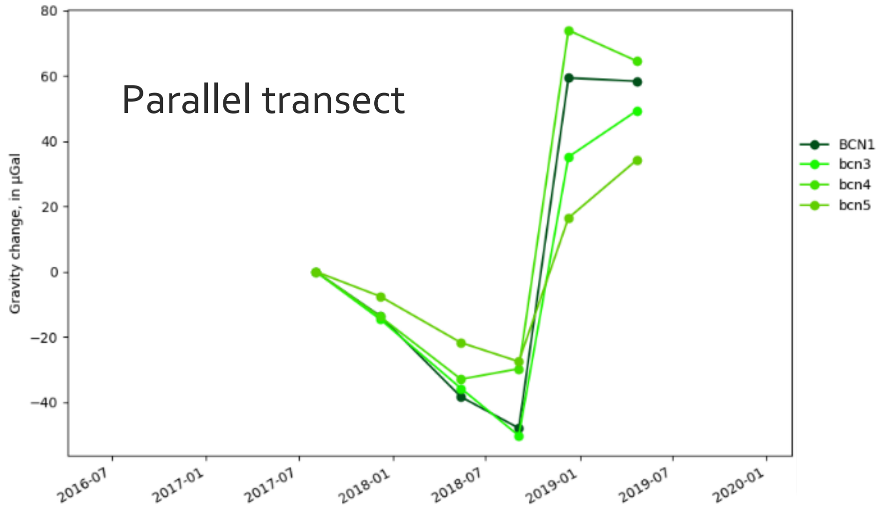
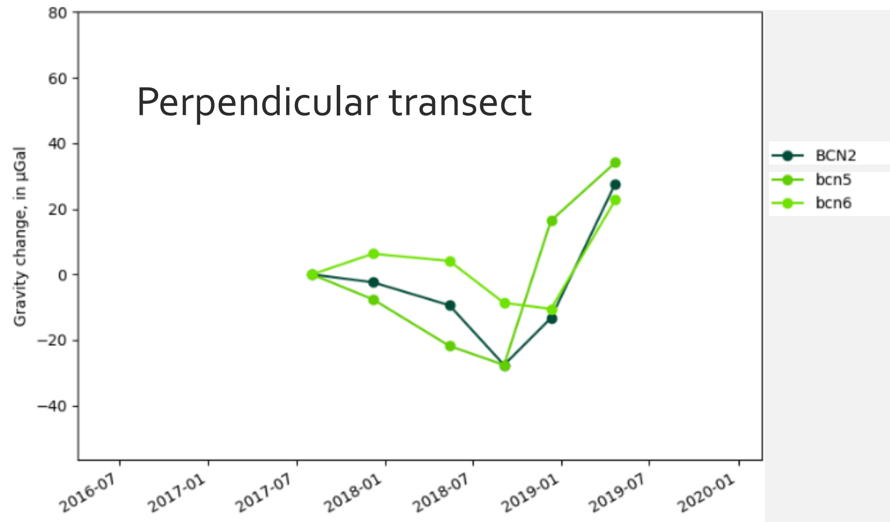
Albuquerque Studies





- In-channel surface-water recharge
- Large storage changes accumulate and dissipate rapidly
- Storage changes extend several hundred meters from the channel

SUMMARY

- Sierra Vista gravity network monitored last in 2015, with several new sites in areas of interest (i.e. EOP).
- Some gravity data are publicly available on ScienceBase in shapefile and .csv format, which would make use on the WHIP quite easy. However, older data are not currently online (pre-2014).
- Smaller recharge projects are a good fit for gravity monitoring if:
  - Recharge is sufficient to result in gravity change larger than instrument error.
  - Must also look at whether recharge is likely to mound or not.

THANK YOU

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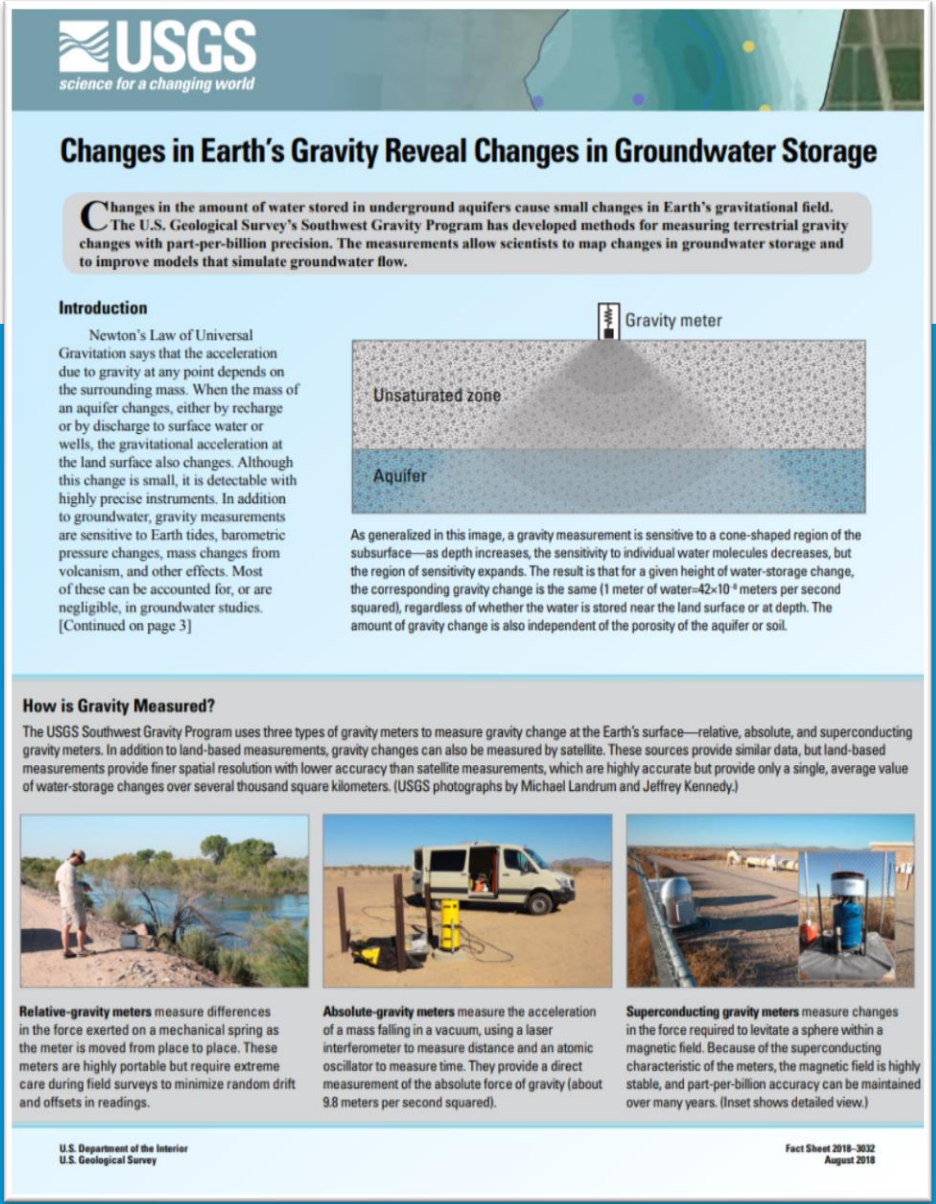
- ekahler@usgs.gov



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Changes in Earth's Gravity Reveal Changes in Groundwater Storage

Changes in the amount of water stored in underground aquifers cause small changes in Earth's gravitational field. The U.S. Geological Survey's Southwest Gravity Program has developed methods for measuring terrestrial gravity changes with part-per-billion precision. The measurements allow scientists to map changes in groundwater storage and to improve models that simulate groundwater flow.

Introduction

Newton's Law of Universal Gravitation says that the acceleration due to gravity at any point depends on the surrounding mass. When the mass of an aquifer changes, either by recharge or by discharge to surface water or wells, the gravitational acceleration at the land surface also changes. Although this change is small, it is detectable with highly precise instruments. In addition to groundwater, gravity measurements are sensitive to Earth tides, barometric pressure changes, mass changes from volcanism, and other effects. Most of these can be accounted for, or are negligible, in groundwater studies.
[Continued on page 3]

Gravity meter
Unsaturated zone
Aquifer

As generalized in this image, a gravity measurement is sensitive to a cone-shaped region of the subsurface—as depth increases, the sensitivity to individual water molecules decreases, but the region of sensitivity expands. The result is that for a given height of water-storage change, the corresponding gravity change is the same (1 meter of water=42×10^{-8} meters per second squared), regardless of whether the water is stored near the land surface or at depth. The amount of gravity change is also independent of the porosity of the aquifer or soil.

How is Gravity Measured?

The USGS Southwest Gravity Program uses three types of gravity meters to measure gravity change at the Earth's surface—relative, absolute, and superconducting gravity meters. In addition to land-based measurements, gravity changes can also be measured by satellite. These sources provide similar data, but land-based measurements provide finer spatial resolution with lower accuracy than satellite measurements, which are highly accurate but provide only a single, average value of water-storage changes over several thousand square kilometers. (USGS photographs by Michael Landrum and Jeffrey Kennedy.)

Relative-gravity meters measure differences in the force exerted on a mechanical spring as the meter is moved from place to place. These meters are highly portable but require extreme care during field surveys to minimize random drift and offsets in readings.

Absolute-gravity meters measure the acceleration of a mass falling in a vacuum, using a laser interferometer to measure distance and an atomic oscillator to measure time. They provide a direct measurement of the absolute force of gravity (about 9.8 meters per second squared).

Superconducting gravity meters measure changes in the force required to levitate a sphere within a magnetic field. Because of the superconducting characteristic of the meters, the magnetic field is highly stable, and part-per-billion accuracy can be maintained over many years. (Inset shows detailed view.)

U.S. Department of the Interior
U.S. Geological Survey

Fact Sheet 2018–3032
August 2018

Want to know more? Read the fact sheet here: https://go.usa.gov/x7KJe