Front – Maurice Tatlow (right) & Paul Ivanich (left)
Rear – Alex Richards (right) & Jim Tyburczy (left)
Photograph by J Ramón Arrowsmith.

MEASURING BEDROCK TOPOGRAPHY USING GRAVITY TO UNDERSTAND SUBSIDENCE ALONG A PORTION OF THE CAP CANAL IN NORTHEAST SCOTTSDALE

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View north from CAP canal at Cactus showing proximity to exposed bedrock.

Photograph by J Ramón Arrowsmith.

ABSTRACT

Subsidence is a major problem in the Phoenix basin and can be especially harmful when not planned for or expected. This study focuses on an area in Northeast Scottsdale where the Central Arizona Project (CAP) canal, which carries Colorado River water as far as Tucson, has subsided approximately 0.5 meters (1.5 feet) in the last 10 years. Remote sensing InSAR (Interferometric Synthetic Aperture Radar) data show a large subsidence bowl, approximately 4km by 2km in this area. Subsidence is caused by excessive groundwater withdrawal, which causes pores in the alluvium once held open by water to collapse due to the loss of pore pressure. This pore volume loss results in a lowering of the ground surface, or subsidence. We are undertaking geophysical studies to investigate possible subsurface controls on this subsidence. We use high sensitivity relative gravity methods, including elevation control using differential GPS, to measure slight variations in the earth's gravitational field caused by density contrasts between bedrock and alluvium. These density contrasts are used to determine the bedrock topography beneath the canal area. We have collected raw data from 540 gravity stations located in an approximately 20 square kilometer area around the canal. We will use these data to understand the shape of the observed subsidence bowl and the relation to bedrock topography.

This work is being performed in conjunction with the Arizona Department of Water Resources (ADWR), specifically Maurice Tatlow, the Central Arizona Project (CAP), specifically Alex Richards, and the Central Arizona-Phoenix Long-Term Ecological Research (CAP-LTER) project.

PROBLEM DESCRIPTION

The Central Arizona Project (CAP) canal is an important source of water for Phoenix and Tucson. A decrease in the amount of water that moves through the canal could have an impact on cities and businesses that rely on that water.

The CAP canal is subsiding between Cactus Road and Shea Boulevard in Northeast Scottsdale (Pool 24 Subsidence Area). The maximum amount of subsidence along the canal has occurred at Via Linda, where it has sunk about 1.5 feet (0.5m) in the past ten years. This means the amount of freeboard, which is the amount of cement liner above the water level in the canal (see Figs. 3 and 4), has decreased in this area. At maximum capacity, there should be about 2 feet of freeboard. A reduction in this amount poses a hazard for the canal lining, and limits the amount of water moving through the canal to less than the desired maximum capacity. Portions of the canal were built with subsidence in mind, and the linings were built such that up to 20 feet of freeboard existed. However, subsidence was not expected to occur in this area, and was therefore not planned for.

Knowing the topography of the subsurface bedrock may provide clues to the amount of subsidence to expect, as well as the reason for the shape of the subsidence bowl observed (see Fig. 2). Remote sensing InSAR (Interferometric Synthetic Aperture Radar) data show a large subsidence bowl, approximately 4km by 2km (2mi by .75mi). This image is produced by satellite measurements taken at two different time periods which are then compared with each other. The differences show up as an interferogram (pictured). This image was produced from data taken in 1995 and 1998. The colors show change only when they are banded, such as in the bowl. Each cycle of color represents a 3cm change in elevation. For example, the pattern of green-yellow-pink-blue-green represents a 3cm elevation change between the time periods described (3 years in this case).

Most subsidence bowls occur around centrally located groundwater pumping wells and their shapes are generally circular. Knowing the bedrock topography may also provide clues to explain the ellipsoid shape observed at the Pool 24 subsidence area.

SUBSIDENCE

Subsidence occurs due to the loss of pore volume in sediment. There is no removal of the solid material, only of the water that saturates it. While the sediment is still saturated, the water helps hold pores open. This may not be an issue near the surface, where vertical stress on the sediment is low. Deeper into the sediment, however, there is a tendency for the pores to collapse, as the grains of the sediment are not strong enough to hold the pores open. But if water is present, it can help keep the pores open by accommodating some of the stress. When the water is drained, the pores are susceptible to collapse. This change in pore volume is seen at the surface as a surface elevation drop, known as subsidence.

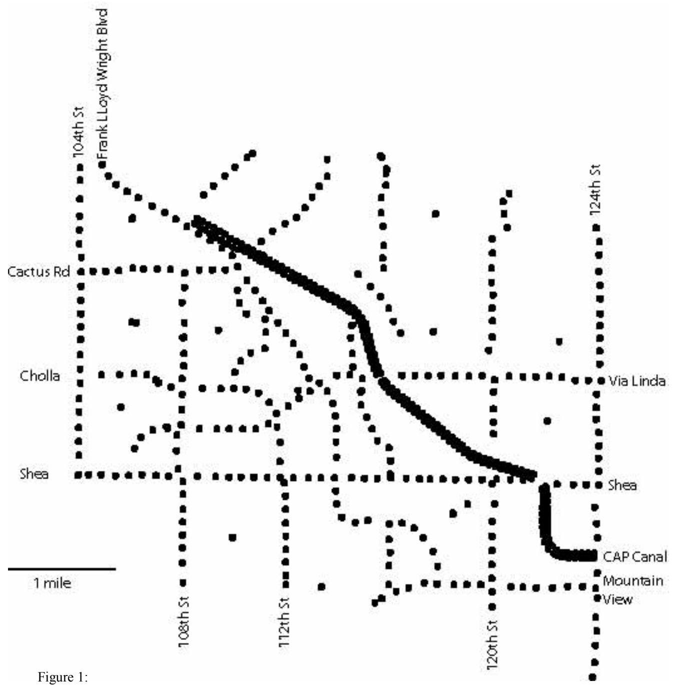

Figure 1:

Shows the locations and the spatial distribution of gravity measurements. Points along the streets are at a 100 meter spacing, and those along the canal (both sides) are at a 50 meter spacing. There are a total of 540 gravity points.

Figure 3:

View SE from north side of canal, looking at the Shea bridge (Shea runs E/W). This area is considered stable (it has not subsided or has subsided only slightly). The cement liner starts halfway between the road and the water surface. "Freeboard" is this exposed part. At this location, there is ~4ft of freeboard. Photograph by J Ramón Arrowsmith.

Figure 4:

View NW from the north side of the canal, looking at the Via Linda bridge (here, Via Linda runs E/W). This is the area of greatest subsidence of the canal (1.5 feet in past 10 years). There is ~2.5ft of freeboard at this location. Photograph by J Ramón Arrowsmith.

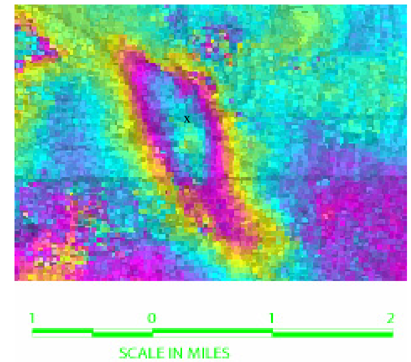

Figure 2: InSAR IMAGE:
Subsidence bowl from InSAR. The 'x' marks the intersection of Via Linda and the CAP canal, where the maximum subsidence has occurred along the canal. The scales of Fig. 1 and this figure are the same.
The basemap is provided courtesy of the Center for Space Science, Austin, TX (Dr. Sean Buckley). It consists of differential radar intensity interferogram for 1995-1998 time period. 1 Color Cycle = Elevation Change of 3cm.

GRAVITY METHODS

There are two main reasons we use gravity for this project rather than another geophysical method. First, the area is developed, which makes the use of some geophysical equipment very difficult. Second is the nature of the problem. Gravity measurements are basically related to the density of the surrounding materials. In this case, the bedrock has a greater density than does the alluvium covering it. If the bedrock slopes away from a mountain front, for example, the gravity value will decrease as you move further away from it (alluvium becomes thicker and bedrock gets deeper). By contouring the gravity data collected over an area, the interface between the bedrock and the alluvium (bedrock topography) can be determined.

The gravity measurements are made with a Scintrex G3 relative gravity meter (gravimeter), which measures relative gravity to 10ths of a milligal (mgal) (1 Gal = 1cm/s^2). This precision is necessary due to the extremely small variations in the gravitational field caused by subsurface anomalies (such as different rock densities). The gravimeter only measures relative gravity, which means only differences in gravity between two stations are measured. Therefore, a looping procedure must be used between a station where the absolute value of the gravitational field is known and a base station in the local field area. This procedure allows us to know the absolute gravity value at a station in the study area (referenced to the absolute station).

A similar procedure is used with-in the study area to determine gravity values for all stations. Absolute stations tie to the base stations in the project area, and those base stations are tied to the rest of the stations. (This procedure is used as there are no absolute stations in proximity to the study area, and ties are necessary every two hours or so.) Each station in the project area is occupied for the same amount of time to reduce error due to settling of the instrument. Loops to base stations are performed every two to three hours to evaluate instrument drift (every gravimeter's reading will change slightly with time, so the process allows us to correct for this). The spacing between stations is 50m (150ft) along the canal and 100m (300ft) on the roadways. Roadways are used for the ease of transportation rather than pre-determined lines.

Differential GPS is used to establish the station locations. Precision within a few centimeters in required in the vertical direction, as only slight variations in the elevation of the gravimeter will have an affect on the reading. Horizontal control is typically better for GPS equipment, but is not as important for gravity work (values to within a few tens of centimeters are acceptable).

Processing of the raw data is required to get useful results. Corrections need to be made for the tides, instrument drift, latitude (as the Earth is not a perfect sphere), elevation, and finally the terrain. The result is a complete Bouguer anomaly, which can be correlated to the bedrock depth, the goal of this study.

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