Gravity Monitoring of Canal Infiltration

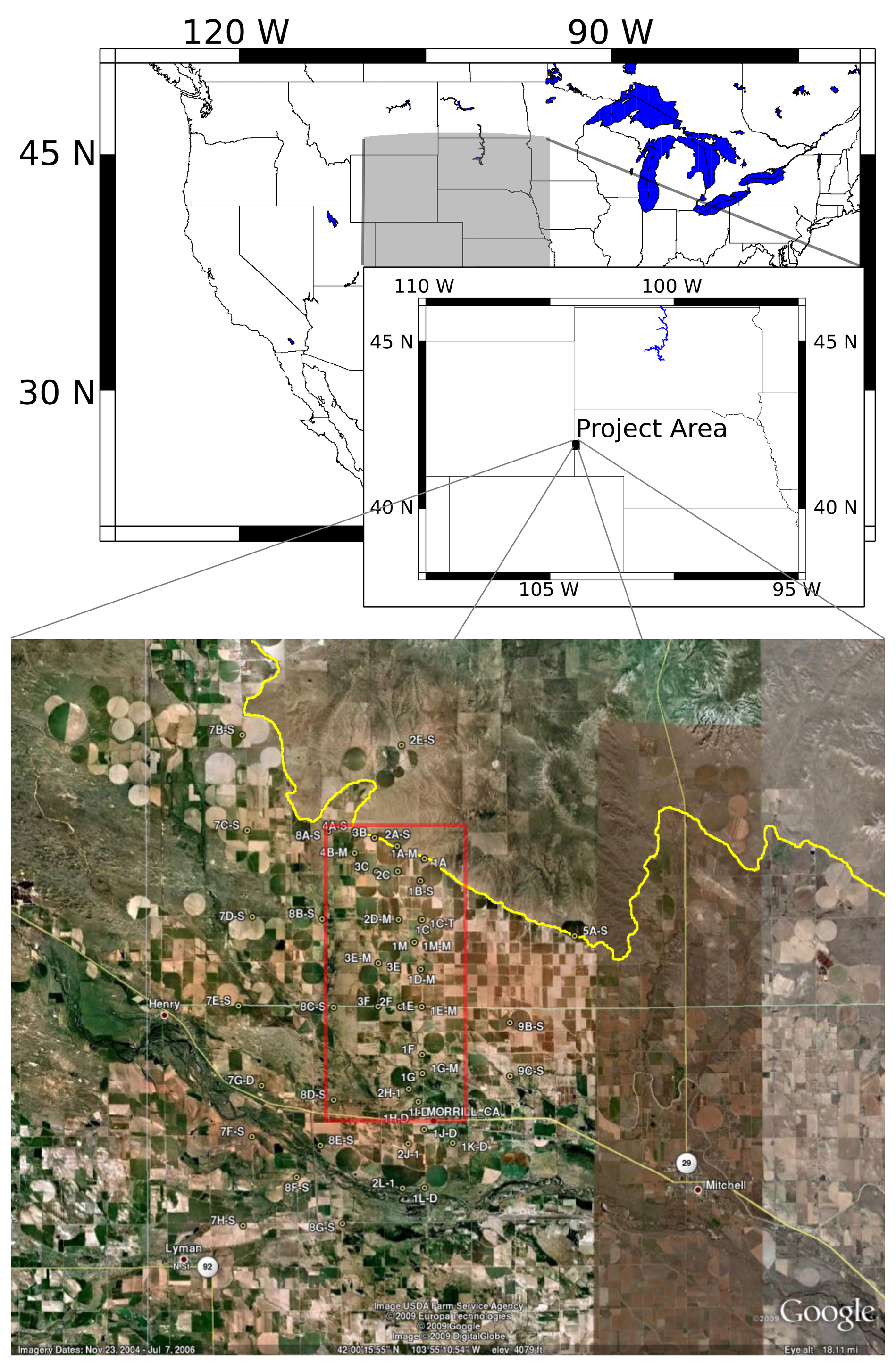
Results from Dutch Flats, NE, USA

Paul Gettings*, David S. Chapman*, Wade Kress+
* Dep't of Geology & Geophysics, University of Utah, Salt Lake City, 84112
+ Water Resources Discipline, U.S. Geological Survey, San Angelo, TX 76903

Abstract

Gravity monitoring provides a cost-effective means of monitoring subsurface mass changes of engineering interest. In July to October 2003, we conducted a gravity monitoring study of canal infiltration in the Dutch Flats irrigated farming area of western Nebraska, USA. An unlined east-west canal on the north edge of the monitoring network leaks southward into the existing shallow aquifer. Due to irrigation requirements, infiltration from the canal started in early spring, before the first measurement campaign, and continued until August. Sixteen gravity stations were colocated on monitoring wells near the canal, with an additional two far-field reference stations. Absolute gravity measurements by the National Geodetic Survey on the reference stations in July and September show no significant change at either station. Relative to the July baseline, the August campaign shows gravity increases of ~20 µGal at the northern-most stations, with smaller changes at other stations. September and October surveys show gravity increases of ~20 µGal more southward, and gravity values decreasing to near zero at the canal. Gravity changes are limited to [-54,+30] µGal during the experiment, suggesting water loss from the shallow aquifer as the dominant process during the gravity monitoring experiment.

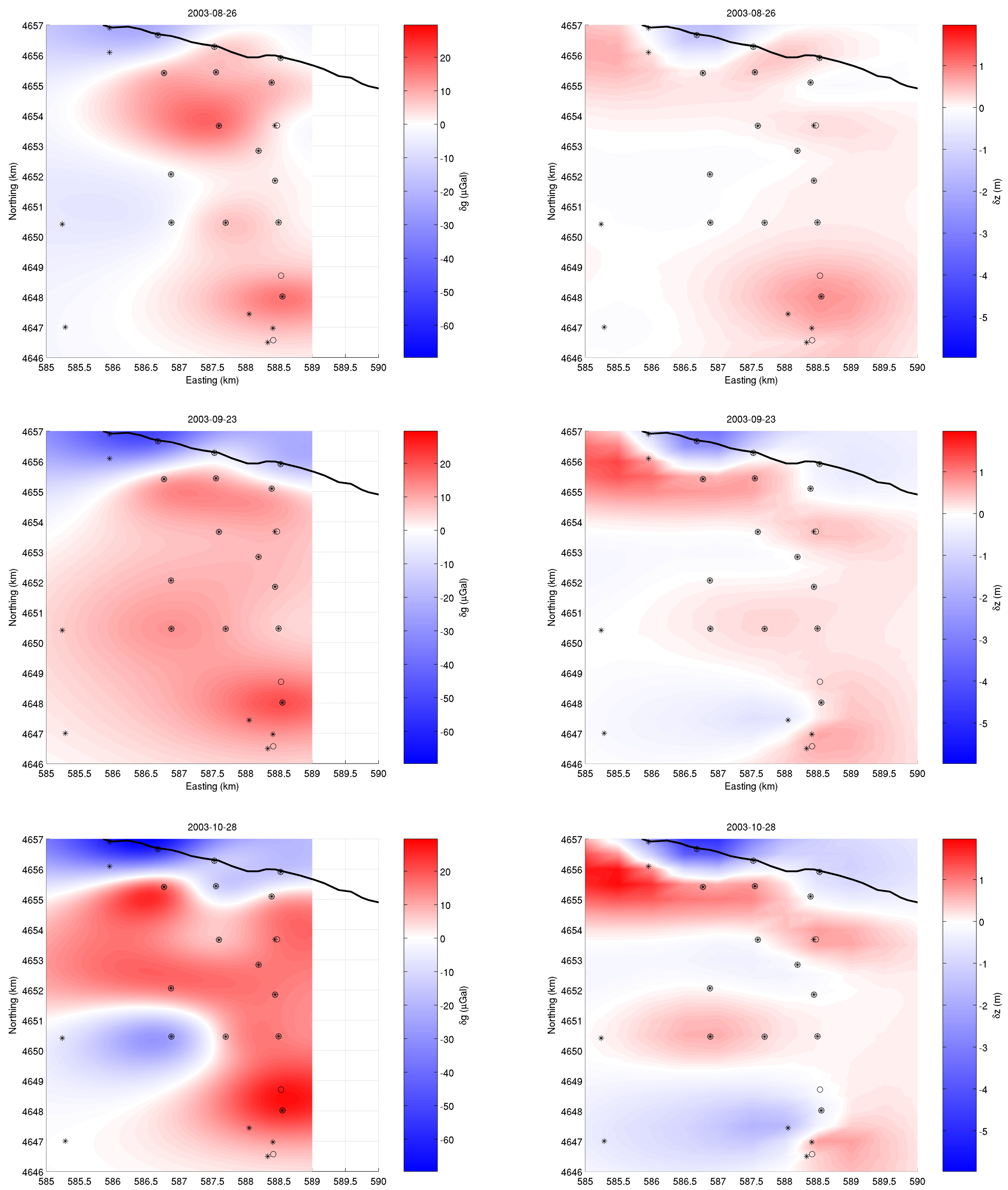
Location Map & Introduction



Dutch Flats, NE infiltration site and monitoring network. Gravity stations are located on existing well clusters, labelled in the detail map with yellow circles and names. Infiltration is controlled by a large, unlined irrigation canal at the north edge of the main network (shown in yellow). The regional hydraulic gradient across the network is to the south; following maps refer to the area boxed in red.

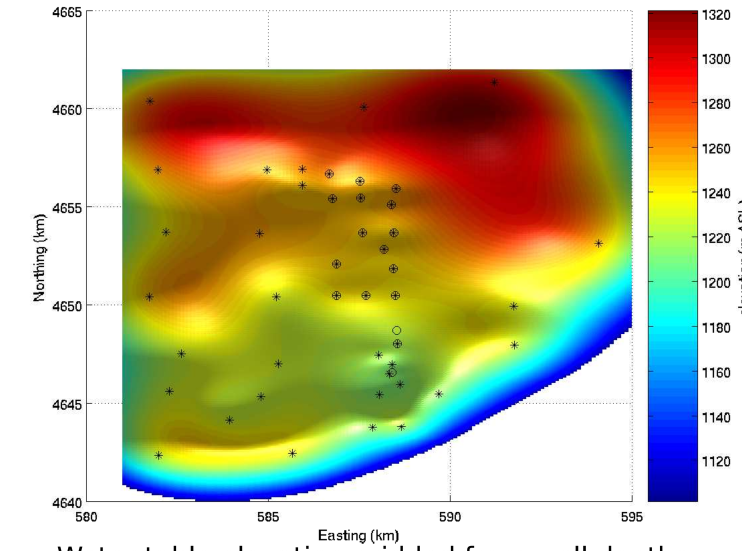
Gravity campaigns were conducted in July, August, September, and October 2003; infiltration peaked in July and ceased by September. Water table measurements were taken near or during the gravity campaigns. GPS campaigns on the gravity stations (wells) showed no significant changes. NGS measured absolute gravity at the SBNM and MORRILL_CA sites during the July and September campaigns, providing absolute control on instrument drift during the project.

Gravity Changes / Water Table Changes



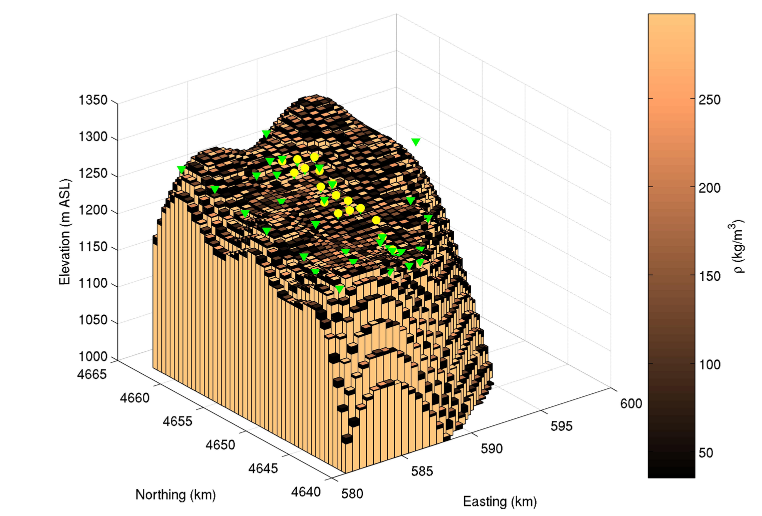
Gravity and water table changes for August, September, and October 2003 campaigns relative to July 2003. Gravity changes are in µGal and water level changes are in m. Wells are marked by stars, and gravity stations by open circles. The irrigation canal is shown by the heavy black line. Since July was the peak of irrigation (and hence infiltration), changes near the infiltration canal are expected to be decreases from July to October. Both gravity and water table changes are shown as grids computed using an equivalent sources method (Cordell, 1992); gravity changes at stations are gridded, but water table changes are computed by differencing gridded water table elevations.

Gravity Modeling of Water Table Changes



Water table elevation gridded from well depths.

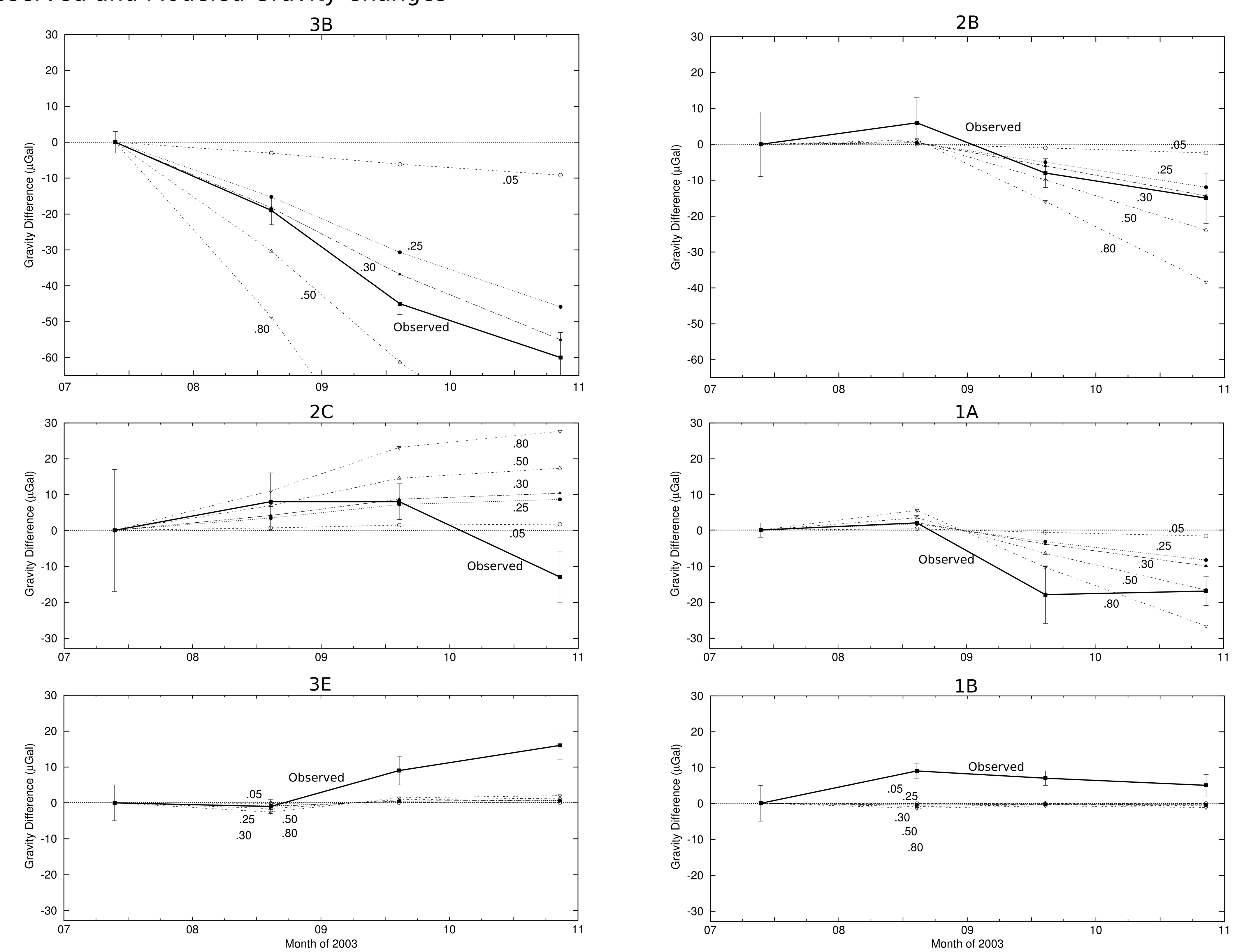
Example conversion of gridded water table elevations to a gravity model for comparison with observations. The water table elevations are gridded at a 100x100m interval, and these elevations are used to construct columns of saturated blocks for gravity modeling. Columns start at an arbitrary depth and approach the surface in 100m increments. Each column is capped by a 100x100m block 10-90 m thick, and a stack of 10x10x1m blocks to the water table elevation. The top layer of 10x10x1m blocks is partially saturated; all others are fully saturated. Porosity is assumed (0.30 in this example) and used to compute the maximum block bulk density.



Water table model - gravity stations yellow, wells green.

The gravity effect of the model is computed using a method of moments (Grant & West, 1965). Gravity effects from two models are differenced for comparison with the observed gravity changes at stations, as a function of assumed porosity.

Observed and Modeled Gravity Changes



Observed and predicted gravity changes for selected wells. Predicted changes are from differencing the gravity effects of water table models. Model results shown for selected porosities - best matches between observed and predicted changes are generally obtained for porosities of ~0.30. The Dutch Flats site is dominantly sandy alluvium in the near surface, with an expected porosity of ~0.30. Top panels show stations at the north end of the network, next to the infiltration source (Tri-State Canal), which have the largest signals. Middle panels show intermediate stations with some water table elevation change; gravity changes (observed and predicted) are more subdued. Bottom panels show two stations with near-zero water table elevation change, and hence little predicted gravity change for any porosity. Observed gravity does show some small signal, so there is likely an additional gravity change signal (such as surface irrigation, precipitation, or construction) at these sites. Repeated absolute gravity at MORRILL_CA and SBNM stations show no change between July and September, so any signals at these stations are local rather than regional.

Conclusions

- Gravity monitoring of Dutch Flats, NE tracked infiltrated canal water as it moved south, and captured drying of the near-canal shallow subsurface.

- Gravity changes modeled with a porosity of ~0.30 agree well with observed changes at stations with water table changes >1 m during the project.

- Observed gravity changes at stations with water table changes <1 m indicate the presence of additional gravity signals of up to 20 µGal.

- Absolute gravity measurements in July and September 2003 allow removal of instrument drift at all stations, and reference stations measured with absolute and relative gravimeters agree within error bounds.