Gravity Monitoring and Modeling of Groundwater Changes at Dutch Flats, Nebraska

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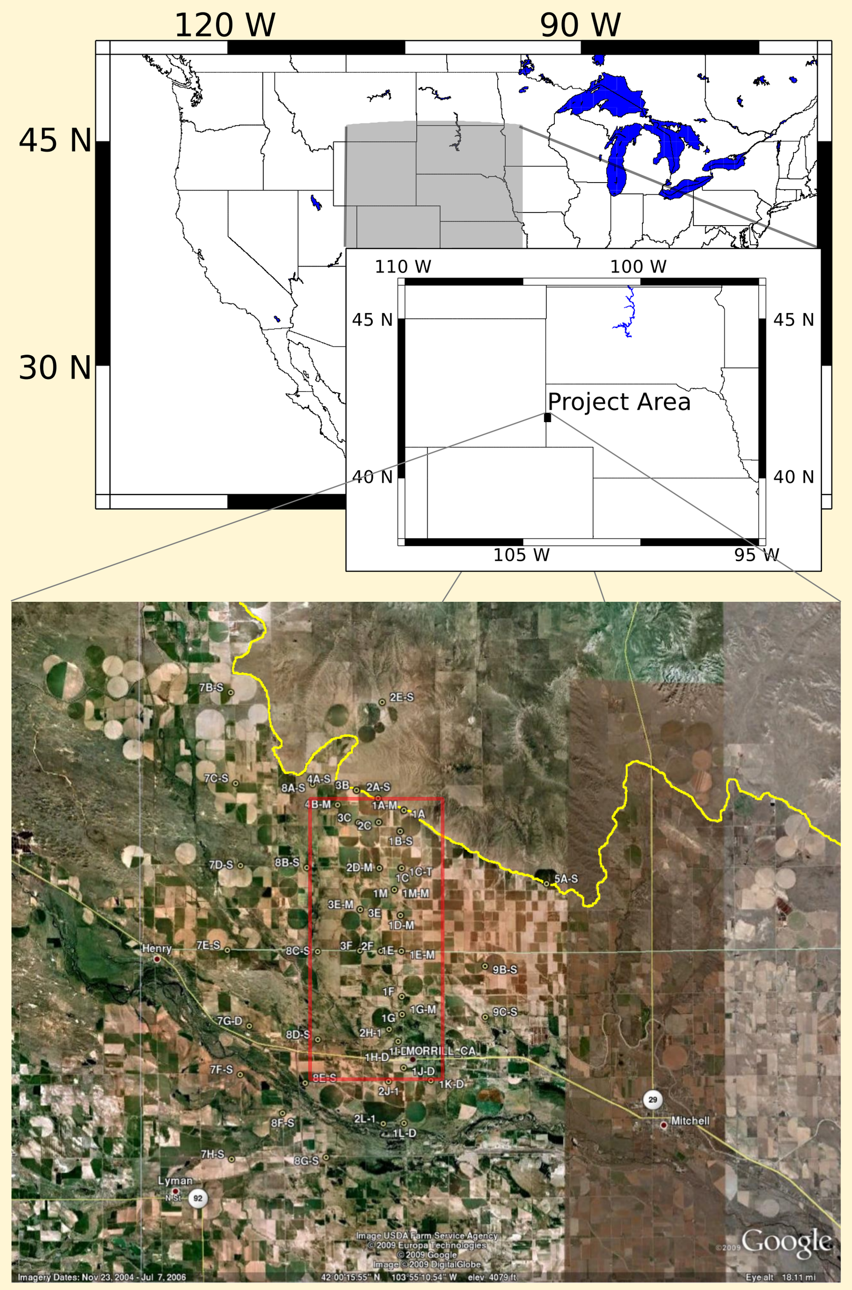
Abstract

Gravity monitoring at the Dutch Flats, Nebraska test site has proven to be an effective and inexpensive means of tracking groundwater changes. In 2003, gravity monitoring at the site began on 16 wells, with absolute gravity control at two far-field stations provided by the NGS. Monthly campaigns from July to October 2003 captured gravity changes associated with canal infiltration and groundwater migration in the near surface. Initial modeling efforts, reported at the 2009 Fall Meeting, used flat-bottomed model spaces of uniform saturation to match predicted and observed changes at some stations, but not all; RMS residuals for repeat campaigns range up to 15 μGal at best-fit porosities of 0.3-0.4.

To provide a better match between observed and modeled changes, basement topography derived from USGS helicopter-based EM data has been added to the modeling. New models incorporate bedrock topography to limit the region of significant storage change, providing a better match between observed and predicted gravity changes; RMS differences for models with bedrock topography are up to 10 μGal, which is the observation noise level.

The study presented here shows an example of integrating 2 geophysical data sets with classical hydrologic information to estimate a hydrologic parameter of interest with good certainty; the techniques developed for this analysis area are applicable to many other gravity monitoring projects.

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.

Acknowledgements

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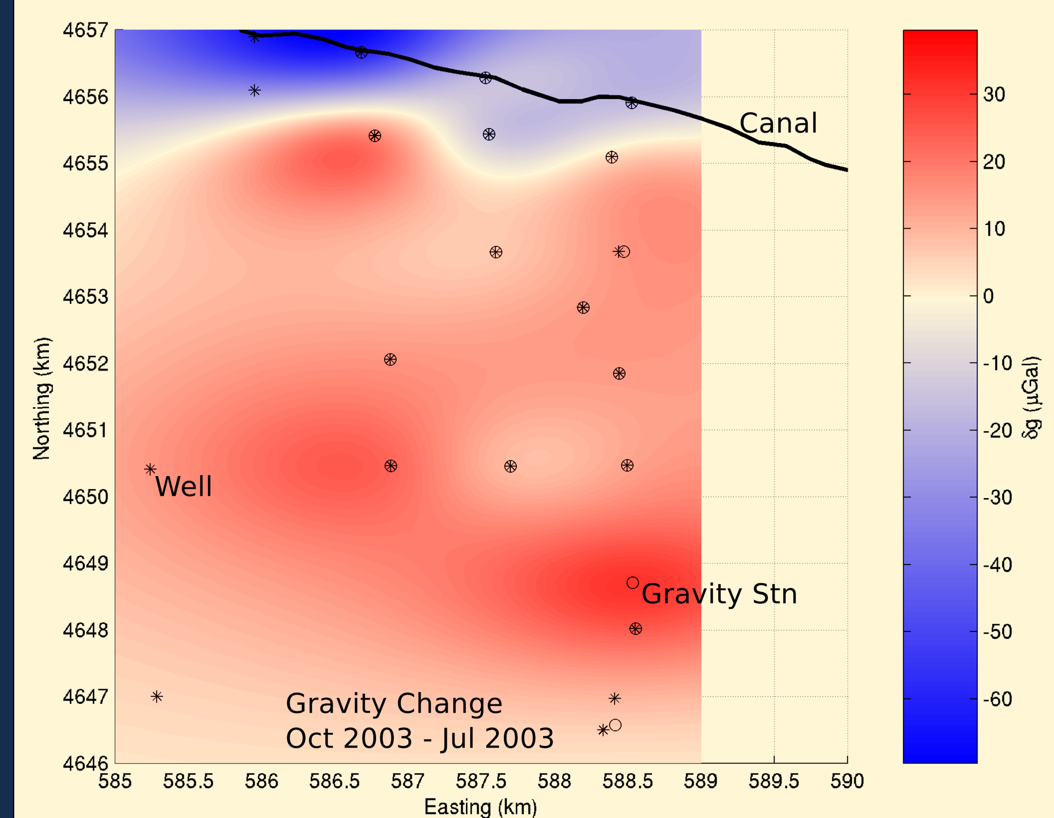
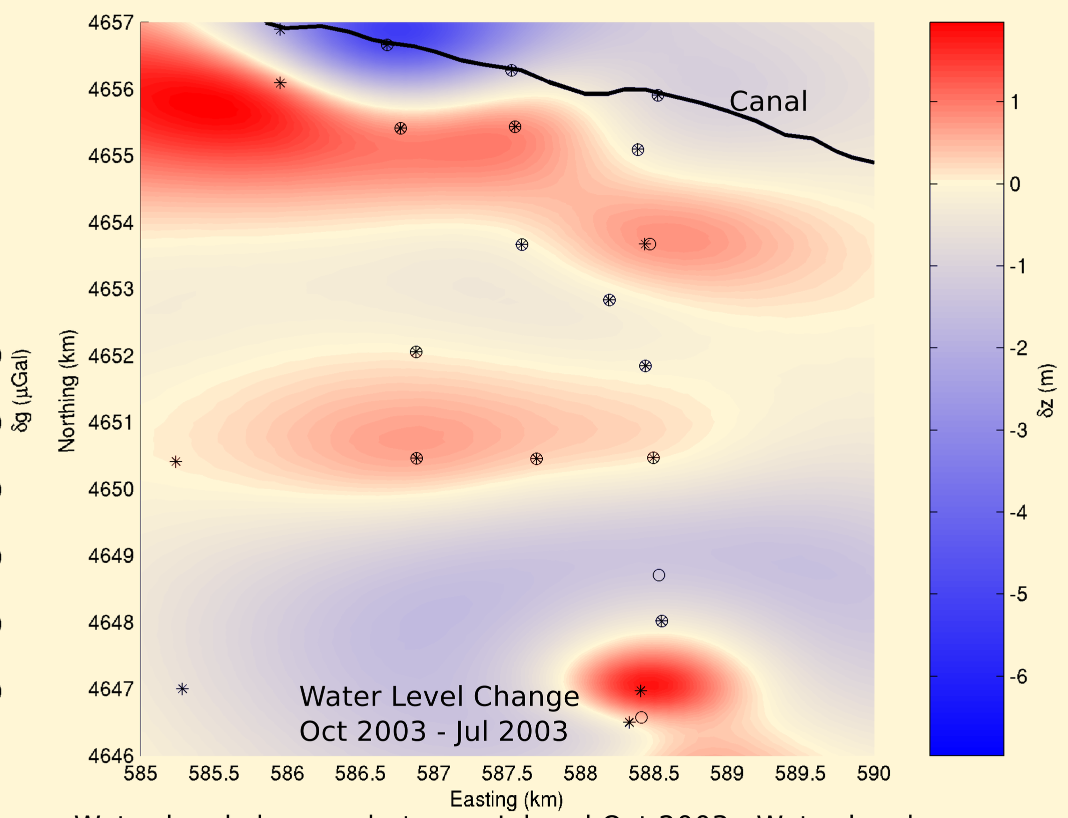
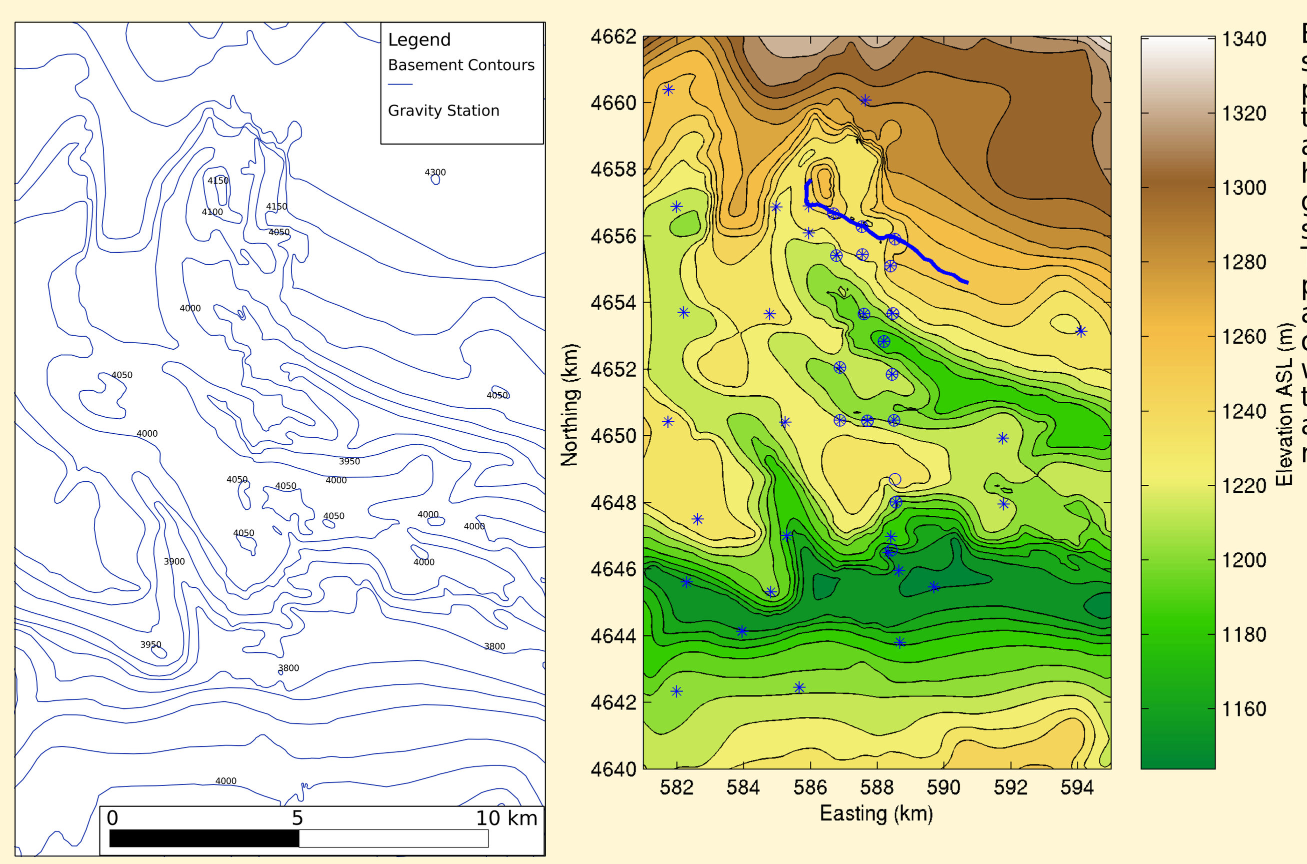
Data & Models



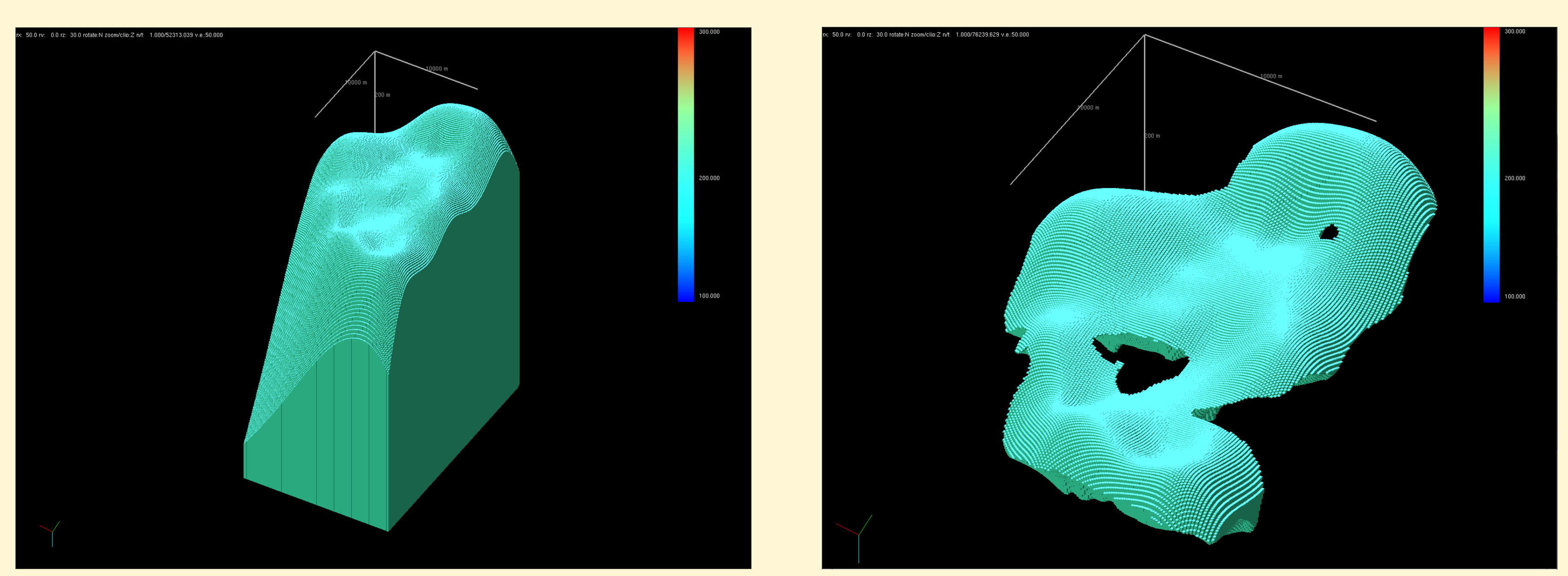
Example grid of gravity change using Oct and Jul 2003 campaigns; for clarity only one difference will be shown on the poster, but calculations were done for all 3 repeat campaigns (Aug, Sep, Oct). Far-field stations SBNM and MORRILL CA are held constant based on absolute gravity measurements by NGS. Gravity changes are gridded using the equivalent source method in Cordell (1992). Changes for Aug and Sep 2003 show a general southward migration of a gravity high from the canal infiltration in Aug 2003; see Gettings et al (2009) for detailed maps of all campaigns.



Water level changes between Jul and Oct 2003. Water levels are measured in the wells at each campaign, and form the upper boundary of models for interpretation. Gridded values calculated using the scattered equivalent source method of Cordell (1992), as with the gravity change data.

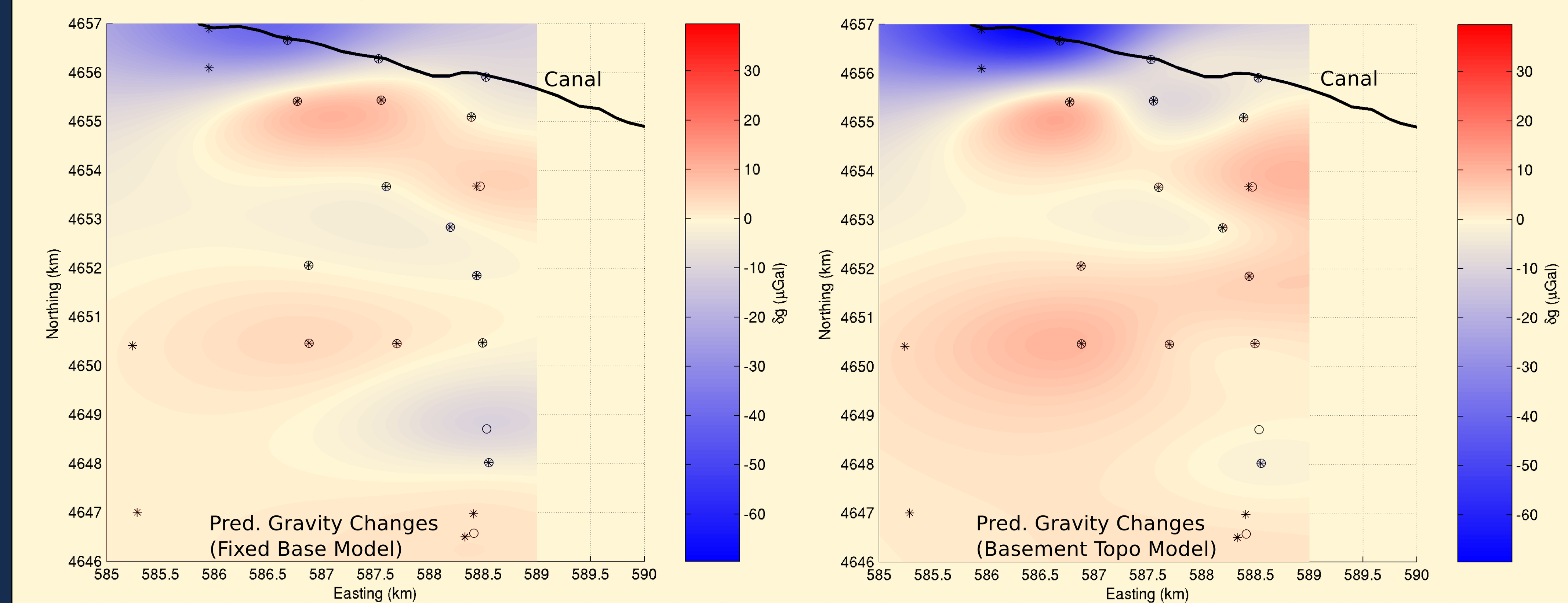


Basement elevations from USGS airborne EM surveys (Pers. Comm., J. Cannia, 2010). Left panel shows the EM-inferred basement topography, in feet ASL. Data were provided as isolines, which had to be rebuilt into a height grid for modeling; the resulting height grid is shown in the right panel with gravity stations as circles, monitoring wells as stars. The "uncontouring" was done by treating each point of the isolines as a discrete data point, and using the multiquadric surface technique of Hardy (1971). The constructed height grid was recontoured in Matlab for comparison with the original isoline data; all critical features are reconstructed within the 100 m grid resolution.

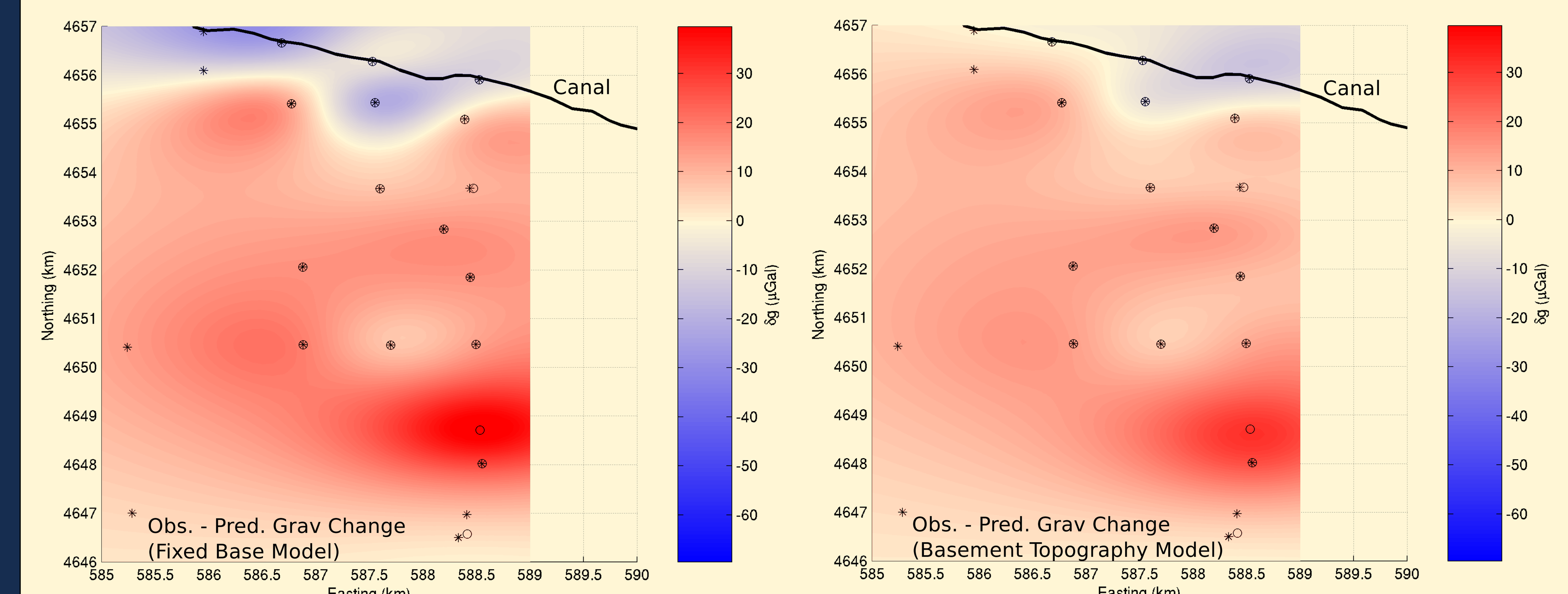


Block-based models used to determine a best-fit average porosity for the Dutch Flats, NE test area; note the 50x vertical exaggeration. These models are for the Oct 2003 campaign. Models are based on rectangular blocks, but sizes vary across the model domain. Model gravity values are computed from the moment method in Grant & West (1965). All blocks have an equal density depending on assumed porosity; examples here have a porosity of 0.2, or a density of 200 kg/m^3. Top surface is set by the gridded water table in both panels. Left panel shows a fixed-base model using an arbitrary minimum elevation. Right panel shows a model using basement topography as the bottom surface; areas where the basement elevation exceeds the inferred water table elevation are assumed to have negligable storage and thus are not included. Model gravity changes are computed from differencing predicted gravity values at each station between campaigns. Modeled changes are then gridded identically to the data for comparison.

Modeling Results & Comparison

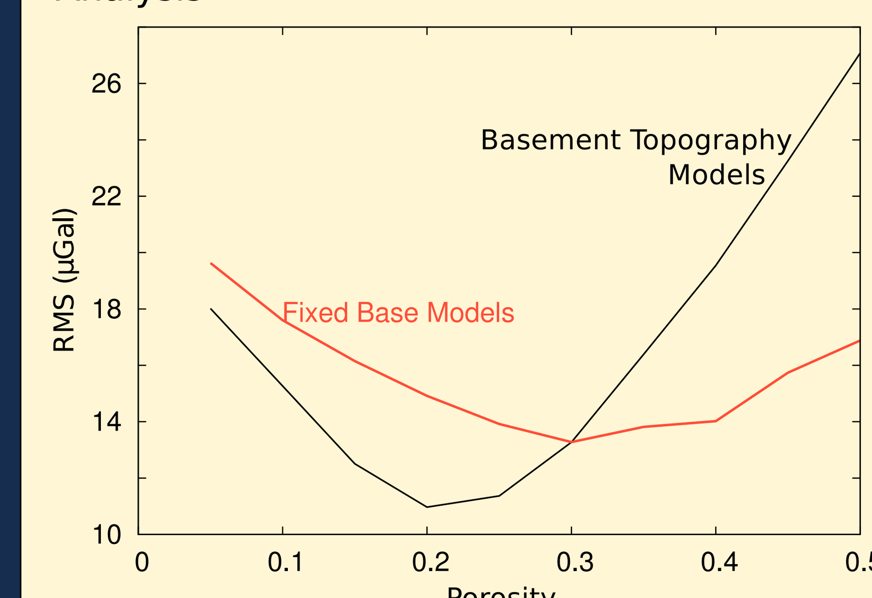


Modeled gravity changes between Jul and Oct 2003 for porosity of 0.2. Gravity values are predicted from the block-based models for each campaign at all gravity stations, and the campaigns subtracted. The data are then gridded identically to the observed changes. Left panel shows predicted gravity using a fixed-base model; right panel shows predicted gravity including basement topography. Basement topography has significant influence in some portions of the model domain.



Difference between observed and modeled gravity changes from Jul to Oct 2003. Left panel shows the difference between the observed and modeled for fixed-base models; right panel models include basement topography. Note that both models under-predict changes at stations 1F and 1G. However, the models with basement topography has a lower overall residual than the fixed-base models. Differences of <10 μGal are not significant due to measurement error.

Analysis



RMS difference of observed and modeled gravity changes by porosity. Fixed base models have larger RMS differences, with a less-well defined best-fit minima. Best-fit porosity varies from 0.2 (basement topography models) to 0.3 (fixed-base models). Observation uncertainty is 10-12 μGal, so more complex modeling is not currently warranted.

Conclusions

1) Gravity campaigns in 2003 show groundwater-related changes, which can be used to infer a best-fit in-situ formation-scale porosity of the near-surface aquifer.

2) Integration of basement topography from processed EM results (isolines) can be accomplished relatively easily on modern computers; incorporation is entirely objective and automatic, with no operator intervention.

3) Multiquadric surface reconstruction of a height field from isolines allows using abundant vector GIS data in grid-based modeling.

4) Addition of basement topography (with assumed negligable storage) improves the fit of a homogenous porosity model to observational error limits (~10 μGal).

5) Integration of helicopter EM (for basement determination), well monitoring, and gravity monitoring allows characterization of project hydrology with the potential for comprehensive coverage of watersheds.

6) Future work will seek to incorporate additional campaigns and extend this integrated approach to other project sites.

References

Cordell, L., 1992. A scattered equivalent-source method for iterpolation and gridding of potential-field data in three dimensions. Geophysics, v57, pp629-636.
Gettings, P., D.S. Chapman, and W. Kress, 2009. Gravity monitoring of canal infiltration: results from Dutch Flats, Nebraska. Eos Trans. AGU, v90, n52, Fall Meeting Supplement, Abstract H53B-0927.
Grant, F.S. and G.F. West, 1965. Interpretation Theory in Applied Geophysics. McGraw-Hill Book Company.
Hardy, R.L., 1971. Multiquadric equations of topography and other irregular surfaces. Journal of Geophysical Research, v76, n8, pp1905-1915.