2008 ANNUAL REPORT
SATELLITE RADAR ACQUISITION AND IMAGING

INTRODUCTION

The Regional Water Planning Commission entered into a joint contract with the University of Nevada, Reno and Washoe County Department of Water Resources in October 2006. This contract consisted of the acquisition, processing, cataloguing, and summarizing deformation grid anomalies found through the use of these satellite radar scenes. Herein contains the second report of work to date under this contract.

Previous technical reports presented evidence for the measurement of land surface "flexure" using differential interferometry (DInSAR). These slight changes in land elevations can be due to changes in the volume of groundwater in regional aquifers (aquifer elasticity). These volumetric changes are due to well field production and the spatial rate and timing of ground water recharge. Other ground water related trends in DInSAR anomalies that can be determined are aquifer storativity and permeability, faults boundaries, lag time of aquifer trends and effects to the land surface.

In our application, land surface deformation is the result of ground water aquifer elasticity. This elasticity is supported by the aquifer's structural framework made of granular media (sand, silt, clay), air and water. Aquifer elasticity does allow for "land surface flexure" given relatively small changes in the volumetric water and air content. For our purposes, "**deformation**" consists of small land surface inflections termed **inflation** (upward) and **deflation** (downward) measured at the scale of 5 millimeters or greater.

PREVIOUS WORK

The Regional Water Planning Commission contracted the initial investigation of using DInSAR locally in 2004. Dr. Gary Oppliger of the University of Nevada, Reno and Michael Widmer of the Washoe County Department of Water Resources undertook this collaborated work. The final report, "***Washoe County DWR/RWPC cooperative study with Dr. Gary Oppliger of the relation between satellite based radar differential interferometry (D-InSAR) ground deformations and groundwater production and level data in the Truckee Meadows***" was presented to the Commission and accepted on August 3, 2005. This work documented that the use of satellite radar could precisely identify vertical land deformation at the sub-centimeter scale due to ground water recharge and pumping. Other complimentary works are listed in the Reference section.

Catalogue of scenes, interferograms and grids from Envisat 1&2

The area of coverage, from Honey Lake to Douglas County, encompasses two satellite scenes and are termed the North and the South. Their common boundaries are matched just north of Lemmon Valley. Table 1 on the following page lists the seven scenes, both South and North, acquired by Washoe County and processed by UNR during the fiscal year 07/08. The first three sets of scenes were acquired by Washoe County, the next four were acquired free of charge from UNR. The first column of the Table indicates the raw satellite data that was processed to a scene. The second column lists the interferograms

that have been formed (as pairs) with the two scene dates used to form the interferogram (columns 3 and 4). Finally, the last column lists whether or not the interferogram has been processed using both the North and South scenes. Future grids can be made from the pairs listed with relative ease.

Table 1
Scenes, interferograms and deformation grids from ENVISAT satellites

Envisat1/2 scenes	Envisat1/2 Interferogram	Pair Dates		South or North scenes processed?
18-Jul-07	pair 37	9-May-07	13-June-07	Both
22-Aug-07	pair 38	13-Jun-07	18-Jul-07	Both
31-Oct-07	pair 39	24-Jan-07	4-Apr-07	Both
13-Feb-08	pair 40	22-Aug-07	31-Oct-07	Both
19-Mar-08	pair 41	11-Oct-06	24-Jan-07	Both
23-Apr-08	pair 42	11-Oct-06	4-Apr-07	Both
28-May-08	pair 43	18-Jul-07	23-Apr-08	South
	pair 45	17-Aug-05	22-Aug-07	Both
	pair 46	6-Oct-04	31-Oct-07	Both
	pair 47	23-Apr-08	28-May-08	South
	pair 48	9-May-07	28-May-08	South
	pair 49	9-May-07	22-Aug-07	Both
	pair 50	19-Mar-08	28-May-08	South
	pair 51	11-Oct-06	13-Feb-08	South
	pair 52	13-Jun-07	28-May-08	South
	pair 53	18-Jul-07	28-May-08	South

Presentation of Envisat 1 & 2 deformation grids

The focus of this report is to identify anomalies that may be associated with very wet and very dry precipitation years as they relate to wellfields and ground water recharge areas, primarily in alluvial basins. During drought periods ground water wells are more heavily relied upon, especially for municipal purposes. Therefore the effects of heavier than usual pumping should result in areas of “deflated” flexure on the land surface. Conversely, during heavy precipitation years and when floods occur, less pumping is relied upon and larger ground water recharge events should create areas of land surface “inflated” flexure.

As the result of cyclic pumping of well fields, there will be re-occurring anomalies over the same areas. Only brief and possible explanations of noted anomalies will be undertaken in these reports. Complete analysis of anomalies can be pursued if warranted. As discussed above, our focus is related to events that increase (recharge) or decrease (pumping) ground water storage. For reference in the discussion that follows, two charts are included that record precipitation. The first shows the percent of average annual precipitation for the Greater Truckee Meadows and the second chart plots the interferogram end dates with monthly precipitation as measured at the Verdi gage. Note that a five-year drought occurs from 2000-2004 followed by an average year and the flood event in December 2005. Water years are from October 1 through September 30.

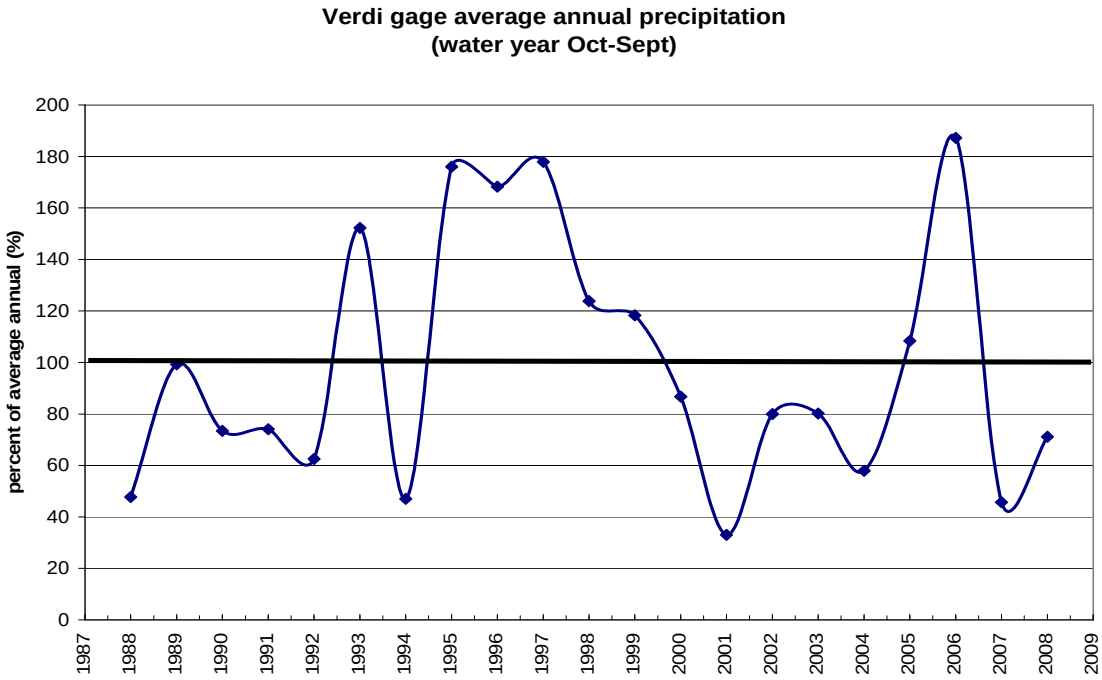

Chart 1. Display of annual precipitation from Verdi Gage as percent average of 21-year record.

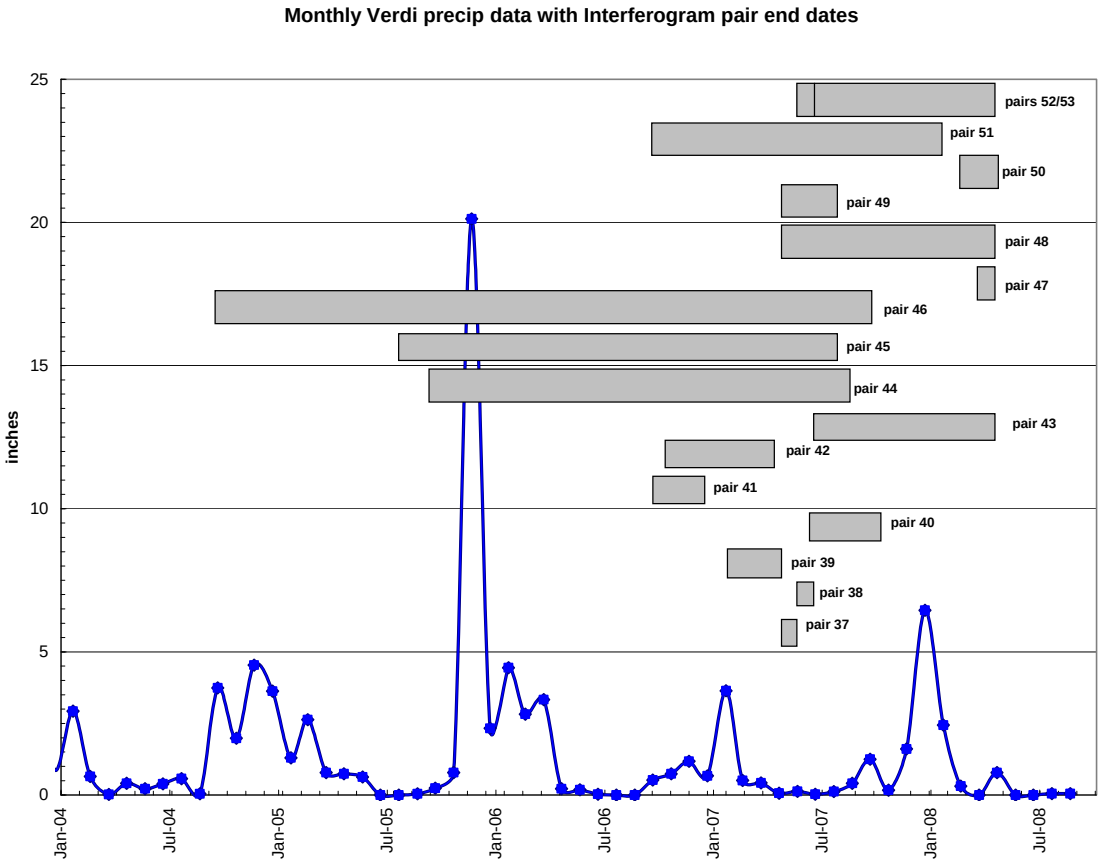

Chart 2. Display of monthly precipitation (Verdi gage) with time frames of deformation grids.

The deformation grids are presented as colored shaded relief of land surface flexure where warm colors represent deflation of the land surface and cool colors inflation of the land surface. These changes are contoured at 5 millimeter intervals. Relatively large areas with variations at 10 millimeters (one inch equals 25 millimeters) or more are discussed. Therefore changes noted in just a few millimeters are not worth discussing. Major roads are plotted for reference and municipal wells are also represented for correlation to deformation anomalies. The Truckee River is included in the maps as are local playas and lakes.

Because we are mostly interested in alluvial basins and consequent land surface deformation, the following grids exclude radar data within the mountainous areas. The reason is that mountainous areas can contain "pockets" of moisture that create radar distortion or anomalies that are not real. Therefore trying to account for these anomalies is unwarranted and confuses the explanation of real anomalies within the adjoining basins. The following radar images are therefore restricted to the alluvial basins and mountain topography, in grey shaded relief, is included for reference.

The reader should understand that the formation of these grids is a function of the "compatibility" of individual satellite scenes. First the scene must have been taken on a satellite track within 250 meters of another in order for them to be processed together as an interferogram and later grid formation. Second, once the individual scene is processed there maybe too much atmospheric noise (commonly from moisture or precipitation) and therefore the scene may be rendered "incoherent" and of little use relative to another scene. Consequently, the number of interferograms is reduced by these constraints.

Figure 1 is a deformation grid (pair 10) of the total survey area (both the South and the North scenes) that encompasses portions of eastern California and western portions of Nevada. Also shown are lakes and playas, noted in blue, with some basins labeled. The deformation data is displayed in color shaded relief with some topography shown. The deformation ranges from deflation of -20mm (warm colors) to inflation of 20mm (cool colors) and most shows very little change (<10mm). The purpose of this Figure is to accustom the reader to the image format and the survey area.

Greater Truckee Meadows

Seven deformation grids are presented and are restricted to the greater Truckee Meadows metropolitan areas. "Noisy" or incoherent data has been eliminated from the grids. However, the data has undergone minor extrapolation within the bounding areas of the excluded data so as to assist in contouring the data and for presentation. Municipal wellfields are shown (red dots) and major roads for reference. **Not all of the grids processed for this report are not shown as they become redundant, are not be very revealing, or contain too much incoherent data.**

Figure 1. *Southern Washoe County map, Smoke Creek to Lake Tahoe*

Figure 2. *Pair 37 May 9, 2007 to June 13, 2007 span of 1 month*

This time period represent the onset of increased ground water pumping. Of interest is the north-northeast linear feature that falls upon the Silver Lake well field in West Lemmon Valley with up to 15mm of deflation. This feature has been noted before (Pair 15, Figure 6 in 2006/2007 Annual Report). The linearity of this feature is assumed to represent faulting that controls the flow of water to the well field (semi-impermeable barrier). Another deflated area seen is over the Central Truckee Meadows well field (up to 10mm) with the re-occurring linear feature (nnw) that is seen repeatedly in interferograms that date back to 1992. Again, an indication of fault structures influencing the flow of water to the well field. The Mt. Rose Fan well field indicates deflation of up to 18mm. Another anomaly shows up in the South Meadows with up to 18mm of deflation. This feature may indicate a decrease in the water table due to overall pumping and/or the cessation of irrigated lands where housing is now being developed. It is interesting to note these features relatively early in the pumping season and may reflect the lack of precipitation of the previous winter.

Figure 3*. Pair 40 August 22, 2007 to October 31, 2007 span of 2 months*

This time frame spans the late 2007 summer pumping period to mid-Autumn. Of particular note is the same linear feature noted over the Silver Lake well field that now indicates 20mm of inflation. The Spanish Springs well field indicates 5-10mm of deflation whereas the Central Truckee Meadows well field indicates up to 15mm inflation, indicative of the cessation of pumping and the onset of TMWA's ground water recharge program. Slight inflation is seen in the Mt. Rose Fan well field of up to 10mm. An anomaly of up to 15mm is indicated at the south end of Washoe Valley that is not understood.

Figure 4*. Pair 41 October 11, 2006 to January 24, 2007 span of 3 months*

Once again the Silver Lake well field anomaly is shown with its sharp southern and eastern boundaries with land surface inflation of up to 15mm. The Central Truckee Meadows anomaly is also detected and shown with up to 20mm of inflated land surface. Both features appear to be indicative of TMWA's ground water recharge program. Minor land surface inflation of less than 10mm is noted in the Mt. Rose Fan well field.

Figure 5*. Pair 42 October 11, 2006 to April 4, 2007 span of 6 months*

This is a longer time frame of Pair 41 and also shows the inflation of up to 25mm of inflation over the Silver Lake and Central Truckee Meadows well fields. The other well fields show slight inflated (~5mm) of flexure over these two instances in time.

Figure 6*. Pair 49 May 9, 2007 to August 22, 2007 span of 3½ months*

This time period is from the beginning to nearly the end of the summer pumping period and during a period of well below normal precipitation (40%). The data over the Silver Lake well field anomaly was mostly incoherent, but still indicates that deflation was occurring and along the familiar NNE linear trend. Other well fields show this deflation that includes the East Lemmon Valley well field (20mm), the Central Truckee Meadow well field (20mm) and the Mt. Rose Fan well field (10mm). Once again the Central Truckee Meadows deflated area shows the north trending lineament on the west side of

this feature. Fifteen mm of deflation is also noted in the northwestern portion of Washoe Valley.

Figure 7. *Pair 50 March 19, 2008 to May 28, 2008 span of 2 months*
The Central Truckee Meadows well field indicates a land surface deflation of 15mm during this Spring time period. Normally the aquifer should be inflating, but a second year of below normal precipitation may have caused this anomaly. Confirmation of TMWA's pumping record and if artificial recharge was occurring could help to differentiate this apparent anomaly. Atmospheric effects may have also created processing problems for this interferogram. The Mt. Rose Fan well field also indicates deflation of up to 5mm.

The anomalies that are shown in the Mogul area are the result of atmospheric moisture and due to the April 28, 2008 earthquake (Magnitude 4.2). UNR is currently processing this interferogram and others to determine the "sense of motion" that occurred during these earthquake swarms. The feature shown in this interferogram is a classic earthquake effect and has been documented with interferograms throughout the world.

Areas outside of Reno/Sparks

Of the interferograms discussed in this report, inspection of features were made outside of the greater Truckee Meadows. Re-occurring features were detected in Sierra Valley, Warm Springs Valley, Carson City, Douglas County, and Honey Lake Valley. These features were coincident with well fields. Of particular mention are the features detected in Sierra Valley where both inflated and deflated flexures of 40-50mm annually occurred. Flexures noted in Warm Springs were relatively minor (10mm). Whereas flexures within Carson City fluctuated by 20mm or more. The Honey Lake Fault Zone, discussed in the previous report, was noted in pair 40. The well field for the Vidler Importation Project at Fish Springs Ranch showed little change throughout all of the interferograms inspected. This is to be expected because of the cessation of irrigation pumping.

DISCUSSION

Re-occurring anomalies consistently show up in the areas of municipal and irrigation well fields. Most have indicated a fluctuation of the land surface on the order of 10-20mm over different time periods. These deformation grids show both a deflation and inflation of land surfaces. This demonstrates the dynamic nature of the land surface as it apparently relates to aquifer "elasticity". The cumulative effects from these inflections are shown to be insignificant within this time period particularly over the largest well field in the Central Truckee Meadows.

Other features that re-appear are probably related to geologic structure as seen over the Silver Lake well field and over the Central Truckee Meadows in all of the figures of this report. These are worth future study as identified fault structures can influence ground water movement. Further evaluation of these structures and the seasonal repetition of inflation and deflation would be of particular value to TMWA as it relates to their production from and recharge to these aquifers. The apparent fault structures noted in the Central Truckee Meadows will be evaluated in order to provide assistance to the Central

Truckee Meadows Remediation District. Major fault structures can influence the migration of the PCE (perchlorethylene) contaminated ground water to both the TMWA and Washoe County well fields.

Inspection of the 2008 interferograms repeatedly show the effects of the earthquakes experienced in the Mogul and Verdi area. These interferograms have assisted the University of Nevada towards delineating land surface ruptures and the areas where lateral and vertical motion have occurred. This work will assist the general public in preparing for future seismic activity. Given the relatively small cost of purchasing and processing these satellites scenes, the program has been invaluable towards understanding these earthquakes.

EXPENDITURES

Under this contract the Regional Water Planning Commission obligated annual expenses of $14,000 for each of three years. During the last two fiscal years $13,326.97 was invoiced against this obligation from UNR for data processing. This means that the program is **under budget** by $14,673.03. Washoe County has expended $11,049.00 for fourteen satellite scene purchases (including the programming for satellites scenes) and $6,540.47 in staff time, totaling $17,589.47 that was originally estimated at $34,000 ($16,410.53 **under budget**). Therefore the entire program for the first two years is under budget by 44%. The expenses forecasted for the next fiscal year should be comparable to the current expenses.

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