3725-00039

Washoe County
Department of
Water Resources
4930 Energy Way
Reno, NV 89502-4106
Tel: (775) 954-4600
Fax: (775) 954-4610

INFORMATIONAL ONLY

February 25, 2007

TO: Jim Smitherman

FROM: Michael Widmer

SUBJECT: Background Report on Satellite Radar Acquisition and Imaging

I would like to request that the attached report be submitted to the Regional Water Planning Commission at their March 7, 2007 meeting. This "BACKGROUND REPORT ON SATELLITE RADAR ACQUISITION AND IMAGING" supports our existing contract with UNR and has the following purpose:

1. provides a background of previous efforts,
2. serves as an introduction to the forthcoming report tied to our contract,
3. provides additional support on the value of this work,
4. provides background information on processes involved in this work, and
5. provides a "pre-contract" archive and description of radar features.

The Regional Water Planning Commission is embarking on the collection of satellite radar scenes for the purpose of monitoring ground water levels within the southern half of Washoe County. Presently, and in the future, these scenes will be used to investigate changes in regional aquifer levels due to concentrated pumping, large-scale recharge events, and the identification of aquifer boundaries. This report documents the catalogue of satellite scenes collected to date and gives a summary of identified ground water anomalies.

As approved by the Regional Water Planning Commission and the Washoe Board of County Commission, a contract was let, in October 2006, to the University of Nevada to provide processing support for satellite radar scenes purchased and archived by Washoe County. Purchasing and processing of these scenes began in 2006. An annual status report and presentation is requested to be given at the April 18, 2007 meeting of the Regional Water Planning Commission.

attachment

c: Rosemary Menard, Water Resources Director
Jeanne Ruefer, Water Resources Planning Manager

Department of
Water Resources

BACKGROUND REPORT ON SATELLITE RADAR ACQUISITION AND IMAGING

Introduction
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 (ground water extraction) and the spatial rate and timing of ground water recharge. Other ground water related trends in DInSAR anomalies can be determined such as aquifer storativity and permeability, faults boundaries, lag time of aquifer trends and land effects.

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.

Typically, monitor wells are used to measure and observe changes in water levels in the aquifer due to rates of change in recharge and discharge. These are point measurements and tens to hundreds of these wells and subsequent measurements are needed to adequately observe aquifer pressure changes on a regional scale. Regional aquifer response to large scale pumping is typically assessed with numerical simulation models of the aquifer. These methods demand substantial resource investments. Consequently, the use of DInSAR serves as a cost effective proxy to ground water monitor wells.

The primary focus of this report is to:

1. provide a background of previous local efforts,
2. serve as an introduction to forthcoming reports,
3. provide additional support on the value of this work,
4. provide background information on processes involved in this work, and
5. provide a "pre-contract" archive and description of radar features.

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. It should be noted that most of the investigation centered upon the Truckee Meadows.

Complimentary to this work is technical memo "***The use of DInSAR for aquifer pumping analysis***" dated May 5, 2005, from Michael Widmer to Jeanne Ruefer within the Department of Water Resources. This memo documents the relationship of ground water pumping and land deflation within the Central and South Truckee Meadows. It also describes much of the processing required from acquisition of raw data to construction of deformation grids, briefly described below.

These research works made use of several satellite scenes and interferograms (see below). Acquisitions of these satellite scenes were made from the University and Washoe County. The next section catalogues these images and describes the major features examined. These images represent additional data funded from other sources.

Satellite history- ERS 1/2, ENVISAT 1/2

Historically, the Europeans, Japan, Canada and the United States have launched radar satellites using this technology. Public and private access to data has been limited and the configurations of each of these satellites are not equal such that the data are not interchangeable. For our purposes, the European satellites are preferred.

The first set of radar satellites launched by the Europeans were the ERS 1 and 2. These were functional from 1992 to 2002. Operational problems have rendered these satellites unusable, ERS 1 in 1996 and ERS 2 in 2002. A second set of satellites were launched under the acronym of ENVISAT. These satellites use an improved technology and the data are often referred to as ASAR (Advanced Synthetic Aperture Radar). Satellite scenes from the ENVISAT satellites are not useable with the ERS data.

How satellite images are processed to deformation grids

Differential Interferometric Synthetic Aperture Radar, or D-InSAR is a technique whereby two geo-referenced satellite scenes are digitally compared to examine any change in microwave phase from the exact same resolution cells (20m pixels). Another way said is that a radar signal or pulse is focused on the earth and timed from when it is emitted to when it is "bounced back" to the satellite. The time in travel can calculate a distance since the radar pulse travels at the speed of light. The radar pulse actually covers a large swath of the earth's surface (100s of square miles), but is discretized at 20 meter sized cells (or pixels). Then comparing one scene to the next, a difference in distance (as calculated with time or phase change in the electromagnetic signal), at the sub centimeter scale, can be realized per cell or pixel. If the change (or no change) is consistent over a large area, the term "coherency" is used to distinguish useable data.

Changes in distance, with coherent data, will be due to land surface displacement in the resolution cell itself. For example, the effects of tectonic movement or deformation can be imaged in this manner, within limitations. These limitations are usually dictated by extensive changes in land use (i.e. subdivision construction, snow cover, farming activities) and different satellite orbit spacing between when the two images were taken.

While cloud cover is usually not an issue, moderate to large precipitation events can disrupt the usability of the data.

Once acquisition of the raw satellite data is received, a very complicated yet automated processing routine is followed to create a satellite "scene". Two scenes of the same "exact" area and with the relatively same orbit (generally within 1000 feet) can be digitally compared with a resulting "interferogram". These are called "pairs" and represent the changes in the land surface over the period of time the scenes represent. These interferogram images or pairs can be difficult to view on a computer screen and require experienced interpretation. Dr. Oppliger has developed a routine to process the interferogram to a "deformation grid". This grid represents true land surface deformation, if indeed any surface change has occurred. By contouring of this deformation grid, interpretation is relatively easy and comprehended by the layperson. This deformation grid is the final product submitted to Washoe County for cataloguing, archiving and interpretation.

Contract program with UNR

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 (by WCDWR), processing (by UNR), cataloguing (by WCDWR), and summarizing deformation grid anomalies found through the use of these satellite radar scenes (by WCDWR). Annual reports are to be presented to the Regional Water Planning Commission. This contract, unless renewed, will expire October 2009. It is projected that acquisition will continue at the rate of one scene per month. As described above, not all scenes will be useable (non-coherent).

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

The Table below lists the data acquired by Washoe County or available from UNR from the European Space Agency's ERS 1 & 2 satellites. The first column indicates the satellite data that has been 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 to a deformation grid. Washoe County has archived these grids. Future grids can be made from the pairs listed with relative ease.

How to interpret deformation grids- what's real and what's not

The focus of this program is related to significant changes in ground water levels as reflected in land surface elevation changes. Lands that have not been developed or have been completely developed make good "reflectors" and it is these lands that are reviewed for slight changes in land surface elevation. Typically, the lands that we are interested are those within wellfields, near the Truckee River or other important water bodies, and near ground water recharge areas. These lands must also overlie important and regionally extensive aquifers.

As discussed briefly above, any large-scale (square miles) change in the land surface will be shown in the deformation grid images. Within our area of investigation this amounts

Table 1
Scenes, interferograms and deformation grids from ERS satellites

ERS1/2 scenes	ERS1/2 Interferogram	Pair Dates		deformation grid
14-Apr-92	pair 1	21-Feb-97	6-Jun-97	no
10-Nov-92	pair 2	14-Apr-92	11-Nov-93	**yes**
30-Mar-93	pair 5	30-Nov-93	19-Oct-95	**yes**
17-Aug-93	pair 6	30-Mar-93	28-Dec-95	no
30-Nov-93	pair 7	10-Nov-92	11-Apr-96	no
19-Oct-95	pair 8	17-Aug-93	21-Feb-97	no
20-Oct-95	pair 9	17-Aug-93	6-Jun-97	no
28-Dec-95	pair 10	14-Apr-92	19-Oct-95	**yes**
11-Apr-96	pair 11	28-Dec-95	24-Sep-99	no
13-Dec-96	pair 12	10-Nov-92	24-Sep-99	no
17-Jan-97	pair 14	30-Mar-93	25-Sep-99	no
21-Feb-97	pair 15	11-Apr-96	26-Sep-99	no
28-Mar-97	pair 16	30-Mar-93	30-Nov-93	**yes**
6-Jun-97	pair 17	19-Oct-95	28-Dec-95	no
11-Jul-97	pair 18	10-Nov-92	30-Mar-93	no
15-Aug-97	pair 21	6-Jun-97	13-Sep-02	**yes**
19-Sep-97	pair 22	30-Mar-93	11-Apr-96	no
31-Jul-98	pair 23	30-Nov-93	28-Dec-95	no
24-Sep-99	pair 24	10-Nov-92	29-Dec-95	no
21-Apr-00	pair 25	30-Mar-93	19-Oct-95	no
13-Sep-02	pair 27	21-Feb-97	13-Sep-02	no
	pair 28	17-Aug-93	14-Sep-02	**yes**
	pair 30	15-Aug-97	31-Jul-98	no
	pair 31	7-Nov-97	31-Jul-98	**yes**

to subdivision grading and building, the growth of crops, changes in lake levels such as Washoe Lake or the North Valley playas of Silver Lake and Swan Lake. Mountainous areas with dense forest will also create problems for data interpretation. Such changes in land surface activity can render interferogram data "incoherent" and this data is often omitted (whited-out) from the deformation grids. Therefore, we typically review theses deformation grids within the lands that have not undergone such land surface changes. This requires a good local knowledge and adequate recording of such activities.

Because this current report is limited to the ERS satellite data, the area of investigation only includes the most southern portion of Washoe County. Figure 1 shows the ERS data considered from west to east the Cold Springs to Spanish Springs valleys and south to Washoe Valley. Future reports (April 2007 and onward) will contain areas further north to and including Honey Lake Valley.

The deformation grids are presented as colored scale of changes (?) where warm colors represent deflation of the land surface and cool colors inflation of land surfaces. These changes are mapped in millimeters such that only variations greater than 10 millimeters (or 1 centimeter) where one inch equals 25 millimeters. Therefore changes noted in just a few millimeters are not worth noting. Also note that when viewing several deformation grids, the color scale is not consistent. This will be corrected in future reports. Major roads are plotted for reference and municipal wells are also represented as small black dots for correlation to deformation anomalies.

The focus of this investigation is of anomalies associated with very wet and very dry precipitation years as they relate to wellfields and ground water recharge areas. Consequently, 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.

Review of ERS 1 & 2 deformation grids

Figure 2. Pair 2 April 14, 1992 and November 11, 1993

This grid shows the interval between the 6th year of drought (April 1992), a fairly wet 3 months of winter (Dec92-Feb93) and the ensuing drought through November 1993. The grid shows little change in land surface between these 19 months. Two anomalies of deflation show up, but are not well defined due to incoherent data being removed. These are over the Silver Lake wellfield in west Lemmon Valley (~10mm) and the Steamboat Hills geothermal area in the S. Truckee Meadows (~10mm). Incoherent data was removed from the areas of Washoe Lake, Silver Lake and Swan Lake (both in Lemmon Valley) and probably reflect these playas regaining water from the past winter months. Incoherent data was also removed from the SE Truckee Meadows and NE Reno that probably reflects construction activities. The central Truckee Meadows trends towards inflation and might reflect recharge from the Truckee River and a reduction in pumping.

Figure 3. Pair 5 November 30, 1993 and October 19, 1995

This grid shows the interval between the near end of the 8-year drought (1987-1994) and a very wet winter and spring (Nov 94-Mar 95). As with the last grid incoherent data is missing at the Lemmon Valley playas, Washoe Lake, NE Reno and SE Truckee Meadows. The Steamboat geothermal area anomaly shows from 5 to 15mm of deflation (actually hypothesized as contraction of the rock reservoir). The other apparent anomaly is centered over the central Truckee Meadows wellfield where up to 10mm (<1/2inch) of deflation appears to have occurred. A similar pattern is shown in west Reno, but at a much less amount. This does correspond to a wellfield (Oppliger et al, 2005). Conversely, the UNR Agricultural Farm lands in east Reno trend towards inflation of land surface (>5mm), but is inconclusive.

Figure 4. Pair 10 April 14, 1992 and October 19, 1995

This deformation grid is similar in time frame from pair 5, but has a "beginning" end-point 19 months earlier. Therefore two very wet winters of 1994 and 1995 occurred between theses two end-points, encompassing 3½ years. The Steamboat geothermal