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LAS VEGAS VALLEY 2000 SUBSIDENCE REPORT

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This information should be considered preliminary. It has not been edited or checked for completeness or accuracy.

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Scope of 2000 Subsidence Study

The 2000 subsidence study was designed to be a follow-up to the 1997-98 study (1998 Subsidence Report to the Las Vegas Valley Water District) and to provide a final report on land subsidence in Las Vegas Valley through the year 2000. The previous 1997-98 study consisted of four principal elements:

- Conventional level survey of benchmark level lines across geologic faults.
- GPS survey of benchmark network established in 1991.
- Re-inventory of earth fissures.
- Application of synthetic aperture radar interferometry (InSAR).

The 2000 study builds on the results obtained in this earlier study and addresses the following elements:

- Development of SAR interferograms for the 1997-99 period for comparison with the InSAR results obtained for 1992-97, allowing a composite time series of InSAR maps to be produced covering the period 1992-99.
- Examination of the SAR interferograms for evidence of horizontal displacements that may accompany the vertical components of subsidence.
- GPS survey of selected benchmarks in the Northwest subsidence bowl to measure vertical and horizontal change since 1998 and to provide ground-truth verification for the InSAR study.
- Conventional level surveys along line #11 across the Eglington fault and along a newly established line #12 through the Northwest subsidence bowl.

The InSAR study was conducted by Dr. Falk Amelung, now at the University of Hawaii, who supervised the seasonal subsidence portion of the study that was conducted by Joern Hoffman, a graduate student at Stanford University. The GPS survey was supervised by Geoff Blewitt, a geodesist with the Nevada Bureau of Mines and Geology, and the conventional level surveys were conducted by Stantec Consultants in Las Vegas.

Part I

Land subsidence in Las Vegas Valley 1997-1999: InSAR Study Results

Falk Amelung

Introduction

This project is a follow-up to an earlier InSAR study on land subsidence in Las Vegas Valley that was conducted on behalf of the Las Vegas Valley Water District in 1997-98 and published in the journal *Geology* in 1999 (Amelung et. al, 1999; see also Bell et al., 1999). This earlier report is referred to here as the 1998 study. In the 1998 study we detected up to 19 cm of subsidence occurring between 1992-1997 in the Northwest subsidence bowl and up to 10 cm of subsidence in Central subsidence bowl (Fig. 1A). Although the 1998 study was looking for long-term subsidence, the interferometric data also suggested the occurrence of seasonal ground surface displacements that may be detectable by interferograms covering only the winter and summer seasons. In the central part of the valley, subsidence seemed to be occurring predominantly during the summer seasons when ground water pumping was heavy. On the other hand, during the winter seasons when ground water levels were recovering, there was a suggestion that uplift, or rebound, may be occurring in these areas.

This present InSAR project had three objectives: 1) measure and document any land subsidence that occurred in Las Vegas Valley during 1997-1999; 2) investigate which areas are undergoing seasonal subsidence and uplift using multiple short-term interferograms; and 3) compare interferograms from ascending and descending satellite orbits in an effort to investigate whether ground displacements are all vertical as assumed, or if there are any horizontal components.

This study is a joint effort by F. Amelung, now at the University of Hawaii, J. Bell, University of Nevada, and J. Hoffman, a graduate student at Stanford University. Most of the SAR processing was done by Hoffman under the supervision of Amelung. Hoffman is pursuing a Ph.D. in Geophysics at Stanford University and most of the data described in this report will be part of his dissertation. Most of the data are also described in an article submitted to Water Resources Research "Seasonal subsidence and rebound in Las Vegas, Nevada observed by synthetic aperture radar interferometry" by J. Hoffman, H. Zebker, D. Galloway and F. Amelung. However, this study also contains additional data not provided in the Hoffman et al. paper, including composite InSAR data covering the period 1997-99.

During the course of this project we obtained a large number of interferograms (Table 1). In this report only those interferograms are shown which best address the above-mentioned research objectives. For the ease of comparison with the 1998 study, all figures (except Fig. 7) are displayed in radar coordinates. We use the same color scale as the 1998 report for the interferograms. Yellow color denotes zero displacement, yellow-white-red-blue color fringes denote subsidence and yellow-blue-red-white fringes denote uplift.

Table 1: Descending interferograms of Las Vegas Valley obtained for this and the previous project. No usable SAR images were acquired between December 1993 and August 1995 because the satellite was in a different mode and orbit.

Date of image pair	Orbit number	Bperp	Time	Figure/comment
92/09/08-93/04/06	6012-9018	-42 m	7.0	Fig. 3A
93/03/02-93/11/02	8517-12024	-380 m	8.2	Fig. 4A
93/03/02-96/01/04	8517-23390	-98 m	34.6	
93/04/06-93/11/02	9018-12024	84 m	7.0	Fig. 4A
93/04/06-96/02/08	9018-23891	67 m	34.6	
93/11/02-96/02/08	12024-23891	-18 m	27.6	
95/09/21-95/11/30	21887-22889	-6 m	2.3	
95/09/21-96/05/24	21887-5721	-71 m	8.2	
95/09/21-97/05/09	21887-10731	-123 m	19.9	
95/11/30-96/05/24	22899-5721	-66 m	5.9	
95/11/30-97/05/09	22889-10731	-118 m	17.5	
96/01/04-96/05/24	23390-5721	386 m	4.7	
96/05/24-96/10/11	5721-772t5	154 m	4.7	Fig. 5B
96/01/04-97/01/24	23390-9228	137 m	12.9	
96/01/04-98/04/24	23390-15741	14 m	28.0	
96/02/08-97/04/04	23891-10230	158 m	14.0	
96/05/24-97/05/09	5721-10731	-52 m	11.7	
96/08/02-97/05/09	6723-10731	197 m	9.3	
96/10/11-97/05/09	7725-10731	-207 m	7.0	Fig. 5C
96/12/20-97/05/09	8727-10731	-251 m	4.7	
97/01/24-97/04/04	9228-10230	-277 m	2.3	
97/01/24-97/05/09	9228-10731	197 m	3.5	
97/02/28-97/05/09	9729-10731	121 m	2.3	
97/04/04-97/08/22	10230-12234	59 m	4.7	Fig. 7A
97/04/04-98/04/24	10230-15741	154 m	12.8	
97/05/09-97/06/13	10731-11232	-12 m	1.2	
97/05/09-97/07/18	10731-11733	-10 m	2.3	11733 strong atmosphere
97/05/09-97/09/26	10731-12735	-118 m	4.7	
97/05/09-97/12/05	10731-13737	-250 m	7.0	
97/05/09-98/01/09	10731-14238	41 m	8.2	
97/05/09-98/02/13	10731-14739	102 m	9.3	
97/05/09-98/04/24	10731-15741			Fig. 2A
97/05/09-98/05/29	10731-16242	-69 m	12.8	
97/05/09-98/03/20	10731-15240	187 m	10.5	
97/05/09-99/01/29	10731-19749	-101 m	21.0	
97/05/09-99/11/05	10731-23757	249 m	30.3	
97/05/09-99/12/10	10731-24258	71 m	31.5	
97/07/18-99/10/01	11733-23256	-508 m	26.8	
97/07/18-98/04/24	11733-15741	-310 m	9.3	
97/07/18-99/11/05	11733-23757	259 m	28	
97/08/22-98/04/24	12234-15741	95 m	8.2	
97/09/26-97/12/05	12735-13737	-132 m	2.3	
97/09/26-98/04/24	12735-15741	-202 m	7.0	Fig. 5D
97/09/26-99/01/29	12735-19749	1 m	16.3	
97/12/05-98/04/24	13737-15741	-69 m	4.7	
98/04/24-99/01/29	15741-19749	238 m	9.3	Fig 2B
98/05/29-99/01/29	16242-19749	33 m	8.2	
98/04/24-99/10/01	15741-23256	-198 m	17.5	
99/01/29-99/12/10	19749-24258	153 m	10.5	Fig. 2C

Land subsidence 1997-1999

The InSAR displacement map in Figure 1B shows that up to 5-6 cm of subsidence occurred in the Northwest subsidence bowl during the period May 1997-December 1999. This map has been obtained from the three shorter term interferograms in Figure 2. Subsidence of about 2-3 cm is also detected in an area between the Eglington fault and I-15, corresponding to the Nellis well field area along Craig Road (part of the North Las Vegas subsidence bowl), as well as in the Central subsidence bowl, southeast of the I-15/US 95 intersection. The greatest amount of subsidence detected during this period was 6-7 cm along South Las Vegas Boulevard (the Las Vegas Strip).

Figure 2 shows the temporal evolution of land subsidence in Las Vegas Valley since May 1997. In the Northwest subsidence bowl about 1.5-1.8 cm of subsidence (0.5-0.6 fringes, yellow-white-red colors) are detected in each of the May 1997 - April 1998 (Fig. 2A), the April 1998 - January 1999 (Fig. 2B) and the January 1999 - December 1999 interferograms (Fig. 2C). Similar amounts of subsidence in the three interferograms each covering 8-11 months suggests that the yearly subsidence in the Northwest subsidence bowl is occurring at an approximately constant rate of 2-2.5 cm/yr. In the following section we show that ground displacements vary between the summer and winter season. In the May 1997 - April 1998 interferogram (Fig. 2A) no significant subsidence is detected outside of the Northwest bowl. In the April 1998 - January 1999 interferogram (Fig. 2B), ~0.7 cm of subsidence is detected in the Central subsidence zone (0.2-0.3 fringes, yellow-white-red colors). The January 1999 - December 1999 interferogram (Fig. 2C) shows that most of the subsidence in the Nellis zone and in the Central subsidence zone seen on the composite 1997-1999 displacement map (Fig. 1B) occurred during this 1999 period.

Subsidence measured with the 1997-1999 interferograms can also be compared with ground-based conventional leveling data. As discussed in Part II, level line 11 was surveyed in July 1997 and November 1999. Figure 3 shows a comparison between the leveling results and the InSAR results extracted from the May 1997 - December 1999 interferogram along the same transect. The results indicate a good agreement in the independently derived data although the time periods for the two data sets are slightly different. The InSAR transect also shows that subsidence increases to almost 5 cm west of line 11, reaching a maximum value near the Lone Mountain/US 95 overpass.

Seasonal interferograms

Figures 4A, B, and C show interferograms for the summers of 1993, 1996, and 1997. The summers of 1998 and 1999 are shown in Fig. 2B and C. We also obtained interferograms for the winters of 1992-93, 1995-1996, 1996-97 and of 1997-98 (Fig. 5A-D). No data are available for the summers of 1994 and 1995 or for the winters of 1993-94 and 1994-95 because of the satellite configuration during these time periods.

The seasonal interferograms clearly show that subsidence occurs primarily during the summer seasons and uplift during the winter seasons. In the Northwest subsidence bowl, ~3 cm (1 fringe) of

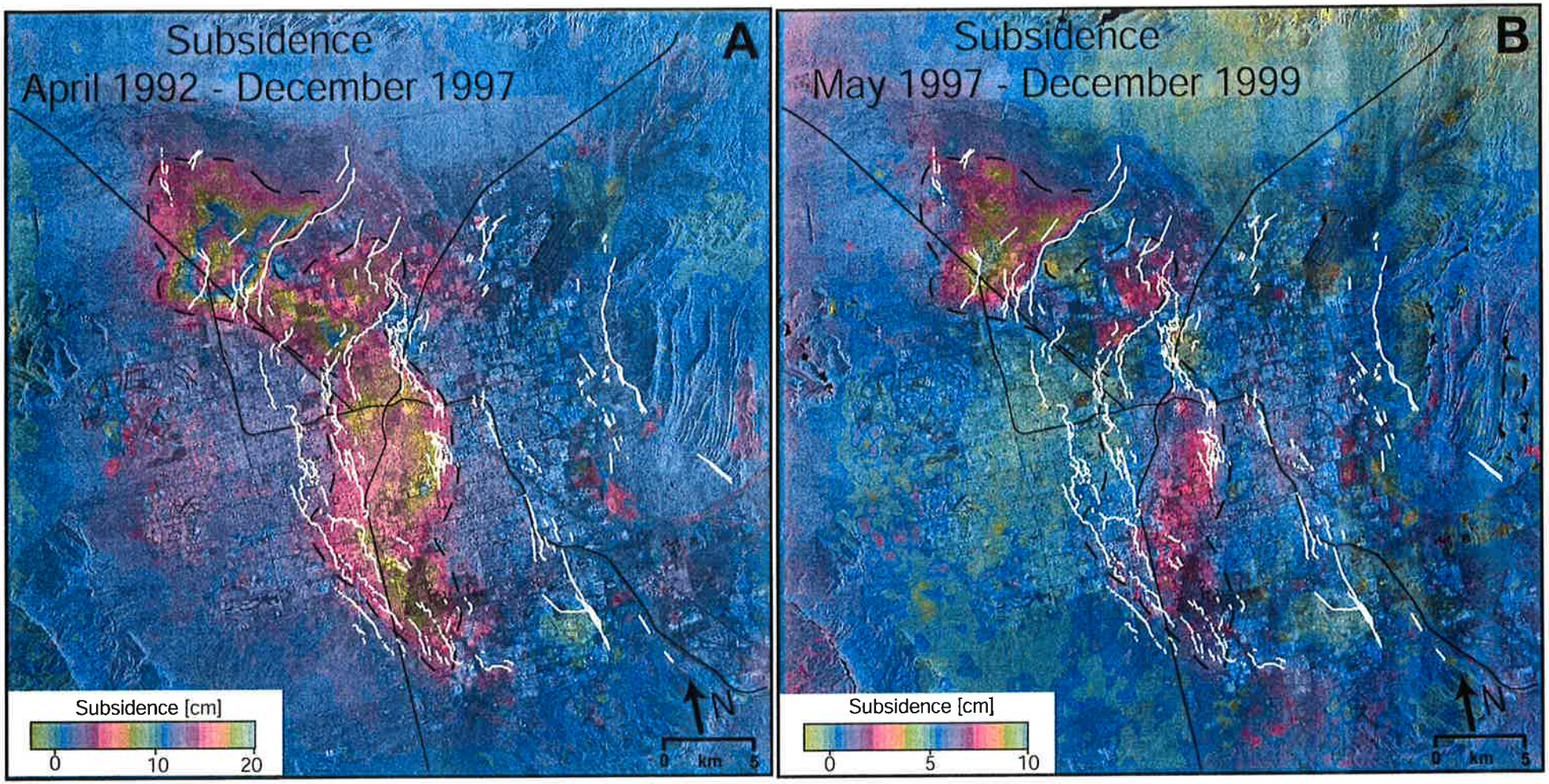

Figure 1. A. Land subsidence in Las Vegas Valley between April, 1992 and December, 1997 (from Amelung et al., 1999). B. Land subsidence between May, 1997 and December, 1999 (this study) obtained by summing the three interferograms shown in Fig. 2. Dashed line delineates the 30 mm subsidence displacement contour on the 1992-97 interferogram.

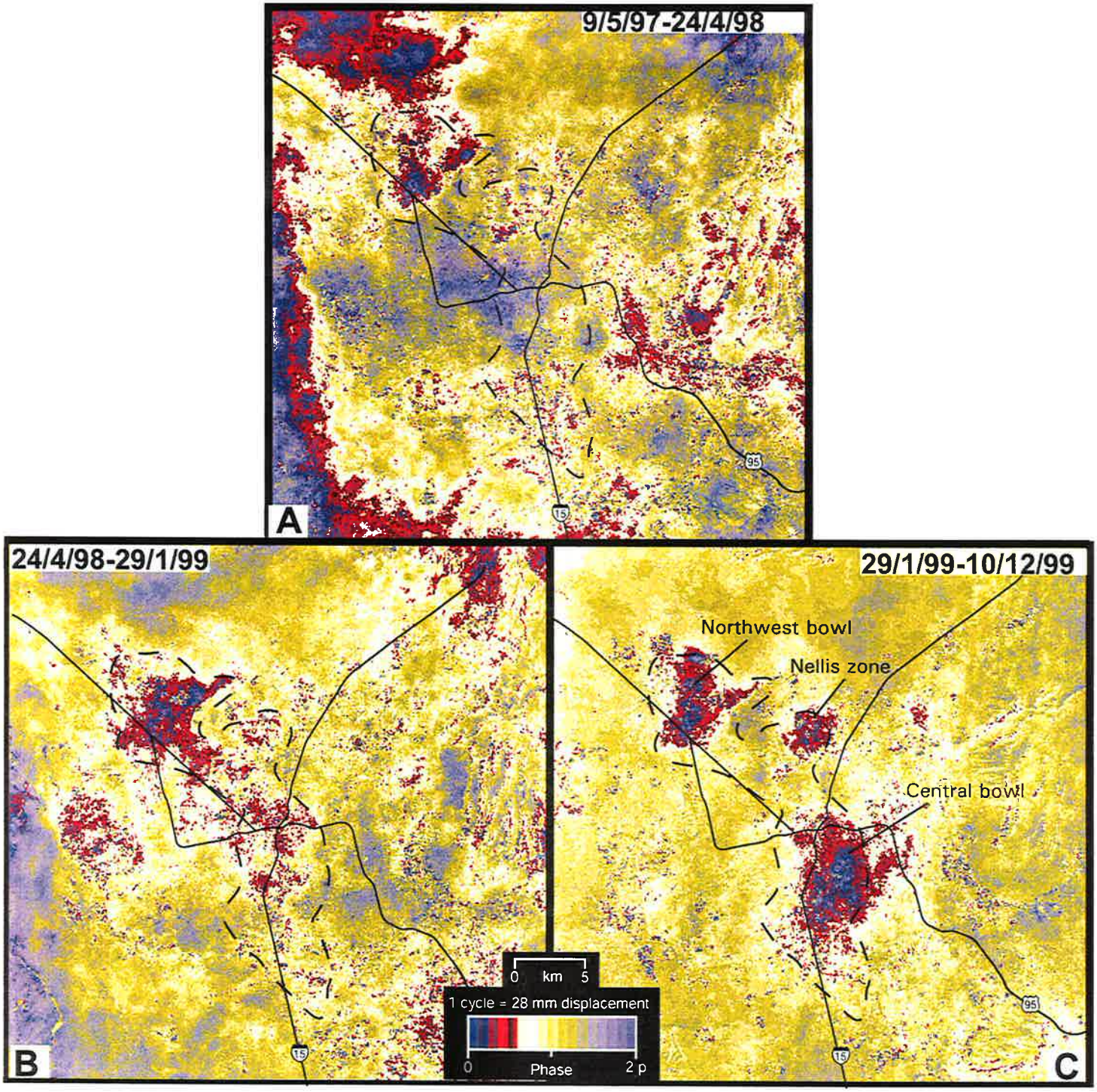

Figure 2. Three interferograms of Las Vegas Valley showing land subsidence occurring over time since May, 1997: A. May, 1997 to April, 1998; B. April, 1998 to January, 1999; C. January, 1999 to December, 1999. One cycle of phase (0-2 pi) represents 28 mm of change in radar line-of-sight distance or 31 mm of subsidence or uplift.

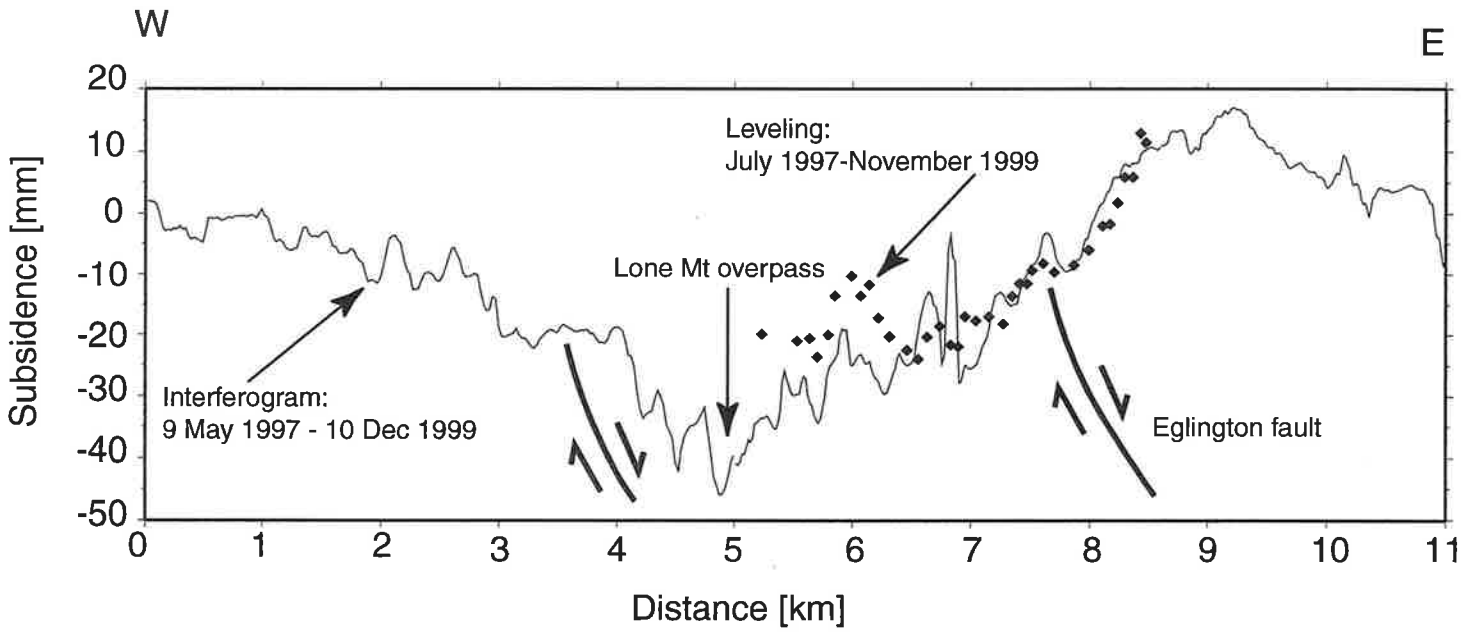

Figure 3. Comparison of vertical displacement measured along level line 11 by conventional leveling and by InSAR in the 1997-99 period. The InSAR transect extends beyond the ends of the level line in order to show the regional trend of subsidence controlling the displacement on line 11. The transect indicates that the largest displacements occur just west of line 11 near the Lone Mountain/US 95 overpass.

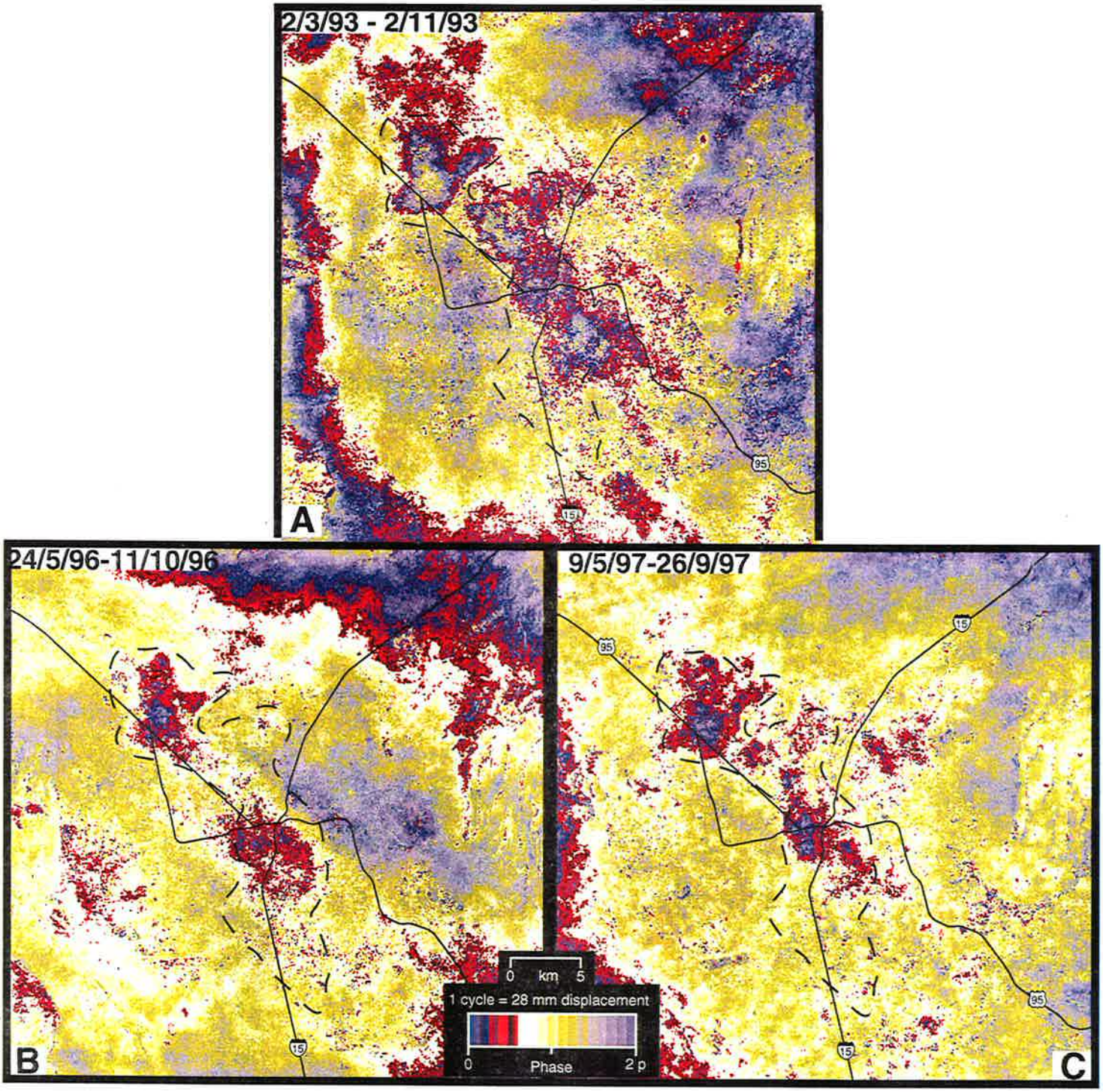

Figure 4. Interferograms covering Las Vegas Valley for the summer periods of 1993 (A), 1996 (B), and 1997 (C). The summers of 1998 and 1999 are covered by Fig. 2B and C; the same color scheme for displacement is used as in Fig. 2. The dashed line is the 30 mm displacement line on the 1992-97 interferograms (Amelung et al., 1999).

subsidence occurred during the summer of 1993 (Fig. 4A) and ~2 cm of subsidence (0.7 fringes, yellow-white-red-blue colors) during each of the summers in 1996 through 1999 (Fig. 4B-C, Fig. 2B,C). The spatial pattern of summer subsidence in this area is remarkably stable in time.

In the Central subsidence zone, 1.4-2.8 cm subsidence (0.5-1 fringes) are detected in the summer 1993 interferogram (Fig. 4A). During the summers of 1996-1999, subsidence occurred in the center of Las Vegas Valley in an area much smaller than during 1993. The subsiding area is also spatially variable over time. During the summer of 1996, subsidence is centered ~1 km south of the intersection of I-15 and US 95 (Fig. 4B); during the summer of 1997, it is centered ~2 km west of the intersection (Fig. 4C); and during the summer of 1999 it is centered ~5 km south of the intersection (Fig. 2C). The pattern of subsidence during summer 1998 is more diffuse (Fig. 2B) but this may be because the interferogram covers part of the following winter period.

The interferograms covering winter periods show two interesting features. First, winter subsidence in the Northwest subsidence bowl is decaying. Whereas up to 2.5 cm subsidence (0.8 fringes) occurred during the 1992-1993 winter in an area covering more than half of the Northwest subsidence bowl (Fig. 5A), less than 1 cm of subsidence is detected in a small area northwest of the Eglington fault in the 1995-96 and 1996-97 winter interferograms (Fig. 5B and C). No subsidence is visible in this area during the 1997/98 winter (Fig. 5D). Second, an extensive area of uplift is detected in the central part of Las Vegas Valley in all four winter interferograms (Fig. 5A-D). The maximum uplift occurring in the area of the I-15/US 95 intersection was 2.5 cm in the winter of 1992-93, ~2 cm in the winter of 1995-96, ~1.8 cm in the winter 1996-1997, and ~2.8 cm in the winter of 1997-98. Smaller areas of uplift are detected during the winters of 1992-93 and 1996-97 in the northern part of the Northwest subsidence bowl (Fig. 5A and C), in the Nellis subsidence area during the winters 1992-3 and 1995-96 (Fig. 5A and B), and in all four winter interferograms south of the Whitney Mesa area.

Comparison of ascending and descending interferograms

A SAR interferogram measures changes in the distance between the satellite and the ground surface in radar line-of-sight (radar range) direction. The incidence angle of the radar beam on the ground is ~23°. The radar is therefore more sensitive to vertical than to horizontal displacements. The phase signature in an interferogram caused by horizontal ground displacements depends on the incidence angle. This is illustrated in Figure 6; on interferograms from descending satellite orbits (satellite traveling south) the radar looks west and ground displacements toward the west result in a radar range increase (Fig. 6A), corresponding to apparent subsidence if the detected range changes are interpreted as vertical deformation. In an interferogram from an ascending satellite orbit (satellite traveling north) the radar looks east and the same ground deformation results in range decrease (Fig. 6B), or apparent uplift. Hence, comparison of interferograms from descending and from ascending orbits provides a means to retrieve the direction of ground displacements. If descending and ascending interferograms are identical, ground deformation is vertical only. On the other hand,

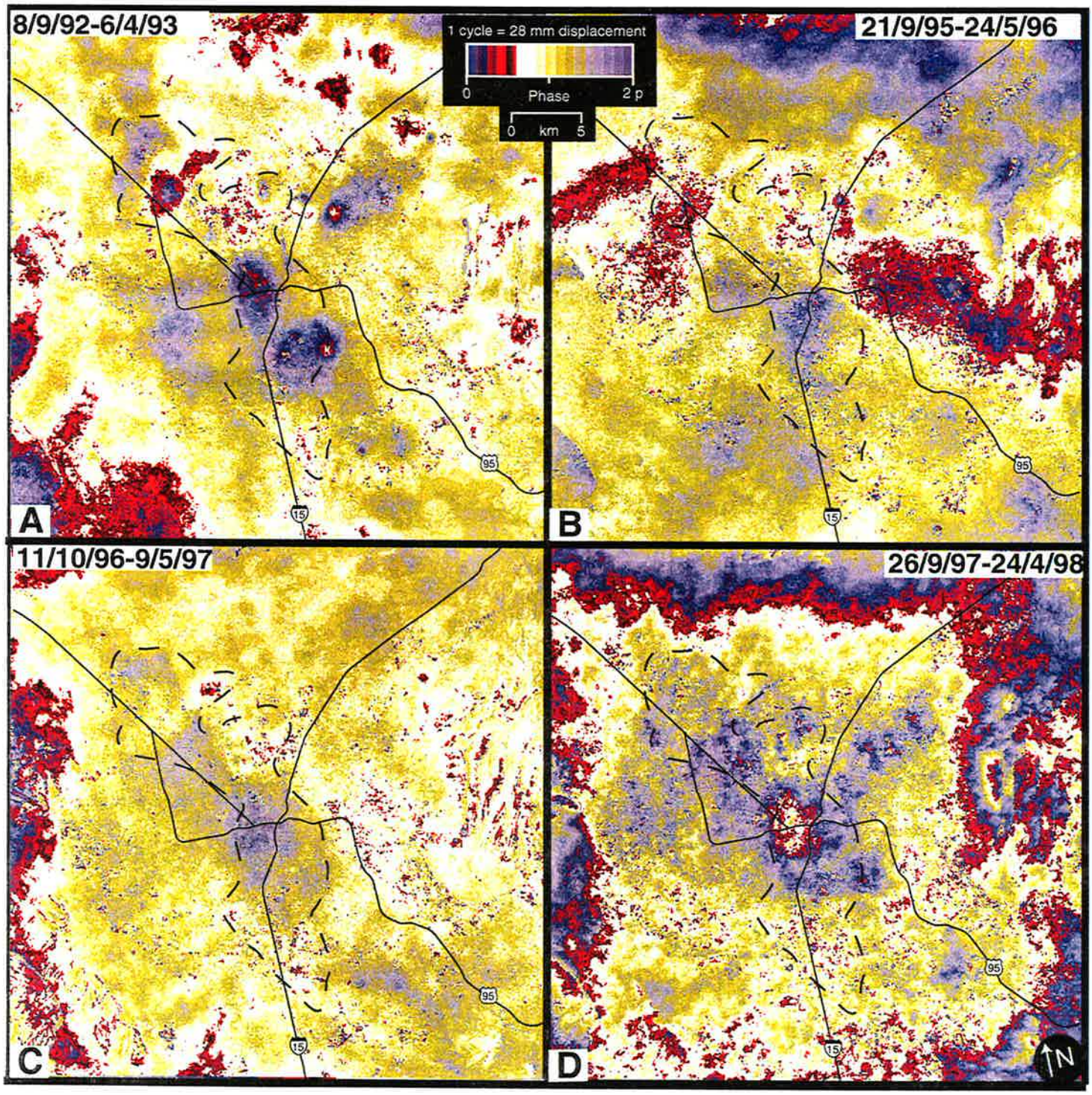

Figure 5. Four winter interferograms of Las Vegas Valley covering the winter of 1993 (A), 1995-96 (B), 1996-97 (C), and 1997-98 (D). The color scale is the same as used in Fig. 2.

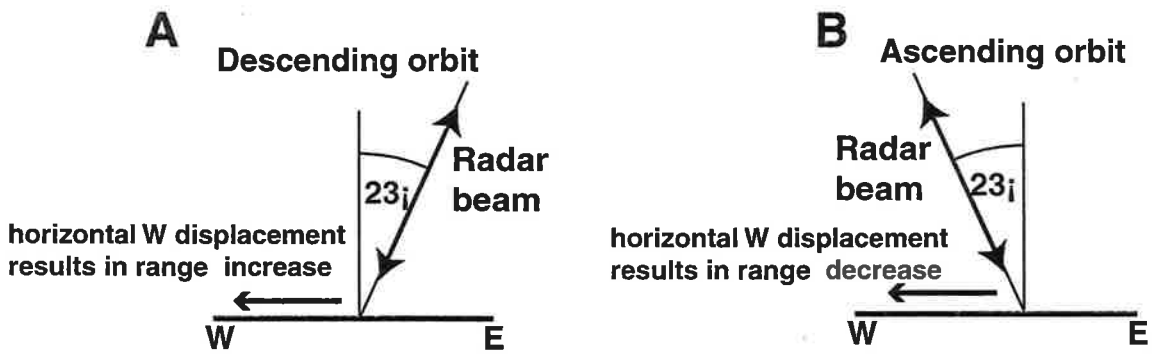

Figure 6. Illustration showing how the difference in phase signatures due to horizontal and vertical deformation is detected by descending and ascending orbit SAR images. In descending orbits (A), the radar is looking west and ground displacements result in an increase in radar range displacement. In ascending orbits (B), the radar is looking east and ground displacements result in range decrease. If both ascending and descending interferograms are similar, ground deformation is vertical only; if there are differences it would be indicative of a horizontal component.

differences between ascending and descending interferograms are indicative of horizontal ground displacements. Note that the interferograms are nearly insensitive to north-south displacements because the radar-look vector has only a small component in this direction.

Figure 7 shows an interferogram from a descending satellite orbit (Fig. 7A) and an interferogram from an ascending satellite orbit (Fig. 7B) for the summer of 1997. Both interferograms cover 4.5 months. The descending interferogram starts 13 days earlier than the ascending interferogram (4 April 1997 versus 17 April 1997). The interferograms are very similar in the northern portion of Las Vegas Valley. The spatial extent and shape of the Northwest subsidence bowl are nearly identical, indicating that no horizontal displacements occur in this area. Both interferograms show subsidence in the Nellis subsidence zone and in two areas east of the Central subsidence zone, and both interferograms show uplift in another area east of the Central subsidence zone. These comparisons indicate that ground deformation is primarily due to vertical movement in these areas; if horizontal displacements are occurring, they are negligible.

However, in the southern part of Las Vegas Valley there are significant differences between the two interferograms. A horizontally elongated area in the south-southwest part of the valley (white-red-blue colors) is seen on the ascending interferogram (Fig. 7B) but not on the descending interferogram (Fig. 7A). This phase signature may be caused by horizontal deformation but it seems more likely to be an atmospheric artifact. This interferogram has significant phase signatures of nearly one fringe (blue-red-white) that probably are also artifacts in the northeast and in the east. We attempted to obtain SAR images for additional comparisons between interferograms from ascending and from descending orbits but unfortunately many SAR images were not available. Since vertical ground deformation is dominant in the northern part of Las Vegas Valley it is likely that this is also the case in the southern part of the valley but the data at this point are preliminary and inconclusive.

Interpretation and Conclusions

1. The 1997-1999 interferograms confirm the conclusions from the 1998 study that subsidence continues in the Northwest subsidence bowl at a fairly constant rate but that it is nearly arrested in the Central subsidence bowl. A maximum of 5-6 cm of subsidence occurred between May 1997 and December 1999 in the Northwest subsidence bowl, indicating a relatively constant rate of 2-2.5 cm/year. About 2-3 cm of subsidence occurred during this time period in the Central subsidence bowl and in the smaller Nellis subsidence zone. Net subsidence during May 1997- December 1999 in these two areas may in part be a seasonal effect because this period covers three summer seasons and only two winter seasons. In fact, a significant amount of the May 1997 to December 1999 subsidence in these two areas occurred in summer 1999. The InSAR data converted from the 1997-99 interferogram to 25 x 35 m pixel data in an Arcview format are shown on Figure 8.

2. Seasonal interferograms between September 1995 and January 1999 show that in the Central subsidence bowl summer subsidence is generally compensated for by winter uplift indicating that residual compaction has stopped in this area. However, residual compaction has not yet stopped in

the northwest subsidence bowl. No winter uplift is observed in this area; this suggests that the elastic expansion of the aquifer-system related to water level recovery in the winter may be compensated for by residual compaction resulting in small to zero net displacements during the winter season.

3. Interferograms from descending and ascending satellite orbits show similar patterns in the Northwest subsidence bowl and in the North Las Vegas subsidence bowl, suggesting that ground displacements in these areas are primarily vertical. However, the level of detection is not optimum for north-oriented horizontal displacements because of the radar line of sight. The data suggest that horizontal displacements may have occurred in the southern part of Las Vegas Valley, but they are considered inconclusive. However, horizontal displacement is certainly a highly probable hypothesis for explaining some of the differences between the northern and the southern bowls, and if verified, it would be another important application of the InSAR methodology.

4. Due to the reduction in subsidence rates observed in other parts of the valley, the maximum amount of subsidence found for the 1997-99 period occurs in the southern part of the valley. Although InSAR has been shown to be generally successful in detecting subsidence in Las Vegas Valley, the vertical displacements detected by InSAR in the southern part of the valley are not as closely calibrated by conventional leveling as in the northern part. The maximum subsidence of 51-70 mm found in the valley for the 1997-99 period occurred along the Las Vegas Strip which is located in the previously recognized Southern subsidence bowl. No independent conventional leveling data are presently available to confirm the magnitude of these displacements. The next highest values found for the two year period occur in the Northwest subsidence bowl where independent leveling data are available to verify the accuracy of the InSAR displacements.

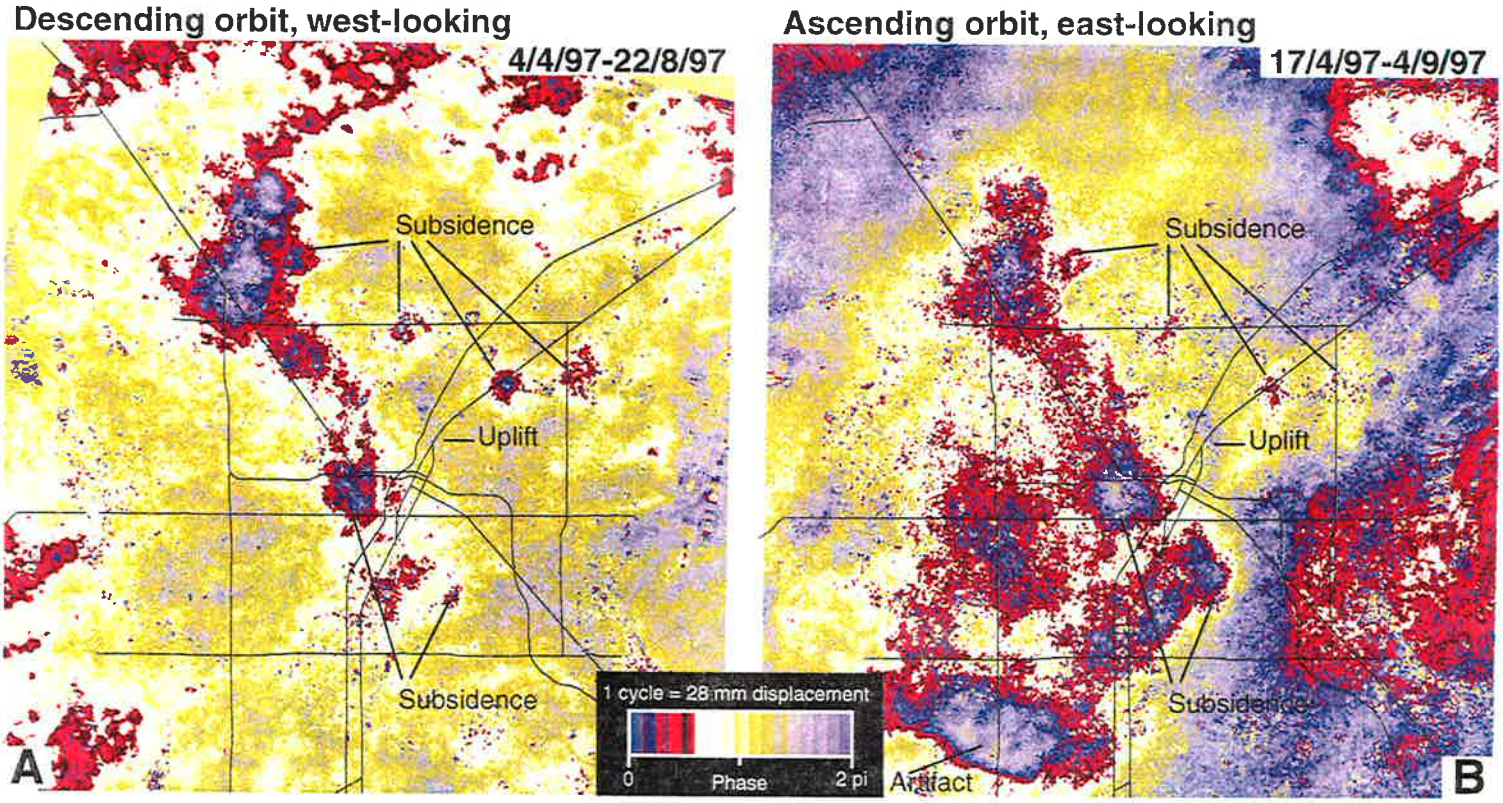

Figure 7. Interferograms covering the same period during the summer of 1997 developed for both descending (A) and ascending (B) orbits. The interferograms are very similar in the northern part of the valley suggesting that the displacements are nearly all vertical. The southern part of the valley shows differences that may be the result of horizontal displacement, but may also be related to atmospheric artifacts. The same color scale is used as in Fig. 2.

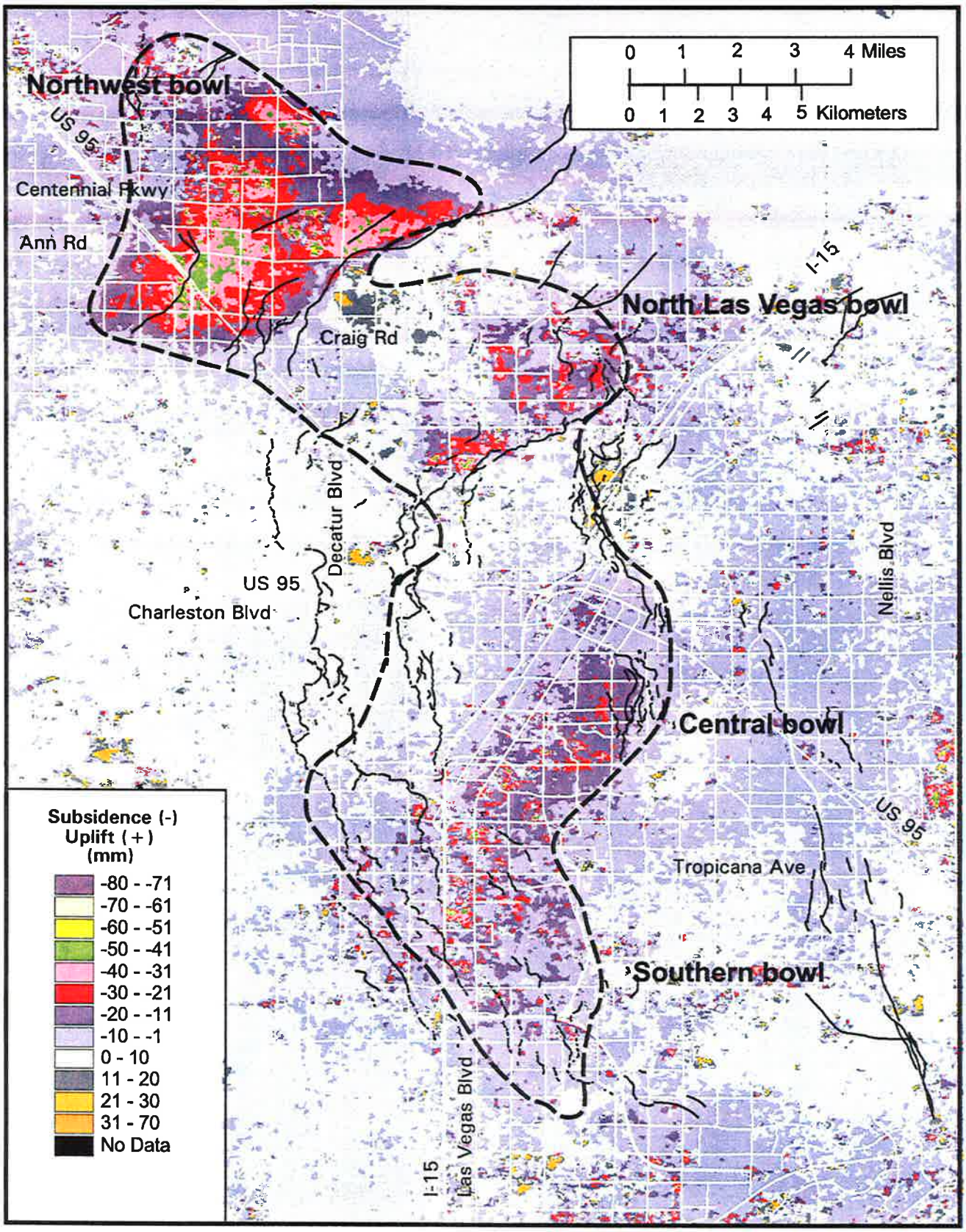

Figure 8. InSAR subsidence data converted from the 1997-99 interferogram (Fig. 1b) to 25 x 35 m pixel values in Arcview. The highest subsidence values in the Northwest subsidence bowl are green and yellow pixel areas having maximum values between 41-50 and 51-60 mm, repsectively. The highest subsidence values detected are yellow and beige areas (51-60 and 61-70 mm) in the Central/Southern subsidence bowls. Dashed line is approximate location of 30 mm subsidence contour for 1992-97 (Fig. 1a).

Part II

GPS and Conventional Level Surveys

John W. Bell

Readjustment of 1998 GPS Survey

Many of the 115 GPS stations established in 1990-91 to monitor subsidence throughout the valley were resurveyed in the 1998 campaign; refer to the 1998 subsidence report for a detailed discussion of this survey. In that study, the 1998 results were compared with earlier campaigns in 1990-91 and 1995 based on the measured GPS ellipsoid heights. GPS is based on a smooth, mathematical ellipsoid datum relative to the center of the earth; ellipsoid heights (distance between the station and the mathematical ellipsoid) are commonly used for comparison of relative changes between survey stations. In contrast, conventional leveling measures elevations relative to the earth's geoid surface which is influenced by gravity and is an irregular surface. The distance between the ellipsoid and geoid at any point is called the geoid height. A GPS ellipsoid height can be converted to a conventional geoid-referenced orthometric height by using a geoid height correction.

In Las Vegas Valley, the geoid surface varies by 1 meter or more depending on location, and in previous GPS surveys, the lack of an accurate geoid model has prevented the use of GPS orthometric heights. In 1999, the National Geodetic Survey (NGS) released a new model, GEOID 99, which includes detailed gravity data and now appears to provide a means for determining reasonably close GPS orthometric heights in the Las Vegas area.

In this study, the 1998 GPS ellipsoid heights were corrected using the GEOID 99 height corrections. The calculated GPS orthometric heights were then compared to conventional, first-order NGS benchmark data available for the same points. A comparison of about six benchmarks in the stable northwest and southwest portions of the valley showed that the GPS orthometric heights agreed within 1-2 cm with the first-order heights indicating that the geoid height corrections are reasonably accurate in these areas. Based on these results, the 1998 GPS network was readjusted using ellipsoid heights for fixed stations that were back-calculated from the first-order heights. Although the original 1998 network adjustment used fixed station heights, it did not utilize the highly accurate first-order elevations, and this new network readjustment now allows more accurate orthometric height measurements in the unstable part of the valley.

In the network readjustment, six first-order benchmark stations were held fixed around the stable perimeter of the valley: D368, D371, J171, U368, P364, and Sloan. The results of the network readjustment are listed in Appendix 1. In addition, other 1998 GPS stations that had companion NGS data were converted to orthometric heights and then compared with the first-order heights originally surveyed in 1963. A comparison for 16 stations (Fig. 9) shows that stations in the areas known to be relatively stable, such as the extreme northwest part of the valley, have GPS heights very close (<1 cm) to the published heights, confirming the lack of long-term subsidence in these areas. In the central

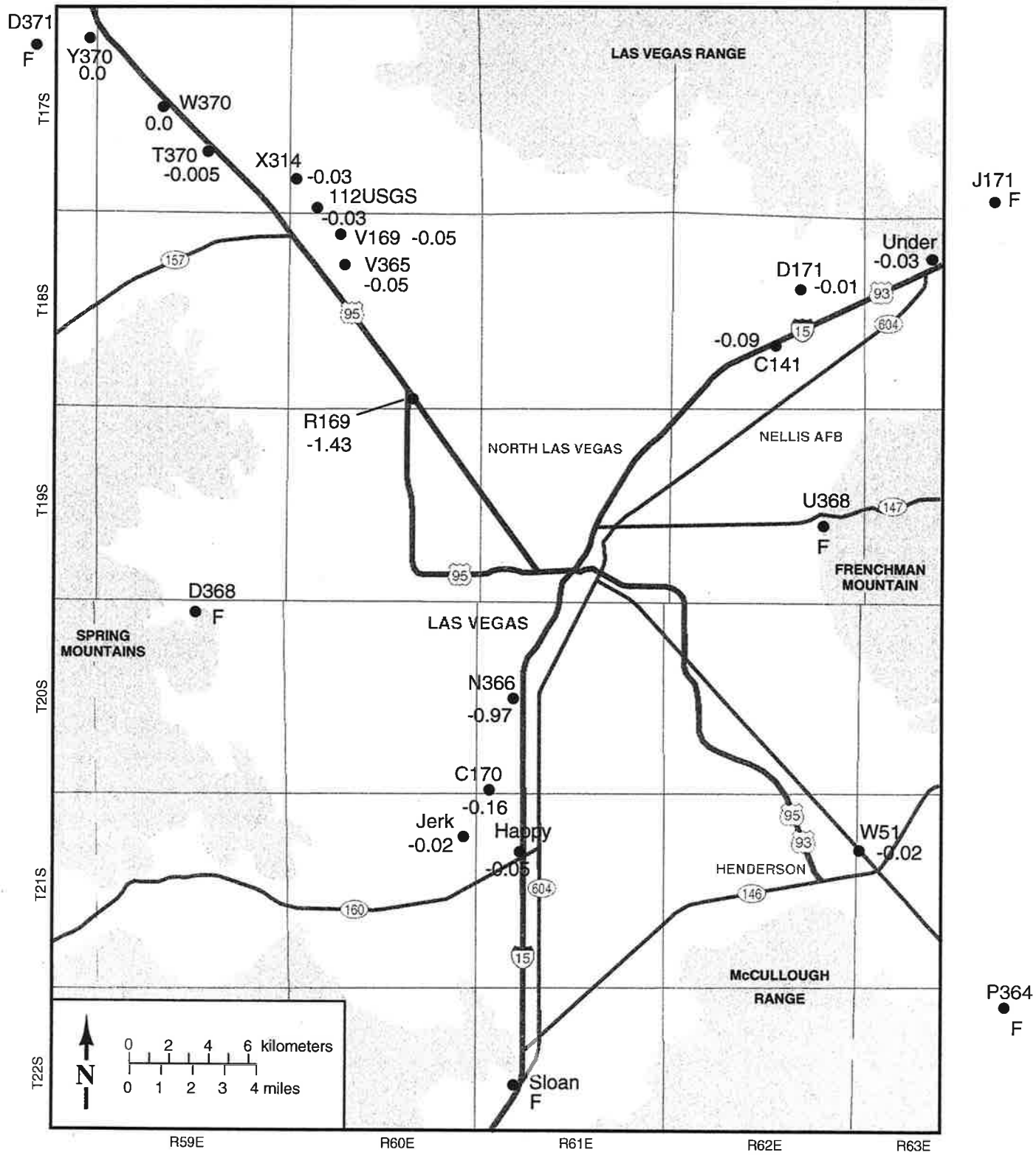

Figure 9. Location of 1998 GPS stations used for comparison with 1963 conventional level heights. The height changes shown in meters were determined by comparing the calculated 1998 orthometric GPS heights with the published first-order 1963 level heights. Benchmark R169 used the 1995 GPS height. Stations held fixed at the first-order level heights are indicated by an "F".

part of the valley, differences between the GPS and 1963 first-order heights are consistent with known magnitudes of subsidence. In particular, benchmark R169 in the Northwest subsidence bowl shows more than 1.4 m of movement since 1963; this benchmark is further discussed below.

In 1998, the Cities of Las Vegas and North Las Vegas resurveyed many of the conventional benchmarks in the northern half of the valley. The results of their level surveys allow an additional direct assessment of the accuracy of our GPS-determined orthometric heights. A comparison of 12 stations (Fig. 10) shows that stations located in the stable areas around the perimeter of the valley have GPS and conventional level data that are in reasonably good agreement (T370 and D171). In the central part of the valley, however, significant differences are evident. As seen on Figure 10, most of the GPS orthometric heights are about 5-10 cm lower than the surveyed level heights. This suggests that the GEOID 99 corrections are not as accurate in the central part of the valley; the difference is most likely related to gravitational differences in the deeper alluvial portions of the valley which may not be accounted for in the model. Nonetheless, we can conclude that the GPS orthometric heights can be reasonably accurate in most parts of the valley if allowing for a 5-10 cm correction for the published GEOID 99 height.

1999 GPS Survey

A GPS survey of 11 stations in the northwest part of the valley was conducted in November, 1999 (Fig. 11). The survey was timed to approximately coincide with the end of the 1999 pumping season. The stations were selected to measure subsidence occurring in the Northwest subsidence bowl between 1998-99 and provide ground-truth control for the InSAR study. The campaign was conducted using a rapid-static methodology with minimum 1 hour observation times per session. A total of eighteen sessions over a three day period provided multiple, redundant observations for each station. Many of the stations are located along Ann Road which extends approximately through the center of the Northwest subsidence bowl. Benchmarks D368 (station 004) and D371 (station 009) provided stable bedrock control; a new station 168 (NGMG GPS-1) was established on a small bedrock knob on west Ann Road. Station 166 on Lone Mountain Road was included as a common benchmark in the level line 11 survey (discussed below).

The baseline results were adjusted using fixed coordinates and heights for D368 and D371 (Fig. 12). The fixed ellipsoid heights for these benchmarks were determined from the surveyed 1963 first-order heights and the GEOID 99 height corrections. Continuous GPS data from the station operated by the Las Vegas Valley Water District (LVVWD) were combined and co-processed with the campaign data. The coordinate adjustment results are listed in Appendix 1.

A comparison of the 1998 and 1999 GPS surveys shows benchmark height changes consistent with the pattern of subsidence in the Northwest bowl (Table 2 and Fig. 13). The changes range from about zero (Stations 114 and 139) to a maximum of 3.5 cm (station 143). The results for both the 1998 and 1999 surveys are considered to be very good because of the small (<1 cm) 1-sigma network adjustment errors.

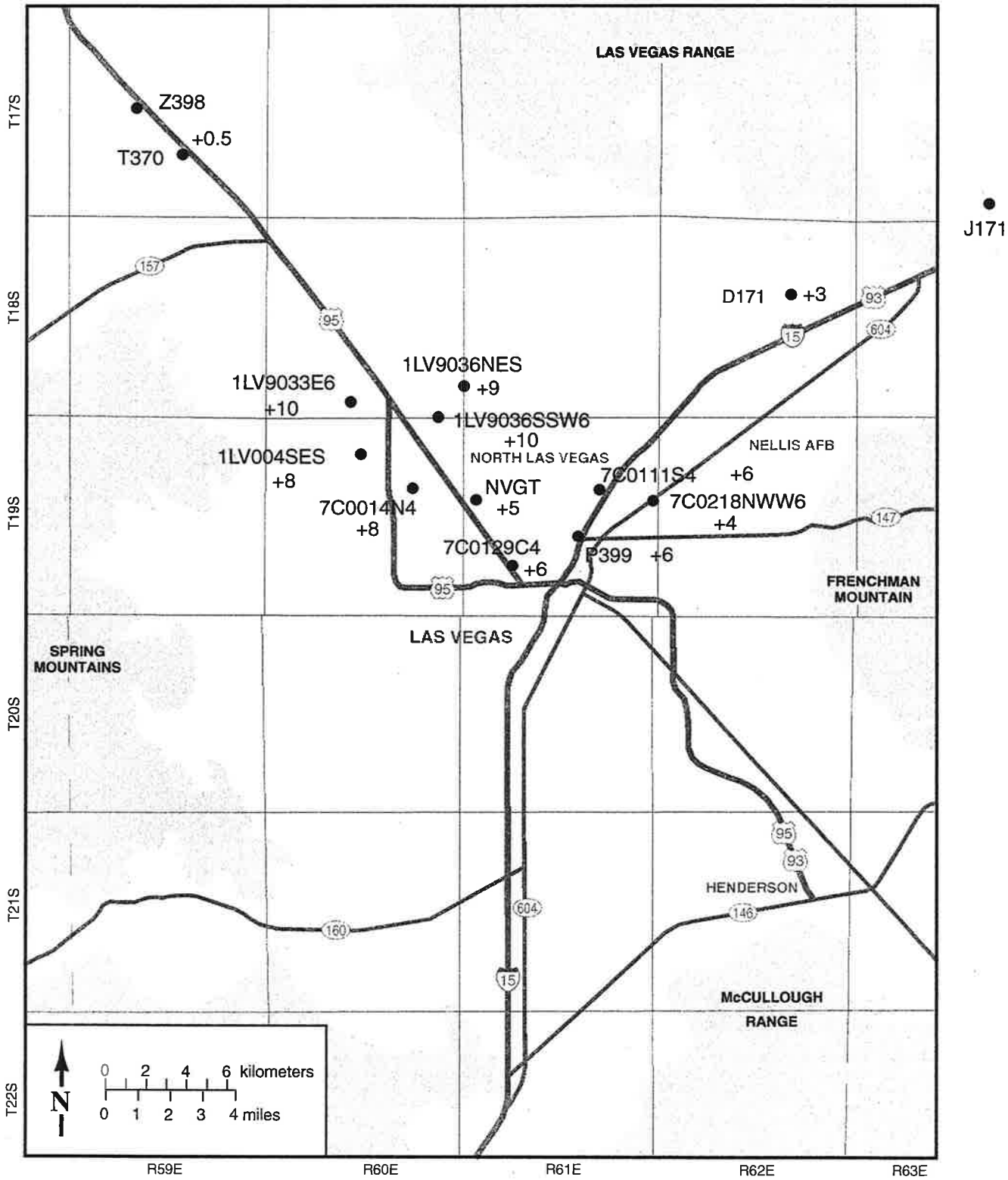

Figure 10. Locations of City of Las Vegas and North Las Vegas benchmarks used for comparison with 1998 GPS orthometric heights. Values are the differences in heights (cm) between the leveled 1998 benchmark heights and the calculated orthmetric heights using the GEOID 99 corrections. The positive values indicate that the calculated orthometric heights are between about 4-10 cm lower than the surveyed heights in the center part of the valley. Benchmarks Z398 and J171 were used to adjust the level results.

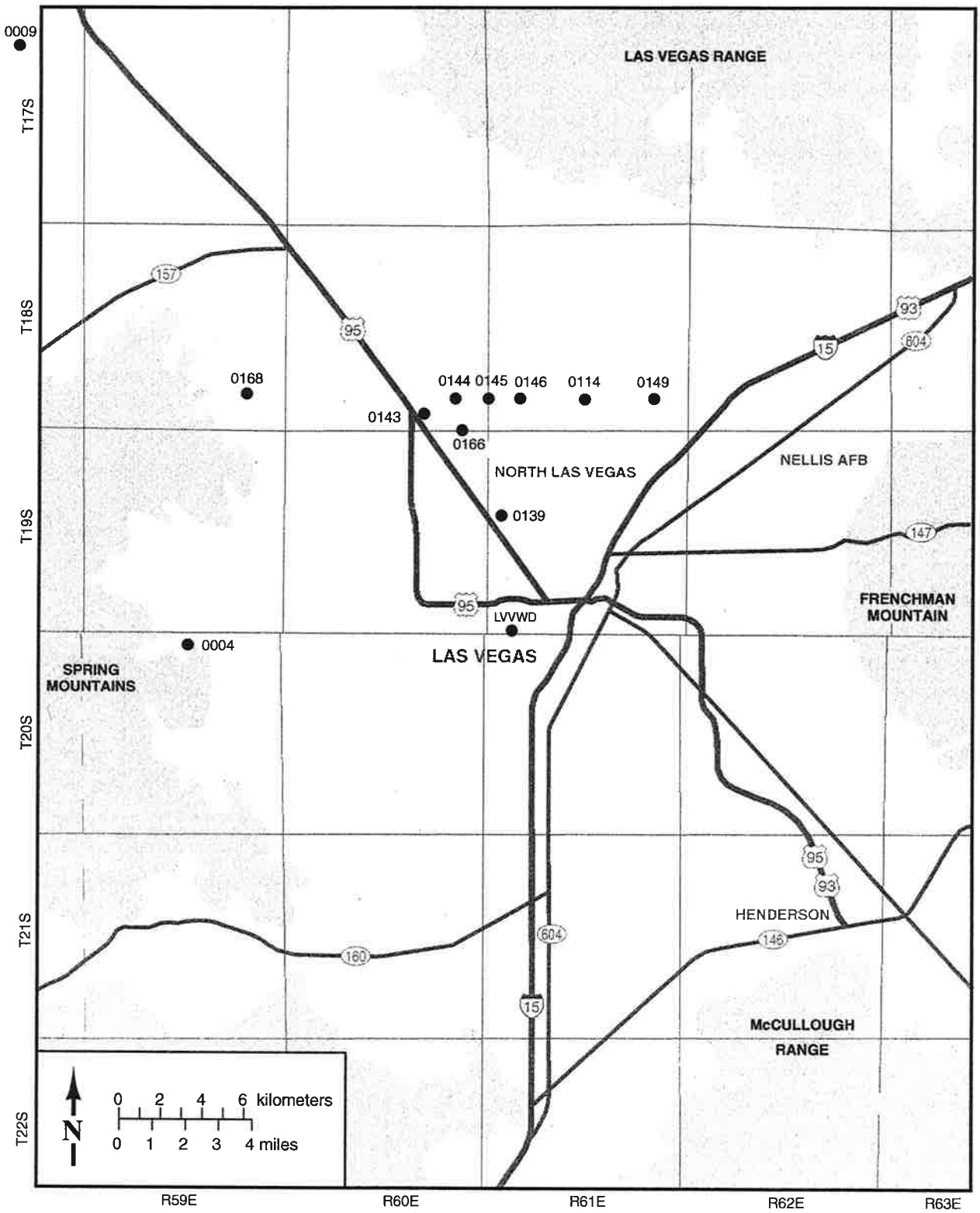

Figure 11. Location and identification number for GPS stations used in the 1998-99 surveys in Las Vegas Valley. See Appendix 1 for station descriptions and data.

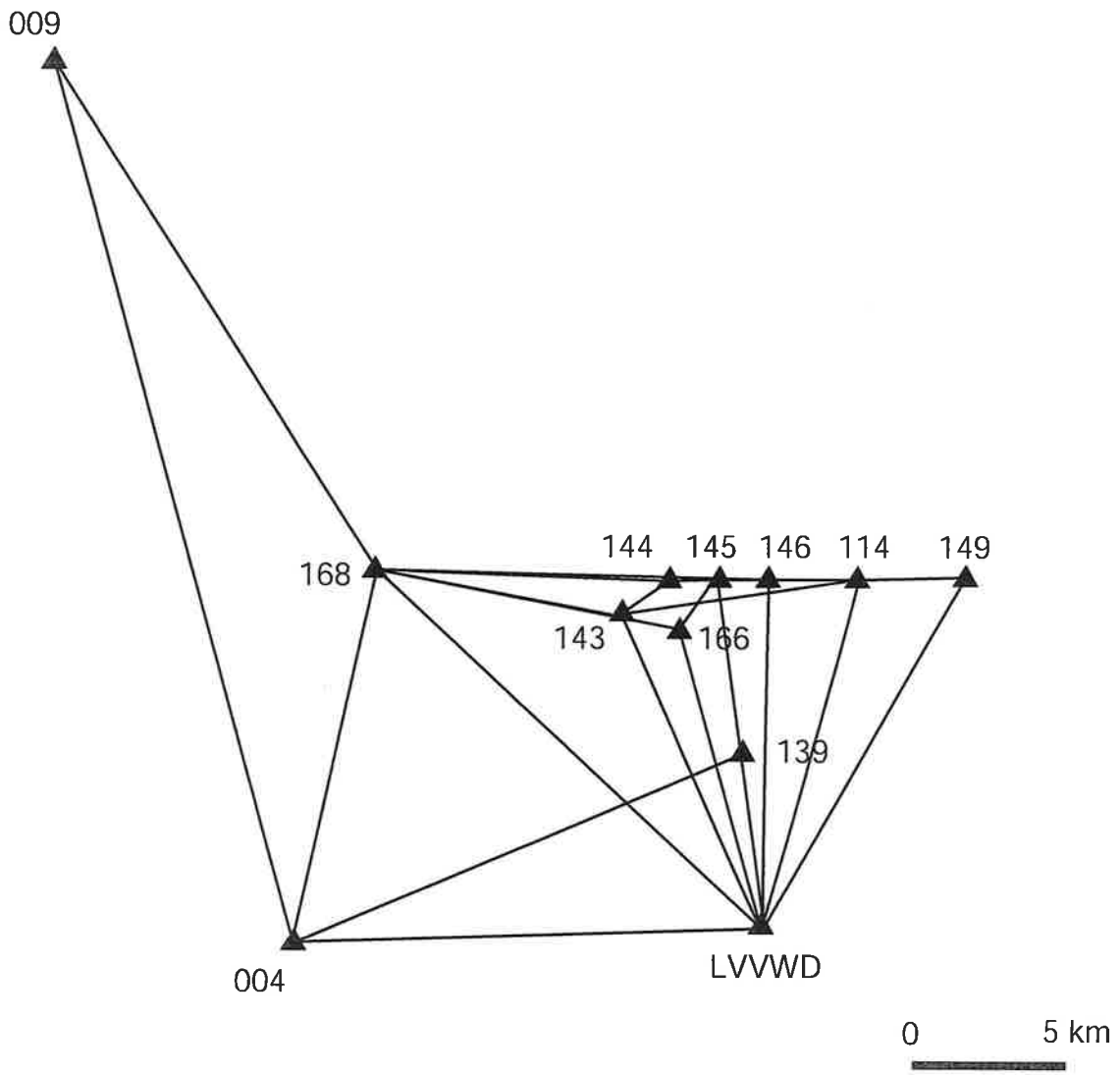

Figure 12. Network map showing GPS stations used in the 1999 campaign and the baselines along which the results were processed. Station LVVWD is the continuous station operated at the LVVWD main well field.

Table 2 . 1998-1999 GPS results showing height changes and estimated 1 σ errors after network adjustment.

Station ID	Name	Latitude	Longitude	1998 ellipsoid ht (m)	1 σ (m)	1999 ellipsoid ht (m)	1 σ (m)	1998-99 change (m)
004	D368	36 09 16.912	115 21 47.198	962.40	—	962.40	—	Fixed
009	D371	36 24 53.335	115 27 05.663	1040.380	—	1040.380	—	Fixed
114	PLS 2050 74.75	36 15 41.031	115 09 23.617	612.1685	0.011	612.1738	0.007	0.0053
139	NVGT	36 12 36.747	115 11 54.424	639.7645	0.009	639.7555	0.006	-0.0090
143	PLS 6902 56.57	36 15 04.239	115 14 33.395	680.1038	0.009	680.0690	0.009	-0.0348
144	PLS 5088 77.76	36 15 39.314	115 13 30.910	672.5027	0.009	672.4754	0.007	-0.0273
145	1LV90 36NES	36 15 41.091	115 12 26.579	653.4187	0.010	653.4058	0.007	-0.0129
146	PLS 8895 29.30.31. 32	36 15 41.411	115 11 20.344	636.9112	0.010	636.907	0.007	-0.0042
149	RLS 4841 25.26.35. 36	36 15 41.581	115 07 01.394	579.9441	0.011	579.927	0.009	-0.0171
166	1LV90 36SSW6	36 14 47.535	115 13 15.428	660.6922	0.010	660.6683	0.008	-0.0239
168	NBMG GPS1	36 15 51.901	115 13 15.428	—	—	864.4109	0.005	—
LVVWD	LVVWD	36 09 34.026	115 11 28.481	—	—	632.4812	0.006	—

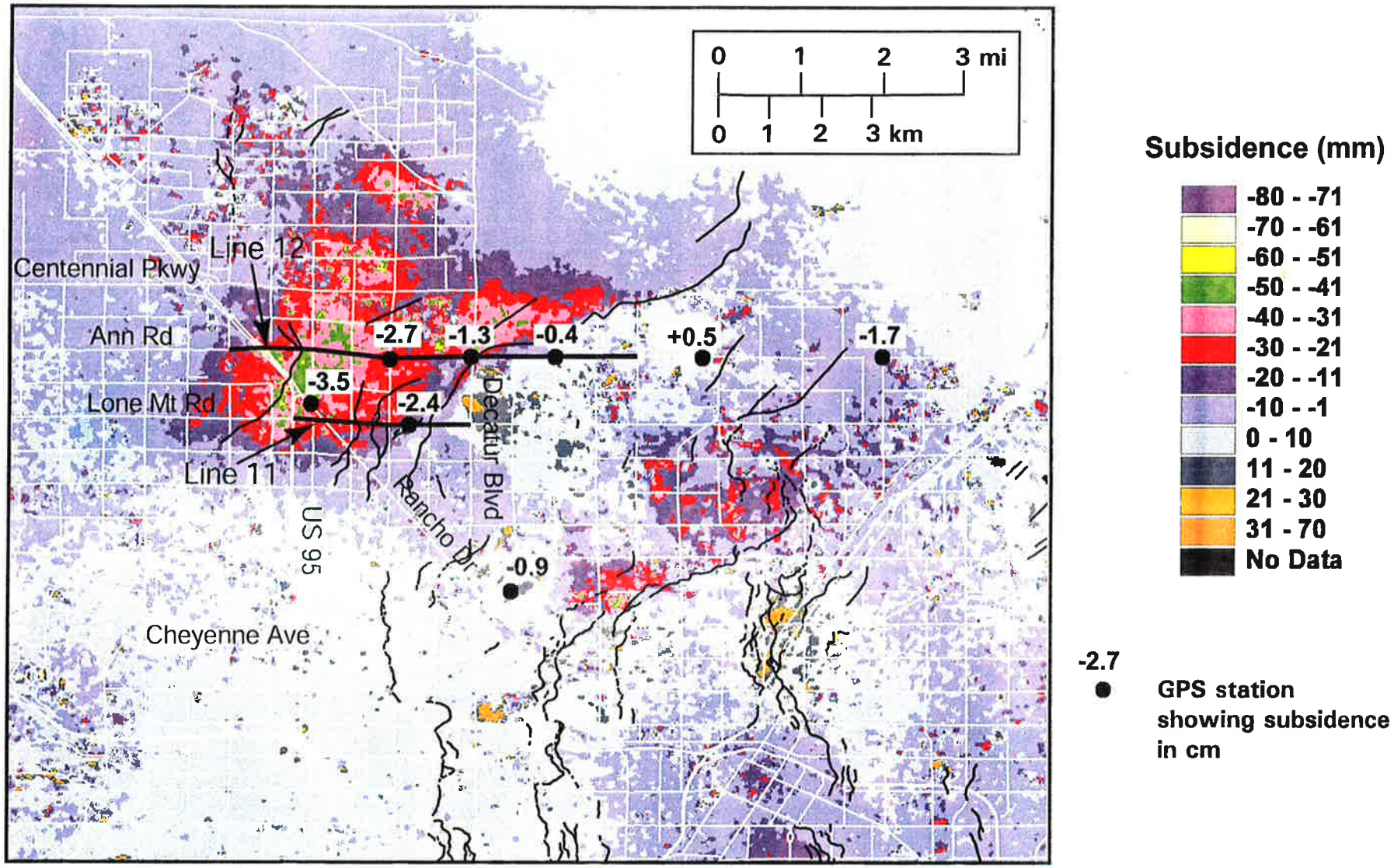

Figure 13. Enlargement of the 1997-99 Arcview map (Fig. 8) showing the 25 x 35 m pixel values in the northwest part of the valley, the location and change of the GPS stations surveyed in 1998-99, and the location of level lines 11 and 12. The highest subsidence values in the northwest subsidence bowl are green and yellow pixels having maximum values between 41-50 and 51-60 mm, respectively.

Conventional Level Line Surveys

Level line 11 was established in 1991 and extends along Lone Mountain Road between US 95 and Decatur Boulevard (Fig. 13). The line was surveyed in November, 1999 at second-order, class I accuracy standards by Stantec Consultants, and the results were compared to both the 1991 and 1997 surveys which were conducted with similar accuracies.

The leveling results (Fig. 14) indicate that the west end of the line subsided more than 3.5 cm relative to the east end, which is held fixed in the line adjustment. The average 1997-99 rate is about 2 cm/year, slightly less than measured in the 1991-97 survey; as shown in Figure 3, the results are in good agreement with the InSAR results for the same period. One difference between the 1997 and 1999 results is evident at stations 34 and 35. These stations are located on the Eglington fault scarp and during the 1997 survey they showed very little (~3 mm) elevation change, forming a spike with a steep differential gradient on the 1991-1997 plot (Fig. 14C). In the 1999 survey (Fig. 14B), these stations are now seen to have subsided about 2 cm, and the spike is no longer apparent, although a relatively steep gradient continues to occur between these stations and station 166. In earlier studies, we showed how differential subsidence may be preferentially localized along faults. Although the exact cause of the spike is unclear, large structural cracks are visible in block walls adjacent to station 34, suggesting that localized tensional strain is associated with the feature.

A new line 12 was surveyed along Ann Road in 1999 in order to provide additional conventional geodetic control through the approximate center of the Northwest bowl (Fig. 13). The line extends from Buffalo Drive on the west to Clayton Street on the east.

Subsidence trends in the Northwest bowl

Long-term subsidence trends are difficult to track in the Northwest bowl because of the destruction of most of the older USGS benchmarks. For this study, composite conventional and GPS data were compiled for USGS benchmark R169 which was located at the northwest corner of Rancho Drive and Rainbow Boulevard. Based on the InSAR mapping of the Northwest subsidence bowl, this location is slightly south of the center of the subsidence bowl.

Figure 15 shows the trend of subsidence on R169 between 1963 and 1999. The benchmark was surveyed at first-order accuracy in 1963 and 1980. The 1990 and 1995 GPS surveys included measurements on the benchmark. The benchmark was destroyed by construction after the 1995 survey, and a new station 143 was surveyed nearby in 1998 and 1999. The elevations plotted for the GPS results are ellipsoid heights converted to orthometric heights with GEOID 99. As noted earlier, the geoid model for this portion of the valley may be in error by as much as 10 cm. Figure 14 shows the elevation trend corrected for the 10 cm error as a dashed line. The plot shows that subsidence appears to have slowed slightly since about 1990, an observation we also made in the 1998 subsidence report. Since 1990, the average subsidence rate has been about 3 cm/year, and the 1998-99 GPS results indicate that the rate is slightly lower: between 2-3 cm, a value consistent with the

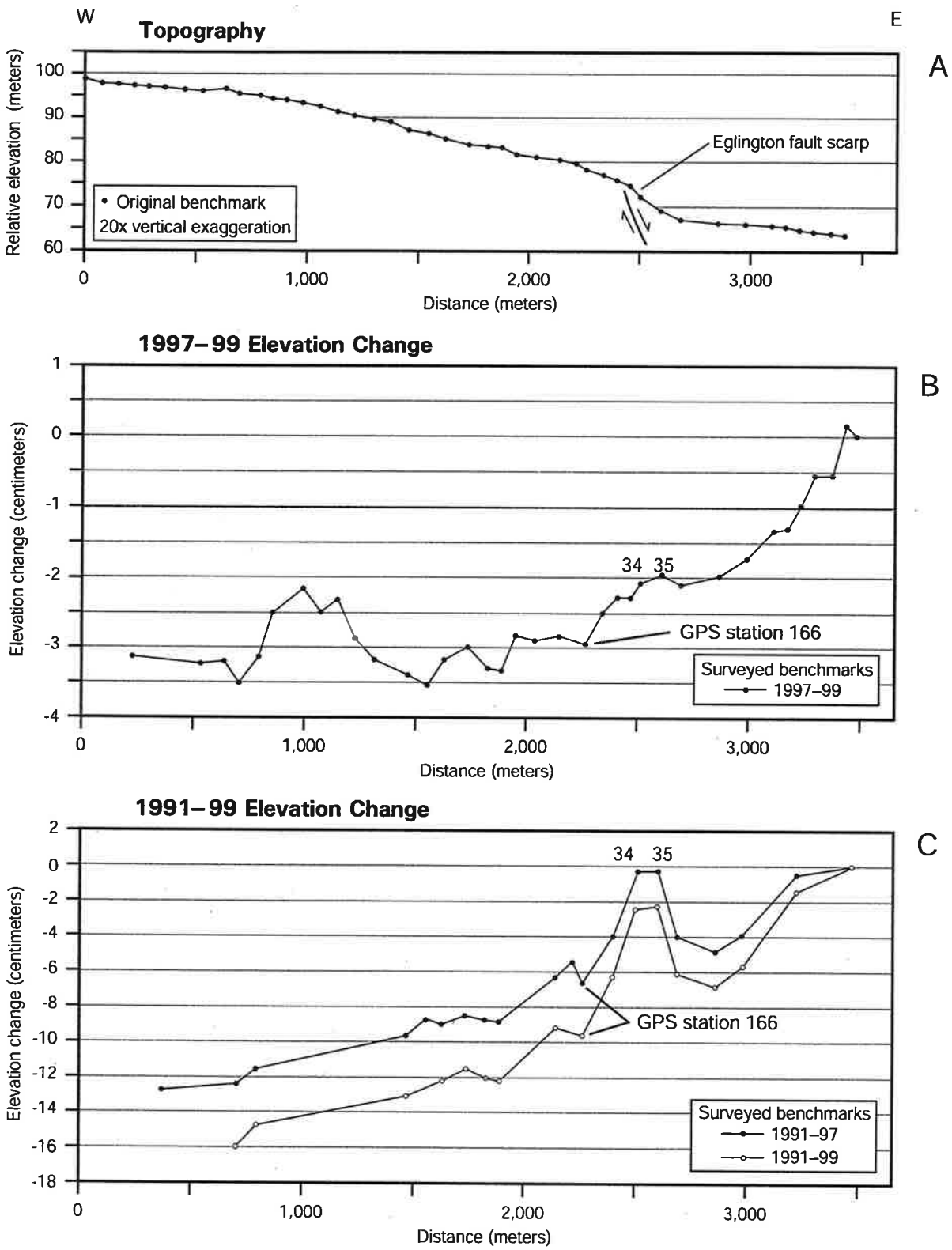

Figure 14. Results of leveling along line 11 for the period 1991–99 (line was established in 1991). Top figure (A) shows the topography and station locations; B shows the elevation change occurring between 1997-99; C shows the cumulative elevation change along the line between 1991-97 and 1991-99. A prominent elevation differential spike occured in the 1991-97 survey where stations 34 and 35 had little movement relative to adjacent stations.

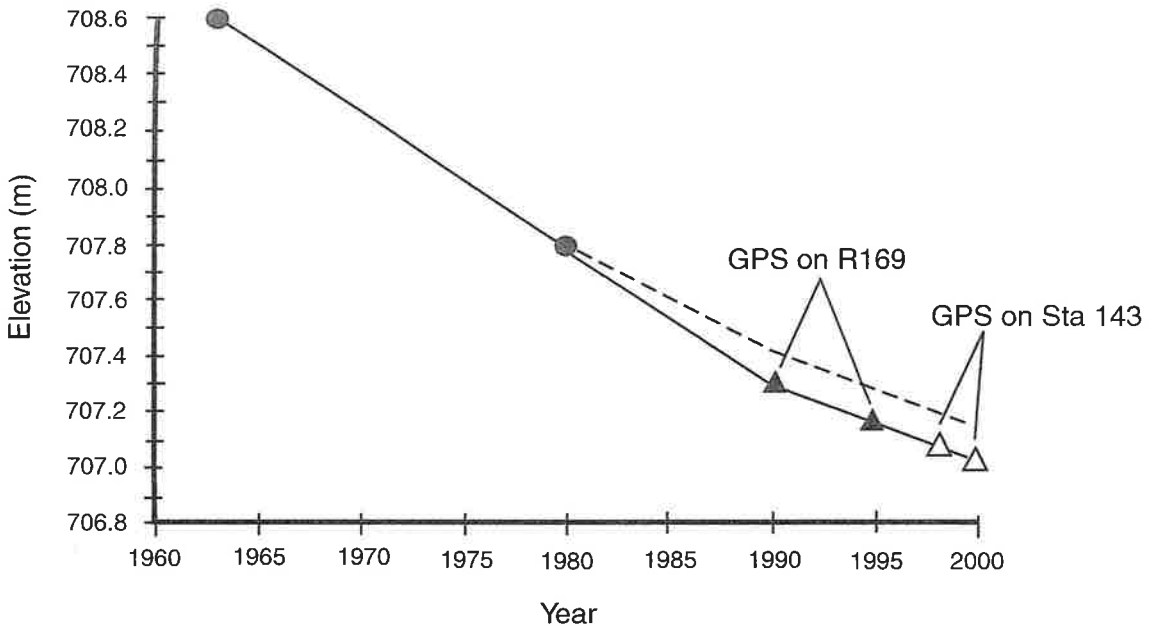

Figure 15. Plot showing trend of elevation change on USGS benchmark R169 located at the corner of Rancho Drive and Rainbow Boulevard in the Northwest subsidence bowl. The benchmark was surveyed by conventional leveling in 1963 and 1980; it was surveyed by GPS in 1990 and 1995. It was destroyed by development in 1996, and Sta 143 was added as a replacement GPS benchmark and surveyed in 1998 and 1999. The GPS orthometric heights for measurements on the R169 benchmark were determined using the GEOID 99 corrections. Dashed line is trend accounting for possible +10 cm error in geoid correction. Sta 143 was assumed to be on the same trend as R169. The average subsidence rate since 1990 is about 3 cm/year.

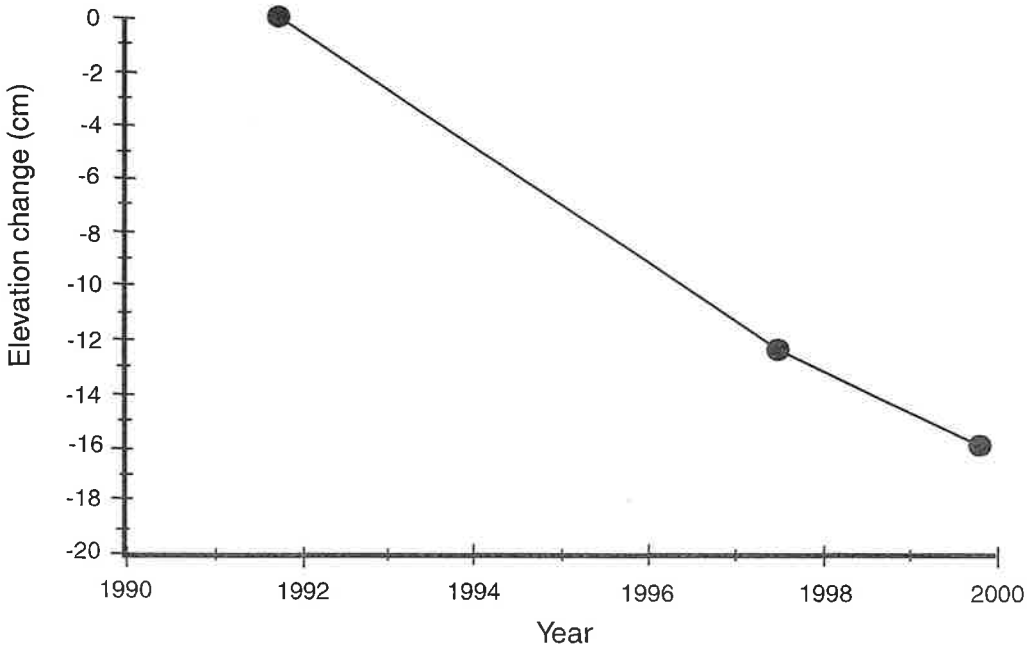

Figure 16. Plot showing trend of maximum subsidence measured along level line 11 since established in 1991. Based on releveling in 1997 and 1999, the average annual subsidence rate determined from the plot is about 2 cm/year.

rate estimated for the same period by InSAR. Figure 16 shows the trend of maximum subsidence measured along level line 11 since 1991. Similar to the trend of R169, there appears to be a slight reduction in the average annual subsidence rate during the last several years.

Horizontal GPS data

The results of the 1998 and 1999 GPS surveys were analyzed for evidence of horizontal displacements by comparing the shift in adjusted horizontal coordinates between the two surveys. Northwest-oriented horizontal displacements of more than 1 cm were measured on some stations, values which were in some cases greater than the measured vertical components. While the horizontal measurements are regarded as very accurate (<5 mm 1-sigma errors), the results are not confirmed by the InSAR study. As discussed previously, a comparison of ascending and descending SAR images can reveal the occurrence of horizontal displacements. A comparison of a pair of interferograms for the summer of 1997 did not show any horizontal components, although the time period covered is short and the detection level is poor in the north direction. Without additional GPS surveys or longer-term InSAR comparisons, it is uncertain if the horizontal vectors measured from the 1998-99 data are real or if they are GPS network adjustment artifacts.

Subsidence map for 1963-2000

In the 1998 subsidence report (Bell et al., 1999), a revised map showing subsidence between 1963-1987 was produced based on the detailed spatial subsidence pattern provided by the InSAR results. During the present study, additional conventional leveling data were compiled from surveys conducted by the Cities of Las Vegas and North Las Vegas and combined with GPS survey data from 1990, 1995, 1998, and 1999 surveys to provide an updated subsidence data base. Figure 17 shows the revised map of subsidence for the period 1963-2000. The principal changes occurring since about 1990 have been in the Northwest subsidence bowl where at least an additional 25-30 cm of subsidence has occurred.

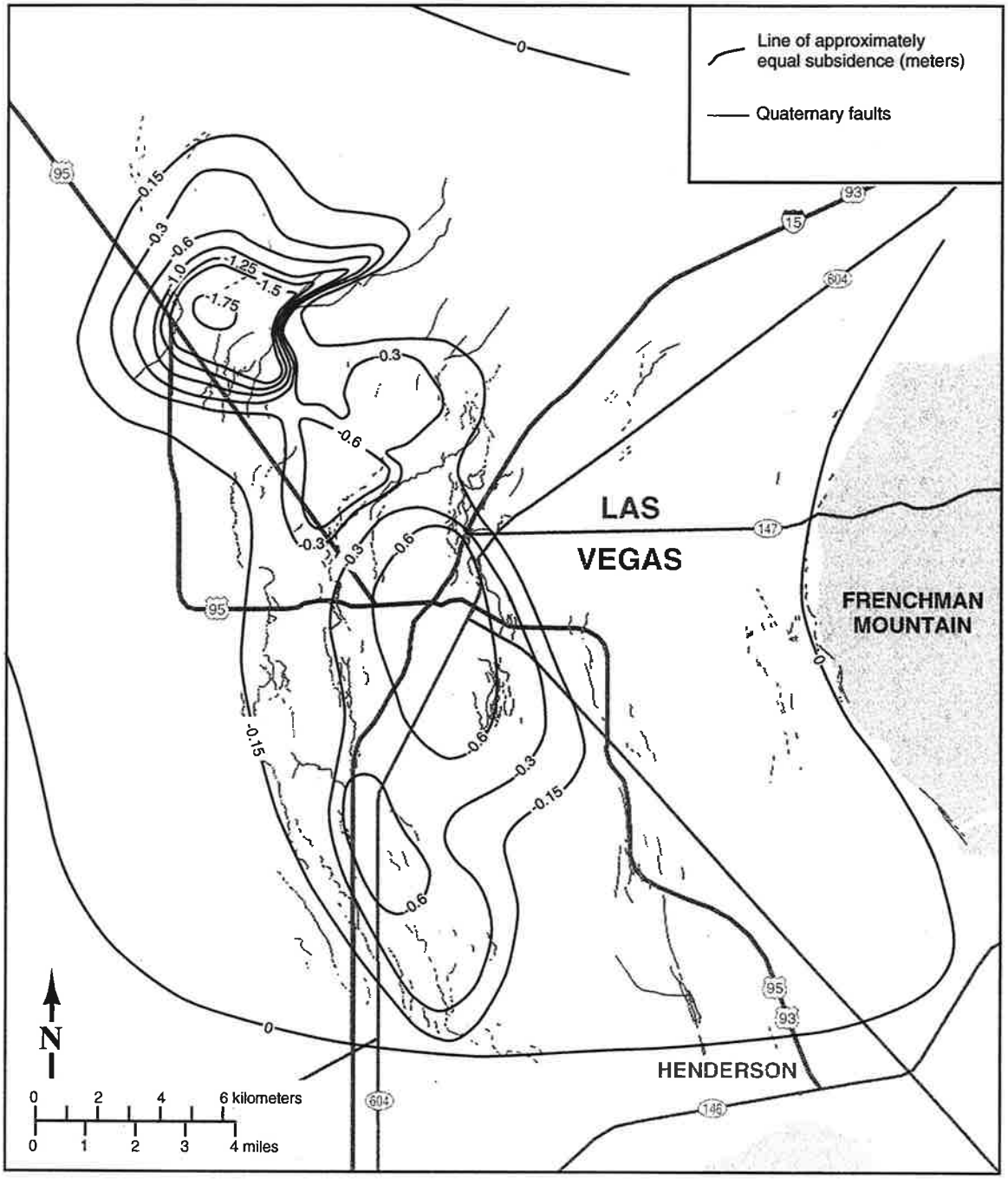

Figure 17. Contour map of subsidence in Las Vegas Valley for 1963-2000.

Summary and Conclusions

An InSAR study included three principal objectives: 1.) to measure and document any land subsidence occurring between 1997-1999; 2.) to investigate areas undergoing seasonal subsidence and uplift using multiple short-term interferograms; and 3). to compare interferograms produced from ascending and descending orbits to detect horizontal ground displacements. The principal results are:

- Interferograms developed for the period 1997-99 confirm the conclusions reached in the 1998 subsidence report: subsidence is continuing in the Northwest subsidence bowl but it is greatly reduced in the central and southern portions of the valley compared to the early to mid-1990's. A maximum of 5-6 cm of subsidence is measured in the Northwest bowl and about 2-3 cm in the Central subsidence bowl and the Nellis zone. In the latter case, almost all of the subsidence measured in the Central bowl and the Nellis zone occurred during the 1999 summer season, suggesting that pumping and/or recharge patterns were different in 1999 than in the previous years. The greatest amounts of subsidence for this period (6-7 cm) were detected along Las Vegas Boulevard (the Strip) in the Southern subsidence bowl.

- Seasonal interferograms between 1995 and 1999 show that summer subsidence in the Central bowl is greatly compensated by winter uplift, resulting in little to no residual compaction. In contrast, the seasonal results indicate that the Northwest bowl continues to display residual compaction and is subsiding at a maximum rate of 2-2.5 cm/year.

- A comparison of 1998 GPS results with surveyed first-order level heights on USGS benchmarks in stable portions of the valley show good agreement, allowing estimates of subsidence to be made from the 1998 GPS data. Although the GEOID 99 model appears to produce reasonably accurate orthometric heights around the perimeter of the valley, the gravity-dependent geoid height corrections may result in orthometric heights that are 5-10 cm too low in the center of the valley.

- The 1999 GPS survey of 11 stations shows that a maximum of 3.5 cm of subsidence occurred since 1998 in the Northwest subsidence bowl, an amount in good agreement with the subsidence measured by InSAR for the same period. The 1998-99 subsidence rate is about 2-3 cm/year on a station located just south of the center of the Northwest subsidence bowl.

- Conventional leveling of line 11 across the Eglington fault shows a maximum subsidence of 3.5 cm of the west end of the line between 1997-99, yielding a rate of about 2 cm/year. A prominent differential gradient in the 1991-97 leveling survey is no longer visible on the 1997-99 survey, but it was coincident with structural cracking of a block wall across the fault scarp, suggesting the presence of localized tensional strain on the fault.

- The long-term trend of subsidence estimated from conventional and GPS surveys on USGS benchmark R169 suggests that since about 1990 the maximum rate of subsidence has declined to about 3 cm/year in the Northwest bowl. A similar decline in annual rates is also seen on the

1991-99 leveling results for line 11. These rates are in good agreement with those estimated by InSAR.

- A comparison of horizontal GPS coordinate data for the 1998 and 1999 surveys shows a small (<2 cm), northwest-oriented shift in station positions. The analysis of 1997 ascending and descending InSAR data failed to detect any horizontal displacement, and it is uncertain whether the displacements are real or an artifact of GPS baseline processing and adjustment.

Recommendations for Future Work

Based on the results of 1999-2000 subsidence studies, the following elements are recommended for future work:

- Geodetically monitor the northwest part of the valley, which continues to subside at an average rate of 2-3 cm/year. Although residual compaction appears to be declining, average subsidence has been fairly constant through the 1990's and if not mitigated by proposed artificial recharge, the movement will likely continue at about the same rate. While this rate is substantially less than the pre-1990 rate (~5 cm/year), it is nonetheless a rate capable of producing long-term urban impacts. As reported in the 1998 subsidence study, continuing subsidence in the Northwest bowl may contribute to the continuing development and/or reactivation of earth fissures along the Eglington and other similar faults.

- The geodetic monitoring program should consist of multiple methodologies in order to provide spatial detail, seasonal and long-term (net) measurements, and cross-verification. The present combination of InSAR, GPS, and conventional leveling provides these components.

- Resurvey the conventional level lines 11 and 12 at least once every two years. These lines were designed to detect steep differential subsidence gradients that may be occurring across the Eglington fault. The results of the 1998 and 1999-2000 studies suggest that although InSAR provides a detailed spatial map of movement, it may not always detect steep gradients, especially if occurring over distances shorter than the average pixel values (~100 m^2).

- Monitor the Central subsidence bowl and the Nellis subsidence zone for seasonal reoccurrence of subsidence. Although residual subsidence appears to be nearly completely arrested in these areas due to the artificial recharge program, the InSAR mapping indicates that these areas both exhibited renewed movement in the summer of 1999. Following several years of little to no subsidence, which included measurable uplift, about 2 cm of subsidence occurred in the 1999 summer season possibly related to a different pattern of groundwater pumping and/or recharge.

- Establish a new geodetic line in the vicinity of the Las Vegas Strip in the Southern subsidence bowl in order to verify vertical movements and associated possible horizontal components. Based on a comparison of ascending and descending SAR interferograms for the summer of 1997, horizontal displacements may be occurring in the southern part of the valley but these displacements have not been confirmed by independent conventional geodetic surveys. A GPS network combined with a level line surveyed seasonally would provide high accuracy resolution of both the vertical (<10 mm) and horizontal (<5 mm) displacements.

References

Amelung, F., Galloway, D.L., Bell, J.W., Zebker, H.A., and Laczniak, R.J., 1999, Sensing the ups and downs of Las Vegas: InSAR reveals structural control of land subsidence and aquifer-system deformation: *Geology*, v. 27, no. 6, p. 483-486.

Bell, J.W., Ramelli, A.R., and dePolo, C.M., 1999, 1998 Subsidence Report: Unpublished report prepared for the Las Vegas Valley Water District, 123 p.

Appendix 1

1998 and 1999 GPS Coordinate Adjustment Results

1998 Survey

COORDINATE ADJUSTMENT SUMMARY

Datum = NAD-83
Coordinate System = Geographic
Zone = Global

Network Adjustment Constraints:
6 fixed coordinates in y
6 fixed coordinates in x
6 fixed coordinates in H

POINT	NAME		OLD COORDS	ADJUST	NEW COORDS	1.00σ
1	110USGS					
		LAT=	36° 25' 46.269764"	+0.000010"	36° 25' 46.269774"	0.004252m
		LON=	115° 23' 19.889733"	+0.000131"	115° 23' 19.889602"	0.003621m
		ELL HT=	850.4123m	+0.0001m	850.4124m	0.008753m
		ORTHO HT=	0.0000m	+0.0000m	0.0000m	NOT KNOWN
2	112USGS					
		LAT=	36° 20' 25.596956"	-0.000171"	36° 20' 25.596786"	0.004591m
		LON=	115° 17' 45.341739"	+0.000576"	115° 17' 45.341163"	0.003943m
		ELL HT=	779.5439m	-0.0006m	779.5434m	0.009759m
		ORTHO HT=	0.0000m	+0.0000m	0.0000m	NOT KNOWN
3	169GWM					
		LAT=	36° 26' 12.968948"	+0.000026"	36° 26' 12.968974"	0.004374m
		LON=	115° 21' 46.589061"	+0.000161"	115° 21' 46.588899"	0.003803m
		ELL HT=	855.1524m	-0.0003m	855.1521m	0.009326m
		ORTHO HT=	0.0000m	+0.0000m	0.0000m	NOT KNOWN
4	170GWM					
		LAT=	36° 26' 12.500270"	+0.000034"	36° 26' 12.500304"	0.004087m
		LON=	115° 19' 55.624712"	+0.000210"	115° 19' 55.624503"	0.003559m
		ELL HT=	942.9595m	-0.0008m	942.9587m	0.008802m
		ORTHO HT=	0.0000m	+0.0000m	0.0000m	NOT KNOWN
5	171GWM					
		LAT=	36° 26' 15.218954"	+0.000044"	36° 26' 15.218998"	0.004048m
		LON=	115° 17' 48.706255"	+0.000251"	115° 17' 48.706005"	0.003533m
		ELL HT=	1068.8901m	-0.0008m	1068.8893m	0.009031m
		ORTHO HT=	0.0000m	+0.0000m	0.0000m	NOT KNOWN
6	1LV00-2NEE6A					
		LAT=	36° 14' 39.639011"	-0.000284"	36° 14' 39.638727"	0.007262m
		LON=	115° 13' 32.564672"	+0.000791"	115° 13' 32.563881"	0.008193m
		ELL HT=	664.4291m	+0.0010m	664.4302m	0.020377m
		ORTHO HT=	0.0000m	+0.0000m	0.0000m	NOT KNOWN
7	1LV00-4SES					
		LAT=	36° 13' 59.810833"	-0.000304"	36° 13' 59.810529"	0.004868m
		LON=	115° 15' 39.116892"	+0.000764"	115° 15' 39.116128"	0.004240m

```
    ELL HT=            686.1661m   +0.0008m            686.1669m    0.010881m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

 8 1LV10-8S4
       LAT=  36° 07' 47.328483" -0.000391"  36° 07' 47.328092"    0.006040m
       LON= 115° 17' 19.554257" +0.000868" 115° 17' 19.553389"    0.004616m
    ELL HT=            789.2345m   +0.0010m            789.2354m    0.012127m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

 9 1LV90-33E6
       LAT=  36° 15' 19.902932" -0.000279"  36° 15' 19.902653"    0.004185m
       LON= 115° 15' 54.508028" +0.000735" 115° 15' 54.507293"    0.003547m
    ELL HT=            696.3144m   +0.0006m            696.3150m    0.008991m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

10 1LV90-36NES
       LAT=  36° 15' 41.096944" -0.000264"  36° 15' 41.096680"    0.004909m
       LON= 115° 12' 26.580379" +0.000818" 115° 12' 26.579561"    0.004130m
    ELL HT=            653.4178m   +0.0008m            653.4187m    0.010337m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

11 1LV90-36SSW6
       LAT=  36° 14' 47.535988" -0.000279"  36° 14' 47.535709"    0.004454m
       LON= 115° 13' 15.428903" +0.000804" 115° 13' 15.428099"    0.003878m
    ELL HT=            660.6914m   +0.0008m            660.6922m    0.009629m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

12 2C90-6SWW6
       LAT=  36° 19' 30.999875" -0.000185"  36° 19' 30.999689"    0.004583m
       LON= 115° 18' 38.738884" +0.000537" 115° 18' 38.738347"    0.003840m
    ELL HT=            824.9551m   -0.0011m            824.9540m    0.009598m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

13 2GWM
       LAT=  36° 19' 31.609236" -0.000183"  36° 19' 31.609053"    0.005236m
       LON= 115° 20' 03.807287" +0.000480" 115° 20' 03.806807"    0.004645m
    ELL HT=            895.1156m   -0.0009m            895.1147m    0.010902m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

14 2LV00-25N4
       LAT=  36° 11' 17.219382" -0.000346"  36° 11' 17.219036"    0.004651m
       LON= 115° 12' 53.688521" +0.000870" 115° 12' 53.687651"    0.003903m
    ELL HT=            655.4963m   +0.0010m            655.4973m    0.009436m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

15 32-33-5-4
       LAT=  36° 20' 09.578599" -0.000178"  36° 20' 09.578421"    0.004890m
       LON= 115° 16' 43.079933" +0.000620" 115° 16' 43.079314"    0.004177m
    ELL HT=            745.1762m   -0.0003m            745.1758m    0.010429m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

16 34-35-3-2
       LAT=  36° 20' 08.359306" -0.000171"  36° 20' 08.359135"    0.005289m
       LON= 115° 14' 34.106345" +0.000669" 115° 14' 34.105676"    0.004507m
    ELL HT=            712.8178m   -0.0003m            712.8175m    0.011373m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN
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17 3GWM
       LAT=  36° 19' 06.911273" -0.000193"  36° 19' 06.911080"    0.004655m
       LON= 115° 21' 47.595750" +0.000438" 115° 21' 47.595312"    0.003923m
    ELL HT=            992.5389m   -0.0006m           992.5383m    0.009879m
  ORTHO HT=              0.0000m   +0.0000m             0.0000m    NOT KNOWN

18 4GWM
       LAT=  36° 18' 30.596232" -0.000213"  36° 18' 30.596018"    0.004863m
       LON= 115° 23' 44.436511" +0.000399" 115° 23' 44.436113"    0.004140m
    ELL HT=           1111.9370m   -0.0005m          1111.9365m    0.010493m
  ORTHO HT=              0.0000m   +0.0000m             0.0000m    NOT KNOWN

19 5-18-117
       LAT=  36° 17' 29.057713" -0.000223"  36° 17' 29.057490"    0.004864m
       LON= 115° 12' 24.562379" +0.000782" 115° 12' 24.561597"    0.003740m
    ELL HT=            676.7602m   +0.0001m           676.7603m    0.009524m
  ORTHO HT=              0.0000m   +0.0000m             0.0000m    NOT KNOWN

20 503+20.08
       LAT=  36° 01' 54.283831" -0.000352"  36° 01' 54.283479"    0.005498m
       LON= 115° 01' 49.523178" +0.001106" 115° 01' 49.522072"    0.004861m
    ELL HT=            554.9684m   -0.0004m           554.9680m    0.012755m
  ORTHO HT=              0.0000m   +0.0000m             0.0000m    NOT KNOWN

21 6135A17
       LAT=  36° 09' 59.916732" -0.000390"  36° 09' 59.916343"    0.005564m
       LON= 115° 07' 05.470471" +0.001015" 115° 07' 05.469457"    0.004078m
    ELL HT=            536.4432m   +0.0006m           536.4439m    0.010811m
  ORTHO HT=              0.0000m   +0.0000m             0.0000m    NOT KNOWN

22 6C02-16SWS
       LAT=  36° 12' 13.820402" -0.000464"  36° 12' 13.819938"    0.005878m
       LON= 115° 03' 43.255672" +0.001098" 115° 03' 43.254574"    0.003929m
    ELL HT=            520.6867m   +0.0006m           520.6872m    0.010590m
  ORTHO HT=              0.0000m   +0.0000m             0.0000m    NOT KNOWN

23 6C02-4SWW6
       LAT=  36° 14' 11.753489" -0.000457"  36° 14' 11.753032"    0.005348m
       LON= 115° 03' 43.165267" +0.001081" 115° 03' 43.164186"    0.003548m
    ELL HT=            539.9187m   +0.0014m           539.9201m    0.009864m
  ORTHO HT=              0.0000m   +0.0000m             0.0000m    NOT KNOWN

24 6C11-13SWW6
       LAT=  36° 07' 06.982773" -0.000414"  36° 07' 06.982359"    0.006608m
       LON= 115° 07' 07.992474" +0.001024" 115° 07' 07.991450"    0.005182m
    ELL HT=            560.9738m   +0.0013m           560.9751m    0.014770m
  ORTHO HT=              0.0000m   +0.0000m             0.0000m    NOT KNOWN

25 6C12-7SE6
       LAT=  36° 08' 04.766713" -0.000427"  36° 08' 04.766286"    0.006968m
       LON= 115° 05' 18.954726" +0.001062" 115° 05' 18.953664"    0.006587m
    ELL HT=            522.7886m   +0.0015m           522.7901m    0.014953m
  ORTHO HT=              0.0000m   +0.0000m             0.0000m    NOT KNOWN

26 7C00-14N4
       LAT=  36° 13' 02.344964" -0.000320"  36° 13' 02.344644"    0.004357m
       LON= 115° 14' 02.846286" +0.000815" 115° 14' 02.845471"    0.003540m
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    ELL HT=            669.2458m   +0.0010m            669.2468m    0.008969m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

27 7C00-36SSW6
       LAT=  36° 09' 33.434207" -0.000373"  36° 09' 33.433834"    0.005028m
       LON= 115° 13' 09.110743" +0.000892" 115° 13' 09.109851"    0.004217m
    ELL HT=            664.3647m   +0.0013m            664.3660m    0.010456m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

28 7C01-11S4
       LAT=  36° 13' 05.173748" -0.000317"  36° 13' 05.173431"    0.005032m
       LON= 115° 07' 36.134425" +0.000962" 115° 07' 36.133462"    0.003712m
    ELL HT=            560.0542m   +0.0012m            560.0554m    0.010249m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

29 7C01-29C4
       LAT=  36° 10' 52.430201" -0.000350"  36° 10' 52.429851"    0.004428m
       LON= 115° 10' 44.885172" +0.000918" 115° 10' 44.884254"    0.003779m
    ELL HT=            611.0990m   +0.0009m            611.0999m    0.009459m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

30 7C01-2C4
       LAT=  36° 14' 22.509891" -0.000303"  36° 14' 22.509588"    0.005291m
       LON= 115° 07' 30.399694" +0.000941" 115° 07' 30.398754"    0.004542m
    ELL HT=            565.7955m   +0.0012m            565.7966m    0.012676m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

31 7C02-18NWW6
       LAT=  36° 12' 52.317617" -0.000362"  36° 12' 52.317255"    0.006158m
       LON= 115° 05' 54.185030" +0.001021" 115° 05' 54.184009"    0.004036m
    ELL HT=            536.4065m   +0.0012m            536.4076m    0.010862m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

32 7C02-28S4
       LAT=  36° 10' 27.190166" -0.000556"  36° 10' 27.189610"    0.006020m
       LON= 115° 03' 10.072408" +0.001160" 115° 03' 10.071249"    0.004461m
    ELL HT=            506.5538m   +0.0013m            506.5551m    0.010881m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

33 7C10-13NNW6
       LAT=  36° 07' 44.982234" -0.000404"  36° 07' 44.981830"    0.005156m
       LON= 115° 13' 12.302203" +0.000895" 115° 13' 12.301308"    0.004100m
    ELL HT=            667.6925m   +0.0014m            667.6939m    0.010606m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

34 7C10-22SWS
       LAT=  36° 05' 59.001477" -0.000421"  36° 05' 59.001055"    0.006840m
       LON= 115° 15' 38.912596" +0.000885" 115° 15' 38.911711"    0.005661m
    ELL HT=            712.5649m   +0.0013m            712.5662m    0.014278m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

35 7C10-24SWS
       LAT=  36° 06' 00.064954" -0.000413"  36° 06' 00.064541"    0.005153m
       LON= 115° 13' 29.219904" +0.000905" 115° 13' 29.218999"    0.004508m
    ELL HT=            674.4603m   +0.0015m            674.4617m    0.011525m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN
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36 7C11-5SSW6
       LAT=  36° 08' 40.348938" -0.000381"  36° 08' 40.348557"    0.004020m
       LON= 115° 11' 06.983944" +0.000928" 115° 11' 06.983015"    0.003199m
    ELL HT=           621.7680m   +0.0013m           621.7693m    0.008678m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

37 80.19
       LAT=  36° 14' 21.430372" -0.000290"  36° 14' 21.430082"    0.005036m
       LON= 115° 10' 28.732021" +0.000877" 115° 10' 28.731144"    0.003886m
    ELL HT=           623.9433m   +0.0006m           623.9439m    0.010548m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

38 802
       LAT=  36° 20' 09.682386" -0.000178"  36° 20' 09.682209"    0.004958m
       LON= 115° 15' 38.976392" +0.000658" 115° 15' 38.975733"    0.004235m
    ELL HT=           726.6584m   -0.0002m           726.6581m    0.010713m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

39 803
       LAT=  36° 20' 07.727941" -0.000169"  36° 20' 07.727772"    0.005439m
       LON= 115° 12' 25.403961" +0.000747" 115° 12' 25.403213"    0.004402m
    ELL HT=           708.9213m   -0.0005m           708.9208m    0.011372m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

40 806
       LAT=  36° 17' 32.169787" -0.000243"  36° 17' 32.169543"    0.004287m
       LON= 115° 18' 53.200188" +0.000611" 115° 18' 53.199578"    0.003652m
    ELL HT=           841.1619m   +0.0003m           841.1621m    0.009122m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

41 817-20-61
       LAT=  36° 12' 09.719030" -0.000335"  36° 12' 09.718695"    0.003908m
       LON= 115° 10' 11.277251" +0.000916" 115° 10' 11.276335"    0.003164m
    ELL HT=           604.7622m   +0.0011m           604.7633m    0.008910m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

42 874
       LAT=  36° 14' 52.276836" -0.000279"  36° 14' 52.276558"    0.004956m
       LON= 115° 09' 12.881942" +0.000901" 115° 09' 12.881041"    0.003881m
    ELL HT=           600.0605m   +0.0007m           600.0611m    0.010587m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

43 888
       LAT=  36° 02' 10.700271" -0.000366"  36° 02' 10.699905"    0.004988m
       LON= 115° 05' 00.336023" +0.001066" 115° 05' 00.334957"    0.004596m
    ELL HT=           592.5038m   +0.0002m           592.5040m    0.012593m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

44 923
       LAT=  36° 09' 33.092691" -0.000375"  36° 09' 33.092316"    0.005324m
       LON= 115° 16' 27.132705" +0.000849" 115° 16' 27.131856"    0.004252m
    ELL HT=           769.6470m   +0.0011m           769.6480m    0.011288m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

45 C141
       LAT=  36° 16' 39.587390" -0.000347"  36° 16' 39.587043"    0.004297m
       LON= 115° 02' 14.489418" +0.001031" 115° 02' 14.488387"    0.003235m
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    ELL HT=          585.5146m   +0.0014m          585.5160m    0.008634m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

46 C170
       LAT=  36° 05' 28.117459" -0.000404"  36° 05' 28.117055"    0.004296m
       LON= 115° 11' 45.659935" +0.000935" 115° 11' 45.659000"    0.003946m
    ELL HT=          652.4503m   +0.0011m          652.4514m    0.010218m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

47 C90-17C4
       LAT=  36° 17' 55.817222" -0.000227"  36° 17' 55.816995"    0.004192m
       LON= 115° 17' 12.105402" +0.000642" 115° 17' 12.104759"    0.003554m
    ELL HT=          766.0320m   -0.0001m          766.0319m    0.008829m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

48 C90-7SE6
       LAT=  36° 18' 43.446794" -0.000208"  36° 18' 43.446585"    0.004387m
       LON= 115° 17' 55.313678" +0.000594" 115° 17' 55.313084"    0.003725m
    ELL HT=          793.4474m   -0.0006m          793.4469m    0.009235m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

49 CLV plate
       LAT=  36° 16' 23.167328" -0.000246"  36° 16' 23.167082"    0.005964m
       LON= 115° 13' 28.983932" +0.000766" 115° 13' 28.983166"    0.005279m
    ELL HT=          676.5024m   +0.0003m          676.5027m    0.016962m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

50 CLV plate1
       LAT=  36° 14' 19.268097" -0.000294"  36° 14' 19.267804"    0.004806m
       LON= 115° 12' 49.649568" +0.000830" 115° 12' 49.648738"    0.003758m
    ELL HT=          647.4881m   +0.0008m          647.4889m    0.009560m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

51 CLV plate2
       LAT=  36° 16' 23.167699" -0.000248"  36° 16' 23.167452"    0.005099m
       LON= 115° 13' 28.983470" +0.000773" 115° 13' 28.982697"    0.004025m
    ELL HT=          676.5013m   +0.0006m          676.5019m    0.010257m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

52 CLV23
       LAT=  36° 09' 33.050784" -0.000375"  36° 09' 33.050409"    0.005351m
       LON= 115° 12' 05.360116" +0.000902" 115° 12' 05.359215"    0.004328m
    ELL HT=          637.3460m   +0.0012m          637.3471m    0.011243m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

53 CNLV
       LAT=  36° 12' 58.895636" -0.000313"  36° 12' 58.895323"    0.003655m
       LON= 115° 07' 39.173553" +0.000958" 115° 07' 39.172594"    0.002793m
    ELL HT=          568.0129m   +0.0013m          568.0142m    0.007310m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

54 D171
       LAT=  36° 17' 59.524137" -0.000309"  36° 17' 59.523829"    0.004433m
       LON= 115° 01' 14.844058" +0.001036" 115° 01' 14.843022"    0.003191m
    ELL HT=          637.6448m   +0.0008m          637.6455m    0.008610m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN
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55 D368
       LAT=  36° 09' 16.912620" +0.000000"  36° 09' 16.912620"        FIXED
       LON= 115° 21' 47.198540" +0.000000" 115° 21' 47.198540"        FIXED
    ELL HT=           962.4200m   +0.0000m           962.4200m        FIXED
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

56 D371
       LAT=  36° 24' 53.335680" +0.000000"  36° 24' 53.335680"        FIXED
       LON= 115° 27' 05.663360" +0.000000" 115° 27' 05.663360"        FIXED
    ELL HT=          1040.3800m   +0.0000m          1040.3800m        FIXED
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

57 EA963+67.37
       LAT=  36° 00' 22.754393" -0.000408"  36° 00' 22.753985"    0.003813m
       LON= 115° 10' 48.303932" +0.000975" 115° 10' 48.302957"    0.003687m
    ELL HT=           667.1637m   +0.0015m           667.1651m    0.010229m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

58 F170 RESET
       LAT=  36° 01' 28.447287" -0.000451"  36° 01' 28.446836"    0.005200m
       LON= 115° 13' 37.336720" +0.000911" 115° 13' 37.335809"    0.005181m
    ELL HT=           726.5867m   +0.0013m           726.5880m    0.012523m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

59 H166
       LAT=  36° 00' 40.007534" -0.000226"  36° 00' 40.007307"    0.006530m
       LON= 114° 57' 02.643046" +0.001142" 114° 57' 02.641904"    0.004918m
    ELL HT=           617.9210m   -0.0009m           617.9201m    0.015034m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

60 H169+87.05
       LAT=  35° 59' 45.514893" -0.000403"  35° 59' 45.514490"    0.004169m
       LON= 115° 07' 47.860751" +0.001038" 115° 07' 47.859712"    0.003998m
    ELL HT=           677.7144m   +0.0012m           677.7156m    0.011451m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

61 HAPPY
       LAT=  36° 02' 50.342523" -0.000376"  36° 02' 50.342147"    0.003986m
       LON= 115° 10' 53.198189" +0.000955" 115° 10' 53.197234"    0.003790m
    ELL HT=           665.9039m   +0.0011m           665.9050m    0.009906m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

62 J171
       LAT=  36° 20' 28.054020" +0.000000"  36° 20' 28.054020"        FIXED
       LON= 114° 55' 04.375440" +0.000000" 114° 55' 04.375440"        FIXED
    ELL HT=           707.2580m   +0.0000m           707.2580m        FIXED
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

63 J399
       LAT=  36° 06' 08.296159" -0.000374"  36° 06' 08.295785"    0.011076m
       LON= 115° 03' 07.594092" +0.001063" 115° 03' 07.593029"    0.011998m
    ELL HT=           483.2446m   +0.0000m           483.2446m    0.022172m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

64 JERK
       LAT=  36° 03' 08.138184" -0.000426"  36° 03' 08.137758"    0.004764m
       LON= 115° 12' 42.438922" +0.000921" 115° 12' 42.438000"    0.004621m
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    ELL HT=            699.6415m   +0.0012m            699.6427m    0.011132m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

65 K366
       LAT=  36° 09' 09.413439" -0.000374"  36° 09' 09.413065"    0.004374m
       LON= 115° 09' 37.288613" +0.000955" 115° 09' 37.287658"    0.003513m
    ELL HT=            595.9387m   +0.0011m            595.9398m    0.009134m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

66 LORENZI
       LAT=  36° 14' 09.272530" -0.000296"  36° 14' 09.272234"    0.004080m
       LON= 115° 14' 28.672613" +0.000784" 115° 14' 28.671829"    0.003399m
    ELL HT=            676.9480m   +0.0011m            676.9491m    0.008662m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

67 LV00-17SEE6
       LAT=  36° 12' 22.487616" -0.000340"  36° 12' 22.487276"    0.006722m
       LON= 115° 16' 44.851410" +0.000780" 115° 16' 44.850630"    0.005682m
    ELL HT=            738.3954m   +0.0008m            738.3962m    0.014551m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

68 LVAFB B
       LAT=  36° 15' 17.677062" -0.000404"  36° 15' 17.676658"    0.004923m
       LON= 115° 01' 45.513625" +0.001092" 115° 01' 45.512533"    0.003543m
    ELL HT=            550.2437m   +0.0020m            550.2457m    0.009553m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

69 LVVWD
       LAT=  36° 09' 34.026014" -0.000368"  36° 09' 34.025646"    0.003412m
       LON= 115° 11' 28.795363" +0.000914" 115° 11' 28.794449"    0.002738m
    ELL HT=            632.4851m   +0.0014m            632.4865m    0.007094m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

70 M364
       LAT=  36° 01' 26.000174" -0.000220"  36° 01' 25.999954"    0.008202m
       LON= 114° 57' 54.610515" +0.001121" 114° 57' 54.609394"    0.006382m
    ELL HT=            591.7149m   -0.0008m            591.7141m    0.018725m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

71 N366
       LAT=  36° 06' 55.926053" -0.000408"  36° 06' 55.925645"    0.004355m
       LON= 115° 11' 04.816118" +0.000941" 115° 11' 04.815176"    0.003536m
    ELL HT=            625.5108m   +0.0015m            625.5122m    0.010841m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

72 NHD32675009
       LAT=  36° 07' 49.622942" -0.000390"  36° 07' 49.622551"    0.004967m
       LON= 115° 09' 17.868957" +0.000971" 115° 09' 17.867986"    0.003938m
    ELL HT=            595.0780m   +0.0013m            595.0793m    0.012045m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

73 NLV5
       LAT=  36° 11' 18.183936" -0.000368"  36° 11' 18.183568"    0.009898m
       LON= 115° 06' 57.222800" +0.000998" 115° 06' 57.221802"    0.007545m
    ELL HT=            534.1404m   +0.0015m            534.1419m    0.016555m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN
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74 NVGT
       LAT=  36° 12' 36.747489" -0.000321"  36° 12' 36.747168"    0.004665m
       LON= 115° 11' 54.425165" +0.000873" 115° 11' 54.424291"    0.003628m
    ELL HT=           639.7635m   +0.0010m           639.7645m    0.009001m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

75 P364
       LAT=  35° 58' 30.480931" +0.000000"  35° 58' 30.480931"        FIXED
       LON= 114° 54' 49.478447" +0.000000" 114° 54' 49.478447"        FIXED
    ELL HT=           681.0410m   +0.0000m           681.0410m        FIXED
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

76 P399
       LAT=  36° 11' 45.839587" -0.000335"  36° 11' 45.839252"    0.003859m
       LON= 115° 08' 26.550610" +0.000954" 115° 08' 26.549656"    0.003012m
    ELL HT=           567.9131m   +0.0013m           567.9143m    0.007905m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

77 PLS2050 74.75
       LAT=  36° 15' 41.032030" -0.000282"  36° 15' 41.031748"    0.005411m
       LON= 115° 09' 23.617631" +0.000886" 115° 09' 23.616745"    0.004058m
    ELL HT=           612.1681m   +0.0004m           612.1685m    0.011003m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

78 PLS3340 78.95
       LAT=  36° 17' 26.791183" -0.000230"  36° 17' 26.790953"    0.004192m
       LON= 115° 15' 12.299072" +0.000708" 115° 15' 12.298364"    0.003497m
    ELL HT=           696.3750m   +0.0000m           696.3750m    0.008810m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

79 PLS5088 77.76
       LAT=  36° 15' 39.314318" -0.000264"  36° 15' 39.314054"    0.004473m
       LON= 115° 13' 30.911422" +0.000784" 115° 13' 30.910638"    0.003785m
    ELL HT=           672.5019m   +0.0008m           672.5027m    0.009948m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

80 PLS5094 145.27
       LAT=  36° 08' 38.501685" -0.000404"  36° 08' 38.501281"    0.005617m
       LON= 115° 07' 06.889844" +0.001016" 115° 07' 06.888828"    0.004515m
    ELL HT=           547.3430m   +0.0012m           547.3442m    0.011705m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

81 PLS6902 56.57
       LAT=  36° 15' 04.239656" -0.000280"  36° 15' 04.239376"    0.004316m
       LON= 115° 14' 33.396104" +0.000769" 115° 14' 33.395335"    0.003605m
    ELL HT=           680.1029m   +0.0009m           680.1038m    0.009422m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

82 PLS7635 78.46
       LAT=  36° 13' 03.118293" -0.000319"  36° 13' 03.117973"    0.003906m
       LON= 115° 10' 12.339321" +0.000909" 115° 10' 12.338412"    0.003137m
    ELL HT=           633.0412m   +0.0010m           633.0422m    0.008825m
  ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

83 PLS8895 29 30 31 32
       LAT=  36° 15' 41.411168" -0.000267"  36° 15' 41.410900"    0.004930m
       LON= 115° 11' 20.345045" +0.000845" 115° 11' 20.344199"    0.003626m
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    ELL HT=          636.9105m   +0.0007m          636.9112m    0.009640m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

84 PLS9388 76.99
       LAT=  36° 05' 34.153377" -0.000380"  36° 05' 34.152998"    0.004856m
       LON= 115° 08' 50.163984" +0.000987" 115° 08' 50.162997"    0.004119m
    ELL HT=          602.1474m   +0.0013m          602.1486m    0.010271m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

85 PLS9399 10 11 14 15
       LAT=  36° 18' 20.854669" -0.000199"  36° 18' 20.854470"    0.005432m
       LON= 115° 08' 03.757185" +0.000874" 115° 08' 03.756311"    0.004703m
    ELL HT=          642.0687m   +0.0000m          642.0687m    0.011593m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

86 RLS4841 25 26 35 36
       LAT=  36° 15' 41.580594" -0.000275"  36° 15' 41.580319"    0.005169m
       LON= 115° 07' 01.394564" +0.000936" 115° 07' 01.393628"    0.004070m
    ELL HT=          579.9433m   +0.0008m          579.9441m    0.011248m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

87 RLS5835 73.27
       LAT=  36° 04' 50.663150" -0.000372"  36° 04' 50.662778"    0.008233m
       LON= 115° 06' 02.871375" +0.001041" 115° 06' 02.870335"    0.006907m
    ELL HT=          561.9692m   +0.0008m          561.9699m    0.015810m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

88 RLS7190 63.44
       LAT=  36° 02' 58.666177" -0.000363"  36° 02' 58.665814"    0.004629m
       LON= 115° 07' 38.087932" +0.001015" 115° 07' 38.086918"    0.004132m
    ELL HT=          601.7429m   +0.0009m          601.7438m    0.010875m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

89 SLOAN
       LAT=  35° 56' 23.987540" +0.000000"  35° 56' 23.987540"        FIXED
       LON= 115° 10' 59.297180" +0.000000" 115° 10' 59.297180"        FIXED
    ELL HT=          781.3400m   +0.0000m          781.3400m        FIXED
  ORTHO HT=            0.0000m   +0.0000m            0.0000m   NOT OBSRVD

90 T19-20S/R62-63E
       LAT=  36° 14' 49.270203" -0.000427"  36° 14' 49.269776"    0.005245m
       LON= 114° 59' 19.907457" +0.001146" 114° 59' 19.906311"    0.003761m
    ELL HT=          553.4141m   +0.0028m          553.4169m    0.010261m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

91 T370
       LAT=  36° 21' 57.159335" -0.000105"  36° 21' 57.159230"    0.004041m
       LON= 115° 21' 25.915774" +0.000343" 115° 21' 25.915431"    0.003366m
    ELL HT=          877.4411m   +0.0002m          877.4413m    0.008280m
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN

92 U368
       LAT=  36° 11' 53.565090" +0.000000"  36° 11' 53.565090"        FIXED
       LON= 115° 00' 37.322430" +0.000000" 115° 00' 37.322430"        FIXED
    ELL HT=          629.5810m   +0.0000m          629.5810m        FIXED
  ORTHO HT=            0.0000m   +0.0000m            0.0000m    NOT KNOWN
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 93 UNDER
        LAT=  36° 19' 02.109358" -0.000287"  36° 19' 02.109071"    0.003423m
        LON= 114° 56' 54.442762" +0.001069" 114° 56' 54.441693"    0.002441m
     ELL HT=           734.7282m   +0.0003m           734.7284m    0.006439m
   ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

 94 V169
        LAT=  36° 19' 41.007301" -0.000187"  36° 19' 41.007113"    0.004720m
        LON= 115° 17' 14.506588" +0.000608" 115° 17' 14.505980"    0.004085m
     ELL HT=           764.0220m   -0.0007m           764.0213m    0.009925m
   ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

 95 V365
        LAT=  36° 18' 50.646007" -0.000204"  36° 18' 50.645803"    0.004405m
        LON= 115° 16' 48.301922" +0.000630" 115° 16' 48.301292"    0.003724m
     ELL HT=           748.2681m   -0.0005m           748.2677m    0.009278m
   ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

 96 W370
        LAT=  36° 23' 47.329971" -0.000041"  36° 23' 47.329929"    0.003327m
        LON= 115° 23' 38.916950" +0.000180" 115° 23' 38.916770"    0.002704m
     ELL HT=           855.3473m   -0.0001m           855.3472m    0.006767m
   ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

 97 W51
        LAT=  36° 04' 04.420702" -0.000316"  36° 04' 04.420386"    0.005336m
        LON= 115° 00' 51.825579" +0.001118" 115° 00' 51.824461"    0.004678m
     ELL HT=           476.5771m   -0.0005m           476.5766m    0.012426m
   ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

 98 WD15+07.95
        LAT=  36° 10' 24.511232" -0.000356"  36° 10' 24.510876"    0.003983m
        LON= 115° 08' 32.596565" +0.000966" 115° 08' 32.595598"    0.003075m
     ELL HT=           585.2568m   +0.0013m           585.2581m    0.008012m
   ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

 99 X314
        LAT=  36° 21' 11.786550" -0.000146"  36° 21' 11.786405"    0.004519m
        LON= 115° 18' 31.126512" +0.000511" 115° 18' 31.126001"    0.003802m
     ELL HT=           796.1446m   -0.0010m           796.1435m    0.009586m
   ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

100 Y370
        LAT=  36° 25' 05.927136" -0.000002"  36° 25' 05.927134"    0.002687m
        LON= 115° 25' 13.354981" +0.000073" 115° 25' 13.354908"    0.002007m
     ELL HT=           892.4566m   -0.0001m           892.4566m    0.005432m
   ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN

101 Z398
        LAT=  36° 23' 09.968020" -0.000056"  36° 23' 09.967964"    0.003433m
        LON= 115° 22' 53.820216" +0.000213" 115° 22' 53.820003"    0.002799m
     ELL HT=           868.9023m   -0.0001m           868.9022m    0.006979m
   ORTHO HT=             0.0000m   +0.0000m             0.0000m    NOT KNOWN
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1999 Survey

COORDINATE ADJUSTMENT SUMMARY

Datum = NAD-83
Coordinate System = Geographic
Zone = Global

Network Adjustment Constraints:
2 fixed coordinates in y
2 fixed coordinates in x
2 fixed coordinates in H

POINT	NAME	OLD COORDS	ADJUST	NEW COORDS	1.00σ
1	004				
	LAT=	36° 09' 16.912620"	+0.000000"	36° 09' 16.912620"	FIXED
	LON=	115° 21' 47.198540"	+0.000000"	115° 21' 47.198540"	FIXED
	ELL HT=	962.4200m	+0.0000m	962.4200m	FIXED
	ORTHO HT=	0.0000m	+0.0000m	0.0000m	NOT KNOWN
2	009				
	LAT=	36° 24' 53.335680"	+0.000000"	36° 24' 53.335680"	FIXED
	LON=	115° 27' 05.663360"	+0.000000"	115° 27' 05.663360"	FIXED
	ELL HT=	1040.3800m	+0.0000m	1040.3800m	FIXED
	ORTHO HT=	0.0000m	+0.0000m	0.0000m	NOT KNOWN
3	114				
	LAT=	36° 15' 41.031916"	+0.000000"	36° 15' 41.031916"	0.003821m
	LON=	115° 09' 23.616763"	+0.000000"	115° 09' 23.616763"	0.003614m
	ELL HT=	612.1740m	+0.0000m	612.1740m	0.007491m
	ORTHO HT=	0.0000m	+0.0000m	0.0000m	NOT KNOWN
4	139				
	LAT=	36° 12' 36.747569"	+0.000000"	36° 12' 36.747569"	0.003557m
	LON=	115° 11' 54.424426"	+0.000000"	115° 11' 54.424426"	0.003008m
	ELL HT=	639.7556m	+0.0000m	639.7556m	0.006802m
	ORTHO HT=	0.0000m	+0.0000m	0.0000m	NOT KNOWN
5	143				
	LAT=	36° 15' 04.239543"	+0.000000"	36° 15' 04.239543"	0.003540m
	LON=	115° 14' 33.395548"	+0.000000"	115° 14' 33.395548"	0.003172m
	ELL HT=	680.0739m	+0.0000m	680.0739m	0.007921m
	ORTHO HT=	0.0000m	+0.0000m	0.0000m	NOT KNOWN
6	144				
	LAT=	36° 15' 39.314500"	+0.000000"	36° 15' 39.314500"	0.003793m
	LON=	115° 13' 30.910508"	+0.000000"	115° 13' 30.910508"	0.003304m
	ELL HT=	672.4793m	+0.0000m	672.4793m	0.007736m
	ORTHO HT=	0.0000m	+0.0000m	0.0000m	NOT KNOWN
7	145				
	LAT=	36° 15' 41.097205"	+0.000000"	36° 15' 41.097205"	0.003472m
	LON=	115° 12' 26.579261"	+0.000000"	115° 12' 26.579261"	0.003149m
	ELL HT=	653.4114m	+0.0000m	653.4114m	0.006873m
	ORTHO HT=	0.0000m	+0.0000m	0.0000m	NOT KNOWN
8	146				
	LAT=	36° 15' 41.411300"	+0.000000"	36° 15' 41.411300"	0.003753m
	LON=	115° 11' 20.344498"	+0.000000"	115° 11' 20.344498"	0.003299m
	ELL HT=	636.9105m	+0.0000m	636.9105m	0.007124m

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 ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

 9 149
       LAT=  36° 15' 41.580702" +0.000000"  36° 15' 41.580702"    0.004643m
       LON= 115° 07' 01.394050" +0.000000" 115° 07' 01.394050"    0.004273m
    ELL HT=           579.9263m   +0.0000m            579.9263m    0.008848m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

10 166
       LAT=  36° 14' 47.535960" +0.000000"  36° 14' 47.535960"    0.003901m
       LON= 115° 13' 15.428226" +0.000000" 115° 13' 15.428226"    0.003523m
    ELL HT=           660.6744m   +0.0000m            660.6744m    0.008167m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

11 168
       LAT=  36° 15' 51.901611" +0.000000"  36° 15' 51.901611"    0.002231m
       LON= 115° 19' 59.031253" +0.000000" 115° 19' 59.031253"    0.001753m
    ELL HT=           864.4109m   +0.0000m            864.4109m    0.004849m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN

12 LVVWD continuous station
       LAT=  36° 09' 34.026062" +0.000000"  36° 09' 34.026062"    0.003412m
       LON= 115° 11' 28.794287" +0.000000" 115° 11' 28.794287"    0.002971m
    ELL HT=           632.4812m   +0.0000m            632.4812m    0.006280m
  ORTHO HT=              0.0000m   +0.0000m              0.0000m    NOT KNOWN
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