The Yolo County GPS Subsidence Network

Recommendations and Continued Monitoring

(Photo: Station LIBRARY, in Woodland)

Submitted by:

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Executive Summary

From July through September, 2005 the third set of observations of the Yolo County GPS Subsidence Network were obtained. This marks the third time the Yolo network has been observed. The original observations were obtained in 1999. The second observation of the network was obtained in 2002. In 2002 the network was expanded to include stations south of the Highway 80 corridor. Also, the City of Sacramento added several stations to the network for the 2002 observations. In the 2005 project a few new stations were added to the network.

The results of the 2005 observations validate the findings of the 2002 results. The results show continuing subsidence in the Davis to Zamora corridor. The 2005 observations also provide an opportunity to take a more in-depth look at the underlying assumptions of subsidence based on the issue of what is believed to be stability. The project incorporates a few continuously operating GPS sites. These sites provide a continuous record of ground movements, both horizontal and vertical. It is in light of these data that we may now be able to refine some of our assumptions about stability against which subsidence is measured.

The 2005 project included the addition of one station (RWF1) that is part of the Davis Deep Aquifer study, and one station (RD2068) that was established for Reclamation District 2068 in Solano County. Both were established in 2004. Including RD2068 entailed adding two additional stations (SURVEYOR and MILLAR) in order to meet the network geometry specification. These two stations were part of earlier subsidence network observations in the Sacramento/San Joaquin River Delta.

Station ellipsoid heights for the 1999, 2002 and 2005 projects, as developed by CSRC, are included in **Appendix A**.

The provisional results of the elevations (orthometric heights) for the 2005 project are included in **Appendix B.** Also included in this appendix are the values obtained from the earlier 1999 and 2002 projects along with the inter-survey subsidence values.

A map of the project showing the local network stations, cumulative subsidence contours and water source information, may be found in **Appendix C**.

The hypothetical results of continued subsidence at rates seen to date is shown for selected stations in **Appendix F**.

The report of the 1999 survey (The Yolo County Subsidence Network: Recommendations for Future Recommendations, Frame and D'Onofrio, 1999) included a series of ten recommendations. The 2002 report (The Yolo County GPS Subsidence Network: Recommendations and Continued Monitoring, Frame and D'Onofrio, 2003) added an additional two recommendations. All of these recommendations are further discussed in Section IV of this report.

I. INTRODUCTION

This report outlines the results of the 2005 Yolo County GPS Subsidence Project. It also includes comparisons with the earlier 1999 and 2002 projects. Each of the recommendations in the 1999 and 2002 reports are addressed with updated comments. This report also includes a discussion of the subsidence findings with respect to a more thorough review of the relationship of subsidence areas to neighboring stable areas and/or subsiding areas with continuous records of earth movement.

As with the earlier 1999 and 2002 projects, the 2005 project was accomplished with cooperation from several agencies. Observation personnel were provided by the California Department of Water Resources, the cities of Woodland and Davis, the US Bureau of Reclamation, the Yolo County Planning, Resources & Public Works Department, and Frame Surveying & Mapping. GPS equipment was supplied by the University of California Davis, the US Bureau of Reclamation, and Frame Surveying & Mapping.

II. BACKGROUND

The 2005 GPS subsidence survey is the third in the series of observations. These observations have been conducted at three year intervals, the previous observations being in 1999 and 2002. The greatest portion of the GPS network has been the same. Several new stations were added in 2002 and four additional stations were added in the 2005 survey.

The results of the 2005 survey indicate that subsidence trends throughout much of the county are continuing. The largest amount of subsidence occurs in the Zamora area, especially near the Zamora extensometer (station ZAMX) which has subsided a total of about 12 to 15 centimeters (roughly 6 inches) over the six years of the project. A map of the subsidence contours based upon the CSRC ellipsoid height analysis is provided in **Appendix C.**

It should be noted that only a very few stations in the network showed no subsidence. It should also be noted that the accuracy of the subsidence values is +/- 2 centimeters.

III. PROJECT ISSUES

All stations observed in the 2002 project were recovered in good condition. There were four additional stations added to the network. One of the stations is part of the Davis Deep Aquifer Study (station RWF1), and one was established in 2004 for Reclamation District 2068 (station RD2068). Station RD2068 is in Solano County. Two additional stations in Solano County (SURVEYOR and MILLAR) were added to allow for a more complete relationship with RD2068. The two additional Solano County stations were part of earlier GPS subsidence projects. Station RWF1 is inside Yolo County and required no additional station observations.

The City of Sacramento stations included in the 2002 survey were not observed in 2005.

There were a greater percentage of re-observations required for this project than for previous projects. All baselines (those inter-station lines indicated on the project map – see **Appendix D**) are observed at least twice. Baseline comparisons must agree within 2 centimeters. In the 2005 project over 15 percent of the baselines did not meet this criterion. All were re-observed and all ultimately met the 2 centimeter criterion.

All other activities associated with the 2005 project were routine.

Provisional coordinates (latitude, longitude and elevations) are included in **Appendix E.**

IV. RECOMMENDATIONS AND COMMENTS

After the 1999 project was completed a series of ten recommendations was made. After the 2002 project an additional two recommendations were made. We will include two additional recommendations in **Section V. NEW RECOMMENDATIONS.**

A summary of the recommendations is immediately below, followed by more detailed information.

Summary of Recommendations

Recommendation	Year	Status
1. Inform the public & make data easily available	1999 2002 2005	Implemented for 1999 & 2002; in process for 2005.
2. Annual field review of network station condition	1999 2002 2005	Not formally implemented.
3. Pre-emptive replacement of endangered station marks	1999 2002 2005	Untested.
4. Re-observe network every 3 years	1999 2002 2005	Implemented.
5. Consider more frequent observations	1999 2002	Discontinued due to lack of demand.
6. Network densification	1999 2002 2005	Limited implementation near Davis.
7. Non-financial support for continued operation of UCD1	1999 2002 2005	Not formally implemented.
8. Establish a new CORS in the north county	1999 2002	Obsolete.
9. Encourage FEMA to adopt network results	1999 2002 2005	Not formally implemented. Early attempt to involve FEMA met no response.
10. Investigate supplemental detection technologies	1999 2002 2005	Not implemented due to lack of demand.
11. Incorporate extensometer data	2002 2005	Implemented.
12. Extend network into Solano County near Davis	2002 2005	Limited implementation in 2005.
13. Review technical approach to data analysis	2005	In process.
14. Document subsidence effects	2005	New.

Recommendation 1. Inform public and private agencies involved in construction, utilities management, public works and related activities in the county about the network and the location of all stations. Information about the project's web site should be included in this information. (Note: As of the date of this report, the website – http://www.yarn.org/subsidence/about.html – not has not been updated. The update is pending final publication of station positions by NGS.)

As noted in the report after the 2002 observations there continues to be anecdotal information about the utility of the network, especially among the surveying community. Survey painting and flagging indicate that the network stations are being used. The County Surveyor reports that many of the stations are used and reported in Records of Survey submitted to him.

Recommendation 2. Task a single entity with visiting each monument in the network annually to assess the integrity of the individual monuments. Any discrepancies in the monument description and condition should be brought to the attention of the interested parties and to the National Geodetic Survey (NGS). Follow proper steps for reporting such discrepancies.

It continues to appear that no agency has accepted this responsibility. It might appear that this is unnecessary since all stations used in the 2005 survey were recovered in good condition. As the network ages experience indicates that some stations may be destroyed due to construction or other activities. It becomes more imperative that this recommendation be followed. In the absence of an agency accepting this responsibility a private entity should be considered to undertake this responsibility on a contractual basis.

Recommendation 3. Identify stations in imminent danger of destruction and replace them in advance, following National Geodetic Survey guidelines. (A copy of these guidelines may be obtained from the NGS California State Geodetic Advisor, Marti Ikehara – Marti.Ikehara@noaa.gov). A station destroyed before replacement represents a permanent break in the subsidence history for that station.

As indicated in Recommendation 2, above, the absence of occasional visits to each of the stations increases the possibility of stations being lost. While there is no difference in the cost of replacing a monument either before or after it is destroyed, replacing it after it has been destroyed breaks the subsidence history of the mark.

Recommendation 4. Re-observe the entire network in three years. Depending on the results of the re-observation, the county can better determine the time period for subsequent re-observations.

It appears that the decision to re-observe the network on a three-year cycle is acceptable to project participants. A review of the latest three-year cycle (2005 – 2002) indicates a slightly larger amount of subsidence at several of the stations than that observed in the first three year cycle (2002 – 1999). The next three year cycle should provide a more definitive overview of subsidence effects. The fact that subsidence rates over one cycle differ from those of another cycle provide additional information about the nature of subsidence. Because subsidence is a result of several factors (e.g., aquifer re-charge, amount of pumping, etc.) it tends to be a non-linear phenomenon.

Recommendation 5. Investigate the benefits of more frequent re-observation of particular areas of the county.

Based on the results of the 2005 survey and its comparison with the 1999 and 2002 surveys it does not appear that more frequent observations of the network will add significantly more reliable information than is provided under the current 3-year observation cycle.

Recommendation 6. Investigate densification of the network in areas of particular interest.

The approach made for this recommendation after the 2002 survey still seems valid. If an area of the county is deemed to need a more densified approach this can be accomplished by either GPS or a combination of GPS and terrestrial observations. In the areas of greatest subsidence this might be worthwhile. This assumes that there is a need for such densified observations. Planned construction in these areas might necessitate that this option be considered.

Recommendation 7. Provide continuing non-financial support for the Continuously Operating Reference Station (CORS) at the University of California, Davis. This site can be of significant value in ongoing subsidence measurement operations.

The CORS site at UC3D provides the only continuous record of land movement in the area. The following figure shows the downward (subsiding) trend of the site as well as the seasonal trends of the site. This seasonal trend seems to be symbolic of sites in subsiding areas. Efforts should be made to ensure continuous operation of the site. As long as it continues in operation it will continue to provide a piece of the framework for continued, accurate monitoring of subsidence in the county.

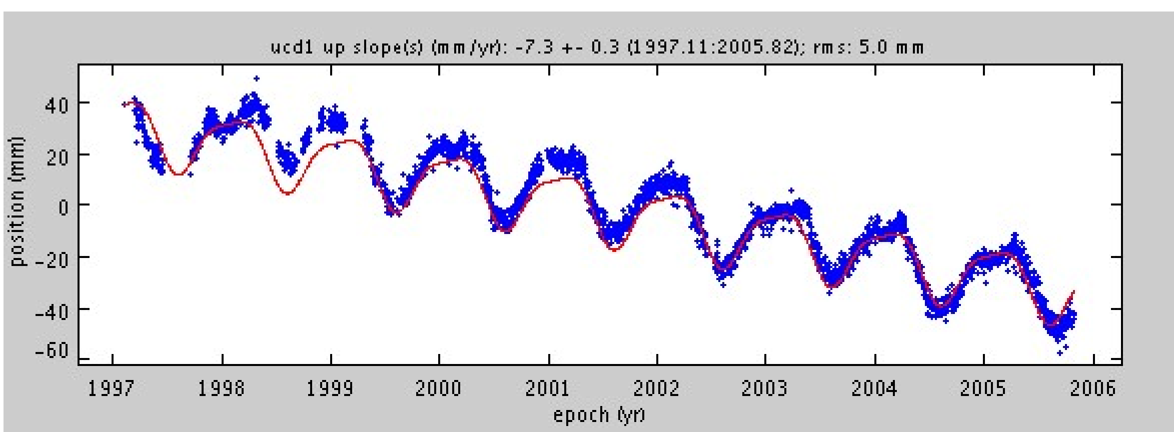

Fig. 1. UCD CORS site vertical record, 1997 through 2005.

Recommendation 8. Investigate the establishment of a CORS site in the north county area.

This recommendation was made prior to the establishment of the Plate Boundary Observatory (PBO) program. The PBO program includes the establishment of over 400 continuous GPS sites in California. Four of these have been established in the vicinity of Yolo County: three in the county (near Woodland, Dixon and Winters), and one to the north in Colusa County (near the city of Colusa). These should help with long term measurements of earth movement and obviate the need for a station in northern Yolo County. This recommendation will be removed from future reports unless there is a need to re-consider the need for a station in that vicinity.

There is an additional continuous tracking GPS site in the Sutter Buttes. This station has been part of the three Yolo County surveys.

Recommendation 9. Consider the merits of encouraging the Federal Emergency Management Agency (FEMA) to adopt the results of the project in its flood plain mapping efforts.

The county should consider following up on this recommendation with FEMA. Since accepting the results of the 1999 survey it appears that FEMA would be receptive to such a request. The 2002 City of Woodland Flood Insurance Rate Maps (FIRMs) were developed using vertical control from the 1999 Yolo project. These FIRMS indicate flood contours in both the NGVD29 and NAVD88 datums.

Recommendation 10. Investigate other supporting technologies as an adjunct to the GPS Subsidence Network within Yolo County.

The 2002 report suggested considering the use of either LIDAR or Synthetic Aperture Radar (SAR) technology which could provide more densified coverage of the project area. Because the accuracy of LIDAR technology is currently less than what is required for Yolo County subsidence monitoring, its application is not recommended at this time.

In the absence of any apparent interest in more densified measure of subsidence, the use of SAR is similarly not recommended at this time. SAR technology offers a potentially better alternative to LIDAR. However, the use of SAR continues to be somewhat more problematic in agricultural areas.

Recommendation 11. Incorporate measurements to relate the two DWR extensometers (at Zamora and Conaway ranch) to the Yolo County Subsidence network.

In July of 2005 DWR personnel took measurements relating both the Conaway and Zamora extensometers to their respective adjacent network station marks (CONAWAY and ZAMX). Continued annual measurements of this nature will simplify tracking the relationship between movement indicated by the extensometers and that indicated by the GPS measurements.

In the 2002 survey, a discrepancy was noted between the amount of subsidence indicated by the GPS results and that indicated by the Stevens chart recorders mounted on the extensometers. This trend – which is attributed to the fact that the extensometers only reflect subsidence in the upper region of the ground (716 feet at Conaway, 1003 feet at Zamora) – continues. See **Appendix H** for details.

Recommendation 12. Seek cooperation with the County of Solano to determine the magnitude and extent of the subsidence in the vicinity of Davis.

The addition of station RD2068 of the Davis Deep Aquifer project and two of its neighboring stations (SURVEYOR and MILLAR) in Solano will help resolve this issue. The inclusion of up to three additional stations in Solano County that were part of the San Joaquin/Sacramento Delta project would provide the necessary observations to complete this recommendation. In the absence of working with Solano County these stations could be added into the base Yolo project. The candidate stations are CURREY (PID AE9856), STORE (PID AE9852) and X 128 RESET (PID JS1613).

V. ADDITIONAL RECOMMENDATIONS

There are now five continuous GPS sites in or near the county. Two of these stations, at UC Davis and Sutter Buttes, have been in continuous operation since 1997. They provide the potential to form a better basis for measuring and monitoring subsidence in the county. These stations are on a more or less north-south axis so might not account for an east-west bias, if any, in the GPS observations. The three additional PBO sites, especially the two in Woodland and Winters, should help resolve this issue. These stations (and the Dixon station) have not been operational long enough to provide any useful data for the current survey but should prove more beneficial in future surveys.

Recommendation 13. Given the longer continuous time series now available at the Sutter Buttes and UC Davis sites, and the apparent subsidence at sites previously believed to be stable, we recommend that the 2005 data be reviewed more thoroughly.

When the Yolo project was initiated in 1999, the survey results were constrained to ellipsoid height values based upon the best information available from NGS. At the time, relatively little work had been done to comprehensively analyze the data being accumulated at northern California continuous GPS monitoring sites.

For the 2005 project, CSRC reanalyzed the data from the 1999, 2002 and 2005 surveys with regard to ellipsoid heights. This analysis was informed by the analysis of data gathered continuously over the 1999-2005 period at the Sutter Buttes and UC Davis permanent GPS stations. Although some discrepancies between the CSRC and NGS values remain, the relative ellipsoid heights derived from the CSRC analysis are considered to be the most reliable indicator of cumulative subsidence at this time. The subsidence contour map (Appendix B) reflects this analysis.

The most significant discrepancies between the NGS and CSRC analyses are found toward the periphery of the county. The magnitude of the discrepancies range from 2cm to 9cm. It is important to note that both analyses show the same areas of concentrated subsidence, in particular the area centered on station ZAMX.

Once the NGS and CSRC height values are reconciled, updated values for the project station positions will be incorporated into the NGS database.

Recommendation 14. Establish a coordinated interagency approach to the identification and documentation of subsidence effects. This would require agencies to gather supplemental data that demonstrates the impact of subsidence upon facilities and operations. Photographs and descriptions of observed impacts (e.g., raised well pads and crushed well casings) will assist in rounding out the understanding of subsidence impacts among the project partners, non-technical officials and the general public. (See **Appendix G** for example photographs.)

VI. CONCLUSION

With the completion of the 2005 project observations, a clearer picture of ongoing subsidence begins to emerge. The 2002 survey indicated subsidence, but the time frame between the 1999 and 2002 surveys was too short to allow definitive measures of subsidence given the myriad potential causes. The 2005 survey results, when compared with the earlier surveys, provide definitive proof of such subsidence. It begins to give a clearer picture of the amount and distribution of subsidence across the project area. As indicated in the 2002 report, the central corridor of the project is undergoing the greatest subsidence. The corridor runs north from Davis, through Woodland, north to Zamora and through to the northeast corner of the county. It is generally characterized as having little or no surface water availability and substantial groundwater pumping. The subsidence does not appear to be strictly uniform – a common characteristic of the phenomenon – but rather the result of several factors. For this reason it is recommended that continued re-observations of the network be planned on a 3-year cycle. It is recommended that other studies of ground water pumping, water usage and related issues be studied as well.

Please note that the horizontal coordinates (latitude and longitude) have changed again for all stations in the network. The county is in the area of the North American and Pacific tectonic plate boundary. This tectonic motion causes all stations in the project move northwesterly a few centimeters per year.

Respectfully submitted:

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APPENDIX A.

CSRC NAD83 Ellipsoid Height Values
from 1999, 2002 and 2005 Surveys (with differences)

4-CH ID	1999	2002	Change	2005	Change	Change
			02-99		05-02	05-99
0308	-6.842	-6.880	-0.038	-6.910	-0.030	-0.068
03BG		-21.122		-21.120		0.002
03DG	-6.730	-6.759	-0.029	-6.762	-0.003	-0.032
03EH	-19.335	-19.347	-0.012	-19.339	0.008	-0.004
1031	-20.402	-20.401	0.001	-20.418	-0.017	-0.016
1069	23.627	23.646	-0.019	23.630	-0.016	0.003
1075	-15.424	-15.424	0.000	-15.425	-0.001	-0.001
1200	47.507	47.483	-0.024	47.494	0.011	-0.013
1699	21.812	21.833	0.021	21.829	-0.004	0.017
2068				-19.213		
ABUT	22.034	22.033	-0.001	22.034	0.001	0.000
ALHA	-18.089	-18.106	-0.017	-18.127	-0.011	-0.038
ANDR		-27.837		-27.845	-0.008	
B849	8.482	8.459	-0.023	8.482	0.023	0.000
BIRD	63.747	63.773	0.026	63.780	0.007	0.033
BRID	33.505	33.527	0.022	33.510	-0.017	0.005
CALD		-25.915		-25.904	0.011	
CANA	-1.250	-1.235	0.015	-1.246	-0.011	0.004
CAST	-25.680	-25.690	-0.010	-25.680	0.010	0.000
CHUR	-6.689	-6.675	0.014	-6.694	-0.019	-0.005
CODY	-17.502	-17.551	-0.049	-17.586	-0.035	-0.084
CONA	-23.079	-23.091	-0.012	-23.088	0.003	-0.009
COTT	60.663	60.711	0.048	60.710	-0.001	0.047
COUR		-23.354		-23.358	-0.004	
COY1	-22.381	-22.383	-0.002	-22.400	-0.017	-0.019
CVAP	-22.180	-22.187	-0.007	-22.217	-0.030	-0.037
DAVE	-11.868	-11.872	-0.004	-11.876	-0.004	-0.008
DRAI	-17.049	-17.053	-0.004	-17.050	0.003	-0.001
DUFO	-10.193	-10.232	-0.039	-10.284	-0.052	-0.091
EX11	-22.835	-22.865	-0.030	-22.863	0.002	-0.028
F859	-16.022	-16.028	-0.006	-16.066	-0.038	-0.044
FERR	-18.509	-18.498	0.011	-18.510	-0.012	-0.001
FORD	-12.948	-12.953	-0.005	-12.989	-0.036	-0.041
FREM	-17.820	-17.782	0.038	-17.798	-0.016	0.022
GAFF		-30.304		-30.294	0.010	
GW17	54.278	54.292	0.014	54.302	0.010	0.024
GW32	82.143	82.169	0.026	82.140	-0.029	-0.003
HERS	-16.223	-16.210	0.013	-16.205	0.005	0.018
JIME	-17.587	-17.586	0.001	-17.586	0.000	0.001
KEAT	5.083	5.112	0.029	5.093	-0.019	0.010
LIBR	-10.801	-10.810	-0.009	-10.824	-0.014	-0.023
MADI	16.177	16.170	-0.007	16.196	0.026	0.019
MILL				-20.869		
PLAI	-11.133	-11.142	-0.009	-11.124	0.020	0.011

RIVE	-18.667	-18.673	-0.006	-18.678	-0.005	-0.011
RUSS	-1.918	-1.899	0.019	-1.916	-0.017	0.002
RWF1				-16.414		
SM15	-23.150	-23.128	0.022	-23.161	-0.033	-0.011
SURV				-18.080		
SUTB	617.087	617.078	-0.009	617.070	-0.008	-0.017
SYCA	-22.449	-22.426	0.023	-22.435	-0.009	0.014
T462		-21.893		-21.889	0.004	
T849	5.687	5.702	0.015	5.684	-0.018	-0.003
TYND	-20.949	-20.936	0.013	-20.965	-0.029	-0.016
UCD1	0.197	0.190	-0.007	0.171	-0.019	-0.026
VINC	17.812	17.828	0.016	17.800	-0.028	-0.012
WILS		-21.685		-21.700	-0.015	
WOOD	8.873	8.892	0.019	8.841	-0.051	-0.032
X200	-0.315	-0.309	0.006	-0.310	-0.001	0.005
YCAP		-1.558		-1.566	-0.008	
Z585	-24.492	-24.521	-0.029	-24.520	0.001	-0.028
ZAMX	-17.289	-17.357	-0.068	-17.411	-0.054	-0.122

Notes:

1. All height values are expressed in meters.

2. The 1999 height value shown for station VINCOR was calculated from the 1999 height value for station PHILLIPS (not shown). PHILLIPS was rendered unsuitable for GPS observations prior to the 2002 monitoring event. VINCOR was installed nearby, and a leveling tie made to transfer the 1999 elevation from PHILLIPS to VINCOR.

APPENDIX B.

FSM Provisional NAVD88 Orthometric Height Values from 1999, 2002 and 2005 Surveys (with differences)

4-CH ID	1999	2002	Change 02-99	2005	Change 05-02	Change 05-99
0308	23.78	23.73	-0.05	23.67	-0.06	-0.11
03BG	9.91	9.91	0.00	9.91	0.00	0.00
03DG	24.13	24.09	-0.04	24.05	-0.04	-0.08
03EH	10.75	10.73	-0.02	10.74	0.01	-0.01
1031	10.26	10.26	0.00	10.23	-0.03	-0.03
1069	54.73	54.71	-0.02	54.68	-0.03	-0.05
1075	14.90	14.87	-0.03	14.85	-0.02	-0.05
1200	77.38	77.38	0.00	77.38	0.00	0.00
1699	52.52	52.50	-0.02	52.46	-0.04	-0.06
2068				12.42		
ABUT	53.03	53.01	-0.02	52.97	-0.04	-0.06
ALHA	12.99	12.97	-0.02	12.95	-0.02	-0.04
ANDR	3.68	3.68	0.00	3.70	0.02	-0.02
B849	39.68	39.68	0.00	39.69	0.01	-0.01
BIRD	94.13	94.11	-0.02	94.08	-0.03	-0.05
BRID	64.21	64.20	-0.01	64.15	-0.05	-0.06
CALD	5.42	5.42	0.00	5.43	0.01	0.01
CANA	29.80	29.79	-0.01	29.77	-0.02	-0.03
CAST	5.27	5.27	0.00	5.28	0.01	-0.01
CHUR	24.13	24.12	-0.01	24.09	-0.03	-0.04
CODY	12.80	12.75	-0.05	12.68	-0.07	-0.12
CONA	7.72	7.71	-0.01	7.68	-0.03	-0.04
COTT	91.51	91.52	0.01	91.49	-0.03	-0.02
COUR	8.06	8.06	0.00	8.06	0.00	0.00
COY1	8.56	8.55	-0.01	8.52	-0.03	-0.04
CVAP	8.05	8.01	-0.04	7.96	-0.05	-0.09
DAVE	19.44	19.39	-0.05	19.39	0.00	-0.05
DRAI	12.99	12.97	-0.02	12.93	-0.04	-0.06
DUFO	20.31	20.25	-0.06	20.18	-0.07	-0.13
EX11	7.88	7.86	-0.02	7.85	-0.01	-0.03
F859	14.23	14.21	-0.02	14.16	-0.05	-0.07
FERR	12.12	12.13	0.01	12.10	-0.03	-0.02
FORD	17.55	17.53	-0.02	17.49	-0.04	-0.06
FREM	12.54	12.56	0.02	12.54	-0.02	0.00
GAFF	0.99	1.00	0.01	1.02	0.02	0.03
GW17	84.85	84.79	-0.06	84.77	-0.02	-0.08
GW32	112.58	112.58	0.00	112.50	-0.08	-0.08
HERS	13.99	13.97	-0.02	13.94	-0.03	-0.05
JIME	12.30	12.30	0.00	12.25	-0.05	-0.05
KEAT	35.84	35.83	-0.01	35.78	-0.05	-0.06
LIBR	19.93	19.90	-0.03	19.86	-0.04	-0.07
MADI	47.03	47.00	-0.03	46.98	-0.02	-0.05
MILL				10.88		
PLAI	19.99	19.96	-0.03	19.96	0.00	-0.03

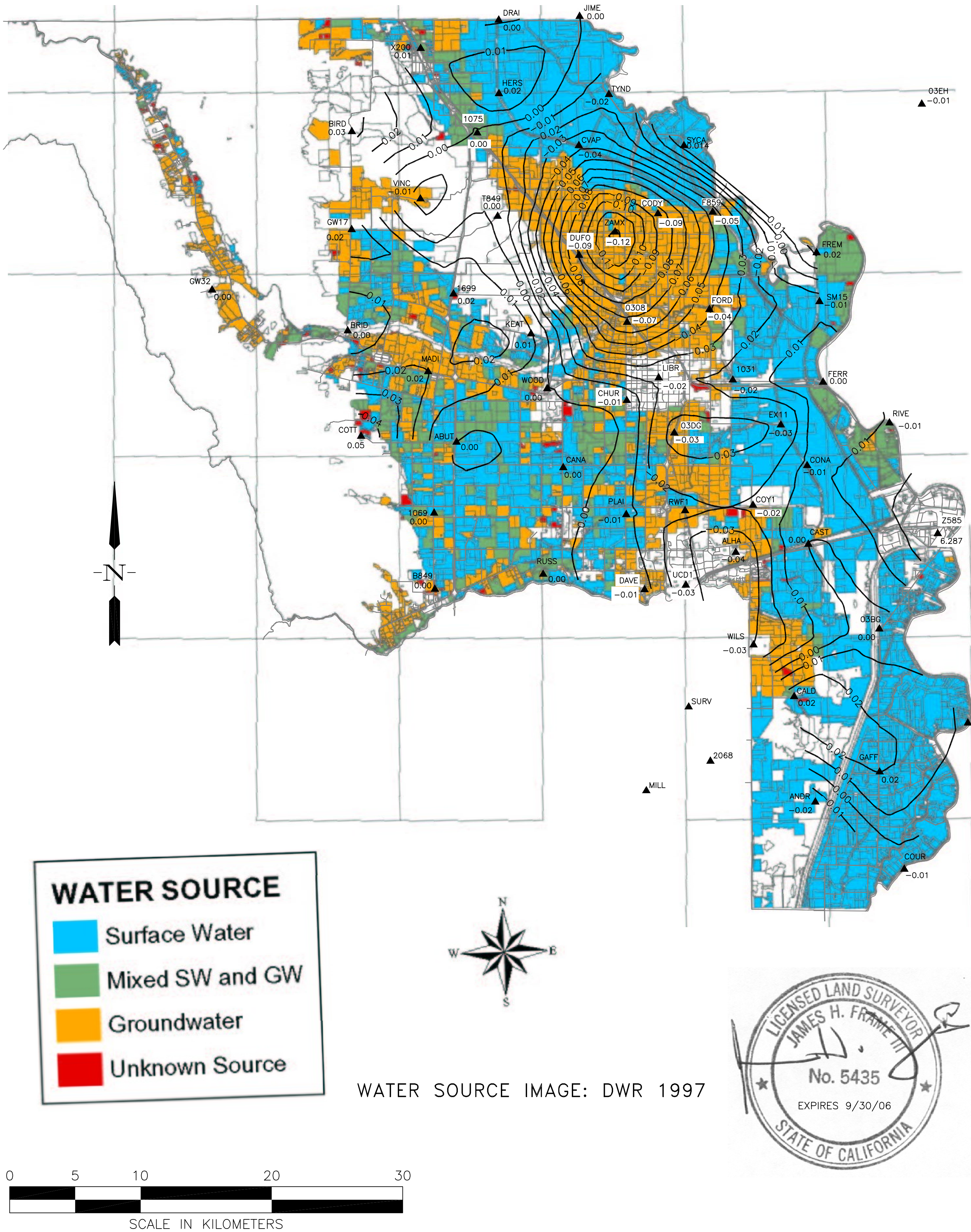
RIVE	12.03	12.02	-0.01	12.01	-0.01	-0.02
RUSS	29.38	29.37	-0.01	29.36	-0.01	-0.02
RWF1				14.60		
SM15	7.30	7.33	0.03	7.27	-0.06	-0.03
SURV				13.45		
SYCA	7.67	7.66	-0.01	7.65	-0.01	-0.02
T462	9.14	9.14	0.00	9.15	0.01	0.01
T849	36.20	36.17	-0.03	36.12	-0.05	-0.08
TYND	9.10	9.08	-0.02	9.04	-0.04	-0.06
UCD1	31.50	31.44	-0.06	31.42	-0.02	-0.08
VINC	48.32	48.28	-0.04	48.24	-0.04	-0.08
WILS	9.61	9.60	-0.01	9.59	-0.01	-0.02
WOOD	39.75	39.74	-0.01	39.70	-0.04	-0.05
X200	29.91	29.88	-0.03	29.85	-0.03	-0.06
YCAP		29.61		29.61	0.00	
Z585	6.35	6.30	-0.05	6.29	-0.01	-0.06
ZAMX	13.10	13.03	-0.07	12.95	-0.08	-0.15

Notes:

1. All height values are expressed in meters.

2. The 1999 height value shown for station VINCOR was calculated from the 1999 height value for station PHILLIPS (not shown). PHILLIPS was rendered unsuitable for GPS observations prior to the 2002 monitoring event. VINCOR was installed nearby, and a leveling tie made to transfer the 1999 elevation from PHILLIPS to VINCOR.

3. The orthometric values shown for 2005 may change following reconciliation between NGS and CSRC methodology.



LICENSED LAND SURVEYOR
JAMES H. FRAME III
No. 5435
EXPIRES 9/30/06
STATE OF CALIFORNIA

FRAME SURVEYING & MAPPING
609 A Street Davis, CA 95616
(530) 756-8584 (TEL) (530) 756-8201 (FAX)

1280-039D

APPENDIX C

CUMULATIVE SUBSIDENCE, 1999 - 2005
SOURCE: CSRC ELLIPSOID HEIGHT DATA
FEBRUARY, 2006 SCALE: 1"= 10KM

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APPENDIX D

YOLO SUBSIDENCE NETWORK

LOCAL NETWORK DIAGRAM

FEBRUARY, 2006 SCALE: 1"= 10KM

APPENDIX E.

NAD83/NAVD88 Station Coordinates

From the provisional NAD83/NAVD88 orthometric height adjustment performed by Frame Surveying & Mapping, epoch 2005.53.

Name	Latitude	Longitude	Elevation
0308	38°43'01.99912"N	121°48'07.54199"W	23.67m
1031	38°40'38.14545"N	121°42'34.07851"W	10.23m
1069	38°35'09.99988"N	121°58'17.45682"W	54.68m
1075	38°50'51.29614"N	121°56'00.25863"W	14.85m
1200	38°47'09.87441"N	121°14'32.09663"W	77.38m
1699	38°44'12.69655"N	121°57'15.85761"W	52.46m
2068	38°24'54.17942"N	121°43'48.53696"W	12.43m
03BG	38°30'20.00966"N	121°34'55.09259"W	9.91m
03DG	38°38'27.43783"N	121°45'39.59676"W	24.05m
03EH	38°51'59.61326"N	121°32'32.95872"W	10.74m
ABUT	38°38'05.70691"N	121°57'06.70369"W	52.97m
ALHA	38°33'31.09844"N	121°42'26.68932"W	12.95m
ANDR	38°23'12.17822"N	121°38'18.72121"W	3.70m
B849	38°32'01.29164"N	121°58'15.18465"W	39.69m
BIRD	38°50'54.73577"N	122°02'37.47813"W	94.08m
BRID	38°42'41.39602"N	122°02'50.18451"W	64.15m
CALD	38°27'33.51381"N	121°39'24.21525"W	5.44m
CANA	38°37'02.05496"N	121°51'30.11681"W	29.77m
CAST	38°33'50.77672"N	121°38'37.80451"W	5.28m
CHUR	38°39'48.00606"N	121°48'09.05896"W	24.09m
CNDR	37°53'47.04470"N	121°16'42.53232"W	11.68m
CODY	38°47'30.59822"N	121°46'29.02105"W	12.68m
CONA	38°37'05.49521"N	121°38'40.42972"W	7.68m
COTT	38°38'20.24510"N	122°02'08.12319"W	91.49m
COUR	38°20'24.76030"N	121°33'40.05187"W	8.06m
COY1	38°35'28.05177"N	121°41'31.83561"W	8.52m
CVAP	38°50'19.76454"N	121°50'39.17729"W	7.96m
DAVE	38°31'59.46481"N	121°47'14.17767"W	19.39m
DRAI	38°55'31.04609"N	121°54'52.46304"W	12.93m
DUFO	38°45'48.09680"N	121°50'39.06873"W	20.18m
EX11	38°38'46.40956"N	121°40'03.02645"W	7.85m
F859	38°47'34.20154"N	121°43'36.01819"W	14.16m
FERR	38°40'32.00765"N	121°37'49.18140"W	12.10m
FORD	38°43'33.23620"N	121°43'47.39279"W	17.49m
FREM	38°45'52.89431"N	121°38'08.00645"W	12.54m
GAFF	38°24'25.68547"N	121°34'56.13691"W	1.02m
GW17	38°46'52.25893"N	122°02'38.10825"W	84.78m
GW32	38°44'21.97173"N	122°09'59.02874"W	112.50m
HERS	38°52'28.84831"N	121°54'51.96597"W	13.94m
JIME	38°55'39.86256"N	121°50'35.87572"W	12.25m
KEAT	38°42'33.52335"N	121°53'11.08379"W	35.78m
LIBR	38°40'44.18520"N	121°46'28.10144"W	19.86m
MADI	38°41'00.22860"N	121°58'36.36143"W	46.98m
MILL	38°23'41.28013"N	121°47'10.32967"W	10.88m
P268	38°28'24.67974"N	121°38'47.02602"W	7.94m

P271	38°39'26.44695"N	121°42'52.32465"W	13.10m
PLAI	38°35'05.49797"N	121°48'11.62253"W	19.96m
RIVE	38°38'50.46155"N	121°34'20.06352"W	12.01m
RUSS	38°32'38.06565"N	121°52'33.83899"W	29.37m
RWF1	38°35'09.99921"N	121°45'05.10194"W	14.60m
SM15	38°43'51.60440"N	121°37'59.39294"W	7.27m
SURV	38°27'08.54500"N	121°44'56.17353"W	13.45m
SUTB	39°12'20.99549"N	121°49'14.10261"W	646.08m
SYCA	38°50'19.12405"N	121°45'06.39012"W	7.65m
T462	38°26'25.99278"N	121°30'17.76296"W	9.15m
T849	38°47'24.93361"N	121°54'56.34535"W	36.12m
TYND	38°52'26.17801"N	121°49'03.81267"W	9.04m
UCD1	38°32'10.44819"N	121°45'04.37875"W	31.42m
VINC	38°48'08.11990"N	121°59'00.32287"W	48.24m
WILS	38°29'41.85159"N	121°41'31.51549"W	9.59m
WOOD	38°40'17.76208"N	121°52'20.38185"W	39.70m
X200	38°54'20.73206"N	121°58'59.79260"W	29.85m
YCAP	38°34'20.34492"N	121°51'18.37410"W	29.61m
Z585	38°34'15.79736"N	121°31'49.55629"W	6.29m
ZAMX	38°46'45.78557"N	121°48'44.63079"W	12.95m

APPENDIX F.

Subsidence Projections

Quantitative monitoring of subsidence in Yolo County has been conducted over a relatively short time span, and presently comprises only 3 monitoring events (1999, 2002 and 2005). The monitoring measurement technology and its associated analytical tools continue to evolve, which may necessitate a comprehensive review of prior analyses. Nevertheless, it may be useful to consider the potential long-term effects of land subsidence by projecting the rates of subsidence observed to date.

In the examples below, a range of cumulative subsidence has been projected to the year 2030 at selected stations in Davis (ALHAMBRA), Woodland (LIBRARY) and the area of most rapid subsidence (ZAMX). The ranges are bounded by the more conservative ellipsoid height results returned by CSRC following a readjustment of the 1999 through 2005 data sets, and on the higher end by values derived from the published 1999 and 2002 NGS orthometric heights and the provisional 2005 orthometric heights produced by Frame Surveying & Mapping.

As more data are gathered in future years and the analytical tools refined, these rates will likely change. Caution is advised in applying these projected results to subsidence mitigation planning efforts.

Site	Cumulative Subsidence 1999 to 2030 Low Projection	Cumulative Subsidence 1999 to 2030 High Projection
ALHAMBRA	-0.20	-0.21
LIBRARY	-0.12	-0.36
ZAMX	-0.63	-0.78

Subsidence values are in meters.

APPENDIX G.

Subsidence Impact Evidence

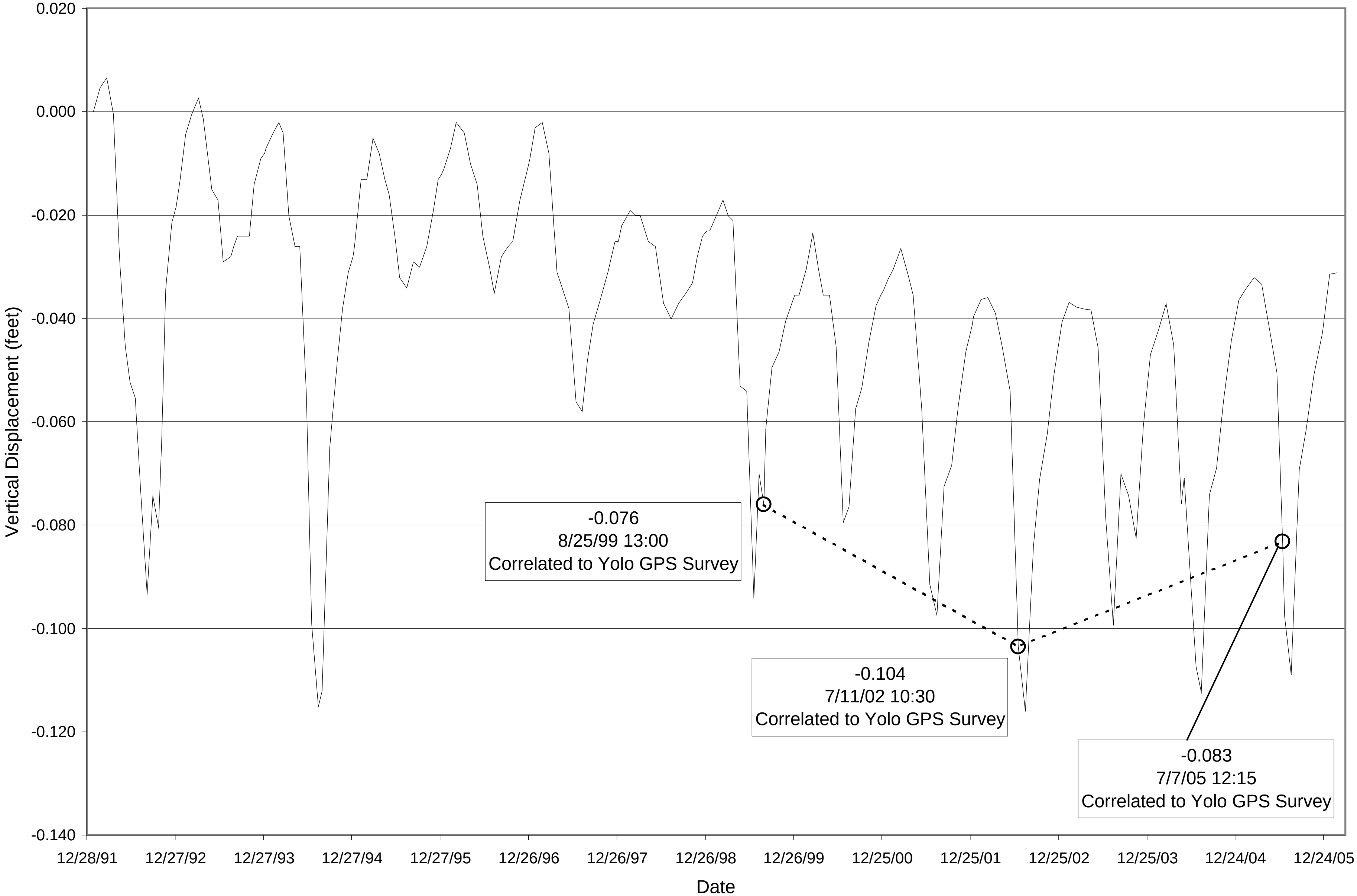
Well pad near Zamora. The pad appears to be fixed to the well casing, while the adjacent ground surface appears to have subsided.

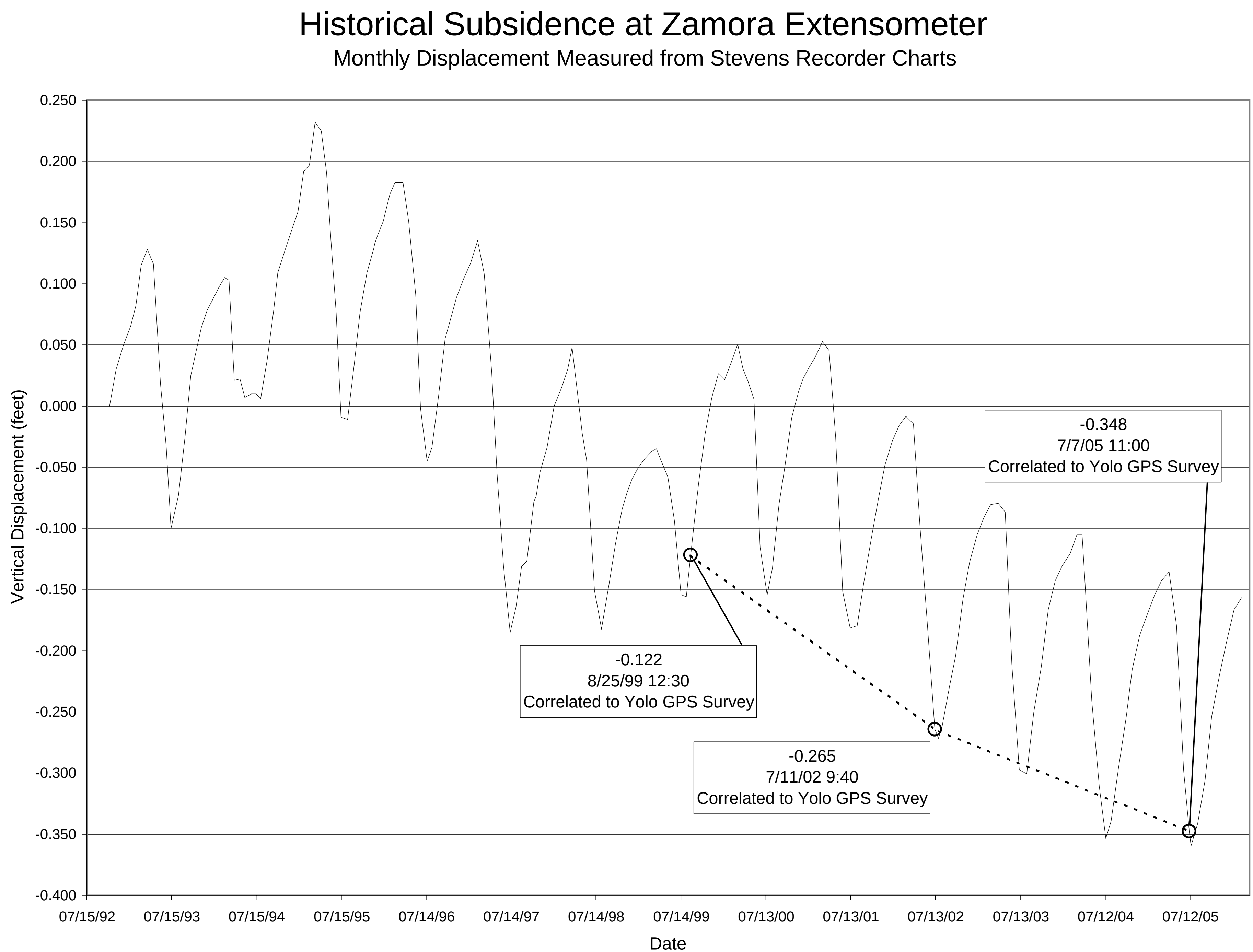
Crushed well screen, Well 22, City of Davis. This is a photo of a monitor displaying a well inspection video. The well screen at 316 feet below the surface appears to have deflected inward in response to downward pressure on the casing above. This might occur when the friction of a subsiding land mass upon a well casing exceeds the compressive strength of the well screen.

APPENDIX H

Historical Subsidence at Conaway Ranch Extensometer

Monthly Displacement Measured from Stevens Recorder Charts




Historical Subsidence at Zamora Extensometer
Monthly Displacement Measured from Stevens Recorder Charts
Vertical Displacement (feet)
0.250
0.200
0.150
0.100
0.050
0.000
-0.050
-0.100
-0.150
-0.200
-0.250
-0.300
-0.350
-0.400
07/15/92
07/15/93
07/15/94
07/15/95
07/14/96
07/14/97
07/14/98
07/14/99
07/13/00
07/13/01
07/13/02
07/13/03
07/12/04
07/12/05
Date
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8/25/99 12:30
Correlated to Yolo GPS Survey
-0.265
7/11/02 9:40
Correlated to Yolo GPS Survey
-0.348
7/7/05 11:00
Correlated to Yolo GPS Survey

Yolo Subsidence Network **GPS/Extensometer Comparisons** **March, 2005**

SITE	SOURCE	YEAR 1999	YEAR 2002	YEAR 2005	NET CHANGE (2005 - 1999)	GPS - EXTENSOMETER (DISCREPANCY)
CONAWAY	GPS	-22.835	-22.865	-22.863	-0.028	
	EXTENSOMETER	-0.023	-0.032	-0.025	-0.002	-0.026
ZAMORA	GPS	-17.289	-17.357	-17.411	-0.122	
	EXTENSOMETER	-0.037	-0.081	-0.106	-0.069	-0.053

GPS SOURCE: 2005 CSRC ELLIPSOID HEIGHTS
EXTENSOMETER SOURCE: DWR
VALUES SHOWN ARE IN METERS