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TECHNICAL MEMORANDUM

DATE: February 26, 2021

Project No.: 941-80-20-22
SENT VIA: EMAIL

TO: Ground-Level Monitoring Committee

FROM: Michael Blazevic, PG, CHG

REVIEWED BY: Andy Malone, PG

SUBJECT: Recommended Scope and Budget of the Ground-Level Monitoring Committee for Fiscal Year 2021/22 (Draft)

BACKGROUND AND PURPOSE

Pursuant to the Optimum Basin Management Program Implementation Plan and the Peace Agreement, the Chino Basin Watermaster (Watermaster) implements a Subsidence Management Plan for the Chino Basin to minimize or stop the occurrence of land subsidence and ground fissuring. The Subsidence Management Plan outlines a program of monitoring, data analysis, and annual reporting. A key element of the Subsidence Management Plan is its adaptive nature—Watermaster can adjust the Subsidence Management Plan as warranted by the data.[1]

The Watermaster Engineer, with the guidance of the Ground-Level Monitoring Committee (GLMC), prepares the annual reports which include the results of the monitoring program, interpretations of the data, recommendations for the Ground-Level Monitoring Program (GLMP) for the following fiscal year (FY), and recommendations for adjustments to the Subsidence Management Plan, if any.

This Technical Memorandum (TM) describes the Watermaster Engineer's recommended activities for the GLMP for FY 2021/22 in the form of a proposed scope of services and budget.

Members of the GLMC are asked to:

- Review this TM prior to March 4, 2021
- Attend a meeting of the GLMC at 9:00 am on March 4, 2021 to discuss the proposed scope-of-work and budget for FY 2021/22
- Submit comments and suggested revisions on the proposed scope of services and budget for FY 2021/22 to the Watermaster by March 19, 2021

[1] The Court approved the Subsidence Management Plan and ordered its implementation in November 2007. The Subsidence Management Plan was updated in 2015, and can be downloaded on their website.

- Attend a meeting of the GLMC at 9:00 am on April 1, 2021 to discuss comments and revisions to the proposed scope of services and budget for FY 2021/22 (if needed)

The final scope of services and budget that is recommended by the GLMC will be included in the Watermaster's FY 2021/22 budget. The final scope of services, budget, and schedule for FY 2021/22 will be included in Section 4 of the *2020/21 Annual Report of the GLMC*.

RECOMMENDED SCOPE OF SERVICES AND BUDGET – FY 2021/22

A proposed scope of services for the GLMP for FY 2021/22 is shown in Table 1 as a line-item cost estimate. The proposed scope of services is summarized below.

Task 1. Setup and Maintenance of the Monitoring Network

The Chino Basin extensometer facilities are key monitoring facilities for the GLMP. They require regular and as-needed maintenance and calibration to remain in good working order and to ensure the recording of accurate measurements.

Task 1.1. Maintain Extensometer Facilities

This subtask includes performing monthly visits to the Ayala Park, Chino Creek, and Pomona extensometer facilities to ensure functionality and calibration of the monitoring equipment and data loggers.

Task 1.2. Annual Lease Fees for CCX Extensometer Site

The County of San Bernardino (County) owns the land the Chino Creek extensometer facility is located on. As such, the Watermaster entered into a lease agreement with the County in 2012 and pays the County and annual rental payment of $1,596.

Task 2. Aquifer-System Monitoring and Testing

This task involves the collection and compilation of hydraulic head and aquifer-system deformation data from the Ayala Park, Chino Creek, and Pomona extensometer facilities.

Task 2.1. Conduct Quarterly Data Collection from Extensometers; Data Checking and Management

This subtask involves the routine quarterly collection and checking of data from the extensometer facilities. Quarterly data collection is necessary to ensure that the monitoring equipment is in good working order and to minimize the risk of losing data because of equipment malfunction. For this sub-task, the complete extensometer records from the Ayala Park, Chino Creek, and Pomona Extensometer Facilities will be loaded to HydroDaVE^{SM} (Hydrologic Database and Visual Explanations) and checked. Both hydraulic head and aquifer-system data from the extensometer facilities will be loaded and checked to HydroDaVE on a quarterly basis.

Table 1. Work Breakdown Structure and Cost Estimates Ground-Level Monitoring Program: FY 2021/22

	Task Description	Notes	Labor (days)		Other Direct Costs						Totals					
			Person Days	Total	Travel	New Equip.	Equip. Rental	Outside Pro	Misc.	Total	Totals by Task	Recommended Budget *FY 2021/22* *a*	Approved Budget *FY 2020/21* *b*	Net Change *FY 2020/21 to 2021/22* *a - b*	Potential Carry-Over *FY 2021/22* *c*	Budget with Carry-Over *FY 2021/22* *a - c*
Task 1. Setup and Maintenance of the Monitoring Network				**$26,214**						**$7,388**	**$33,602**	**$33,602**	**$32,988**	**$614**	**$0**	**$33,602**
1.1	Maintain Extensometer Facilities															
1.1.1	Routine maintenance of Ayala Park, Chino Creek, and Pomona extensometer facilities		14	$19,825	$1,056	$250	$152			$1,458	$21,283	$21,283	$20,818	$465	$0	$21,283
1.1.2	Replacement/repair of equipment at extensometer facilities		4	$6,390	$264	$2,000	$70	$2,000		$4,334	$10,724	$10,724	$10,574	$150	$0	$10,724
1.2	Annual Lease Fees for the Chino Creek extensometer facility		0	$0					$1,596	$1,596	$1,596	$1,596	$1,596	$0	$0	$1,596
Task 2. MZ-1: Aquifer-System Monitoring and Testing				**$30,736**						**$680**	**$31,416**	**$31,416**	**$27,392**	**$4,024**	**$0**	**$31,416**
2.1	Conduct Quarterly Data Collection from Extensometers; Data Checking and Management															
2.1.1	Download data from the Ayala Park Extensometer facility		2	$2,687	$230		$76			$306	$2,993	$2,993	$2,930	$63	$0	$2,993
2.1.2	Download data from the Chino Creek Extensometer facility		2	$2,687	$26					$26	$2,713	$2,713	$2,650	$63	$0	$2,713
2.1.3	Download data from Pomona Extensometer facility		4	$5,374	$272		$76			$348	$5,722	$5,722	$5,596	$126	$0	$5,722
2.1.4	Process, check, and upload data to database		13	$19,988						$0	$19,988	$19,988	$16,216	$3,772	$0	$19,988
2.2	Conduct Pilot Injection Test in the Managed Area		0	$0						$0	$0	$0	$0	$0	$0	$0
2.2.1	Coordinate testing with pumpers		0	$0						$0	$0	$0	$0	$0	$0	$0
2.2.2	Equip CH-15B and CH-17 with high-frequency water-level monitoring devices		0	$0						$0	$0	$0	$0	$0	$0	$0
Task 3. Basin Wide Ground-Level Monitoring Program (InSAR)				**$5,122**						**$85,000**	**$90,122**	**$90,122**	**$114,694**	**-$24,572**	**$0**	**$90,122**
3.1	Acquire TerraSAR-X data and prepare interferograms for 2021/22		1	$1,851				$85,000		$85,000	$86,851	$86,851	$86,808	$43	$0	$86,851
3.2	Check and review InSAR results		2	$3,271						$0	$3,271	$3,271	$3,194	$77	$0	$3,271
3.3	Conduct a pilot study with the new Sentinel-1A satellite		0	$0						$0	$0	$0	$24,692	-$24,692	$0	$0
Task 4. Perform Ground-Level Surveys				**$6,808**						**$192,203**	**$199,011**	**$43,265**	**$51,828**	**-$8,563**	**$0**	**$43,265**
4.1	Conduct Spring-2022 Elevation surveys in Northwest MZ-1		0.5	$926				$25,157		$25,157	$26,083	$26,083	$34,784	-$8,701	$0	$26,083
4.2	Conduct Spring-2022 Elevation Survey in the Northeast Area		0	$0				$47,069		$47,069	$47,069	$0	$0	$0	$0	$0
4.3	Conduct Spring-2022 Elevation Survey in the Southeast Area		0	$0				$49,797		$49,797	$49,797	$0	$0	$0	$0	$0
4.4	Conduct Spring-2022 Elevation and EDM Surveys in the Managed Area/Fissure Zone Area		0	$0				$52,270		$52,270	$52,270	$0	$0	$0	$0	$0
4.5	Replace Destroyed Benchmarks (if needed)		0	$0				$17,910		$17,910	$17,910	$11,300	$11,300	$0	$0	$11,300
4.6	Process, Check, and Update Database		4	$5,882						$0	$5,882	$5,882	$5,744	$138	$0	$5,882
Task 5. Data Analysis and Reporting				**$85,654**						**$0**	**$85,654**	**$85,654**	**$74,932**	**$10,722**	**$0**	**$85,654**
5.1	Prepare Draft 2020/21 Annual Report of the Ground-Level Monitoring Committee		20.5	$33,354						$0	$33,354	$33,354	$35,196	-$1,842	$0	$33,354
5.2	Prepare Final 2020/21 Annual Report of the Ground-Level Monitoring Committee		10.5	$19,546						$0	$19,546	$19,546	$19,088	$458	$0	$19,546
5.3	Compile and Analyze Data from the 2021/22 Ground-Level Monitoring Program		14	$21,144						$0	$21,144	$21,144	$20,648	$496	$0	$21,144
5.4	Conduct Reconnaissance-Level Subsidence Investigation of the Northeast Area (southeast part)															
5.4.1	Collect and compile available InSAR, ground-level survey, lithologic, piezometeric level, and pumping and recharge data		2.75	$4,442						$0	$4,442	$4,442	$0	$4,442	$0	$4,442
5.4.2	Prepare lithologic cross-sections and data graphics of pumping, piezometeric leves, and InSAR time-histories; share with the GLMC		4.25	$7,168						$0	$7,168	$7,168	$0	$7,168	$0	$7,168
Task 6. Develop a Subsidence-Management Plan for Northwest MZ-1				**$281,842**						**$564**	**$219,325**	**$219,195**	**$252,139**	**-$32,944**	**$89,424**	**$129,772**
6.1	Aquifer-System Monitoring															
6.1.1	Collect pumping and piezometric level data from agencies every two months; check and upload data to HDX		9.75	$12,669						$0	$12,669	$12,669	$10,599	$2,070	$0	$12,669
6.1.2	Prepare and analyze charts and data graphics of pumping and recharge (Northwest MZ-1), piezometric levels, and aquifer-system deformation from PX		8.25	$11,913						$0	$11,913	$11,913	$11,634	$279	$0	$11,913
6.2	Update the Hydrogeologic Conceptual Model			$0						$0	$0	$0	$0	$0	$0	$0
6.2.1	Construct a one-dimensional (1D) compaction model at the PX location		0	$0						$0	$0	$0	$17,637	-$17,637	$0	$0
6.2.2	Calibrate 1D model to derive hydraulic and mechanical properties of aquifers/aquitards and estimate the pre-consolidation stress(es)		0	$0						$0	$0	$0	$16,442	-$16,442	$0	$0
6.3	Update the Chino Basin MODFLOW Model to Enable Simulations of Subsidence															
6.3.1	Add SUB package to the MODFLOW model utilizing results from 1D models at PX, MVWD-28, and AP		0	$0						$0	$0	$0	$39,432	-$39,432	$0	$0
6.3.2	Calibrate SUB package utilizing ground motion data from InSAR, surveys, and extensometers		0	$0						$0	$0	$0	$29,984	-$29,984	$0	$0
6.3.3	Prepare a draft technical memorandum summarizing the model updates and distribute to the GLMC		0	$0						$0	$0	$0	$36,988	-$36,988	$0	$0
6.3.4	Prepare for and conduct a meeting to receive feedback and comments on draft memorandum	a	7.25	$7,058	$84					$84	$7,142	$7,142	$7,142	$0	$7,142	$0
6.3.5	Incorporate the GLMC comments and prepare a final technical memorandum		3.25	$5,326						$0	$5,326	$5,326	$5,326	$0	$5,326	$0
6.4	Refine and Evaluate Subsidence-Management Alternatives															
6.4.1	Evaluate the Baseline and Initial Subsidence-Management Alternatives		10	$20,489						$0	$20,489	$20,489	$20,060	$429	$20,060	$429
6.4.2	Develop Subsidence-Management Alternative 2 (SMA-2)		4	$8,214						$0	$8,214	$8,214	$8,072	$142	$8,072	$142
6.4.3	Prepare and present straw-man SMA-2 to GLMC	a	2	$4,006	$120					$120	$4,126	$3,996	$3,996	$0	$3,996	$0
6.4.4	Review with other agencies that will be required to implement the SMA-2		1.5	$2,929						$0	$2,929	$2,929	$2,860	$69	$2,860	$69
6.4.5	Revise SMA-2 based on comments; circulate to the GLMC and other agencies for comments		2	$4,013						$0	$4,013	$4,013	$3,944	$69	$3,944	$69
6.4.6	Finalize SMA-2		2	$4,046						$0	$4,046	$4,046	$3,964	$82	$3,964	$82
6.4.7	Update groundwater production and replenishment plans per SMA-2		4.5	$9,146						$0	$9,146	$9,146	$8,944	$202	$8,944	$202
6.4.8	Run groundwater model to evaluate the basin response to SMA-2		4	$8,159						$0	$8,159	$8,159	$7,968	$191	$7,968	$191
6.4.9	Prepare maps, charts, and tables to characterize the basin response to SMA-2		7.25	$12,986						$0	$12,986	$12,986	$12,694	$292	$12,694	$292
6.4.10	Summarize evaluation of SMA-2 and present results to the GLMC	a	2.25	$4,548	$120					$120	$4,668	$4,668	$4,454	$214	$4,454	$214
6.4.11	Develop two additional Subsidence-Management Alternatives (SMA-3 and SMA-4)		3.5	$7,130						$0	$7,130	$7,130	$0	$7,130	$0	$7,130
6.4.12	Review with other agencies that will be required to implement the SMA-3 and SMA-4		1.75	$3,319						$0	$3,319	$3,319	$0	$3,319	$0	$3,319
6.4.13	Revise SMA-3 and SMA-4 based on comments; circulate to the GLMC and other agencies for comments		2.25	$4,399						$0	$4,399	$4,399	$0	$4,399	$0	$4,399
6.4.14	Finalize SMA-3 and SMA-4		2.375	$4,704						$0	$4,704	$4,704	$0	$4,704	$0	$4,704
6.4.15	Update groundwater production and replenishment plans per SMA-3 and SMA-4		4.875	$9,749						$0	$9,749	$9,749	$0	$9,749	$0	$9,749
6.4.16	Run groundwater model to evaluate the basin response to SMA-3 and SMA-4		5	$9,503						$0	$9,503	$9,503	$0	$9,503	$0	$9,503
6.4.17	Prepare maps, charts, and tables to characterize the basin response to SMA-3 and SMA-4		7.25	$13,382						$0	$13,382	$13,382	$0	$13,382	$0	$13,382
6.4.18	Summarize evaluation of SMA-3 and SMA-4 and present results to the GLMC	a	2.5	$4,883	$120					$120	$5,003	$5,003	$0	$5,003	$0	$5,003
6.4.19	Prepare a draft technical memorandum documenting the development and evaluations of the subsidence-management alternatives; distribute to the GLMC		21.25	$36,765						$0	$36,765	$36,765	$0	$36,765	$0	$36,765
6.4.20	Incorporate the GLMC comments and prepare a final technical memorandum		5.25	$9,547						$0	$9,547	$9,547	$0	$9,547	$0	$9,547
Task 7. Meetings and Administration				**$52,052**						**$407**	**$52,459**	**$52,459**	**$51,250**	**$1,210**	**$0**	**$52,459**
7.1	Prepare for and Conduct Four Meetings of the Ground-Level Monitoring Committee	a	14	$26,116	$240					$240	$26,356	$26,356	$25,838	$518	$0	$26,356
7.2	Prepare for and Conduct One As-Requested Ad-Hoc Meeting	a	3	$5,857	$167					$167	$6,024	$6,024	$5,804	$221	$0	$6,024
7.3	Perform Monthly Project Management		6	$11,108						$0	$11,108	$11,108	$10,848	$260	$0	$11,108
7.4	Prepare a Recommended Scope and Budget for the GLMC for FY 2022/23		4.75	$8,970						$0	$8,970	$8,970	$8,760	$210	$0	$8,970
Totals												**$555,713**	**$605,223**	**-$49,509**	**$89,424**	**$466,290**

Notes:

a Assumes in-person meetings.

Task 3. Basin-Wide Ground-Level Monitoring Program (InSAR)

This task involves the annual collection and analysis of Synthetic Aperture Radar (SAR) scenes to estimate the vertical ground motion across the western portion of Chino Basin from March 2021 to March 2022.

As part of the approved scope and budget of the GLMC for FY 2020/21, the GLMC directed the Watermaster Engineer to perform a pilot study of the Sentinel-1A InSAR data. The TM documenting the objectives, methods, results, and conclusions and recommendations of the pilot study is included in Attachment A. The conclusions from the pilot study were relied upon in recommending Tasks 3.1 and 3.2 for FY 2021/22.

Task 3.1. Acquire TerraSAR-X SAR Data (German Aerospace Center) and Prepare Interferograms for 2021/22

In this sub-task, six SAR scenes that will be acquired by the TerraSAR-X satellite from March 2021 to March 2022 are purchased from the German Aerospace Center. General Atomics (formerly Neva Ridge Technologies) uses the SAR scenes to prepare 12 interferograms that describe the incremental and cumulative vertical ground motion that occurred from March 2021 to March 2022 and since 2011.

Task 3.2. Check and Review InSAR Results

In this sub-task, the Watermaster Engineer reviews the InSAR results with General Atomics and performs checks for reasonableness and accuracy of the InSAR estimates of vertical ground motion across the western Chino Basin.

Task 4. Perform Ground-Level Surveys

This task involves conducting elevation surveys at benchmark monuments across defined areas of western Chino Basin to estimate the vertical ground motion that occurred since the prior survey. Electronic distance measurements (EDM surveys) are also performed between benchmark monuments to estimate horizontal ground motion in areas where ground fissuring due to differential land subsidence is a concern.

The table below documents the areas surveyed over the last five years as part of the GLMP.

Ground Level Monitoring Program Ground-Level Survey History Over the Last Six Years

Ground-Level Survey Area	Ground-Level Survey Completed (Y/N)?					
	2016	2017	2018	2019	2020	2021[b]
Managed Area	Y	N	Y	N	N	N
Fissure Zone Area[a]	Y	N	Y	N	N	N
Central Area	N	N	N	N	N	N
Northwest Area	Y	Y	Y	Y	Y	Y
San Jose Fault Zone Area[a]	Y	Y	Y	Y	Y	Y
Southeast Area	Y	Y	Y	N	N	N
Northeast Area	N	N	Y	Y	Y	N

(a) Denotes EDM survey area.
(b) The 2021 ground-level surveys are scheduled to begin in early March 2021.

The ground-level surveys efforts recommended for FY 2021/22 include the following Tasks.

Task 4.1. Conduct Spring-2022 Elevation surveys in Northwest MZ-1

In this subtask, the surveyor conducts elevation and EDM surveys at the established benchmarks in Northwest MZ-1 in spring 2022. The elevation survey will begin at the Pomona Extensometer Facility and includes benchmarks across Northwest MZ-1. The elevation survey will be referenced to a newly established elevation datum at the Pomona Extensometer. The EDM survey is performed across the San Jose Array of benchmark monuments.

The vertical elevation survey is recommended in FY 2021/22 because of the recent subsidence that has occurred in Northwest MZ-1 and will support the development of a subsidence management plan in Northwest MZ-1. The EDM survey is ***not*** *recommended to be performed across the San Jose fault zone because the surveys have demonstrated since 2013 that the horizontal strain measured between benchmark pairs appears to behave elastically.*

Task 4.5. Replace Destroyed Benchmarks (if needed)

In this sub-task, the surveyor replaces benchmark monuments that have been destroyed since the last survey, if any.

Task 4.6. Process, Check, and Update Database

In this sub-task, the Watermaster Engineer receives and catalogs the survey results provided by the surveyor, prepares the data for display as a GIS layer, and performs checks against InSAR and extensometer data for reasonableness and accuracy.

The ground-level surveys efforts **not** recommended for FY 2021/22 include the following Tasks.

Task 4.2. Conduct Spring-2021 Elevation Survey in the Northeast Area

This survey is not recommended for FY 2021/22 because heads have been relatively stable or increasing across most of this area and recent ground motion as measured by InSAR and ground-level surveys has been minor in this area.

Task 4.3. Conduct Spring-2021 Elevation in the Southeast Area

This survey is not recommended for FY 2021/22 because over the past several years hydraulic heads have been relatively stable in this area and recent ground motion as measured by InSAR and the Chino Creek Extensometer has been stable in this area.

Task 4.4. Conduct Spring-2021 Elevation and EDM Surveys in the Managed Area

This survey is not recommended for FY 2021/22 because over the past several years hydraulic heads at PA-10 and PA-7 have increased to their highest levels since implementation of the GLMP in 2003; and, recent ground motion as measured by InSAR, ground-level surveys, and the Ayala Park Extensometer has been minor in this area.

Task 5. Data Analysis and Reporting

Task 5.1. Prepare Draft 2020/21 Annual Report of the Ground-Level Monitoring Committee

Prepare the text, tables, and figures for a draft 2020/21 Annual Report of the GLMC and submit the report to the GLMC by September 24, 2021 for review and comment.

Task 5.2. Prepare Final 2020/21 Annual Report of the Ground-Level Monitoring Committee

Update the text, tables, and figures based on the comments received from the GLMC and prepare a final *2020/21 Annual Report of the GLMC* by October 29, 2021. Responses to comments will be included as an appendix to the final report. The report will be included in the agenda packet for the November 2021 Watermaster meetings for approval.

Also, as part of Task 5, Watermaster's Engineer will work with the GLMC to develop concepts for streamlining the Annual Report of the Ground-Level Monitoring Committee and the reporting process for future years. Watermaster's Engineer will present a recommended approach to streamline the report and reporting process to the GLMC, Watermaster's staff, and Watermaster's legal counsel during the scheduled meetings of the GLMC in FY 2021/22.

Task 5.3. Compile and Analyze Data from the 2021/22 Ground-Level Monitoring Program

In this task, monitoring data generated from the GLMP during 2021/22 is checked, mapped, charted, and analyzed as the first step in the preparation of the subsequent annual report. Some of the maps, charts, and tables are shared with the GLMC at its meetings in early 2022 during the development of a recommended scope and budget for FY 2022/23.

Task 5.4. Conduct Reconnaissance-Level Subsidence Investigation of the Northeast Area

In the Northeast Area, the long- and short-term InSAR estimates indicate that persistent downward ground motion has occurred in a concentrated area south of the Ontario International Airport between Vineyard Avenue and Archibald Avenue. The western edge of this subsiding area exhibits a steep subsidence gradient, or "differential subsidence." Subsidence may have occurred in this area in response to declining hydraulic heads, but there is not enough historical hydraulic head data in this area to confirm this relationship. One of the recommendations from the *2019/20 Annual Report of the GLMC* was to recommend ways to investigate the occurrence and mechanisms of the observed subsidence in this area. This task will include data collection, review, and analysis of available borehole and lithologic data, pumping and recharge data, high-frequency hydraulic head measurements, and InSAR estimates of vertical ground motion at up to four locations in the southeast part of the Northeast Area. Figures and charts will be prepared to support the data analysis, interpretations, and any recommendations for future investigations and monitoring.

Task 6. Develop a Subsidence-Management Plan for Northwest MZ-1

The development of the Subsidence Management Plan for Northwest MZ-1 is a multi-year effort with the objective to minimize or stop the occurrence of subsidence in this area. Background information and the conceptual framework for this effort is described in detail in the *Work Plan to Develop a Subsidence-Management Plan for Northwest MZ-1*.[2] Tasks in the Work Plan that are recommended for implementation in FY 2021/22 include:

Task 6.1. Aquifer-System Monitoring

The monitoring of piezometric levels and pumping at wells in Northwest MZ-1 will continue through various techniques, including: (i) SCADA-based monitoring by the Monte Vista Water District; (ii) monitoring of piezometric levels via sonar[3]; (iii) monitoring of piezometric levels via pressure transducers at City of Pomona production wells; and (iv) manual measurements of piezometric levels. The PX facility will measure and record both depth-specific piezometric and aquifer-system-deformation data. These data will improve the understanding of the hydrogeology in Northwest MZ-1, will be used to develop the Subsidence Management Plan for Northwest MZ-1, and will be used to update the plan in the future as appropriate.

In this subtask, all data is collected, compiled, checked, and analyzed every two months. Charts and data graphics of pumping, piezometric levels, and aquifer-system deformation will be updated to support the data collection and analysis.

Task 6.4. Refine and Evaluate the Subsidence-Management Alternatives

The objective of this task is to identify "subsidence-management alternatives" that will minimize or eliminate the future occurrence of subsidence in Northwest MZ-1.

First, the updated Chino Basin MODFLOW model will be used to characterize the basin response to Baseline Management Alternative (BMA) and the Initial Subsidence Management Alternative (ISMA), their ability to raise and hold piezometric levels above the pre-consolidation stress, and their ability to minimize or abate the ongoing subsidence in Northwest MZ-1. The alternatives also will be evaluated on the institutional changes that will need to occur and the costs of the associated water-supply plans.

Using the results of the ISMA, a new method to increase and hold piezometric levels at the estimated pre-consolidation stress will be described and called the Subsidence-Management Alternative 2 (SMA-2). The assumptions of the SMA-2, including the groundwater production and replenishment plans of the Chino Basin parties, will be described, and agreed upon by the GLMC. The updated Chino Basin MODFLOW model will be used to characterize the basin response to SMA-2, its ability to raise and hold piezometric levels above the pre-consolidation stress, and its ability to minimize or abate the ongoing subsidence in Northwest MZ-1. The alternative also will be evaluated on the institutional changes that will need to occur and the costs of the associated water-supply plans.

GLMC meetings will be held to review the model results and evaluations. The GLMC can select a recommended subsidence-management alternative or choose to develop and evaluate two additional subsidence-management alternatives (SMA-3 and SMA-4). SMA-3 and SMA-4 will be developed and

[2] Work Plan to Develop a Subsidence-Management Plan for Northwest MZ-1

[3] The use of sonar technology to measure piezometric levels in wells in currently being used in Monte Vista Water District wells 28 and 31.

evaluated in the same fashion as with SMA-2. A draft and final technical memorandum will be prepared to document the evaluation of all subsidence-management alternatives and the preferred alternative as recommended by the GLMC.

Task 7. Meetings and Administration

Task 7.1. Prepare for and Conduct Four Meetings of the Ground-Level Monitoring Committee

This sub-task includes preparing for and conducting four meetings of the GLMC:

- July 2021 – Implementation of the GLMP for FY 2021/22
- September 2021 – Review the draft 2020/21 Annual Report of the Ground-Level Monitoring Committee
- February 2022 – Review the draft recommended scope and budget for FY 2022/23
- March 2022 – Review the final recommended scope and budget for FY 2022/23 (if needed)

Task 7.2. Prepare for and Conduct One As-Requested Ad-Hoc Meeting

This sub-task includes preparing for and conducting one ad-hoc meeting of the GLMC, as requested by the GLMC or Watermaster staff.

Task 7.3. Perform Monthly Project Management

This sub-task includes monthly project administration and management, including staffing, financial and schedule reporting to Watermaster and sub-contractor coordination.

Task 7.4. Prepare a Recommended Scope and Budget for the GLMC for FY 2022/23

This sub-task includes preparing a draft and final recommended scope and budget for FY 2022/23 for the GLMC to support the Watermaster's budgeting process.

Attachment A

Comparison of the Sentinel-1A and TerraSAR-X InSAR Datasets Across the Chino Basin

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TECHNICAL MEMORANDUM

DATE: February 26, 2021

Project No.: 941-80-20-21
SENT VIA: EMAIL

TO: Ground-Level Monitoring Committee

FROM: Michael Blazevic, PG, CHG

REVIEWED BY: Andy Malone, PG

SUBJECT: Comparison of the Sentinel-1A and TerraSAR-X InSAR Datasets Across the Chino Basin

BACKGROUND AND OBJECTIVES

Since the inception of the Ground Level Monitoring Program (GLMP), the Chino Basin Watermaster (Watermaster) has employed various methods to monitor vertical ground motion via extensometers, traditional ground-level surveys, and the remote-sensing technique of Interferometric Synthetic Aperture Radar (InSAR). Analysis of these data over time has shown that InSAR is increasingly a reliable and accurate method for monitoring vertical ground motion across most of the areas of subsidence concern in the Chino Basin for the following reasons:

- Improvements in satellite technology over time have increased the spatial resolution, temporal resolution, and accuracy of InSAR; and
- Land-use changes from agricultural to urban have added hard, consistent radar wave reflectors to the ground surface over time. As such, InSAR results are now coherent and useful across most of the areas of subsidence concern.

For the GLMP, the InSAR-derived estimates of vertical ground motion across the areas of subsidence concern are used by the GLMC to:

- Provide an aerially continuous estimation of the occurrence and magnitude of vertical ground motion across the western Chino Basin over time. Monitoring of vertical ground motion via InSAR since 2006 across the Chino Basin helped identify land subsidence and the pattern of concentrated differential subsidence across the San Jose Fault in Northwest MZ-1.
- Identify areas of differential subsidence. Differential subsidence is sometimes indicative of the existence of groundwater barriers (i.e., the Riley Barrier in the Managed Area and the San Jose Fault in Northwest MZ-1); hence, the information derived from InSAR has improved the hydrogeologic understanding of the groundwater basin.
- Provide calibration data for the computer-simulation modeling of aquifer-system deformation and land subsidence across the Chino Basin. Specifically, Watermaster's Engineer is updating the Chino Valley Model (CVM) by adding a subsidence package (SUB) to

the MODFLOW model so that it can be used to simulate historical and potential future land subsidence across Northwest MZ-1. The SUB package will be calibrated across Northwest MZ-1 using the InSAR estimates of historical vertical ground motion.

Since 2011, the GLMC has chosen to acquire and use a single Synthetic Aperture Radar (SAR) scene from the TerraSAR-X satellite that covers only the western portion of the Chino Basin. This decision was based on:

- Observations that InSAR-derived estimates of ground motion from 1992-2005 indicated that little if any subsidence had occurred within the eastern portion of the basin; and
- The desire to manage costs for the GLMP. However, it has been shown in the Watermaster's State of the Basin Reports (WEI, 2019)[1] that hydraulic heads have decreased across the central and eastern portions of the Chino Basin since about 2005. Subsidence may have occurred in these areas in response to the declining heads, yet these areas have not been monitored for vertical ground motion since 2009.

There is a new satellite that was launched in 2014 by the European Space Agency, Sentinel-1A, that provides InSAR estimates of vertical ground motion across the state of California, including the entire Chino Basin. InSAR estimates of vertical ground motion from Sentinel-1A are freely available from the California's Department of Water Resources (DWR).[2] As part of the approved scope and budget of the GLMC for FY 2020/21, the GLMC directed the Watermaster Engineer to perform a study comparing the Sentinel-1A and TerraSAR-X InSAR datasets across the Chino Basin. The questions to be answered by the study are:

- Has land subsidence occurred in the eastern portion of Chino Basin during the period 2015 to 2018 as hydraulic heads have declined over this period? If so, what is its magnitude and spatial distribution? Does the GLMC see a concern for land subsidence that would warrant ongoing monitoring of eastern Chino Basin via InSAR?
- Across the western portion of the Chino Basin, how do the estimates of vertical ground motion derived from Sentinel-1A compare with those derived from TerraSAR-X in terms of spatial distribution, magnitude, coherence, and accuracy?
- If the GLMC were to switch to using Sentinel-1A, would the monitoring program be compromised? If so, how?

The purpose of this technical memorandum is to answer these questions and develop recommendations for the GLMC on the potential future uses of the Sentinel-1A and TerraSAR-X InSAR datasets for the GLMP.

METHODS

To answer the questions above, the following methods were used:

[1] West Yost, formerly Wildermuth Environmental, Inc. (2019). Chino Basin Optimum Basin Management Program, 2018 State of the Basin Report.

[2] SGMA Data Viewer (ca.gov)

- Identify, download, and compile the Sentinel-1A moving annual cumulative displacement InSAR rasters for the entire Chino Basin from the DWR over a three-year period between 2015 and 2018.
- Utilize ArcMap's Spatial Analyst extension to extract monthly vertical ground motion displacements from the moving annual cumulative displacement InSAR rasters.
- Compare various aspects of the Sentinel-1A and TerraSAR-X[3] estimates of vertical ground motion – namely the magnitude of vertical ground motion, coherence, and the spatial resolution of ground motion across the Chino Basin.

RESULTS

Sentinel-1A and TerraSAR-X InSAR Processing Procedures

A brief summary of the InSAR processing procedures used by TRE ALTAMIRA and General Atomics (GA) for the Sentinel-1A and TerraSAR-X InSAR data, respectively, was provided by GA (S. Yarborough, personal communication, January 19, 2021):

Sentinel-1A

- SAR data is processed in large polygons across California. One processing polygon covers the entire Chino Basin.
- Ascending and descending satellite track data are combined to estimate differential vertical ground motion from radar line-of-sight (RLoS) measurements for a given time period.
- Differential vertical ground motion estimates are compared with observations from GPS stations located across California using 100 m radius of motion estimates around each station to derive absolute vertical measurements. For reference, one station is located in the Chino Basin near Rancho Cucamonga.
- Absolute vertical ground motion measurements are projected to 100 m x 100 m grids across each processing polygon and interpolated to regular time intervals (1st day of each month). Any voids are filled by spatial interpolation in each processing polygon. Each grid is an average of all measurements within a single 100 m x 100 m grid, located at the grid center.

For a more detailed description of these processes, see TRE ALTAMIRA (2020).[4]

TerraSAR-X

- The approximate InSAR processing footprint extends from Falling Springs (north) to Villa Park (south) and from La Puente (west) to the Ontario International Airport (east).
- Differential vertical ground motion is measured along the RLoS between each radar collection.
- Vertical ground motion offsets resulting from RLoS errors are removed with a combination of interferometric processing, and a reference patch in an observed stable location in the Chino Basin. The current reference patch is a 750 m x 750 m area, centered approximately

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[3] The TerraSAR-X InSAR rasters between the time-period 2015 and 2018 were readily available for this study as part of the long-term ground motion monitoring conducted for the GLMP.
[4] TRE ALTAMIRA (2020). *InSAR land surveying and mapping services in support of the DWR SGMA program.*

at the intersection of W. Phillips Blvd and S. White Avenue in Pomona, CA. Any vertical motion in the reference patch is assumed to show the constant offset resulting from RLoS errors, and the average value measured across the patch in each differential vertical motion height map is then removed from the vertical motion height map. The normalized differential height maps are then summed to provide a total displacement over the desired time-period.

- Small voids are filled by spatial interpolation in each InSAR frame, providing continuous high-resolution measurements over areas with intermittent signal loss.
- Sequential measurements are summed, providing a normalized total vertical ground motion estimate for a given time period.
- Normalized RLoS measurements are projected to 15 m x 15 m grids. Each grid is an average of all measurements within a single 15 m x 15 m grid, located at the grid center.

Sentinel-1A and TerraSAR-X InSAR Dataset Information

Table 1 lists the basic dataset description and information for the Sentinel-1A and TerraSAR-X InSAR datasets.

Table 1. Sentinel-1A and TerraSAR-X InSAR Dataset Information

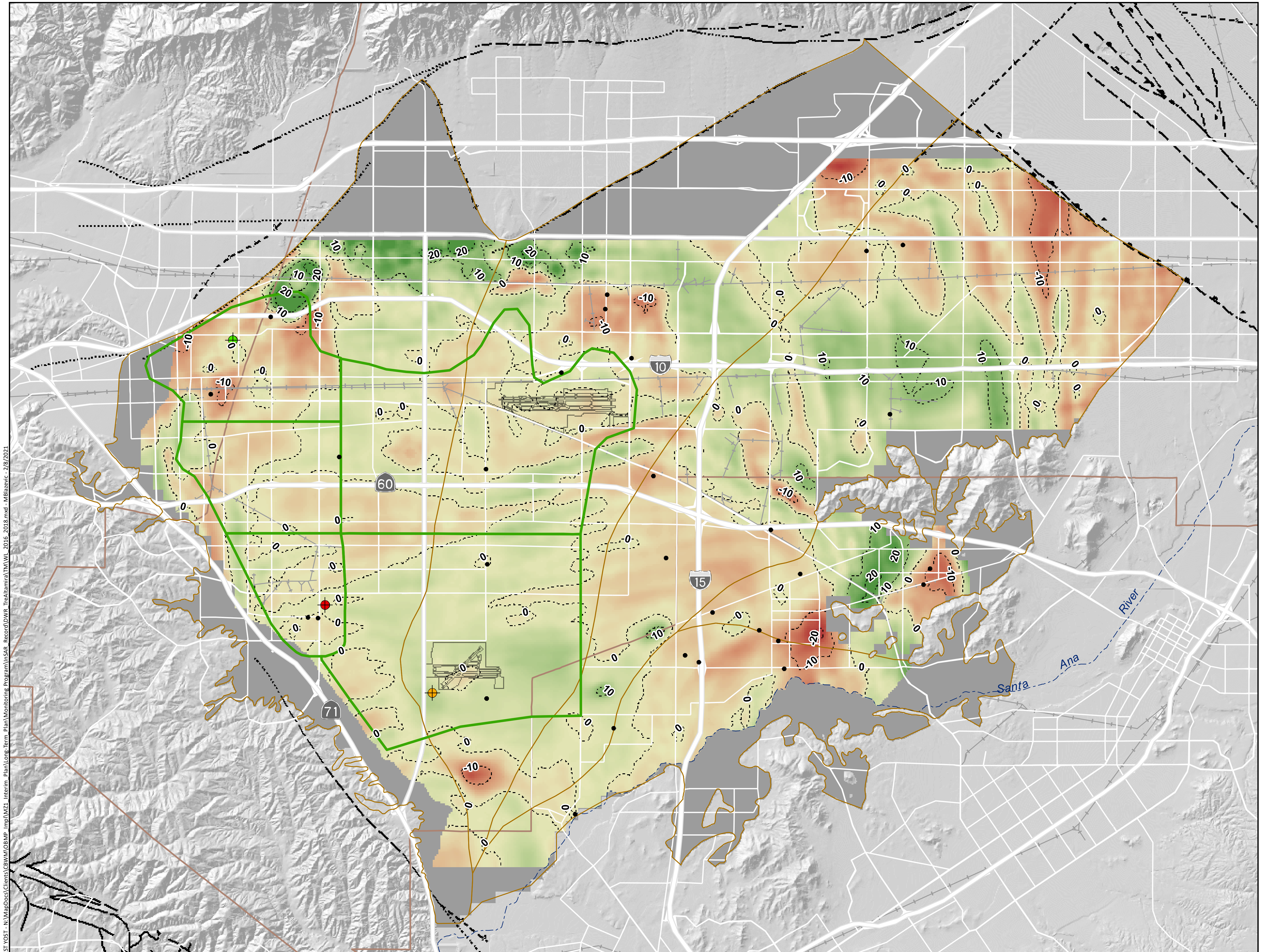
Dataset Description	Sentinel-1A	TerraSAR-X
Processor	TRE ALTAMIRA	General Atomics
Current Availability	June 2015 – September 2019	March 2011 – March 2020
Current Coverage	Entire Chino Basin	Western Chino Basin
Current Acquisition Frequency	Monthly	Every Two Months
Spatial Resolution	100 m	15 m
Accuracy	+/- 1.6 cm	+/- 0.8 cm
Cost	Free	$87,000

Sentinel-1A and TerraSAR-X InSAR Observations

It has been shown in the Watermaster's State of the Basin Reports (WEI, 2019) that hydraulic heads have decreased across the central and eastern portions of the Chino Basin since about 2005. Subsidence may have occurred in these areas in response to the declining heads, yet these areas have not been monitored for vertical ground motion since 2009. For reference, Figure 1 shows the change in groundwater levels for the two-year period between spring 2016 and spring 2018 across the Chino Basin. Groundwater levels have generally remained stable across most of the areas of subsidence concern but have declined up to 10 ft across parts of Northwest MZ-1. East of the areas of subsidence concern, groundwater levels have decreased in the central and northern portions of the basin by about 10 ft.

Figure 2 shows the total vertical ground motion estimated by the Sentinel-1A between June 2015 and May 2018 across the entire Chino Basin. The main observations from Figure 2 are:

- The InSAR coherence is good across the entire Chino Basin.



N

0 1 2
Miles

Groundwater Level Change (ft)
Spring 2016 to Spring 2018

20 ft Increase
0 ft
-20 ft Decrease

Area not Included in the Change Calculation Due to Lack a of Groundwater Level Data

Contour of Groundwater-Level Change (ft)

Well with Groundwater Level Time History

OBMP Management Zones

Areas of Subsidence Concern

Pomona Extensometer Facility

Ayala Park Extensometer Facility

Chino Creek Extensometer Facility

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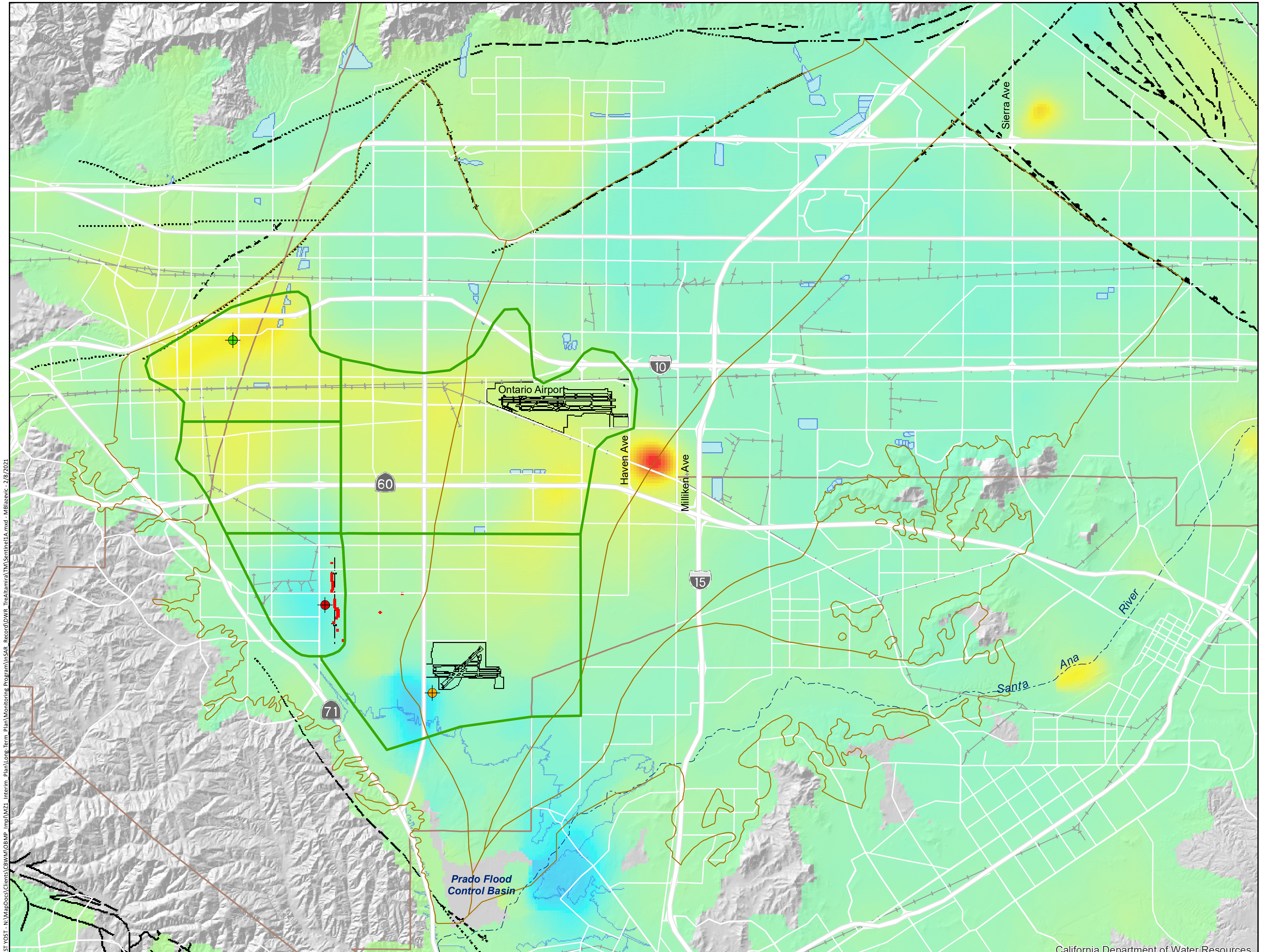
Figure 1

Groundwater Level Change
Spring 2016 to Spring 2018

Chino Basin Watermaster
Ground-Level Monitoring Committee



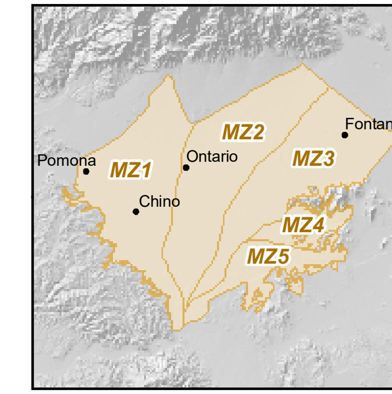


Figure 2

Vertical Ground Motion Estimated by Sentinel-1A June 2015 to May 2018

Chino Basin Watermaster

Ground-Level Monitoring Committee

- Estimates of vertical ground motion are mostly downward across the areas of subsidence concern. The spatial pattern of vertical ground motion estimated by the Sentinel-1A is consistent with the long-term ground motion trends measured by the TerraSAR-X and is consistent with the spatial pattern and groundwater level change shown in Figure 1 between 2016 and 2018.
- Estimates of vertical ground motion are mostly upward across the eastern portion of the basin. The spatial pattern of vertical ground motion estimated by Sentinel-1A is not consistent with the spatial pattern and groundwater level change shown in Figure 1 between 2016 and 2018.
- There are focused patterns of vertical ground motion that are not explained by changes in groundwater levels shown in Figure 1. These areas are located just southeast of the Ontario Airport between Haven Avenue and Milliken Avenue, along the Santa Ana River, and just northeast of the intersection of the 210 Fwy and Sierra Avenue. Examination of these areas in Google Earth shows they correspond to recent earthwork construction activities and/or excavation activities.

Figures 3 and 4 show total vertical ground motion estimated across the western Chino Basin between June 2015 and May 2018 from Sentinel-1A and TerraSAR-X. Across the areas of subsidence concern, the main observations are:

- The spatial pattern of vertical ground motion is generally consistent between the two InSAR datasets.
- Between the two InSAR data sets, the spatial resolution of TerraSAR-X is noticeably better and the spatial details of subsidence are better delineated with TerraSAR-X.
- The magnitudes and directions of ground motion are not always consistent between the Sentinel-1A and TerraSAR-X InSAR datasets. InSAR data from TerraSAR-X across the western portion of Central MZ-1, Northwest MZ-1, and Northeast Area show greater magnitudes of downward vertical ground motion compared to the Sentinel-1A InSAR data. Where TerraSAR-X InSAR data is coherent across the southern part of the Managed Area (near Ayala Park), it shows slightly greater upward ground motion compared to the Sentinel-1A InSAR data. Across other parts of the western Chino Basin, the vertical ground motion magnitude and direction estimated by the two satellites is variable and not consistent.

Figures 5 and 6 are time-series charts that compare the hydraulic heads at C-15 and P-30 to vertical ground motion as measured by Sentinel-1A and TerraSAR-X between 2015 and 2018. For reference, the point locations are shown on Figure 3. The main observations and interpretations from Figures 5 and 6 are:

- The Sentinel-1A InSAR data are plotted on a monthly time-step, whereas the TerraSAR-X InSAR data are plotted on a two-month time-step. Because of this, Sentinel-1A InSAR data shows slightly more variability month to month compared to TerraSAR-X InSAR data. Both Sentinel-1A and TerraSAR-X InSAR data generally show a similar pattern of vertical ground motion annually.
- Both Sentinel-1A and TerraSAR-X InSAR data show a persistent downward vertical ground motion trend between 2015 and 2018.
- Sentinel-1A InSAR data shows a consistent pattern of upward ground motion in the fall of each year. This pattern of upward ground motion in the fall of each year is not observed in the TerraSAR-X InSAR data.

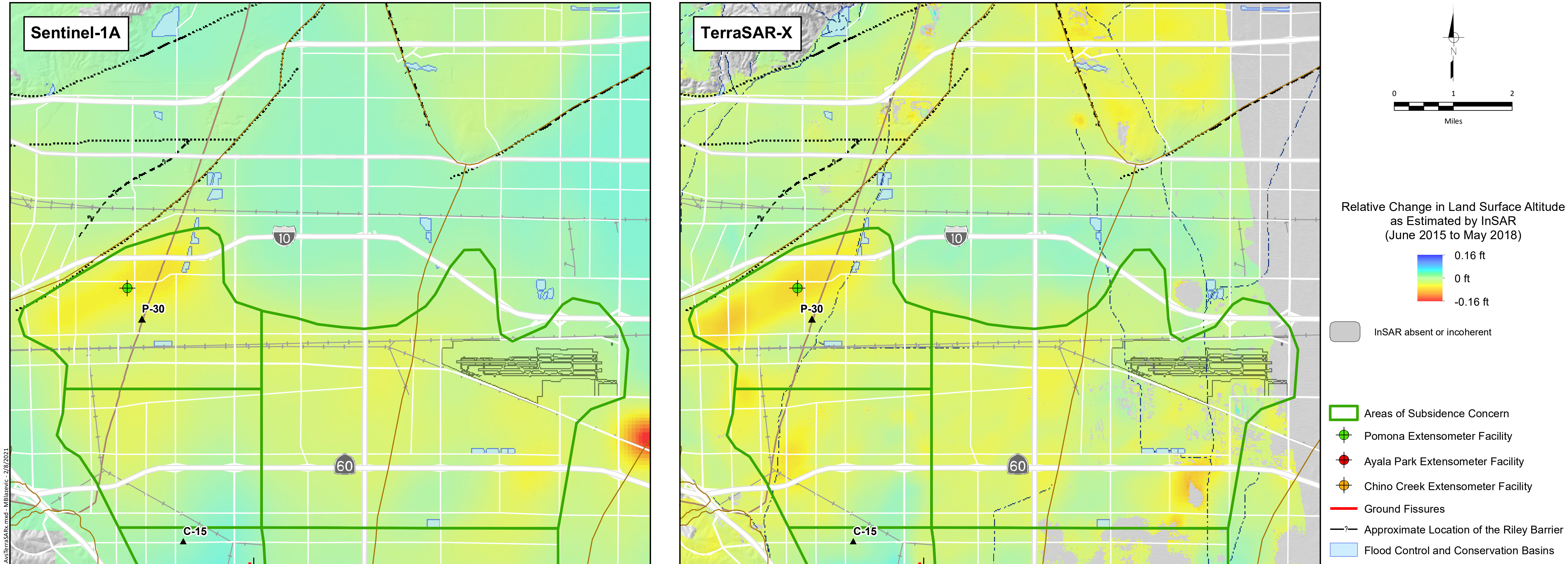


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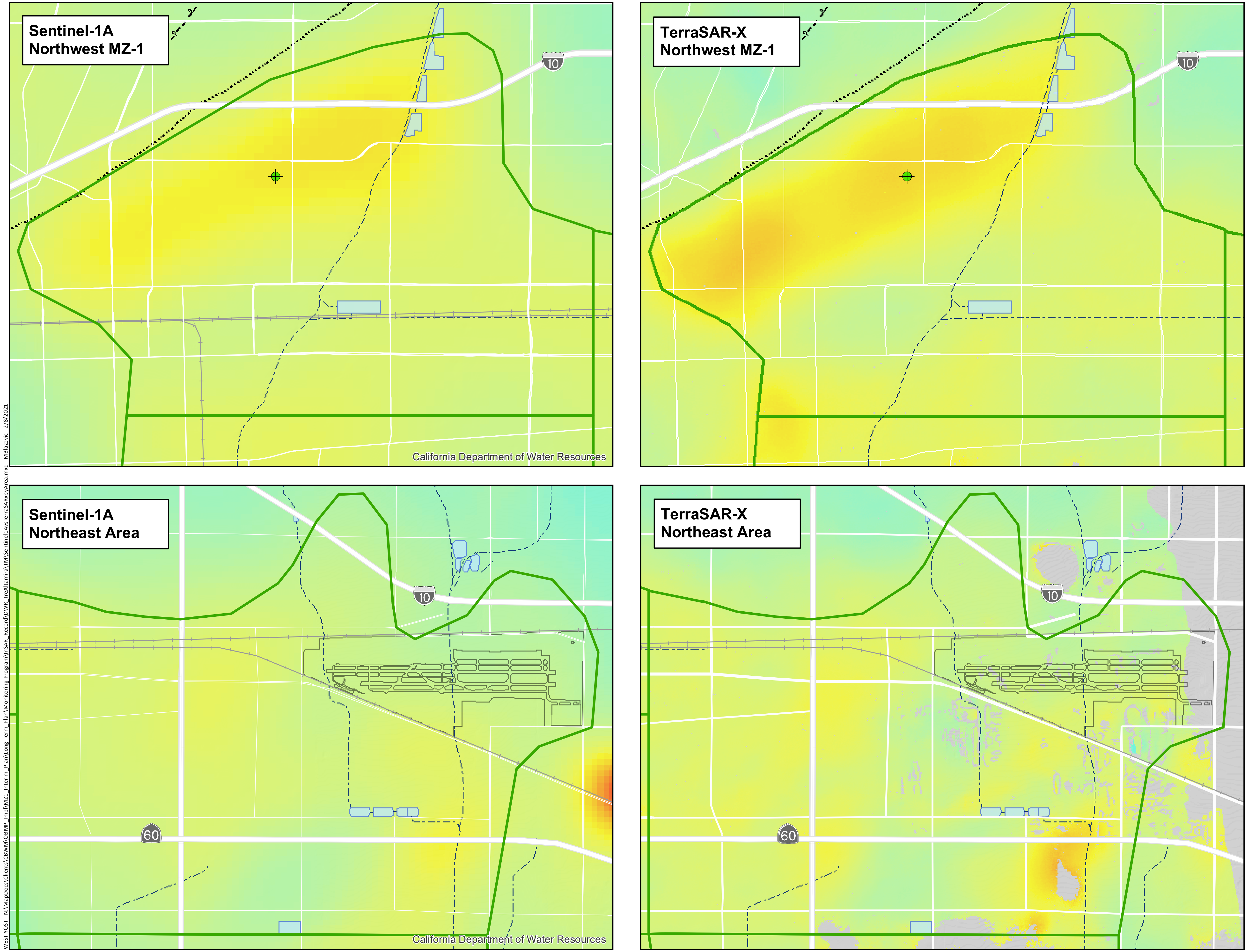
Figure 3

Sentinel-1A
Total Vertical Ground Motion
Estimated across the Chino Basin
June 2015 to May 2018

Chino Basin Watermaster
Ground-Level Monitoring Committee



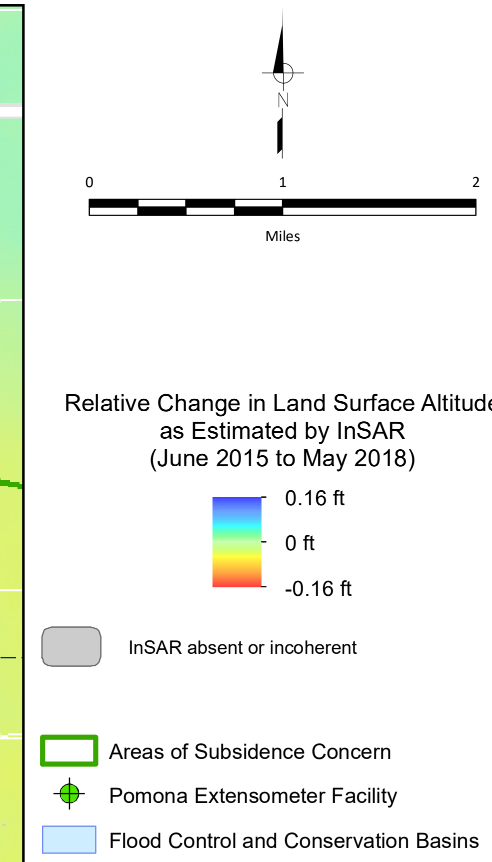


Figure 4

Sentinel-1A Versus TerraSAR-X Total Vertical Ground Motion Estimated across Northwest MZ-1 and Northeast Area June 2015 to May 2018

Chino Basin Watermaster
Ground-Level Monitoring Committee

Figure 5. Cumulative Vertical Ground Motion Displacement Measured by the Sentinel-1A and TerraSAR-X Satellites at City of Chino 15
August 2015 to May 2018

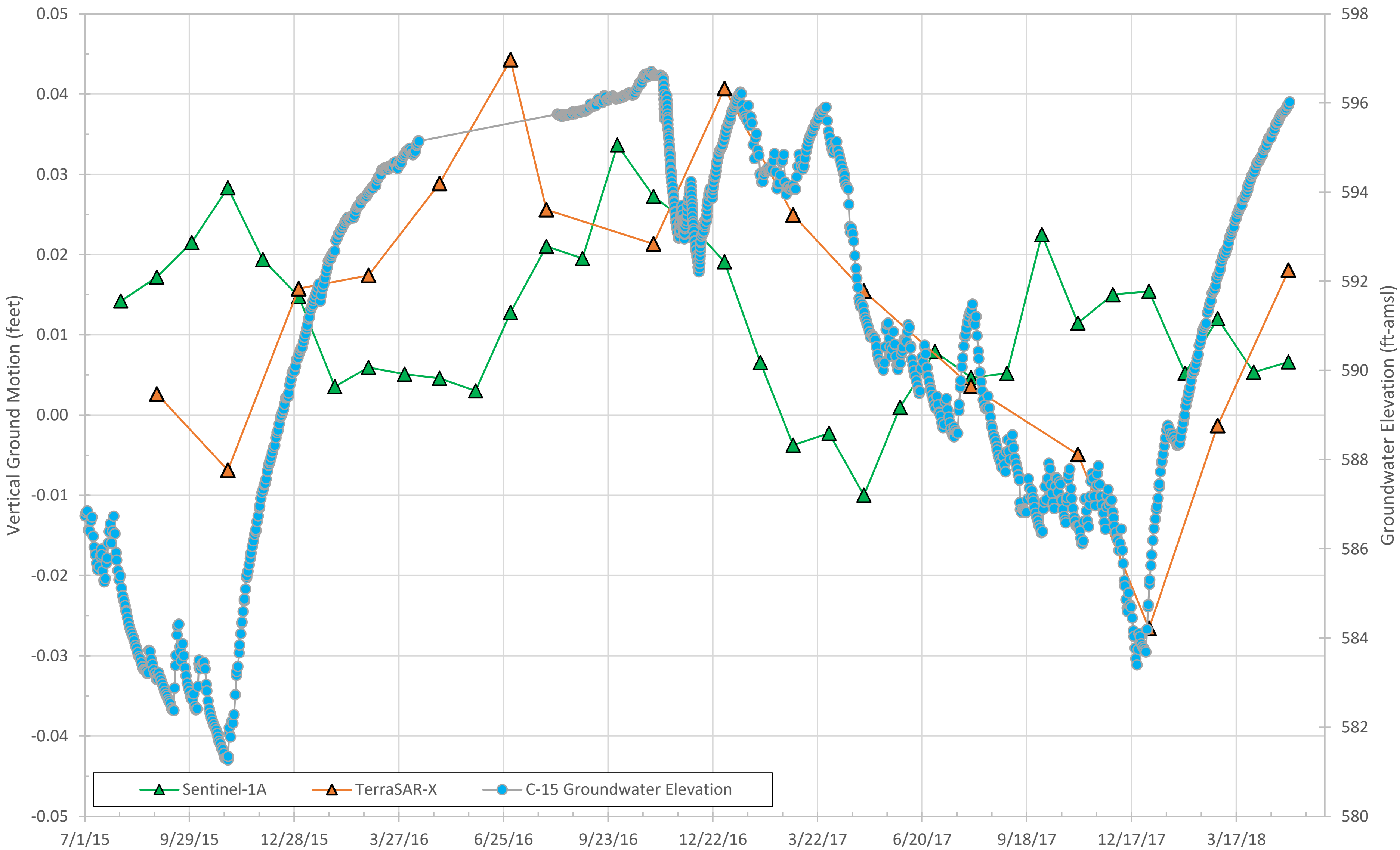
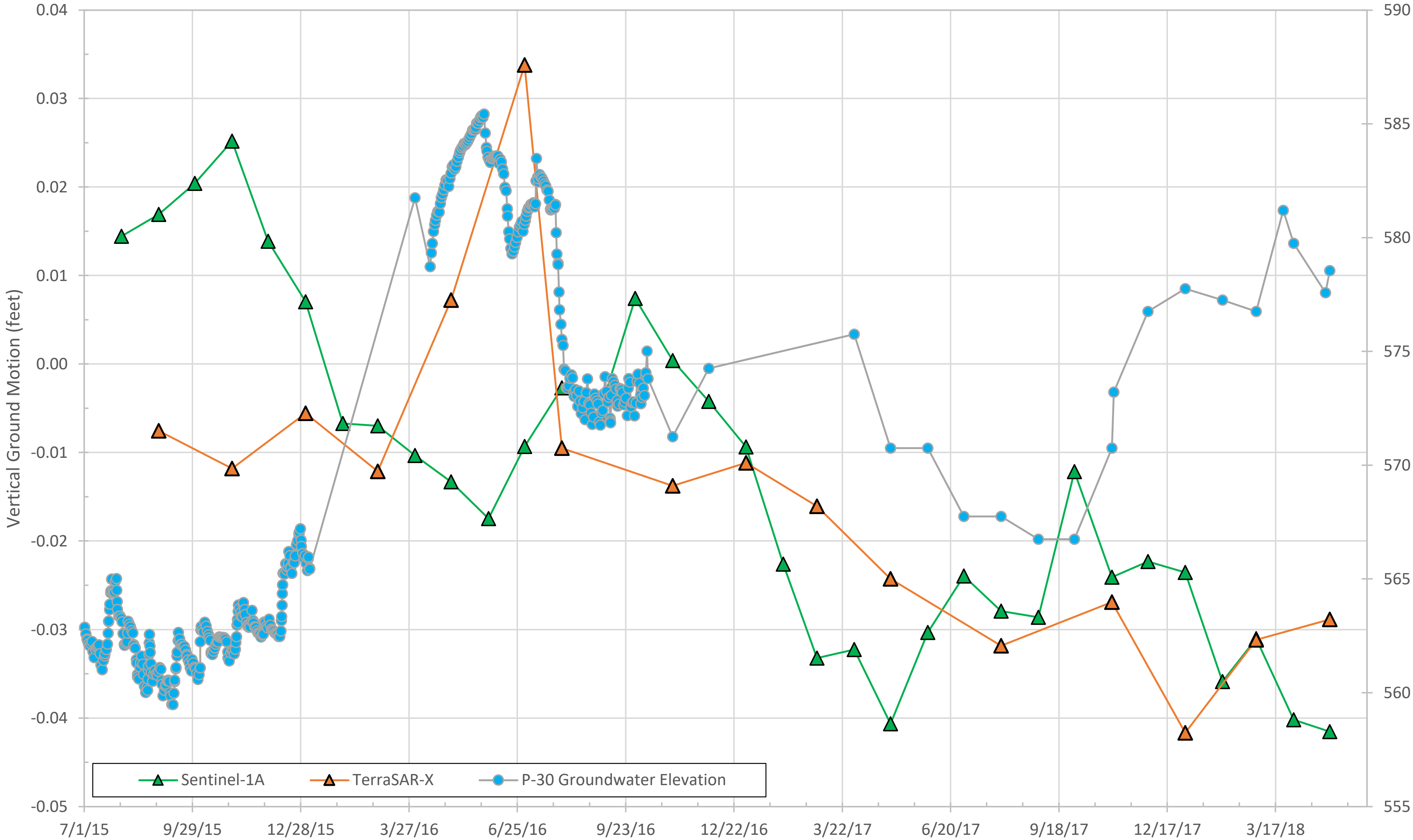


Figure 6. Cumulative Vertical Ground Motion Displacement Measured by the Sentinel-1A and TerraSAR-X Satellites at City of Pomona 30

August 2015 to May 2018



- The vertical ground motion magnitudes measured by the two InSAR data sets at each point location is inconsistent.
- The seasonal fluctuations of hydraulic head at C-15 and P-30 are coincident with the seasonal fluctuations of vertical ground motion measured by the TerraSAR-X InSAR data.
- The seasonal fluctuations of hydraulic head at C-15 and P-30 are not coincident with the seasonal fluctuations of vertical ground motion measured by the Sentinel-1A InSAR data. For example, in Figure 5, there are instances where Sentinel-1A estimates upward vertical ground motion but hydraulic head at C-15 is declining or stable.

One explanation for the limited relationship between the hydraulic head at C-15 and P-30 and the vertical ground motion observed with the Sentinel-1A InSAR data is that the Sentinel-1A grid size (100 m) is much larger compared to the TerraSAR-X grid size (15 m). Likewise, the TerraSAR-X accuracy (+/- 8 mm) is twice that of the Sentinel-1A accuracy (+/- 16 mm). A larger grid size and decreased accuracy will smooth-out the ground displacement magnitude over a larger area and produce less accurate ground motion results at specific point locations.

CONCLUSIONS AND RECOMMENDATIONS

Based on the figures, information, and observations discussed above, we summarize the advantages and limitations of both the Sentinel-1A and TerraSAR-X InSAR data sets in Table 2.

The recommendations from this study are:

- The GLMC should continue using TerraSAR-X for the following reasons:
  - TerraSAR-X InSAR data is available at a higher spatial resolution compared to the freely available Sentinel-1A InSAR data. Higher spatial resolution InSAR can better delineate areas of subsidence and better identify areas of differential subsidence. High-resolution InSAR is more appropriate over urban areas, such as the Chino Basin, where the finer detail can identify risk to infrastructure, characterize rapidly developing small features which may lead to ground fissures, and more accurately depict the depth and spatial extent of broad subsidence features.
  - TerraSAR-X InSAR data is purchased at higher vertical accuracy compared to the feely available Sentinel-1A InSAR data. For subsidence model calibration purposes, the TerraSAR-X InSAR data will provide more accurate calibration targets for vertical ground motion compared to the Sentinel-1A InSAR data. The vertical ground motion estimated by TerraSAR-X has shown to be coincidental with changes to hydraulic heads (see Figures 5 and 6). For the areas of subsidence concern, this relationship indicates hydraulic heads, which are controlled by the pumping and recharge stresses in the area, have at least some control on the pattern and rate of subsidence and that the information could be used as management criteria to protect against the future occurrence of land subsidence.
  - TerraSAR-X InSAR data has been collected for the GLMP since 2011. The GLMC is also in the process of developing a Subsidence Management Plan for Northwest MZ-1. To maintain continuity of the InSAR record during development and completion of the Northwest MZ-1 Subsidence Management Plan, it is recommended the GLMC continue

to use TerraSAR-X InSAR data, at least until the Northwest MZ-1 Subsidence Management Plan is completed.

- Based on the spatial pattern of vertical ground motion estimated by Sentinel-1A between 2015 and 2018 across the eastern Chino Basin, there is no immediate need to monitor vertical ground motion across the eastern Chino Basin. The GLMC could evaluate using the freely available Sentinel-1A InSAR data about once every five years to check for vertical ground motion trends across the eastern Chino Basin.

Table 2. Sentinel-1A and TerraSAR-X Advantages and Limitations

Criteria	Sentinel-1A	TerraSAR-X
Spatial Coverage	Coverage for the entire Chino Basin.	The GLMP only purchases InSAR for the western Chino Basin.
Spatial Resolution	Published to the DWR SGMA Data Viewer at a spatial resolution of 100 m.	Processed by GA at a spatial resolution of 15 m.
Vertical Accuracy	Published to the DWR SGMA Data Viewer at an accuracy of +/- 16 mm.	Processed by GA at an accuracy of +/- 8 mm.
Acquisition Frequency	Monthly.	Bimonthly (every two months).
Period of Record	As of December 2020, the InSAR is available for the time-period between June 2015 and September 2020.	The InSAR has been used by the GLMP since 2011 and is currently available through March 2020.
Continuity	The frequency at which new InSAR scenes will be available through the DWR SGMA Data Viewer is unknown.	The GLMP collects InSAR on a year-round basis in order to maintain continuity in the InSAR record from year-to-year.
Cost	The InSAR is freely available through the DWR SGMA Data Viewer website. There would be associated costs to download, re-project, and load the rasters to ArcMap for viewing and analysis.	The InSAR is ordered, purchased, and processed by GA each fiscal year. The cost is $87,000 and includes time by the Watermaster Engineer to review the InSAR deliverables with GA and load the InSAR rasters to ArcMap for viewing and analysis.