

AGENDA
WATER ISSUES COMMITTEE MEETING
WITH BOARD OF DIRECTORS *
ORANGE COUNTY WATER DISTRICT
18700 Ward Street, Fountain Valley, CA 92708
Wednesday, October 10, 2018, 8:00 a.m. – Boardroom

* The OCWD Water Issues Committee meeting is noticed as a joint meeting with the Board of Directors for the purpose of strict compliance with the Brown Act and it provides an opportunity for all Directors to hear presentations and participate in discussions. Directors receive no additional compensation or stipend as a result of simultaneously convening this meeting. Items recommended for approval at this meeting will be placed on the **October 17, 2018** Board meeting Agenda for approval.

PLEDGE OF ALLEGIANCE

ROLL CALL

ITEMS RECEIVED TOO LATE TO BE AGENDIZED

RECOMMENDATION: Adopt resolution determining need to take immediate action on item(s) and that the need for action came to the attention of the District subsequent to the posting of the Agenda (requires two-thirds vote of the Board members present, or, if less than two-thirds of the members are present, a unanimous vote of those members present.)

VISITOR PARTICIPATION

Time has been reserved at this point in the agenda for persons wishing to comment for up to three minutes to the Board of Directors on any item that is not listed on the agenda, but within the subject matter jurisdiction of the District. By law, the Board of Directors is prohibited from taking action on such public comments. As appropriate, matters raised in these public comments will be referred to District staff or placed on the agenda of an upcoming Board meeting.

At this time, members of the public may also offer public comment for up to three minutes on any item on the Consent Calendar. While members of the public may not remove an item from the Consent Calendar for separate discussion, a Director may do so at the request of a member of the public.

CONSENT CALENDAR (ITEMS NO. 1 –9)

All matters on the Consent Calendar are to be approved by one motion, without separate discussion on these items, unless a Board member or District staff request that specific items be removed from the Consent Calendar for separate consideration.

1. MINUTES OF WATER ISSUES COMMITTEE MEETING HELD SEPTEMBER 12, 2018

RECOMMENDATION: Approve minutes as presented

2. AGREEMENT WITH INTERA FOR CAPTURE ZONE MODELING AND ANALYSIS OF NORTH BASIN EXTRACTION WELL EW-1

RECOMMENDATION: Agendize for October 17 Board meeting: Authorize issuance of Agreement to Intera for Three-Dimensional Capture Zone Analysis for OCWD North Basin Extraction Well EW-1 for an amount not to exceed \$76,932

3. AGREEMENT TO RAMBOLL TO CONDUCT GEOPHYSICAL INVESTIGATION IN LOWER OFF-RIVER CHANNEL

RECOMMENDATION: Agendize for October 17 Board meeting: Authorize issuance of agreement to Ramboll for a geophysical investigation of the Lower Off-River Channel for an amount not to exceed \$23,000

4. SPONSORING UCI SUSTAINABLE GROUNDWATER WORKSHOP

RECOMMENDATION: Agendize for October 17 Board meeting: Authorize partnering with Water UCI in hosting workshop on Sustainable Groundwater and contribute up to \$15,000 to UCI to host the workshop

5. CONTRACT GBM-2018-1 DESTRUCTION OF MONITORING WELL WBS-3R AND CONSTRUCTION OF REPLACEMENT MONITORING WELL OCWD-HG2: NOTICE OF COMPLETION

RECOMMENDATION: Agendize for October 17 Board meeting:

- 1) Ratify issuance of Change Order No. 1 to BEKS Acquisition dba BC2 Environmental to decrease the Contract amount by \$871; and
- 2) Accept completion of work and authorize filing a Notice of Completion for Contract GBM-2018-1, Destruction of Monitoring Well WBS-3R and Construction of Replacement Monitoring Well OCWD-HG2

6. ALAMITOS BARRIER IMPROVEMENT PROJECT: NOTICE OF COMPLETION FOR CONTRACT NO. AB-2016-1 ALAMITOS BARRIER IMPROVEMENT PROJECT INJECTION WELL IMPROVEMENTS

RECOMMENDATION: Agendize for October 17 Board meeting:

- 1) Ratify Change Order Number 7 to Kiewit Infrastructure West Company for a total deduction in the amount of (\$14,378.70); and
- 2) Accept the completion of work and authorize filing a Notice of Completion for Contract AB-2016-1 Alamitos Barrier Improvement Project Injection Well Improvements

7. ANNUAL SANTA ANA RIVER STREAM GAUGING JOINT FUNDING AGREEMENT WITH THE UNITED STATES GEOLOGICAL SURVEY

RECOMMENDATION: Agendize for October 17 Board meeting:

- 1) Approve and authorize Joint Funding Agreement with USGS to conduct stream gauging of the Santa Ana River below Prado Dam and Santiago Creek at Santa Ana for the period of November 1, 2018 to October 31, 2019; and
- 2) Authorize payment of \$55,832 to the USGS for OCWD's share of costs for these services

8. AGREEMENT TO TETRA TECH FOR SANTIAGO PUMP STATION MODIFICATIONS PROJECT DESIGN AND CONSTRUCTION SUPPORT SERVICES

RECOMMENDATION: Agendize for October 17 Board meeting: Authorize issuance of Agreement to Tetra Tech for an amount not to exceed \$178,000 for the Santiago Pump Station Modifications Project Design and Construction Support Services

9. TERMINATION OF AGREEMENT TO KEH & ASSOCIATES FOR DESIGN SERVICES FOR THE ANAHEIM LAKE VALVE VAULT PROJECT

RECOMMENDATION: Agendize for October 17 Board meeting: Authorize termination of Agreement No. 1324 with KEH & Associates, Inc. and execute a new agreement with the same terms and conditions with Gannett Fleming for design services for the Anaheim Lake Valve Vault Project

MATTERS FOR CONSIDERATION

10. PHASE II SCOPING STUDY ON FORECAST-INFORMED RESERVOIR OPERATIONS (FIRO) AT PRADO DAM

RECOMMENDATION: Agendize for October 17 Board meeting: Authorize amending agreement with UC San Diego/Scripps Institution of Oceanography by adding an amount not to exceed \$325,000 for Phase II of Scoping Study on Forecast-Informed Reservoir Operations at Prado Dam

11. APPROVAL OF COMMON INTEREST AND JOINT DEFENSE AGREEMENT FOR UPPER SANTA ANA WATERSHED HABITAT CONSERVATION PLAN

RECOMMENDATION: Agendize for October 17 Board meeting: Approve and authorize execution of Common Interest and Joint Defense Agreement for the Upper Santa Ana River Habitat Conservation Plan, subject to review as to form by General Counsel

INFORMATIONAL ITEMS

12. IRVINE RANCH WATER DISTRICT – STRAND RANCH STORAGE PROGRAM

13. OCWD TO RECEIVE STEPHEN J. KLAINE ENVIRONMENTAL AWARD

CHAIR DIRECTION AS TO ITEMS IF ANY TO BE AGENDIZED AS MATTERS FOR CONSIDERATION AT THE OCTOBER 17 BOARD MEETING

DIRECTORS' ANNOUNCEMENTS/REPORTS

GENERAL MANAGER'S ANNOUNCEMENTS/REPORTS

ADJOURNMENT

WATER ISSUES COMMITTEE MEMBERS

Committee Members

Cathy Green
Bruce Whitaker
James Vanderbilt
Vicente Sarmiento
Tri Ta

Alternates

Shawn Dewane
Steve Sheldon
Dina Nguyen
Roger Yoh
Denis Bilodeau

In accordance with the requirements of California Government Code Section 54954.2, this agenda has been posted at the guard shack entrance and in the main lobby of the Orange County Water District, 18700 Ward Street, Fountain Valley, CA and on the OCWD website not less than 72 hours prior to the meeting date and time above. All written materials relating to each agenda item are available for public inspection in the office of the District Secretary. Backup material for the Agenda is available at the District offices for public review and can be viewed online at the District's website: www.ocwd.com

Pursuant to the Americans with Disabilities Act, persons with a disability who require a disability-related modification or accommodation in order to participate in a meeting, including auxiliary aids or services, may request such modification or accommodation from the District Secretary at (714) 378-3233, by email at jdurant@ocwd.com by fax at (714) 378-3373. Notification 24 hours prior to the meeting will enable District staff to make reasonable arrangements to assure accessibility to the meeting.

As a general rule, agenda reports or other written documentation has been prepared or organized with respect to each item of business listed on the agenda, and can be reviewed at www.ocwd.com. Copies of these materials and other disclosable public records distributed to all or a majority of the members of the Board of Directors in connection with an open session agenda item are also on file with and available for inspection at the Office of the District Secretary, 18700 Ward Street, Fountain Valley, California, during regular business hours, 8:00 am to 5:00 pm, Monday through Friday. If such writings are distributed to members of the Board of Directors on the day of a Board meeting, the writings will be available at the entrance to the Board of Directors meeting room at the Orange County Water District office.

MINUTES OF BOARD OF DIRECTORS MEETING
WATER ISSUES COMMITTEE
ORANGE COUNTY WATER DISTRICT
September 12, 2018 @ 8:00 a.m.

Director Green called the Water Issues Committee meeting to order at 8:00 a.m. in the District Boardroom. The Assistant District Secretary called the roll and reported a quorum of the insert

Committee Members

Cathy Green
Bruce Whitaker
James Vanderbilt (absent)
Vicente Sarmiento
James Vanderbilt (absent)

OCWD

Mike Markus – General Manager
Mike Wehner – Assistant General Manager
Joel Kuperberg – General Counsel
Christina Fuller–Assistant District Secretary

Alternates

Shawn Dewane (absent)
Steve Sheldon
Dina Nguyen
Roger Yoh (absent)
Denis Bilodeau
Tri Ta

CONSENT CALENDAR

The Consent Calendar was approved upon motion by Director Whitaker, seconded by Director Nguyen, and carried [5-0].

Ayes – Green, Whitaker, Sheldon, Nguyen, Ta

1. Minutes of Water Issues Committee Meeting Held August 8, 2018

The Minutes of the Water Issues Committee meeting held August 8, 2018 were approved as presented.

2. FY2018-19 Coastal Pumping Transfer Program

Recommended for approval at September 19 Board meeting: Authorize the General Manager to make partial Basin Equity Assessment payments of up to 50% of the expected fiscal year end payment to coastal CPTP participants if requested.

3. Agreements to Habitat West Inc. for Temporary Labor Services at Field Headquarters and Prado Wetlands

Recommended for approval at September 19 Board meeting: 1) Authorize issuance of Agreement to Habitat West Inc. for temporary labor services at Field Headquarters (Department 1060) in the amount of \$35,000 and 2) Authorize issuance of Agreement to Habitat West Inc. for temporary labor services at the Prado Wetlands (Department 1062) in the amount of \$10,000.

4. City of Huntington Beach – Well #9 Partial Basin Equity Assessment Exemption Agreement - Amendment #1

Recommended for approval at September 19 Board meeting: 1) Authorize execution of Amendment #1 to the Limited Term Partial Basin Equity Assessment Exemption Agreement with City of Huntington Beach subject to minor edits approved by legal counsel; and 2) Increase the Agreement Project Cost from \$2.80 million to \$3.52 million.

5. Golden State Water Company Wilson Well #1 - Petition for Exemption of Payment of Replenishment Assessment and Basin Equity Assessment and Schedule Public Hearing

Recommended for approval at September 19 Board meeting: 1) Receive and file Petition for Exemption from Golden State Water Company for Wilson Well #1 groundwater pumping from payment of the Replenishment Assessment and Basin Equity Assessment; 2) Receive and file staff report evaluating Golden State Water Company petition; and 3) Schedule a Public Hearing on this matter on October 3, 2018 for the FY2018-19 RA and BEA, in accordance with Section 38.1 of the District Act.

6. Intellectual Property Plan Agreement with University of Nevada Reno to Support Collaborative Research Grant

Recommended for approval at September 19 Board meeting: Approve and authorize General Manager to execute Intellectual Property Plan Agreement with University of Nevada Reno.

7. Amendment Number 1 to Agreement with The California State University Long Beach Foundation for Fish Studies and Statistics Analysis

Recommended for approval at September 19 Board meeting: Approve and authorize execution of Amendment Number 1 to Agreement 1205 between CSULB Foundation and OCWD for a cost not to exceed \$80,000.

8. Amendment Number 1 to Drought Grant Contract with The Santa Ana Watershed Project Authority (SAWPA) and Assignment Agreement with the Municipal Water District of Orange County (MWDOC)

Recommended for approval at September 19 Board meeting: Approve and authorize execution of Amendment number 1 to the Drought Solicitation Implementation Grant Funding Contract between SAWPA and OCWD and the Implementation Grant Funding Assignment Agreement between OCWD and MWDOC.

MATTERS FOR CONSIDERATION

9. Revised Project Budget for the GWRS Final Expansion Project and Issuance of Amendment No. 2 to Black & Veatch for the Design of the GWRS Final Expansion Project in an Amount Not to Exceed \$386,900

GWRS Program Manager Sandy Scott-Roberts reported that the design for the GWRS Final Expansion Project is currently approximately 60% complete. She reported that staff received an updated construction cost estimate for the project and would like to revise the project budget to reflect a more realistic cost estimate including equipment additions and modifications to the original design. Ms. Scott-Roberts advised that in addition, staff has asked Black and Veatch to complete additional evaluations to provide benefit to OCWD as part of the GWRSFE design contract.

She presented the revised project budget and reported that the GWRS Final Expansion Project Budget has increased by \$39 million due to the addition of new equipment/facilities for the benefit of the project. She stated the estimated construction costs have increased for the Advanced Water Treatment Facility expansion, plant 2 effluent pump station, and OCSD headworks modification components, while the cost estimates for the flow equalization tank and pipeline rehabilitation project components have decreased slightly.

Upon motion by Director Whitaker, seconded by Director Sarmiento and carried [5-0], the Committee recommended that the Board at its September 19 meeting: 1) Revise the Project Budget for the GWRS Final Expansion Project from \$252,800,000 to \$292,118,000; and 2) Authorize issuance of amendment no. 2 to agreement no. 1248 with Black & Veatch for design phase services for the GWRS Final Expansion Project for an amount not to exceed \$386,900.

Ayes – Green, Whitaker, Sarmiento, Sheldon, Nguyen

10. Certification of Environmental Impact Report for Prado Dam Deviation and Sediment Management Demonstration Project

Executive Director Greg Woodside recalled that the Orange County Water District (District) and the Army Corps of Engineers (Corps) have worked together for many years to steadily increase the volume of storm water that can be temporarily retained behind Prado Dam. He reported that the District and the Corps have prepared environmental documentation for a 5-year Prado Dam deviation to temporarily expand the Prado Dam buffer pool from elevation 498 feet to 505 feet, resulting in 10,000 acre-feet of additional flood season storage capacity. Mr. Woodside stated this increase is during the flood season, which extends from October 1 to the end of February. He advised the environmental documentation also included refinements to the Prado Sediment Management Demonstration Project, which would remove 120,000 cubic yards of sediment from Prado Basin.

Upon motion by Director Sarmiento, seconded by Director Nguyen and carried [5-0], the Committee recommended that the Board at its September 19 meeting: Adopt a resolution, which includes the following actions: 1) Certifying the Final Environmental Impact Report for the 5-year Prado Dam Deviation and Prado Basin Sediment Management Demonstration Project; 2) Adopting the Findings of Fact and the Mitigation Monitoring Reporting Program; 3) Approving the District's participation in the 5-year Prado Dam deviation; 4) Approving the revised Prado Basin Sediment Management Demonstration Project; 5) Authorizing staff to complete the permitting process with the Army Corps of Engineers and the resource agencies, execute the permits received from the Army Corps of Engineers and the resource agencies, and prepare and implement the Habitat Management Program for the 5-year Deviation and Sediment Management Demonstration Project; 6) Authorize staff to advertise opening for 2-year limited term employee contract for monitoring natural resources in Prado Basin in connection with the 5-year Prado Dam deviation; 7) Authorize Amendment No. 3 to Agreement 0625 with HDR Engineering, Inc. in an amount not to exceed \$99,400 for Prado Basin Sediment Management Demonstration Project Bid Document modifications and engineering support during bidding and construction; and 8) Authorizing staff to file Notice of Determination.

Ayes – Green, Whitaker, Sarmiento, Nguyen, Bilodeau

INFORMATIONAL ITEMS

11. Basin Storage Update for Water Year 2017-18

Principal Engineer Tim Sovich stated that staff evaluated water level conditions throughout the basin and constructed groundwater elevation contour maps representing the end of the water year. He reported that with using the "full basin" benchmark for all three aquifer layers in the basin, an accumulated overdraft of 277,000 acre-feet (AF) was calculated as of June 30, 2018. He advised that the basin experienced an annual storage increase of 51,000 AF for water year 2017-18.

12. GWRS Unit I Pipeline Rehabilitation Project Update

Ms. Scott-Roberts reported that work on the GWRS Unit I Pipeline Rehabilitation Project has begun by F.D. Thomas, Jamison, and CSI. She advised that the inside of the pipeline is being coated with an epoxy lining. She stated the work is currently on-schedule and will continue through September 30th. Ms. Scott-Roberts reported that after the epoxy has been applied and cured to the satisfaction of OCWD, the pipeline will be slowly returned to service by OCWD water production with oversight by Jamison Engineering. She advised that staff anticipates that GWRS will be back up to full production by October 3rd.

CHAIR DIRECTION AS TO ITEMS IF ANY TO BE AGENDIZED AS MATTERS FOR CONSIDERATION AT THE SEPTEMBER 19 BOARD MEETING

It was agreed to place items No. 2-10 on the Consent Calendar at the September 19 Board meeting.

ADJOURNMENT

There being no further business, the meeting was adjourned at 9:35 a.m.

Cathy Green, Chair

AGENDA ITEM SUBMITTAL

Meeting Date: October 10, 2018

To: Water Issues Committee
Board of Directors

From: Mike Markus

Staff Contact: D. Mark / R. Herndon /
B. Hunt

Budgeted: Partial

Budgeted Amount: \$40,000

Cost Estimate: \$76,932

Funding Source: General Fund and
Proposition 1 Grant

Program/Line Item No.:

1075.53010.1711

General Counsel Approval: N/A

Engineers/Feasibility Report: N/A

CEQA Compliance: N/A

**Subject: AGREEMENT WITH INTERA FOR CAPTURE ZONE MODELING AND
ANALYSIS OF NORTH BASIN EXTRACTION WELL EW-1**

SUMMARY

Capture zone modeling and analysis of extraction well EW-1 is needed to evaluate the well's performance, optimize its operation, and meet a requirement of the Proposition 1 Implementation Grant awarded for the project. Staff recommends issuing an Agreement for this work to Intera, the firm that developed the groundwater model for the North Basin RI/FS, for an amount not to exceed \$76,932.

Attachment: Intera's September 10, 2018 proposal for Three-Dimensional Capture Zone Analysis for OCWD North Basin Extraction Well EW-1

RECOMMENDATION

Agendize for October 17 Board meeting: Authorize issuance of Agreement to Intera for Three-Dimensional Capture Zone Analysis for OCWD North Basin Extraction Well EW-1 for an amount not to exceed \$76,932.

BACKGROUND/ANALYSIS

North Basin extraction well EW-1 began operating in October 2017. The target pumping rate range for EW-1 (840 to 1,000 gallons per minute) was based on the lateral extent of the up-gradient VOC plume, and two-dimensional capture zone modeling conducted using a groundwater model developed for the previous North Basin Groundwater Protection Project. Since that time, the District retained the modeling firm Intera to develop a more refined groundwater model of the North Basin area in support of a National Contingency Plan-compliant Remedial Investigation and Feasibility Study (RI/FS). Intera completed the initial model refinement and calibration in May 2017. Subsequently, the model has undergone additional refinement in response to U.S. Environmental Protection Agency (EPA) comments. The model may be refined further if deemed necessary based on data from the monitoring wells installed for the North Basin RI (currently in progress).

As the name implies, the capture zone of a pumping well is the lateral and vertical region of aquifer in which groundwater will flow into the well and not flow past the well. For optimal capture and containment of a contaminant plume, the three-dimensional capture zone should be large enough to encompass the width and depth of the plume. This assumes the well's pumping capacity and depth are sufficient to attain a large enough capture zone. If not, then the capture zone may be smaller than the plume, meaning some portion of the plume will not be captured. On the other hand, if a well is operated at too high of a pumping rate or extends too far below the bottom of the plume, then the well may be unnecessarily capturing clean groundwater. The goal of this analysis is to identify the optimal range of pumping based on plume characteristics.

To help evaluate the performance and optimize the EW-1 operation, three-dimensional capture zone analysis using the refined groundwater model is recommended. Based on that analysis, the EW-1 pumping rate may be modified and/or portions of the screened interval of the well may be sealed off to optimize removal of groundwater containing volatile organic compounds (VOCs). Also, conducting the refined capture zone analysis is a requirement of the Proposition 1 grant award to OCWD for the EW-1 project. The capture zone modeling and analysis will be conducted in accordance with the EPA guidance document: *A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems*, EPA/600/ R-08/003, January 2008.

Because of the large size of the North Basin VOC plume, the North Basin groundwater model developed by Intera is a regional model. Detailed three-dimensional capture zone analysis of EW-1 will require further discretization and refinement of the model in the vicinity of EW-1. Staff requested Intera to submit a proposed scope of work and cost estimate for the capture zone analysis (attached). It will be significantly more cost effective for Intera to conduct this work, compared to retaining a different modeling consultant. It would take considerable time and expense for another modeling firm to come up to speed on the hydrogeology and the model, and then make the necessary refinements. Also, Intera is currently under an Agreement with OCWD to conduct the modeling for the North Basin RI/FS. So, it will be beneficial to the District to have one consultant conducting the modeling for both the EW-1 project and North Basin RI/FS. Consequently, staff is recommending a sole-source award of an Agreement with Intera for an amount not to exceed \$76,932. Half of those costs should be reimbursed to the District by the State under the Proposition 1 grant for the EW-1 Project.

PRIOR RELEVANT BOARD ACTION(S)

3-16-2016, R016-3-27 - Approval of EW-1 Project with Discharge to the Sewer.

September 10th, 2018

Mr. Dave Mark
Principal Hydrogeologist
Orange County Water District
18700 Ward Street
Fountain Valley, CA 92708


RE: Proposal to conduct 3D capture zone analyses for OCWD North Basin Extraction Well 1 (EW-1)

Dear Mr. Mark,

INTERA Inc. is pleased to submit this proposal to conduct 3D capture zone analyses for the OCWD EW-1, located within the Orange County North Basin (North Basin). EW-1 is an important extraction well that captures groundwater contaminated with volatile organic carbons (VOCs) emanating from source areas in the eastern most portion of the basin. The capture zone analyses will identify the extent of groundwater capture by EW-1. It is our understanding that this analysis will support on-going and future remedial activities and investigation in the North Basin. INTERA has developed the numerical groundwater model for the North Basin and will be utilizing this model to perform the 3D capture zone analyses.

Please do not hesitate to contact me if you have any questions about the proposed scope, schedule, or budget. We appreciate the opportunity to submit this proposal.

Sincerely,



Abhishek Singh, PhD, CA PE 89384
Manager - California Operations, Senior Water Resources Engineer
INTERA Incorporated
3868 W. Carson Street, #316, Torrance, CA 90503
asingh@intera.com | Mobile: 217.721.0301 | Office: 424.275.4055

Enclosure: *Proposal for Three-Dimensional (3D) Capture Zone Analyses for OCWD North Basin Extraction Well 1 (EW-1)*



Proposal for Three-Dimensional (3D) Capture Zone Analyses for OCWD North Basin Extraction Well 1 (EW-1)

Introduction

The North Basin site, located in the cities of Fullerton, Anaheim and Placentia, contains a five-mile long plume of contamination that has caused five drinking wells to be taken out of service. The contamination consists of industrial solvents, referred to as volatile organic compounds (VOCs), that spilled into the ground from past industrial/manufacturing activities. Residents' drinking water is safe; however, the contamination is moving toward the deep aquifer of the Orange County Groundwater Basin which is managed by OCWD. The North Basin Cleanup effort will control the plume from spreading and prevent further well closures. After conducting extensive studies and research, OCWD has implemented a multiprong cleanup strategy that includes voluntary cleanup work, litigation, settlement agreements, state and federal oversight, and solicitation of grant funding. As part of the cleanup efforts, OCWD has installed six (6) extraction wells for hydraulic control and pump and treat remediation of the VOC plume. In 2017, OCWD began to pump from Extraction Well 1 (EW-1), 1 which is considered one of the most important of the original six wells due to its location upgradient of two drinking water wells.

In 2014, OCWD hired INTERA to build a refined conceptual and numerical groundwater model of the North Basin, incorporating site-specific hydrogeologic, lithological, and water quality data. The model was based on the existing regional OCWD model, while being updated, refined, and calibrated to the most recent hydraulic and contaminant concentration data (from 2005 – 2014). The model simulates the Shallow Aquifer as a single layer, the aquitard as another layer, and the Principal Aquifer as 10 layers. The aquitard has been refined and calibrated such that various zones showing downward migration of contaminants are simulated. The modeling was completed in 2017 and has been favorably reviewed by stakeholders and regulators. Model refinements are currently underway to respond to technical review comments.

To support operational and cleanup objectives for the EW-1 project, OCWD is interested in evaluating the three-dimensional (3D) capture zone for the EW-1 well, in relation to contamination in the Shallow and Principal aquifers. This proposal describes the tasks and level of effort required to evaluate the 3D capture zone for EW-1. The EPA's EPA guidance document, "A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems, EPA/600/R-08/003, January 2008", will form the basis for the capture zone analysis entailed as part of this evaluation.

Proposal for 3D Capture Zone Analyses for
OCWD North Basin Extraction Well 1 (EW-1)

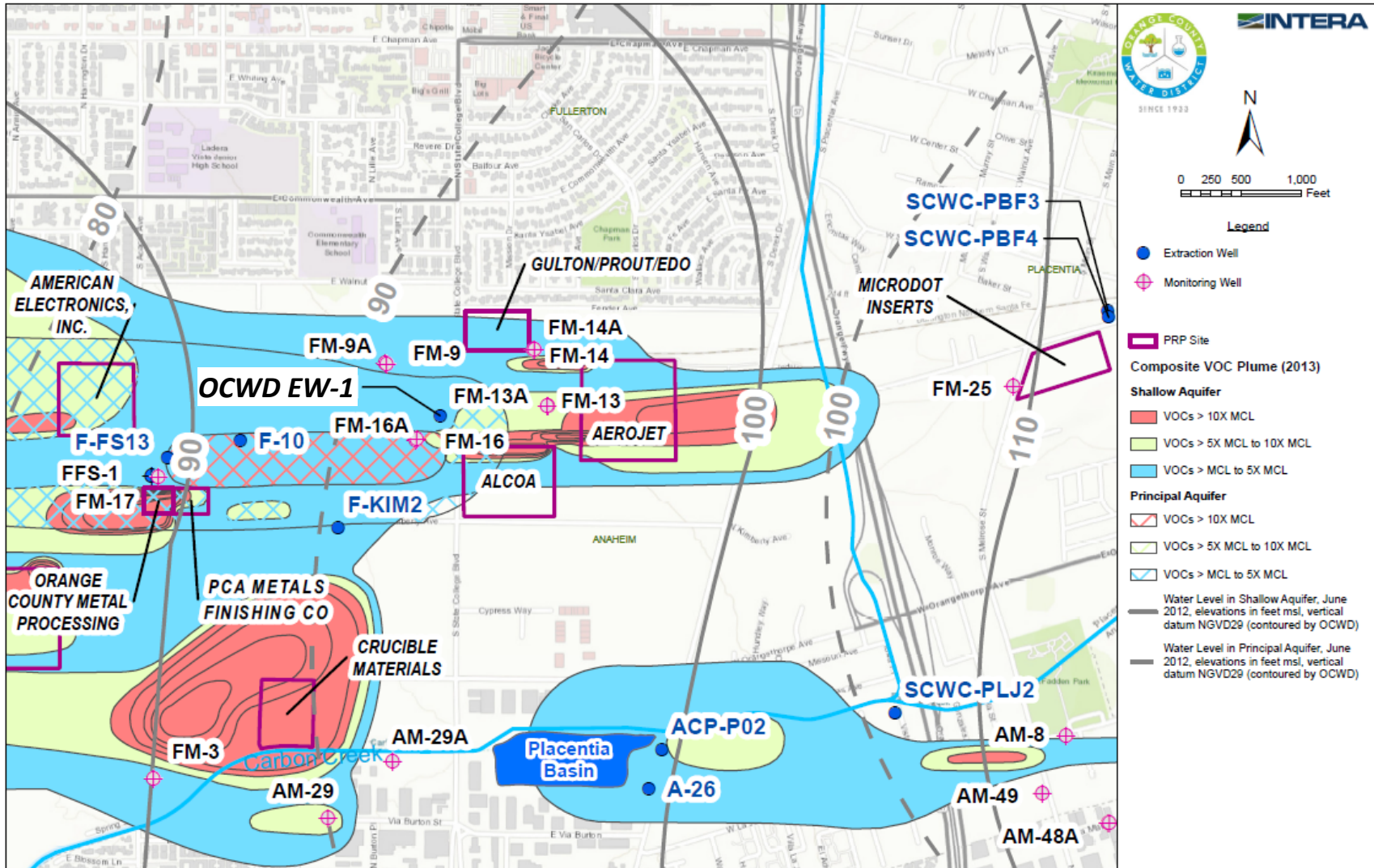


Figure 1: 2013 VOC Plumes, extraction, and monitoring wells around the EW-1 area

Scope of Work

The purpose of this scope is to describe the sub-tasks and level of effort required to conduct three-dimensional capture zone analysis for EW-1. The analysis will be conducted based on the refined and calibrated North Basin groundwater model.

The following sub-tasks are proposed for this evaluation:

- 1) Additional refinement and calibration around EW-1: the model currently simulates the Shallow Aquifer and upper aquitard as single layers. However, there is evidence of locally perched conditions in the Shallow Aquifer may act as transient sources for VOCs in the area, impacting contaminant concentration in the groundwater. Comparison of water levels at several shallow PRP wells and OCWD wells (screened at different depths within the Shallow aquifer) indicate vertical gradients within the Shallow aquifer. Furthermore, the aquitard between the Shallow and Principal aquifers is discontinuous or absent in and around the EW-1 area. For this reason, we propose additional model layering and horizontal refinement within the Shallow Aquifer around the EW-1 area. Current model cells range from 125 – 500 feet (ft) in dimension. We anticipate refining the model locally by adding at least one additional model layer and refining the cells locally to 25 – 100 ft. For this refinement INTERA will review well logs, water levels, and water quality data from shallow monitoring wells to evaluate the local hydrogeology and stratigraphy in and around EW-1. Note, that the current model is built using MODFLOW-NWT, which facilitates the simulation of unsaturated/unconfined conditions.

INTERA will subsequently adjust model properties – horizontal and vertical hydraulic conductivities, specific yields, and storage coefficients in the Shallow Aquifer, upper aquitard and upper Principal – to improve the calibration of hydraulic head and remain consistent with observed concentration trends. Heads and water quality data in the Principal Aquifer will also be used to ensure adequate calibration in the upper part of the Principal Aquifer, which are in communication with the Shallow Aquifer through the discontinuous/absent aquitard in the area. INTERA will evaluate the concentration data in the EW-1 area to ensure that the hydrogeology around area is adequately calibrated with respect to water quality trends.

INTERA will use the flow data-set from 2005-2017 and the concentration data-set from 2008 – 2017 for the model refinement and calibration effort. Weekly (up to a total of four) conference calls with OCWD Hydrogeologists are anticipated to ensure close coordination and knowledge-sharing during the model refinement and calibration phase. The refinements made to the model as part of the EW-1 capture zone analysis will be incorporated into the subsequent revised version of the North Basin model.

- 2) Particle tracking to simulate capture zones: once the model has been refined and calibrated adequately, INTERA will perform particle-tracking simulations using the MODPATH (Pollock, 1994) to evaluate the capture zone for EW-1. The particle-tracking will be performed using the transient groundwater flow model for the baseline period of 2005-2017. In keeping with EPA's guidance document on capture zone analysis, this will entail releasing particles from multiple locations and depths in the area upgradient of EW-1. Concentration trends at PRP and OCWD monitoring/production wells will be reviewed to decide on initial distribution of particles, ensuring that the particles cover the existing VOC plume within the Shallow and Principal Aquifers. The particle tracking simulations will be repeated with different (up to three) extraction rates at EW-1.

These results will be communicated via (up to two) conference calls between INTERA and OCWD.

- 3) Three-dimensional and transient visualization: Particle traces that are captured by EW-1 (exit or stop at the groundwater well), will be extracted and used to define the three-dimensional capture zone for the well. We will use the USGS software, "Model Viewer", a free program for three-dimensional visualization of ground-water model results (Hsieh and Winston, 2002), to visualize and communicate model results with OCWD. Figure 2 shows an example 3D visualization using this interface.

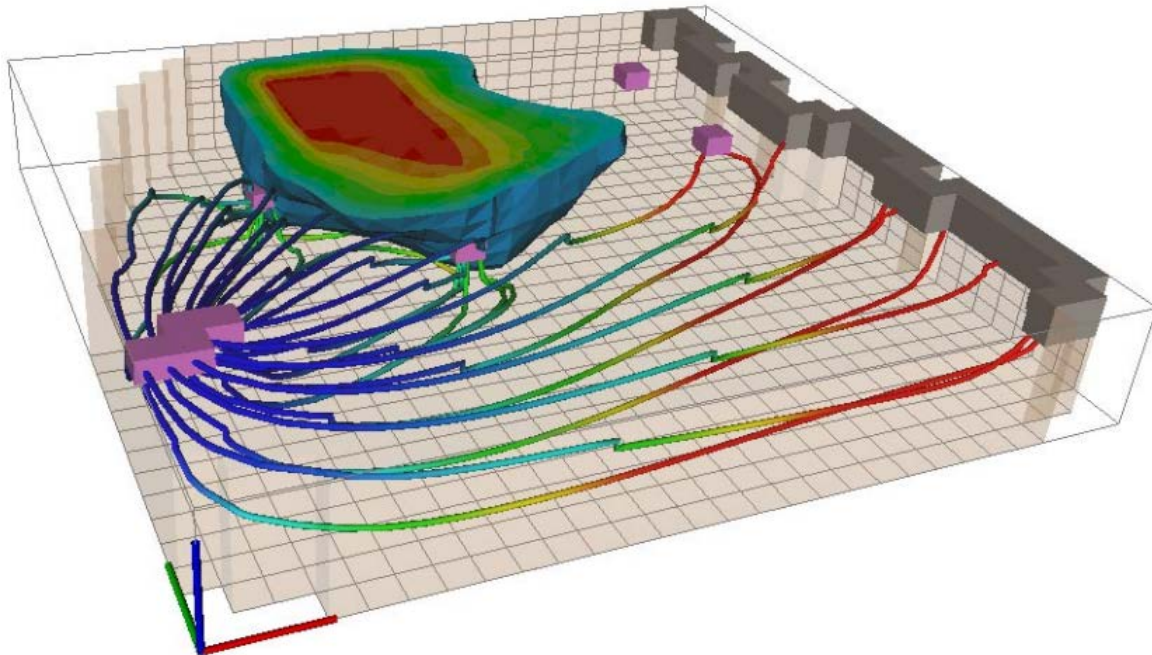


Figure 2: 3D Visualization of particle tracks (and contaminant plume) in Model Viewer.

*Proposal for 3D Capture Zone Analyses for
OCWD North Basin Extraction Well 1 (EW-1)*

Alternatively, ESI's GW3D interface can be used to visualize and communicate model results. GW3D seamlessly integrates with Groundwater Vistas, the modeling platform for the North Basin model. With either option, transient particle tracks can be animated to show the time-evolution of the capture around the extraction well. Finally, 3D GIS analysis (using ArcScene) will be used to consolidate the particle tracks within a three-dimensional volume representing the capture zone for EW-1. Different capture zones will be computed for different production rates.

These results will be communicated via a conference call between INTERA and OCWD.

- 4) Documentation and Communication of Model Results: INTERA will prepare a technical memorandum to document all model refinements as well as the particle tracking simulations, and capture zone analysis. These results will also be communicated with OCWD during an in-person meeting at the OCWD office. OCWD will review the memo and provide feedback and comments over a period of two weeks. INTERA will address all review comments in one round of model/memo revisions.

Proposal for 3D Capture Zone Analyses for
OCWD North Basin Extraction Well 1 (EW-1)

Cost

The level of effort and corresponding cost associated with the sub-tasks described above are shown in the table below:

		3D Capture Zone Analysis for EW1							
		Task 1. Model Refinement and Recalibration		Task 2. Particle Tracking and Capture Zone Simulations		Task 3. 3D Processing and Visualization		Task 4. Documentation	
Staff Name	Rate/ Hour	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost
Principal Engineer/Scientist I	\$250	Rate provided for information purposes							
Principal Engineer/Scientist III	\$225	Rate provided for information purposes							
Principal Engineer/Scientist III	\$210	Rate provided for information purposes							
Senior Engineer/Scientist I (Singh)	\$195	60	\$11,700	16	\$3,120	16	\$3,120	40	\$7,800
Senior Engineer/Scientist II	\$170	Rate provided for information purposes							
Senior Engineer/Scientist III (Suribhatla)	\$150	80	\$12,000	40	\$6,000	40	\$6,000	40	\$6,000
Senior Engineer/Scientist IV	\$142	Rate provided for information purposes							
Engineer/Scientist I (O'Connell)	\$125	Rate provided for information purposes							
Engineer/Scientist II (O'Connell)	\$110	40	\$4,400	16	\$1,760	16	\$1,760	40	\$4,400
Engineer/Scientist III (Harding)	\$100	Rate provided for information purposes							
Engineer/Scientist IV	\$90	Rate provided for information purposes							
Graphics/GIS	\$87	16	\$1,392	8	\$696	32	\$2,784	32	\$2,784
Technical Editor	\$76	0	\$0	0	\$0	0	\$0	16	\$1,216
Project Associate	\$73	Rate provided for information purposes							
Sub-Task Hours/Costs		196	\$29,492	80	\$11,576	104	\$13,664	168	\$22,200
Totals	\$76,932								

AGENDA ITEM SUBMITTAL

Meeting Date: October 10, 2018

To: Water Issues Committee
Board of Directors

From: Mike Markus

Staff Contact: G. Woodside/A. Hutchinson

Budgeted: Yes

Budgeted Amount: \$25,000

Cost Estimate: \$23,000

Funding Source: General Fund

Program/Line Item No. 1044.51112

General Counsel Approval: Yes

Engineers/Feasibility Report: N/A

CEQA Compliance: N/A

**Subject: AGREEMENT TO RAMBOLL TO CONDUCT GEOPHYSICAL
INVESTIGATION IN LOWER OFF-RIVER CHANNEL**

SUMMARY

The District's Lower Off-River Channel has a recharge rate that is lower than adjacent areas. This is likely due to shallow, fine-grained sedimentary layers that restrict recharge. Staff recommends conducting a geophysical survey to characterize the shallow sediments in the Lower Off-River Channel to assess the feasibility of removing fine-grained sediments and thereby improve overall recharge rates.

Attachment: Ramboll Proposal to Conduct Geophysical Investigation in Lower Off-River Channel

RECOMMENDATION

Agendize for October 17 Board meeting: Authorize issuance of agreement to Ramboll for a geophysical investigation of the Lower Off-River Channel for an amount not to exceed \$23,000.

BACKGROUND/ANALYSIS

In response to severe flooding in 1969, the US Army Corps of Engineers and Orange County Flood Control District constructed improvements in the early 1970s to the Santa Ana River Channel that created an approximately 300 feet channel of uniform width. In OCWD's recharge area where the river was wider than 300 feet, new facilities were created, including the Weir Ponds, Upper Off-River Channel, Lower Off-River Channel, Five Coves Basins, Lincoln Basin and the eastern edge of Burriss Basin. All of these facilities serve to convey water to downstream facilities. The recharge capacity of these facilities vary due to local groundwater levels and shallow geologic conditions.

The two facilities that appear to have the most potential for recharge are the Lower Off-River Channel and the Five Coves Basins. Recharge rates in the Lower Off-River Channel are lower than the adjacent Santa Ana River Channel. An investigation of shallow sediments in the Lower Off-River Channel from ground surface to about 20 to 50 feet below ground surface (bgs) indicated that a shallow fine-grained layer exists in multiple areas in the channel. This shallow fine-grained layer consists primarily of silt and clay, ranges in thickness from about one-half foot to three feet thick, and typically extends from about one to four feet bgs (OCWD, 1999). The extent of the Lower Off-River Channel, which covers approximately 60 acres, is shown in Figure 1.



Figure 1
Location of Lower Off-River Channel and Area of Investigation

A more recent investigation using Fiber Optic Distributed Temperature Sensing (FODTS) in the Lower Off-River Channel showed wide variations in recharge rates, which were attributed to geologic conditions and clogging (Ellis, 2018).

Given the presence of shallow, fine-grained sediments it is likely that the recharge capacity of the Lower Off-River Channel could be improved if the areal and vertical distribution of fine-grained sediments could be determined and these sediments removed. Investigatory techniques used to date are useful for determining site-specific conditions, but are less useful for determining the large, areal and vertical extent of sedimentary layers.

Electromagnetic Induction (EM)

Electromagnetic induction (EM) is a technique that can quickly provide a three-dimensional picture of subsurface conditions over a wide area that takes advantage of the different behavior of sediments to an applied electric current. In simple terms, fine-grained sediments that contain clays, tend to be very conductive and more easily transmit an electric current compared to sands, which are resistive and thus do not easily transmit electric currents. Unlike conventional resistivity techniques, EM does not require ground contact. This eliminates direct electrical coupling problems and allows much more rapid data acquisition.

For the Lower Off-River Channel, the EM survey would be conducted with a DualEM421s system. The DualEM421s is a Canadian manufactured EM system that is considered state-of-the-art. It consists of a 12 ft long sensor and two small batteries, GPS receiver and light weight Toughbook computer used for navigation and data storage, cables etc. Collected data are synchronized with location data provided by GPS system. The DualEM421s is towed behind an All-Terrain Vehicle (ATV) as shown in Figure 2.



Figure 2
DualEM421s sensor pulled behind an ATV

Data Processing

Collected data is processed using specialized software to create digital three-dimensional maps of resistivity. These data are presented as “slices” of resistivity with depth. An example output is shown in Figure 3. Staff can use this output to locate fine-grained layers (low resistivity), determine the areal extent at each depth range and then determine whether or not it is feasible to remove these layers.

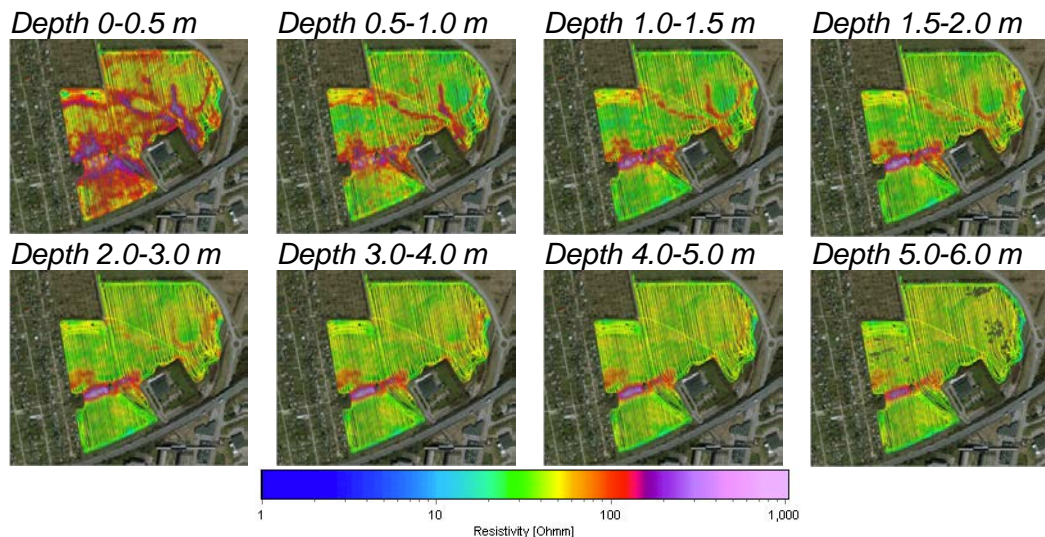


Figure 3
Sample Results: Figures show variations in resistivity (i.e., sediment type) with depth

Recommendation

Staff has coordinated with Ramboll and the Chino Basin Watermaster to mobilize the testing equipment to southern California so that both projects can be done within the same timeframe. This reduced the project costs to OCWD by \$4,000.

There are few vendors that do this type of analysis and have experience with processing data to look at potential impacts of sedimentary layers on recharge rates. Tucson Water conducted a similar survey of their recharge basins using Zonge International, Inc. (Tucson). Several attempts were made to obtain a quote from Zonge but they were unresponsive.

Staff recommends issuance of agreement to Ramboll for a geophysical investigation of the Lower Off-River Channel for an amount not to exceed \$23,000.

References:

OCWD, 1999. Staff Report, Off-River Recharge Basin Silt Layer Removal and Recharge Test, Prepared by: Greg D. Woodside, March 16, 1999.

Ellis, W. 2018. Determining Spatial and Temporal Variability of Percolation Rates from a River-Side Recharge Basin Using Fiber Optic Distributed Temperature Sensing. Master of Science Thesis, California State University, Long Beach.

PRIOR RELEVANT BOARD ACTION(S)

3/21/12, R12-3-12 - Authorizing agreement with CSULB to conduct research in Off-River and Santa Ana River Channels.

Intended for
Orange County Water District
18700 Ward Street, Fountain Valley, CA 92708 Environmental Health

Document type
Proposal

Date
March 2018

GEOPHYSICAL INVESTIGATION, LOWER OFF-RIVER CHANNEL DUALEM



GEOPHYSICAL INVESTIGATION, LOWER OFF-RIVER CHANNEL DUALEM

Revision **1**
Date **30/03/2018**
Made by **MAXH**
Checked by **PRT**
Approved by
Description **Proposal DUALEM**

Ref

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ATTACHMENTS

Attachment A: Ramboll's Standard Terms and Conditions

1. SCOPE OF WORK AND AREA OF INTEREST

The objective of this proposal is to conduct Ground Conductivity Meter (GCM) surveys at the Lower Off-River Channel in Anaheim for the Orange County Water District (OCWD). The scope of work is to use GCM to map the near surface geology on the selected site. It is expected that the survey will provide information about how the geology and the sediments will vary within the survey area.

The survey will use the DUALEM method which has proven to be effective in providing this type of information. This is illustrated by a selection of references (see Section 10).

1.1 Areas of interest

OCWD has identified the following site, shown on Figure 1, where the DUALEM survey will take place.

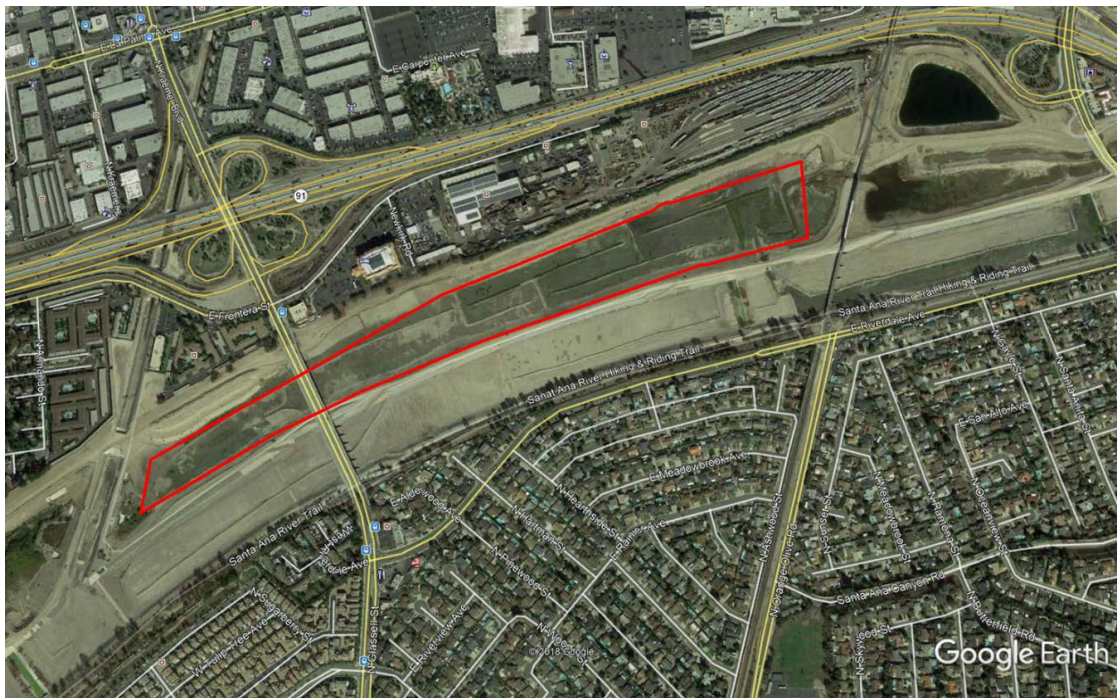


Figure 1 Location of the survey area.

The survey area is approximately 1.5km long and 120m wide. We propose to a dense line spacing (1-2m) between survey runs. Depending on the accessibility we estimated that the survey can be done in maximum 2 days.

2. PERSONNEL AND HEALTH AND SAFETY

2.1 Personnel

Geophysicist Peter Thomsen will be the field operation manager, responsible for the field operation and data processing. Geophysicist Max Halkjaer will take part in the field operation and be responsible for QA/QC. The geophysicists are familiar with the hardware as well as software. Hydrogeologist Dr. Farid Achour will serve as our local project manager. Patrick Campbell will act as Principal in Charge. Project team resumes are attached.

Ramboll will reserve the right to add more/replace staff members as needed to maintain an efficient and ongoing operation.

2.2 Health and safety

Prior to the execution of the field operation a Health and Safety plan will be developed for the specific project activities. A minimum one field team member will have First Aid certificate including CPR.

3. DUALEM 421 INSTRUMENTATION

For the EM survey Ramboll recommends the DualEM421s system. The DualEM421s is a Canadian manufactured EM system with fixed frequency, a transmitter coil and 6 different receiver coils (<http://www.dualem.com/products/>). Three horizontal coils (HCP) at a distances of 1, 2 and 4 m from the transmitter coil, and three vertical receiver coils (PRP) at 1,1 m, 2,1 m and 4,1 m from the transmitter coil, results in 6 apparent resistivity in 6 different depths. Through geophysical inversion the 6 data point are interpreted to a smooths layered resistivity model. Depth of investigation is calculated based on data and inverted model, and varies under normal conditions from 6-8 m.

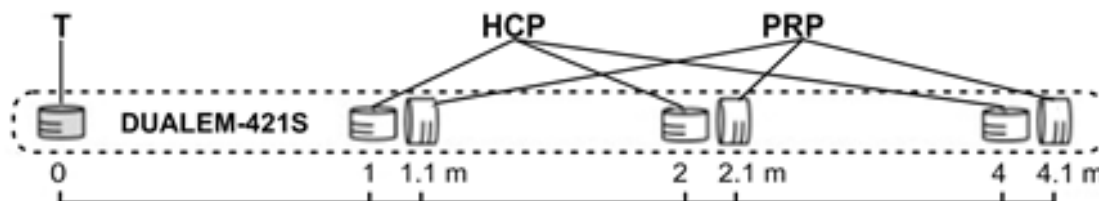


Figure 2 The DualEM421s sensor

The DualEM system is considered state of art for GCM instruments (Ground Conductivity Meters), and consists of a 4 m long sensor and two small batteries, GPS receiver and light weight Toughbook computer used for navigation and data storage, cables etc.

Collected data are synchronized with GPS time provided by GPS system. The GPS (Trimble SPS850 or equivalent) will be used for the survey.

Ramboll introduced the DualEM-system early 2013. For the last 4 years Ramboll has executed more than 60 projects, where DualEM has been included for mapping the sub-surface.

Projects vary from pre-geotechnical investigations, mapping of subsurface conditions related to infiltration of rainwater, mapping of contaminated sites, macro archaeological investigations and UXO's. Clients have included contractors, municipalities and national authorities, as described in the references in Section 10.

4. FIELD OPERATION

Ramboll will strive to achieve the good data quality. It is crucial that the system is configured and operated with forethought. For example, reliable and accurate data require that:

- All conductive parts as batteries, GPS, backpacks etc. are kept at least 3m from the sensor
- The sensor is operated as close to the terrain surface as possible, approximate 30 cm
- Vibrations / motion induced noise shall be kept to a minimum
- Pitch and roll of the sensor should be kept to a minimum and checked frequently during the survey

The data acquisition phase procedure includes following steps:

- Preparation and mobilization
- Survey lines imported to the navigation unit
- Acquisition of production data
- Data transfer and archiving
- Equipment maintenance
- Debriefing
- Data quality control and daily reporting

During the last four years Ramboll has done more 90 DUALEM projects. The instrumentation has been hand carried and towed behind an ATV vehicle. The choice of configuration is dependent on the size of the survey and the terrain conditions. We determine that the configuration where the system is pulled by an ATV providing data with a line spacing of 10-20ft is the optimum choice for this project.

Ramboll has designed a sled to accommodate for efficient field operation and strong data quality. Vibrations, pitch and role, and distance to the ground is kept to a minimum. The sled contains no metal parts. It is pulled approximately 4m behind an ATV, as shown in Figure 3, avoiding noise and bias signals caused by induced electromagnetic currents in metal parts such as batteries, GPS and the ATV itself.



Figure 3 The DualEM421s sensor pulled behind an ATV

During surveying, georeferenced video will be taken, using Garmin VIBR or similar camera.

During the processing and inversion of the data the height of the sensor will be taken into account.

4.1 Support from the client

It is expected that the client will provide an ATV to be used for the operation. There are no specific demands when it comes to the ATV though we will need a hitch hook or another point where the rope from the sensor can be attached. To be able to access all kinds of terrain, the ATV should preferably have 4 Wheel Drive.

The sensor will be shipped in advance from Denmark to OCWD in a box of 80x255x100cm (31.5x100.4x39.4inch) and a total weight of approx. 200kgs (440 pounds). It will be shipped to and from an OCWD address.

It is expected that the client will help us moving the sensor and instrumentation from OCWD's premises to the survey area.

5. PROCESSING AND INVERSION

For processing and inversion the software package Aarhus Workbench, with a special designed application for GCM data, is used (<http://www.aarhusgeosoftware.dk/aarhus-workbench>). The Workbench is a well-documented high level software package used for processing and inversion of electromagnetic and geoelectrical geophysical data.

Data are collected with 10 Hz repetition frequency. Data are filtered, moved laterally to common midpoint and soundings are extracted for every 2 meter along the survey lines. Position are measured by GPS and lateral moved to the common midpoint.

5.1 Processing steps

Raw data are imported and filtered using a band width of 3-5 metres. Sections where data are disturbed by external noise element, e.g. when passing electrical cables are deleted and soundings are extracted for every 2 metres. Each sounding consist of the six measured resistivity data, as shown in Figure 4.

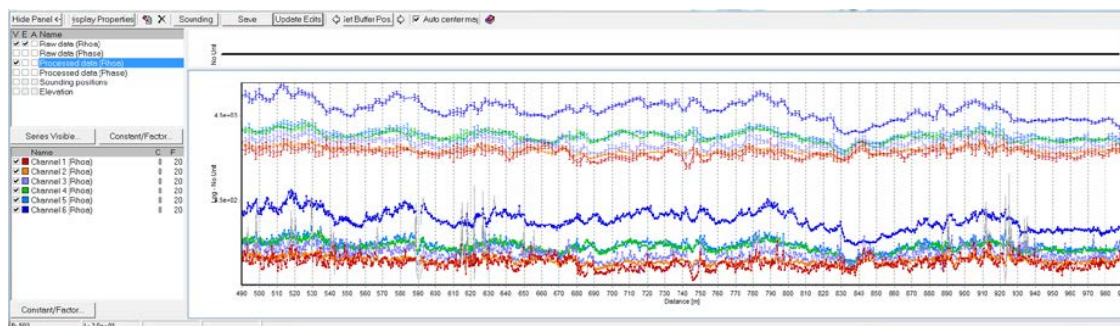


Figure 4 The lower section is raw data, and the upper section of six data are the filtered processed data. Screen shot from Aarhus Workbench

In general the processing includes:

- QC and conversion of the collected raw data to UTM Zone 10N (WGS84)
- Input defined raw data format in Workbench
- Deletion of disturbed data, which includes observations from the field
- Filtering and conversion to sounding for every 2 metres

5.2 Inversion

The processed data are inverted using a spatially constrained inversion (SCI) approach, where neighbouring soundings are constrained in a multi layered inversion. Figure 5 is multi-layered SCI-inversion of the data section, as displayed on Figure 4.

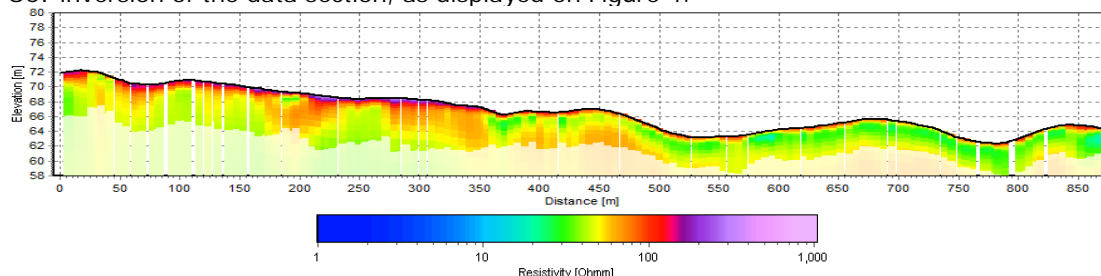


Figure 5 Multi layered SCI inversion of the section

The height of the sensor is included in the inversion scheme and subtracted from the resulting model. The result is a smooth coherent resistivity model along the inverted line.

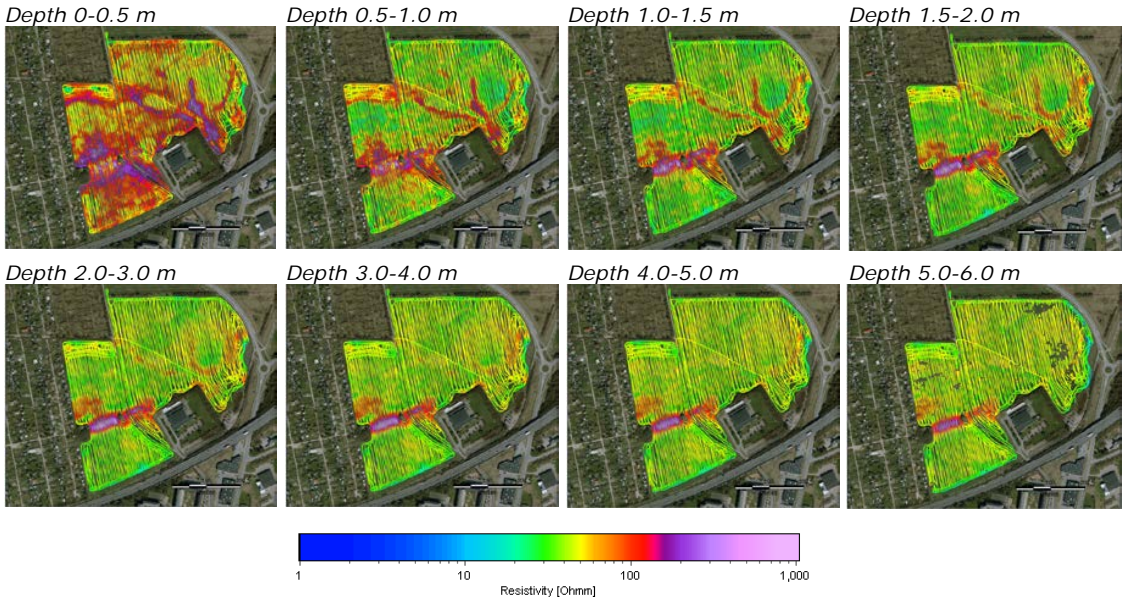
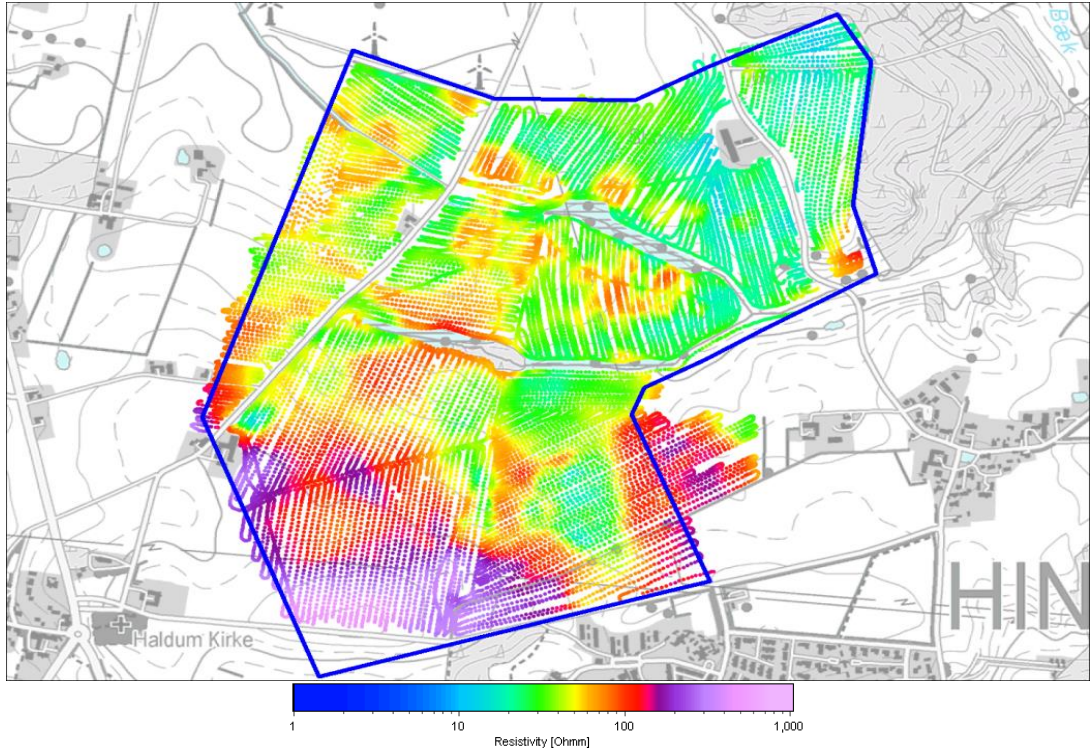


Figure 6 The results will be presented as a number of horizontal slices representing the variations in resistivity with depth.

6. QUALITY ASSURANCE AND QUALITY CONTROL

The data will be checked by the geophysicist onsite to provide real time confirmation of field measurements.

Furthermore the data quality is checked offsite by the Ramboll project team on a daily basis including final processing.

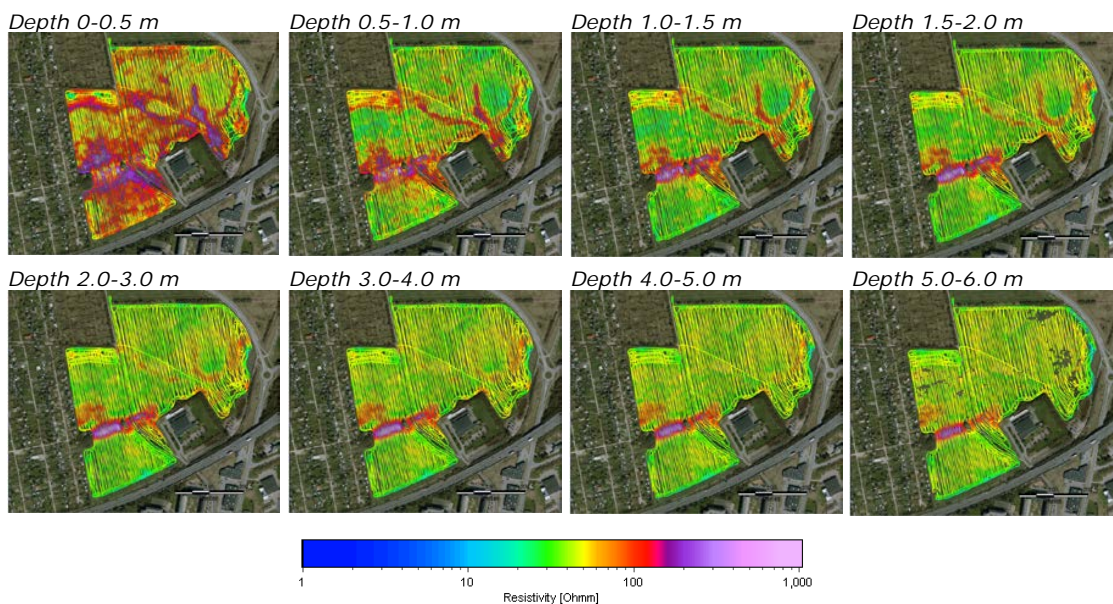
A daily report (email) outlining the production and data quality assessment will be submitted to the client. The daily report includes information of field crew, production, weather report, HSE issues, contact to stakeholders and observation of terrain.

7. DELIVERABLES

The deliveries from the DUALEM survey will include:

- A report including detailed description of data collection, processing and inversion.

Technical sections including horizontal slices representing the variations in resistivity with depth,



- Figure 6, and a number of model sections, as shown in Figure 5.
- Digital deliveries:
 - Digital ascii files: Raw data files as output files from the DUALEM instrument
 - Processed and inverted resistivity data prepared to be presented in GIS or other software platforms

A draft and final report will be delivered in a PDF format. Our scope includes responding to one round of comments on the draft report

Raw data and processed data can be provided as requested. All files will be labelled and listed.

The data and the report will be delivered no later than 4 weeks after the last day of surveying.

8. TIME SCHEDULE

We estimate that the total survey can be done within two days of field time. If OCWD finds that there are other sites where the type of data can create value, we will be happy to do such areas within the budget described below as long as it can be done within the two days.

Inverted model results will be delivered within 5 days after the daily report has been delivered.

We will be able to do the field work by May 2018.

9. BUDGET AND CONDITIONS

The budget is based on a minimum of two days of field work.

The price is based on a mobilization/demobilization cost and a day rate. The day rate includes all costs related to the field operation (except the ATV), data processing and inversion and a report.

All prices are in USD exclusive of VAT and any taxes.

Mobilization / demobilization and preparation	USD 9,000
2 days of field operation, processing, inversion and report	USD 18,000
Total	USD 27,000

Ramboll's standard Terms and Conditions (attached) will apply.

10. REFERENCES

/1/ Viezzoli, A., A. V. Christiansen, E. Auken, and K. I. Sørensen, 2008, Quasi-3D modeling of airborne TEM data by Spatially Constrained Inversion, *Geophysics*, 73, 3, F105-F113

MAPPING INFILTRATION CAPACITY OF THE UNSATURATED ZONE IN AN URBAN DEVELOPMENT AREA NEAR IKAST

Assessment of the potential for natural infiltration of rainwater is crucial for planning Sustainable Urban Drainage System (SUDS) solutions. Predictions of future climate show an increased frequency of heavy rain events, increasing the demand for management of rainwater runoff, either through direct infiltration, retention basins or delayed discharge to recipients and sewage systems.

Rambøll conducted an investigation on the infiltration capacity in a planned development, totaling 48 ha.

Initially a detailed geophysical mapping of the shallow subsurface was conducted using the DualEM421 system. Based

on the subsurface electrical resistivity variations and the overall plan for urban development, a total of 10 geotechnical boreholes were drilled. For each borehole a lithologic description was made and near surface groundwater table was measured.

This information was combined to evaluate the thickness and composition of the unsaturated zone. The figure below illustrates the thickness of the unsaturated zone. Green colors show areas with more than 2 m unsaturated zone, red between 0 and 2 m and blue colors show the location of wetlands.

CUSTOMER

The Municipality of Ikast-Brande

LOCATION

Ikast

PROJECT COUNTRIES

Denmark

PERIOD

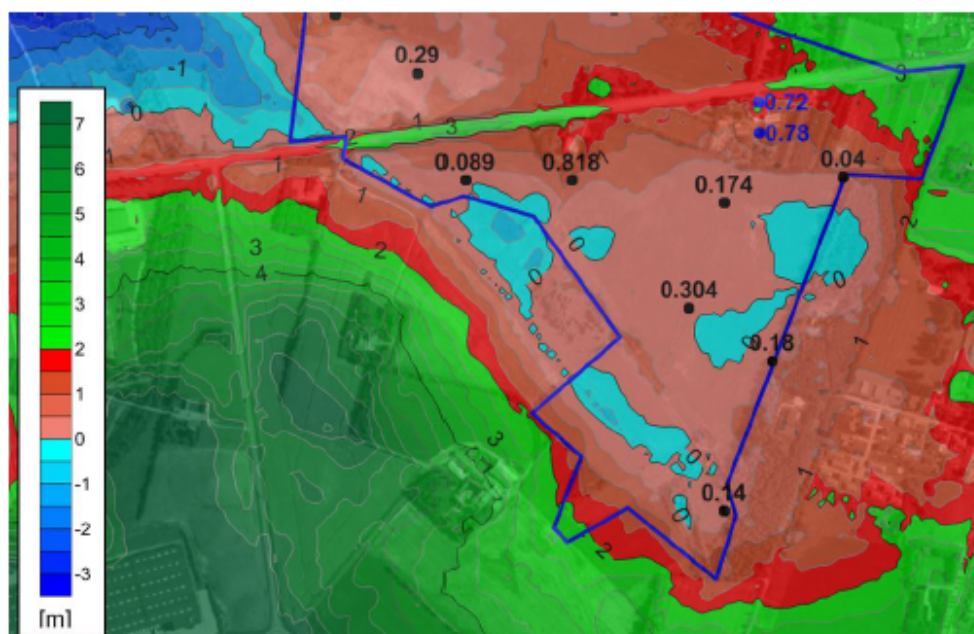
2016

SERVICES PROVIDED

Detailed geophysical mapping, total of 150 line km DualEM421

10 boreholes

Calculation thickness and resistivity of the unsaturated zone



GEOPHYSICAL INVESTIGATION FOR SUDS SOLUTIONS, GLADSAXE

As part of future climate change adaptation in an area of the Municipality of Gladsaxe, near Copenhagen, is looking to Sustainable Urban Drainage Systems (SUDS) solutions, including rainwater infiltration. Prior to a detailed design of SUDS solutions in Gladsaxe, detailed investigations must be carried out in order to determine where these systems can be located.

In order to assess the near surface sediments where rainwater infiltration is possible, a full surface detailed geophysical investigation was carried out by Ramboll. This study used the electromagnetic method DualEM. With the DualEM system the electrical

resistivity of the subsurface is mapped up to a depth of approx. 10 m, where it is possible to map where the clayey and sandy subsurface sediments

On the figure below, red colors indicate high resistivity (sandy sediments), and green colors indicate low resistivity areas (clayey sediments). Combined with borehole information, the mapped resistivity can be used to delineate areas of permeable sandy sediments and less permeable clay sediments.

The dense distributed geophysical data, information from boreholes, and infiltration tests carried out in the area, forms data material when designing SUDS solutions.

CUSTOMER

GEUS/GrønPleje

LOCATION

Gladsaxe

PROJECT COUNTRIES

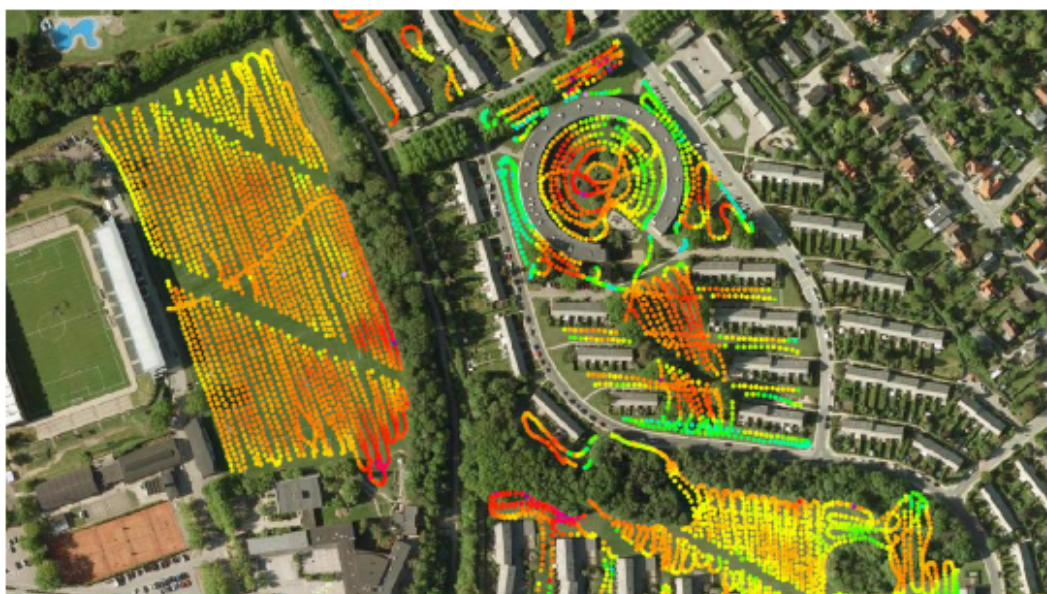
Denmark

PERIOD

2013

SERVICES PROVIDED

Geophysical mapping for Sustainable Urban Drainage Systems





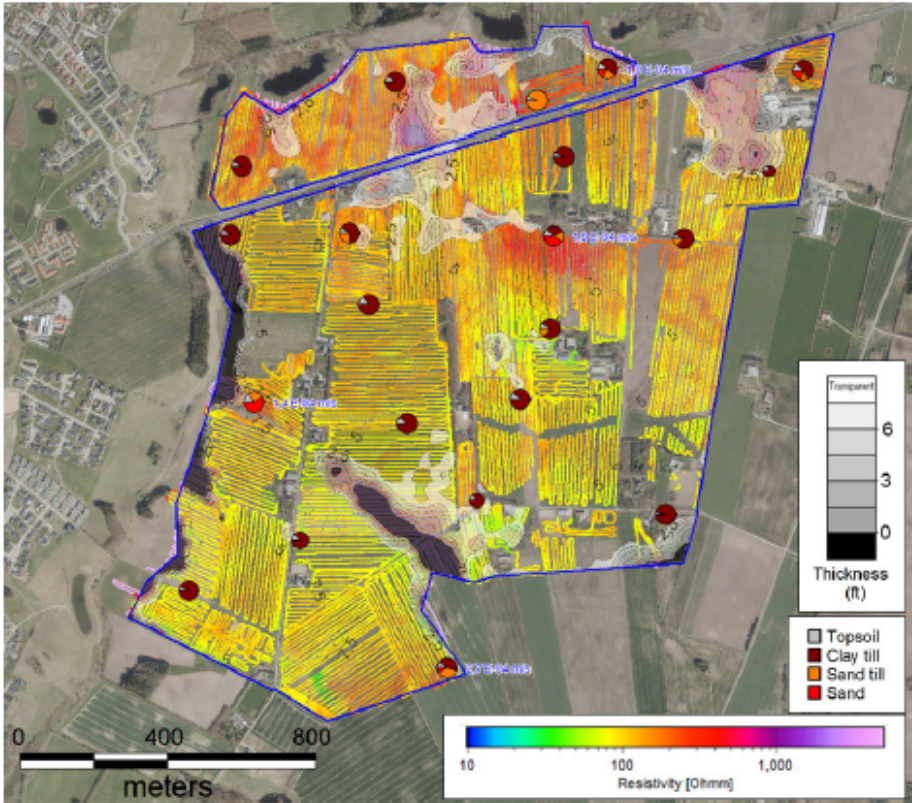
WATER

ASSESSMENT OF POTENTIAL FOR NATURAL INFILTRATION OF RAINWATER

Detailed geophysical mapping (DualEM421), boreholes and infiltrations test has been conducted and potential for natural infiltration of rainwater has been assessed in a future development area. Size of the investigated area is approx. 500 acres and a total of 150 miles of DualEM was collected at a distance of 30 feet between lines. From the results of the DualEM survey a total of 21 boreholes and 4 infiltrations tests were completed.

Based on soil description and hydraulic head measurements the nature of the unsaturated zone was evaluated. The investigation serves as base for assessment of potential infiltration sites and acts as input data for overall dewatering plans for the area.

CUSTOMER
The Municipality of Viborg
LOCATION
Taphede
PROJECT COUNTRIES
Denmark
PERIOD
2016
SERVICES PROVIDED
Detailed geophysical mapping, total of 150 miles of DualEM421, 21 boreholes and 4 infiltration tests. Calculation thickness and resistivity of the unsaturated zone



ASSESSMENT OF NEAR SURFACE HYDRAULIC CONDITIONS FOR FUTURE URBAN DEVELOPMENT NEAR VIBORG

Assessment of the potential for natural infiltration of rainwater is crucial for planning Sustainable Urban Drainage System (SUDS) solutions. Predictions of future climate show an increased frequency of heavy rain events, increasing the demand for management of rainwater runoff, either through direct infiltration, retention basins or delayed discharge to recipients and sewage systems.

Ramboll conducted an investigation on the infiltration capacity in a planned development, totaling 400 ha.

Initially a detailed geophysical mapping of the shallow subsurface was conducted using the DualEM421 system. Based

on the subsurface electrical resistivity variations and the overall plan for urban development, a total of 24 geotechnical boreholes were drilled. For each borehole a lithologic description was made and near surface groundwater table was measured.

The collected geophysical and borehole data was combined with data from 34 existing boreholes in order to evaluate the thickness and composition of the unsaturated zone. The figure below illustrates the thickness of the unsaturated zone. Green colors show areas with more than 2,5 m unsaturated zone, red between 0 and 2,5 m and blue colors show the location of wetlands.

CUSTOMER

The Municipality of Viborg

LOCATION

Viborg

PROJECT COUNTRIES

Denmark

PERIOD

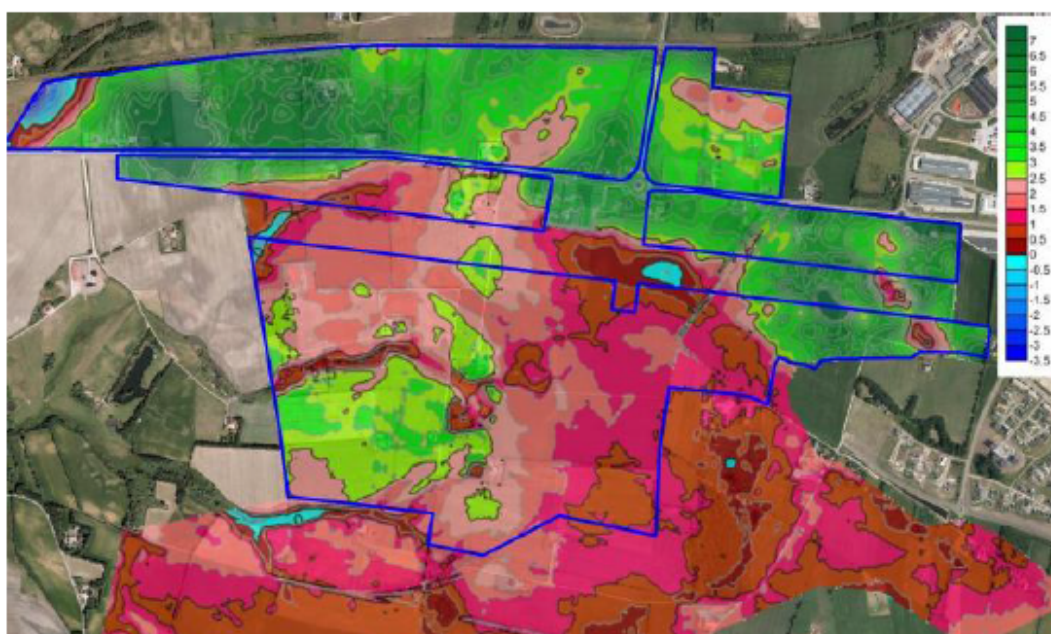
2016

SERVICES PROVIDED

Detailed geophysical mapping, total of 243 line km DualEM421

24 boreholes

Calculation thickness and resistivity of the unsaturated zone



GEOPHYSICAL SCREENING AS PRE-GEOTECHNICAL INVESTIGATIONS FOR LIGHT RAIL CONNECTION TO AALBORG AIRPORT

A new light rail connection between the city of Aalborg and the nearby airport is being constructed in order to improve mobility in the region. As a pre-geotechnical investigation, a geophysical screening was conducted using the DualEM method. DualEM is a geophysical method optimized for detailed mapping of the subsurface electrical conductivity to a depth of 5 to 10 m.

Through the DualEM screening, it was possible to map the varying conditions along the three proposed routes. Some parts of the routes are characterized by low resistivity, equating to clayey sediments, while other parts are characterized by higher

resistivity, showing more sandy sub-surface sediments. Potential areas with unstable sediments were identified, and the extension of a known former landfill site was mapped.

The results from the DualEM survey were used to optimize the location of subsequent geotechnical boreholes. The boreholes are located strategically in relation to the variation along each of the three proposed routes.

CUSTOMER

The Municipality of Aalborg

LOCATION

Aalborg

PROJECT COUNTRY

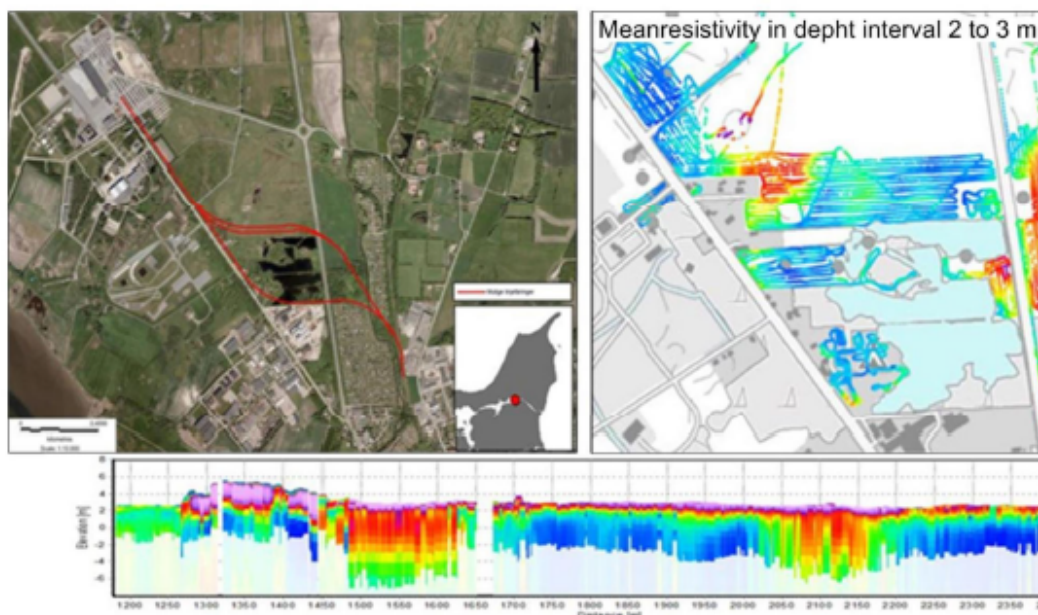
Denmark

PERIOD

2014

SERVICES PROVIDED

Detailed geophysical investigation
Geotechnical boreholes



PRE-GEOTECHNICAL SCENING OF AN URBAN DEVELOPMENT AREA NEAR HOLSTEBRO

When preparing for new developments, it is crucial to know the subsurface conditions. Presence of near-surface unstable sediments like peat and gyttja can complicate foundations, while the planning of Sustainable Urban Drainage Systems (SUDS) solutions also depends of the subsurface conditions.

As pre-geotechnical screening of a proposed development near Holstebro, Rambøll conducted a detailed geophysical survey was conducted, using the DualEM421 method. The DualEM system is designed for detailed mapping of the subsurface down to approx. 10 m below surface.

The survey area was in total 83 hectares and consisted of low-lying farmlands, with a number of smaller ponds and watering holes.

Based on the results from the DualEM survey a number of potential problematic areas were identified and recommendations for subsequent geotechnical investigations were provided.

CUSTOMER

The Municipality of Holstebro

LOCATION

Sondergaard

PROJECT COUNTRIES

Denmark

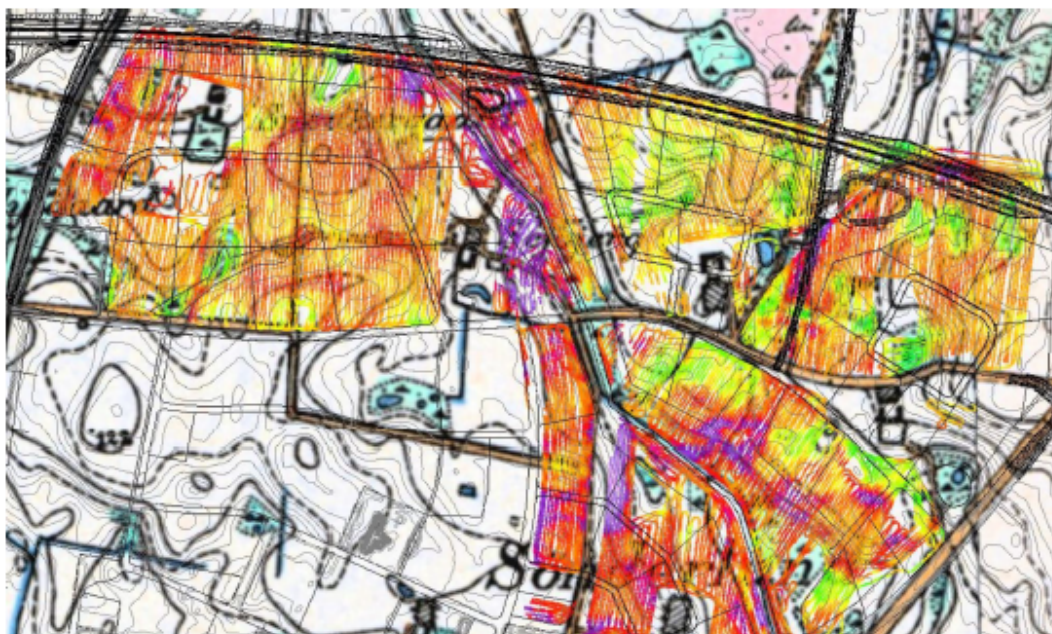
PERIOD

2016

SERVICES PROVIDED

Detailed geophysical mapping, total of 165 line km DualEM421

Recommendations for geotechnical investigations





WATER

ASSESSMENT OF NEAR-SURFACE HYDRAULIC CONDITIONS FOR URBAN DEVELOPMENT SPARK-MARSELISBORG CENTER

SPARK-Marselisborg Center, which hosts a public hospital for physical rehabilitation is looking to utilize its open grounds for climate adaptation initiatives. Currently, run-off from the grounds enters the sewage system. The overall plan is to separate the rainwater run-off and either infiltrate the rainwater on grounds, or delay the runoff in retention basins or delayed discharge to existing sewage systems.

Knowledge about subsurface conditions is essential for assessing the potential for rainwater infiltration. Rambøll conducted a detailed geophysical mapping of the shallow subsurface using DualEM421, which maps out the subsurface

electrical resistivity to a depth of 10 m.

Based upon this evaluation, a total of 10 boreholes were installed in order to obtain a detailed lithologic description of the sediments and information on the groundwater table. Five infiltration tests were performed by direct infiltration applying the doublet-ring infiltration method. Link between resistivity from DualEM421 and infiltration rate were identified.

The combined investigations resulted in a comprehensive dataset for assessing potential for infiltration and evaluation of possible climate adaption solutions.

CUSTOMER

SPARK

LOCATION

Aarhus

PROJECT COUNTRIES

Denmark

PERIOD

2016

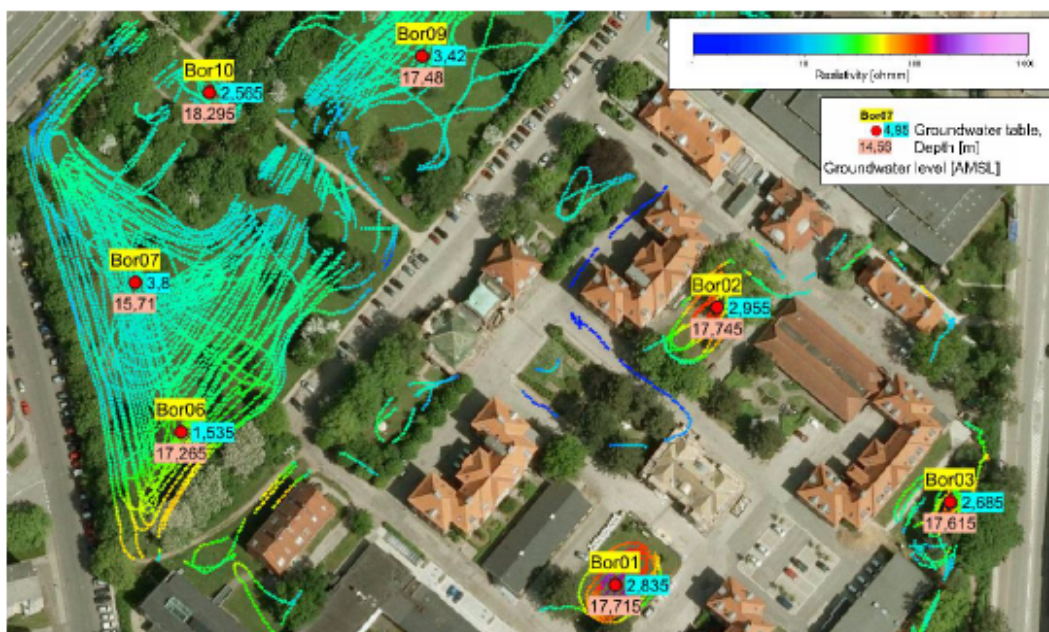
SERVICES PROVIDED

Detailed geophysical mapping, total of 30 line km DualEM421

10 boreholes

5 infiltration tests

Calculating thickness and resistivity of the unsaturated zone



MAPPING RAINWATER INFILTRATION AND WASTE IN THE CITY OF SEEST - A FORMER FIREWORK PLANT SITE

Because of future urban development the Municipality of Kolding wanted to map the near-surface geology of a former firework plant site in Seest. The primary purpose of the mapping was to investigate the possibility of rainwater infiltration in the area and secondarily to map foundation remnants.

The geophysical mapping was carried out using the Dualem method in which detailed information on the electrical resistivity of the soil down to approx. 10 meters was collected.

In combination with information from investigation drillings and infiltration tests the resistivity from the Dualem mapping can be part of a data material for

planning sustainable urban drainage solutions.

The mapping showed low resistivity under the very near-surface. This indicates clay deposits which will make infiltration difficult.

The mapping also showed sub areas with a higher resistivity indicating more sandy/permeable layers, possibly making infiltration possible.

At the same time, the mapping indicates where to find remains of the firework plant

CUSTOMER

The Municipality of Kolding

LOCATION

Seest, western Denmark

PROJECT COUNTRY

Denmark

PERIOD

2014-2015

SERVICES PROVIDED

Geophysical mapping, Sustainable urban drainage



**ATTACHMENT A
RAMBOLL'S STANDARD TERMS AND CONDITIONS**

GENERAL TERMS AND CONDITIONS

Ramboll US Corporation, a Virginia corporation, ("Ramboll") agrees to provide professional services under the following General Terms and Conditions:

- 1. Fees:** Ramboll bills for its services on a time and materials basis using standard hourly rates. If requested, we will provide an estimate of the fees for a particular task, and we will not exceed that estimate without prior Client approval. For deposition and testimony we charge premium hourly rates. In certain circumstances we will undertake an assignment on a fixed fee basis if the requirements can be clearly defined.
- 2. Invoicing:** Ramboll bills its clients on a monthly basis using a standard invoice format. This format provides for a description of work performed and a summary of professional fees, expenses, and communication and reproduction charges. For more detailed invoicing requests, Ramboll reserves the right to charge for invoice preparation time by staff members.
- 3. Payment:** Ramboll invoices are payable UPON RECEIPT. Ramboll reserves the right to assess a late charge of 1.5 percent per month for any amounts not paid within 30 days of the receipt date. Ramboll also reserves the right to stop work or withhold work product if invoices remain unpaid for more than 60 days past the receipt date. If Ramboll's work relates to a business transaction, Ramboll shall be paid in a timely fashion, without regard to whether or when the transaction closes. If Ramboll legal counsel determines that Ramboll is required to take legal action to obtain payment for unpaid invoices and Ramboll prevails in court, Client agrees to pay all of Ramboll's costs associated with the legal action, including reasonable legal fees.
- 4. Subcontractors:** Ramboll has a policy that its Clients should directly retain other contractors whose services are required in connection with field services for a project (e.g., drillers, analytical laboratories, transporters). As a service to you, we will advise you with respect to selecting other such contractors and will assist you in coordinating and monitoring their performance. In no event will we assume any liability or responsibility for the work performed by other contractors you may hire. When Ramboll engages a subcontractor on behalf of the Client, the expenses incurred, including rental of special equipment necessary for the work, will be billed as they are incurred, at cost plus 15 percent. By engaging us to perform these services, you agree to indemnify, defend and hold Ramboll, its directors, officers, employees, and other agents harmless from and against any claims, demands, judgment, obligations, liabilities and costs (including reasonable attorneys' and expert fees) relating in any way to the performance or non-performance of work by another contractor, except claims for personal injury or property damage to the extent caused by the negligence or willful misconduct of Rambolls' employees.
- 5. Reimbursable Expenses:** Project-related expenses including travel, priority mail, and overnight delivery, outside reproduction and courier services will be billed at cost plus 15 percent. The use of company-owned cars, trucks, and vans will be charged at \$125 per day. The use of company-owned equipment and protective clothing will be billed in accordance with our standard fee schedule. The cost of project-related communications, to include in-house telephone, facsimile, postage, and reproduction, computers, data compilation, and CADD will be charged at a total of 6 percent of the total labor charges.

6. Access and Information: Client agrees to grant or obtain for Ramboll reasonable access to any sites to be investigated as part of Ramboll's scope of work. Client also agrees to indicate to Ramboll the boundary lines of the site and the location of any underground structures, including tanks, piping, water, telephone, electric, gas, sewer, and other utility lines. Client agrees to notify Ramboll of any hazardous site conditions or hazardous materials, about which Client has knowledge and to which Ramboll's employees or contractors may be exposed while performing services on behalf of Client, including providing copies of relevant Material Safety Data Sheets. Client also shall make available to Ramboll all information within its control necessary to allow Ramboll to perform its services and agrees to comply with reasonable requests by Ramboll for clarification or additional information. Client shall be responsible for the accuracy of this information. Ramboll shall not be responsible for any damage to underground structures or utilities to the extent such damage was caused by incomplete or inaccurate information provided to us by the client or other party. Client agrees to make Ramboll aware of any unsafe conditions at any project site about which Client has knowledge.

7. Reporting Requirements: Client may be required under federal, state or local statutes or regulations to report the results of Ramboll's services to appropriate regulatory agencies. Ramboll is not responsible for advising Client about its reporting obligations and Client agrees that it shall be responsible for all reporting, unless Ramboll has an independent duty to report under applicable law. In those situations, Ramboll will provide Client with advance notice that Ramboll believes that it has an obligation to report as well as the substance of the report it intends to make.

8. RCRA Compliance: Client shall be responsible for complying with the Resource Conservation and Recovery Act, 42 U.S.C. Section 6901 et. seq. ("RCRA") and its implementing regulations in connection with Ramboll's work under this Agreement. Client may request Ramboll's assistance in meeting its RCRA and other similar waste management obligations, including analytical testing to assist Client in proper characterization of waste, identifying potential transporters and disposal facilities for waste (provided that Client shall make the final selection of both the transporter and disposal facility), entering into subcontracts or purchase order arrangements with the transporters and/or disposal facilities selected by Client, and preparing manifests for the Client's approval and execution. Client agrees that, by virtue of providing these services, Ramboll shall not be deemed a "generator" or a party who "arranges" for the "transportation," "treatment" or "disposal" of any "hazardous waste" or "hazardous substance" (as those terms are defined in the Comprehensive Environmental Response Compensation and Liability Act or "CERCLA", 42 U.S.C. Section 9601). Client agrees to indemnify, defend and hold Ramboll, its directors, officers, employees and agents, harmless from and against any and all claims, demands, judgments, obligations, liabilities, any costs (including reasonable attorneys' and expert fees) relating to: (1) Ramboll's work in assisting Client with its RCRA obligations; and (2) the transportation, treatment, and disposal of hazardous substances or hazardous waste generated by the field activities conducted for Client.

9. Confidentiality: We treat all information obtained from Clients as confidential, unless such information is previously known to us, comes into the public domain through no fault of ours, or is furnished to us by a third party who is under no obligation to keep the information confidential. If we are subpoenaed to disclose confidential information obtained from you or about our work for you, we will give you reasonable notice and the opportunity to object before releasing any confidential information.

10. Independent Contractor: Client agrees that Ramboll is acting as an independent contractor and shall retain responsibility for and control over the means for performing its services. Nothing in these Terms and Conditions shall be construed to make Ramboll or any of its officers, employees or agents, an employee or agent of Client.

11. Standard of Care: In performing services, we agree to exercise professional judgment, made on the basis of the information available to us, and to use the same degree of care and skill ordinarily exercised in similar circumstances by reputable consultants performing comparable services in the same geographic area. This standard of care shall be judged as of the time the services are rendered, and not according to later standards. Ramboll makes no other warranty or representation, either express or implied, with respect to its services. Estimates of cost, recommendations and opinions are made on the basis of our experience and professional judgment; they are not guarantees. Reasonable people may disagree on matters involving professional judgment and, accordingly, a difference of opinion on a question of professional judgment shall not excuse a Client from paying for services rendered.

Client recognizes that there may be hazardous conditions at sites to be investigated as part of Ramboll's work. Client acknowledges that Ramboll has neither created nor contributed to the existence of any hazardous, toxic or otherwise dangerous substance or condition at the site(s) which are covered by Ramboll's work. Client also recognizes that some investigative procedures may carry the risk of release or dispersal of pre-existing contamination, even when exercising due care. Client releases Ramboll from any claim (including claims under CERCLA or state law) that it is an "operator" of any site where it performs work for Client or a "generator" or a party who "arranges" for the "transportation," "treatment" or "disposal" of any "hazardous substance" (as those terms are defined in CERCLA), by virtue of its work for Client at any site.

12. Insurance: Ramboll shall maintain the following insurance coverage while it performs the work described in Exhibit "A:" (1) statutory Workers Compensation and Employer's Liability Coverage; (2) General Liability for bodily injury and property damage of \$1,000,000 aggregate; (3) Automobile Liability with \$1,000,000 combined single limit; and (4) Professional Liability and Contractor's Pollution Liability with a combined single limit of \$1,000,000 per claim and in the aggregate. If Client desires additional insurance or special endorsements, premiums associated with that coverage would be considered a reimbursable expense. Upon request, we will provide you with a certificate of insurance.

13. Third Parties: Ramboll's services are solely for Client's benefit and may not be relied upon by any third party without Ramboll's express written consent. Any use or dissemination of Ramboll work products (including Ramboll reports), without the written consent of Ramboll, shall be at Client's risk and Client shall indemnify and defend Ramboll from any and all claims, demands, judgments, liabilities and costs (including reasonable attorneys' and expert fees), related to the unauthorized use or dissemination of Ramboll's work. Client also agrees to be solely responsible for and to defend, indemnify, and hold Ramboll harmless from and against any and all claims, demands, judgments, liabilities and costs (including reasonable attorneys' and expert fees), asserted by third parties arising out of or in any way related to our performance or non-performance of services, except for claims of personal injury or property damage to the extent caused by the negligence or willful misconduct of Ramboll's employees.

14. Limitation of Liability: Ramboll shall be liable only for direct damages that result from Ramboll's negligence or willful misconduct in the performance of its services. UNDER NO CIRCUMSTANCES SHALL RAMBOLL BE LIABLE FOR INDIRECT, CONSEQUENTIAL, SPECIAL, OR PUNITIVE DAMAGES, OR FOR DAMAGES CAUSED BY THE CLIENT'S FAILURE TO PERFORM ITS OBLIGATIONS UNDER LAW OR CONTRACT. Ramboll shall not be liable for and Client shall indemnify Ramboll from and against all claims, demands, liabilities and costs (including attorneys' and expert fees) arising out of or in any way related to our performance or non-performance of services, including all on-site activities except to the extent caused by Ramboll's negligence or willful misconduct. In no event shall our liability exceed the amount paid to us by you for our professional services (net of reimbursable expenses) and Client specifically releases Ramboll for any damages, claims, liabilities and costs in excess of that amount.

15. Termination: This Agreement may be terminated by either party upon ten (10) days written notice to the other. If Client terminates the Agreement, Client agrees to pay Ramboll for all services performed until the effective date of the termination. Client's obligations under Paragraphs 3, 4, 8, 9, 11, 13, 14, 16, 18 and 20 shall survive termination of this Agreement and/or completion of the services hereunder.

16. Disputes: All disputes under this Agreement shall be resolved by binding arbitration under the rules of the American Arbitration Association. If our personnel or documents are subpoenaed for depositions or court appearance in any dispute related to the project (except disputes between Ramboll and Client related to our services), Client agrees to reimburse us at our then current billing rates for responding to those subpoenas, including out-of-pocket reimbursable expenses.

17. Scope of Agreement: Once Client has signed Ramboll's proposal, that proposal and these Terms and Conditions shall constitute the complete and exclusive Agreement between the parties and will supersede all prior or contemporaneous agreements, whether written or oral. No provision of these Terms and Conditions may be waived, altered or modified except in writing and signed by Ramboll. Client may use standard business forms, such as purchase orders, for convenience only; any provision on those forms that conflict with these Terms and Conditions shall not apply.

18. Nonsolicitation: Both Ramboll and Client agree during the term of this Agreement and for 12 months following its termination for any reason, neither party will solicit for employment, or hire as an employee or contractor, any personnel of the other party involved in the performance of services hereunder.

19. Force Majeure: Ramboll shall not be liable in any way because of any delay or failure in performance hereunder due to unforeseen circumstances or causes beyond its control, including without limitation strike, lockout, embargo, riot, war, act of terrorism, fire, act of God, accident, failure or breakdown of components necessary to order completion, subcontractor or supplier non-performance, inability to obtain labor, materials or manufacturing facilities, or compliance with any law, regulation or order.

20. Intellectual Property. If Ramboll delivers a written product to the Client, Ramboll hereby grants to Client a perpetual, nonexclusive, royalty-free license to copy, modify and otherwise utilize the product in connection with the Client project for which the Services were provided. Ramboll retains all intellectual property rights.

REVISION – January 2018

AGENDA ITEM SUBMITTAL

Meeting Date: October 10, 2018

To: Water Issues Committee
Board of Directors

From: Mike Markus

Staff Contact: A. Hutchinson

Budgeted: No

Budgeted Amount: \$0

Cost Estimate: \$15,000

Funding Source: General Fund

Program/Line Item No. 1010.51112

General Counsel Approval: N/A

Engineers/Feasibility Report: N/A

CEQA Compliance: N/A

Subject: SPONSORING UCI SUSTAINABLE GROUNDWATER WORKSHOP

SUMMARY

Water UCI, an interdisciplinary center for water at the University of California, Irvine (UCI) is hosting a workshop that brings together water experts from the European Union and California to discuss governance and conflict resolution tools. Felica Marcus of the State Water Resources Control Board has agreed to be a dinner speaker. Water UCI has requested OCWD be one of the event sponsors.

RECOMMENDATION

Agendize for October 17 Board meeting: Authorize Sponsoring the Water UCI workshop on Sustainable Groundwater for an amount of \$15,000.

BACKGROUND/ANALYSIS

Over the past several months, staff from Water UCI, OCWD, the State Water Resources Control Board and the US Geological Survey have been collaborating on developing what is hoped will be the first of a series of annual workshops on different water issues.

The first workshop is centered around governance and conflict resolution. These topics are especially germane with the passage of the Sustainable Groundwater Management Act (SGMA) in September 2014. The European Union has addressed, and continues to address, similar problems with the implementation of its Water Framework Directive (adopted in October 2000) and its daughter Groundwater Directive (adopted in December 2006).

Five topics have been identified for this first workshop, corresponding to major challenges for both California's stakeholders in implementing SGMA, as well as European stakeholders implementing the European Water and Groundwater Directives. Each topic will be presented by a European expert on European cases, followed by a comparative California-EU discussion to identify similarities, differences, and possible lessons.

Besides trying to bring constructive examples from the European Union experience to California's groundwater stakeholders, the workshop aims at delivering a more general message that the exchange of international experience can be a useful instrument to improve groundwater governance and management.

Workshop Objectives:

- Use comparative case studies of European Union groundwater policy, governance, and management to draw significant lessons for SGMA implementation.
- Identify possible conflicts in SGMA implementation, e.g. inter-basins conflicts and/or conflicts between stakeholders (public or private), conflicts at various geographic scales (local, regional or international), and explore techniques for their anticipation, prevention, and mitigation.

Workshop Output:

- Online publication of the workshop's proceedings drafted as a practical reference tool for use by practitioners. The proceedings will gather all case studies presented during the workshop, summarize the discussions and resulting conclusions, and will be complemented by an executive summary.

Target Groups:

- The workshop will address 25 to 40 participants, focusing on hydrogeologists, geologists, water engineers, environmental professionals, water economists, regulators, lawyers/attorneys, and policy-makers. Participants will come from:
 - State and Local Public Water Institutions, e.g. Department of Water Resources (DWR), State Water Resources Control Board (SWRCB), California Department of Food & Agriculture, California Environmental Protection Agency (Cal/EPA), Groundwater Sustainability Agencies (GSAs), county water districts, groundwater management districts, irrigation districts, storage districts, community service districts, municipalities, and flood control districts. Workshop participants will ideally be mainly comprised of GSA managers (those that will implement SGMA), and higher-level policy makers (those that help shape state and local water management decisions).
 - Private Stakeholders, e.g. Associations such as California Farmers Union and California Farm Bureau Federation, individual farmers, engineering companies, and consulting firms.

Topics:

- 1) *Governance and management issues*
 - i) Presentation of issues in EU policy by a European expert
 - ii) Discussion by all participants, for instance:

Models of decision-making; moving towards more local management, e.g., water agencies in France and GSAs in California; river basins as the basis of water management; surface water and groundwater integrated management; river basin management plans vs GSPs.

Public information and awareness raising, stakeholder consultation, capacity-building.

Implementation issues related to the transposition of the EU directives into national legislatures; bridging science and policy; impact assessments and possible revision of existing water directives.

2) *Quantity issues*

- i) Presentation of issues in EU policy by a European expert
- ii) Discussion by all participants, for instance:
 - Reallocation schemes
 - Extractable volumes (limitation of withdrawals), permits for groundwater abstraction, databases and control, demand management and ways to reduce over-pumping, administrative authorizations vs water rights and withdrawals permits.
 - Contrast with performance metrics identified in SGMA.

3) *Quality issues of a technical and regulatory nature*

- i) Presentation of issues in EU policy by a European expert
- ii) Discussion by all participants, for instance:
 - Non-point source pollution
 - EU maximum admissible concentrations vs California maximum contaminant levels and their application in the field

4) *Conflicts 1: Typology of water disputes, groundwater at risk of use, conflict indicators*

- i) Presentation of issues in EU policy by a European expert
- ii) Discussion by all participants, for instance:
 - Urban vs agricultural settings
 - Inter-basins disputes (no overlap in France, while in California possibility of overlap between GSAs)
 - Groundwater rights in the EU and California
 - Groundwater and land-use, water quantity-quality nexus
 - Groundwater – surface water interactions/impacts/conflicts

5) *Conflicts 2: From conflict to cooperation, techniques of management and resolution of conflicts*

- i) Presentation of issues in EU policy by a European expert
- ii) Discussion by all participants, for instance:
 - Techniques for the anticipation, prevention and mitigation of conflicts
 - Examples of successful cases, to avoid court litigations, and lessons learned

Examples of failures and lessons learned

The value of data and public information in conflict avoidance and mitigation

Dates & Location:

Monday 24th and Tuesday 25th June 2019

University of California, Irvine

Attendance is free of charge but limited to 25-40 participants. Two lunches, refreshment breaks and a formal dinner, with Felicia Marcus of the State Water Resources Control Board, will be offered.

Organizing Committee:

- Chair: Jean Fried, Professor and Project Scientist, Urban Planning and Public Policy, University of California, Irvine, USA
- David Feldman, Professor and Director, Water UCI, University of California, Irvine, USA
- Jacques Ganoulis, Professor and Special Secretary for Water, Ministry of Environment and Energy, Athens, Greece
- Adam Hutchinson, Recharge Planning Manager, Orange County Water District, USA
- Lena Salame, Conflict Management and Mediation Expert, Paris, France

Advisers:

- Erik Ekdahl, Deputy Director, Division of Water Rights, State Water Resources Control Board, Sacramento, USA
- Eric Reichard, Director, USGS California Water Center, San Diego, USA

Workshop Chairs:

- David Feldman, Professor and Director, Water UCI, University of California, Irvine, USA
- Mike Markus, General Manager, Orange County Water District, USA

Workshop Budget:

The current estimated budget for the workshop is \$45,000. The bulk of these costs are for the venue and to provide travel expenses for the European participants. The SWRCB and US Geological Survey are contributing staff resources for the workshop. OCWD and UCI Water will be reaching out to organizations, such as the Water Replenishment District of Southern California, Department of Water Resources, and others to sponsor this event.

Recommendation

Staff recommends sponsoring the Water UCI workshop on Sustainable Groundwater for an amount of \$15,000.

PRIOR RELEVANT BOARD ACTION(S)

None

AGENDA ITEM SUBMITTAL

Meeting Date: October 10, 2018

To: Water Issues Committee
Board of Directors

From: Mike Markus

Staff Contact: R. Herndon/ D. Field

Budgeted: Yes

Budgeted Amount: \$25,216

Cost Estimate: \$24,345 (final cost)

Funding Source: R&R

Program/ Line Item No.: R17031

General Counsel Approval: N/A

Engineers/Feasibility Report: Yes

CEQA Compliance: Yes.

**Subject: CONTRACT GBM-2018-1 DESTRUCTION OF MONITORING WELL WBS-3R
AND CONSTRUCTION OF REPLACEMENT MONITORING WELL OCWD-HG2:
NOTICE OF COMPLETION**

SUMMARY

BEKS Acquisition Inc. dba BC2 Environmental (BC2) has completed all work under Contract GBM-2018-1 for the destruction of monitoring well WBS-3R and construction of replacement monitoring well OCWD-HG2. The final costs were \$24,345, which is \$871 under the Board-approved project budget.

RECOMMENDATIONS

Agendize for October 17 Board meeting:

1. Ratify issuance of Change Order No. 1 to BEKS Acquisition dba BC2 Environmental to decrease the Contract amount by \$871; and
2. Accept completion of work and authorize filing a Notice of Completion for Contract GBM-2018-1, Destruction of Monitoring Well WBS-3R and Construction of Replacement Monitoring Well OCWD-HG2.

BACKGROUND/ANALYSIS

In March 2018, the Board approved destruction of corroded and structurally-unstable monitoring well WBS-3R and construction of replacement monitoring well OCWD-HG2 in the city of Anaheim. In July 2018, the Board awarded Contract GBM-2018-1 to BC2. The work was completed by BC2 in August 2018.

Change Order No. 1

Several bid item adjustments were made to reconcile the original bid quantities with the actual quantities of work/materials completed/installed. The total of these adjustments results in a contract credit to OCWD for \$871 and was approved under the General Manager's authority as Change Order No. 1.

Table 1 below summarizes the approved budget and expenditures (pending completion of surveying services) to complete the project.

Table 1.
Summary of Costs for Destruction of Monitoring Well WBS-3R and Construction of Replacement Monitoring Well OCWD-HG2

Task	Approved Budget	Completed Work & Anticipated Expenditures
WBS-3R Destruction	\$2,496	\$2,496
OCWD-HG2 Construction (replacement well)	22,720	21,849
Construction Inspection Services ⁽¹⁾	0	0
Surveying Services	3,000	3,000
PROJECT TOTAL:	\$28,216	\$27,345

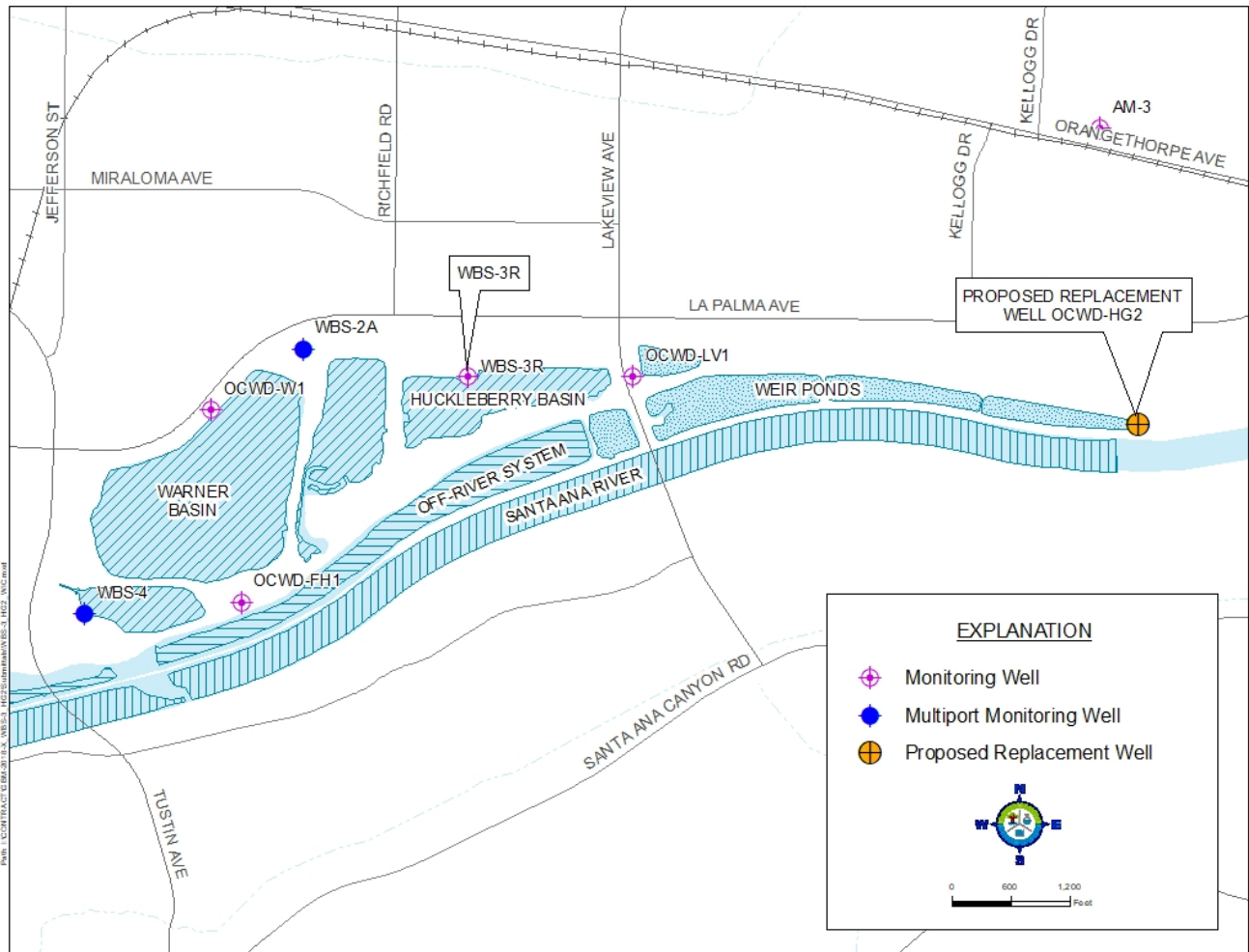
(1) Inspection services performed by OCWD geologist.

PRIOR RELEVANT BOARD ACTIONS

7/18/2018 R18-7-79 Award Contract No. GBM-2018-1 Destruction of Monitoring Well WBS-3R and Construction of Replacement Monitoring Well OCWD-HG2 to BEKS Acquisition dba BC2 Environmental.

3/21/2018 M18-28 Approve Destruction of Monitoring Well WBS-3R and Construction of Replacement Monitoring Well OCWD-HG2.

Figure 1
Well Locations





CHANGE ORDER NO. 1
CONTRACT NO. GBM-2018-1

TO: BEKS Acquisition Inc. dba BC2 Environmental
1150 West Trenton Avenue
Orange, CA 92867

You are hereby directed modify the scope of work and costs to comply with this Change Order.

DESCRIPTION OF CHANGE:

Change Order No. 1 dated September 18, 2018 includes the following bid item adjustments:

1. Reduce Bid Item 6 by 12 Linear Feet Install Well Casing & Screen: (\$216.00)
2. Reduce Bid Item 7 by 18 Linear Feet Install 8x20 (#3 sand) Filter Pack: (\$216.00)
3. Increase Bid Item 8 by 15 Linear Feet Install Bentonite Pellet Bottom Seal: \$555.00
4. Increase Bid Item 9 by 3 Linear Feet Install Cement and Bentonite Annular Seals: \$96.00
5. Reduce Bid Item 10 by 2 Hours Conduct Well Development: (\$590.00)
6. Reduce Bid Item 13 by 100 Linear Feet Borehole Abandonment: (\$500.00)

PAYMENT:

Net Contract Adjustment: (\$871.00)

CONTRACT TIME:

No increase to contract completion.

ACCEPTANCE:

Contractor accepts the terms and conditions stated above as full and final settlement of any and all claims arising from this Change Order and acknowledges that the compensation (time and cost) set forth in the Change Order comprises the total compensation due for the work or change defined in the Change Order, including all impact on any unchanged work. By signing the Change Order, the Contractor acknowledges and agrees that the stipulated compensation includes payment for all Work contained in the Change Order, plus all payment for the interruption of schedules, extended overhead costs, delay, and all impact, ripple effect or cumulative impact on all other Work under this Contract. The signing of the Change Order acknowledges full mutual accord and satisfaction for the change, and that the time and/or cost under the Change Order constitute the total equitable adjustment owed the Contractor as a result of the change. The Contractor agrees to waive all rights, without exception or reservation of any kind whatsoever, to file any further claim or request for equitable adjustment of any type, for any reasonably foreseeable cause that shall arise out of or as a result of this Change Order or the impact of this Change Order on the remainder of the Work under this contract.

Contractor agrees to perform the above-described work in accordance with the above terms and in compliance with applicable sections of the Contract Documents

This Change Order is hereby agreed to, accepted and approved, all in accordance with the General Provisions of the Contract Documents.

ORANGE COUNTY WATER DISTRICT

By: *David M. Field* 9/19/18
Project Manager Date

By: *Alex J. Anderson* 9/19/18
District Hydrogeologist Date

By: *[Signature]* 9/19/18
Executive Director Date

By: *[Signature]* 09-19-18
General Manager Date

CONTRACTOR

By: *Kurt Samuelson* 09/18/2018
Date

Title: President

By: *[Signature]* 09/18/2018
Date

Title: General Manager

**CONTRACT GBM-2018-1 CHANGE ORDER NO. 1
COST TABLE**

BID ITEM	DESCRIPTION	UNITS	BC2 BID			ACTUAL INVOICE		CHANGE	
			QTY.	UNIT PRICE	TOTAL	QTY.	TOTAL	QTY.	TOTAL
OCWD-HG2 WELL CONSTRUCTION									
1	Mobilize to OCWD-HG2	Lump Sum	1	\$4,000.00	\$4,000.00	1	\$4,000.00	0	\$0.00
2	Contain & Dispose	Lump Sum	1	\$450.00	\$450.00	1	\$450.00	0	\$0.00
3	Demobilize	Lump Sum	1	\$1,500.00	\$1,500.00	1	\$1,500.00	0	\$0.00
4	Site clean-up (includes vault)	Lump Sum	1	\$1,000.00	\$1,000.00	1	\$1,000.00	0	\$0.00
5	Drill 8-inch dia. Borehole	Linear Feet	100	\$65.00	\$6,500.00	100	\$6,500.00	0	\$0.00
6	Well Casing & Screen	Linear Feet	65	\$18.00	\$1,170.00	53	\$954.00	(12)	(\$216.00)
7	8x20 (#3 sand) filter pack	Linear Feet	30	\$12.00	\$360.00	12	\$144.00	(18)	(\$216.00)
8	Bentonite Pellet bottom seal	Linear Feet	35	\$37.00	\$1,295.00	50	\$1,850.00	15	\$555.00
9	Cement grout & Bentonite pellet seal	Linear Feet	35	\$32.00	\$1,120.00	38	\$1,216.00	3	\$96.00
10	Well Development	Hours	10	\$295.00	\$2,950.00	8	\$2,360.00	(2)	(\$590.00)
11	Disinfect Well Casing	Lump Sum	1	\$450.00	\$450.00	1	\$450.00	0	\$0.00
12	Video Camera Survey	Lump Sum	1	\$1,425.00	\$1,425.00	1	\$1,425.00	0	\$0.00
13	Borehole Abandonment	Linear Feet	100	\$5.00	\$500.00	0	\$0.00	(100)	(\$500.00)
WBS-3R WELL DESTRUCTION									
14	Mobilize to WBS-3R	Lump Sum	1	\$650.00	\$650.00	1	\$650.00	0	\$0.00
15	Contain & Dispose	Lump Sum	1	\$500.00	\$500.00	1	\$500.00	0	\$0.00
16	Pressure Well Casing	Linear Feet	78	\$7.00	\$546.00	78	\$546.00	0	\$0.00
17	Excavate, cement cap, & back-fill	Lump Sum	1	\$500.00	\$500.00	1	\$500.00	0	\$0.00
18	Demobilize	Lump Sum	1	\$300.00	\$300.00	1	\$300.00	0	\$0.00
19	Sheeting, shoring & bracing	Lump Sum	0	\$0.00	\$0.00	0	\$0.00	0	\$0.00
20	Miscellaneous	Cost + 15%	0	\$0.00	\$0.00	0	\$0.00	0	\$0.00
GRAND TOTALS:					\$25,216.00		\$24,345.00		(\$871.00)

AGENDA ITEM SUBMITTAL

Meeting Date: October 10, 2018

To: Water Issues Committee
Board of Directors

From: Mike Markus

Staff Contact: C. Olsen/R. Bouley

Budgeted: Yes

Budgeted Amount: \$3,805,172

Final Cost: \$3,790,793

Funding Source: SRF loan and LACDPW

Program/Line Item No. C12003

General Counsel Approval: Yes

Geology/Engineers Report: Approved

CEQA Compliance: Yes

Subject: ALAMITOS BARRIER IMPROVEMENT PROJECT: NOTICE OF COMPLETION FOR CONTRACT NO. AB-2016-1: ALAMITOS BARRIER IMPROVEMENT PROJECT INJECTION WELL IMPROVEMENTS

SUMMARY

Kiewit Infrastructure West Company (Kiewit) has completed construction of Contract No. AB-2016-1 - Alamos Barrier Injection Well Improvement Project. The seventeen new injection wells are fully operational and injecting water into the barrier. Staff recommends issuing the project Notice of Completion.

RECOMMENDATION

Agendize for October 17 Board meeting:

- 1) Ratify Change Order Number 7 to Kiewit Infrastructure West Company for a total deduction in the amount of (\$14,378.70); and
- 2) Accept the completion of work and authorize filing a Notice of Completion for Contract AB-2016-1 Alamos Barrier Improvement Project Injection Well Improvements.

BACKGROUND/ANALYSIS

The Alamos Barrier was initially constructed in 1964 to protect the Orange County Groundwater Basin (Basin) and the Central Basin of Los Angeles County from seawater intrusion through the Alamos Gap. The Barrier facilities include 41 injection wells and 220 active monitoring well sites and are jointly owned by OCWD and the Los Angeles County Department of Public Works (LACDPW). LACDPW operates and maintains the barrier, while the Water Replenishment District of Southern California (WRD) and OCWD purchase and provide the injection water supply. OCWD pays for a portion of the operation and maintenance costs incurred by LACDPW, prorated based on the proportion of the amount of injection water purchased by OCWD.

Contract No. AB-2016-1 was awarded to Kiewit Infrastructure West Company (Kiewit) on May 24, 2017 to construct the Alamos Barrier Improvement Project Injection Well Improvements, consisting of installing the well vaults, well piping and telemetry for seventeen new wells along the Alamos Channel. Figure 1, below, shows the alignment of the existing and new wells along the Alamos Barrier:



Figure 1
Alamitos Barrier Improvement Project Injection Well Improvements Site Plan

Project Budget and Estimated Costs

The Alamitos Barrier Improvement Project is partially funded by a Proposition 84 Integrated Regional Water Management (IRWM) Implementation Grant in the amount of \$1,000,000. In addition, LACDPW has agreed to provide up to \$1,253,000 to pay for 50% of the construction costs for new facilities located between Points B and C as illustrated in Figure 1. The remaining project cost is funded by a low-interest rate State Revolving Fund (SRF) loan from the State Water Resources Control Board (SWRCB) Division of Financial Assistance.

There have been seven executed change orders to date on this project. Change orders Nos. 1 – 6 were authorized and ratified by the Board on June 20, 2018. Since that time, there has been one additional change order, CCO No. 7, with a credit of (\$14,378.70) due to OCWD. Change order No. 7 includes additional costs for removal of buried debris not shown on the plans, installation of additional conduit, replacement of monitoring wellheads after installation due to redesign, and installation of transformers in all communication pedestals. Change order No. 7 also includes a credit to OCWD since Kiewit used precast well vaults in lieu of casting the well vaults in place.

The total of all change orders is \$240,793. A summary of the project budget is shown in Table 1:

Table 1
Alamitos Barrier Improvement Project Injection Well Improvements Budget

Description	Budgeted	Projected Expenses
Pre-Design/Pre-Construction	\$ 125,000	\$ 125,000
Design		
- Wellhead Facilities Engineering Design	\$ 207,084	\$ 207,084
Amendment No. 1	\$ 91,328	\$ 91,328
Construction		
- Drilling & Well Installation (Contract AB-2015-1)	\$ 9,984,335	\$ 9,984,335
CCO's 1-10	\$ 393,535	\$ 393,535
- Well Equipping and Vaults	\$ 3,550,000	\$ 3,550,000
CCO's 1-6	\$ 256,395	\$ 255,172
CCO 7	\$ 0	\$ (14,379)
- Construction Management		
Well Installation	\$ 703,000	\$ 703,000
Well Equipping and Vaults	\$ 423,000	\$ 423,000
- Community Relations	\$ 30,000	\$ 30,000
- Surveying Services	\$ 13,000	\$ 13,000
Subtotal for Design & Construction	\$ 15,776,677	\$ 15,761,075
<i>Contingency for Drilling Contract (Remaining)</i>	\$ 114,332	\$ 0
<i>Contingency for Injection Well Improvements</i>	\$ 98,605	\$ 0
Total Project Budget	\$ 15,989,614	\$ 15,761,075
Proposition 84 Grant	\$ (1,000,000)	\$ (1,000,000)
Costs to be paid by LACDPW (one-half of cost for facilities between Points B and C)	\$ (1,253,000)	\$ (1,253,000)
NET ESTIMATED COST TO OCWD	\$ 13,736,614	\$ 13,508,075

Staff recommends ratifying Change Order No. 7 to Kiewit, accepting completion of work, and authorizing filing a Notice of Completion for Contract AB-2016-1.

PRIOR RELEVANT BOARD ACTION(S):

06/20/18, M18-71 – Approve Change Orders to Contract No. AB-2016-1, Alamitos Barrier Improvement Injection Well Improvements (Kiewit Infrastructure Company).

05/24/17, R17-5-79 – Award Contract No. AB-2016-1, Alamitos Barrier Improvement Injection Well Improvements, to Kiewit Infrastructure West Company.

02/15/17, M17-22 – Authorizing publication of Notice Inviting Bids for Contract No. AB-2016-

1 Alamitos Barrier Improvement Project Injection Well Improvements.

10/21/15, R15-10-151 – Award Contract No. AB-2015-1, Alamitos Barrier Improvement Project to Jensen Drilling Company, amending Agreement with CH2M Hill for additional well construction design services, and revising project budget.

8/5/2015, R15-8-105 - Approve and authorize execution of a no fee Sublicense Agreement with the Orange County Flood Control Division, the designated “Sublicensee” to Los Angeles Department of Water and Power (LADWP) License Agreement P-86836, for a period of 3 years to provide alternative access to the Los Alamitos Channel through the adjacent LADWP Haynes Generating Station property during construction of the Alamitos Barrier Improvement Project.

10/15/14, R14-10-139 - Approve and authorize execution of the *License Agreement for Construction Staging and Ingress and Egress* (P-86836) with the LADWP that includes annual rental costs for a temporary staging area, including two years rental for \$61,336, a refundable Security Deposit of \$32,987, and a refundable Restoration Deposit of \$32,987; and Authorize issuance of Services Agreement to CCR for an amount not to exceed \$30,000 for community outreach support on the Alamitos Barrier Improvement Project.

9/17/14, R14-9-126 - Approve and authorize execution of the cost-sharing *Agreement for Construction of Additional Facilities for the Alamitos Barrier Project Supplement No. 7* with the LACDPW for the design and construction of injection and monitoring well facilities and payment by LACDPW to OCWD at one-half of the cost of the new facilities located between Points B and C for a total not to exceed \$1,253,000; and Approve an increase to the Alamitos Barrier Improvement Project budget by \$4,693,000 for a revised total capital project budget of \$14,752,000.

2/19/14, R14-2-24 - Approve and authorize execution of Proposition 84 Integrated Regional Water Management Implementation Grant Funding Contract with SAWPA for a reimbursement amount not to exceed \$1 million for the Alamitos Barrier Improvement Project.

1/15/14, R14-1-4 - Authorize execution of two Easement Deeds for monitoring well and adjacent piezometer OCWD-34V3/OCWD-PZ7, and for piezometer OCWD-PZ9 with the Golden Rain Foundation for the temporary construction easements and 50-year non-exclusive maintenance easements, including compensation of \$11,897, and recordation and acceptance of the deeds.

7/24/13, R13-7-93 - Authorize issuance of an Agreement to Geoscience Support Services, Inc. for an amount not to exceed \$1,126,450 for the Alamitos Barrier Improvement Project construction management services.

5/22/13, R13-5-50 - Authorize issuance of an Agreement to CH2M Hill for an amount not to exceed \$207,084 for the design of the Alamitos Barrier Improvement Project; and Authorize issuance of Request for Proposals for construction management services for the Alamitos Barrier Improvement Project.

3/20/13, R13-3-25 – Adopt the resolution Certifying the Final Environmental Impact Report (State Clearinghouse #2012031027) for the Orange County Water District Alamitos Barrier

Improvement Project; Approve the Geologists/Engineers Report; Establish project budget of \$10,059,000; Authorize Request for Proposals for engineering design; and Authorize publication of Notice Inviting Bids for Drilling and Well Construction.

2/20/13, R13-2-15 - Adopt the Santa Ana Watershed Project Authority's One Water One Watershed 1.0 Plan and the Updated Ranked Project List.

7/21/10, M10-95 – Authorize staff to initiate an environmental assessment and Engineer's Report evaluating near-term measures to improve performance of the Alamitos Seawater Barrier.

AGENDA ITEM SUBMITTAL

Meeting Date: October 10, 2018

To: Water Issues Committee
Board of Directors

From: Mike Markus

Staff Contact: R. Herndon

Budgeted: Yes

Budgeted Amount: \$57,000

Cost Estimate: \$55,832

Funding Source: General Fund

Program/ Line Item No.: 1075.51112.9900

General Counsel Approval: Yes

Engineers/Feasibility Report: NA

CEQA Compliance: NA

Subject: ANNUAL SANTA ANA RIVER STREAM GAUGING JOINT FUNDING AGREEMENT WITH THE UNITED STATES GEOLOGICAL SURVEY

SUMMARY

The United States Geological Survey (USGS) has proposed to continue providing stream gauging (flow and quality) services along the Santa Ana River and Santiago Creek for the period November 1, 2018 to October 31, 2019. The District's share of the stream gauging costs is \$55,832 for 2018-19.

Attachment: Joint Funding Agreement for November 1, 2018 to October 31, 2019

RECOMMENDATION

Agendize for October 17 Board meeting:

1. Approve and authorize Joint Funding Agreement with USGS to conduct stream gauging of the Santa Ana River below Prado Dam and Santiago Creek at Santa Ana for the period of November 1, 2018 to October 31, 2019; and
2. Authorize payment of \$55,832 to the USGS for OCWD's share of costs for these services.

BACKGROUND/ANALYSIS

Flow and quality measurements along the Santa Ana River (SAR) and Santiago Creek are key data used by District staff for a wide range of programs, including calculation of base and storm flows for the annual SAR Watermaster Report, estimation of Forebay recharge and losses to the ocean, and the Prado Water Conservation Program. Data from these stream gauging stations were integral to the District's successful completion of its water rights permit from the State Water Resources Control Board in 2008.

In addition to the Prado gauge, several upstream stations along the SAR and its tributaries were determined by the Watermaster to be vital to the calculation of base and storm flows, as required by the 1969 Judgment. OCWD has established joint funding of SAR stream gauging at the Prado and Santiago Creek stations, while San Bernardino Valley Municipal Water District (SBVMWD) has agreed to continue managing the joint

funding agreement for upstream gauges. USGS costs of measuring and maintaining these stream gauges are shared among the four Watermaster agencies: OCWD, SBVMWD, Inland Empire Utilities Agency, and Western Municipal Water District.

Staff recommends that OCWD continue to contract with the USGS to conduct stream gauging at the Santa Ana River at Prado and Santiago Creek stations for the 2018-19 year. The USGS will fund approximately 25 percent of the program, with 75 percent financial participation by OCWD. Total cost to OCWD for FY18-19 is \$55,832, which includes up to 12 additional manual flow measurements during storm periods to improve gauge calibration and flow measurement accuracy, as requested by District staff.

PRIOR RELEVANT BOARD ACTION(S)

11/15/2017, R17-11-145 Approve and authorize execution of Joint Funding Agreement with USGS to conduct flow and quality monitoring of the Santa Ana River below Prado Dam and Santiago Creek at Santa Ana for the period of November 1, 2017 to October 31, 2018; and authorize payment of \$54,608 to the USGS for OCWD's share of costs for stream flow and quality monitoring services.



United States Department of the Interior

U.S. GEOLOGICAL SURVEY
California Water Science Center
6000 J Street, Placer Hall
Sacramento, CA 95819
Phone: (916) 278-3000 Fax: (916) 278-3070
<https://ca.water.usgs.gov>

September 26, 2018

Mr. Michael R. Markus, P.E., General Manager
Orange County Water District
Post Office Box 8300
Fountain Valley, California 92728-8300

Attn: Roy Herndon

Dear Mr. Markus:

This letter confirms discussions between our respective staffs, concerning the continuation of the cooperative water resources program between the Orange County Water District (District) and the U.S. Geological Survey (USGS) for the period November 1, 2018 to October 31, 2019.

The program contains two elements (see Enclosure 1). The first element consists of the operation and maintenance of one streamflow station, Santiago Creek at Santa Ana (11077500), which was added to the program in Fiscal Year 2005. In addition, the USGS will conduct 12 extra measurements at Santa Ana River below Prado Dam (11074000)¹. The measurements will be based on planned releases by the Los Angeles Army Corps of Engineers during the water year with specific focus during the wet season of November to April. The second element consists of the continued collection of water-quality data at the Santa Ana River below Prado Dam (11074000) gaging station. The USGS will continue to monitor continuous specific conductance and temperature, and collect samples for dissolved solids concentration twice monthly. Mean conductivity weighted by discharge will also be computed and furnished to your agency.

¹ Operation and Maintenance for this site is currently funded by the Groundwater and Streamflow Information Program as a Federal Priority Streamgage (formerly under the National Streamflow Information Program (NSIP)). These funds are subject to annual review of Federal Appropriations Availability.

Mr. Michael R. Markus, General Manager- Orange County Water District

The proposed program and associated costs are as follows:

<u>Program Element</u>		<u>OCWD Funds</u>	<u>USGS Funds</u>	<u>Total Funds</u>
1. – Streamflow monitoring				
11074000	Santa Ana River below Prado Dam ²	\$16,332	\$ -0-	\$16,332
11077500	Santiago Creek at Santa Ana	15,650	7,850	23,500
2. – Water Quality monitoring				
11074000	Santa Ana River below Prado Dam			
A.	Continuous temperature and Continuous conductance	12,550	6,300	18,850
B.	Bi-monthly sampling for TDS	8,350	4,200	12,550
C.	Mean conductance computation	2,950	-0-	2,950
TOTAL		\$55,832	\$18,350	\$74,182

Total cost of the proposed program is \$74,182. Cost to the District is \$55,832, and subject to the availability of Federal matching funds, the USGS will provide \$18,350.

Enclosed are two originals of Joint Funding Agreement (JFA) 19ZGJFA02400, signed by our agency, for your approval. If you are in agreement with this proposed program, please return one fully executed JFA to our office. Work performed with funds from this agreement will be conducted on a fixed-price basis. Auditors are now enforcing a regulation that requires agreements where cooperator funding is at or exceeds \$25,000 to be billed quarterly. Therefore, this agreement reflects a quarterly billing, however, per requests made by your staff, billing for the full annual cost for this agreement will be issued with the first quarter bills of the Federal fiscal year (January) or as close to that date as is achievable.

The USGS is required to have an agreement in place prior to any work being performed on a project. We request that a fully executed JFA be returned prior to November 1, 2018. If it is not received by November 1, we will be required to suspend operations until an agreement is received.

² Cost per measurement is \$1,361. If fewer measurements are made in WY19, a credit will be given in the WY20 fiscal year at the WY19 rate. If more measurements are requested by OCWD, an amendment will be processed to add funding to this WY19 agreement.

Mr. Michael R. Markus, General Manager- Orange County Water District

If you have any questions concerning this program, please contact Scott Patterson, in our Poway Field Office at (858) 679-4015, or Al Caldwell, Deputy Associate Director for Data, at (619) 225-6103. If you have any administrative questions, please contact Tammy Seubert, in our Sacramento Office, at (916) 278-3040.

Sincerely,



Eric G. Reichard
Director, USGS California Water Science Center

Enclosures

cc: Scott Nygren,
Director of Field Operations
Orange County Water District
Field Headquarters
4060 E. La Palma Ave.
Anaheim, California 92807

Al Caldwell, USGS CAWSC

Scott Patterson, USGS, CAWSC

Mr. Michael R. Markus, General Manager- Orange County Water District

Enclosure 1

Proposed Program - November 1, 2018 to October 31, 2019

WATERMASTER SERVICE
Santa Ana River - Fiscal Year 2019
Agreements with USGS for Surface-Water Measurements and Quality Monitoring

Station Number	Station Name	Type Service	Total Cost	USGS	Others	Santa Ana River	Western - S. Bndo.	Contracting Agency
11051499 ^B	Santa Ana River near Mentone (main river gage)	SW	23,500	7,850	15,650		X	SBVMWD
11051502 ^B	Santa Ana River near Mentone (supplementary gage)	SW	14,150	4,750	9,400		X	SBVMWD
11055000 ^D	Mill Creek near Mentone	SW	16,750	-0-	16,750		X	SBVMWD
11055500	Plunge Creek near East Highlands	SW	23,500	7,850	15,650		X	SBVMWD
11055700	City Creek Canal near Highland	SW	14,150	4,750	9,400		X	SBVMWD
11055800	City Creek near Highland	SW	23,500	7,850	15,650		X	SBVMWD
11057500	San Timoteo Creek near Loma Linda	SW	26,050	26,050	-0-		X	N/A (FPS)
11058500	East Twin Creek near Arrowhead Springs	SW	23,500	7,850	15,650		X	SBVMWD
11058600	Waterman Canyon Creek near Arrowhead Springs	SW	23,500	7,850	15,650		X	SBVMWD
11059300	Santa Ana River at E Street near San Bernardino	SED	16,650	-0-	16,650		X	SBVMWD
11060400	Warm Creek near San Bernardino	SW	23,500	7,850	15,650		X	SBVMWD
11061000 ^C	Fontana UWC Infiltration line near Fontana (MVM)	SW	5,500	1,850	3,650		X	SBVMWD
11062000 ^{A & E}	Lytle Creek near Fontana	SW	26,050	26,050	-0-		X	N/A (FPS)
11062399 ^A 11062400 ^A	Fontana UWC Surface Diversion near Fontana (Weirs # 2&3)	SW	15,650	-0-	15,650		X	SBVMWD
11062450 ^A	Fontana PH forebay Spillway near Fontana	SW	15,650	-0-	15,650		X	SBVMWD
11062700 ^F	Lytle Creek Diversion to Fontana Powerhouse AVM near Fontana	SW	1,400	-0-	1,400		X	SBVMWD
11062800 ^A	Fontana UWC Return from Afterbay	SW	15,650	-0-	15,650		X	SBVMWD
11063510	Cajon Creek below Lone Pine Creek near Keenbrook	SW	23,500	7,850	15,650		X	SBVMWD
11063680	Devil Canyon Creek near San Bernardino	SW	23,500	7,850	15,650		X	SBVMWD
11065000	Lytle Creek at Colton	SW	23,500	7,850	15,650		X	SBVMWD
11066460 ^{A & D}	Santa Ana River at MWD Crossing (includes extra measurements)	SW QW/TDS	33,000 13,700	11,050 4,600	21,950 9,100	X X		SBVMWD SBVMWD
11071900	Temescal Creek at Corona Lake near Corona	SW	17,500	-0-	17,500	X		SBVMWD
11072100	Temescal Creek above Main St., near Corona	SW	23,500	7,850	15,650	X		SBVMWD
11073360 ^A	Chino Creek at Schaefer Avenue	SW	23,500	7,850	15,650	X		SBVMWD
11073495 ^A	Cucamonga Creek near Mira Loma	SW	23,500	7,850	15,650	X		SBVMWD

Mr. Michael R. Markus, General Manager- Orange County Water District

Station Number	Station Name	Type Service	Total Cost	USGS	Others	Santa Ana River	Western - S. Bndo.	Contracting Agency
340742117161701	Gilbert Street Precipitation Gage at San Bernardino	Precipitation	9,100	-0-	9,100	X		SBVMWD
340526116561301	Mill Creek Precipitation near Forest Falls	Precipitation	9,100	-0-	9,100	X		SBVMWD
341429116583101	Big Bear Lake Precipitation near Big Bear	Precipitation	9,100	-0-	9,100	X		SBVMWD
341509117312601 ^E	Middle Fork Lytle Creek Precipitation Gage near Lytle Creek	Precipitation	5,450	5,450	-0-	X		N/A (FPS)
11074000 ^{B, D, & E}	Santa Ana River below Prado Dam	SW	26,050	26,050	-0-	X		N/A (FPS)
	Extra Measurements in WY19	SW	16,332	-0-	16,332	X		OCWD
	Continuous Temperature and Continuous Conductance	QW	18,850	6,300	12,550	X		OCWD
	Bi-monthly Sampling for TDS	TDS	12,550	4,200	8,350	X		OCWD
	Mean Conductance Computation	QW	2,950	-0-	2,950	X		OCWD
11077500	Santiago Creek at Santa Ana	SW	23,500	7,850	15,650	X		OCWD
11078000 ^{A & E}	Santa Ana River at Santa Ana	SW	26,050	26,050	-0-	X		N/A (FPS)
TOTALS			672,882	249,200	423,682			

^A Data furnished quarterly to Watermaster.

^B Data furnished monthly to Watermaster.

^C Reduced Cost based on Magnetic Meter Installation, records provided by Fontana Water Company and reviewed by USGS.

^D Includes two USGS discharge measurements per month, plus review and publication of measurements made by San Bernardino Valley Water Conservation District.

^E Data used in support of the Santa Ana Watermaster Program.

^F Data provided annually by Southern California Edison for AVM Quality Check/Review.

2019 FY
TOTAL FUNDING BREAKDOWN FOR ENCLOSURE 1

	Agency Funds	USGS Funds	Agreement Total Funds
San Bernardino Valley Municipal Water District (SBVMWD)	\$367,850	\$121,200	\$489,050
Orange County Water District (OCWD)	55,832	18,350	74,182
Federal Priority Streamgages under the Groundwater and Streamflow Information Program ^E	-0-	109,650	109,650
TOTAL	\$423,682	\$249,200	\$672,882

Form 9-1366
(May 2018)

U.S. Department of the Interior
U.S. Geological Survey
Joint Funding Agreement
FOR

Customer#: 600000805
Agreement#: 19ZGJFA02400
Project #: ZG00GZV
TIN #: 95-6002277

Page 1 of 2

Water Resource Investigations

Fixed Cost Agreement YES[X] NO[]

THIS AGREEMENT is entered into as of the 1st day of November, 2018, by the U.S. GEOLOGICAL SURVEY, California Water Science Center, UNITED STATES DEPARTMENT OF THE INTERIOR, party of the first part, and the ORANGE COUNTY WATER DISTRICT, party of the second part.

1. The parties hereto agree that subject to the availability of appropriations and in accordance with their respective authorities there shall be maintained in cooperation for cooperative water resources investigations in the Orange County Water District area as outlined in the USGS program letter dated September 26, 2018 (Scope of Work), herein called the program. The USGS legal authority is 43 USC 36C; 43 USC 50, and 43 USC 50b.

2. The following amounts shall be contributed to cover all of the cost of the necessary field and analytical work directly related to this program. 2(b) include In-Kind-Services in the amount of \$0.00.

- (a) \$18,350.00 by the party of the first part during the period
November 1, 2018 to October 31, 2019
- (b) \$55,832.00 by the party of the second part during the period
November 1, 2018 to October 31, 2019
- (c) Contributions are provided by the party of the first part through other USGS regional or national programs, in the amount of : \$0.00

Description of the USGS regional/national program:
Not Applicable

- (d) Additional or reduced amounts by each party during the above period or succeeding periods as may be determined by mutual agreement and set forth in an exchange of letters between the parties.
- (e) The performance period may be changed by mutual agreement and set forth in an exchange of letters between the parties.

3. The costs of this program may be paid by either party in conformity with the laws and regulations respectively governing each party.

4. The field and analytical work pertaining to this program shall be under the direction of or subject to periodic review by an authorized representative of the party of the first part.

5. The areas to be included in the program shall be determined by mutual agreement between the parties hereto or their authorized representatives. The methods employed in the field and office shall be those adopted by the party of the first part to insure the required standards of accuracy subject to modification by mutual agreement.

6. During the course of this program, all field and analytical work of either party pertaining to this program shall be open to the inspection of the other party, and if the work is not being carried on in a mutually satisfactory manner, either party may terminate this agreement upon 60 days written notice to the other party.

7. The original records resulting from this program will be deposited in the office of origin of those records. Upon request, copies of the original records will be provided to the office of the other party.

8. The maps, records, or reports resulting from this program shall be made available to the public as promptly as possible. The maps, records, or reports normally will be published by the party of the first part. However, the party of the second part reserves the right to publish the results of this program and, if already published by the party of the first part shall, upon request; be furnished by the party of the first part; at cost, impressions suitable for purposes of reproduction similar to that for which the original copy was prepared. The maps, records, or reports published by either party shall contain a statement of the cooperative relations between the parties. The Parties acknowledge that scientific information and data developed as a result of the Scope of Work (SOW) are subject to applicable USGS review, approval, and release requirements, which are available on the USGS Fundamental Science Practices website (<https://www2.usgs.gov/fsp/>).

Form 9-1366
(May 2018)

Page 2 of 2

U.S. Department of the Interior
U.S. Geological Survey
Joint Funding Agreement
FOR

Water Resource Investigations

Customer#: 600000805
Agreement#: 19ZGJFA02400
Project #: ZG00GZV
TIN #: 95-6002277

9. Billing for this agreement will be rendered quarterly. Invoices not paid within 60 days from the billing date will bear Interest, Penalties, and Administrative cost at the annual rate pursuant the Debt Collection Act of 1982, (codified at 31 U.S.C § 3717) established by the U.S. Treasury.

USGS Technical Point of Contact

Name: Scott Patterson
Supervisory Hydrologic Technician
Address: 12110 Tech Center Drive
Poway, CA 92064
Telephone: (858) 679-4015
Fax: (858) 679-4019
Email: rspatter@usgs.gov

Customer Technical Point of Contact

Name: Mr. Michael R. Markus, P.E.
General Manager
Address: Post Office Box 8300
Fountain Valley, CA 92728-8300
Telephone: (714) 378-3200
Fax:
Email:

USGS Billing Point of Contact

Name: Tamara Seubert
Budget Analyst
Address: 6000 J Street - Placer Hall
Sacramento, CA 95819
Telephone: (916) 278-3040
Fax: (916) 278-3070
Email: tseubert@usgs.gov

Customer Billing Point of Contact

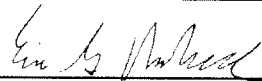
Name:
Address:
Telephone:
Fax:
Email:

U.S. Geological Survey
United States
Department of Interior

ORANGE COUNTY REGIONAL
WATER DISTRICT

Signature

Signatures

By  Date: 9/26/2018
Name: Eric G. Reichard
Title: Director, USGS California Water Science Center

By _____ Date: _____
Name:
Title:

By _____ Date: _____
Name:
Title:

By _____ Date: _____
Name:
Title:

AGENDA ITEM SUBMITTAL

Meeting Date: October 10, 2018
To: Water Issues Committee
Board of Directors
From: Mike Markus
Staff Contact: C. Olsen/R. Bouley
Budgeted: Yes
Budgeted Amount: \$70,000
Cost Estimate: \$178,000
Funding Source: R&R
Program/Line Item No. R18028
General Counsel Approval: N/A
Engineers/Feasibility Report: N/A
CEQA Compliance: N/A

Subject: AGREEMENT TO TETRA TECH FOR SANTIAGO PUMP STATION MODIFICATIONS PROJECT DESIGN AND CONSTRUCTION SUPPORT SERVICES

SUMMARY

On August 15, 2018, the Board authorized staff to issue a Request for Proposals (RFP) for the Santiago Pump Station Modifications Design Services. A total of three proposals were received on September 18, 2018. Staff has evaluated the proposals and recommends awarding an agreement to Tetra Tech for the Santiago Pump Station Modifications Project Design and Construction Support Services.

RECOMMENDATION

Agendize for October 17 Board meeting: Authorize issuance of Agreement to Tetra Tech for an amount not to exceed \$178,000 for the Santiago Pump Station Modifications Project Design and Construction Support Services.

BACKGROUND/ANALYSIS

Orange County Water District (OCWD) owns the Santiago Basins which are located near the intersection of Villa Park Road and N. Hewes Street, along the borders of the Cities of Orange and Villa Park and the County of Orange. OCWD pumps Santa Ana River water from Burriss Basin to the Santiago Basins through the 66-inch Santiago Pipeline for recharge and stormwater storage. The Santiago Basins consist of Bond Basin and Blue Diamond Basin, two former sand-gravel pits that OCWD currently operates as groundwater recharge basins. There are two pump stations located in Bond Basin – one on the bottom of the basin and one floating pump station. Santiago Basin is considered full when the water elevation is 285 feet and OCWD will use these two pump stations to drain the basin down to water elevation 190 feet - An operating range of 95 feet. Figure 1, below, shows the configuration of the basins and the location of the two Santiago Basin Pump Stations.



Figure 1 – Santiago Basins

In 2002, OCWD constructed the Santiago Pump Station in the bottom of Bond Basin to provide the ability to drain the basin and increase aquifer recharge by pumping back to Burris Basin and/or discharging water to Santiago Creek. Since the depth of the water varies greatly as the basin fills and percolates, this pump station was designed with four fixed speed submersible pumps of varying power and capacity. The intent of this design was to allow OCWD to use different pumps as the water elevation changed. The design of these pumps proved to be incompatible with the depth of the water when the basin was full, and three of the four pumps failed after construction. Only the pump designed for basin water elevations within the top forty-five feet of the basin remained after the other three failed.

OCWD constructed the Santiago Floating Pump Station in 2011 to replace the pumping capacity of the two large failed pumps. The floating pump station barge was designed and built to accommodate two large fixed speed pumps and two smaller fixed speed pumps at its ultimate build out. The two large pumps were designed for lower water levels in the basin, and the two small pumps were designed for higher water elevations. Since the remaining pump in the original station still worked at higher water elevations, only the large pumps were installed on the floating pump station. In addition, only the station barge controls and pump power connections for the large pumps were installed. The smaller pumps, controls and power cables were never installed. However, the floating pump station barge can accommodate adding the smaller pumps, associated barge controls and power cables.

Recently, the last operating submersible pump from the original pump station failed. Without this pump, OCWD cannot pump water from Bond Basin to Santiago Creek or Burris Basin when the water elevation in Bond Basin is within the top forty-five feet of the basin (elevation 285 feet – 240 feet).

Staff has identified two options to modify the Santiago Pump Station: Option 1 – Complete the full build out of the floating pump station with two additional pumps and associated barge controls and power cables; or Option 2 – Install Variable Frequency Drives (VFD) for the existing floating pump station to allow the speed of the two existing large fixed speed pumps to be varied, expanding their capability.

Depending on the option chosen, the preliminary construction cost estimate ranges from \$750,000 - \$1,500,000. The design consultant will prepare a detailed evaluation of pros and cons for each option and cost estimates for each as part of their scope.

To modify the Santiago Pump Station and restore OCWD’s capacity to pump from Santiago Basin at water elevations above 245 feet, Staff requires the services of an engineering consultant to conduct an evaluation of these two alternatives and prepare engineered construction drawings and bid documents. On August 15, 2018, the Board authorized staff to issue a Request for Proposals (RFP) for the Santiago Pump Station Modifications Design Services. An RFP was sent to six companies and advertised on OCWD’s web page on August 21, 2018. The scope of the RFP included design services and support from the Engineer during bidding and construction. Staff received three proposals on September 18, 2018, from AKM Consulting Engineers (AKM), Stantec Consulting Services Inc. (Stantec), and Tetra Tech. The proposals were independently reviewed and scored by engineering staff, and the scoring of the proposals included evaluating each firm’s approach to work, schedule and work plan, experience on similar projects, project team, and record of success on similar projects. Tetra Tech received the highest score from the review panel. However, upon review of the fee proposal, it was apparent that their initial fee (\$224,000) included a higher level of effort than was required by the RFP. Since Tetra Tech’s proposal was ranked highest by the review panel, staff contacted Tetra Tech to clarify the level of effort required. Tetra Tech provided a revised fee based upon the clarification of the required level of effort required for the project. The scoring and fee results for all firms are presented in Table 1, below:

Table 1: Proposal Scores and Fees

Firm	Score (out of a possible 100)	Proposed Fee
Tetra Tech	88	\$ 178,000
Stantec	86.3	\$ 190,504
AKM	83.5	\$ 142,676

Tetra Tech’s proposal provides a strong team with relevant prior experience and an excellent understanding of the project needs. Given the rankings of the proposals, Tetra Tech’s understanding of the project needs, anticipation of the project’s potential issues, and their previous experience with similar projects, staff recommends award of an Agreement to Tetra Tech for an amount not to exceed \$178,000 for the Santiago Pump Station Modifications Project Design and Construction Support Services.

PRIOR RELEVANT BOARD ACTION(S):

08/15/2018 M18-97: Establish A Project Budget and Authorize Issuance of RFP for Santiago Pump Station Modifications Design Services

AGENDA ITEM SUBMITTAL

Meeting Date: October 10, 2018

To: Water Issues Committee
Board of Directors

From: Mike Markus

Staff Contact: C. Olsen/A. Perry

Budgeted: N/A

Budgeted Amount: N/A

Cost Estimate: N/A

Funding Source: R&R

Program/Line Item No. R17028

General Counsel Approval: N/A

Engineers/Feasibility Report: N/A

CEQA Compliance: N/A

**Subject: TERMINATION OF AGREEMENT TO KEH & ASSOCIATES FOR
DESIGN SERVICES FOR THE ANAHEIM LAKE VALVE VAULT
PROJECT**

SUMMARY

With authorization from the Board on August 15, 2018, an agreement to KEH & Associates, Inc. for design services for the Anaheim Lake Valve Vault Project was executed. On August 31, 2018, KEH officially joined Gannett Fleming. The same staff that was to provide services for the design project remain with Gannett Fleming.

RECOMMENDATION

Agendize for October 17 Board meeting: Authorize termination of Agreement No. 1324 with KEH & Associates, Inc. and execute a new agreement with the same terms and conditions with Gannett Fleming for design services for the Anaheim Lake Valve Vault Project.

BACKGROUND/ANALYSIS

The Anaheim Lake pipeline distributes water to various locations including Anaheim Lake, Miller Basin, Kraemer Basin, Atwood Channel, and the Carbon Creek Diversion Channel. Several connections to the Anaheim Pipeline are directly buried within a small area just north of the spillway between OC-28 and Anaheim Lake, and are inaccessible without deep excavation. These connections were constructed from the late 1980s to the early 1990s. During construction, several valves were directly buried and access to the valves has been nonexistent.

Two of the existing valves within the project limits are 48-inch butterfly valves that transfer water from the Warner Pipeline to the Anaheim Pipeline. The two valves are at the end of their expected lifespan and are in need of replacement. This project will replace the two valves and will also include the construction of a single or two side-by-side subterranean vaults that would house a total of five valves. The five total valves include the two 48-inch butterfly valves from the Warner Pipeline to the Anaheim pipeline, two additional existing 48-inch valves that connect the Warner Pipeline to the Atwood Channel, and one 72-inch valve that allows the District to distribute water

received from Metropolitan Water District deliveries via OC-28 to the Anaheim Pipeline. The project location can be seen in Figure 1.



Figure 1: Existing Anaheim Lake Buried Valve Location

Enclosing the five valves in a subterranean vault would allow staff to access the valves and perform routine inspections and maintenance as required. The vault would be similar to the Kraemer valve vault which was constructed in 2012 and had similar components and constraints. The preliminary construction cost estimate is \$1.5 million and the design consultant will prepare a detailed cost estimate as part of their scope.

A Request for Proposals (RFP) for design services of the Anaheim Lake Valve Vault Project was publicized on May 7, 2018. A total of two proposals, KEH & Associates and Michael Baker, were received by the RFP due date of May 31, 2018. With Board authorization on August 15, 2018, an agreement with KEH was executed. On August 31, 2018 KEH officially joined Gannett Fleming. While the company has a new name, the same design team from KEH that was to provide services for the Anaheim Lake Valve Vault Project will remain with Gannett Fleming and on the project.

PRIOR RELEVANT BOARD ACTION(S)

8/15/2018, R18-8-110: Authorize agreement to KEH & Associates for design services for Anaheim Lake Valve Vault Project.

12/20/2017 M17-170: Authorize Issuance of RFP for the Anaheim Lake Valve Vault Project

AGENDA ITEM SUBMITTAL

Meeting Date: October 10, 2018

To: Board of Directors

From: Mike Markus

Staff Contact: G. Woodside/A. Hutchinson

Budgeted: Yes

Budgeted Amount: \$250,000

Cost Estimate: \$325,000

Funding Source: General Fund

Program/Line Item No. 1044.53001

General Counsel Approval: N/A

Engineers/Feasibility Report: N/A

CEQA Compliance: N/A

Subject: PHASE II SCOPING STUDY ON FORECAST-INFORMED RESERVOIR OPERATIONS (FIRO) AT PRADO DAM

SUMMARY

Enhanced weather and runoff forecasting has the potential to increase the efficiency of storm water capture at Prado Dam and reduce potential losses to the ocean. Phase I of a Scoping Study on forecast-informed reservoir operations (FIRO) at Prado Dam has been completed. Staff recommends proceeding with Phase II of the Scoping Study.

Attachment(s):

1. Presentation
2. Draft FIRO Viability Assessment Workplan Outline
3. Paper written by Scripps staff: Cannon, F., C.W. Hecht, J.M. Cordeira, and F.M. Ralph, 2018: Synoptic and mesoscale forcing of southern California extreme precipitation. Journal of Geophysical Research - Atmospheres. (conditionally accepted for publication).
4. Phase II Scoping Study Proposal for FIRO at Prado Dam

RECOMMENDATION

Agendize for October 17 Board meeting: Authorize amending agreement with UC San Diego/Scripps Institution of Oceanography by adding an amount not to exceed \$325,000 for Phase II of Scoping Study on Forecast-Informed Reservoir Operations at Prado Dam.

BACKGROUND/ANALYSIS

Stormwater represents a significant source of water used by OCWD to recharge the groundwater basin. Over the last 20 years, OCWD has captured and recharged an average of 50,000 acre-feet per year (afy) of stormwater with a maximum of 85,000 af in 2005, which was a record wet year in Orange County. Much of this recharge is made possible by the capture of stormwater in the Prado Dam Conservation Pool. OCWD continues to work closely with the US Army Corps of Engineers (USACE) to manage the conservation pool and to increase the amount of water that can be temporarily impounded in the conservation pool. Currently, the Conservation Pool can rise to elevation 498 feet mean sea level (ft msl) (approx. 10,000 af of storage) during the

storm season and to 505 ft msl (approx. 20,000 af of storage) during the non-storm season.

To increase the amount of stormwater that can be temporarily impounded in the Conservation Pool, OCWD has been working with the USACE on a Feasibility Study to permanently allow for the temporary impoundment of stormwater up to elevation 505 ft msl year-round. Until the Feasibility Study is complete, OCWD is working to allow for storage up to 505 ft msl during the storm season on a temporary basis (5-yrs) or until the Feasibility Study is completed.

Forecast-Informed Reservoir Operations (FIRO)

Advances in weather and stormwater runoff forecasting hold promise to allow USACE to capture more stormwater at Prado Dam. Temporary storage of stormwater by USACE at Prado Dam must be done in a manner that does not negatively affect the primary flood risk management role of Prado Dam. Future increases in the volume of stormwater that USACE can capture at Prado Dam need to be implemented in such a manner that the dam's flood risk management capability remains essentially the same. For this to happen, more refined weather and runoff forecasting tools need to be provided to USACE for their operation of Prado Dam.

To increase the efficiency of stormwater capture, staff recommends proceeding with Phase 2 of the Scoping Study to examine Forecast-Informed Reservoir Operations (FIRO). FIRO represents the next generation of operating water reservoirs using the best available technology. Moreover, given the importance of atmospheric river (AR) storms on water supplies in California, FIRO represents a methodology to take advantage of our increasing understanding of AR storms which are infrequent but provide a large percentage of total precipitation.

Results of Phase I Scoping Study

Due to the complex nature of FIRO, a multi-phase study that builds on the prior phases is necessary. The recommended approach is patterned after a similar study by Sonoma Water on Lake Mendocino. Phase I of the Scoping Study has been completed. This phase included forming a steering committee and developing the process to create a FIRO Viability Assessment Workplan for Prado Dam.

The members of the steering committee were carefully selected to represent key organizations and bring together innovative leaders from those organizations that collaborate and contribute expertise and resources to accomplish common goals. The Prado Dam Steering Committee and support staff membership include:

Steering Committee Co-Chairs

- Greg Woodside: Executive Director of Planning and Natural Resources, OCWD
- F. Martin Ralph: Director, Center for Western Weather and Water Extremes (CW3E), Scripps Institution of Oceanography, University of California, San Diego

Steering Committee Members

- Jay Jasperse: Chief Engineer, Sonoma Water
- Michael Anderson: State Climatologist, California Department of Water Resources (DWR)
- Cary Talbot: Division Chief, U.S. Army Corps of Engineers (USACE), Engineering Research and Development Center
- Alan Haynes: NOAA National Weather Service (NWS), Hydrologist-in-Charge, California Nevada River Forecast Center (CNRFC)
- Rene Vermeeren: Chief, Hydrology and Hydraulics Branch, Engineering Division, USACE, Los Angeles District
- Jon Sweeten: Hydraulic Engineer, Reservoir Regulation Section, USACE, Los Angeles District
- James Tyler: Manager, Real Estate/Finance and Engineering, Orange County Public Works
- Ken Corey: Assistant Field Supervisor, U.S. Fish and Wildlife Service, Palm Springs

Steering Committee Support

- Adam Hutchinson: Recharge Planning Manager, OCWD
- John Spencer, Civil Engineer, Orange County Public Works
- Arleen O'Donnell: Civil Engineer, Eastern Research Group, Inc.
- Robert Hartman: Hydrologist, Robert K. Hartman Consulting Services
- Dr. Forest Cannon: Staff Scientist, CW3E
- Dr. Ali Hamidi: Post-Doctoral Scholar, CW3E

The Steering Committee convened three times in 2018, with a fourth meeting scheduled for October 16, 2018. Other activities have been conducted by via email and conference calls. The Steering Committee completed a draft FIRO Viability Assessment Work Plan Outline, which is attached. This Work Plan outline sets the stage for the work to be completed in Phase II, which will include preliminary technical studies needed to support preparation of the full Workplan. Actual implementation of the Workplan (Phase III) would be a separate activity. The various phases and estimated timeline for completion are listed in Table 1.

Staff at the Center for Western Weather and Water Extremes (CW3E) at Scripps, has already completed some technical studies related to weather patterns in the Santa Ana River watershed and Southern California. This work was led by Dr. Cannon Forest and is presented in a paper that has been conditionally accepted for publication (see attached paper).

Table 1: Phases of FIRO Study and Schedule

Phase	Activity	Schedule
I	Scoping Study, Develop FIRO Viability Assessment Work Plan Outline, preliminary technical studies	2018
II	Scoping Study Part 2, Conduct Technical Studies to Complete FIRO Viability Assessment Work Plan	2019
III	Execute FIRO Viability Assessment	2021

IV	Conduct FIRO at Prado Dam as Part of Major Deviation	2022*
V	FIRO incorporated into Prado Dam Water Control Manual as permanent feature.	2025*

*Phase IV/V schedule dependent on hydrology and completion of the Santa Ana River Mainstem Project.

Additional Details Regarding Phase II Scoping Study

Phase II of the Scoping Study involves conducting the technical studies to complete a full FIRO Viability Assessment Workplan for Prado Dam. Table 2 summarizes the major tasks to be carried out in Phase II. A copy of the Phase II Scoping Study proposal from Scripps is attached. It is estimated that Phase II will take one year to complete.

Table 2: Phase II Scoping Study Tasks and Activities

Task	Activities
Task 1: Prado FIRO Steering Committee Co-Leadership	Convene quarterly meetings of the FIRO-SC, with working sessions in between meetings. Create sub-groups (focus areas may include technical studies, hydrologic models, decision support system scoping, etc.) as needed.
Task 2: Co-lead Creation of Workplan to Assess Viability of FIRO at Prado Dam	Prepare a draft and final work plan: The final work plan will form the scope for the FIRO Viability Assessment with each component noted as: (A) not started, (B) in progress or, (C) completed. It will identify lead roles and potential funding sources, and propose a schedule for completion
Task 3: Plan and Execute FIRO Workshop	Planning and executing a workshop that brings together key stakeholders and experts.
Task 4: Preliminary Technical Study	Identify key scientific, hydrologic, engineering, biological, and/or operational gaps and proposing solutions to fill these gaps to enable FIRO implementation. Initiate technical analyses as needed to support work plan development.

The proposed budget for Phase 2 of the Scoping Study is \$325,000.

Benefits to OCWD

The primary benefit to OCWD is the potential development of a customized FIRO tool that will be used by the USACE to manage the water conservation pool at Prado Dam. Even slight improvements in stormwater capture efficiency at Prado will more than offset the costs needed to develop a FIRO tool and yield long-term benefits to the groundwater basin. By partnering with the USACE and Sonoma Water, OCWD will be at the vanguard of an approach that will likely become a statewide and even national approach to managing reservoirs more efficiently for storm water capture.

PRIOR RELEVANT BOARD ACTION(S)

6/21/17, R17-6-90 - Approve Scoping Study on Forecast-Informed Reservoir Operations (FIRO) at Prado Dam with Scripps Institution of Oceanography.



Phase II Scoping Study on Forecast-Informed Reservoir Operations at Prado Dam

Water Issues Committee
October 10, 2018



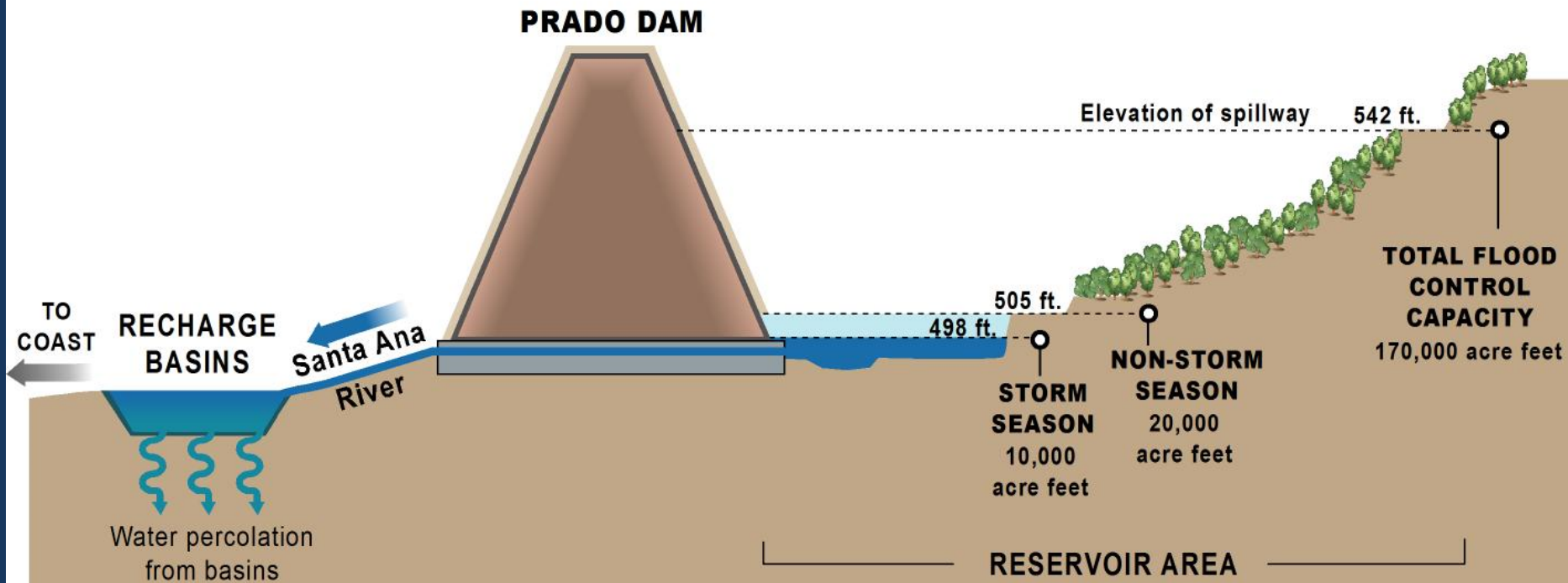
Efforts to Increase Stormwater Capture at Prado

- Formally seeking stormwater capture to elevation 505 feet above mean sea level (ft) in flood season
 - Permanent change to 505 ft year-round being evaluated in Prado Basin Feasibility Study being conducted by Corps with OCWD as local sponsor
 - Temporary deviation to 505 ft in review at Corps South Pacific Division
- Evaluating potential for elevations above 505 ft through Forecast Informed Reservoir Operations
- **Challenge:** Increased stormwater capture elevation cannot impact dam's flood risk management purpose



WATER CONSERVATION ELEVATIONS

ABOVE SEA LEVEL





Forecast-Informed Reservoir Operations (FIRO)

- Using enhanced weather forecasting and runoff estimation tools to inform future reservoir operations
- Includes growing understanding of atmospheric river (AR) storms
- Pilot study completed for Lake Mendocino led by Dr. Martin Ralph/Scripps, Army Corps, and Sonoma Water



FIRO Scoping Study

- Two phases
- Phase I Complete
 - Form Prado FIRO Steering Committee
 - Create detailed FIRO Viability Assessment Work Plan Outline
 - Conduct Preliminary Technical Studies



FIRO Steering Committee chaired by Dr. Marty Ralph and Greg Woodside

Includes staff from:

- Sonoma Water
- USACE
- National Weather Service
- DWR
- Orange County DPW
- USFWS





Phase II of Scoping Study

- Task 1: Prado FIRO Steering Committee Co-Leadership
- Task 2: Co-lead Creation of FIRO Viability Assessment Work Plan
- Task 3: Plan and Execute FIRO Workshop
- Task 4: Preliminary Technical Study
 - Explore precipitation forecast skill
 - Evaluate forecast lead time needed for FIRO at Prado Dam



Prado Dam FIRO Timeline

Phase I: Scoping Study, Develop FIRO Viability Assessment Work Plan Outline

Phase II: Conduct Technical Studies; Complete FIRO Viability Assessment Work Plan

Phase III: Execute FIRO Viability Assessment

Phase IV: Conduct FIRO at Prado Dam as part of Major Deviation

Phase V: FIRO incorporated into Prado Dam Water Control Manual as permanent feature.

2018

2019

2021

2022*

2025*

*Phase IV/V timeline dependent on hydrology and completion of the Santa Ana River Mainstem Project.



Recommendation

Agendize for October 17 Board meeting:

- Authorize amending agreement with UC San Diego/Scripps Institution of Oceanography by adding an amount not to exceed \$325,000 for Phase II Scoping Study on Forecast-Informed Reservoir Operations at Prado Dam.

Prado Dam Forecast Informed Reservoir Operations Draft Work Plan Outline



October 2, 2018

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Acronyms (to come)

PRADO FIRO Scoping Study

Draft Work Plan Outline

1. Introduction

A. History of Forecast Informed Reservoir Operations

California's water supplies rely on adequate precipitation, which largely depends on atmospheric rivers (ARs). The absence of AR storms often leads to drought, whereas strong ARs can cause flooding. Currently, most reservoirs are operated without the benefit of AR forecasts. However, the Center for Western Weather and Water Extremes (CW3E) is now developing skill in forecasting ARs. Predicting the timing and intensity of these critical precipitation events (and the lack thereof) is essential to providing water managers and dam operators with the information they need with enough lead time to operate reservoirs to adapt to floods and drought. This cost-effective management approach, called Forecast Informed Reservoir Operations (FIRO), offers an opportunity to make better use of existing multi-purpose reservoirs across the state and region.

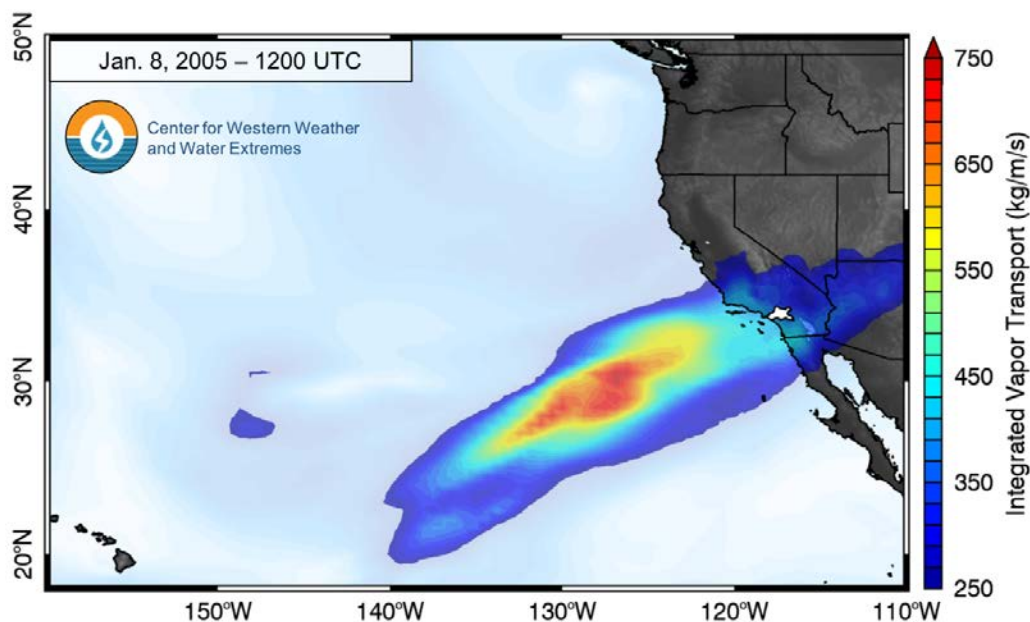


Figure 1. Landfalling AR that impacted the Santa Ana River watershed and Prado Dam in early January 2005.

FIRO uses data from watershed monitoring programs and improved weather and water runoff forecasting to help water managers selectively retain or release water from reservoirs in a flexible manner that more effectively reflects prevailing and anticipated conditions. FIRO represents an innovative use of emerging science and technology to optimize limited resources and adapt to changing climate conditions without costly reservoir infrastructure improvements.

FIRO was first initiated in 2014 by the creation of a steering committee to develop and test FIRO at the pilot reservoir, Lake Mendocino, in the Russian River watershed. The Lake Mendocino FIRO preliminary viability assessment (2017) indicates that FIRO-based operations can potentially provide significant

benefit to water supply while also supporting salmon recovery and maintaining flood risk management. The final viability assessment is expected to be released in 2020.

Forecast-coordinated operations for the Yuba-Feather River system in northern California also illustrate the potential benefits of FIRO. In this case, parallel reservoirs (Lake Oroville on the Feather River and New Bullards Bar Reservoir on the Yuba River) are operated for target flows at a common downstream location below the Yuba and Feather River confluence. By using forecasts and models of reservoir operation integrated into a decision support system (DSS), water managers from different agencies can assess potential release schedules and ensure coordinated operation so that flow is not exceeded at the downstream control point.

This Prado Dam FIRO scoping study builds on past success and follows the process established by the Lake Mendocino pilot project.

B. Project Objectives

Prado was chosen for FIRO exploration based on technical applicability, the need for a water control manual (WCM) update (due to the upcoming completion of dam modifications), and the cooperative relationships between stakeholder agencies.

The U.S. Army Corps of Engineers (USACE) is working closely with the Orange County Water District (OCWD) on this scoping study. OCWD's mission is to ensure a reliable supply of high-quality water for more than 2.5 million residents in north and central Orange County while protecting environmental habitats and natural resources.

This collaborative scoping study will explore the potential application of FIRO at Prado Dam on the Santa Ana River. The Lake Mendocino experience in the upper Russian River watershed will inform the process, which will build on lessons learned about ARs as the source of heavy West Coast precipitation and runoff. As the owner and operator of Prado Dam, USACE has complete control regarding the dam's operation. If FIRO identifies potential modifications to the dam's operations, such modifications would be implemented only after USACE reviews and approves them. Additionally, this study may inform the USACE in using weather forecasting technology at other USACE dams.

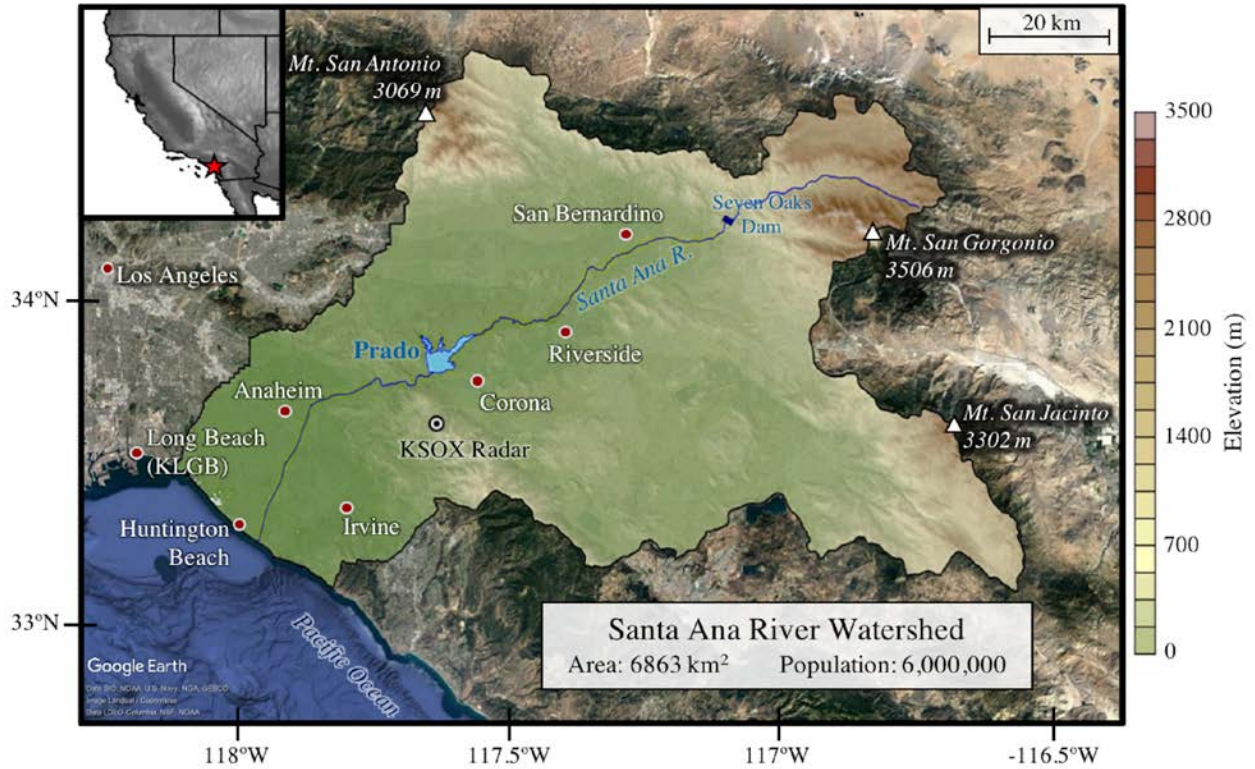


Figure 2. Santa Ana River watershed and Prado Dam location.

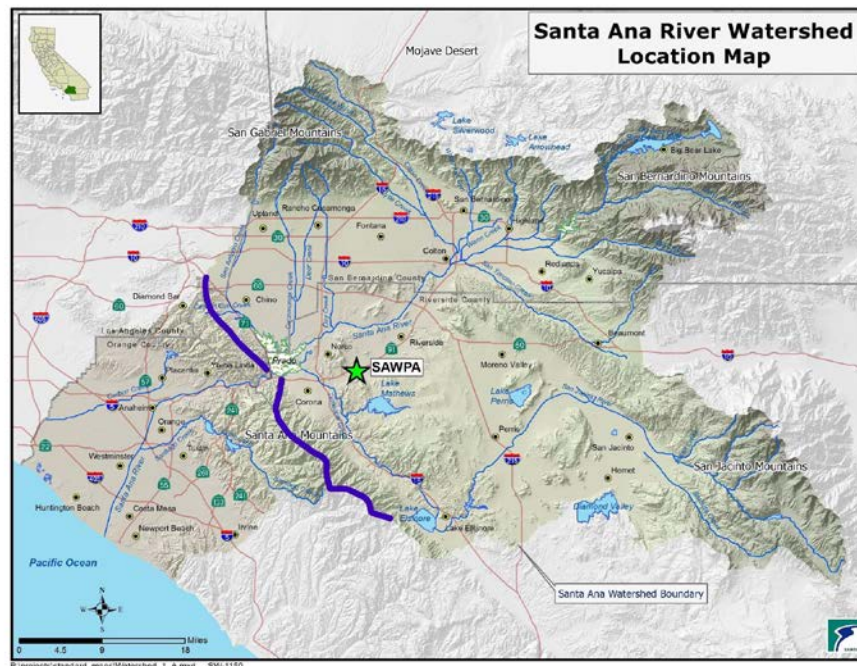


Figure 3. Prado Dam's contributing area.

The purpose of this project is to answer the following question: Can current and improved forecasts of land-falling ARs and associated precipitation and runoff be sufficiently leveraged in Prado Dam

operations to enhance water conservation (e.g., stormwater capture and recharge) while not compromising (or even improving) flood mitigation and environmental objectives?

To answer this question, a detailed work plan will be developed to determine the viability of FIRO at Prado Dam. The work plan objectives include:

- i. Summarizing existing studies.
- ii. Identifying additional research, data, and analyses needed to demonstrate FIRO viability.
- iii. Developing a work process flow outline for a DSS.
- iv. Identifying scenarios where the USACE can implement FIRO (including evaluating different reservoir target elevations).
- v. Developing a strategy that will allow USACE to perform trial implementations of FIRO.
- vi. Establishing performance criteria from item v above to support the USACE’s integration of FIRO into a future version of the Prado Dam WCM.
- vii. Outlining a range of mitigation options to protect and enhance natural resources.

C. FIRO Viability Assessment Process

FIRO efforts at Prado Dam will involve both evaluating current forecasting technology as well as identifying and executing needs-based research. Figure 3 shows the general evaluation process that was used for the Lake Mendocino FIRO project. This tested process is fully applicable to the Prado Dam scoping study, and the FIRO team will follow this structure to conduct the study.

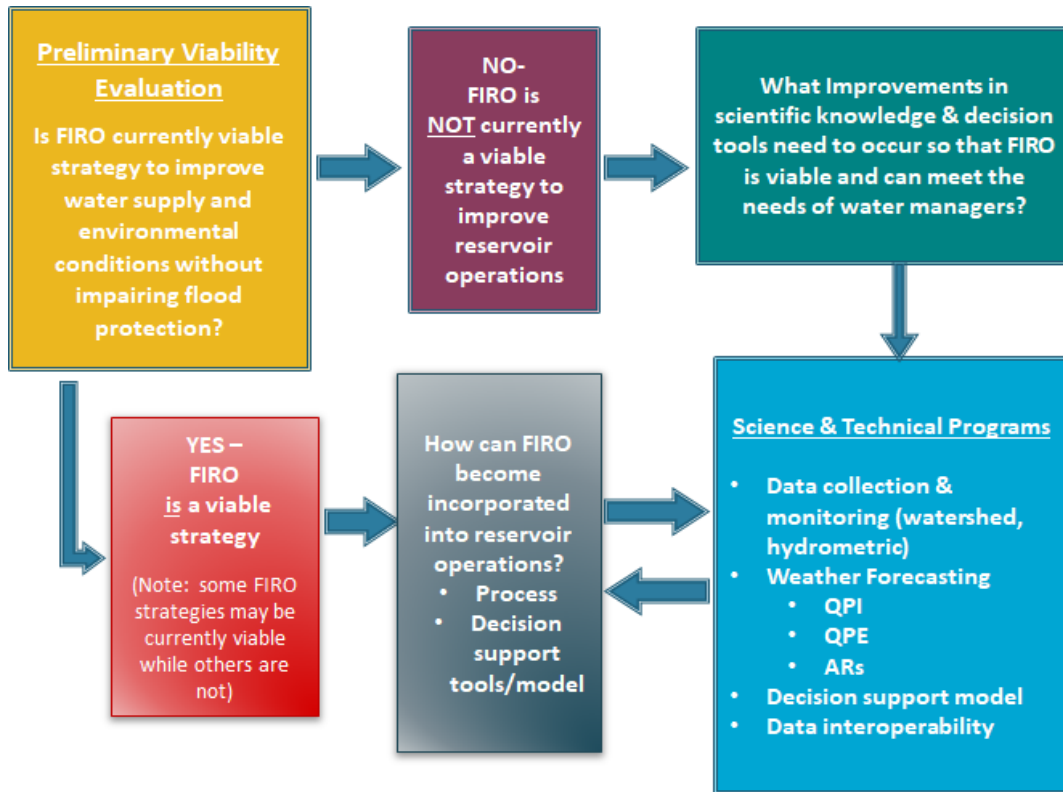


Figure 4. Preliminary viability assessment process.

The FIRO team will use established and agreed-to metrics and criteria to assess the ability of various strategies to improve the full spectrum of outcomes for Prado Dam operations. The team will identify and pursue research and development activities that have clear potential to improve FIRO outcomes while executing the work plan. The timeline for assessments and associated work will be established by agreement of the Steering Committee (SC) within the confines of available funding.

D. Prado Dam FIRO Steering Committee

The Prado Dam SC was formed in 2017. It is co-chaired by Dr. F. Martin Ralph, Director of the Center for CW3E, and Greg Woodside, Executive Director of Planning and Natural Resources at OCWD. Committee members were carefully selected to represent key organizations, and they bring together innovative leaders from those organizations that collaborate and contribute expertise and resources to accomplish common goals. Prado Dam SC and support staff membership are outlined below, followed by the SC's vision, mission, goals, and strategies.

Co-Chairs

- Greg Woodside: Executive Director of Planning and Natural Resources, OCWD
- F. Martin Ralph: Director, CW3E Scripps Institution of Oceanography, University of California, San Diego

Members

- Jay Jasperse: Chief Engineer, Sonoma Water
- Michael Anderson: State Climatologist, California Department of Water Resources (DWR)
- Cary Talbot: Division Chief, USACE, Engineering Research and Development Center
- Alan Haynes: NOAA National Weather Service (NWS), Hydrologist-in-Charge, California Nevada River Forecast Center (CNRFC)
- Rene Vermeeren: Chief, Hydrology and Hydraulics Branch, Engineering Division, USACE, Los Angeles District
- Jon Sweeten: Hydraulic Engineer, Reservoir Regulation Section, USACE, Los Angeles District
- James Tyler: Manager, Real Estate/Finance and Engineering, Orange County Public Works (OCPW)
- Ken Corey: Assistant Field Supervisor, U.S. Fish and Wildlife Service (USFWS), Palm Springs

Support Staff

- Adam Hutchinson: Recharge Planning Manager, OCWD
- John Spencer, Civil Engineer, OCPW
- Arleen O'Donnell: Civil Engineer, Eastern Research Group, Inc.
- Robert Hartman: Hydrologist, Robert K. Hartman Consulting Services
- Dr. Forest Cannon: Staff Scientist, CW3E
- Dr. Ali Hamidi: Post-Doctoral Scholar, CW3E



Figure 5. May 17, 2018, Prado Dam SC meeting at Prado Dam.

(From left: Rob Hartman, Jon Sweeten, Mike Anderson, Jay Jasperse, John Spencer, Forest Cannon, Marty Ralph, Greg Woodside, Cary Talbot, Cuong Ly, Rene Vermeeren, Van Crisostomo, James Tyler, Arleen O'Donnell)

SC Vision, Mission, Goal, and Strategies

- Vision: Develop robust forecast data and tools that support increased flexibility in reservoir operations, improving water conservation, flood control, and habitat management outcomes.
- Mission: Guide a highly collaborative engagement process to ensure that deliverables reflect interdisciplinary perspectives and interagency input.
- Goal: Develop clear pathways for assessing the viability of FIRO at Prado Dam.
- Strategies: Draft a work plan outlining tasks, roles, schedule, and requirements for assessing FIRO viability; conduct preliminary technical studies; and develop a preliminary viability assessment based on current forecast skill and a final viability assessment based on potential improvements in forecast skill.

Process for Achieving Mission

- Hold quarterly SC meetings, at least two of which each year are in person.
- Develop meeting agendas and circulate meeting notes; document and track action items.
- Conduct conference calls, site visits, small working group meetings, and other means of coordination.
- Hold an annual workshop to engage/coordinate with and learn from each other.
- Pursue communication and outreach opportunities.
- Develop a strategy for launching the work plan, including funding and implementation commitments.

2. Project Background and Description

A. Santa Ana River Watershed

I. Physical Characteristics

The Santa Ana River, more than 90 miles long, is the longest river entirely within Southern California. The effective contributing drainage of the entire river is approximately 2,450 square miles, 2,255 square miles (92 percent) of which are captured behind Prado Dam. The river originates in the San Bernardino Mountains and flows southwesterly through San Bernardino, Riverside, and Orange counties before terminating at the Pacific Ocean. The Santa Ana River watershed is ringed by the rugged San Gabriel, San Bernardino, and San Jacinto Mountains, each containing at least one peak greater than 10,000 feet in elevation. These mountains and their foothills represent about one-third of the total drainage area.

Principal tributaries above Prado Dam, listed clockwise, include San Antonio/Chino Creek, Cucamonga Creek, Lytle Creek, Mill Creek, San Timoteo Creek, and the San Jacinto River, which flows into Temescal Creek. The Lytle, Mill, and San Timoteo creeks converge with the Santa Ana River just above the city of Riverside. The others discharge directly into Prado Reservoir. Santiago Creek is the largest tributary to the lower Santa Ana River downstream from Prado Dam.

The Santa Ana River has an average gradient of 240 feet/mile in the mountains and about 20 feet/mile closer to Prado Reservoir. The average gradient of the principal tributaries in the mountains is 700 feet/mile and 30 feet/mile in the valleys.

Prado Dam is the principal flood control dam in the watershed. Two other flood control dams receive runoff from relatively small portions of the mountainous upper watershed: San Antonio Dam on San Antonio Creek (drainage area 27 mi²) and Seven Oaks Dam on Santa Ana River (drainage area 177 mi²). See Figure 6 for locations of dams in the Santa Ana River watershed.

The FIRO team will add physical characteristics relevant to the study to the work plan as they are identified during the analysis and evaluations.

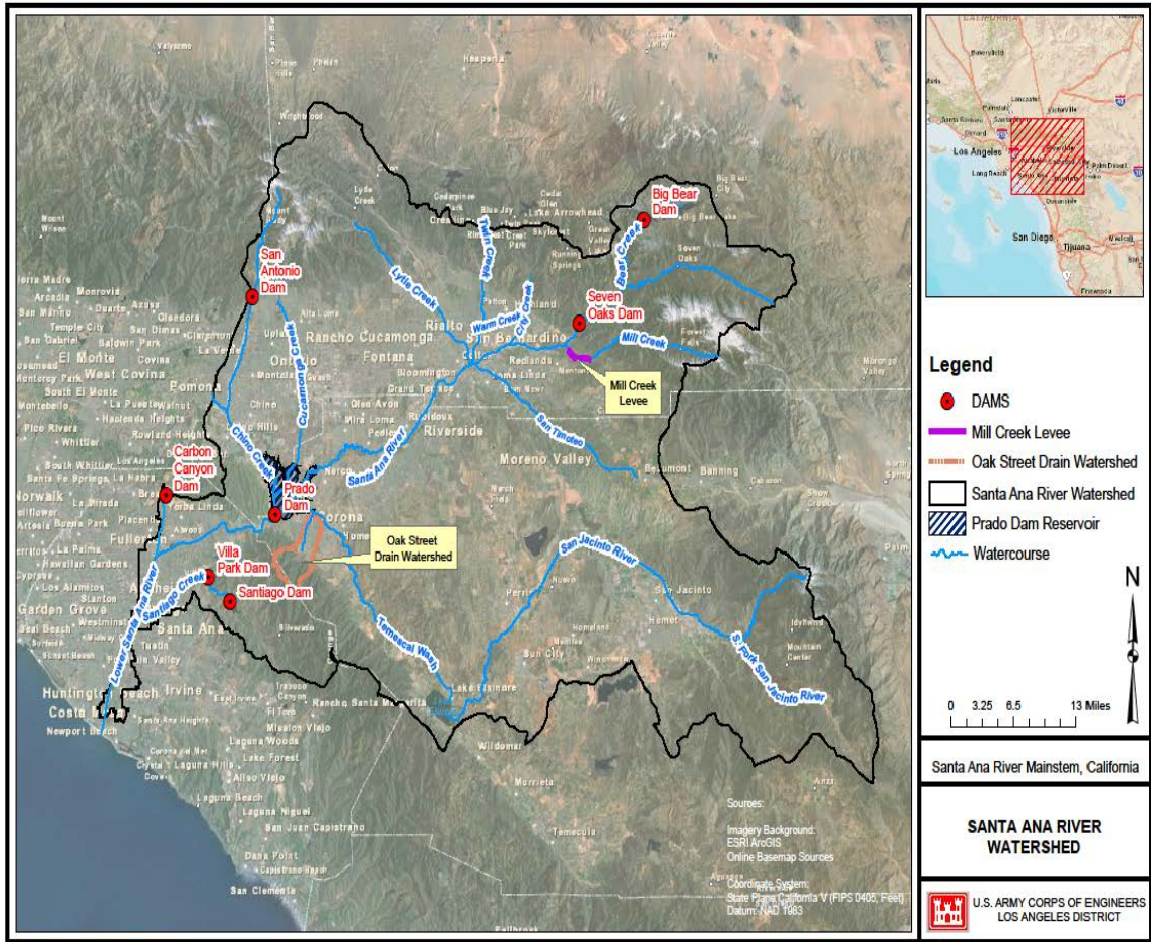


Figure 6. Location of dams in the Santa Ana River watershed.

II. Environmental Assets and Considerations

This section will characterize the ecological resources of the area, highlighting threatened and endangered species, as well as species of special concern, and the implications of habitat health for these species on reservoir operations.



Figure 7. Photo of least Bell's vireo with chicks (Courtesy of B. Peterson, USFWS).

1) Threatened and Endangered Species

- Least Bell's vireo
- Southwestern willow flycatcher
- Santa Ana sucker
- Western yellow-billed cuckoo
- Coastal California gnatcatcher

2) Governing Documents, Biological Opinions

Governing documents to be incorporated in the work plan include habitat conservation plans, species recovery plans, designations of critical habitat, and Biological Opinions (BOs). Conditions for the existing stormwater capture program are outlined in BOs issued by the USFWS. BOs associated with USACE/OCWD requests for water conservation include BO 1-6-95-F-28, issued in 1995 for non-flood season water conservation to elevation 505 feet; BO FWS-WRIV-2102.3, issued in 2002 for flood season water conservation to elevation 498 feet; and BO FWS-WRIV-09B0192-18F0101, issued in 2018 for a 5-year flood season deviation to 505 feet.

3) Goals

The environmental goals for water conservation in Prado Basin are to maintain and enhance natural resources in concert with temporary stormwater capture; this section will describe the environmental goals in detail. Environmental goals will be incorporated into the overall FIRO program goals.

4) Relationships with Water Level (Frequency, Duration, and Time of Year)

If FIRO implementation recommends water conservation to higher elevations than the existing operations, the team will need to evaluate impacts from additional days of habitat inundation. Other

impacts to assess include increased sediment deposition and effects on wildlife movement, as well as potential impacts to the channel downstream of the dam. The team would prepare National Environmental Policy Act (NEPA)/California Environmental Quality Act (CEQA) documentation separately, but the work plan will outline issues that may require analysis separate from NEPA/CEQA documentation (such as issues that may merit special study; e.g., vireo habitat impacts).

B. Water Management

I. Prado Dam

This section will include key information about Prado Dam, including owner, purpose, and storage capacity, as well as how it is operated for flood risk management and managed for water conservation. Temporary capture of stormwater at Prado Dam is referred to as “water conservation” because it conserves water that would otherwise flow to the ocean.

This section will also describe how Prado Dam is operated in tandem with upstream dams. Historical operations, such as inflows, storage levels, and outflow levels will also be described to provide context for evaluating future operations.

II. Seven Oaks Dam

This section will include key information about Seven Oaks Dam, including owner, purpose, and storage capacity. It will also describe how the dam is operated for flood risk management and water conservation, and how it is operated in tandem with San Antonio and Prado dams. Historical operations, such as inflows, storage levels, and outflow levels will also be described to provide context for evaluating future operations.

III. San Antonio Dam

This section will include key information about San Antonio Dam, including owner, purpose, and storage capacity. It will also describe how the dam is operated for flood risk management and water conservation, and how it is operated in tandem with Seven Oaks and Prado dams. Historical operations, such as inflows, storage levels, and outflow levels will also be described to provide context for evaluating future operations.

IV. Groundwater Recharge

This section will describe the surface water recharge system that OCWD has developed downstream of Prado Dam, including the number and types of recharge facilities, diversion capacities, storage capacities, and recharge capacities, and how these capacities change with time during the storm season. This section will also present estimates of how stormwater recharge varies with the water conservation pool volume at Prado Dam.

V. Upper Santa Ana River Stormwater Recharge

This section will describe the existing and planned stormwater recharge activities of agencies upstream of Prado. This includes onsite infiltration of stormwater required in municipal separate storm sewer system permits. The section will also describe stormwater recharge by OCWD downstream of Prado. Although OCWD has developed a system capable of capturing and recharging large quantities of stormwater, there are limits to the flows that can be diverted from the Santa Ana River. Prado Dam is critical to capturing these high-flow events that otherwise would be lost to the ocean.

C. Water Management Context and Challenges

I. History of OCWD/USACE Collaboration and Agreements

This section will describe the history of OCWD's collaboration with USACE, which dates back to the construction of Prado Dam (completed in 1941). Some key dates are as follows:

- **1991:** USACE and OCWD begin to formalize water conservation (stormwater capture) operations at Prado Dam through Memorandums of Agreement (MOAs).
- **1993:** MOA provides for winter and spring conservation pool elevations of 494/505 feet above mean sea level (MSL), respectively.
- **2006:** MOA provides for winter and spring conservation pool elevations of 498/505 feet above MSL, respectively.
- **2018:** Deviation provides for 505 feet above MSL in winter and spring for the next five years. It is anticipated that a new MOA may make this conservation pool permanent in the near future (pending Prado Basin final viability assessment).

Stormwater conserved at Prado Dam is temporarily held in the buffer pool. OCWD coordinates with USACE to drain the stormwater temporarily captured at the dam as quickly as possible for recharge into the Orange County Groundwater Basin. OCWD does not have a dedicated water supply pool at Prado Dam. Prado Dam's primary purpose is flood risk management, and USACE has complete authority and discretion to operate Prado Dam and release water held in the buffer pool as it deems necessary.

II. Improving Water Conservation, Flood Risk Management, and Environmental Objectives

- Prado FIRO water conservation objectives are to:
 - Minimize the occurrence of water released from the buffer pool prior to a storm not being captured for downstream groundwater recharge due to an over-forecast of Prado inflow.
 - Maximize use of available Prado Dam conservation buffer storage space.
 - Operate dam in flood season with flexibility for slight exceedance of buffer pool, elevation being the paradigm (slight rise above buffer pool elevation and then drain down in less than five days or other predetermined timeframe).
 - Provide analysis and framework for potentially higher temporary storage space in the future.
- Prado FIRO flood risk management objectives are to:
 - Ensure that at a minimum, any FIRO alternative must not have a negative impact on the flood control capacity of Prado Dam. During this work, the flood control capacity of Prado Dam will increase (see Section 2.D). Evaluations will take this shifting capacity into account. In the process developing and evaluating alternatives, it is entirely possible that the flood control capacity of Prado Dam can be improved.
- Prado FIRO environmental objectives are to:
 - Explore habitat enhancement options that could offer environmental co-benefits.
 - Avoid and, where avoidance is not possible, minimize and mitigate negative impacts on natural resources.

D. Project Phases and Timelines

- I. **Phase A:** Reach 9 construction, BNSF Bridge, Reach 9 channel modifications → 2023
- II. **Phase B:** Completion of interior dikes in reservoir, raise spillway → 2028
- III. **Phase C:** Santa Ana River Main stem (SARM) project complete → 2028

3. Catalog and Assessment of Existing Monitoring Programs

A. Surface Observations

The NWS collects precipitation data from approximately 80 stations in the Santa Ana River watershed. About 25 of these stations are quality-controlled and ingested for hydrologic modeling. These stations are operated and maintained by several agencies, including the Bureau of Land Management (one station), the U.S. Forest Service (seven stations), the California Department of Forestry and Fire (two stations), the counties of San Bernardino and Riverside (12 stations combined), the U.S. Geological Survey (USGS; two stations), and USACE (one station). The stations are situated primarily in the 1,000- to 5,000-foot elevation range, with the lowest elevation at 640 feet MSL and the highest at 6,903 feet MSL. Precipitation measured at these stations is aggregated into 6- and 24-hour blocks and quality-controlled at the NWS CNRFC. These data are then spatially distributed using a tool employing a [PRISM climatology](#) background and distance weighting to form mean areal precipitation values for each of the sub-basins used in the CNRFC's hydrologic modeling. A subset of the gages that report precipitation also report temperature (four stations). The CNRFC uses these stations to collect and quality-control 6-hour mean temperatures and 24-hour maximum and minimum temperatures similarly to how it quality-controls precipitation data, ultimately producing mean areal temperatures for each of the sub-basins used in the CNRFC's hydrologic modeling.

The CNRFC uses seven USGS stream gages as part of its hydrologic modeling system for the Santa Ana basin. Additional ALERT stream gaging stations in the basin are operated and maintained by the counties of San Bernardino and Riverside.

B. Remote Sensing

The NWS operates a Weather Surveillance Radar (WSR-88D) in the Santa Ana Mountains located at 3,106 feet MSL. The radar detects precipitation and winds aloft over the watershed.

A few elements of the California DWR/NOAA Environmental Research Laboratory AR observing system can contribute to the monitoring effort for the Prado Dam FIRO. An AR observatory on the coast is located at the Santa Barbara Airport. This observing system can be used to determine the onshore flux of water vapor associated with ARs making landfall in the region. A snow-level radar is located in Devil's Canyon and provides freezing elevation (elevation where rain turns to snow). A number of GPS-met stations are in the region and quantify water vapor concentration related to precipitation amounts in AR storms.

C. Potential Enhancements

The CNRFC has judged that the network of precipitation and temperature gages throughout the Santa Ana River watershed is adequate for current hydrologic forecasting services provided by their agency. Temperature tends to be relatively smooth when analyzed spatially, primarily varying due to elevation, and is exclusively used in the snow model portion of the CNRFC suite of hydrologic forecasting tools. Thus, a much smaller set of temperature gages can adequately capture the spatial variability in temperature. If forecast demands change during this work, enhancements to the gaging network to support CNRFC forecasting may be required.

The existing gaging network is adequate for the operational decisions that USACE and OCWD currently make. The exploration of FIRO alternatives may place additional demands on observations. This study will consider additional observations.

D. Environmental

OCWD, USACE, the Santa Ana Watershed Association, and other stakeholders implement environmental monitoring programs in Prado Basin. OCWD intensively monitors vireo nesting, vegetation health, and other natural resources. Stakeholders also collect data on natural resources in the Santa Ana Canyon downstream of Prado Dam.

4. Catalog and Review of Existing Models

This section will present an overview of the various types of models in the Santa Ana River watershed which are listed in the table below. Subsequent subsections will describe key models in more detail. The FIRO team will consider and leverage available models while exploring and resolving this study’s questions.

Model (Source)	Purpose
Surface Water Model (Wildermuth Environmental)	Supports water supply/water quality analyses as part of Santa Ana Watershed Project Authority task force.
Surface Water Model (Geoscience Support Services)	Updates Wildermuth model.
CHPS: Community Hydrologic Prediction System (NOAA/NWS/CNRFC)	Use multiple models to generate Prado inflow forecast.
Integrated Surface/Groundwater Model (Geoscience Support Services)	Integrates five groundwater basin models and surface water model (probably not relevant to FIRO).
Corps Water Management System (USACE)	Interface allows use of multiple USACE models (e.g., HEC-RAS, HEC-ResSim).
Los Angeles District Prado Reservoir Model (USACE)	Spreadsheet model informs reservoir operations during storm periods.
OCWD Recharge Facilities Model (OCWD, Jacobs)	Simulates operation of OCWD groundwater recharge facilities downstream of Prado Dam.
Climate Change Analysis for the Santa Ana River Watershed (U.S. Department of the Interior Bureau of Reclamation, VIC model)	Downscales climate modeling for Santa Ana River watershed. https://www.usbr.gov/lc/socal/basinstudies/OWOW/References/FinalReport/TM%201%20Climate%20Change.pdf
Five Year (2017 to 2022) Planned Deviation to the Prado Dam Water Control Plan and Sediment Management Demonstration Project Biological Assessment (USACE, HEC-RAS)	Includes simulations of Prado Dam operations. https://www.spl.usace.army.mil/Portals/17/docs/publicnotices/AppendixD_BA_wTech_Repts.pdf?ver=2017-08-21-170237-623

A. Hydrologic/Hydraulic

I. CHPS—Community Hydrologic Prediction System (NOAA/NWS/CNRFC)

CHPS provides the structure for running multiple rainfall-runoff models above Prado Dam. The Prado watershed inflow forecast model is currently divided into eight basins. Each basin has components for simulating and forecasting rain-snow elevation, snow accumulation and melt (SNOW-17), soil runoff (SAC-SMA), and hydrograph routing (LAG/K). Forcing input includes a 10-day temperature forecast, six-day quantitative precipitation forecast (QPF), and six-day freezing-level forecast. While most model

components are run on a six-hour timestep, some tributaries (Lytle Creek, San Timoteo Creek, and Temescal Creek) are run on an hourly time step.

CHPS also produces probabilistic inflow hydrographs using the Hydrologic Ensemble Forecast Service (HEFS). HEFS forecasts include both short-range (15-day) and long-range (365-day) simulations. Short-range probabilities are produced from hourly hydrographs based on a hybrid of both CNRFC QPF forecasts and the Global Ensemble Forecast System (GEFS) forcings. Long-range products are produced on a daily time step based on climatological forcings beyond 15 days.

The CHPS model continuously produces forecasts 365 days per year. During flood events, forecasts are produced every six hours. CHPS allows hydrologic forecasters to make real-time adjustments to the model during flood events. Forecasts for the Prado Reservoir are run from the Joint Operations Center in Sacramento, where both NWS forecasters and California DWR forecasters collaborate in operational forecasting.

The current operational Prado inflow model was last updated in 2014. Additional detail could be added to the model by forecasting San Antonio Creek, Cucamonga Creek, and Chino Creek.

More information about CNRFC modeling can be found at <https://www.cnrfc.noaa.gov/about/>.

The current inflow predictions for the combined inflow from all contributing areas into Prado Dam are provided by the CNRFC twice daily and during forecasted extreme events four times daily upon request from the USACE. From this information, a simple spreadsheet program is used to predict the water level within Prado Dam. The direction of the USACE is to incorporate QPF into the USACE CWMS Santa Ana River basin model and determine the overall flood risk within the basin, with emphasis on the flooding potential downstream of the dam. Enhancements to incorporate rainfall predictions under FIRO (5-day forecast) into the CWMS to develop inflow into Prado that would be applied to predict the water level within Prado. This additional information would help USACE water managers for both water conservation and flood operations.

B. Groundwater

The Integrated Surface/Groundwater Model (Geoscience Support Services) simulates groundwater flow near Prado Dam. The model is scheduled to be completed and available for use in January 2019.

C. Weather and Climate

In addition to standard forecast tools available to the NWS, including global forecasts from the National Centers for Environmental Prediction (NCEP), European Centre for Medium-Range Weather Forecasts (ECMWF), and other centers, CW3E maintains an online AR research and forecasting “portal” that contains archived and real-time observations, gridded analyses, and gridded numerical weather prediction forecasts of AR-related information over the northeast Pacific and western United States (<http://arportal.ucsd.edu>). The gridded analyses and forecasts on the AR portal are created from NCEP Global Forecast System (GFS) and GEFS data provided by the NOAA National Operational Model Archive and Distribution System (NOMADS). These forecast products focus on identifying and tracking ARs over the northeast Pacific with attention to their structure, intensity, and orientation at landfall along the U.S. West Coast. Displays of integrated water vapor transport (IVT) and other gridded forecast parameters are computed from the deterministic GFS and 20-member GEFS data.

The GEFS IVT forecast probability-over-threshold maps over the northeast Pacific can provide essential uncertainty analysis for AR landfall potential. For example, Figure 8 (below) shows a 16-day forecast time-latitude (following the U.S. West Coast) depiction of the fraction of GEFS members ensemble (including the control member) with IVT magnitudes > 250 kg/m/s for the period six days before an extreme event that impacted the Santa Ana River watershed. The vertical dashed black lines denote the time after model initialization on February 13, 2017, at 00Z (right to left), whereas the dashed horizontal line denotes the latitude corresponding to the U.S. West Coast map between 32° and 42° N.



Figure 8. Depiction of the fraction of GEFS ensemble members with IVT magnitudes > 250 kg/m/s for the period six days before an extreme event that impacted the Santa Ana River watershed.

While global numerical weather prediction models, such as GFS, can explicitly simulate the largest weather scales on Earth and resolve some mesoscale fluid dynamic features, they do not explicitly resolve the smallest orographic uplift, surface flux, or cloud microphysics scales. Thus, to generate the best forecast possible, simulating the unresolved physical processes that are key to AR evolution and impacts requires a regional numerical weather prediction model that is specifically tailored to West Coast precipitation.

CW3E has invested in developing an optimal version of the Weather Research and Forecasting (WRF) model that is configured for AR precipitation in the western United States (West-WRF) and runs at 3-km resolution. The *Journal of Hydrometeorology* has published a manuscript summarizing West-WRF forecast performance (Martin et al., 2018) and detailing its advantages relative to global-scale forecasts or other regional-scale models not specifically developed for ARs. The manuscript introduces a systematic evaluation of West-WRF and GFS forecasts relative to the dedicated network of observations, explores the sources of forecast errors in QPF and atmospheric state variables, and investigates the role that explicitly modeled scales or sub-grid parameterized scales play in driving these errors. West-WRF forecasts were also used to demonstrate the benefit of high-resolution simulation to freezing level height prediction during the 2017 water year (Henn et al., *submitted*) and have led to additional publications and conference presentations over the course of the study.

The development of West-WRF has demonstrated operational utility and broader impacts. Nearly 500 unique West-WRF near real time (NRT) forecasts have been produced over the past three winter

seasons. During the Lake Oroville Dam spillway event in February 2017, the California DWR Flood Operations Center used NRT precipitation and freezing level height forecasts for hazard forecasting.

5. Identification, Review, and Assessment (Comparison with Operational Baseline) of Contemporary Hydrologic Forecast Modeling

A. WRF-Hydro (National Water Model)

The Weather Research and Forecasting Model Hydrological modeling system (WRF-Hydro), which was developed by the National Center for Atmospheric Research (NCAR) and its research partners, simplifies the coupling of terrestrial hydrological models with the WRF model. WRF-Hydro accounts for physical processes, including surface and subsurface flow, soil moisture, and streamflow routing, and has been used to successfully forecast streamflow. In WRF-Hydro, the Noah Land Surface Model is enhanced with overland and river flow routing via the NCAR Distributed Hydrological Modeling System. WRF-Hydro is computationally suitable for investigating the role of a physically enhanced description of terrestrial hydrology on land-atmosphere feedbacks in a multi-month simulation. WRF-Hydro is also the core model of the National Water Center's operational hydrologic model, the National Water Model (NWM). The NWM provides high-resolution forecasts (of soil moisture, surface runoff, snow water equivalent, etc.) at 2.7 million stream locations nationwide (<http://water.noaa.gov/map#forecast-chart>), including the Santa Ana River streamflow. The NWM has the potential for regional improvement. One example is to consider soil moisture observation data for calibrating the WRF-Hydro model, which is an ongoing project at CW3E for Lake Mendocino and can be considered for the current study area as well.

B. GSSHA (USACE ERDC)

The need for hydrologic simulations in non-Hortonian and mixed watersheds prompted USACE to invest in developing the Gridded Surface Subsurface Hydrologic Analysis (GSSHA) model. GSSHA is a fully distributed, physical-process-based, gridded hydrologic numerical tool suitable for engineering analysis and design that simulates the hydrologic response of a watershed subject to given hydrological inputs. GSSHA can simulate the following physical processes: precipitation distribution, precipitation interception, infiltration, evapotranspiration, surface water retention, surface runoff routing, unsaturated zone modeling, saturated groundwater flow, overland sediment erosion, transport and deposition, and constituent fate and transport for overland flows. The USACE Engineer Research and Development Center (ERDC) has built and calibrated multiple spatial-resolution GSSHA models of the Russian River watershed for the Lake Mendocino FIRO project to test the applicability and benefit of using this next-generation hydrologic model in water management operations. CW3E is using these GSSHA models to investigate uncertainty in forecasting runoff by examining atmospheric forcing data. The FIRO team will also investigate this approach's application in the Santa Ana River watershed and benefit to operations at Prado Dam.

NOAA scientists are looking at the GSSHA model's ability to simulate soil moisture in the Lake Mendocino watershed, along with the effort to do the same with the NWM. GSSHA is applicable across various scales, from small watersheds to large river basins. Fine-resolution inset models can be constructed around features of interest in large basins. This flexibility in application lets GSSHA be tailored to the individual study area and for the simulation's exact purpose, be it river flows, groundwater stages, soil moistures, or reservoir water levels. GSSHA has been verified to be able to simulate all these physical states. Coupling the model with weather forecasts enables forecasting of a variety of hydrologic parameters, contributing to better management decisions. ERDC has contracted

with NCAR to couple GSSHA with its existing ensemble and data assimilation methods, increasing the potential utility of its forecasts. While the NWM provides hydrologic forecasting for the entire continental United States, the application of GSSHA will be specific to each study.

6. Meteorological Analysis, Assessment, and Research

A. AR Climatology for Santa Ana River

The ~2450 mi² Santa Ana River watershed flows from the San Gabriel, San Bernardino, and San Jacinto Mountains to its terminus at the Pacific Ocean. These mountains form a barrier to moisture transport in winter storms, including from ARs, and force moist flow upward to generate clouds and precipitation. Rainfall accumulation during several extreme events each winter season accounts for 40 to 50 percent of annual precipitation, with large interannual variability in total precipitation arising due primarily to differences in AR activity. Thus, these relatively infrequent extreme events contribute significantly to flood hazards and water supply within the Santa Ana River watershed. USACE operations at Prado Dam have historically accounted for such storms, but recent advances in understanding ARs, the physical mechanisms that generate precipitation in the watershed, and how to better predict them yield the potential to enhance water conservation and flood control capacity at the dam. This study builds on a decade of science on how ARs work on the U.S. West Coast and on experience in developing the concept of FIRO at Lake Mendocino, a drought and flood-prone reservoir in northern California. Progress toward identifying the physical drivers of extreme precipitation in Phase 1 of FIRO at Prado led to both advancements in AR science and improved understanding of regional meteorological influences on water supply and flood hazards. These results provide a foundation for continued research toward improved predictability of extreme precipitation events for water resource management and hazard mitigation.

The *Journal of Geophysical Research* (Cannon et al., 2018; Appendix II) has conditionally accepted a study diagnosing regional meteorological influences on extreme precipitation based upon case studies and the full record of 107 extreme precipitation events from 1981 to 2017, which were performed in Tasks 4.1 and 4.2 of Phase 1. That study addressed the following preliminary science goals:

- Use global forecast models and satellite data to investigate the large-scale event conditions that produced ARs, their mechanisms for extreme precipitation, and subsequent differences in precipitation intensity and timing over the Santa Ana River watershed.
- Investigate mesoscale precipitation processes, including orographic enhancement, embedded convection, and cloud microphysics, which contributed to the spatiotemporal variability of precipitation within the watershed during each event. These analyses will utilize precipitation observations from a dense network of rain gages and NEXRAD radar data within the watershed as well as high-resolution regional weather model output (West-WRF).

Cannon et al. (2018) found that Southern California water resources depend on a small number of extreme precipitation events each winter season, which dictate the highly variable interannual accumulations in the region. In the Santa Ana River watershed, 107 extreme events contributed nearly half of total precipitation between 1981 and 2017. Two-thirds of these extreme events occurred in association with landfalling ARs, though all events featured enhanced moisture transport into the watershed. The synoptic-scale conditions and precipitation mechanisms associated with these events were highly variable, as demonstrated by the orientation of moisture transport into the Santa Ana River watershed and the position of each event's attendant cyclone. Figure 9 shows a schematic of surface

low pressure centers and the axis of enhanced IVT magnitude for 107 extreme precipitation events at the time of the maximum IVT over the Santa Ana River watershed. The central low pressure and IVT orientation for the two case studies discussed in Cannon et al. (2018) and the Prado years 1 and 2

scoping proposals are labeled in black.

Figure 9. Schematic of surface low pressure centers and the axis of enhanced IVT magnitude for 107 extreme precipitation events at the time of the maximum IVT over the Santa Ana River watershed.

The influence of orographic lift, synoptic-scale forcing for ascent, and convective instability on precipitation were evaluated using an “ingredients-based” approach across the record of 107 extreme events. While terrain-normal water vapor flux explains a majority of the observed precipitation variance during landfalling ARs, the variance amongst extreme events in the Santa Ana River watershed was also strongly influenced by large-scale dynamics that support the development of non-orographic and convective precipitation. Event-to-event variability in these mechanisms is an important area of continued research toward better understanding precipitation mechanisms and their predictability.

B. Predictability of Extreme Precipitation Events

Tasks 4.3 and 4.4 in Phase 2 of the OCWD funding proposal will yield insight into the viability of FIRO at Prado Dam by 1) evaluating the predictability of identified meteorological influences in extreme events and 2) defining inflow uncertainty at Prado according to USACE and OCWD lead time requirements. These tasks include the following:

- Explore forecast skill for each 2017 case study and the record of 107 extreme events. AR forecast tools developed at CW3E will be leveraged to understand how each event’s dominant

precipitation influences affected its forecast skill. This task will additionally investigate QPF error in relation to findings from Tasks 4.1 and 4.2.

- Evaluate forecast skill over lead time in collaboration with USACE and OCWD to ensure that scientific advancements address current operations and needs for FIRO at Prado. This task identifies the probabilistic skill of inflow forecasts for the record of extreme events according to the lead times necessary for FIRO at Prado, as determined by operational constraints.

These analyses will provide key information regarding current forecast skill, challenges to improved predictability, and operational needs for FIRO at Prado. Results from Phase 2 will serve as the foundation for research toward improving prediction of water conservation and hazards in the Santa Ana River watershed, and they will support the transferability of West-WRF regional mesoscale forecasting in NRT to Prado interests. Section 6.C below describes West-WRF development for FIRO at Lake Mendocino and transferability to Prado. Additionally, Section 6.D details a major AR monitoring program to improve predictability through airborne reconnaissance and data assimilation.

C. West-WRF Transferability to Prado

Ensuring reliable water supply and mitigating flood risk in the western United States requires detailed forecasts of the atmospheric, surface, and subsurface water cycle at lead times of several days. In practice, observations of streamflow and hydrologic models that estimate streamflow based on atmospheric forcing (e.g., precipitation) provide the necessary information for operational water management. Thus, for a well-calibrated hydrologic model, a dominant source of uncertainty in predicting streamflow is the QPF that is used to force the model. As a result, improvements in QPF skill have considerable potential to augment the operation of water conservation infrastructure (e.g., dams and levees).

We have previously contended that because ARs provide more than 50 percent of the annual precipitation in many western U.S. regions, the purposeful construction of high-resolution numerical weather prediction models for accuracy during ARs is a crucial exercise to benefit QPF skill and water supply prediction. The proposed work plan includes using West-WRF modeling capabilities to benefit meteorological understanding and improved forecast skill in the Santa Ana River watershed. A key step will be identifying the primary sources of QPF errors in West-WRF NRT in Southern California and targeting those physical problems for continued model development. An important focus of understanding the sources of West-WRF QPF error during ARs (Martin et al., 2018) will be the development of ensemble simulations to account for uncertainty in the model's initial state, unresolved processes, and parameterization errors (Berner et al., 2014). Ensemble generation in West-WRF represents a significant advancement toward quantifying and understanding individual sources of uncertainty and reducing initial condition errors in forecasts of western U.S. weather for water resource conservation and hazard mitigation. These efforts will potentially improve the forecasts associated with the full range of storm magnitudes.

D. Assessment of AR Recon Benefits and Application

The Atmospheric River Reconnaissance (AR Recon) project is exploring use of dropsonde measurements in and around ARs over the northeast Pacific Ocean to improve the prediction of landfalling ARs on the U.S. West Coast, including their associated precipitation and streamflow. Previous research has shown that AR forecasting is more skillful at long lead times than precipitation alone (Lavers et al., 2016) and can be leveraged to increase forecast lead time of high-impact events. However, it is also understood that initial condition errors in and around ARs offshore at one to three days lead time are the leading

source of model error. To provide increasingly skillful forecasts of ARs and their associated impacts, improved observations ahead of landfall are required, including through airborne observation campaigns (Doyle et al., 2014; Ralph et al., 2014; Neiman et al., 2016; Cordeira et al., 2017).

AR Recon in 2016 and 2018 helped improve predictions of landfalling ARs on the U.S. West Coast by supplementing conventional global forecast model data assimilation with dropsonde observations of the full atmospheric profile within ARs. The development of methodologies to effectively assimilate these airborne observations into forecast models is ongoing and will be completed over the coming years in collaboration with NOAA/NCEP, the ECMWF, and the Naval Research Laboratory as key objectives for a newly formed AR Recon Modeling and Data Assimilation Steering Committee. Given the physical relationship between improved initial conditions and predictability, as well as the need for better understanding of AR dynamics, AR Recon is expected to result in vastly improved outcomes for water management and emergency preparedness in the West.

7. Evaluation Framework, Scenarios, and Criteria

A. Evaluation Framework

A viability assessment of FIRO for Prado Dam must be effectively and clearly demonstrated to develop a compelling case for integrating weather and water forecasts into routine operations for the project. Assessment requires goals and metrics for measurement. The project objectives are fairly straightforward, as described in Section 1. That is:

- Improve opportunities for stormwater recharge below Prado Dam by appropriately using the “buffer space” within the flood control pool while maintaining or enhancing the flood mitigation capacity of the project and maintaining or enhancing the environmental benefits associated with listed threatened or endangered species.

Metrics and criteria will be drawn from these three objectives: 1) stormwater recharge, 2) flood management capacity, and 3) environmental benefits and outcomes. The project team will take the baseline condition from current practices by OCWD, USACE/SPL, and USFWS as of 2018. The team will also develop specific metrics for each objective in collaboration with agency personnel and representatives.

B. Validation of Precipitation and Inflow Forecasts

An underlying premise of FIRO is that the precipitation and streamflow forecasts are skillful. To establish expectations and a baseline for project investment improvements, the project team will assess the skill of CNRFC’s contemporary forecasts. The CNRFC has issued and archived QPFs and inflow forecasts. These forecasts will be validated over the period of record for which they are available, understanding that the underlying technology (and most likely the skill) is not stationary over this period. Similar to the Lake Mendocino preliminary viability assessment, this work will statistically analyze the forecasts to characterize their skill and reliability in the FIRO process.

C. Assessment of Lead Time Requirement(s)

Applying forecasts to the operation of Prado Dam requires an understanding of how and when the forecasts impact decision-making. Factors that affect the lead time requirement may include:

- The time needed to transit water from the dam to the ocean.
- The time needed to draft the reservoir down to a specific level.
- The time needed to issue evacuation notices and remove people and resources from harm’s way.

The project team will assess the operational profile for Prado Dam and suggest forecast lead time requirement(s). These lead-time requirements will be used to focus the forecast validation (above) and research needed to improve weather and streamflow forecasts.

D. Modeled Evaluation Scenarios

The goal of this work is to demonstrate the value of forecasts in an objective decision model. The SC will finalize a decision model of the approaches, but it is envisioned that they will apply Sonoma Water’s Ensemble Forecast Operations (EFO) model as well as the USACE’s Hydrologic Engineering Center (HEC) toolset (CWMS, HEC-WAT). Both approaches will conduct “bookend” studies that characterize the

system benefits with 1) no forecasts and 2) perfect forecasts. Each will also attempt to estimate the system benefits using forecasts that are consistent with those operationally available at the current time. If properly defined, this analysis should describe the potential for research investments to improve system outcomes.

I. **EFO (1985–2017 GEFS hindcasts)**

- 1) Existing WCM Operations
- 2) Perfect Inflow Forecasts
- 3) Perfect QPF
- 4) Current Forecast Skill

II. **HEC CWMS/WAT (Period of Record, Monte Carlo)**

- 1) Existing WCM Operations
- 2) Perfect Inflow Forecasts
- 3) Perfect QPF
- 4) Approximated Forecast Skill

E. Development of Evaluation Criteria

SC members and associates will collaboratively develop evaluation criteria based on anticipated system outcomes and project goals. Examples include:

- Average annual change in downstream stormwater recharge
- Frequency and duration of critical habitat inundation during specific seasons
- Frequency and duration of key inundation features within the flood pool (e.g., Corona Airport)

8. Assessment of Potential Socioeconomic Benefits

A. Municipal/Government Services

I. Water Supply

Municipal water demand is expected to rise slowly over time with population growth. Water demand has exceeded local supply in the OCWD area since before 1950. The shortfall is primarily made up for by costly and energy-intensive imports from the Colorado River and the California State Water Project. Santa Ana River water flows primarily by gravity to OCWD recharge facilities. FIRO may allow reservoir operators to maintain higher water levels during wet and dry seasons, as well as greater control over release rates. Less water will be lost to the ocean and more water will go into aquifer recharge, increasing Santa Ana River yields to the groundwater recharge system. This will decrease reliance on water imports, increasing water supply reliability and yielding economic benefits that can be quantified directly. The value of increased recharge and increased water supply reliability can be calculated based on the value of the water to OCWD and, ultimately, to all water consumers. FIRO may also decrease greenhouse gas emissions associated with Orange County's water supplies by reducing the demand for imported water.

II. Flood Risk Management

Since the construction of the Prado Dam, the flood risk in the lower Santa Ana River watershed has been largely due to local topography, not to the flooding of the Santa Ana River, which is constrained in a concrete channel and rated to provide protection against a 100-year flood. Nonetheless, the impacts of a major urban flood below Prado Dam would be staggering. Moderating this risk is the basis of the USACE investments described in Section 2.D. In addition, the impacts of climate change on flooding represent another source of risk. FIRO represents a potential tool that the USACE can use to improve flood risk management and adapt to a changing climate.

B. Environmental Services

Unlike in some other watersheds, there are limited ecological issues downstream of the Prado Dam, as the lower Santa Ana River is highly modified for flood risk management purposes and beginning 8 miles downstream of the dam, is constrained in a concrete channel. Upstream of the dam, the Prado reservoir itself provides critical habitat for the endangered least Bell's vireo. The habitat protection benefits that Prado Reservoir provides can be estimated under existing reservoir operations and with FIRO to estimate the benefit of improved reservoir operations in terms of ecosystem services. Methods would need to be evaluated to determine the best approach for valuing least Bell's vireo population and supporting habitat.

C. Business: Commercial/Industrial

Quantifying the benefits to commercial and industrial water users downstream of the Prado Dam will follow a similar method to quantifying these benefits to residential users, as decreased reliance on water imports will lower water prices for all users. Similarly, benefits in terms of improved flood control for extreme flood events will accrue to commercial and industrial interests for residential properties in the lower Santa Ana River watershed. Many businesses operate within or near Prado Reservoir. Existing damage functions that estimate losses to these businesses at selected water elevations within the reservoir can be used to quantify potential FIRO benefits.

9. Implementation Strategies and Timeline

A. Pathway

Potential implementation pathways need to account for initial implementation on a test basis and new technology incorporation on an ongoing basis. The initial implementation could be formulated as a deviation to the Prado Dam WCM for one or two flood seasons, depending on hydrology; a WCM update could be proposed to permanently incorporate FIRO into Prado Dam operations. The WCM update should include a framework to allow future technology developments to be incorporated without requiring a formal re-update of the manual.

B. Santa Ana River FIRO DSS

Collected and developed FIRO technologies will be combined into an interactive DSS that facilitates testing and evaluation and provides a testbed for proposed new Prado Dam operations. It is envisioned that the platform will rely upon the foundation established by the California DWR's Forecast Coordinated Operations DSS, as implemented for the Yuba-Feather project and subsequently expanded to the San Joaquin and Russian Rivers. The DSS will collect data and streamflow forecasts, run selected reservoir models, and provide options for release decisions along with impacts. The selected release will be routed to the CNRFC for use in downstream forecasts. Mock operations will simulate multiple operational approaches to develop a sense of the relative benefits of different strategies.

The DSS development will be a combined effort involving the California DWR (California Data Exchange Center), CW3E, and contracting support. Deployment will include training for the Prado FIRO community, with specific focus on SPL for operational decision support.

C. Timeline and Relationship with Project Phases (A, B, C)

Section 2.D defines the approximate timelines for completing elements of the SARM flood risk management project. Phase A is the current condition and extends until the Reach 9 construction features are completed. Phase B extends from the end of Phase A to the completion of the SARM project. Phase C starts after completion of the SARM project. During Phase A, the Prado Dam release rates are limited due to construction in the channel downstream of the dam. During Phase B, the release rate limitations associated with downstream construction will no longer apply, but dam operations may be limited due to construction of remaining SARM features. It is anticipated that Phase C will provide the greatest flexibility to implement FIRO.

10. Technical and Scientific Programs Necessary to Support Prado Reservoir FIRO Viability A

The FIRO process combines application development and research. A series of questions arose during development of the work plan outline. The answers to these questions will impact how FIRO is structured and performed for Prado Dam. In addition, as work continues, there will undoubtedly be additional questions that arise and are worthy of team assessment. The Prado SC will discuss, consider, and prioritize these assessments as they arise.

A. Identified in Advance

- What is the relationship between inundation duration and critical habitat in the Prado flood pool? Does the relationship vary during the flood season?
- How reliable/accurate is the USGS stream gage below Prado Dam?
- Do we need to model the reach below Prado Dam to avoid wasting water when side flows are high?
- What is the best way to characterize the operations at the Seven Oaks and San Antonio Dams?
- **What are the current OCWD recharge rates and how do they change with maintenance and other conditions? Are there any plans to increase them?**

B. Identified in the Process of Work Plan Development - TBD

Synoptic and Mesoscale Forcing of Southern California Extreme Precipitation

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Conditionally Accepted – Journal of Geophysical Research: Atmospheres

Revised 4 September 2018

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Key Points:

1. In the Santa Ana river watershed, 107 extreme events contributed nearly half of total precipitation between 1981 and 2017.
2. Total integrated vapor transport, including in atmospheric rivers, is the leading source of variability in extreme event precipitation.
3. The characteristic orographic precipitation distribution in extreme events is modified by synoptic and mesoscale dynamical forcing.

39 **Abstract**

40 Southern California water resources are heavily dependent on a small number of extreme
41 precipitation events each winter season, which dictate the region's highly-variable interannual
42 accumulations. In the Santa Ana River Watershed, on average, three extreme events per year
43 contribute half of annual precipitation, yet there are relatively few studies of the synoptic to
44 mesoscale processes that drive precipitation during these events. This study uses an ingredients-
45 based approach to identifying the contributions of orographic forcing, dynamical forcing and
46 convective instability to extreme precipitation in the watershed in 107 storms that produced
47 roughly 50% of all precipitation from 1981-2017. The influence of dynamical forcing and
48 convective instability on event precipitation distributions is investigated relative to the dominant
49 influence of orographic forcing that is typically found in landfalling atmospheric rivers. Case
50 studies of two high-impact events from the 2017 winter season demonstrate differences in the roles
51 of synoptic ascent and mesoscale convective features in modifying precipitation location, rate and
52 accumulation over the watershed. The February 17-18, 2017 case study included a narrow cold-
53 frontal rainband that produced high-intensity short-duration precipitation over low elevations of
54 the watershed. In the 107 extreme event record, similar modification of the precipitation
55 distribution toward non-orographic rainfall was related to significant changes in the synoptic-scale
56 circulation that favored enhanced dynamics and upstream ascent associated with frontogenesis.
57 Variability in precipitation mechanisms is of primary interest to weather forecasters and water
58 managers as it modifies event impacts and predictability.

59

60 **Keywords:** Extreme precipitation; Atmospheric Rivers; Southern California hydroclimate

61 **1. Introduction**

62 California water resources are heavily influenced by precipitation that exhibits extreme
63 interannual variability (Dettinger et al. 2011). Along the U.S. West Coast, and in California in
64 particular, only a few winter storms and atmospheric river (AR) events each winter season explain
65 the majority of variance in annual accumulated precipitation (Dettinger et al. 2016). However, in
66 Southern California single extreme precipitation events have a disproportionately large effect on
67 annual precipitation (Haynes, 2001) and streamflow. This effect is observed in the Santa Ana River
68 Watershed where 50% of annual discharge occurs during ~3 days per year (Warrick and Rubin,
69 2007). Thus, the goal of this study is to investigate Southern California extreme precipitation
70 events in order to characterize their driving mechanisms and to define their climatological
71 contribution to regional water resources.

72 Southern California hydroclimate is defined by the importance of individual high-
73 magnitude events (Dettinger et al. 2011) and features distinctive characteristics related to its
74 geography. Regional topography is characterized by transverse (east-west oriented) coastal ranges,
75 which force orographic precipitation preferentially during landfalling ARs with southerly flow and
76 water vapor transport that is orthogonal to topography (Harris and Carvalho, 2017). Consequently,
77 the southerly direction of water vapor transport and landfalling AR orientation that are frequently
78 associated with heavy precipitation in Southern California are generated by different synoptic-
79 scale conditions than those impacting central and northern California (Oakley and Redmond, 2014;
80 Hecht and Cordeira, 2017). Heavy precipitation events over Southern California often occur in
81 association with low-pressure centers that are comparatively closer to the location of AR landfall
82 than Northern California (Haynes, 2001), which increases the likelihood of enhanced mesoscale
83 and synoptic-scale forcing for precipitation (e.g., convection or quasi-geostrophic forcing for

84 ascent, respectively) associated with the parent low-pressure in addition to orographic precipitation
85 (Small et al. 2002; Oakley et al. 2017). In general, the spatiotemporal distribution of precipitation
86 in landfalling winter storms is dependent upon three primary forcing mechanisms for ascent:
87 Orographic forcing for ascent, dynamical forcing for ascent (e.g. synoptic and frontal), and
88 convective forcing for ascent related to instability (Houze et al. 1976; Lee, 1984; Katzfey, 1995);
89 precipitation may be forced by any combination of these mechanisms (Lin and Chiao, 2001).

90 Research on landfalling ARs in California has predominantly focused on the presence and
91 strength of the moist low-level jet stream and its influence on orographic forcing for ascent and
92 precipitation in complex terrain (e.g. Neiman et al. 2002, 2009; Ralph et al. 2005; 2013). Southern
93 California's steep coastal mountains are efficient generators of orographic precipitation and may
94 additionally modify onshore flow ahead of landfalling fronts through low-level blocking and the
95 generation of a barrier jet (Nieman et al. 2002, 2004), which may redistribute precipitation.
96 Individual case studies of landfalling ARs over Southern California have also studied the influence
97 of synoptic-scale and convective forcing for ascent and precipitation (e.g. Neiman et al. 2004;
98 Oakley et al. 2017), but no systematic evaluation of the climatology of these forcing mechanisms
99 and their association with regional precipitation extremes during landfalling ARs exists. The
100 relative lack of emphasis on the influence of synoptic-scale and convective forcing for ascent on
101 regional extreme precipitation events suggests a knowledge gap that is potentially problematic for
102 water resources management, hazard mitigation, and forecasting.

103 The objective of this study is to use observational and reanalysis data to examine two
104 unique case study events that produced extreme precipitation accumulations in the Santa Ana River
105 Watershed of Southern California during January and February 2017. These two events are
106 characterized with respect to a regional climatology of extreme precipitation and identified as the

107 result of two distinctive representative sub-categories of meteorological conditions that led to
108 differences in spatial and temporal precipitation distributions. Each event poses a different set of
109 forecasting challenges, with notable implications for water resource management on the Santa Ana
110 River, such as at Prado Dam. This analysis represents an important step towards (1) understanding
111 mechanisms responsible for Southern California precipitation extremes and their variability across
112 scales, and (2) defining important challenges where improvements may augment predictability for
113 water resource management.

114

115 **1.1 Study region: The Santa Ana River watershed of Southern California**

116 The Santa Ana River flows from the San Gabriel, San Bernardino and San Jacinto
117 Mountains, which arc around the eastern edge of the watershed at elevations exceeding 3500 m,
118 to its terminus at the Pacific Ocean (Fig. 1). The watershed encompasses an area of 4406 km²,
119 includes the densely populated southeastern portion of the Los Angeles metropolitan area, receives
120 minimal annual precipitation (~500 mm/year), and is home to a variety of water projects and
121 effective management strategies aimed at meeting resource demand (Hutchinson, 2017). For
122 example, Prado Dam on the Santa Ana River provides 2.4 million people in Orange County with
123 up to 70% of annual water supply through groundwater recharge (Hutchinson, 2017). Despite the
124 importance of Prado Dam to water supply, its primary purpose is flood risk management due to
125 significant flood events in recent history (Swanson and Hatheway, 1990). Water management at
126 the dam for groundwater recharge downstream requires adaptive planning within the U.S. Army
127 Corps of Engineer operating manual. Thus, improved understanding and predictability of
128 precipitation events has the potential to augment regional water resource management. While the
129 focus of this manuscript is on the Santa Ana River Watershed, its cool-season precipitation-driven

130 discharge, small area, high relief, transverse orientation and high level of urbanization are
131 generally characteristic of Southern California watersheds.

132

133 **2. Methodology**

134 **2.1 Precipitation data**

135 Estimated precipitation from Parameter Regression on Independent Slopes Method
136 (PRISM; Daly et al. 1994, 2002) data are used to identify extreme events impacting the Santa Ana
137 River watershed. PRISM is a statistical methodology for interpolating station-based climate data
138 using a dynamic knowledge-based framework of prevailing meteorology in an area. The regression
139 scheme accounts for complex climate regimes associated with orography, rain shadows,
140 temperature inversions, slope aspect, coastal proximity and other factors (Daly et al. 1994). Data
141 are available spatially on a 4-km horizontal grid and temporally every 24 h for the period 1981–
142 present. While the Santa Ana River watershed has a relatively dense precipitation sampling
143 network that improves the quality the PRISM dataset, it is important to note that the data’s ability
144 to represent extreme precipitation in complex topography has not been quantified for this
145 watershed. The PRISM dataset is complemented by higher temporal resolution National Weather
146 Service (NWS) observations in order to better evaluate precipitation characteristics (e.g., intensity,
147 areal coverage, convection, etc.) of each case study. These observations include (1) five-minute
148 temporal resolution precipitation observations at Long Beach (KLGB), CA and (2) base and
149 composite reflectivity data from the Santa Ana Mountains (KSOX) NWS Next-Generation
150 Weather Radar (NEXRAD; NOAA, 1991) installation (Fig. 1). These radar data are essential to
151 regional hazard forecasting at short lead times as they are frequently used by regional NWS

152 forecasters to identify mesoscale features with intense precipitation rates before they propagate
153 onshore (Gomberg et al. 2018).

154

155 **2.2 Extreme precipitation event definition**

156 Analyses of individual precipitation events are performed based on the identification of
157 extreme precipitation in PRISM data during winter seasons (October through April) 1981–2017.
158 The area-averaged total precipitation over the Santa Ana River watershed, based on all PRISM
159 grid points within the watershed (408 grid points at 4-km resolution), received 93% of its
160 precipitation during winter. An extreme precipitation event is subsequently defined as the 95th
161 percentile of 2-day basin area-averaged precipitation totals. Event independence is achieved by
162 retaining only the date of maximum precipitation for consecutive 95th percentile dates within a 5-
163 day period. A two-day accumulation period (e.g. Warner et al. 2012) is used to identify events in
164 order to account for issues associated with the timing of a given event relative to the PRISM 12
165 UTC daily-aggregation period. These criteria identified 107 extreme events in the Santa Ana River
166 watershed from 1981 through 2017, including the two case study events in January and February
167 2017.

168 The 107 extreme events contained 2-day precipitation totals that accounted for ~44% of
169 total precipitation in the watershed from 1981 to 2017 and 3-day precipitation totals that exceeded
170 50% of total precipitation. Further results indicate that, on average, three extreme events in any
171 single year produce ~50% of that year's annual precipitation similar to findings from Haynes
172 (2001) for the greater coastal Southern California region. The number of extreme events in a
173 season, which ranges from zero to six, correlates with annual precipitation with a coefficient of
174 0.90, whereas the annual total of extreme event precipitation has a correlation coefficient of 0.95

175 with annual total precipitation. Because extreme events play a critical role in water resources in
176 the study region, they are the sole focus of this research.

177

178 **2.3 Analysis of synoptic conditions**

179 The synoptic-scale meteorological conditions during extreme precipitation events are
180 investigated using National Center for Environmental Prediction Climate Forecast System
181 Reanalysis and operational analysis (CFSR) data (Saha et al. 2010, 2014). The NCEP–CFSR data
182 are contained on a 0.5° latitude x 0.5° longitude horizontal grid every six hours at 0000, 0600,
183 1200, and 1800 UTC for the period 1979–2017. The NCEP–CFSR data are used to calculate and
184 derive meteorological parameters commonly invoked in analyses of landfalling ARs such as
185 geopotential heights and wind at multiple isobaric levels, integrated water vapor (IWV), and
186 integrated vapor transport (IVT; calculated for the column extending from the surface to 200 hPa).
187 The data are also used to calculate vertical profiles of equivalent potential temperature and
188 divergence of the Q-vector for a layer between 700 hPa and 500 hPa (Hoskins et al. 1978, 1980)
189 in order to assess convective and synoptic-scale forcing for ascent, respectively. Note that Q-
190 vectors represent the advection of the temperature gradient by the horizontal change in the
191 geostrophic wind. Regional convergence of the Q-vector represents QG forcing for ascent and
192 synoptic-scale upward vertical motion, whereas regional divergence of the Q-vector represents QG
193 forcing for descent and synoptic-scale downward vertical motion (Hoskins, 1978). Weaknesses of
194 Q-vectors include their neglect of advections and temporal changes in the ageostrophic wind,
195 frictional effects, diabatic heating and cooling, and the vertical advection of ω , all which can be
196 significant at times (Funk, 2011). Here, the 700-500 hPa layer was evaluated as it extends low
197 enough to capture low-level thermal advection (while remaining in the free atmosphere where the

198 neglect of friction is less problematic) and is high enough to capture significant differential
199 vorticity advection.

200 The “typical” synoptic-scale conditions associated with extreme precipitation events are
201 often investigated using composite mean analysis of meteorological variables (e.g. Cannon et al.
202 2017); however, the wide-variety of synoptic-scale conditions associated with landfalling ARs
203 impacting Southern California (Haynes, 2001) is not well represented by this methodology. This
204 discrepancy is demonstrated by qualitative analyses of the locations of each mean surface low-
205 pressure center and the axis of IVT orientation at the time of maximum IVT over the watershed
206 for the 107 extreme events (Fig. 2a). This schematic was created by subjectively identifying the
207 orientation of moisture transport toward the Santa Ana River watershed in each event, using IWW
208 and IVT at the time of maximum IVT entering the watershed during the 2-day precipitation event
209 accumulation period, and then identifying the surface low pressure center associated with that
210 transport. While many automated algorithms exist for similar purposes, this exercise was
211 performed manually on account of the variety of event types, which are not equally well identified
212 across automated procedures (based on preliminary testing). Although each event contained a
213 surface low (i.e., a parent cyclone) and corridor of enhanced moisture transport, the range of
214 synoptic-scale conditions included well-developed lows in the northeast Pacific, closed and cut-
215 off lows, post-frontal events, anticyclone-dominated events and post-tropical cyclone events (e.g.
216 Haynes et al. 2001). According to a catalog of ARs (Rutz et al. 2014), approximately two-thirds
217 of these 107 extreme precipitation events occurred in association with AR conditions over the
218 watershed. The two case study events from 2017 are also identified in Fig. 2a. Note that a
219 composite analysis of these events at the time of maximum IVT entering the watershed (Fig. 2b)

220 does not capture the variability amongst their synoptic conditions, which is shown to significantly
221 influence precipitation processes within individual events (Section 3).

222

223 **2.4 Case study event selection**

224 The 2016–17 water year in the Santa Ana River watershed was strongly influenced by two
225 landfalling ARs that occurred on 22–23 January 2017 and 17–18 February 2017. Both events
226 generated enhanced streamflow in the Santa Ana River and contributed large volumes of water to
227 storage at Prado. The high reservoir inflow during these events necessitated rapid releases of water
228 to the ocean to preserve flood control capacity at the dam (Swenson and Hatheway, 1990). These
229 releases occurred at flow rates that far exceeded what can be utilized for ground water recharge by
230 Orange County Water District (Hutchinson, 2017), highlighting the potential benefit of improved
231 understanding of precipitation processes and their predictability to reservoir management. The
232 synoptic-to-mesoscale conditions that defined each event are subsequently evaluated to determine
233 their potential impact on the spatiotemporal distribution of precipitation within the watershed.
234 Mechanisms responsible for forcing for ascent during the two case study events are additionally
235 compared to the 107 extreme events in the watershed to determine how representative the case
236 study events are of the climatology (Section 3).

237 The record 2016–2017 water year for most of California produced only slightly above average
238 rainfall across Southern California and partial relief from a multi-year drought (California
239 Department of Water Resources, 2018). Regional precipitation increased to above average (based
240 on PRISM, not shown) following widespread precipitation associated with a landfalling AR that
241 propagated south along the California coast on 22–23 January. The event occurred in association
242 with an extratropical cyclone with sea-level pressure of 975 hPa located off the coast of

243 Washington (132°W, 46°N) that was far removed from the AR and the Santa Ana River watershed
244 (Fig. 3a). The location of the low-pressure center relative to its frontal location and the AR suggests
245 that the cyclone was occluded and in the later stages of its lifecycle. This event featured an upper-
246 tropospheric $\sim 90 \text{ m s}^{-1}$ anticyclonically curved jet stream wind maximum at 250 hPa located over
247 the eastern North Pacific and Continental U.S. embedded within a positively tilted upper-
248 tropospheric trough (Fig 3a). The Santa Ana River watershed was located on the anticyclonic shear
249 side of the jet stream wind maximum and downstream of the upper-tropospheric trough axis.

250 A second landfalling AR produced widespread precipitation across Southern California on
251 17–18 February 2017. This AR occurred in association with synoptic-scale conditions that
252 noticeably differed from the event on 22–23 January. This February event featured an extratropical
253 cyclone with a sea-level pressure of $\sim 985 \text{ hPa}$ located over the northern California coastline
254 (122°W, 37°N) that was relatively proximal to the landfalling AR and the Santa Ana River
255 Watershed (Fig. 3b). The cyclone was inferred to be earlier in its life cycle as its pressure had
256 decreased $\sim 18 \text{ hPa}$ in the preceding 24 hours (not shown). The IVT during this event contained a
257 more southerly direction and was weaker in magnitude at the coast as compared to January event
258 ($700\text{--}800 \text{ kg m s}^{-1}$ vs. $800\text{--}1000 \text{ kg m s}^{-1}$), suggesting weaker moisture flux within the Santa Ana
259 River watershed (Fig. 3). The duration of AR conditions over the watershed was 24 hours for the
260 January case and 21 hours for the February case (based on the Rutz et al. (2014) AR catalog that
261 uses MERRA 3-hour resolution IVT).

262 The February event occurred in association with an upper-tropospheric $\sim 80 \text{ m s}^{-1}$
263 cyclonically curved jet stream wind maximum at 250 hPa and negatively tilted upper-tropospheric
264 trough over the eastern North Pacific (Fig. 3b). The Santa Ana River watershed was located under
265 the exit region of the cyclonically curved jet stream wind maximum. A second jet stream wind

266 maximum centered around $\sim 47^\circ\text{N}$ and 115°W was also present during the February event. The
267 sea-level pressure center was located in both the exit region of the dominant cyclonically curved
268 jet to the south and the equatorward entrance region of the incipient jet streak to the north. Event
269 differences in the location, orientation, and curvature of the jet streaks, combined with the
270 magnitudes and tilts of the upper-tropospheric trough axes, may have influenced variability in
271 precipitation processes over the Santa Ana Watershed at the time of AR landfall, as discussed in
272 subsequent sections.

273

274 **3. Results and discussion**

275 **3.1 IVT, atmospheric rivers and orographic forcing of precipitation**

276 *a. Event total precipitation*

277 The composite PRISM 2-day precipitation accumulation over the Santa Ana River
278 watershed demonstrates a strong orographic precipitation gradient that is consistent with a well-
279 established understanding of precipitation over the western U.S. (Roe, 2005). This pattern emerges
280 as orographic lifting is the primary mechanism that induces ascent during landfalling ARs (Neiman
281 et al. 2009; Ralph et al. 2013). However, cumulative distribution functions of precipitation by
282 elevation for all 107 extreme events demonstrate considerable event-to-event variability in the
283 relative importance of orographic enhancement to the spatiotemporal distribution of watershed
284 precipitation (Fig. 4). Larger proportions of event-accumulated precipitation at lower elevations
285 are indicative of events where the orographic enhancement factor is diminished relative to the
286 mean distribution, whereas events with a higher proportion of precipitation at high elevations
287 indicate the event's relative dependence on topography for producing lift. The observed variability

288 is a preliminary indicator of forcing for ascent from mechanisms in addition to orographic lift,
289 possibly including dynamical and convective forcing for ascent. The 22–23 January 2017 event
290 occurred in association with an orographic precipitation distribution that was similar to the
291 composite mean, whereas the 17–18 February 2017 event exhibited a spatial precipitation
292 distribution with the weakest orographic signal in the climatology, indicating the additional
293 contributions of other lifting mechanisms. The percentage of 2-day precipitation that fell below
294 the median elevation of the watershed (derived from PRISM as 487 m) ranged from 31% to 58%
295 across all 107 events.

296 Variability in the dominance of the orographic forcing signal across extreme events is first
297 evaluated based on the IVT magnitude and its direction proximal to the Santa Ana River watershed.
298 An IVT-based polar coordinate diagram (e.g. Hecht and Cordeira, 2017) of the 107 event 2-day
299 precipitation totals and 2-day time-integrated IVT (2-day IVT) magnitude and direction
300 demonstrate that 2-day IVT is almost exclusively from 180°-270° and has a mean orientation of
301 228° (southwesterly), which is nearly orthogonal to the basin-averaged topographic orientation
302 (Fig. 4c; quantiles are plotted to scale the large event-to-event differences in both variables for
303 clarity, while statistics are calculated on actual values). The largest precipitation events are
304 generally associated with the largest 2-day IVT magnitudes and southwesterly transport.
305 Precipitation correlates to 2-day IVT with a coefficient of 0.56 and to the component of 2-day IVT
306 that is orthogonal to basin-averaged aspect with a coefficient of 0.62. These correlations are
307 sensitive to the synoptic conditions driving individual events.

308 AR conditions (defined here as features of IVT $> 250 \text{ kg m}^{-1} \text{ s}^{-1}$ and length $> 2000 \text{ km}$; based
309 on Rutz et al. 2014) were present in 67% of all 107 extreme events, and a closed-low (defined here
310 as an area of low 500-hPa geopotential height with a distinct center of cyclonic circulation that can

311 be completely encircled by one or more height contours; Oakley and Redmond, 2014) within 10°
312 of the Santa Ana was present in 35% of 107 events (e.g. the February 2017 event) (Table 1). At
313 least one of these features was present in 84% of all extreme events. While closed lows in
314 proximity to the watershed typically exhibited reduced IVT, additional dynamical mechanisms for
315 ascent (discussed in Sections 3.2 and 3.3) likely augmented event precipitation. Events that
316 consisted of an AR and no closed-low proximal to the Santa Ana (e.g. the January 2017 event)
317 demonstrated a higher correlation between 2-day precipitation and 2-day upslope IVT (coefficient
318 of 0.67), a more westerly orientation and a 10% increase in precipitation relative to the 107-event-
319 mean. The 20 (18) events featuring a closed-low and meeting (not meeting) AR conditions
320 demonstrated a decreased correlation coefficient of 0.48 (0.57), a more southerly orientation and
321 a 3% (13%) decrease in precipitation relative to the mean.

322 Results in Table 1 must be interpreted with caution, as the number of samples is small.
323 However, the apparent modification of the relationship between precipitation and 2-day upslope
324 IVT in varying synoptic conditions motivates an in-depth analysis of the physical mechanisms that
325 generated precipitation in extreme events in subsequent sections. It is worth noting that our isolated
326 focus on extreme events is a fundamental distinction relative to previous studies that showed a
327 strong relationship between IVT direction and precipitation accumulation (e.g. Hecht and
328 Cordeira, 2017). Additionally, the results presented here, based on CFSR and PRISM, cannot be
329 directly compared to previous research that identified a stronger relationship between precipitation
330 and storm-total upslope moisture flux in coastal Northern California using *in-situ* and remotely
331 sensed observations (correlation coefficient of 0.86; Ralph et al. 2013), though the weaker
332 relationship observed in Southern California is consistent with Rutz et al. (2014; their Fig. 2a).

333

334 *b. Instantaneous precipitation*

335 NEXRAD radar reflectivity analyses from KSOX illustrate that the January event contained
336 a maximum in reflectivity over the foothills of the San Bernardino Mountains at the western extent
337 of the watershed (Fig. 5). The location of maximum precipitation is consistent with inferred
338 upslope moisture flux during the landfalling AR (Ralph et al. 2004, Nieman et al. 2009) and that
339 shown in the event-averaged spatial precipitation distribution in Fig. 4a. Contrastingly, the
340 February event contained a convective narrow cold-frontal rainband (NCFR; Houze et al. 1976;
341 Hobbs et al. 1982; Koch and Kocin, 1991) that propagated onshore and produced maximum rain
342 rates away from topography (Fig. 5b). The most intense precipitation rates in extratropical
343 cyclones are often associated with NCFRs, which are aligned parallel to the cold front and warm
344 sector moisture transport (Hobbs and Persson, 1982). The advancing cold front has a component
345 of motion toward the warm sector that penetrates beneath conditionally unstable prefrontal air and
346 drives the release of potential instability (Geerts and Hobbs, 1995). The convective precipitation
347 associated with the NCFR in the February event is the primary reason for the comparative
348 weakening of the orographically dominated precipitation signal in the cumulative distribution plot
349 (Fig. 4b), although orographic forcing still played an important role in producing event-total
350 precipitation, as inferred from the radar (Fig. 5b).

351 The influence of orographic and NCFR processes on precipitation during the February event
352 is further illustrated by 5-min resolution precipitation accumulation observations from KLGB
353 during the two events (Fig. 5c). While the January event featured a precipitation rate of 2–3 mm
354 (5 min)⁻¹ associated with orographic precipitation during the period of maximum IVT associated
355 with AR landfall, the February event featured a precipitation rate of ~6 mm (5 min)⁻¹ associated
356 with the passage of the NCFR that resulted in a 30-minute period that produced approximately

357 50% of the event total precipitation. Event differences in precipitation processes, and subsequent
358 differences in precipitation distributions within the watershed, are important for both water
359 management and hazard mitigation in Southern California.

360

361 **3.2 Mesoscale forcing of precipitation**

362 Spatial and vertical gradients in equivalent potential temperature (θ_e) are used to
363 investigate whether instability played a role in precipitation generation in case studies (Fig. 6) as
364 well as in the climatology of extreme events (Fig. 7). At the time of event-maximum IVT over the
365 watershed, the January event featured an AR with a positive 1000–850 hPa θ_e gradient that implied
366 potential stability and contrasted with the less potentially stable gradient (i.e. moist-neutral profile)
367 observed during the February case (Fig. 6). Given the February event was nearly moist-neutral, it
368 was also not strongly statically unstable; surface-based convective available potential energy
369 (CAPE) values were below 150 J kg^{-1} (not shown). Importantly, low CAPE values do not preclude
370 convection in environments with additional dynamical forcing. In this case, the development of
371 convection leading to the NCFR likely occurred in association with forced ascent of the moist air
372 ahead of the cold front, as determined by the co-location of a corridor of enhanced mid-
373 tropospheric ascent (Fig. 6d) with a region of lower-tropospheric frontogenesis (Fig. 6f) along the
374 IVT maximum entering the watershed. Here, frontogenesis is calculated using the Petterssen
375 (1936) frontogenesis equation. The along-front parallel structure of these two features and across-
376 front displacement suggests a northwesterly tilt of the frontal circulation with height, which would
377 suggest a shallow thermally direct ageostrophic circulation capable of providing enhanced low-
378 level forcing for ascent of moist air in the region of the NCFR (Markowski and Richardson, 2010).

379 The climatology of 1000–850 hPa θ_e gradients in 107 extreme events indicates that the
380 majority of events contain profiles that are moist-neutral at the time of maximum IVT entering the
381 watershed and statically stable environments (Fig. 7d). Thus, to determine whether differences in
382 the synoptic conditions of individual events influence their development of non-orographic
383 mesoscale vertical motions, the strongest negative vertical velocity (i.e., upward vertical motion;
384 ascent) at 600 hPa over the region of enhanced IVT magnitudes $\geq 250 \text{ kg m}^{-1} \text{ s}^{-1}$ upstream of the
385 Santa Ana River watershed (boxed region in Fig. 7a) for each event was correlated with the 500-
386 hPa geopotential height, IVT magnitude and 1000–850 hPa θ_e gradients at each grid point in the
387 domain (Figs. 7a,b). The correlation analysis illustrates that stronger ascent upstream of the Santa
388 Ana River watershed correlates with lower geopotential heights and higher IVT magnitudes
389 proximate to the composite upper-level trough and corridor of enhanced IVT along the AR,
390 respectively (cf. Figs. 2 and 7a,b). Note that stronger ascent does not correlate with an increase in
391 IWV (not shown); thus stronger ascent correlated with enhanced IVT requires an associated
392 increase in the strength of the low level winds in the AR. Additionally, it does appear that the
393 cyclonic curvature of the region of significant correlation with IVT magnitude likely occurs in
394 association with a more southerly-oriented corridor of enhanced IWV.

395 Stronger ascent is not correlated with enhanced potential instability as quantified by
396 correlation with the 1000–850 hPa θ_e gradient (Figs. 7a), and profiles of θ_e (Fig. 7d). These results
397 indicate that enhanced ascent likely occurs in association with dynamical processes that both
398 influence IVT in the AR and contribute to the release of potential instability (Fig. 7b). Notably,
399 correlation of the maximum calculated frontogenesis value within the upstream box to the 500 hPa
400 geopotential height, IVT and 600 hPa vertical velocity fields for all cases indicates the influence
401 of frontally-forced ascent of AR moisture in the climatology of extreme events (Fig. 7c).

402 The probable cause of the mesoscale forcing for vertical motion in these events is also
403 evaluated using composite differences between groups of events with strong and weak orographic
404 precipitation signals (Fig. 8). This analysis is derived from categorization of events based on the
405 10th and 90th percentiles of the percentage of basin precipitation falling below the median elevation
406 of the watershed in each event (36% and 50%, respectively; Fig. 8a). Composite analysis of the
407 differences between the 11 events with the least orographic-enhanced precipitation signal (i.e.
408 events with the largest percentage precipitation accumulation below the watershed's median
409 elevation) and the 11 events with the most orographic-enhanced precipitation signal (i.e., events
410 with the smallest percentage precipitation accumulation below the watershed's median elevation)
411 illustrates that 500-hPa geopotential heights are lower in the region of the upper-level trough west
412 of Southern California in events with the least orographic-enhanced precipitation (Fig. 8b). The
413 concurrent IVT magnitude does not contain significant differences upstream of the watershed
414 between categories, but is significantly larger over the southwest U.S. in the events with more
415 orographic-enhanced precipitation (Fig. 8c). This result is possibly attributable to the lack of a
416 dynamical mechanism to precipitate moisture from the flow, as evidenced by the shallower trough
417 and significant reduction of upstream ascent (Fig. 8d). Furthermore, these mechanisms are
418 consistent with the case study analysis shown in Fig. 6d; the 17–18 February 2017 event contained
419 a comparatively deep and proximal upper-level trough associated with cyclogenesis, strong ascent
420 over the cold-frontal boundary, and the largest proportion of precipitation below the watershed's
421 median elevation.

422

423 **3.3 Synoptic-scale forcing of precipitation**

424 The aforementioned mesoscale convection and precipitation differences over the Santa
425 Ana River watershed also appear to be influenced by differences in the synoptic-scale flow patterns
426 associated with each event (as discussed in Section 3.1 and illustrated in Fig. 6). The synoptic-
427 scale flow patterns include differences across each case study in the locations of the low-pressure
428 centers (Figs. 9a,b), locations of upper-tropospheric jet streak wind maxima relative to the Santa
429 Ana River watershed (Figs. 9c,d), and 500-hPa trough wavelengths and tilt upstream of the Santa
430 Ana River watershed (Figs. 9e,f). Concomitant differences in synoptic-scale forcing for ascent
431 associated with these different flow patterns can be described by QG theory and related dynamics
432 associated with QG forcing for ascent.

433 For example, the juxtaposition of the Santa Ana River watershed with the dynamically
434 unfavorable region for QG forcing for ascent beneath (1) the anticyclonic shear side of the upper-
435 tropospheric jet streak (Fig. 9c) and (2) a location of weak (or zero) inferred differential cyclonic
436 vorticity advection by the geostrophic wind (Fig. 9e) during the January event likely produced
437 weak synoptic-scale upward vertical motion and little-to-no synoptic-scale precipitation at the time
438 of maximum IVT. Alternatively, the juxtaposition of the Santa Ana River watershed with the
439 dynamically favorable region for QG forcing for ascent beneath (1) the exit region of the
440 cyclonically curved upper-tropospheric jet streak during the February event (Fig. 9d) (Beebe and
441 Bates, 1955; Carlson, 1998) and (2) a location of inferred differential cyclonic absolute vorticity
442 advection by the geostrophic wind (Fig. 9f) during the February event likely produced modest
443 synoptic-scale upward vertical motion and precipitation in addition to orographic forcing. These
444 inferences are supported by GOES infrared satellite imagery (Fig. 10), which illustrate shallow
445 cloud top temperatures of ~ 250 K (~ 6 km altitude, based on the Vandenberg Sounding on that day)
446 in the region of unfavorable QG forcing for ascent during the January event, with low clouds

447 upstream of the watershed (Fig. 10a), and broad deep cloud top temperatures of ~230 K (~9.2 km
448 altitude based on the Vandenberg Sounding on that day) in the region of favorable QG forcing for
449 ascent during the February event (Fig. 9b). Note that just because these analyses reveal an
450 unfavorable environment for synoptic-scale forcing for ascent does not imply a lack of observed
451 upward vertical motion; both events contained upward vertical motion at 600 hPa at the time of
452 maximum IVT, although ascent in the January event was considerably weaker and spatially limited
453 (Fig. 6).

454 The aforementioned implied differences in QG forcing for ascent can be summarized and
455 quantified by the Q-vector and its divergence (Hoskins et al. 1978, 1980). At the time of maximum
456 IVT, the Santa Ana River watershed was located beneath a region of Q-vector divergence during
457 the January event (Fig. 11a) and beneath a region of Q-vector convergence during the February
458 event (Fig. 11b). The Q-vector analyses can also demonstrate an important linkage between the
459 synoptic scale and mesoscale. For example, if the orientation of the Q-vector points toward warmer
460 potential temperatures offshore and upstream of the Santa Ana River watershed during the
461 February event, it would portend a frontogenetic thermally direct ageostrophic circulation in the
462 plane of the lower-tropospheric front (Funk, 2011). The rising branches of these ageostrophic
463 circulations and regions of frontogenesis are known to produce banded precipitation structures in
464 conjunction with the release of potential instability, particularly in deepening baroclinic systems
465 (Markowski and Richardson, 2010). Frontogenesis in the region of enhanced IVT confirms that
466 this process played a key role in the development of the observed NCFR during the February event
467 (Fig. 6f) and the lack of a “normal” orographic precipitation gradient as compared to climatology
468 (Fig. 4b). The temporal evolution of Q-vector divergence for a single gridpoint over the Santa Ana
469 watershed displays a maximum in synoptic forcing for ascent at the time of maximum IVT over

470 the watershed in the February event (Fig. 11c). Contrastingly, the evolution of synoptic forcing in
471 the January event demonstrates sustained divergence over the course of the event with a maximum
472 at the time of maximum IVT.

473 While both events featured enhanced IVT associated with a landfalling AR, these results
474 suggest that events with precipitation distributions that feature a weaker orographic signal may
475 preferentially occur in association with synoptic-scale flow patterns defined by amplified mid-
476 tropospheric flow, strong QG forcing for ascent and upward vertical motion proximal to the AR
477 that may contribute to dynamical forcing of precipitation (Figs. 7-9 and 11). Alternatively,
478 precipitation distributions that feature a stronger orographic signal may preferentially occur in
479 association with synoptic-scale flow patterns defined by more zonal mid-tropospheric flow, QG
480 forcing for descent and downward vertical motion proximal to the AR, without dynamical forcing
481 contributions to precipitation processes (Fig. 7-9 and 11). Q-vector composite differences between
482 the weak and strong orographic precipitation distribution events also support this theory. Although
483 we do not attempt to quantify the contribution of individual mechanisms to event-total
484 precipitation, it is important to acknowledge the numerous factors that influence the precipitation
485 distribution.

486

487 **4. Conclusions**

488 Southern California water resources are dependent on a small number of extreme
489 precipitation events each winter season, which dictate the highly-variable interannual
490 accumulations of the region. In the Santa Ana River watershed, 107 extreme events contributed
491 nearly half of total precipitation between 1981 and 2017. Two-thirds of these extreme events
492 occurred in association with landfalling ARs, though all events featured enhanced moisture

493 transport into the watershed. The synoptic-scale conditions and precipitation mechanisms
494 associated with these events were highly variable. The influence of orographic lift, dynamical
495 forcing for ascent and convective instability on precipitation were evaluated from an “ingredients-
496 based” approach. While terrain-normal water vapor flux explains a majority of the observed
497 precipitation variance during landfalling ARs, in general, the variance amongst extreme events in
498 the Santa Ana River watershed may also be strongly influenced by large-scale dynamics that
499 support the development of non-orographic and convective precipitation. Understanding event-to-
500 event differences in precipitation processes and their influence on precipitation distributions within
501 the watershed is important for both water management and hazard mitigation in Southern
502 California.

503 Extreme events that had comparatively near-shore upper-tropospheric troughs and
504 associated QG forcing for ascent (as evidenced by the February case study) supported precipitation
505 distributions with apparently weak elevation dependence. Events characterized by synoptic-scale
506 forcing for ascent and convective precipitation reduced the dominant influence of the orographic
507 forcing signal on observed precipitation. Based on case study analysis, QG forcing for ascent in
508 one such event produced synoptic-scale upward vertical motion upstream of the Santa Ana River
509 watershed and generated frontally forced mesoscale convection. An important subject of future
510 work will be the use of *in-situ* and remotely sensed meteorological observations in Southern
511 California to better characterize the influence of different synoptic and mesoscale forcing
512 conditions on physical processes, such as the relationship between storm-total upslope moisture
513 flux and precipitation (e.g. Ralph et al. 2013). This study also motivates future work on identifying
514 whether or not NCFR are common features of landfalling ARs that can produce large precipitation
515 rates in addition to orographic precipitation. Oakley et al. (2017) found that development of

516 convection along the NCFR contributes significantly to hazards related to post fire debris flows in
517 Southern California.

518 Variability in the location, duration and intensity of precipitation, related to the interaction
519 of moisture transport with topography and the dynamics of the synoptic-scale flow, has not been
520 investigated previously. This work is an important first step in identifying additional mechanisms
521 for precipitation during landfalling ARs, including an evaluation of Q-vector divergence fields
522 over enhanced moisture transport. These results are also useful for understanding how landfalling
523 ARs develop mesoscale convective features that are associated with high-intensity precipitation
524 rates related to the NCFR and related hazards (e.g. Oakley et al. 2017). The ability to identify these
525 conditions through frontogenesis calculation, as performed here, may aid situational awareness
526 and forecast skill without explicitly resolving convection in a mesoscale model.

527 A notable caveat of this work is the simplified approach to evaluating the events based on
528 the time of maximum IVT over the watershed, which typically corresponds to the maximum
529 precipitation accumulation, but does not account for pre-AR or post-AR (i.e., post-frontal)
530 precipitation. Many of the extreme events feature post-frontal shallow convective precipitation,
531 which can produce heavy rainfall rates and additionally contribute to or exacerbate hazards such
532 as flooding and post-fire debris flows (Oakley et al. 2017). However, the research presented here
533 is focused on precipitation processes during landfalling ARs, and analyzing the full evolution of
534 individual events is beyond the scope of the current work. Additionally, mesoscale model
535 simulations are necessary to evaluate the evolution of forced convection along fronts, orographic
536 precipitation, and the microphysical properties that contribute to variability in the event-to-event
537 precipitation distribution (Martner et al. 2008).

538

539 Acknowledgements

540 This research was supported by the National Aeronautics and Space Administration
541 (NASA) grant NNX14AD77G. Any opinions, findings, and conclusions or recommendations
542 expressed in this publication are those of the authors and do not necessarily reflect the views of
543 NASA. Additional support was provided by the Orange County Water District and the U.S. Army
544 Corps of Engineers (USACE) as part of Forecast Informed Reservoir Operations (FIRO) under
545 grant W912HZ-15-2-0019. The NCEP–CFSR data used in this research were developed by the
546 NOAA (<https://rda.ucar.edu/datasets/ds093.0/>). NEXRAD Radar data were developed by the
547 NOAA National Weather Service (NWS) and are accessible through the National Center for
548 Environmental Information (NCEI; <https://www.ncdc.noaa.gov/data-access/radar-data>). Station
549 precipitation data used in this research are also available through NCEI
550 (<https://www.ncdc.noaa.gov/data-access/land-based-station-data>). PRISM data are provided by
551 the PRISM Climate Group at Oregon State University (www.prism.oregonstate.edu).

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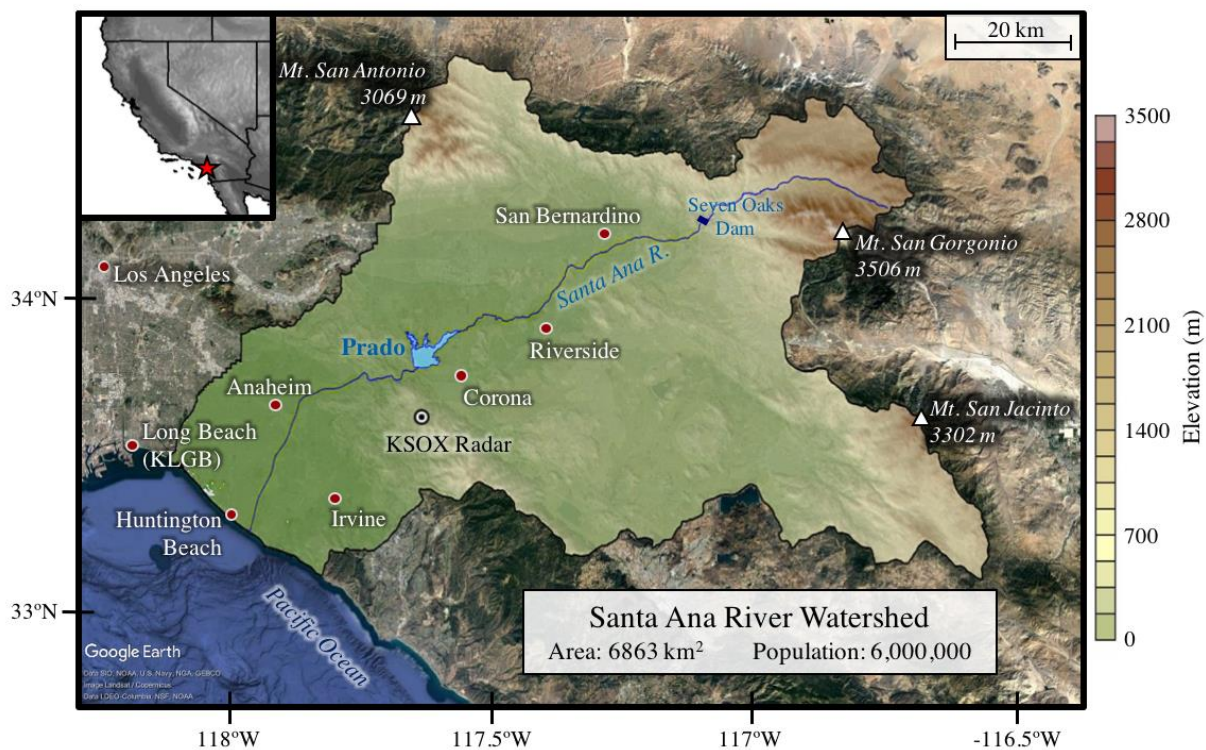
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657 **Tables**
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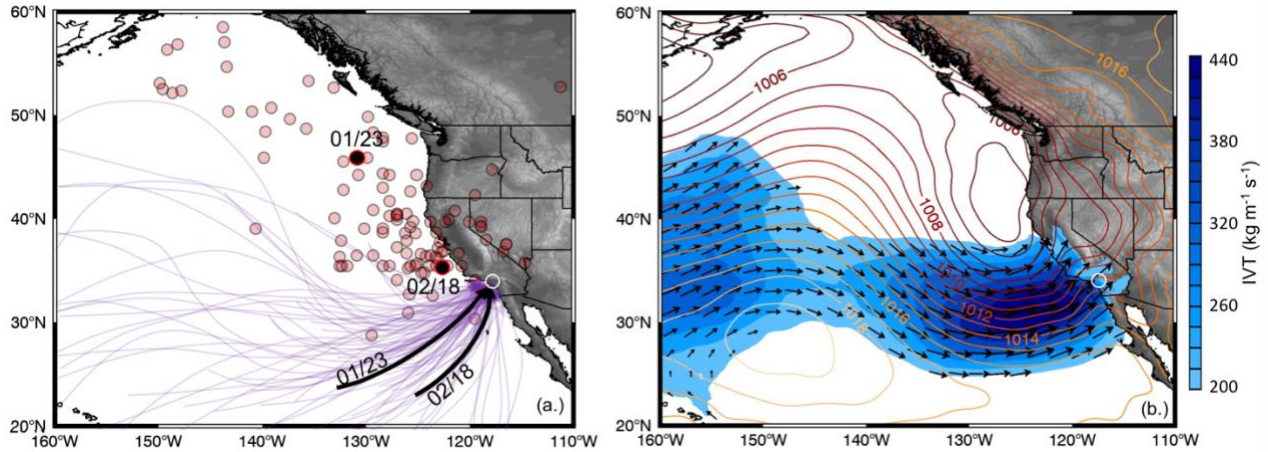
	All	AR	Closed Low	AR w/o Closed Low	Closed Low w/o AR	AR and Closed Low	No AR and No Closed Low
Number of Events	107	72	38	52	18	20	17
Percentage of Events	100	67%	36%	48%	17%	19%	16%
% of Average Precipitation	22.1(mm)	106%	92%	110%	87%	97%	88%
% of Average 2-day IVT	3.9×10^7 (kg m ⁻¹)	112%	89%	115%	70%	106%	79%
Average Direction of 2-day IVT	228°	229°	212°	236°	215°	210°	238°
Correlation (Precip, 2-day IVT)	0.62	0.62	0.48	0.67	0.57	0.49	0.47

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 661 **Table 1:** The number 107 extreme events that demonstrated; AR conditions, a closed-low within
 662 10° of the Santa Ana, the combination of those features, or the absence of both. The average
 663 precipitation and 2-day IVT direction are given relative to the 107-event mean. Average 2-day
 664 IVT direction and the correlation between precipitation and the upslope component of 2-day IVT
 665 are also listed for each event category.
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668 **Figures**
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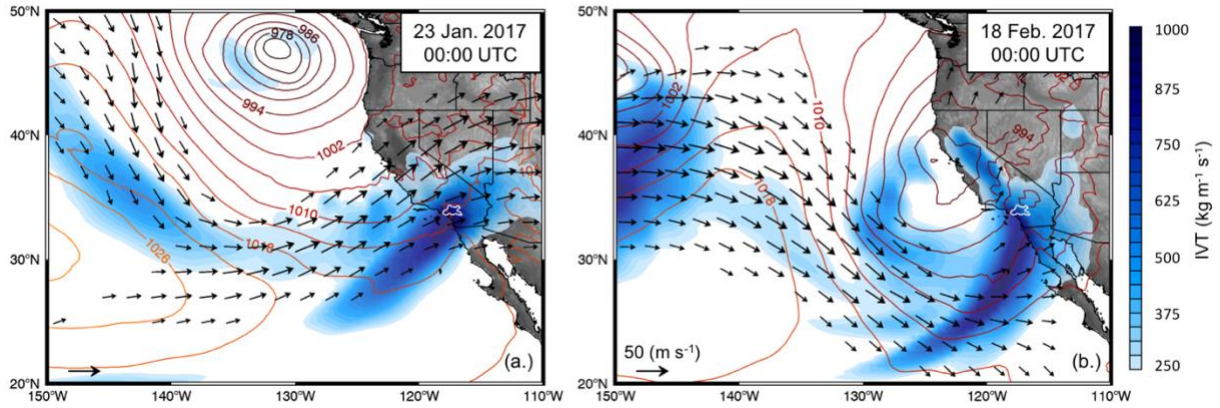


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672 **Figure 1:** Topographic map of the Santa Ana River watershed study region. Watershed statistics
673 provided by Santa Ana Watershed Project Authority (<http://www.sawpa.org/>).
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Figure 2: Schematic of surface low pressure centers and the axis of enhanced IVT magnitude for 107 extreme precipitation events at the time of event-maximum IVT over the watershed (a). The central low pressure and IVT orientation for the two case studies discussed in the text are labeled in black; the location of the watershed is circled in white. Composite sea level pressure (hPa; red contours) and IVT magnitude ($\text{kg m}^{-1} \text{s}^{-1}$; shading) and IVT vectors (plotted for magnitude $> 150 \text{ kg m}^{-1} \text{s}^{-1}$) for the 107 events (b).



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Figure 3: Integrated vapor transport ($\text{kg m}^{-1}\text{s}^{-1}$; shaded) sea level pressure (hPa; contour) and 250-hPa winds (m s^{-1} ; vector; plotted for magnitudes $>15\text{ms}^{-1}$) at the time of watershed maximum IVT magnitude during the 23 January 2017 case study event (a) and the 18 February 2017 case study event (b).

CONDITIONALLY ACCEPTED

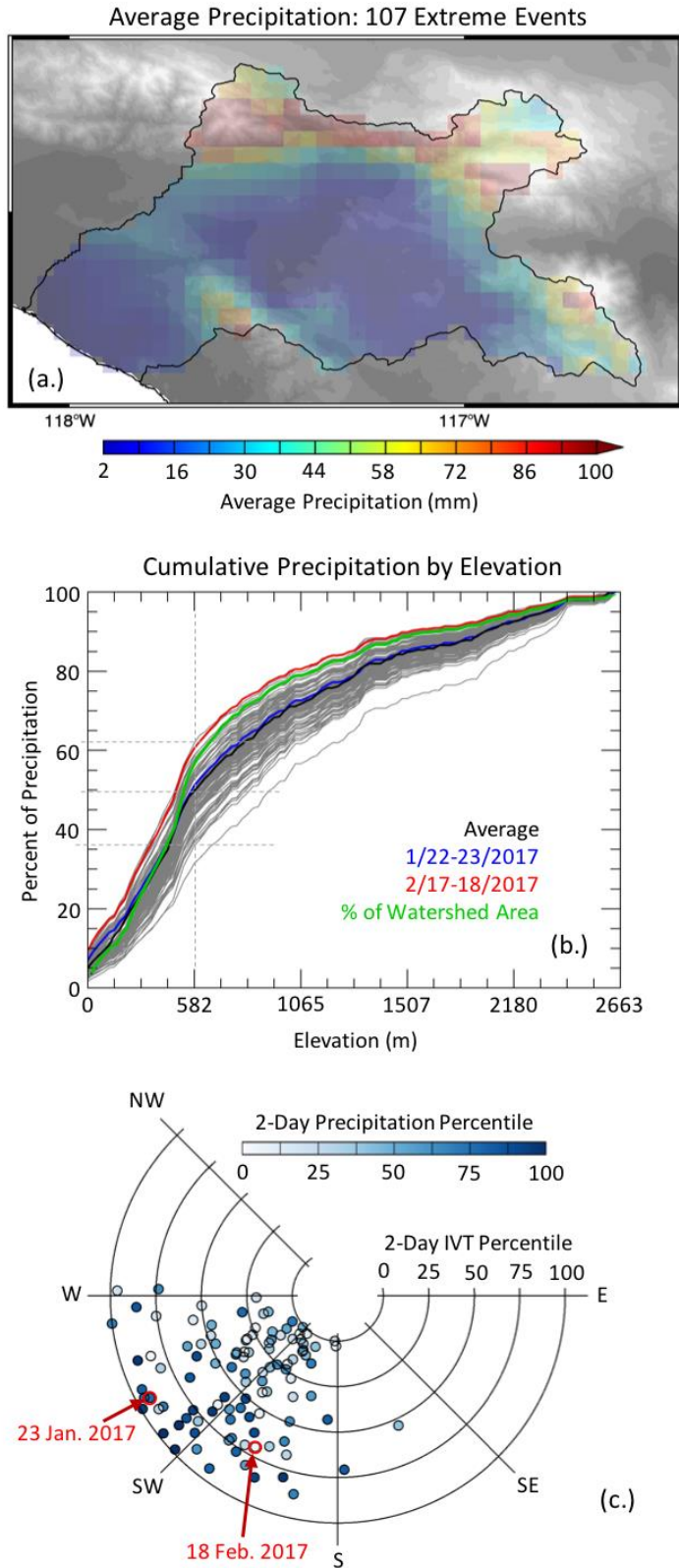
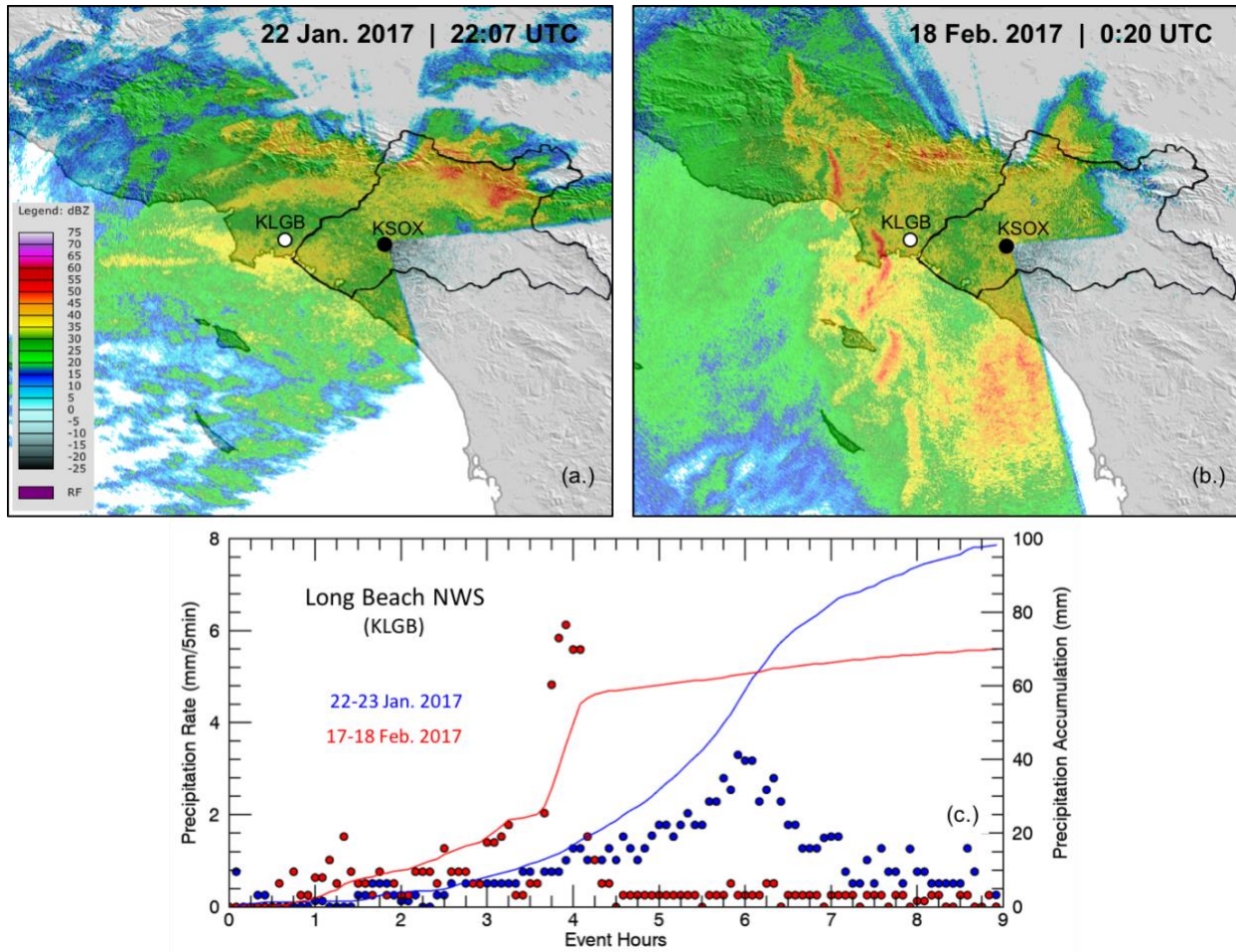
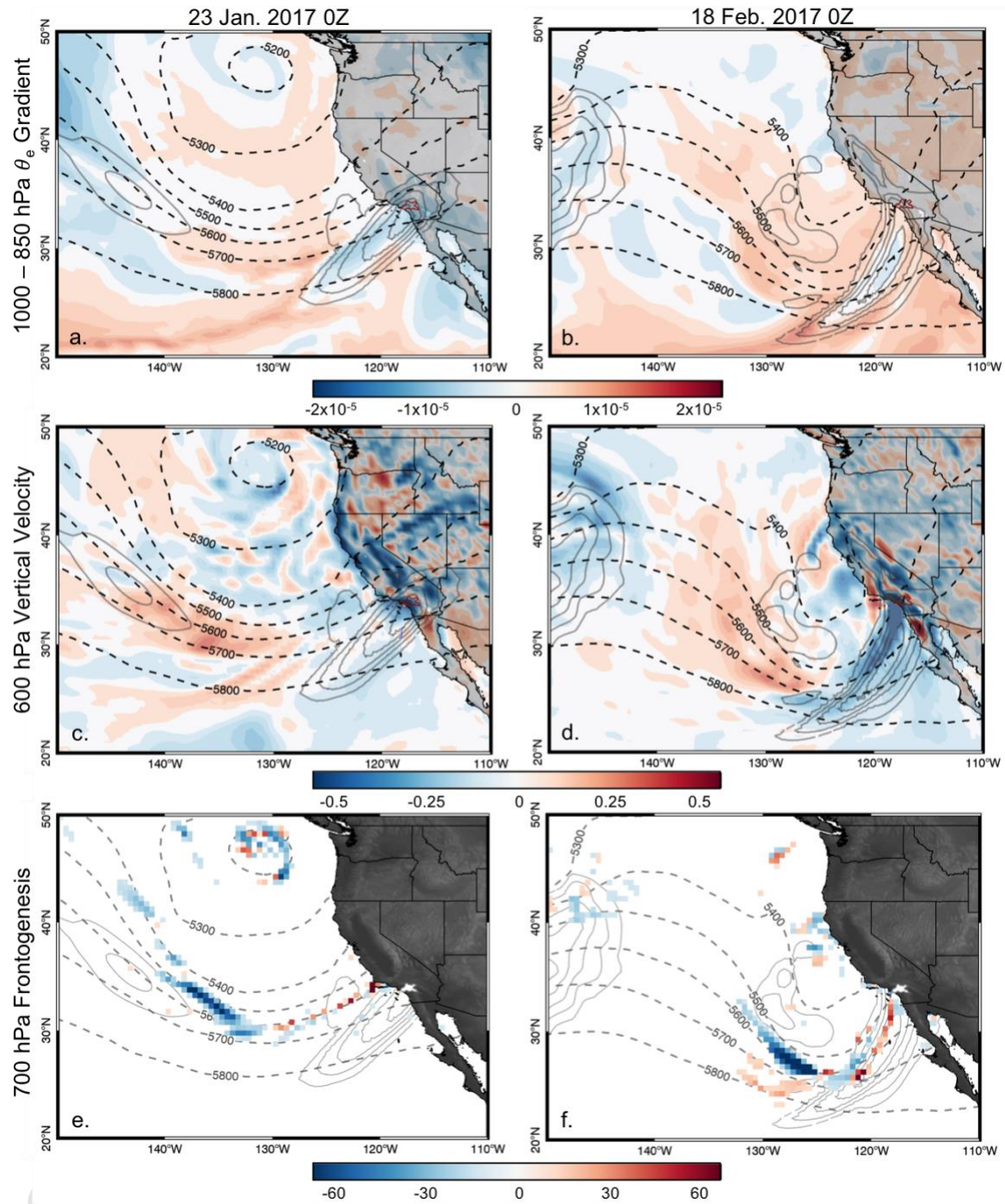


Figure 4: Average 2-day PRISM accumulated precipitation (mm; shaded) for 107 extreme events (a). Cumulative precipitation percent by elevation (b), with colors indicating each of the 2017 case study event distributions (red and blue) and percent watershed area by elevation (green; same axis as precipitation). Panel (c) shows the quantile ranking and direction of the total time integrated vapor transport over the 2-day PRISM precipitation accumulation period. Each event circle is shaded according to its precipitation ranking.



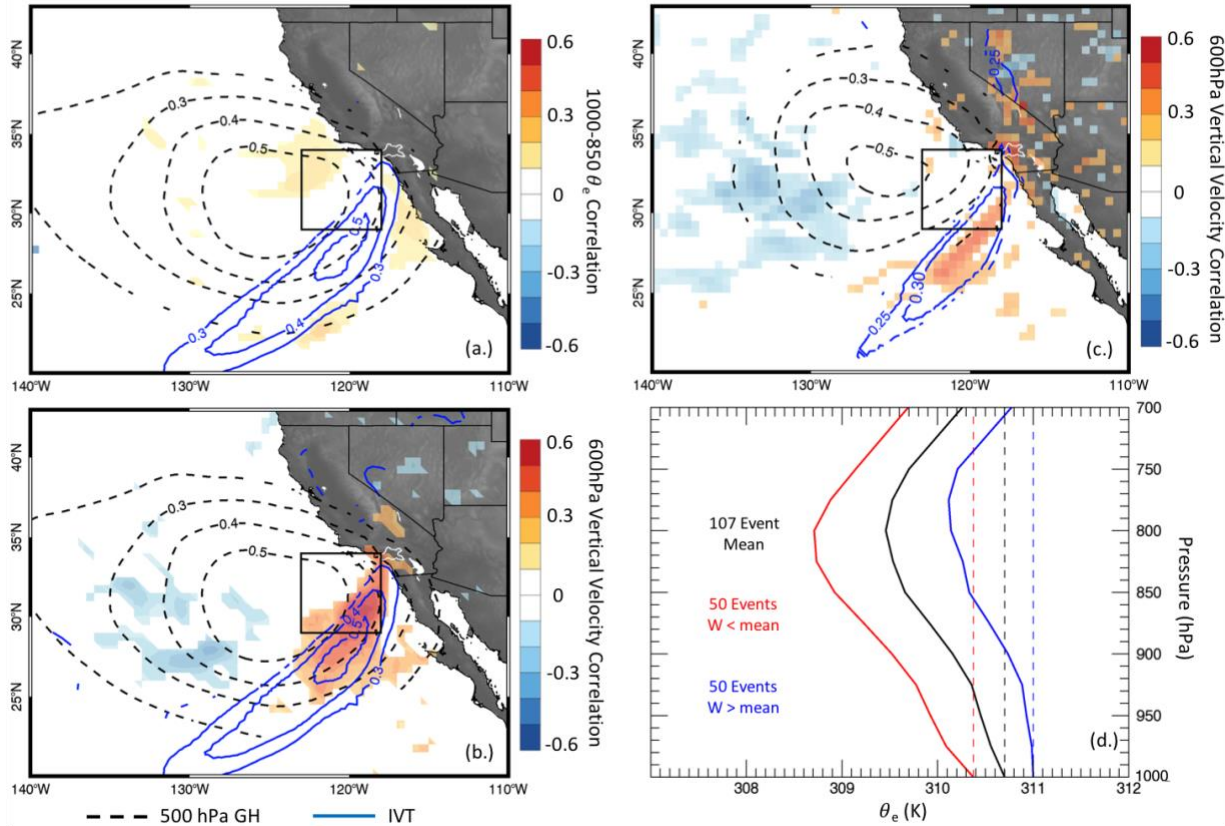
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Figure 5: Radar base reflectivity (dBz; shaded) for two case study events at the time of the maximum precipitation rate at Long Beach (KLGB), CA (a,b). Long Beach Airport NWS station precipitation rate and 9-hour event accumulation at 5-minute resolution for the two case study events (c). The January event's accumulation period begins on 22 Jan. at 17:00 UTC and the February event's accumulation period begins on 17 Feb. at 21:00 UTC.



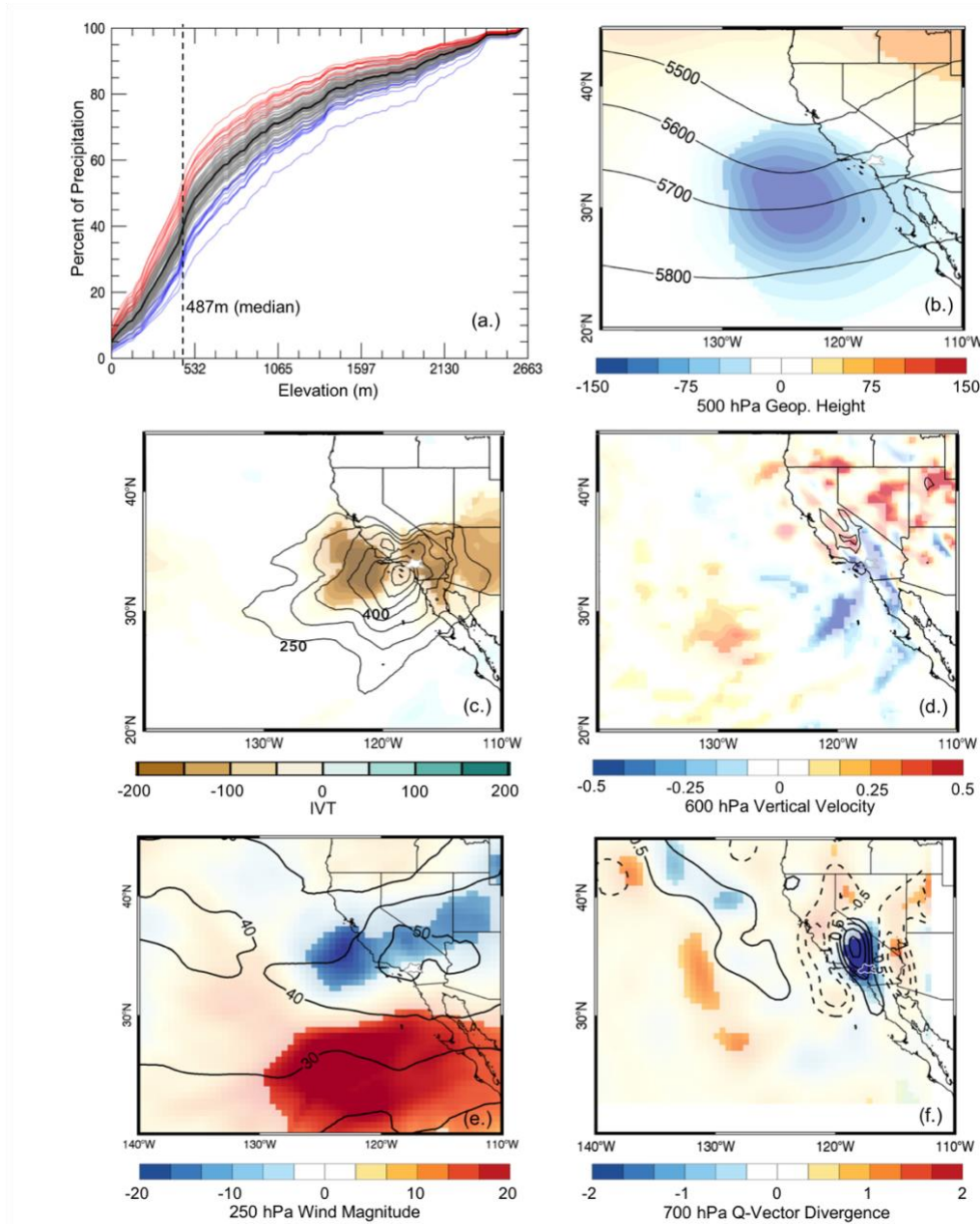
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Figure 6: 500 hPa Geopotential Height (m; dashed black contour) and IVT magnitude ($\text{kg m}^{-1}\text{s}^{-1}$; solid gray contour) at the time of watershed maximum IVT (00:00 UTC in both cases) is shown for the January event in all left column panels and the February event in all righthand panels. The 1000-850 hPa θ_e gradients (K Pa^{-1} ; shaded) (a, b), 600-hPa vertical velocity (m s^{-1}) (c, d), and 700 hPa frontogenesis ($\text{K } 100\text{km}^{-1} \text{ day}^{-1}$) (e, f) are shown in colorfill for each event.

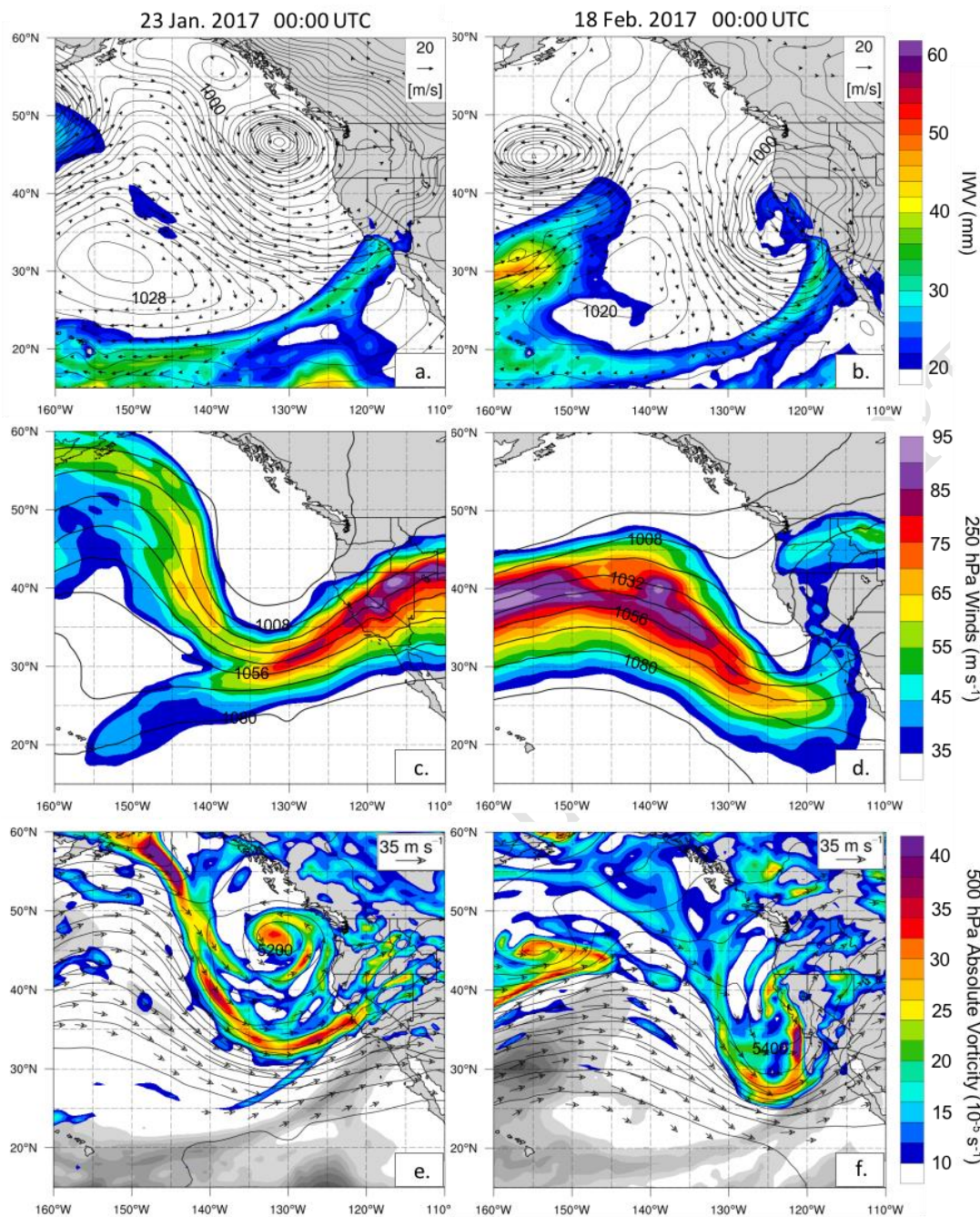


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Figure 7: Correlation of 500 hPa Geopotential Height (m; dashed contour), IVT magnitude ($\text{kg m}^{-1}\text{s}^{-1}$; blue contour) and 1000-850 hPa θ_e gradients (K Pa^{-1} ; color) with minimum 600-hPa vertical velocity over regions of IVT greater than 250 within a box immediately upstream of the Santa Ana Watershed (black outline) for 107 at the time of maximum IVT (a). The same contour fields are shown in panels (b), but the color shading displays 600 hPa vertical velocity (m s^{-1} ; shaded). The correlation of those variables to maximum frontogenesis in the upstream box is shown in panel (c). Only statistically significant values are shown, based on a Monte Carlo approach for p -values < 0.05 . Panel (d) shows the average θ_e profiles (K) over regions of IVT greater than 250 $\text{kg m}^{-1}\text{s}^{-1}$ within the upstream box, categorized by the average of all events in black, and events with the strongest 600 hPa ascent in red and the weakest in blue.

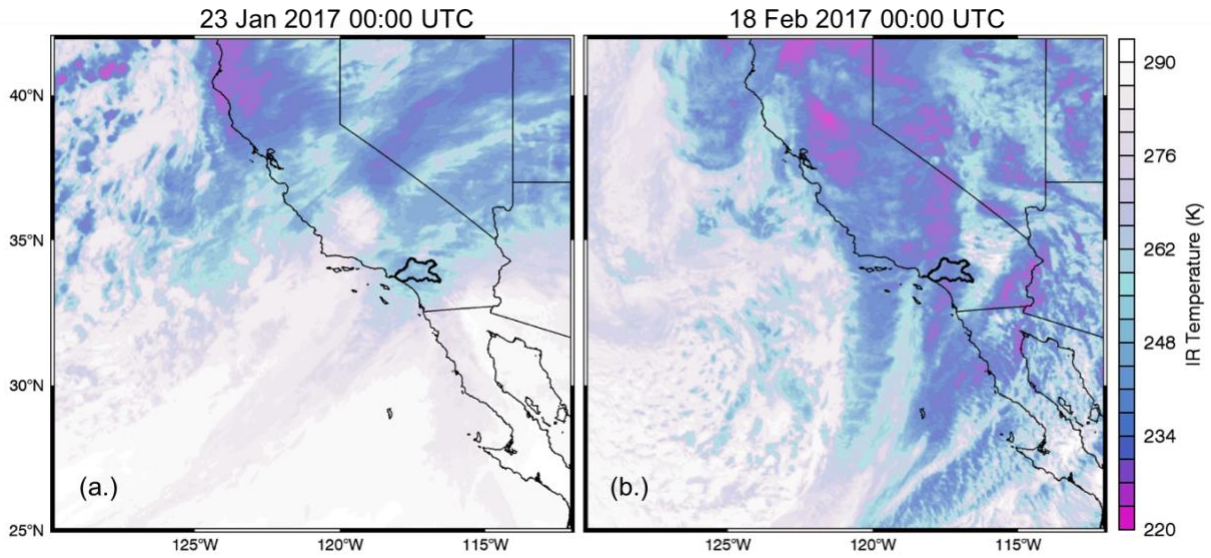
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744 **Figure 8:** Cumulative precipitation by elevation for 107 extreme events (a). Distributions with
 745 greater than 90th percentile percent precipitation below the median watershed elevation are
 746 colored red and those below the 10th are blue. Panels (b) through (f) show the composite of 10th
 747 percentile PDF events (contour) and their relative difference compared to the 90th percentile
 748 composite (color; calculated as 90th percentile minus 10th percentile), for 500 hPa geopotential
 749 height (m; b), IVT magnitude (kg m⁻¹s⁻¹; c), 600 hPa vertical velocity (m s⁻¹; d), 250 hPa wind
 750 magnitude (m s⁻¹; e), and 700 hPa Q-vector divergence (10¹⁵ K m⁻²s⁻¹; f) at the time of maximum
 751 watershed IVT. Non-significant values are faded white (based on a Welch's t-test; $p < 0.05$).



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754 **Figure 9:** Integrated water vapor (mm; color), sea-level pressure (contoured every 2 hPa) and
 755 850-hPa winds ($m s^{-1}$; vectors scaled according to reference vector) for the January (a) and
 756 February (b) events. 250-hPa wind speed ($m s^{-1}$; shaded according to scale) and 250-hPa
 757 geopotential height (contoured every 12 dam) for the January (c) and February (d) events. 500-
 758 hPa cyclonic absolute vorticity ($10^{-5} s^{-1}$; shaded according to scale), 500-hPa geopotential height
 759 (contoured ever 50 m) and 500-hPa winds ($m s^{-1}$; vectors) for the January (e) and February (f)
 760 events, with IWV underlain (mm; grayshade every 4 mm starting at 20 mm). All panels are for
 761 the time of maximum IVT entering the watershed (00:00 UTC in both cases).



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Figure 10: Geostationary Operational Environmental Satellite (GOES-15) infrared cloud top temperature (K; shaded) during the period of maximum IVT over the Santa Ana watershed for the (a) January and (b) February events.

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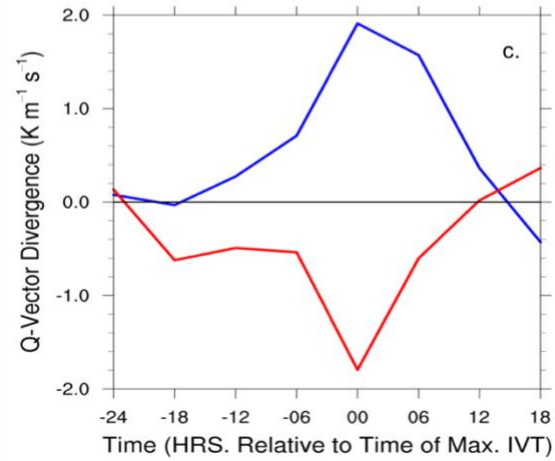
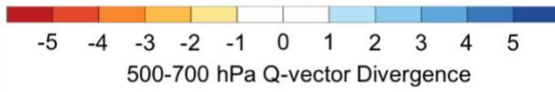
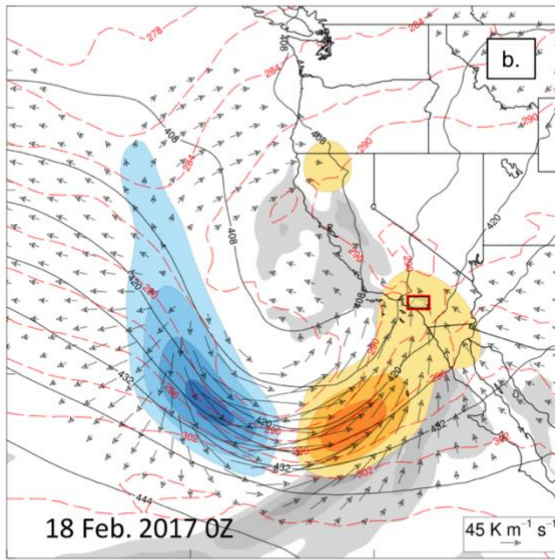
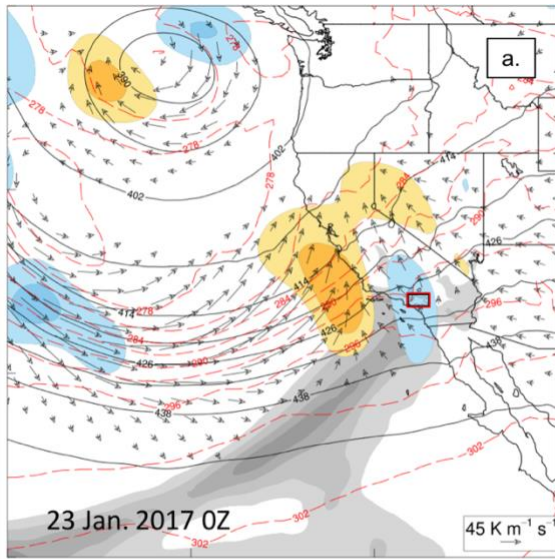


Figure 11: 700-500 hPa Q-vectors ($10^{11} \text{ K m}^{-1}\text{s}^{-1}$; vectors according to reference), Q-vector divergence ($10^{15} \text{ K m}^{-2}\text{s}^{-1}$; shaded according to scale), geopotential height (m; black contours), potential temperature (K; red contours), and integrated water vapor (mm, grayshade every 4 mm starting at 20 mm) at (a) 0000 UTC 23 January 2017 and (b) 0000 UTC 18 February 2017. A 48-hour time series of Q-vector divergence for a gridpoint covering the coastal portion of the watershed is shown for the January (blue) and February (red) events in panel (c). The 00 time step corresponds to the time of maximum IVT entering the watershed in each event.

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Phase 2 Scoping Study

Forecast-Informed Reservoir Operations at Prado Dam: Detailed Work Plan and Technical Analyses

PI: F. Martin Ralph, Ph.D.

Center for Western Weather and Water Extremes at UC San Diego/Scripps Institution of Oceanography

Period of performance: November 1, 2018 – November 1, 2019

Overview and Purpose

This proposal continues the process to explore the potential for forecast-informed reservoir operations (FIRO) at Prado Dam on the Santa Ana River and seeks to answer the following key question:

Can current and improved forecasts of landfalling atmospheric rivers and associated precipitation and runoff be used to inform reservoir operations at Prado Dam to enhance water supply availability while also supporting flood risk management and environmental needs?

This proposal uses the successful approach that was applied for FIRO in northern California at Lake Mendocino in the upper Russian River watershed. This approach is based on collaboration with, and consensus among, key partners whose interests and authorities participate as members of a FIRO Steering Committee (FIRO-SC) for facilitated discussions to inform how best to optimize reservoir operations for multiple benefits. Participation of the U.S. Army Corps of Engineers (USACE), as the primary authority that owns, operates and maintains Prado Dam for flood risk management purposes, is critically important to this process.

Phase 1 accomplishments include:

- Formation of a fully functioning FIRO-SC with agreed-upon objectives and operating principles.
- Identification of meteorological drivers of extreme precipitation in the Santa Ana watershed.
- Identification of key issues in the watershed affecting Prado Dam operational flexibility.
- Exploration of mitigation options for least Bell's vireo.
- Development of a work plan framing document.
- Development of an annotated work plan outline, to which all FIRO-SC members contributed.
- Panel presentation on Prado Dam FIRO at the fifth annual FIRO workshop held at Scripps Institution of Oceanography on August 1, 2018.

Phase 2 will build on this foundation to develop a detailed work plan to determine the viability of FIRO at Prado Dam. The work plan will summarize existing studies; identify additional research, data, and analyses needed to demonstrate FIRO feasibility; develop a work process flow outline for a decision support system (DSS); identify scenarios for FIRO implementation (including various elevations at Prado Dam); explore options for future major deviation requests to test FIRO implementation; consider, in close cooperation with USACE, possible Water Control Manual revision(s) for a permanent change to

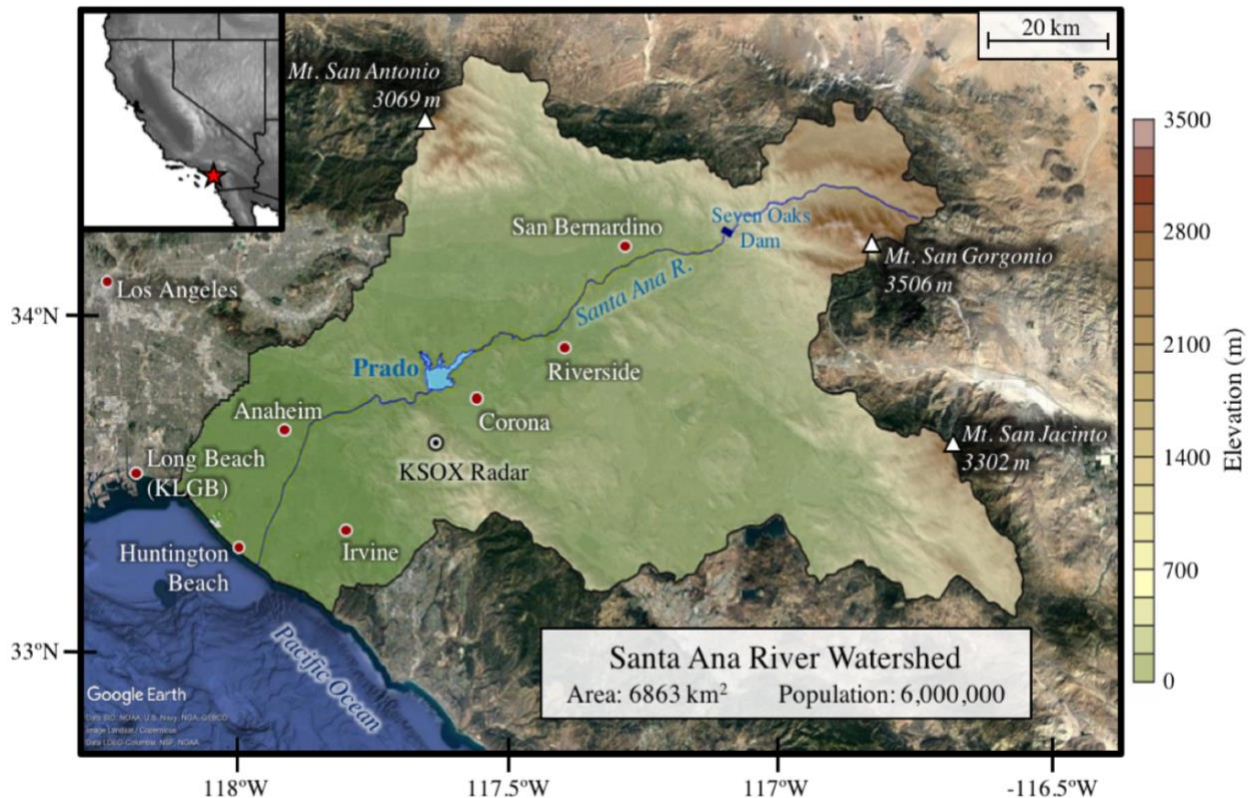
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implement FIRO; and outline a range of mitigation options. Phase 2 will include the following major tasks:

- Convening quarterly meetings of the FIRO-SC, with working sessions in between meetings.
- Creating sub-groups (focus areas may include technical studies, hydrologic models, decision support system scoping, etc.) as needed.
- Planning and executing a workshop that brings together key stakeholders and experts.
- Initiating technical analyses as needed to support work plan development.
- Identifying key scientific, hydrologic, engineering, biological, and/or operational gaps and proposing solutions to fill these gaps to enable FIRO implementation.
- Preparing a draft and final work plan: The final work plan will form the scope for the FIRO Preliminary Viability Assessment with each component noted as: (A) not started, (B) in progress or, (C) completed. It will identify lead roles and potential funding sources, and propose a schedule for completion.

Context



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The Watershed and Its Regional Weather and Climate

The ~6900 km² Santa Ana River watershed flows from the San Gabriel, San Bernardino, and San Jacinto Mountains, to its terminus at the Pacific Ocean. These mountains form a barrier to moisture transport in winter storms, including from atmospheric rivers (ARs), and force moist flow upward to generate clouds and precipitation. Rainfall accumulation during several extreme events each winter season accounts for 40 to 50 percent of annual precipitation, with large inter-annual variability in total precipitation arising due primarily to differences in AR activity. Thus, these relatively infrequent extreme events contribute significantly to flood hazards and water supply within the Santa Ana River watershed. USACE operations at Prado Dam have historically accounted for such storms, but recent advances in understanding ARs, the physical mechanisms that generate precipitation in the watershed, and how to better predict them yield the potential to enhance water supply reliability and flood control capacity at the dam. This project builds on a decade of science on how ARs work on the U.S. West Coast, and on experience in developing the concept of FIRO at Lake Mendocino, a drought and flood-prone reservoir in northern California. Progress toward identifying the physical drivers of extreme precipitation in Phase 1 of FIRO at Prado led to both advancements in AR science and improved understanding of regional meteorological influences on water supply and flood hazards.

Engaging Key Stakeholders

The Prado Dam FIRO-SC consists of key partners and stakeholders who are all strongly engaged in the FIRO effort. Below is a list of members, staff supporting the committee and others who regularly attend meetings.

Prado Dam FIRO-SC

Co-chairs:

- Greg Woodside: Executive Director of Planning and Natural Resources, OCWD
- F. Martin Ralph: Director, Center for Western Weather and Water Extremes, Scripps Institution of Oceanography, UC San Diego

Members:

- Jay Jasperse: Chief Engineer, Sonoma Water
- Michael Anderson: State Climatologist, California Department of Water Resources
- Cary Talbot: Division Chief, USACE, Engineering Research and Development Center
- Alan Haynes: NOAA National Weather Service (NWS), Hydrologist-in-Charge, California Nevada River Forecast Center
- Rene Vermeeren: Chief, Hydrology and Hydraulics Branch, Engineering Division, USACE, Los Angeles District
- Jon Sweeten: Hydraulic Engineer, Reservoir Regulation Section, USACE, Los Angeles District
- James Tyler: Manager, Real Estate/Finance and Engineering, Orange County Public Works
- Ken Corey: Field Supervisor, U.S. Fish and Wildlife Service, Palm Springs

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Committee support:

- Adam Hutchinson: Recharge Planning Manager, OCWD
- John Spencer: Civil Engineer, Orange County Public Works
- Arleen O'Donnell: Civil Engineer and Consultant, Eastern Research Group
- Robert Hartman: Hydrologist, Robert K. Hartman Consulting Services
- Dr. Forest Cannon: Project Scientist, Center for Western Weather and Water Extremes (CW3E)
- Dr. Ali Hamidi: Postdoctoral Scholar, CW3E

Other Key Stakeholders/Partners

- Cuong Ly: USACE, Los Angeles District (South Pacific Division)
- Van. G. Crisostomo: USACE, Los Angeles District

After a kickoff meeting between CW3E and OCWD on December 4, 2017, the FIRO-SC held meetings on the following dates:

- March 6, 2018 (Prado Dam)
- May 17, 2018 (USACE, Los Angeles District)
- July 30, 2018 (Scripps Institution of Oceanography)
- October 16, 2018 (to be held at OCWD)

Participants, pictured below, include representatives from OCWD, USACE Los Angeles District, South Pacific Division and Engineer Research and Development Center, U.S. Fish and Wildlife Service, Sonoma Water, NOAA NWS California Nevada River Forecast Center, California Department of Water Resources San Bernardino, Riverside and Los Angeles counties, as well as Sonoma Water and Scripps. This proposed effort incorporates information exchanged at this key preliminary meeting and illustrates a core strategy of FIRO at Lake Mendocino—i.e., inclusion of key individuals representing the disciplines and agencies who have relevant interests and expertise.



March 6, 2018, FIRO-SC meeting at Prado Dam.

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May 17, 2018, Prado Dam FIRO-SC meeting at USACE, Los Angeles District.

Technical Approach

Task 1: Prado FIRO-SC Co-Leadership

This task supports efforts of F. M. Ralph as FIRO-SC co-lead with a co-chair from OCWD (to be determined). Key areas of responsibility include quarterly meetings of the FIRO-SC (joint with OCWD co-chair); support from a technical and strategic communications team, including continued agenda development and meeting facilitation, report writing, maintenance of a project website at CW3E; CW3E administrative staff support and associated travel, including participation in Association of California Water Agencies and national meetings; and briefings in Washington, D.C. and Sacramento as appropriate.

Task 2: Co-Lead Creation of a Work Plan to Assess the Viability of FIRO at Prado Dam

Building on the annotated work plan outline developed during Phase 1, the CW3E team will help guide and coordinate the Prado FIRO-SC to define the FIRO study and its desired outcomes, as well as develop the strategy and team to accomplish this, including staff support. These goals require developing a final work plan, conducting FIRO-SC conference calls, communicating the plans and results at suitable venues (agencies, conferences, etc.), coordinating with agency staff supporting the planning and project, and traveling to relevant meetings.

Task 3: Plan and Execute FIRO Workshop

The CW3E team will organize and facilitate at least two face-to-face meetings of the FIRO-SC at Scripps, OCWD, or another convenient location. It is anticipated that, as established during Phase 1, the CW3E technical support team will convene discussions with OCWD staff in between the FIRO-SC meetings to debrief on the previous meeting and prepare for the upcoming meeting. One of the meetings will coincide with a broader workshop involving the technical teams carrying out the planning. The Prado FIRO-SC will develop the meeting agendas and identify the dates. This task supports the planning,

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facilitation, and logistics for the meetings, including refreshments, meeting space, audiovisual equipment, and other relevant costs.

Task 4: Preliminary Technical Study

Progress toward identifying the physical drivers of extreme precipitation in Phase 1 of FIRO at Prado led to both advancements in AR science and improved understanding of regional meteorological influences on water supply and flood hazards. Cannon et al. (2018) detailed the results from Phase 1 in a manuscript that the *Journal of Geophysical Research* has conditionally accepted. Per Tasks 4.1 and 4.2 (Appendix 1) in the Phase 1 proposal, Cannon et al. (2018) identified the impacts of AR-type storms on the Santa Ana River watershed, including two notable case studies from 2017 that necessitated USACE flood control operations at Prado Dam. This study defined the multiple meteorological processes that control regional rainfall rates and accumulation in extreme events. The conditionally accepted version of the manuscript is attached for reference (Appendix 2). Continued research in Phase 2 builds on the results of Cannon et al. (2018) to complete:

- **Task 4.3:** Explore forecast skill for each 2017 case study and a record of recent extreme events. CW3E-developed AR forecast tools will be leveraged to understand how each event's development and dominant precipitation influences affected forecast skill for that event. This task will additionally investigate quantitative precipitation forecast error in relation to findings from Tasks 4.1 and 4.2.
- **Task 4.4:** Evaluate forecast skill over lead time in collaboration with USACE and OCWD to ensure that scientific advancements address current operations and needs for FIRO at Prado. This task identifies the probabilistic skill of inflow forecasts for the record of extreme events according to the lead times necessary for FIRO at Prado, as determined by operational constraints.

These analyses will yield insight into the viability of FIRO at Prado Dam by identifying the meteorological processes that generate extreme precipitation events in the Santa Ana River watershed, evaluating their predictability, and defining inflow uncertainty according to USACE and OCWD lead time requirements.

Timeline and Deliverables

Phase 1: Completed

December 2017	Kickoff meeting held
March 2018	Prado FIRO-SC created
May 2018	FIRO-SC terms of reference finalized
July 2018	Workshop conducted at Scripps Seaside Forum
October 2018*	Technical studies 4.1 and 4.2 characterizing atmospheric river conditions affecting Prado published (Cannon et al. 2018; Appendix 2) FIRO-SC meets to finalize work plan outline (October 16); Washington, D.C .and Sacramento outreach meetings

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*Since this proposal is being submitted prior to October 1, the October deliverables above are underway and will be completed within the Phase 1 period of performance.

Phase 2: Period of Performance November 1, 2018 – November 1, 2019

November 2018	Develop timeline and assign tasks for drafting the work plan
February 2019	FIRO-SC meets to review draft work plan and timeline
May 2019	FIRO-SC meets to finalize work plan and begin near-term tasks (funding permitted)
July 2019	FIRO workshop
October 2019	Publish final work plan; FIRO-SC meets, transitions to execute work plan; complete technical studies 4.3 – 4.4; execute work plan and begin outreach

Budget

Below are the estimated costs for people, travel, and supplies relevant to Tasks 1–4 described above, executed over two years in two phases.

- **Phase 1:** \$250,000 executed from November 1, 2017, to October 31, 2018 (completed)
- **Phase 2:** \$325,000 to be executed from November 1, 2018, to October 31, 2019

Task	Description	Phase 1 (\$K)	Phase 2 (\$K)	Total (\$K)
1	Co-chair Prado FIRO-SC — lead, coordination, administrative support, and travel	45.0	50.0	95.0
2	Develop work plan — co-lead, technical writing, travel	80.0	100.0	180.0
3	Plan and execute workshops — facilitation, logistics staff, room/supplies	60.0	65.0	125.0
4	Preliminary technical study — analyze/publish, conferences	65.0	110.0	175.0
Totals		250.0	325.0	575.0

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Appendix 1

Technical Study for Prado Dam FIRO Assessment — Task 4: Proposed Meteorological Analyses

F. Cannon, F.M. Ralph (CW3E)

The objectives of the proposed analyses in the original two-year proposal were to establish the predictability of high-impact precipitation events within the Santa Ana River watershed and to define the potential for FIRO at Prado according to inflow uncertainty and USACE lead time requirements.

Analyses were proposed as four subtasks with complementary objectives. Tasks 4.1 and 4.2 were completed during Phase 1, and Tasks 4.3 and 4.4 build upon their results in Phase 2. Diagnostic analyses in Phase 1 focused on three AR events during the winter of 2016/17 that either produced, or were forecast to produce, high-magnitude precipitation and elevated discharge rates on the Santa Ana River. Case studies were performed for January 22–23, February 17–18, and February 27–28, 2017. Each of the selected events was attributable to AR conditions, yet each event was also meteorologically unique, resulting in significant variability of precipitation accumulation across the Santa Ana River watershed and adjacent regions.

The *Journal of Geophysical Research* has conditionally accepted a study (Cannon et al. 2018; Appendix 2) diagnosing regional meteorological influences on extreme precipitation based on case studies and the full record of 107 extreme precipitation events from 1981 to 2017, which was performed in Tasks 4.1 and 4.2 of Phase 1. Tasks 4.3 and 4.4 in Phase 2 will yield insight into the viability of FIRO at Prado Dam by evaluating the predictability of those identified meteorological influences in extreme events, and defining inflow uncertainty at Prado according to USACE and OCWD lead time requirements.

- **Task 4.1 (Completed):** Use global forecast models and satellite data to investigate the large-scale event conditions that produced ARs, their mechanisms for extreme precipitation, and subsequent differences in precipitation intensity and timing over the Santa Ana River watershed.
- **Task 4.2 (Completed):** Investigate mesoscale precipitation processes, including orographic enhancement, embedded convection, and cloud microphysics, which contributed to spatiotemporal variability of precipitation within the watershed during each event. These analyses will use precipitation observations from a dense network of rain gauges and NEXRAD radar data within the watershed as well as high-resolution regional weather model output (West-WRF).
- **Task 4.3:** Explore forecast skill for each 2017 case study and a record of recent extreme events. CW3E-developed AR forecast tools will be leveraged to understand how each event's development and dominant precipitation influences affected the forecast skill for that event. This task will additionally investigate quantitative precipitation forecast error in relation to findings from Tasks 4.1 and 4.2.

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- **Task 4.4:** Evaluate forecast skill over lead time in collaboration with USACE and OCWD to ensure that scientific advancements address current operations and needs for FIRO at Prado. This task identifies the probabilistic skill of inflow forecasts for the record of extreme events according to the lead times necessary for FIRO at Prado, as determined by operational constraints.

Appendix 2

Conditionally Accepted Publication

Synoptic and Mesoscale Forcing of Southern California Extreme Precipitation

Journal of Geophysical Research: Atmospheres

Synoptic and Mesoscale Forcing of Southern California Extreme Precipitation

Forest Cannon¹, Chad W. Hecht¹, Jason M. Cordeira², and F. Martin Ralph¹

¹ *Center for Western Weather and Water Extremes – Scripps Institution of Oceanography, University of California, San Diego, USA*

² *Department of Atmospheric Science and Chemistry – Plymouth State University, Plymouth, New Hampshire, USA*

Conditionally Accepted – Journal of Geophysical Research: Atmospheres

Revised 4 September 2018

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Key Points:

1. In the Santa Ana river watershed, 107 extreme events contributed nearly half of total precipitation between 1981 and 2017.
2. Total integrated vapor transport, including in atmospheric rivers, is the leading source of variability in extreme event precipitation.
3. The characteristic orographic precipitation distribution in extreme events is modified by synoptic and mesoscale dynamical forcing.

39 **Abstract**

40 Southern California water resources are heavily dependent on a small number of extreme
41 precipitation events each winter season, which dictate the region's highly-variable interannual
42 accumulations. In the Santa Ana River Watershed, on average, three extreme events per year
43 contribute half of annual precipitation, yet there are relatively few studies of the synoptic to
44 mesoscale processes that drive precipitation during these events. This study uses an ingredients-
45 based approach to identifying the contributions of orographic forcing, dynamical forcing and
46 convective instability to extreme precipitation in the watershed in 107 storms that produced
47 roughly 50% of all precipitation from 1981-2017. The influence of dynamical forcing and
48 convective instability on event precipitation distributions is investigated relative to the dominant
49 influence of orographic forcing that is typically found in landfalling atmospheric rivers. Case
50 studies of two high-impact events from the 2017 winter season demonstrate differences in the roles
51 of synoptic ascent and mesoscale convective features in modifying precipitation location, rate and
52 accumulation over the watershed. The February 17-18, 2017 case study included a narrow cold-
53 frontal rainband that produced high-intensity short-duration precipitation over low elevations of
54 the watershed. In the 107 extreme event record, similar modification of the precipitation
55 distribution toward non-orographic rainfall was related to significant changes in the synoptic-scale
56 circulation that favored enhanced dynamics and upstream ascent associated with frontogenesis.
57 Variability in precipitation mechanisms is of primary interest to weather forecasters and water
58 managers as it modifies event impacts and predictability.

59

60 **Keywords:** Extreme precipitation; Atmospheric Rivers; Southern California hydroclimate

61 **1. Introduction**

62 California water resources are heavily influenced by precipitation that exhibits extreme
63 interannual variability (Dettinger et al. 2011). Along the U.S. West Coast, and in California in
64 particular, only a few winter storms and atmospheric river (AR) events each winter season explain
65 the majority of variance in annual accumulated precipitation (Dettinger et al. 2016). However, in
66 Southern California single extreme precipitation events have a disproportionately large effect on
67 annual precipitation (Haynes, 2001) and streamflow. This effect is observed in the Santa Ana River
68 Watershed where 50% of annual discharge occurs during ~3 days per year (Warrick and Rubin,
69 2007). Thus, the goal of this study is to investigate Southern California extreme precipitation
70 events in order to characterize their driving mechanisms and to define their climatological
71 contribution to regional water resources.

72 Southern California hydroclimate is defined by the importance of individual high-
73 magnitude events (Dettinger et al. 2011) and features distinctive characteristics related to its
74 geography. Regional topography is characterized by transverse (east-west oriented) coastal ranges,
75 which force orographic precipitation preferentially during landfalling ARs with southerly flow and
76 water vapor transport that is orthogonal to topography (Harris and Carvalho, 2017). Consequently,
77 the southerly direction of water vapor transport and landfalling AR orientation that are frequently
78 associated with heavy precipitation in Southern California are generated by different synoptic-
79 scale conditions than those impacting central and northern California (Oakley and Redmond, 2014;
80 Hecht and Cordeira, 2017). Heavy precipitation events over Southern California often occur in
81 association with low-pressure centers that are comparatively closer to the location of AR landfall
82 than Northern California (Haynes, 2001), which increases the likelihood of enhanced mesoscale
83 and synoptic-scale forcing for precipitation (e.g., convection or quasi-geostrophic forcing for

84 ascent, respectively) associated with the parent low-pressure in addition to orographic precipitation
85 (Small et al. 2002; Oakley et al. 2017). In general, the spatiotemporal distribution of precipitation
86 in landfalling winter storms is dependent upon three primary forcing mechanisms for ascent:
87 Orographic forcing for ascent, dynamical forcing for ascent (e.g. synoptic and frontal), and
88 convective forcing for ascent related to instability (Houze et al. 1976; Lee, 1984; Katzfey, 1995);
89 precipitation may be forced by any combination of these mechanisms (Lin and Chiao, 2001).

90 Research on landfalling ARs in California has predominantly focused on the presence and
91 strength of the moist low-level jet stream and its influence on orographic forcing for ascent and
92 precipitation in complex terrain (e.g. Neiman et al. 2002, 2009; Ralph et al. 2005; 2013). Southern
93 California's steep coastal mountains are efficient generators of orographic precipitation and may
94 additionally modify onshore flow ahead of landfalling fronts through low-level blocking and the
95 generation of a barrier jet (Nieman et al. 2002, 2004), which may redistribute precipitation.
96 Individual case studies of landfalling ARs over Southern California have also studied the influence
97 of synoptic-scale and convective forcing for ascent and precipitation (e.g. Neiman et al. 2004;
98 Oakley et al. 2017), but no systematic evaluation of the climatology of these forcing mechanisms
99 and their association with regional precipitation extremes during landfalling ARs exists. The
100 relative lack of emphasis on the influence of synoptic-scale and convective forcing for ascent on
101 regional extreme precipitation events suggests a knowledge gap that is potentially problematic for
102 water resources management, hazard mitigation, and forecasting.

103 The objective of this study is to use observational and reanalysis data to examine two
104 unique case study events that produced extreme precipitation accumulations in the Santa Ana River
105 Watershed of Southern California during January and February 2017. These two events are
106 characterized with respect to a regional climatology of extreme precipitation and identified as the

107 result of two distinctive representative sub-categories of meteorological conditions that led to
108 differences in spatial and temporal precipitation distributions. Each event poses a different set of
109 forecasting challenges, with notable implications for water resource management on the Santa Ana
110 River, such as at Prado Dam. This analysis represents an important step towards (1) understanding
111 mechanisms responsible for Southern California precipitation extremes and their variability across
112 scales, and (2) defining important challenges where improvements may augment predictability for
113 water resource management.

114

115 **1.1 Study region: The Santa Ana River watershed of Southern California**

116 The Santa Ana River flows from the San Gabriel, San Bernardino and San Jacinto
117 Mountains, which arc around the eastern edge of the watershed at elevations exceeding 3500 m,
118 to its terminus at the Pacific Ocean (Fig. 1). The watershed encompasses an area of 4406 km²,
119 includes the densely populated southeastern portion of the Los Angeles metropolitan area, receives
120 minimal annual precipitation (~500 mm/year), and is home to a variety of water projects and
121 effective management strategies aimed at meeting resource demand (Hutchinson, 2017). For
122 example, Prado Dam on the Santa Ana River provides 2.4 million people in Orange County with
123 up to 70% of annual water supply through groundwater recharge (Hutchinson, 2017). Despite the
124 importance of Prado Dam to water supply, its primary purpose is flood risk management due to
125 significant flood events in recent history (Swanson and Hatheway, 1990). Water management at
126 the dam for groundwater recharge downstream requires adaptive planning within the U.S. Army
127 Corps of Engineer operating manual. Thus, improved understanding and predictability of
128 precipitation events has the potential to augment regional water resource management. While the
129 focus of this manuscript is on the Santa Ana River Watershed, its cool-season precipitation-driven

130 discharge, small area, high relief, transverse orientation and high level of urbanization are
131 generally characteristic of Southern California watersheds.

132

133 **2. Methodology**

134 **2.1 Precipitation data**

135 Estimated precipitation from Parameter Regression on Independent Slopes Method
136 (PRISM; Daly et al. 1994, 2002) data are used to identify extreme events impacting the Santa Ana
137 River watershed. PRISM is a statistical methodology for interpolating station-based climate data
138 using a dynamic knowledge-based framework of prevailing meteorology in an area. The regression
139 scheme accounts for complex climate regimes associated with orography, rain shadows,
140 temperature inversions, slope aspect, coastal proximity and other factors (Daly et al. 1994). Data
141 are available spatially on a 4-km horizontal grid and temporally every 24 h for the period 1981–
142 present. While the Santa Ana River watershed has a relatively dense precipitation sampling
143 network that improves the quality the PRISM dataset, it is important to note that the data’s ability
144 to represent extreme precipitation in complex topography has not been quantified for this
145 watershed. The PRISM dataset is complemented by higher temporal resolution National Weather
146 Service (NWS) observations in order to better evaluate precipitation characteristics (e.g., intensity,
147 areal coverage, convection, etc.) of each case study. These observations include (1) five-minute
148 temporal resolution precipitation observations at Long Beach (KLGB), CA and (2) base and
149 composite reflectivity data from the Santa Ana Mountains (KSOX) NWS Next-Generation
150 Weather Radar (NEXRAD; NOAA, 1991) installation (Fig. 1). These radar data are essential to
151 regional hazard forecasting at short lead times as they are frequently used by regional NWS

152 forecasters to identify mesoscale features with intense precipitation rates before they propagate
153 onshore (Gomberg et al. 2018).

154

155 **2.2 Extreme precipitation event definition**

156 Analyses of individual precipitation events are performed based on the identification of
157 extreme precipitation in PRISM data during winter seasons (October through April) 1981–2017.
158 The area-averaged total precipitation over the Santa Ana River watershed, based on all PRISM
159 grid points within the watershed (408 grid points at 4-km resolution), received 93% of its
160 precipitation during winter. An extreme precipitation event is subsequently defined as the 95th
161 percentile of 2-day basin area-averaged precipitation totals. Event independence is achieved by
162 retaining only the date of maximum precipitation for consecutive 95th percentile dates within a 5-
163 day period. A two-day accumulation period (e.g. Warner et al. 2012) is used to identify events in
164 order to account for issues associated with the timing of a given event relative to the PRISM 12
165 UTC daily-aggregation period. These criteria identified 107 extreme events in the Santa Ana River
166 watershed from 1981 through 2017, including the two case study events in January and February
167 2017.

168 The 107 extreme events contained 2-day precipitation totals that accounted for ~44% of
169 total precipitation in the watershed from 1981 to 2017 and 3-day precipitation totals that exceeded
170 50% of total precipitation. Further results indicate that, on average, three extreme events in any
171 single year produce ~50% of that year's annual precipitation similar to findings from Haynes
172 (2001) for the greater coastal Southern California region. The number of extreme events in a
173 season, which ranges from zero to six, correlates with annual precipitation with a coefficient of
174 0.90, whereas the annual total of extreme event precipitation has a correlation coefficient of 0.95

175 with annual total precipitation. Because extreme events play a critical role in water resources in
176 the study region, they are the sole focus of this research.

177

178 **2.3 Analysis of synoptic conditions**

179 The synoptic-scale meteorological conditions during extreme precipitation events are
180 investigated using National Center for Environmental Prediction Climate Forecast System
181 Reanalysis and operational analysis (CFSR) data (Saha et al. 2010, 2014). The NCEP–CFSR data
182 are contained on a 0.5° latitude x 0.5° longitude horizontal grid every six hours at 0000, 0600,
183 1200, and 1800 UTC for the period 1979–2017. The NCEP–CFSR data are used to calculate and
184 derive meteorological parameters commonly invoked in analyses of landfalling ARs such as
185 geopotential heights and wind at multiple isobaric levels, integrated water vapor (IWV), and
186 integrated vapor transport (IVT; calculated for the column extending from the surface to 200 hPa).
187 The data are also used to calculate vertical profiles of equivalent potential temperature and
188 divergence of the Q-vector for a layer between 700 hPa and 500 hPa (Hoskins et al. 1978, 1980)
189 in order to assess convective and synoptic-scale forcing for ascent, respectively. Note that Q-
190 vectors represent the advection of the temperature gradient by the horizontal change in the
191 geostrophic wind. Regional convergence of the Q-vector represents QG forcing for ascent and
192 synoptic-scale upward vertical motion, whereas regional divergence of the Q-vector represents QG
193 forcing for descent and synoptic-scale downward vertical motion (Hoskins, 1978). Weaknesses of
194 Q-vectors include their neglect of advections and temporal changes in the ageostrophic wind,
195 frictional effects, diabatic heating and cooling, and the vertical advection of ω , all which can be
196 significant at times (Funk, 2011). Here, the 700-500 hPa layer was evaluated as it extends low
197 enough to capture low-level thermal advection (while remaining in the free atmosphere where the

198 neglect of friction is less problematic) and is high enough to capture significant differential
199 vorticity advection.

200 The “typical” synoptic-scale conditions associated with extreme precipitation events are
201 often investigated using composite mean analysis of meteorological variables (e.g. Cannon et al.
202 2017); however, the wide-variety of synoptic-scale conditions associated with landfalling ARs
203 impacting Southern California (Haynes, 2001) is not well represented by this methodology. This
204 discrepancy is demonstrated by qualitative analyses of the locations of each mean surface low-
205 pressure center and the axis of IVT orientation at the time of maximum IVT over the watershed
206 for the 107 extreme events (Fig. 2a). This schematic was created by subjectively identifying the
207 orientation of moisture transport toward the Santa Ana River watershed in each event, using IWV
208 and IVT at the time of maximum IVT entering the watershed during the 2-day precipitation event
209 accumulation period, and then identifying the surface low pressure center associated with that
210 transport. While many automated algorithms exist for similar purposes, this exercise was
211 performed manually on account of the variety of event types, which are not equally well identified
212 across automated procedures (based on preliminary testing). Although each event contained a
213 surface low (i.e., a parent cyclone) and corridor of enhanced moisture transport, the range of
214 synoptic-scale conditions included well-developed lows in the northeast Pacific, closed and cut-
215 off lows, post-frontal events, anticyclone-dominated events and post-tropical cyclone events (e.g.
216 Haynes et al. 2001). According to a catalog of ARs (Rutz et al. 2014), approximately two-thirds
217 of these 107 extreme precipitation events occurred in association with AR conditions over the
218 watershed. The two case study events from 2017 are also identified in Fig. 2a. Note that a
219 composite analysis of these events at the time of maximum IVT entering the watershed (Fig. 2b)

220 does not capture the variability amongst their synoptic conditions, which is shown to significantly
221 influence precipitation processes within individual events (Section 3).

222

223 **2.4 Case study event selection**

224 The 2016–17 water year in the Santa Ana River watershed was strongly influenced by two
225 landfalling ARs that occurred on 22–23 January 2017 and 17–18 February 2017. Both events
226 generated enhanced streamflow in the Santa Ana River and contributed large volumes of water to
227 storage at Prado. The high reservoir inflow during these events necessitated rapid releases of water
228 to the ocean to preserve flood control capacity at the dam (Swenson and Hatheway, 1990). These
229 releases occurred at flow rates that far exceeded what can be utilized for ground water recharge by
230 Orange County Water District (Hutchinson, 2017), highlighting the potential benefit of improved
231 understanding of precipitation processes and their predictability to reservoir management. The
232 synoptic-to-mesoscale conditions that defined each event are subsequently evaluated to determine
233 their potential impact on the spatiotemporal distribution of precipitation within the watershed.
234 Mechanisms responsible for forcing for ascent during the two case study events are additionally
235 compared to the 107 extreme events in the watershed to determine how representative the case
236 study events are of the climatology (Section 3).

237 The record 2016–2017 water year for most of California produced only slightly above average
238 rainfall across Southern California and partial relief from a multi-year drought (California
239 Department of Water Resources, 2018). Regional precipitation increased to above average (based
240 on PRISM, not shown) following widespread precipitation associated with a landfalling AR that
241 propagated south along the California coast on 22–23 January. The event occurred in association
242 with an extratropical cyclone with sea-level pressure of 975 hPa located off the coast of

243 Washington (132°W, 46°N) that was far removed from the AR and the Santa Ana River watershed
244 (Fig. 3a). The location of the low-pressure center relative to its frontal location and the AR suggests
245 that the cyclone was occluded and in the later stages of its lifecycle. This event featured an upper-
246 tropospheric $\sim 90 \text{ m s}^{-1}$ anticyclonically curved jet stream wind maximum at 250 hPa located over
247 the eastern North Pacific and Continental U.S. embedded within a positively tilted upper-
248 tropospheric trough (Fig 3a). The Santa Ana River watershed was located on the anticyclonic shear
249 side of the jet stream wind maximum and downstream of the upper-tropospheric trough axis.

250 A second landfalling AR produced widespread precipitation across Southern California on
251 17–18 February 2017. This AR occurred in association with synoptic-scale conditions that
252 noticeably differed from the event on 22–23 January. This February event featured an extratropical
253 cyclone with a sea-level pressure of $\sim 985 \text{ hPa}$ located over the northern California coastline
254 (122°W, 37°N) that was relatively proximal to the landfalling AR and the Santa Ana River
255 Watershed (Fig. 3b). The cyclone was inferred to be earlier in its life cycle as its pressure had
256 decreased $\sim 18 \text{ hPa}$ in the preceding 24 hours (not shown). The IVT during this event contained a
257 more southerly direction and was weaker in magnitude at the coast as compared to January event
258 ($700\text{--}800 \text{ kg m s}^{-1}$ vs. $800\text{--}1000 \text{ kg m s}^{-1}$), suggesting weaker moisture flux within the Santa Ana
259 River watershed (Fig. 3). The duration of AR conditions over the watershed was 24 hours for the
260 January case and 21 hours for the February case (based on the Rutz et al. (2014) AR catalog that
261 uses MERRA 3-hour resolution IVT).

262 The February event occurred in association with an upper-tropospheric $\sim 80 \text{ m s}^{-1}$
263 cyclonically curved jet stream wind maximum at 250 hPa and negatively tilted upper-tropospheric
264 trough over the eastern North Pacific (Fig. 3b). The Santa Ana River watershed was located under
265 the exit region of the cyclonically curved jet stream wind maximum. A second jet stream wind

266 maximum centered around $\sim 47^\circ\text{N}$ and 115°W was also present during the February event. The
267 sea-level pressure center was located in both the exit region of the dominant cyclonically curved
268 jet to the south and the equatorward entrance region of the incipient jet streak to the north. Event
269 differences in the location, orientation, and curvature of the jet streaks, combined with the
270 magnitudes and tilts of the upper-tropospheric trough axes, may have influenced variability in
271 precipitation processes over the Santa Ana Watershed at the time of AR landfall, as discussed in
272 subsequent sections.

273

274 **3. Results and discussion**

275 **3.1 IVT, atmospheric rivers and orographic forcing of precipitation**

276 *a. Event total precipitation*

277 The composite PRISM 2-day precipitation accumulation over the Santa Ana River
278 watershed demonstrates a strong orographic precipitation gradient that is consistent with a well-
279 established understanding of precipitation over the western U.S. (Roe, 2005). This pattern emerges
280 as orographic lifting is the primary mechanism that induces ascent during landfalling ARs (Neiman
281 et al. 2009; Ralph et al. 2013). However, cumulative distribution functions of precipitation by
282 elevation for all 107 extreme events demonstrate considerable event-to-event variability in the
283 relative importance of orographic enhancement to the spatiotemporal distribution of watershed
284 precipitation (Fig. 4). Larger proportions of event-accumulated precipitation at lower elevations
285 are indicative of events where the orographic enhancement factor is diminished relative to the
286 mean distribution, whereas events with a higher proportion of precipitation at high elevations
287 indicate the event's relative dependence on topography for producing lift. The observed variability

288 is a preliminary indicator of forcing for ascent from mechanisms in addition to orographic lift,
289 possibly including dynamical and convective forcing for ascent. The 22–23 January 2017 event
290 occurred in association with an orographic precipitation distribution that was similar to the
291 composite mean, whereas the 17–18 February 2017 event exhibited a spatial precipitation
292 distribution with the weakest orographic signal in the climatology, indicating the additional
293 contributions of other lifting mechanisms. The percentage of 2-day precipitation that fell below
294 the median elevation of the watershed (derived from PRISM as 487 m) ranged from 31% to 58%
295 across all 107 events.

296 Variability in the dominance of the orographic forcing signal across extreme events is first
297 evaluated based on the IVT magnitude and its direction proximal to the Santa Ana River watershed.
298 An IVT-based polar coordinate diagram (e.g. Hecht and Cordeira, 2017) of the 107 event 2-day
299 precipitation totals and 2-day time-integrated IVT (2-day IVT) magnitude and direction
300 demonstrate that 2-day IVT is almost exclusively from 180°-270° and has a mean orientation of
301 228° (southwesterly), which is nearly orthogonal to the basin-averaged topographic orientation
302 (Fig. 4c; quantiles are plotted to scale the large event-to-event differences in both variables for
303 clarity, while statistics are calculated on actual values). The largest precipitation events are
304 generally associated with the largest 2-day IVT magnitudes and southwesterly transport.
305 Precipitation correlates to 2-day IVT with a coefficient of 0.56 and to the component of 2-day IVT
306 that is orthogonal to basin-averaged aspect with a coefficient of 0.62. These correlations are
307 sensitive to the synoptic conditions driving individual events.

308 AR conditions (defined here as features of IVT $> 250 \text{ kg m}^{-1} \text{ s}^{-1}$ and length $> 2000 \text{ km}$; based
309 on Rutz et al. 2014) were present in 67% of all 107 extreme events, and a closed-low (defined here
310 as an area of low 500-hPa geopotential height with a distinct center of cyclonic circulation that can

311 be completely encircled by one or more height contours; Oakley and Redmond, 2014) within 10°
312 of the Santa Ana was present in 35% of 107 events (e.g. the February 2017 event) (Table 1). At
313 least one of these features was present in 84% of all extreme events. While closed lows in
314 proximity to the watershed typically exhibited reduced IVT, additional dynamical mechanisms for
315 ascent (discussed in Sections 3.2 and 3.3) likely augmented event precipitation. Events that
316 consisted of an AR and no closed-low proximal to the Santa Ana (e.g. the January 2017 event)
317 demonstrated a higher correlation between 2-day precipitation and 2-day upslope IVT (coefficient
318 of 0.67), a more westerly orientation and a 10% increase in precipitation relative to the 107-event-
319 mean. The 20 (18) events featuring a closed-low and meeting (not meeting) AR conditions
320 demonstrated a decreased correlation coefficient of 0.48 (0.57), a more southerly orientation and
321 a 3% (13%) decrease in precipitation relative to the mean.

322 Results in Table 1 must be interpreted with caution, as the number of samples is small.
323 However, the apparent modification of the relationship between precipitation and 2-day upslope
324 IVT in varying synoptic conditions motivates an in-depth analysis of the physical mechanisms that
325 generated precipitation in extreme events in subsequent sections. It is worth noting that our isolated
326 focus on extreme events is a fundamental distinction relative to previous studies that showed a
327 strong relationship between IVT direction and precipitation accumulation (e.g. Hecht and
328 Cordeira, 2017). Additionally, the results presented here, based on CFSR and PRISM, cannot be
329 directly compared to previous research that identified a stronger relationship between precipitation
330 and storm-total upslope moisture flux in coastal Northern California using *in-situ* and remotely
331 sensed observations (correlation coefficient of 0.86; Ralph et al. 2013), though the weaker
332 relationship observed in Southern California is consistent with Rutz et al. (2014; their Fig. 2a).

333

334 *b. Instantaneous precipitation*

335 NEXRAD radar reflectivity analyses from KSOX illustrate that the January event contained
336 a maximum in reflectivity over the foothills of the San Bernardino Mountains at the western extent
337 of the watershed (Fig. 5). The location of maximum precipitation is consistent with inferred
338 upslope moisture flux during the landfalling AR (Ralph et al. 2004, Nieman et al. 2009) and that
339 shown in the event-averaged spatial precipitation distribution in Fig. 4a. Contrastingly, the
340 February event contained a convective narrow cold-frontal rainband (NCFR; Houze et al. 1976;
341 Hobbs et al. 1982; Koch and Kocin, 1991) that propagated onshore and produced maximum rain
342 rates away from topography (Fig. 5b). The most intense precipitation rates in extratropical
343 cyclones are often associated with NCFRs, which are aligned parallel to the cold front and warm
344 sector moisture transport (Hobbs and Persson, 1982). The advancing cold front has a component
345 of motion toward the warm sector that penetrates beneath conditionally unstable prefrontal air and
346 drives the release of potential instability (Geerts and Hobbs, 1995). The convective precipitation
347 associated with the NCFR in the February event is the primary reason for the comparative
348 weakening of the orographically dominated precipitation signal in the cumulative distribution plot
349 (Fig. 4b), although orographic forcing still played an important role in producing event-total
350 precipitation, as inferred from the radar (Fig. 5b).

351 The influence of orographic and NCFR processes on precipitation during the February event
352 is further illustrated by 5-min resolution precipitation accumulation observations from KLGB
353 during the two events (Fig. 5c). While the January event featured a precipitation rate of 2–3 mm
354 (5 min)⁻¹ associated with orographic precipitation during the period of maximum IVT associated
355 with AR landfall, the February event featured a precipitation rate of ~6 mm (5 min)⁻¹ associated
356 with the passage of the NCFR that resulted in a 30-minute period that produced approximately

357 50% of the event total precipitation. Event differences in precipitation processes, and subsequent
358 differences in precipitation distributions within the watershed, are important for both water
359 management and hazard mitigation in Southern California.

360

361 **3.2 Mesoscale forcing of precipitation**

362 Spatial and vertical gradients in equivalent potential temperature (θ_e) are used to
363 investigate whether instability played a role in precipitation generation in case studies (Fig. 6) as
364 well as in the climatology of extreme events (Fig. 7). At the time of event-maximum IVT over the
365 watershed, the January event featured an AR with a positive 1000–850 hPa θ_e gradient that implied
366 potential stability and contrasted with the less potentially stable gradient (i.e. moist-neutral profile)
367 observed during the February case (Fig. 6). Given the February event was nearly moist-neutral, it
368 was also not strongly statically unstable; surface-based convective available potential energy
369 (CAPE) values were below 150 J kg^{-1} (not shown). Importantly, low CAPE values do not preclude
370 convection in environments with additional dynamical forcing. In this case, the development of
371 convection leading to the NCFR likely occurred in association with forced ascent of the moist air
372 ahead of the cold front, as determined by the co-location of a corridor of enhanced mid-
373 tropospheric ascent (Fig. 6d) with a region of lower-tropospheric frontogenesis (Fig. 6f) along the
374 IVT maximum entering the watershed. Here, frontogenesis is calculated using the Petterssen
375 (1936) frontogenesis equation. The along-front parallel structure of these two features and across-
376 front displacement suggests a northwesterly tilt of the frontal circulation with height, which would
377 suggest a shallow thermally direct ageostrophic circulation capable of providing enhanced low-
378 level forcing for ascent of moist air in the region of the NCFR (Markowski and Richardson, 2010).

379 The climatology of 1000–850 hPa θ_e gradients in 107 extreme events indicates that the
380 majority of events contain profiles that are moist-neutral at the time of maximum IVT entering the
381 watershed and statically stable environments (Fig. 7d). Thus, to determine whether differences in
382 the synoptic conditions of individual events influence their development of non-orographic
383 mesoscale vertical motions, the strongest negative vertical velocity (i.e., upward vertical motion;
384 ascent) at 600 hPa over the region of enhanced IVT magnitudes $\geq 250 \text{ kg m}^{-1} \text{ s}^{-1}$ upstream of the
385 Santa Ana River watershed (boxed region in Fig. 7a) for each event was correlated with the 500-
386 hPa geopotential height, IVT magnitude and 1000–850 hPa θ_e gradients at each grid point in the
387 domain (Figs. 7a,b). The correlation analysis illustrates that stronger ascent upstream of the Santa
388 Ana River watershed correlates with lower geopotential heights and higher IVT magnitudes
389 proximate to the composite upper-level trough and corridor of enhanced IVT along the AR,
390 respectively (cf. Figs. 2 and 7a,b). Note that stronger ascent does not correlate with an increase in
391 IWV (not shown); thus stronger ascent correlated with enhanced IVT requires an associated
392 increase in the strength of the low level winds in the AR. Additionally, it does appear that the
393 cyclonic curvature of the region of significant correlation with IVT magnitude likely occurs in
394 association with a more southerly-oriented corridor of enhanced IWV.

395 Stronger ascent is not correlated with enhanced potential instability as quantified by
396 correlation with the 1000–850 hPa θ_e gradient (Figs. 7a), and profiles of θ_e (Fig. 7d). These results
397 indicate that enhanced ascent likely occurs in association with dynamical processes that both
398 influence IVT in the AR and contribute to the release of potential instability (Fig. 7b). Notably,
399 correlation of the maximum calculated frontogenesis value within the upstream box to the 500 hPa
400 geopotential height, IVT and 600 hPa vertical velocity fields for all cases indicates the influence
401 of frontally-forced ascent of AR moisture in the climatology of extreme events (Fig. 7c).

402 The probable cause of the mesoscale forcing for vertical motion in these events is also
403 evaluated using composite differences between groups of events with strong and weak orographic
404 precipitation signals (Fig. 8). This analysis is derived from categorization of events based on the
405 10th and 90th percentiles of the percentage of basin precipitation falling below the median elevation
406 of the watershed in each event (36% and 50%, respectively; Fig. 8a). Composite analysis of the
407 differences between the 11 events with the least orographic-enhanced precipitation signal (i.e.
408 events with the largest percentage precipitation accumulation below the watershed's median
409 elevation) and the 11 events with the most orographic-enhanced precipitation signal (i.e., events
410 with the smallest percentage precipitation accumulation below the watershed's median elevation)
411 illustrates that 500-hPa geopotential heights are lower in the region of the upper-level trough west
412 of Southern California in events with the least orographic-enhanced precipitation (Fig. 8b). The
413 concurrent IVT magnitude does not contain significant differences upstream of the watershed
414 between categories, but is significantly larger over the southwest U.S. in the events with more
415 orographic-enhanced precipitation (Fig. 8c). This result is possibly attributable to the lack of a
416 dynamical mechanism to precipitate moisture from the flow, as evidenced by the shallower trough
417 and significant reduction of upstream ascent (Fig. 8d). Furthermore, these mechanisms are
418 consistent with the case study analysis shown in Fig. 6d; the 17–18 February 2017 event contained
419 a comparatively deep and proximal upper-level trough associated with cyclogenesis, strong ascent
420 over the cold-frontal boundary, and the largest proportion of precipitation below the watershed's
421 median elevation.

422

423 **3.3 Synoptic-scale forcing of precipitation**

424 The aforementioned mesoscale convection and precipitation differences over the Santa
425 Ana River watershed also appear to be influenced by differences in the synoptic-scale flow patterns
426 associated with each event (as discussed in Section 3.1 and illustrated in Fig. 6). The synoptic-
427 scale flow patterns include differences across each case study in the locations of the low-pressure
428 centers (Figs. 9a,b), locations of upper-tropospheric jet streak wind maxima relative to the Santa
429 Ana River watershed (Figs. 9c,d), and 500-hPa trough wavelengths and tilt upstream of the Santa
430 Ana River watershed (Figs. 9e,f). Concomitant differences in synoptic-scale forcing for ascent
431 associated with these different flow patterns can be described by QG theory and related dynamics
432 associated with QG forcing for ascent.

433 For example, the juxtaposition of the Santa Ana River watershed with the dynamically
434 unfavorable region for QG forcing for ascent beneath (1) the anticyclonic shear side of the upper-
435 tropospheric jet streak (Fig. 9c) and (2) a location of weak (or zero) inferred differential cyclonic
436 vorticity advection by the geostrophic wind (Fig. 9e) during the January event likely produced
437 weak synoptic-scale upward vertical motion and little-to-no synoptic-scale precipitation at the time
438 of maximum IVT. Alternatively, the juxtaposition of the Santa Ana River watershed with the
439 dynamically favorable region for QG forcing for ascent beneath (1) the exit region of the
440 cyclonically curved upper-tropospheric jet streak during the February event (Fig. 9d) (Beebe and
441 Bates, 1955; Carlson, 1998) and (2) a location of inferred differential cyclonic absolute vorticity
442 advection by the geostrophic wind (Fig. 9f) during the February event likely produced modest
443 synoptic-scale upward vertical motion and precipitation in addition to orographic forcing. These
444 inferences are supported by GOES infrared satellite imagery (Fig. 10), which illustrate shallow
445 cloud top temperatures of ~ 250 K (~ 6 km altitude, based on the Vandenberg Sounding on that day)
446 in the region of unfavorable QG forcing for ascent during the January event, with low clouds

447 upstream of the watershed (Fig. 10a), and broad deep cloud top temperatures of ~ 230 K (~ 9.2 km
448 altitude based on the Vandenberg Sounding on that day) in the region of favorable QG forcing for
449 ascent during the February event (Fig. 9b). Note that just because these analyses reveal an
450 unfavorable environment for synoptic-scale forcing for ascent does not imply a lack of observed
451 upward vertical motion; both events contained upward vertical motion at 600 hPa at the time of
452 maximum IVT, although ascent in the January event was considerably weaker and spatially limited
453 (Fig. 6).

454 The aforementioned implied differences in QG forcing for ascent can be summarized and
455 quantified by the Q-vector and its divergence (Hoskins et al. 1978, 1980). At the time of maximum
456 IVT, the Santa Ana River watershed was located beneath a region of Q-vector divergence during
457 the January event (Fig. 11a) and beneath a region of Q-vector convergence during the February
458 event (Fig. 11b). The Q-vector analyses can also demonstrate an important linkage between the
459 synoptic scale and mesoscale. For example, if the orientation of the Q-vector points toward warmer
460 potential temperatures offshore and upstream of the Santa Ana River watershed during the
461 February event, it would portend a frontogenetic thermally direct ageostrophic circulation in the
462 plane of the lower-tropospheric front (Funk, 2011). The rising branches of these ageostrophic
463 circulations and regions of frontogenesis are known to produce banded precipitation structures in
464 conjunction with the release of potential instability, particularly in deepening baroclinic systems
465 (Markowski and Richardson, 2010). Frontogenesis in the region of enhanced IVT confirms that
466 this process played a key role in the development of the observed NCFR during the February event
467 (Fig. 6f) and the lack of a “normal” orographic precipitation gradient as compared to climatology
468 (Fig. 4b). The temporal evolution of Q-vector divergence for a single gridpoint over the Santa Ana
469 watershed displays a maximum in synoptic forcing for ascent at the time of maximum IVT over

470 the watershed in the February event (Fig. 11c). Contrastingly, the evolution of synoptic forcing in
471 the January event demonstrates sustained divergence over the course of the event with a maximum
472 at the time of maximum IVT.

473 While both events featured enhanced IVT associated with a landfalling AR, these results
474 suggest that events with precipitation distributions that feature a weaker orographic signal may
475 preferentially occur in association with synoptic-scale flow patterns defined by amplified mid-
476 tropospheric flow, strong QG forcing for ascent and upward vertical motion proximal to the AR
477 that may contribute to dynamical forcing of precipitation (Figs. 7-9 and 11). Alternatively,
478 precipitation distributions that feature a stronger orographic signal may preferentially occur in
479 association with synoptic-scale flow patterns defined by more zonal mid-tropospheric flow, QG
480 forcing for descent and downward vertical motion proximal to the AR, without dynamical forcing
481 contributions to precipitation processes (Fig. 7-9 and 11). Q-vector composite differences between
482 the weak and strong orographic precipitation distribution events also support this theory. Although
483 we do not attempt to quantify the contribution of individual mechanisms to event-total
484 precipitation, it is important to acknowledge the numerous factors that influence the precipitation
485 distribution.

486

487 **4. Conclusions**

488 Southern California water resources are dependent on a small number of extreme
489 precipitation events each winter season, which dictate the highly-variable interannual
490 accumulations of the region. In the Santa Ana River watershed, 107 extreme events contributed
491 nearly half of total precipitation between 1981 and 2017. Two-thirds of these extreme events
492 occurred in association with landfalling ARs, though all events featured enhanced moisture

493 transport into the watershed. The synoptic-scale conditions and precipitation mechanisms
494 associated with these events were highly variable. The influence of orographic lift, dynamical
495 forcing for ascent and convective instability on precipitation were evaluated from an “ingredients-
496 based” approach. While terrain-normal water vapor flux explains a majority of the observed
497 precipitation variance during landfalling ARs, in general, the variance amongst extreme events in
498 the Santa Ana River watershed may also be strongly influenced by large-scale dynamics that
499 support the development of non-orographic and convective precipitation. Understanding event-to-
500 event differences in precipitation processes and their influence on precipitation distributions within
501 the watershed is important for both water management and hazard mitigation in Southern
502 California.

503 Extreme events that had comparatively near-shore upper-tropospheric troughs and
504 associated QG forcing for ascent (as evidenced by the February case study) supported precipitation
505 distributions with apparently weak elevation dependence. Events characterized by synoptic-scale
506 forcing for ascent and convective precipitation reduced the dominant influence of the orographic
507 forcing signal on observed precipitation. Based on case study analysis, QG forcing for ascent in
508 one such event produced synoptic-scale upward vertical motion upstream of the Santa Ana River
509 watershed and generated frontally forced mesoscale convection. An important subject of future
510 work will be the use of *in-situ* and remotely sensed meteorological observations in Southern
511 California to better characterize the influence of different synoptic and mesoscale forcing
512 conditions on physical processes, such as the relationship between storm-total upslope moisture
513 flux and precipitation (e.g. Ralph et al. 2013). This study also motivates future work on identifying
514 whether or not NCFR are common features of landfalling ARs that can produce large precipitation
515 rates in addition to orographic precipitation. Oakley et al. (2017) found that development of

516 convection along the NCFR contributes significantly to hazards related to post fire debris flows in
517 Southern California.

518 Variability in the location, duration and intensity of precipitation, related to the interaction
519 of moisture transport with topography and the dynamics of the synoptic-scale flow, has not been
520 investigated previously. This work is an important first step in identifying additional mechanisms
521 for precipitation during landfalling ARs, including an evaluation of Q-vector divergence fields
522 over enhanced moisture transport. These results are also useful for understanding how landfalling
523 ARs develop mesoscale convective features that are associated with high-intensity precipitation
524 rates related to the NCFR and related hazards (e.g. Oakley et al. 2017). The ability to identify these
525 conditions through frontogenesis calculation, as performed here, may aid situational awareness
526 and forecast skill without explicitly resolving convection in a mesoscale model.

527 A notable caveat of this work is the simplified approach to evaluating the events based on
528 the time of maximum IVT over the watershed, which typically corresponds to the maximum
529 precipitation accumulation, but does not account for pre-AR or post-AR (i.e., post-frontal)
530 precipitation. Many of the extreme events feature post-frontal shallow convective precipitation,
531 which can produce heavy rainfall rates and additionally contribute to or exacerbate hazards such
532 as flooding and post-fire debris flows (Oakley et al. 2017). However, the research presented here
533 is focused on precipitation processes during landfalling ARs, and analyzing the full evolution of
534 individual events is beyond the scope of the current work. Additionally, mesoscale model
535 simulations are necessary to evaluate the evolution of forced convection along fronts, orographic
536 precipitation, and the microphysical properties that contribute to variability in the event-to-event
537 precipitation distribution (Martner et al. 2008).

538

539 Acknowledgements

540 This research was supported by the National Aeronautics and Space Administration
541 (NASA) grant NNX14AD77G. Any opinions, findings, and conclusions or recommendations
542 expressed in this publication are those of the authors and do not necessarily reflect the views of
543 NASA. Additional support was provided by the Orange County Water District and the U.S. Army
544 Corps of Engineers (USACE) as part of Forecast Informed Reservoir Operations (FIRO) under
545 grant W912HZ-15-2-0019. The NCEP–CFSR data used in this research were developed by the
546 NOAA (<https://rda.ucar.edu/datasets/ds093.0/>). NEXRAD Radar data were developed by the
547 NOAA National Weather Service (NWS) and are accessible through the National Center for
548 Environmental Information (NCEI; <https://www.ncdc.noaa.gov/data-access/radar-data>). Station
549 precipitation data used in this research are also available through NCEI
550 (<https://www.ncdc.noaa.gov/data-access/land-based-station-data>). PRISM data are provided by
551 the PRISM Climate Group at Oregon State University (www.prism.oregonstate.edu).

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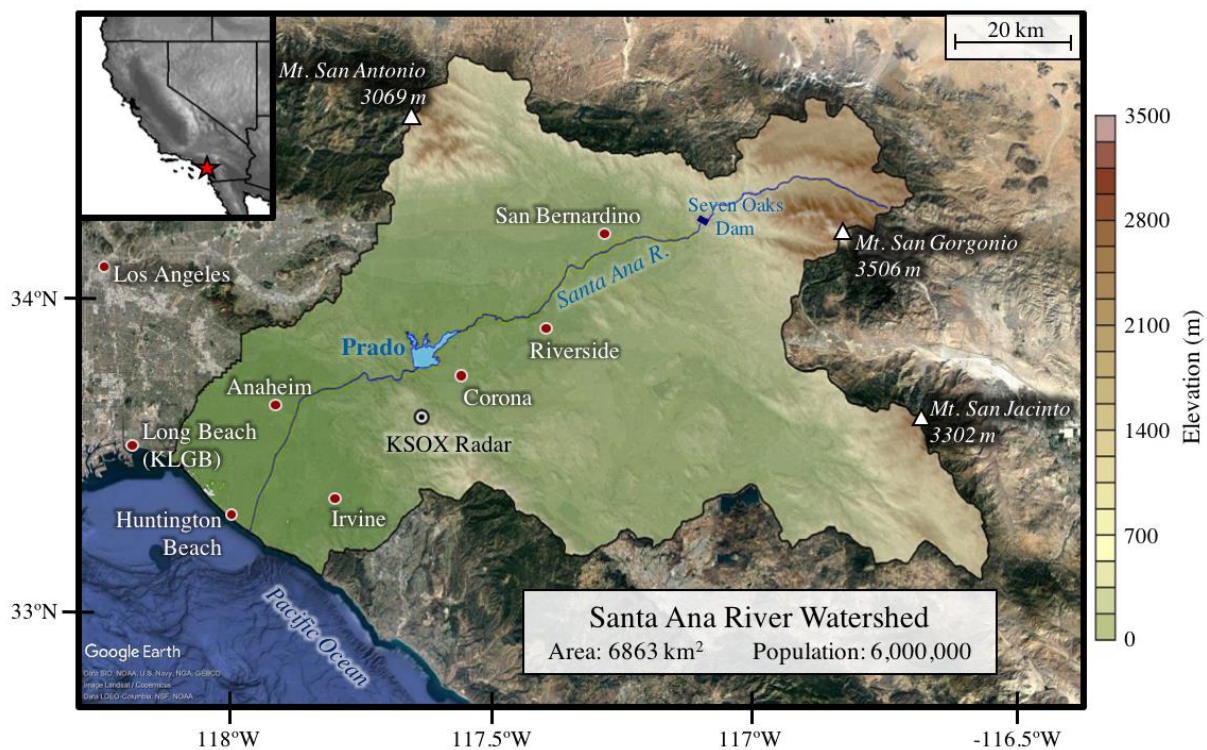
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657 **Tables**
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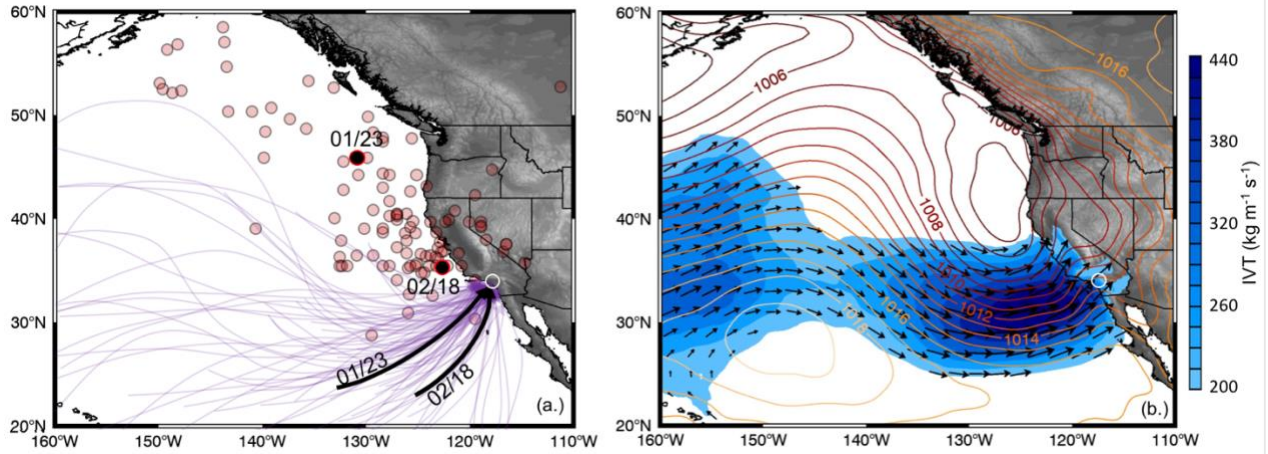
	All	AR	Closed Low	AR w/o Closed Low	Closed Low w/o AR	AR and Closed Low	No AR and No Closed Low
Number of Events	107	72	38	52	18	20	17
Percentage of Events	100	67%	36%	48%	17%	19%	16%
% of Average Precipitation	22.1(mm)	106%	92%	110%	87%	97%	88%
% of Average 2-day IVT	3.9×10^7 (kg m ⁻¹)	112%	89%	115%	70%	106%	79%
Average Direction of 2-day IVT	228°	229°	212°	236°	215°	210°	238°
Correlation (Precip, 2-day IVT)	0.62	0.62	0.48	0.67	0.57	0.49	0.47

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 661 **Table 1:** The number 107 extreme events that demonstrated; AR conditions, a closed-low within
 662 10° of the Santa Ana, the combination of those features, or the absence of both. The average
 663 precipitation and 2-day IVT direction are given relative to the 107-event mean. Average 2-day
 664 IVT direction and the correlation between precipitation and the upslope component of 2-day IVT
 665 are also listed for each event category.
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668 **Figures**
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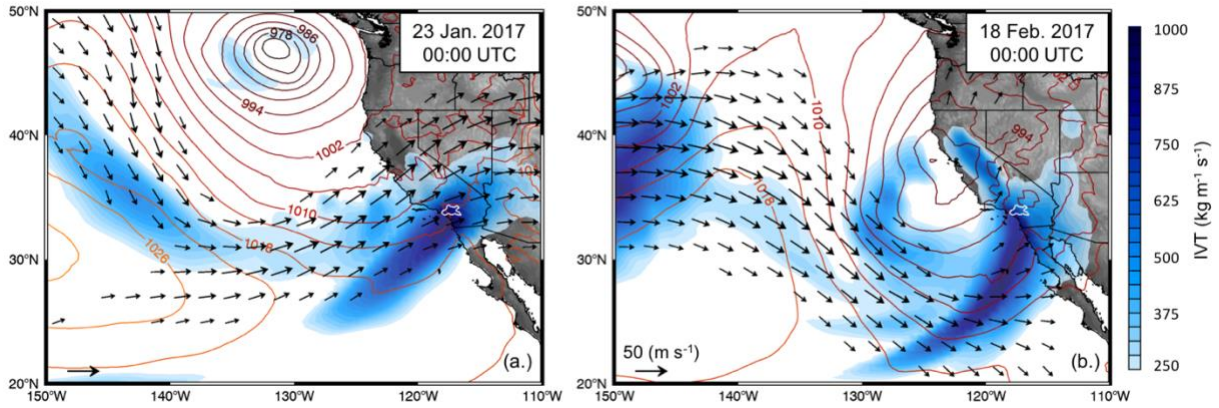


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672 **Figure 1:** Topographic map of the Santa Ana River watershed study region. Watershed statistics
673 provided by Santa Ana Watershed Project Authority (<http://www.sawpa.org/>).
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Figure 2: Schematic of surface low pressure centers and the axis of enhanced IVT magnitude for 107 extreme precipitation events at the time of event-maximum IVT over the watershed (a). The central low pressure and IVT orientation for the two case studies discussed in the text are labeled in black; the location of the watershed is circled in white. Composite sea level pressure (hPa; red contours) and IVT magnitude ($\text{kg m}^{-1} \text{s}^{-1}$; shading) and IVT vectors (plotted for magnitude $> 150 \text{ kg m}^{-1} \text{s}^{-1}$) for the 107 events (b).



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Figure 3: Integrated vapor transport ($\text{kg m}^{-1}\text{s}^{-1}$; shaded) sea level pressure (hPa; contour) and 250-hPa winds (m s^{-1} ; vector; plotted for magnitudes $>15\text{ms}^{-1}$) at the time of watershed maximum IVT magnitude during the 23 January 2017 case study event (a) and the 18 February 2017 case study event (b).

CONDITIONALLY ACCEPTED

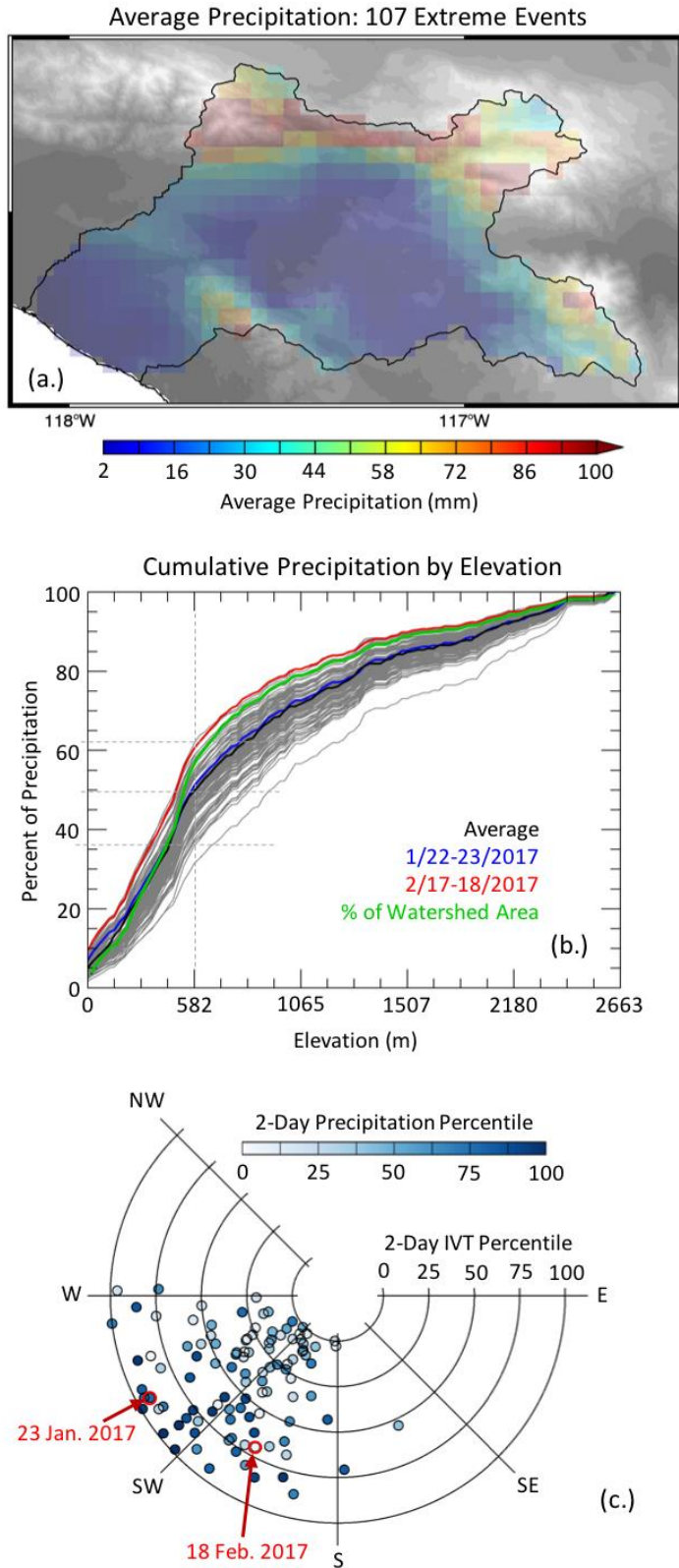
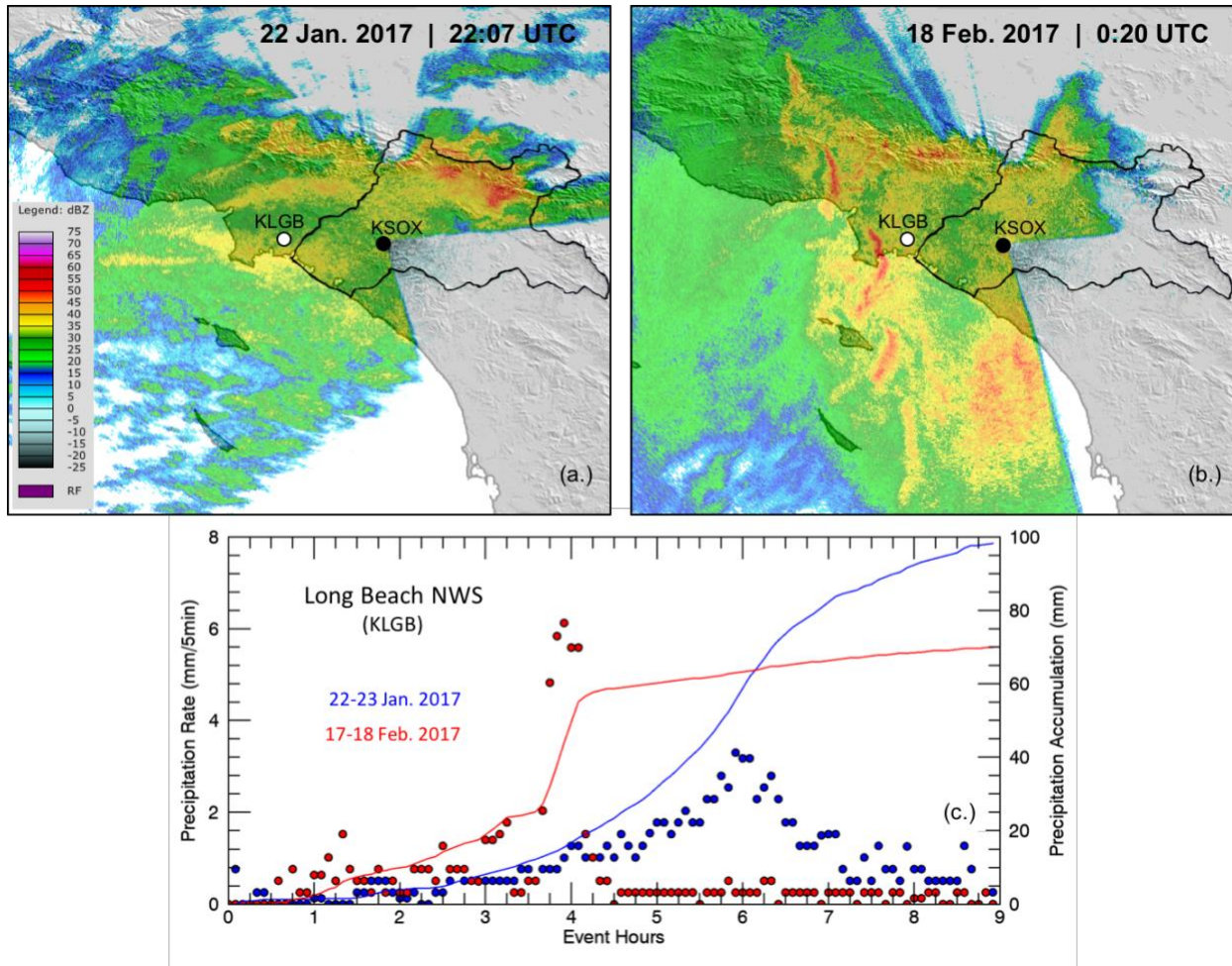
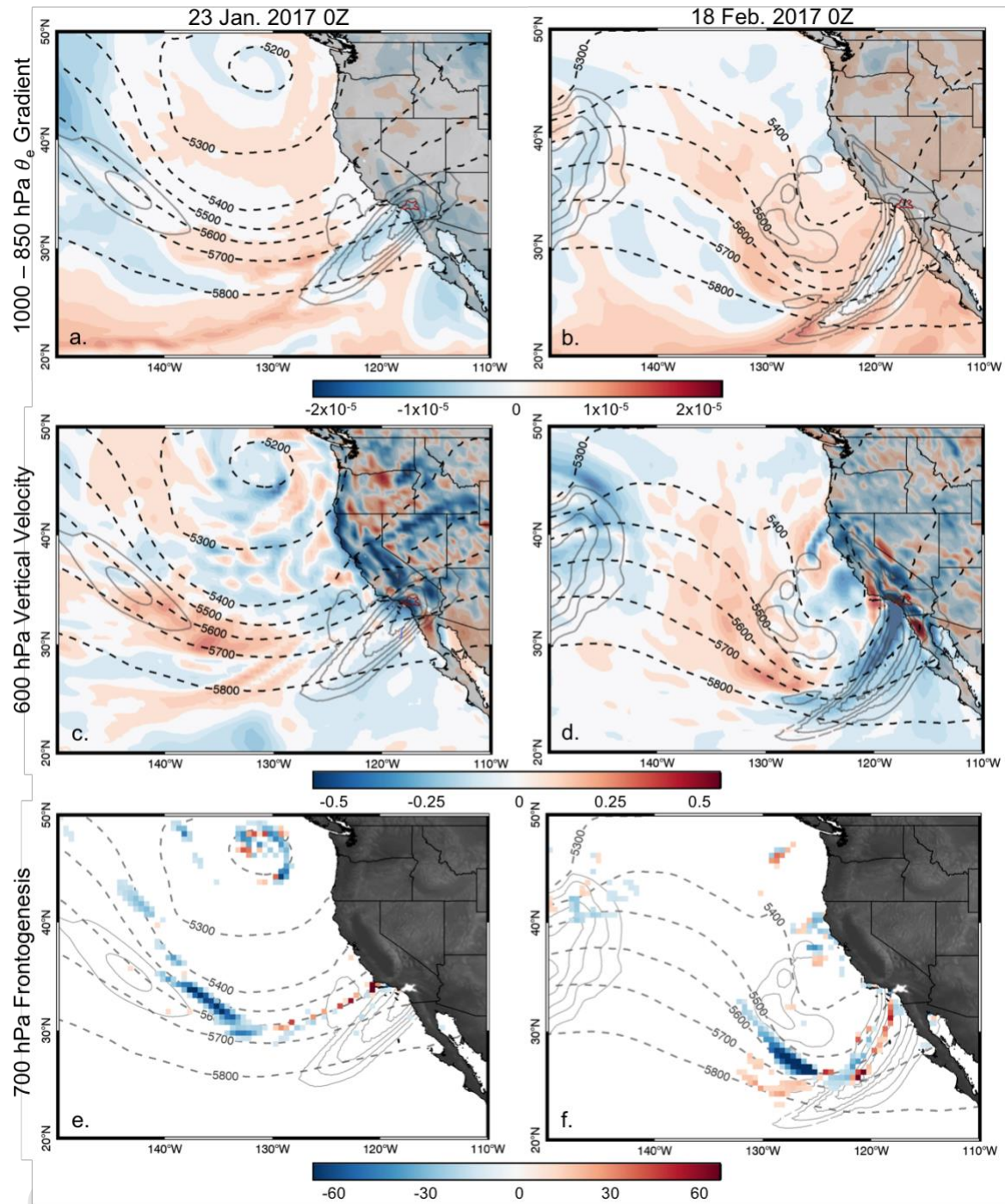


Figure 4: Average 2-day PRISM accumulated precipitation (mm; shaded) for 107 extreme events (a). Cumulative precipitation percent by elevation (b), with colors indicating each of the 2017 case study event distributions (red and blue) and percent watershed area by elevation (green; same axis as precipitation). Panel (c) shows the quantile ranking and direction of the total time integrated vapor transport over the 2-day PRISM precipitation accumulation period. Each event circle is shaded according to its precipitation ranking.



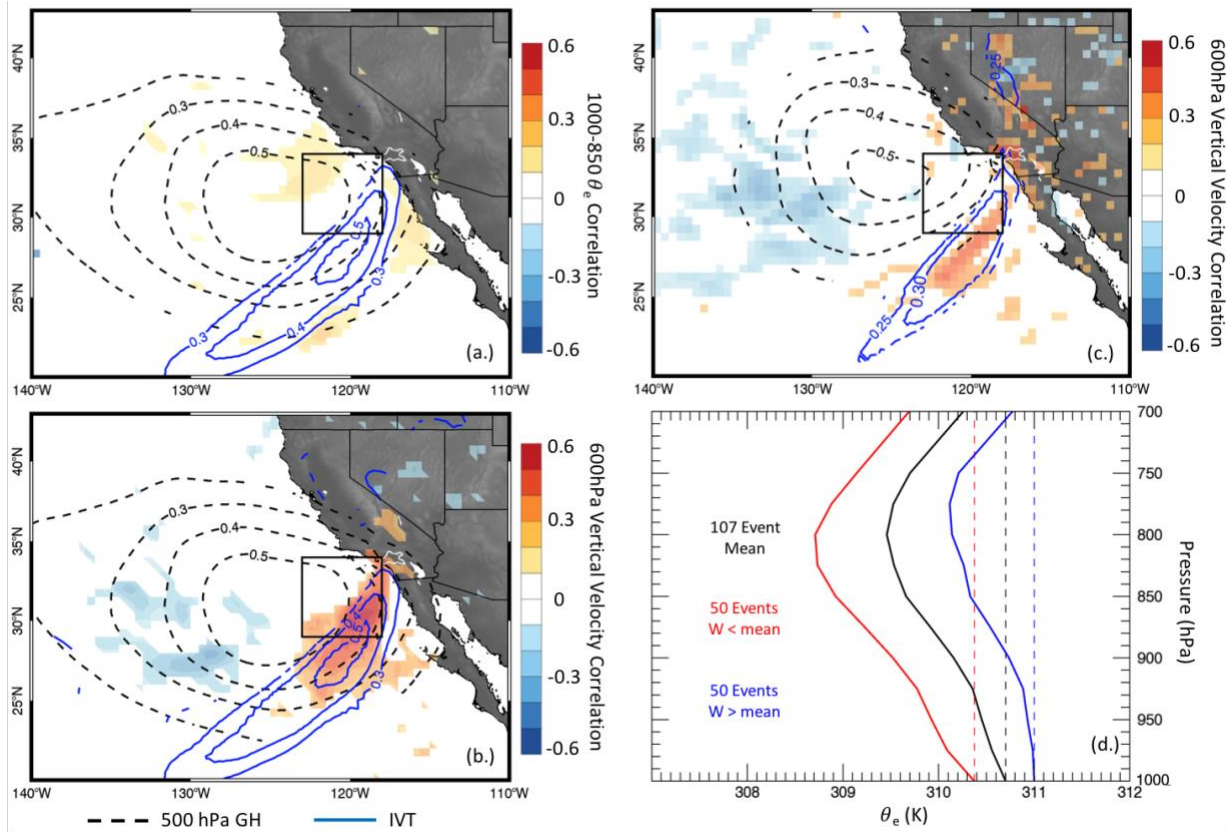
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Figure 5: Radar base reflectivity (dBz; shaded) for two case study events at the time of the maximum precipitation rate at Long Beach (KLGB), CA (a,b). Long Beach Airport NWS station precipitation rate and 9-hour event accumulation at 5-minute resolution for the two case study events (c). The January event's accumulation period begins on 22 Jan. at 17:00 UTC and the February event's accumulation period begins on 17 Feb. at 21:00 UTC.



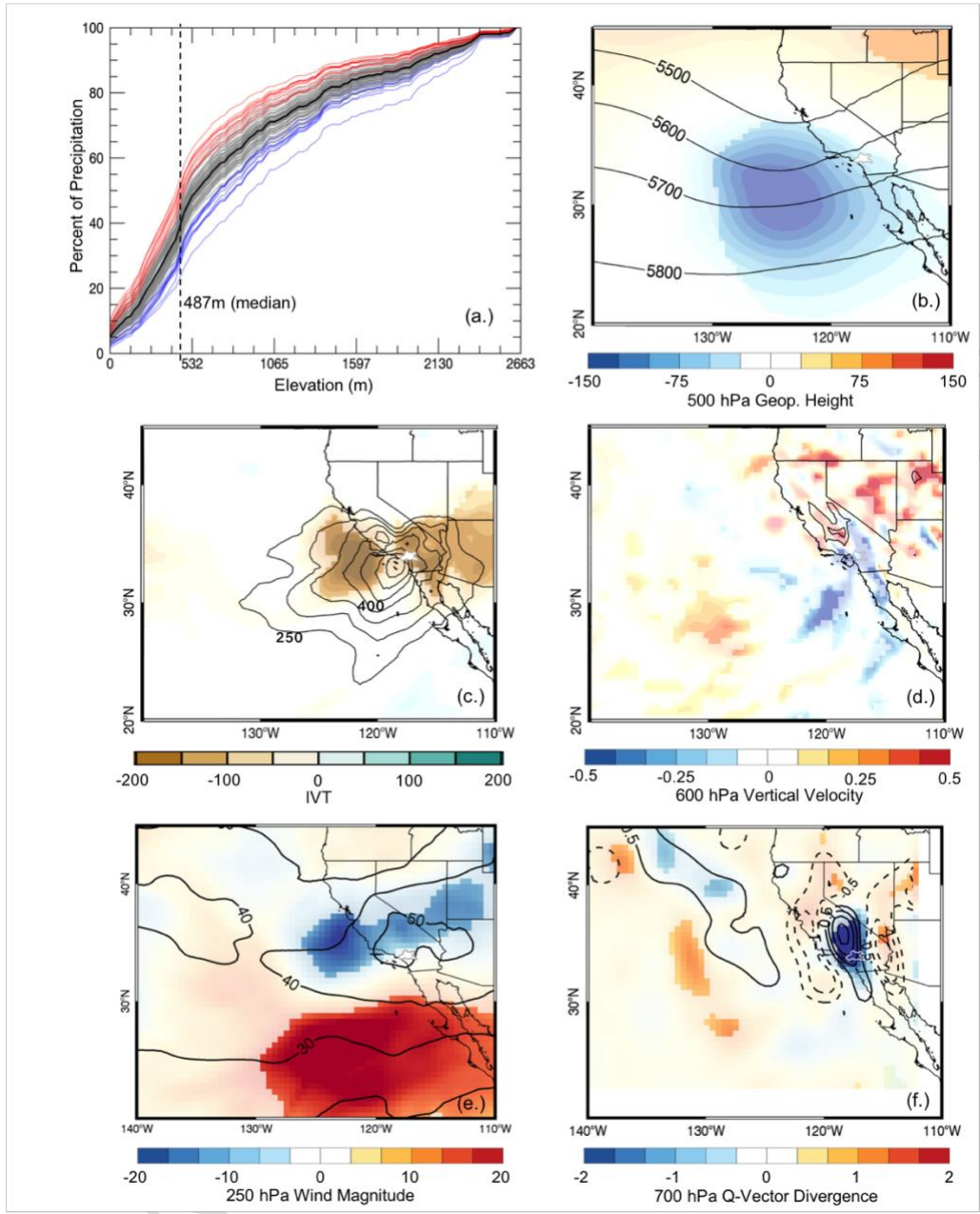
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Figure 6: 500 hPa Geopotential Height (m; dashed black contour) and IVT magnitude ($\text{kg m}^{-1}\text{s}^{-1}$; solid gray contour) at the time of watershed maximum IVT (00:00 UTC in both cases) is shown for the January event in all left column panels and the February event in all righthand panels. The 1000-850 hPa θ_e gradients (K Pa^{-1} ; shaded) (a, b), 600-hPa vertical velocity (m s^{-1}) (c, d), and 700 hPa frontogenesis ($\text{K } 100\text{km}^{-1} \text{ day}^{-1}$) (e, f) are shown in colorfill for each event.



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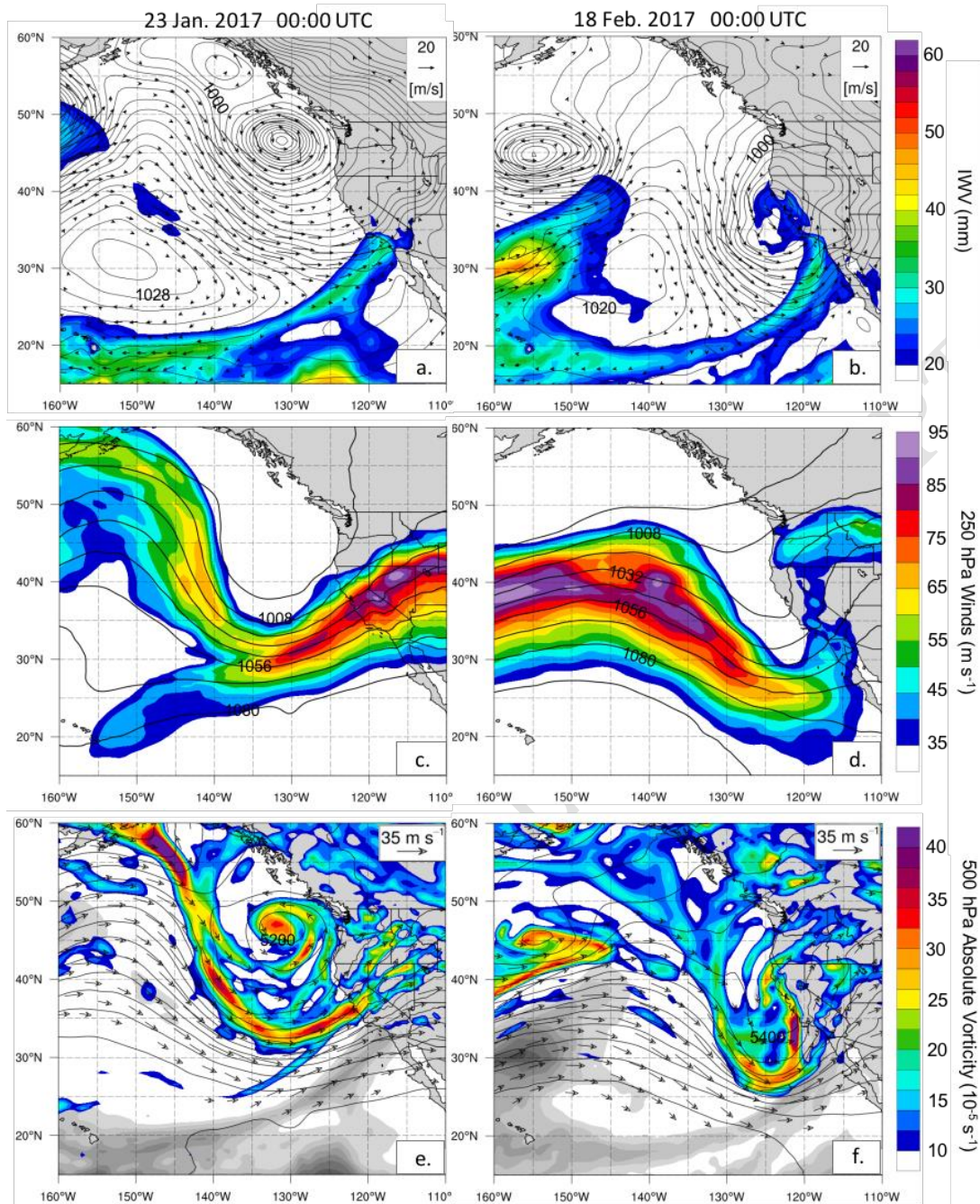
Figure 7: Correlation of 500 hPa Geopotential Height (m; dashed contour), IVT magnitude ($\text{kg m}^{-1}\text{s}^{-1}$; blue contour) and 1000-850 hPa θ_e gradients (K Pa^{-1} ; color) with minimum 600-hPa vertical velocity over regions of IVT greater than 250 within a box immediately upstream of the Santa Ana Watershed (black outline) for 107 at the time of maximum IVT (a). The same contour fields are shown in panels (b), but the color shading displays 600 hPa vertical velocity (m s^{-1} ; shaded). The correlation of those variables to maximum frontogenesis in the upstream box is shown in panel (c). Only statistically significant values are shown, based on a Monte Carlo approach for p -values < 0.05 . Panel (d) shows the average θ_e profiles (K) over regions of IVT greater than 250 $\text{kg m}^{-1}\text{s}^{-1}$ within the upstream box, categorized by the average of all events in black, and events with the strongest 600 hPa ascent in red and the weakest in blue.



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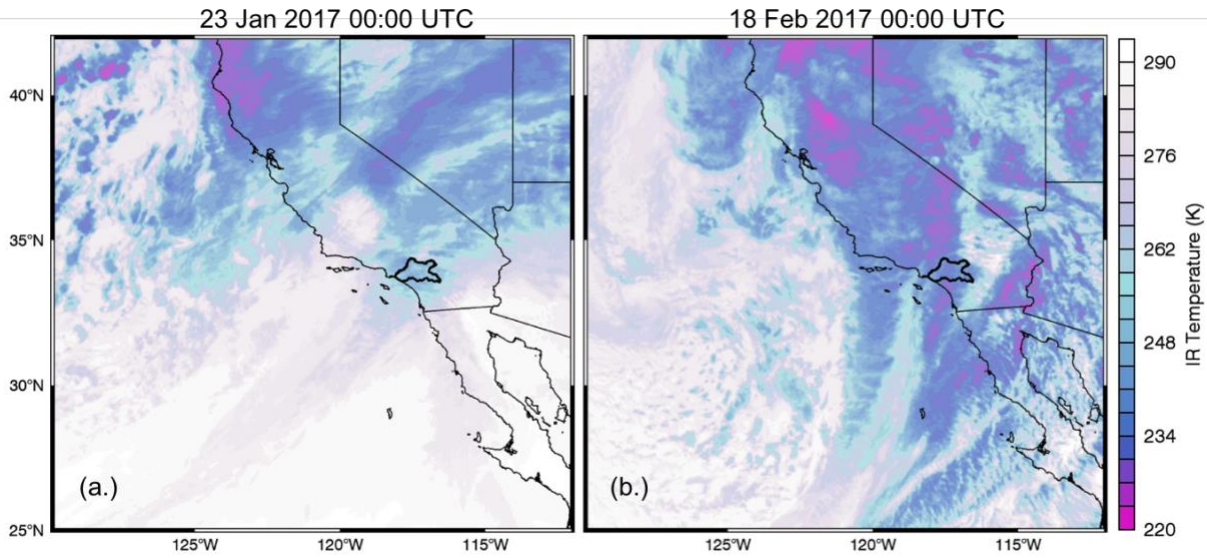
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744 **Figure 8:** Cumulative precipitation by elevation for 107 extreme events (a). Distributions with
 745 greater than 90th percentile percent precipitation below the median watershed elevation are
 746 colored red and those below the 10th are blue. Panels (b) through (f) show the composite of 10th
 747 percentile PDF events (contour) and their relative difference compared to the 90th percentile
 748 composite (color; calculated as 90th percentile minus 10th percentile), for 500 hPa geopotential
 749 height (m; b), IVT magnitude ($\text{kg m}^{-1}\text{s}^{-1}$; c), 600 hPa vertical velocity (m s^{-1} ; d), 250 hPa wind
 750 magnitude (m s^{-1} ; e), and 700 hPa Q-vector divergence ($10^{15} \text{ K m}^{-2}\text{s}^{-1}$; f) at the time of maximum
 751 watershed IVT. Non-significant values are faded white (based on a Welch's t-test; $p < 0.05$).



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Figure 9: Integrated water vapor (mm; color), sea-level pressure (contoured every 2 hPa) and 850-hPa winds (m s^{-1} ; vectors scaled according to reference vector) for the January (a) and February (b) events. 250-hPa wind speed (m s^{-1} ; shaded according to scale) and 250-hPa geopotential height (contoured every 12 dam) for the January (c) and February (d) events. 500-hPa cyclonic absolute vorticity (10^{-5} s^{-1} ; shaded according to scale), 500-hPa geopotential height (contoured ever 50 m) and 500-hPa winds (m s^{-1} ; vectors) for the January (e) and February (f) events, with IWV underlain (mm; grayshade every 4 mm starting at 20 mm). All panels are for the time of maximum IVT entering the watershed (00:00 UTC in both cases).



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Figure 10: Geostationary Operational Environmental Satellite (GOES-15) infrared cloud top temperature (K; shaded) during the period of maximum IVT over the Santa Ana watershed for the (a) January and (b) February events.

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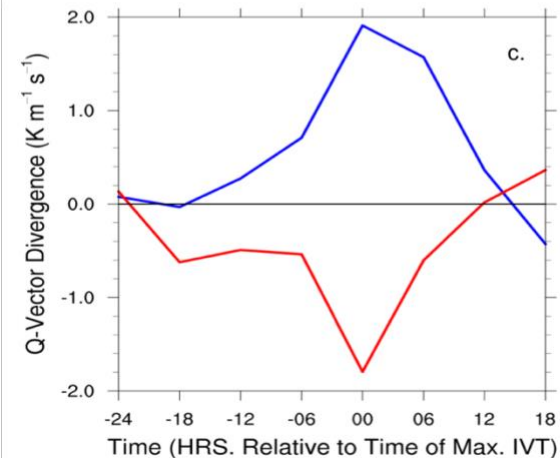
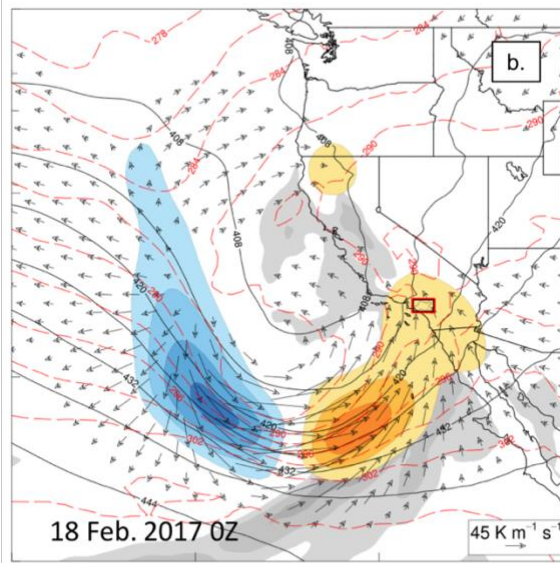
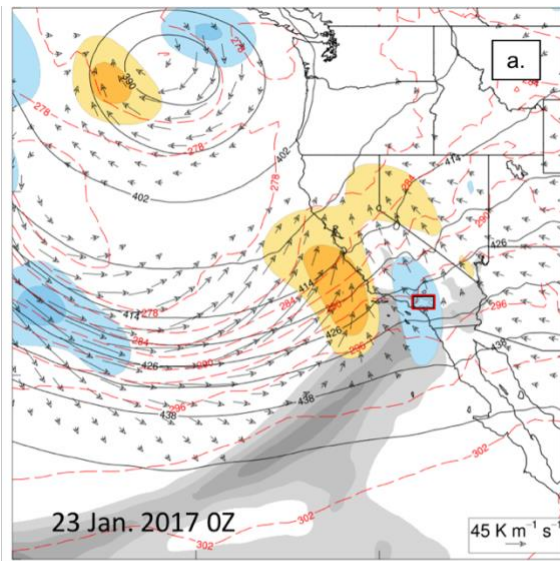


Figure 11: 700-500 hPa Q-vectors ($10^{11} \text{ K m}^{-1} \text{s}^{-1}$; vectors according to reference), Q-vector divergence ($10^{15} \text{ K m}^{-2} \text{s}^{-1}$; shaded according to scale), geopotential height (m; black contours), potential temperature (K; red contours), and integrated water vapor (mm, grayshade every 4 mm starting at 20 mm) at (a) 0000 UTC 23 January 2017 and (b) 0000 UTC 18 February 2017. A 48-hour time series of Q-vector divergence for a gridpoint covering the coastal portion of the watershed is shown for the January (blue) and February (red) events in panel (c). The 00 time step corresponds to the time of maximum IVT entering the watershed in each event.

AGENDA ITEM SUBMITTAL

Meeting Date: October 10, 2018

To: Water Issues Committee
Board of Directors

From: Mike Markus

Staff Contact: G. Woodside

Budgeted: N/A

Budgeted Amount: N/A

Cost Estimate: N/A

Funding Source: N/A

Program/Line Item No.: N/A

General Counsel Approval: Required

Engineers/Feasibility Report: N/A

CEQA Compliance: N/A

**Subject: APPROVAL OF COMMON INTEREST AND JOINT DEFENSE
AGREEMENT FOR UPPER SANTA ANA WATERSHED HABITAT
CONSERVATION PLAN**

SUMMARY

Santa Ana Watershed agencies are collaborating to develop an Upper Santa Ana River Habitat Conservation Plan (HCP). The HCP will provide the basis for agencies to secure regulatory permits for their projects that affect flow in the river and its tributaries. An agreement has been proposed that provides for the agencies to share privileged and confidential documents and also provide for a common defense if the HCP is legally challenged.

Attachment(s):

- Presentation
- Common Interest and Joint Defense Agreement

RECOMMENDATION

Agendize for October 17 Board meeting: Approve and authorize execution of Common Interest and Joint Defense Agreement for the Upper Santa Ana River Habitat Conservation Plan, subject to review as to form by General Counsel.

BACKGROUND/ANALYSIS

In 2014, water agencies in the upper watershed began a collaborative effort to prepare an Upper Santa Ana River Habitat Conservation Plan. This Habitat Conservation Plan (HCP) will be a comprehensive, regional plan to manage land and create wildlife habitat that includes most of the watershed tributary to Prado Dam, excluding the San Jacinto Watershed and Temescal Creek. Such a plan would enable participants to avoid or minimize resource conflicts that delay or prevent the completion of individual proposed water management projects. The Board approved the District's participation in development of the HCP in May 2016.

San Bernardino Valley Municipal Water District (Valley District) is taking the lead in the development of the Upper Santa Ana HCP. Other participants include Western Municipal Water District, City of San Bernardino Municipal Water Department, City of Riverside Public Utilities, San Bernardino Valley Water Conservation District, East Valley Water

District, West Valley Water District, County of San Bernardino Flood Control District, Inland Empire Utilities Agency, and the City of Rialto.

Development of the Upper Santa Ana HCP is an important effort because it provides a mechanism that allows water interests, resource agencies, and other stakeholders to address endangered species issues on a regional scale, collaboratively, and over the long-term. Together, the group can anticipate, prevent, and resolve controversies and conflict during the HCP planning process including issues associated with endangered species impacts resulting from both projects and potential conservation measures.

Completion of the Upper Santa Ana HCP will provide the basis for the upper watershed agencies to implement their water management projects. Some of these water management projects will decrease the amount of water reaching Prado Dam. In general terms, the upper watershed agencies have existing water rights from the State of California to implement the projects being evaluated in the HCP. Additionally, the 1969 Santa Ana River Judgement precludes OCWD from opposing projects upstream of Prado Dam that affect flows in the river except under limited grounds.

Approval of the HCP will facilitate agencies in the upper watershed securing permits required for their projects. Absent the HCP, recycled water and stormwater capture projects may result in removing water from the Santa Ana River at a rate that leaves insufficient water to support riparian habitat in Prado Basin and may adversely impact associated beneficial uses in Prado Basin. Additionally, the reduced river flows could adversely affect operations of the OCWD Prado Wetlands. OCWD's primary purpose for participating in the HCP is to make sure there is adequate water remaining in the river for environmental needs, including sustaining the mitigation investments OCWD has made in Prado Basin.

OCWD has invested millions of dollars in habitat and mitigation efforts in Prado Basin, and the riparian habitat managed for mitigation purposes requires sufficient flows in the river and the presence of shallow groundwater. The continued success of the cooperative water conservation program at Prado with the Army Corps of Engineers requires the continued health of riparian habitat in Prado Basin.

Summary of Proposed Common Interest and Joint Defense Agreement

The purpose of the proposed agreement is to allow the agencies developing the HCP to share confidential and privileged information among themselves. Given the possibility that development or approval of the HCP may result in litigation, the agencies are considering a proposed Common Interest and Joint Defense Agreement.

The proposed agreement, if approved, would provide an exception to what might otherwise be considered a waiver of attorney-client privilege or work product doctrine, as well as any other protections that would apply for documents and information created by the participating agencies.

Key terms of the proposed agreement include the following:

1. Common Interest. The members would join together to work cooperatively in approval of the HCP and related permits in coordination with the USFWS and other permitting agencies, and to initiate or defend themselves in any legal proceedings that may occur related to the HCP.
2. No Waiver of Legal Privileges, Doctrines or Protections. Any exchange of documents or other information between or among the members in connection with the Common Interest is not intended to waive any attorney-client privilege, attorney work product doctrine, or any other protection from disclosure to third parties that may otherwise be available. Any such written or oral communication made between or among members is and will remain privileged and protected from disclosure to any third party.
3. Covered Communications. The written or oral communications covered by the agreement include documents, memoranda, correspondence, drafts, notes, reports, factual summaries, transcript digests, communications among counsel, or counsel and a member, including its representatives.
4. Confidentiality. In addition to preserving privileged communications, the members agree that all such communications shall be kept confidential, and to take certain steps to ensure those communications are kept confidential.
5. Prohibited Sharing. No member shall disclose privileged communications without the written consent of the other members and their respective counsel, except to its representatives as set out or as may be required by applicable law.
6. Joint Defense. The parties agree to jointly defend legal challenges to the HCP and the related permits.

In the event that the District determined in the future the development of the HCP was adverse to the District's interest and decided to legally challenge the HCP, the District can withdraw from the agreement and proceed with legal action after withdrawal. Although District staff believe it is unlikely at this time, should the District determine to challenge the HCP, a potential document that could be challenged is the EIR/EIS prepared for the HCP. In a legal challenge to an EIR/EIS, the District's challenge would be based on documents in the public record as part of the EIR/EIS process. If the District was to withdraw from the agreement, documents that were shared in common interest would need to be returned per the agreement and could not be used in legal proceedings against the HCP. However, since a legal challenge to an EIR/EIS is based on documents in the public record, the District would still be able to challenge the EIR/EIS, if needed.

Staff has reviewed the proposed agreement with the District's General Counsel and General Counsel concurs with approval of the proposed agreement and has proposed some minor modifications that should further clarify the parties' intent.

Staff recommends that the Board approve and authorize execution of the Common Interest and Joint Defense Agreement for the Upper Santa Ana River Habitat Conservation Plan, subject to review as to form by General Counsel.

PRIOR RELEVANT BOARD ACTION(S)

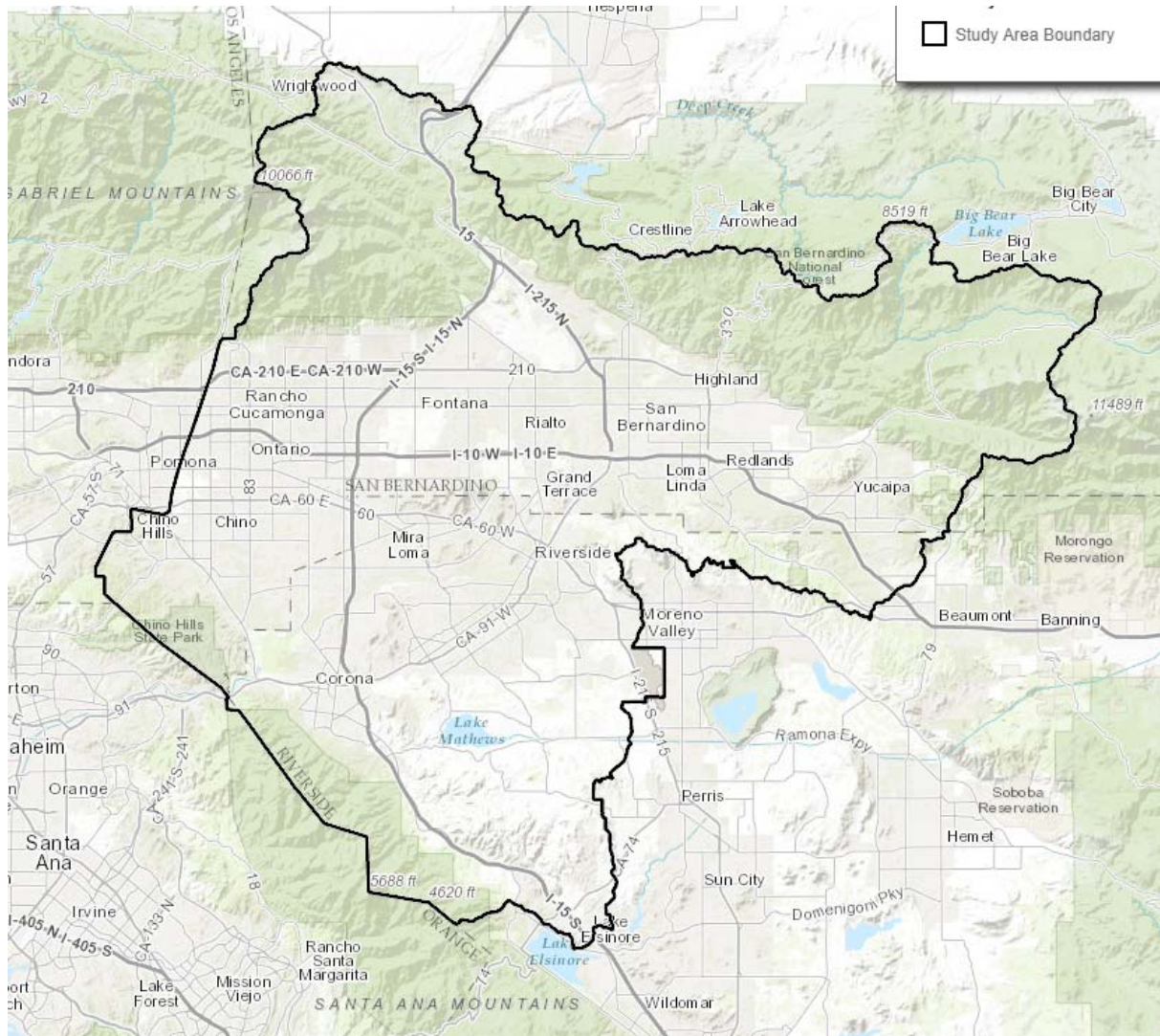
7-19-2017, R17-7-101- Approve and authorize execution of cost share agreement for Upper Santa Ana Watershed Model with San Bernardino Valley Municipal Water District, Western Municipal Water District, and Inland Empire Utilities Agency subject to approval as to form by General Counsel, and (2) authorize payment of the District's model development cost share in an amount not to exceed \$326,624 to San Bernardino Valley Municipal Water District.

5-18-2016, M16-71 - Authorize the District's participation in the Upper Santa Ana River Habitat Conservation Plan as a participating agency and funding partner and authorize payment of \$118,400 to the San Bernardino Valley Municipal Water District for the District's cost share for development of the Habitat Conservation Plan



Upper Santa Ana HCP Common Interest and Joint Defense Agreement

Water Issues Committee
October 10, 2018



Upper Santa Ana Habitat Conservation Plan (HCP) Study Area



HCP Main Components

- Covered Activities (projects and O&M)
- Covered Species
- Conservation Activities
- Incidental Take Permit



Burrowing Owl



Pond Turtle



Arroyo Toad



Southwestern Willow Flycatcher



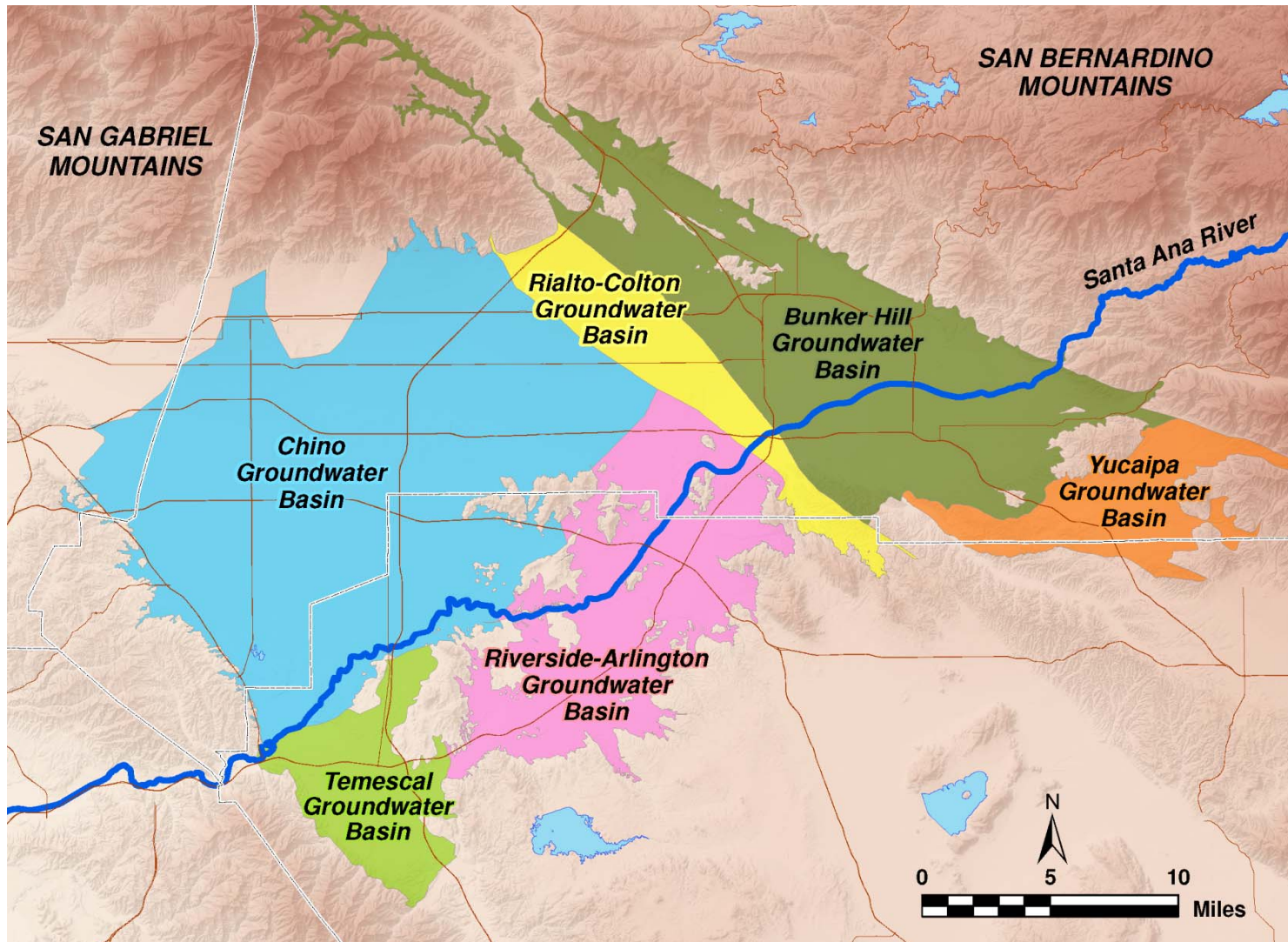
Potential Impacts to OCWD

- HCP will facilitate recycled water/storm water projects that decrease SAR flows
- Reduced flows may impact Prado Basin habitat & OCWD wetlands

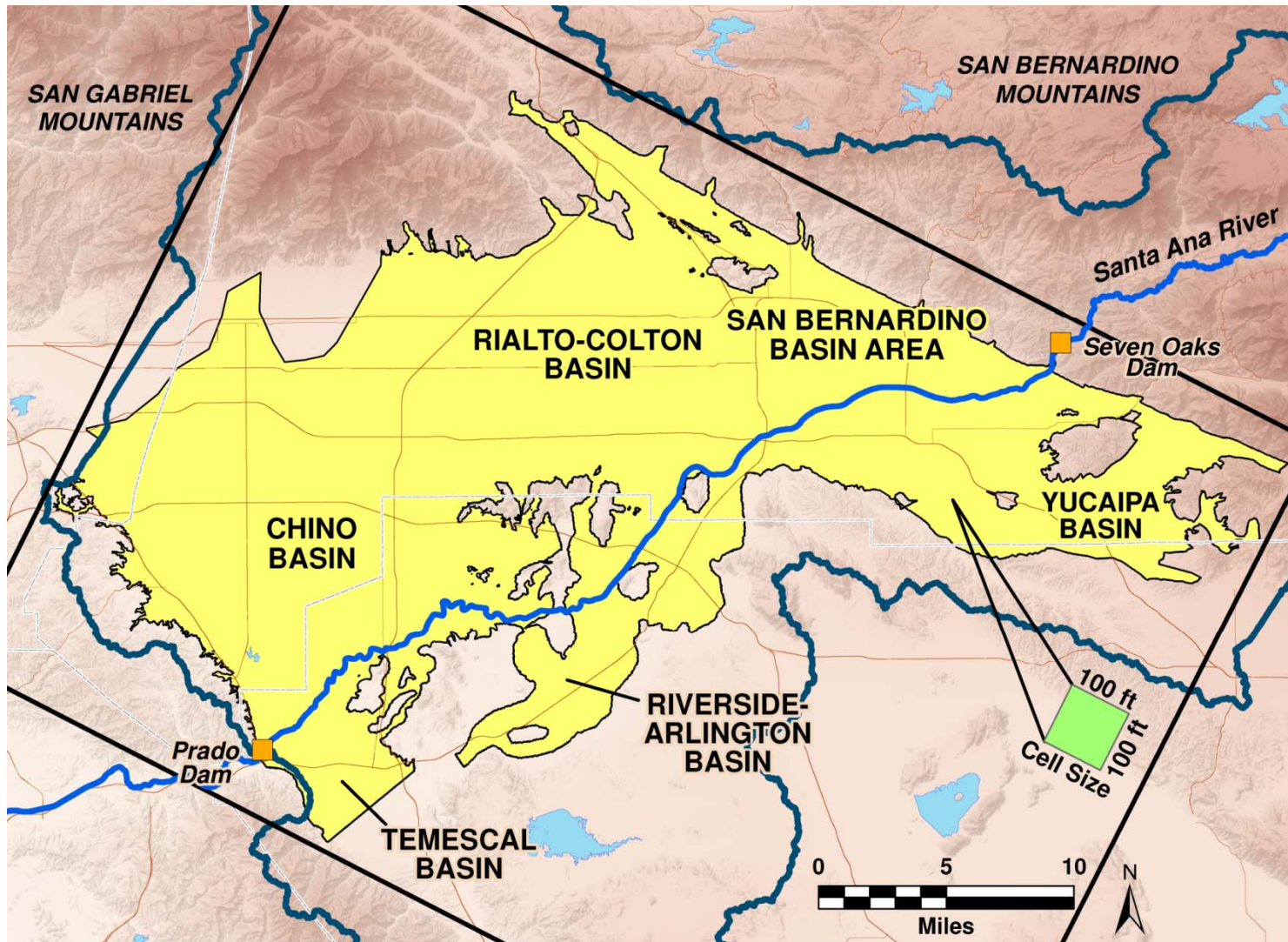


OCWD Participation in HCP

- Approved by Board in May 2016
- Active participation enables consideration of District's interests in Prado Basin:
 - Protects District's investments in habitat programs & Prado wetlands operation
 - Prado Dam water conservation with Army Corps requires maintaining healthy habitat



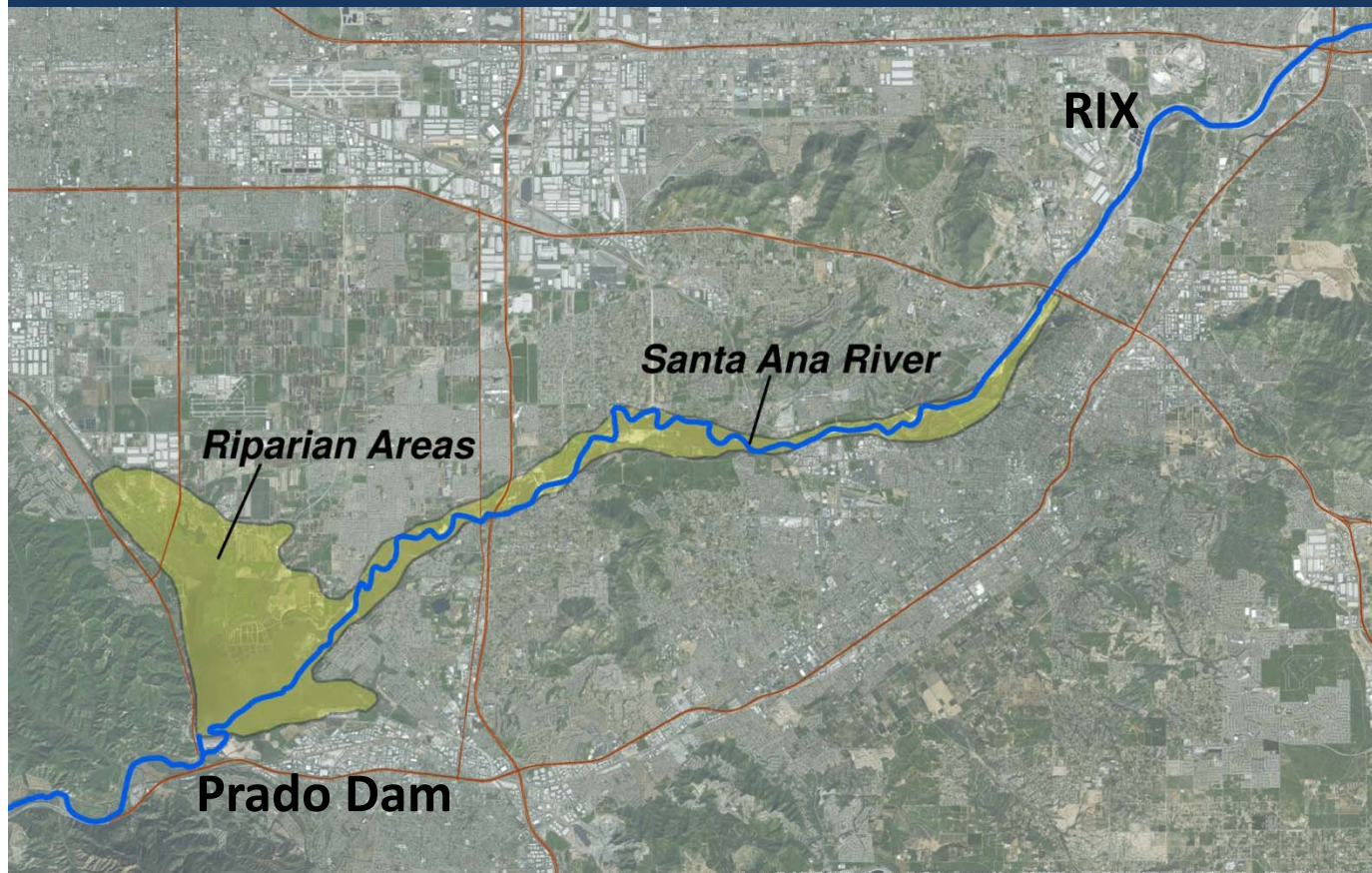
Main Groundwater Basins in Upper Watershed



New
Integrated
Model –

Merged 5
groundwater
models and
surface water
model

Integrated Model will Improve Shallow Groundwater Simulation Capabilities



- ✓ Use 1 ft contour topography to refine model's land surface in riparian vegetation area
- ✓ Account for model-calculated evapotranspiration



Common Interest and Joint Defense Agreement

- Proposed agreement provides for agencies to share privileged and confidential documents and for a common defense if HCP is legally challenged
- Parties include agencies upstream of Prado participating in HCP development



Maintain OCWD Options

- In the event District determined in the future that development of HCP was adverse to District's interest and decided to legally challenge the HCP, District can withdraw from the agreement and proceed with legal action after withdrawal.
- Although District staff believe it is unlikely at this time, should the District determine to challenge the HCP, a potential document that could be challenged is the EIR/EIS prepared for the HCP.
- In a legal challenge to an EIR/EIS, the District's challenge would be based on documents in the public record as part of the EIR/EIS process.
- Since a legal challenge to an EIR/EIS is based on documents in the public record, the District would still be able to challenge the EIR/EIS, if needed.



Staff Recommendation

Agendize for October 17 Board meeting:
Approve and authorize execution of
Common Interest and Joint Defense
Agreement for the Upper Santa Ana
River Habitat Conservation Plan,
subject to review as to form by General
Counsel.

UPPER SANTA ANA RIVER HCP

COMMON INTEREST AND JOINT DEFENSE AGREEMENT

This Common Interest and Joint Defense Agreement (“Agreement”) is entered into by and among the undersigned parties (the “Members” and each a “Member”), and their respective counsel, regarding the Members’ common interest in cooperating to secure an incidental take permit and certain other federal, state and local permits (collectively the “Permits”) for activities anticipated under a habitat conservation plan under preparation for the Upper Santa Ana River (the “USAR HCP”). The parties to this Agreement are referred to collectively as the “Common Interest Group.”

WHEREAS, the Members have joined together for the purpose of developing and implementing the USAR HCP in coordination with and securing the Permits from the U.S. Fish and Wildlife Service (“USFWS”) and other government agencies, as appropriate, such as the California Department of Fish and Wildlife, the U.S. Army Corps of Engineers, the applicable Regional Water Quality Control Board and other governmental agencies (collectively, the “Permitting Agencies”);

WHEREAS, the Members believe that issuance of the Permits and approval of the USAR HCP may result in litigation given anticipated high levels of public interest and a history of past litigation in connection with disputes associated with the use and management of the Santa Ana River;

WHEREAS, the Members wish to work cooperatively in securing the Permits and adoption of the USAR HCP and in initiating or defending any legal proceedings that may arise in connection therewith (“Proceedings”) (collectively, the “Common Interest”);

WHEREAS, the Members believe that sharing of confidential and privileged information among the Common Interest Group will be mutually beneficial in advancing their collective interest in securing the Permits and approval of the USAR HCP and participating cooperatively in any Proceedings;

WHEREAS, the Members agree to rely on their Common Interest as an exception to what might otherwise be considered a waiver of attorney-client privilege or work product doctrine, as well as any other protections that would apply for documents and information created by one Member and shared with one or more other Members; and

WHEREAS, in accordance with the provisions herein, the Members also agree to keep confidential any privileged documents and information exchanged in advancing the Permits and the USAR HCP and participating in Proceedings.

NOW THEREFORE, in consideration of the mutual covenants contained in this Agreement and other good and valuable consideration, the receipt and sufficiency of which are hereby

acknowledged, the Members agree as follows:

1. **Common Interest.** The Members have joined together to work cooperatively in seeking to secure the Permits and approval of the USAR HCP in coordination with the USFWS and other Permitting Agencies, and to initiate or defend themselves in Proceedings.
2. **No Waiver of Legal Privileges, Doctrines or Protections.** Any exchange of documents or other information between or among the Members in connection with the Common Interest is not intended to waive any attorney-client privilege, attorney work product doctrine, or any other protection from disclosure to third parties that may otherwise be available (“Legal Privilege”). Any such written or oral communication made between or among Members is and will remain privileged and protected from disclosure to any third party (“Privileged Communications”).
3. **Covered Communications.** The written or oral communications covered by this Agreement include documents, memoranda, correspondence, drafts, notes, reports, factual summaries, transcript digests, communications among counsel, or counsel and a Member, including its “Representatives” (defined below), any joint or several interview of prospective witnesses, or the sharing or exchange via any media, including but not limited to electronic media, as well as any other material and information related to the Common Interest which would otherwise be protected from disclosure to third parties.
4. **Confidentiality.** In addition to preserving the Legal Privilege of Privileged Communications, the Members agree that all such communications shall be kept confidential, and to take certain steps to ensure those communications are kept confidential.
 - a. **Markings.** The Members shall mark all Privileged Communications exchanged pursuant to this Agreement with substantially the following language: “Confidential and Privileged Communication Provided Pursuant to Common Interest Agreement.”
 - b. **Other Purposes.** No Member shall use any Privileged Communication exchanged pursuant to this Agreement for purposes unrelated to the Common Interest.
 - c. **Permissible Sharing.** Each Member may share Privileged Communications received from another Member with members of its legislative body, officers and employees, as well as engaged consultants, assistants and professionals, including counsel (“Representatives”). The Members may mutually agree by a two-thirds vote to share, or to delegate to one Member the right to share, certain Privileged Communications received from another Member with the Permitting Agencies in the interest of advancing the Common Interests.

- c. **Opportunity to Cure.** Notwithstanding section 6(b), unless such conduct is willful or intentional, in the event that a Member becomes aware of any circumstances relating to its conduct that are inconsistent with the maintenance of any privilege or protection which may apply to Privileged Communications, such Member shall provide the Common Interest Group with written notice of such conduct, including copies of any disclosed Privileged Communications, within two (2) business days of becoming aware of such conduct. That Member shall have a ten (10) business day opportunity to cure such noncompliance by taking all reasonable efforts to ensure that all impermissibly disclosed Privileged Communications are returned or destroyed.
 - d. **Communications.** Upon the effective date of the withdrawal of a withdrawing Member, the withdrawing Member's counsel shall no longer be entitled to receive Privileged Communications. With the exception of Privileged Communications (a) that may be retained as required under applicable corporate record keeping policies or by applicable law or court order or (b) which are collected and maintained as an archived computer system backup as part of information technology backup procedures maintained in the normal course of business, at the request of any furnishing Member or its counsel, all Privileged Communications sent to the withdrawing Member shall be immediately returned by the withdrawing Member to the furnishing Member or destroyed, at the election of the withdrawing Member.. This provision shall not require the destruction of information utilized in any report which has de-identified information relating to a withdrawing Member's project prepared by a consultant for purposes of the Common Interest Group Proceedings.
 - e. **Protection.** Members and counsel agree that any privilege by which the confidentiality of any materials and copies is protected shall remain in full force and effect during and subsequent to such withdrawal and the withdrawing Member or its counsel shall be obligated to protect and maintain such privilege indefinitely. The Member and its counsel shall not use any Privileged Communications received or exchanged prior to withdrawal for any purpose counter to or inconsistent with the Common Interest except as may be required by applicable law, rule or regulation.
7. **Covered Parties.** This Agreement is binding upon each of the parties hereto, as well as their respective undersigned counsel. Each Member shall be responsible for compliance by its Representatives with this Agreement.
8. **No Attorney-Client Relationship or Duty of Loyalty.** Nothing contained herein shall be deemed to create, either expressly or by implication, an attorney-client relationship or duty of loyalty between any undersigned Member's counsel and any other Member.

9. **Integration.** This Agreement supersedes all other agreements, whether written or oral, between and among the Members relating to the subject matter herein.
10. **Modifications.** Modifications of this Agreement can be made if such modifications are in writing and are signed by all of the parties to this Agreement.
11. **Effective Date.** This Agreement is effective as of the date of execution indicated next to the signature of each Member and its counsel below and, as to any additional entity added to the Common Interest Group, as of the date of execution of an addendum to this Agreement, as set out in Section 5 hereof, by that entity and its counsel.
12. **Duration and Termination.** The Members agree that this Agreement shall remain in effect until the later of (a) completion or abandonment of the Common Interest and (b) the execution of a final negotiated resolution of any Proceedings which may arise in connection with the Permits or the USAR HCP, provided that the Common Interest Group may at any time by written instrument terminate this Agreement (such date being the "Termination Date"). If this Agreement is terminated by written instrument by each of the Members, the Members and counsel agree that any privilege by which the confidentiality of any materials and copies is protected shall remain in full force and effect subsequent to such termination and each Member or its counsel shall be obligated to protect and maintain such privilege after the Termination Date. Upon the termination of this Agreement, at the request of a furnishing Member or its counsel, all Privileged Communications provided to a receiving Member shall be returned by such receiving Member to the furnishing Member or destroyed, at the election of the receiving Member, with the exception of Privileged Communications (a) that may be retained as required under applicable corporate record keeping policies or by applicable law or court order or (b) which are collected and maintained as an archived computer system backup as part of information technology backup procedures maintained in the normal course of business.
13. **Application.** The terms of this Agreement apply to the final, executed Agreement, all drafts of this Agreement, and all Privileged Communications relating to this Agreement.
14. **Multiple Counterparts.** This Agreement may be executed in multiple counterparts, each signature being made part of the whole Agreement as if executed as one document. Original, facsimile, and electronic signatures are sufficient and may be employed to execute this Agreement.
15. **Choice of Law.** The application and interpretation of this Agreement shall be governed by the California Evidence Code and the laws of the State of California.

AGREED TO AND ACCEPTED BY:

Member: San Bernardino Valley Municipal Water District

By: _____ Date: _____
Its: Title:

Counsel: Varner & Brandt, LLP

By: _____ Date: _____

Counsel: Downey Brand, LLP

By: _____ Date: _____

Member: East Valley Water District

By: _____ Date: _____
Its: Title:

Counsel: JC Law Firm

By: _____ Date: _____

Member: West Valley Water District

By: _____ Date: _____
Its: Title:

Counsel: Tafoya & Garcia LLP

By: _____ Date: _____

Member: San Bernardino County Flood Control District

By: _____ Date: _____
Its: Title:

[Signatures continued following page]

Counsel: County Counsel, County of San Bernardino

By: _____ Date: _____

Member: City of Rialto

By: _____ Date: _____
Its: Title: _____

Counsel: Brownstein, Hyatt, Farber, Schreck, LLP

By: _____ Date: _____

Member: San Bernardino Municipal Water Department

By: _____ Date: _____
Its: Title: _____

Counsel: Somach, Simmons & Dunn LLP

By: _____ Date: _____

Member: Riverside Public Utilities

By: _____ Date: _____
Its: Title: _____

Counsel: City Attorney's Office, City of Riverside

By: _____ Date: _____

Member: Western Municipal Water District

By: _____ Date: _____
Its: Title: _____

[Signatures continued following page]

Counsel: Best Best & Krieger LLP

By: _____ Date: _____

Member: Inland Empire Utilities Agency

By: _____ Date: _____
Its: _____ Title: _____

Counsel: JC Law Firm

By: _____ Date: _____

Member: Orange County Water District

By: _____ Date: _____
Its: _____ Title: _____

Counsel: Rutan & Tucker, LLP

By: _____ Date: _____

Member: Metropolitan Water District of Southern California

By: _____ Date: _____
Its: _____ Title: _____

Counsel: Office of General Counsel, Metropolitan Water District

By: _____ Date: _____

Member: San Bernardino Valley Water Conservation District

By: _____ Date: _____
Its: _____ Title: _____

[Signatures continued following page]

Counsel: Rutan & Tucker, LLP

By: _____

Date: _____

[Addendum]



AGENDA ITEM SUBMITTAL

Meeting Date: October 10, 2018

To: Water Issues Committee
Board of Directors

From: Mike Markus

Staff Contact: J. Kennedy

Budgeted: N/A

Budgeted Amount: N/A

Cost Estimate: N/A

Funding Source: N/A

Program/ Line Item No.: N/A

General Counsel Approval: N/A

Engineers/Feasibility Report: NA

CEQA Compliance: NA

Subject: IRVINE RANCH WATER DISTRICT – STRAND RANCH STORAGE PROGRAM

SUMMARY

Director Dewane recently requested information regarding the Irvine Ranch Water District (IRWD) storage programs in the California central valley. A representative from IRWD will present an overview of its Strand and Stockdale Integrated Water Banking Projects (Water Banks) as well as a proposed pilot program with the Municipal Water District of Orange County (MWDOC) that would allow IRWD to share water storage supplies. IRWD will also provide an overview of the Kern Fan Groundwater Storage Project for which IRWD and Rosedale-Rio Bravo Water Storage (Rosedale) were recently awarded \$67.5 million in Water Storage Investment Program funding from the California Water Commission.

RECOMMENDATION

Informational

BACKGROUND/ANALYSIS

IRWD has diversified its water supply portfolio by developing Water Banks located in the southern San Joaquin Valley in Kern County. The purpose of these projects is to provide for the recharge, storage and recovery of water that can be relied upon during major droughts and periods of supply interruptions. IRWD's Water Banks are designed to supply water during drought periods.

IRWD has secured water supplies for its water banking projects through exchange partnerships with other agencies. These partnerships allow agencies with surplus water to store water in IRWD's Water Banks in return for transferring 50 percent of the water to IRWD. To facilitate the delivery of banked water into IRWD's service area, IRWD has executed agreements with the Metropolitan Water District of Southern California (Metropolitan) and MWDOC. Water can be delivered into IRWD's service area, in accordance with these agreements, as "Extraordinary Supply". Water classified as "Extraordinary Supply" is additive to an agencies supply during periods when Metropolitan has declared a Water Supply Allocation.

Currently, IRWD and MWDOC are considering entering into a Pilot Program Agreement that would allow IRWD to share Extraordinary Supply benefits from its Water Banks with MWDOC and its member agencies. At the Committee meeting, IRWD will present an overview of its Water Banks, the proposed Pilot Program with MWDOC and the associated costs. IRWD will also provide an overview of the Kern Fan Groundwater Storage Project for which IRWD and Rosedale-Rio Bravo Water Storage were recently awarded \$67.5 million in Water Storage Investment Program funding from the California Water Commission.

PRIOR RELEVANT BOARD ACTION(S) N/A

AGENDA ITEM SUBMITTAL

Meeting Date: October 10, 2018

To: Water Issues Committee
Board of Directors

From: Mike Markus

Staff Contact: J. Kennedy

Budgeted: N/A

Budgeted Amount: N/A

Cost Estimate: N/A

Funding Source: N/A

Program/ Line Item No.: N/A

General Counsel Approval: N/A

Engineers/Feasibility Report: NA

CEQA Compliance: NA

Subject: OCWD TO RECEIVE STEPHEN J. KLAINÉ ENVIRONMENTAL AWARD

SUMMARY

The District's Environmental Education Program has been selected to receive the 2018 Stephen J. Klaine Environmental Education Award which recognizes an individual, group or organization for significant contributions to environmental education. The award will be acknowledged at the Society of Environmental Toxicology and Chemistry (SETAC) North America 38th Annual Meeting in Sacramento, California. Jason Dadakis will attend to receive the award on behalf of the District.

RECOMMENDATION

Informational



SOCIETY OF ENVIRONMENTAL TOXICOLOGY AND CHEMISTRY

ENVIRONMENTAL QUALITY THROUGH SCIENCE®

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SEP 26 2018

O.C.W.D

**NORTH AMERICA
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21 September 2018

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Fountain Valley, CA 92708

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NEK Associates, LTD, USA

Dear Denis

Immediate Past-President

Tom Augspurger
Federal Government, USA

On behalf of the SETAC North America Awards & Fellowships Committee and Board of Directors, it gives me great pleasure to inform you that Orange County Water District Environmental Education Program has been selected to receive the 2018 Stephen J. Klaine Environmental Education Award.

Member-at-Large

Sarah Bowman
State Government, USA

Board Members

Jennifer Bouldin
Arkansas State University, USA

The Stephen J. Klaine Environmental Education Award (formerly the SETAC/Menzie Environmental Education Award) recognizes an individual, group or organization for significant contributions to environmental education. The award is named in honor of Steve Klaine, who touched the lives of so many with his dedication to environmental science, teaching and mentoring of students during his 30-year career. Therefore the award, formerly known as the SETAC/Menzie Environmental Education Award, was renamed in 2016 to pay tribute to his efforts.

Markus Hecker

University of Saskatchewan, Canada

The award will be acknowledged at the SETAC North America 38th Annual Meeting in Sacramento, California.

Jim Lazorchak

Federal Government, USA

Fernando Martínez-Jerónimo
Escuela Nacional de Ciencias
Biológicas-I.P.N., Mexico

Being a recipient of this award, you are offered a meeting registration waiver. If you would like to take advantage of this offer or have any questions, you may contact Laura Swanson by email laura.swanson@setac.org or by phone 850 469 1500, extension 103.

Teresa Norberg-King

Federal Government, USA

Lisa Ortego

Bayer Crop Science, USA

Sue Robinson

INTERA Incorporated, USA

Jeffery Steevens

Federal Government, USA

Again, congratulations on your award!

Eric Van Genderen

International Zinc Association, USA

Kristie L. Willett

University of Mississippi, USA

Student Member

Alex MacLeod
University of Maryland, USA

Ex Officio

Executive Director

Greg Schiefer
SETAC North America

John Toll
President, SETAC North America